PETROCHEMICAL CHARACTER OF THE SYENITIC ROCKS FROM THE YAMATO MOUNTAINS, EAST ANTARCTICA

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Abstract: Syenitic rocks occupying an area of at least 400 km^2 in the Yamato Mountains, East Antarctica, are classified into three major types on the basis of the field occurrence and petrography; two-pyroxene syenite, clinopyroxene quartz monzo-syenite and clinopyroxene syenite. Major and trace elements Rb, Sr, Zr, Th and U are presented to reveal the petrochemical features of the syenitic rocks.

The two-pyroxene syenite which has a charnockitic appearance is the earlier member among the syenitic rocks. The spacial relation between the clinopyroxene quartz monzo-syenite and the clinopyroxene syenite is not observed.

All the syenitic rocks show roughly smooth trends in the major elements variation diagrams, but they overlap extensively with increasing SiO_2. The Rb, Th and U contents of the syenitic rocks are similar to those of the average crust, and Sr and Zr are much more enriched than the ordinary granitic rocks.

The wide range of SiO_2 in the clinopyroxene quartz monzo-syenite and higher Rb/Sr and K/Rb ratios in the two-pyroxene syenite than the former might not prove the formation of the clinopyroxene quartz monzo-syenite from the two-pyroxene syenite by magmatic differentiation. On the other hand, it is possible that the clinopyroxene quartz monzo-syenite and the clinopyroxene syenite may be genetically related judging from their petrochemical similarity.

1. Introduction

It is characteristic of the Yamato Mountains (approximately lat. 71.5°S, long. 35.5°E) that various kinds of syenitic rocks are extensively distributed among the high-grade metamorphic rocks in comparison with the Lützow-Holm Bay region. The syenitic rocks are estimated to occupy at least 400 km^2 of the Yamato Mountains region which consists of scattering exposures covering the area of 20 × 60 km. The syenitic rocks are classified into several types on the basis of the field occurrence and petrography, though their mutual relationships are not always apparent. This paper presents major and some trace elements of the syenitic rocks, and reveals the chemical distinction among the syenitic rock types.

2. Geological Setting

Geology and petrography of the Yamato Mountains have been described in previous papers (KIZAKI, 1965; OHTA and KIZAKI, 1966; SHIRAISHI, 1977; SHIRAISHI *et al.*, 1978, 1982a, b; YANAI *et al.*, 1982; ASAMI and SHIRAISHI, 1983).

The Yamato Mountains are made up of high grade regional metamorphic rocks, syenitic rocks and granitic rocks (Fig. 1). The metamorphic rocks are composed of two-pyroxene biotite gneiss group, granitic gneiss and biotite amphibolite group and migmatitic gneiss. General presence of orthopyroxene in the two-pyroxene biotite gneiss group indicates the metamorphic grade attained to the granulite-facies conditions, whereas the features of the mineral paragenesis in the granitic gneiss and biotite amphibo-

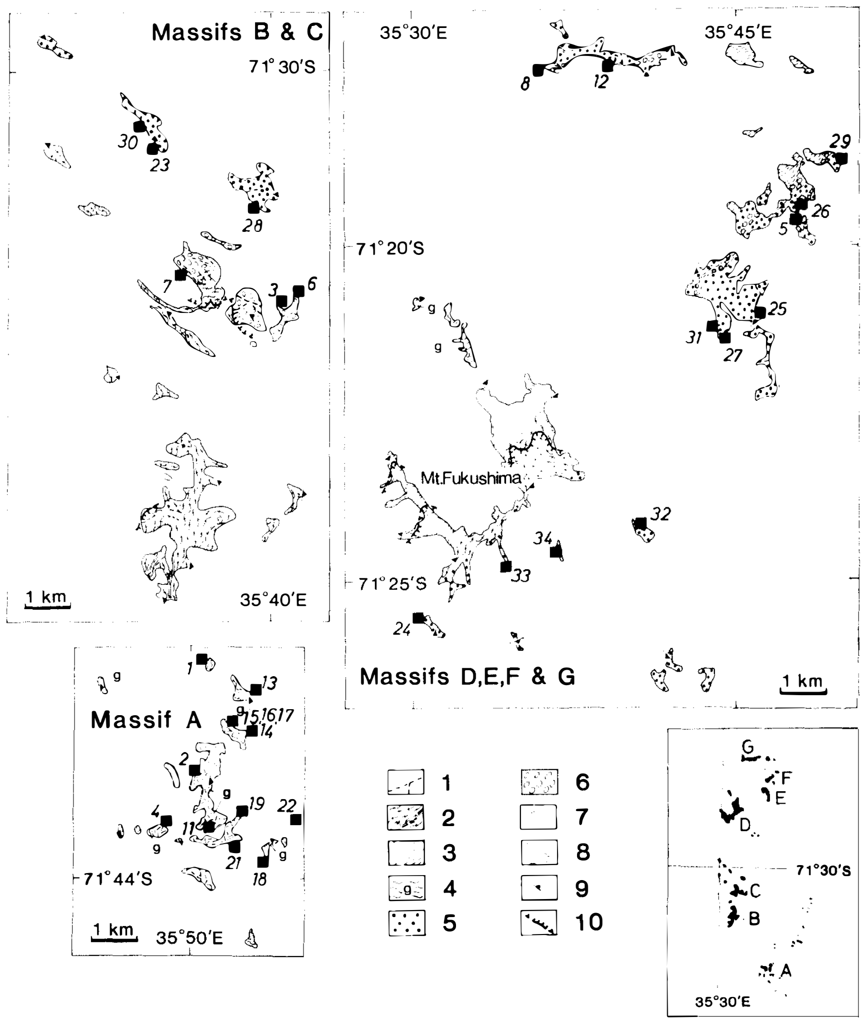

Fig. 1. Geological map of the Yamato Mountains showing specimens localities. 1: Granite and pegmatite, 2: Granitic gneiss and biotite amphibolite group, 3: Migmatitic gneiss, 4: Two-pyroxene biotite gneiss group, 5: Clinopyroxene syenite, 6: Porphyritic two-pyroxene syentite, 7: Clinopyroxene quartz monzo-syenite, 8: Two-pyroxene syenite, 9: Foliation, 10: Thrust fault.

lite group suggest the amphibolite-facies grade (ASAMI and SHIRAISHI, 1983; SHIRAISHI *et al.*, 1982b). Although the field relation between these facies groups is not yet established, it seems to be tectonic (SHIRAISHI *et al.*, 1982b). Migmatitic gneiss which occurs in a transitional zone between the two-pyroxene biotite gneiss and the granitic gneiss includes the paleosomes of the former and two-pyroxene amphibolite, and its foliated structure is conformable to that of the granitic gneiss. Therefore, it is possible that the age of the amphibolite-facies metamorphism is later than that of the granulite-facies metamorphism (SHIRAISHI *et al.*, 1982b).

Pink microcline granite and pegmatite are widely distributed, especially in the central Yamato Mountains. They form discordant dykes, concordant sheets, pools, stocks or veins in all the other rock types.

3. Description of Syenitic Rocks

3.1. Classification of syenitic rock

The syenitic rocks generally occur as large isolated masses or nunataks. Therefore, it is difficult to observe their relations to the other rock groups, even among such various syenitic rock types as described below. The syenitic rocks in the Yamato Mountains were first described as the pyroxene syenite by KIZAKI (1965). Successive investigations elucidated many types of the syenitic rocks and designated many rock names. In this study they are classified into three major rock types on the basis of the field occurrence and petrography.

(1) Two-pyroxene syenite

This rock includes the two-pyroxene syenite gneiss in the northern Yamato Mountains (SHIRAISHI, 1977), the porphyritic syenite in the central part of the mountains (YANAI *et al.*, 1982) and quartz syenitic charnockite in the southernmost part of the mountains (SHIRAISHI *et al.*, 1982a). Although there are some lithologic varieties, it could be subdivided into K-feldspar porphyritic type and even-grained type which includes fine- to coarse-grained varieties. All varieties are characterized by the presence of blue-gray to dark gray colored feldspars and quartz. The porphyritic type predominates in the central and northern parts of the mountains, whereas the even-grained type occurs in the southernmost part. The two-pyroxene syenite intrudes into the two-pyroxene biotite gneiss group and includes xenolithic blocks of the two-pyroxene biotite gneiss, two-pyroxene amphibolite and calc-silicate gneiss of this group in the southernmost region. The porphyritic two-pyroxene syenite in the central part of the mountains thrusts over the granitic gneiss and biotite amphibolite group.

(2) Clinopyroxene quartz monzo-syenite

This rock is found only in the southernmost part of the mountains. It has been referred to be a part of the two-pyroxene syenite by KIZAKI (1965). The rock is a light gray to brown-colored, homogeneous, medium- to coarse-grained rock. Flow-like structure is sometimes observed. Many round or lenticular enclaves of the two-pyroxene syenite, the two-pyroxene biotite gneiss and calc-silicate gneiss, being around a few decimeters in diameter are included in the rock. Therefore, it is evident that the clinopyroxene quartz monzo-syenite intruded after the emplacement of the two-pyroxene syenite.

(3) Clinopyroxene syenite

The rock of this type has been subdivided into clinopyroxene syenite gneiss and clinopyroxene quartz syenite gneiss by SHIRAISHI (1977) in the northern part of the mountains, and coarse-grained massive syenite and medium-grained massive syenite by YANAI *et al.* (1982) in the central part. This rock is very heterogeneous in mineral association and modal composition as well as in texture. Although SHIRAISHI (1977) described that the layers or blocks of the porphyritic two-pyroxene syenite are included in this rock in the northern part of the mountains, the exact relation between them is not well known.

3.2. Brief petrography of the syenitic rocks

The classification according to modal quartz and feldspars contents is applied to the syenitic rocks as shown in Fig. 2 (IUGS SUBCOMMISSION ON THE SYSTEMATICS OF IGNEOUS ROCKS, 1973). Three major types of the syenitic rocks overlap each other, and are distributed in a large area from alkali-syenite to quartz monzonite. The ranges of the modal composition of the constituent minerals are listed in Table 1. Color indices show wide variations especially in the clinopyroxene quartz monzo-syenite. The variations of the color index are mainly caused by the modal compositions of clinopyroxene and biotite. It is characteristic of the syenitic rocks in this region that biotite is present in a large amount.

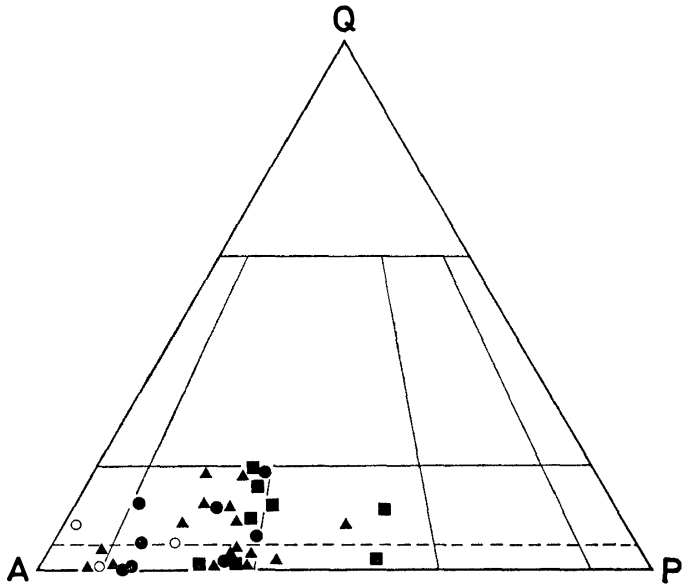

Fig. 2. Modal distribution of quartz (Q), K-feldspar (A) and plagioclase (P) of the syenitic rocks from the Yamato Mountains, based on the IUGS SUBCOMMISSION (1973) system. Solid circle: two-pyroxene syenite, open circle: porphyritic two-pyroxene syenite, square: clino-pyroxene quartz monzo-syenite, triangle: clinopyroxene syenite.

(1) Two-pyroxene syenite

The even-grained type of this rock consists of biotite, clinopyroxene, orthopyroxene, a large amount of K-feldspar and small amounts of plagioclase and quartz. K-feldspar is mesoperthitic and occasionally shows Carlsbad twinning. Accessory minerals are

Table 1. Modal compositions of the syenitic rocks.

	1	2	3	4
K-feldspar	38.5–64.0%	61.9–77.0%	23.3–47.5%	43.2–73.0%
Plagioclase	7.4–18.1	4.9– 7.9	11.5–33.5	5.9–43.7
Quartz	1.4–13.7	0.5– 6.5	0.6–15.3	0.7–14.8
Clinopyroxene	2.3–14.6	5.9–12.8	3.8–21.8	0 –12.9
Orthopyroxene	0.4– 5.9	0.4– 2.0	0	0
Biotite	8.9–23.0	2.0–16.0	8.8–31.3	tr. –14.7
Hornblende	0 – 2.5	0 –tr.	0 – 2.5	0 –13.8
Apatite	0 – 0.8	0.4– 1.0	tr. – 1.1	tr. – 1.6
Opaque minerals	tr. – 1.3	0.2– 1.9	0.3– 1.5	0.1– 2.5
Sphene	0	0	tr. – 0.2	tr. – 0.7
Color index	19.6–43.4	15.2–37.0	20.4–55.3	4.0–30.5

1: Two-pyroxene syenite, 2: Porphyritic two-pyroxene syenite,
3: Clinopyroxene quartz monzo-syenite, 4: Clinopyroxene syenite.

apatite, zircon and secondary hornblende. Ilmenite is the most predominant opaque mineral, but no magnetite is found. The K-feldspar porphyritic type has the same constituent minerals as the even-grained type. K-feldspar includes tiny opaque minerals which are arranged as small rods, probably resulting in schillerization. Petrography of the K-feldspar was studied in detail by OHTA and KIZAKI (1966). The porphyritic two-pyroxene syenite from the central part of the mountains shows recrystallization textures such as corroded orthoclase by newly developed microcline which is graphically intergrown with albite, radiating aggregates of biotite rods with symplektitically intergrown quartz, and granoblastic equigranular matrix composed of microcline, albite and quartz aggregates. Most of orthopyroxene is partly altered to the biotite. These modifications are probably made by later granite and pegmatite activity, because such phenomena are generally seen near the microcline granite stocks and pegmatite apophyses in the central part of the mountains.

(2) Clinopyroxene quartz monzo-syenite

This rock is generally hypidiomorphic in texture, and tends to be allotriomorphic in the melanocratic variety. Constituent minerals are K-feldspar, plagioclase, quartz, biotite and clinopyroxene with or without dark green hornblende. Orthopyroxene has not been found. K-feldspar shows string or vein type of perthites. Sphene is a very common accessory mineral as well as apatite, zircon and ilmenite.

(3) Clinopyroxene syenite

This rock is much variable from place to place in both modal composition and texture. The mafic constituents are a combination of clinopyroxene, hornblende and biotite, and the felsic constituents are mainly K-feldspar and sodic plagioclase with or without quartz. K-feldspar shows distinct perthitic textures of vein type. Clinopyroxene is remarkably replaced by green hornblende. Ilmenite and magnetite are common opaque minerals.

4. Petrochemistry

Major elements of newly presented sixteen analyses were determined by a com-

Table 2. Average compositions and standard devition of the syenitic rock types.

	1			2			3		
	X̄	(12)	s	X̄	(10)	s	X̄	(12)	s
(wt %)									
SiO_2	57.23		2.50	55.02		4.26	59.12		3.49
TiO_2	0.93		0.20	1.39		0.28	0.91		0.28
Al_2O_3	14.10		1.16	14.76		1.33	14.65		0.91
Fe_2O_3	1.54		0.36	1.40		0.64	2.00		0.52
FeO	4.21		1.12	5.25		0.94	3.08		0.78
NnO	0.09		0.04	0.10		0.03	0.06		0.03
MgO	5.18		1.53	4.84		2.01	3.30		1.46
CaO	5.24		1.08	5.25		1.65	4.13		1.26
Na_2O	3.04		0.57	3.20		0.62	3.78		0.50
K_2O	6.62		0.74	6.07		0.62	7.13		0.33
P_2O_5	0.74		0.30	1.08		0.31	0.69		0.40
K_2O/Na_2O	2.18			1.90			1.89		
O.R.	27		9	19		7	38		10
		(5)			(9)			(12)	
Rb (ppm)	291		35	165		53	244		68
Sr	836		90	1687		436	1598		540
Zr	350		170	445		113	526		161
		(6)			(9)			(2)	
Th	16.3		12.8	7.4		6.7	10.5		1.1
U	3.8		1.5	2.5		2.3	4.6		2.1
K/Rb	188			305			243		
Rb/Sr	0.35			0.10			0.15		
Th/U	4.29			2.96			2.28		

( ): Number of specimens analyzed.
O.R.: Oxidation ratios [mol. $(2Fe_2O_3 \times 100)/(2Fe_2O_3+FeO)$].
X̄: Average value, s: Standard deviation.
1: Two-pyroxene syenite and porphyritic two-pyroxene syenite.
2: Clinopyroxene quartz monzo-syenite. 3: Clinopyroxene syenite.

bination of wet-chemical methods and flame-photometry. Trace elements, Rb, Sr and Zr were determined by X-ray fluorescence spectrometry, and Th and U by gamma-ray spectrometry (SHIRAISHI and KANAYA, 1983).

Table 2 lists the mean and standard deviations for the major trace elements in each syenitic rock type. Details of the analytical results are given in Appendix, including the data which were published in the previous papers (KIZAKI, 1965; SHIRAISHI, 1977; YANAI *et al*., 1982). Localities of the specimens are shown in Fig. 1.

4.1. *Major elements*

In the AFM (wt % Na_2O+K_2O–total Fe as FeO–MgO) diagram of major elements (Fig. 3), there seems to exist a regular trend common to every rock type. It is higher in Mg/Fe+Mg than the normal calc-alkaline trend. This trend is clearly different from that of the intrusive charnockitoids from the Humboldt Mountains and Petermann Range in Central Queen Maud Land as well as from other localities in East Antarctica (Fig. 3) (RAVICH and KAMENEV, 1975; SHERATON, 1982).

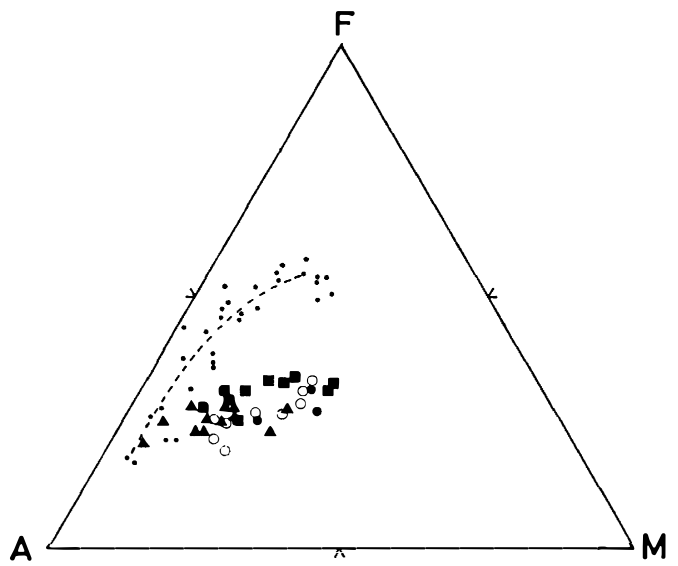

Fig. 3. AFM (Na_2O+K_2O–total Fe as FeO–MgO) diagram for the syenitic rocks. Symbols as in Fig. 2. Dots and broken line show the composition and trend of intrusive charnockitoids from the Humboldt Mountains and Petermann Range of Central Queen Maud Land, East Antarctica (RAVICH and KAMENEV, 1975).

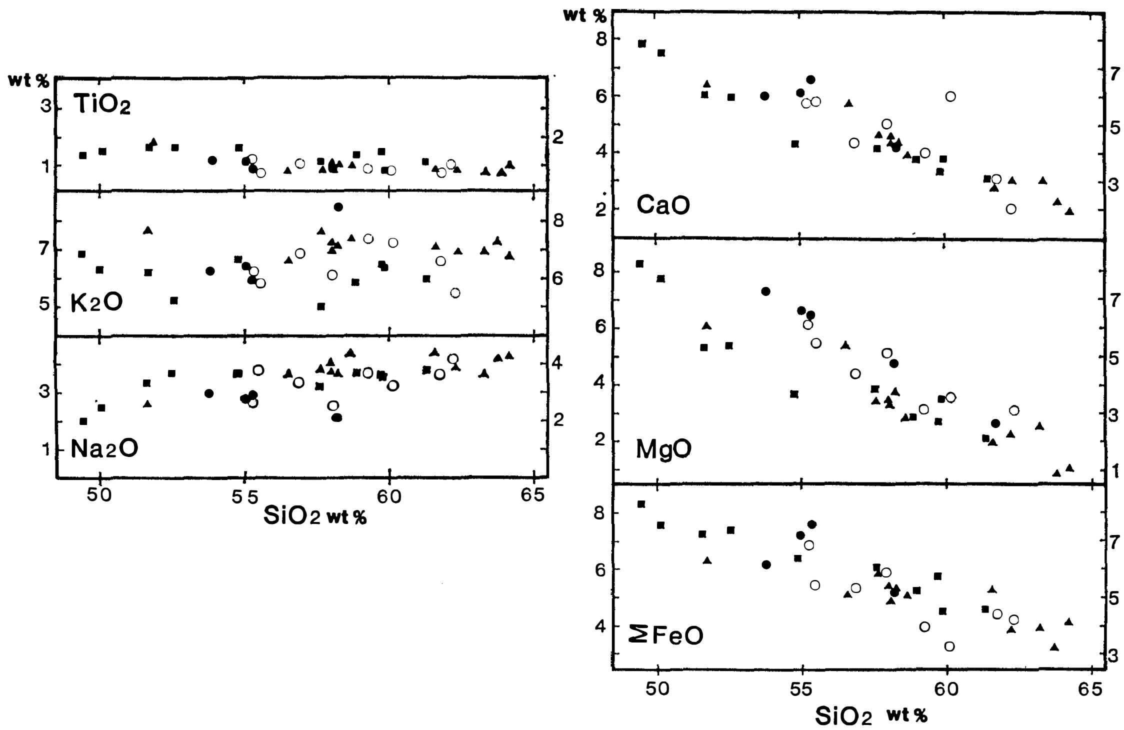

Fig. 4. SiO_2 versus oxides plots of the syenitic rocks. Symbols as in Fig. 2.

Harker variation diagram illustrates the following features (Fig. 4).

1) The two-pyroxene syenite including the porphyritic two-pyroxene syenite has a relatively limited SiO_2 content of intermediate composition.

2) Both the clinopyroxene quartz monzo-syenite and the clinopyroxene syenite

have a wide range of SiO_2, reflecting their heterogeneity in mineral composition. The former is more basic than the latter.

3) The CaO, MgO and FeO (total) contents vary inversely with SiO_2 content in each rock type.

4) It is noteworthy that the K_2O content of all the rock types is roughly constant with increasing SiO_2 and remarkably high compared with the syenitic rock of the charnockitoid varieties from East Antarctica (RAVICH and KAMENEV, 1975), though the range is broad. On the other hand, Na_2O increases slightly with increasing SiO_2 in three rock types. High K_2O/Na_2O ratio is characteristic in all the rock types (Table 2).

Moreover, the oxidation ratio (mol. $(2Fe_2O_3 \times 100)/(2Fe_2O_3 + FeO)$) is remarkably low throughout the three rock types and the value is the highest in the clinopyroxene syenite in which a small amount of magnetite is ubiquitous and the lowest in the clinopyroxene quartz monzo-syenite (Table 2).

4.2. Trace elements

It is worth noting that Sr in the clinopyroxene quartz monzo-syenite and the clinopyroxene syenite is twice that of the two-pyroxene syenites (Table 2). The Sr content of the syenitic rocks is much higher than the average value of granite (147 ppm), quartz monzonite (271 ppm) and alkali syenite (553 ppm) of the world (FAURE, 1978). The Rb contents of the syenitic rocks are almost the same as that of ordinary granite and syenite of which ranges are wide (HEIER and BILLINGS, 1970). The K/Rb and Rb/Sr ratios are illustrated in Fig. 5. It is noted that these diagrams discriminate different types of the syenitic rocks. The K/Rb ratio is the highest in the clinopyroxene quartz monzo-syenite and the lowest in the two-pyroxene syenite. The average K/Rb ratio of the clinopyroxene syenite (243) is close to the assumed ratio (230) of upper crust (HEIER and BILLINGS, 1970). An inverse relation is found between Rb and Sr in Fig. 5(b). The clinopyroxene syenite is intermediate in K/Rb and Rb/Sr ratios among the syenitic rocks and shows a wide range of these ratios.

The Rb-rich minerals in these syenitic rocks are expected to be biotite and K-feldspar. Biotite has generally much lower K/Rb ratio than K-feldspar (HEIER and

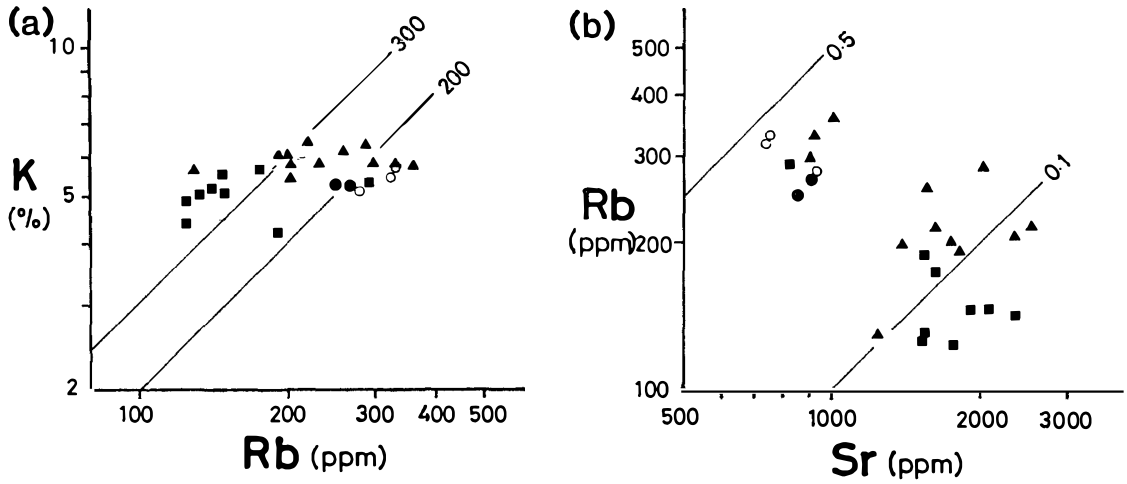

Fig. 5. Logarithmic plots of K versus Rb (a) and Rb versus Sr (b). Symbols as in Fig. 2.

BILLINGS, 1970). The relation between the modal compositions of these minerals and the K/Rb ratio are shown in Fig. 6. It appears that the difference of K/Rb in each syenite depends mainly on the volume of the biotite and K-feldspar except for a few cases. Moreover, Fig. 6 also shows that the difference between the clinopyroxene quartz monzo-syenite and the clinopyroxene syenite may be not only due to the volume of these minerals but also to the difference of their own K/Rb ratio. In Fig. 6, a few clinopyroxene syenites which have a small amount of biotite but have a large amount of K-feldspar show very low K/Rb ratio. It is likely that K-feldspar in these clinopyroxene syenites contains much Rb than that in the other clinopyroxene syenites.

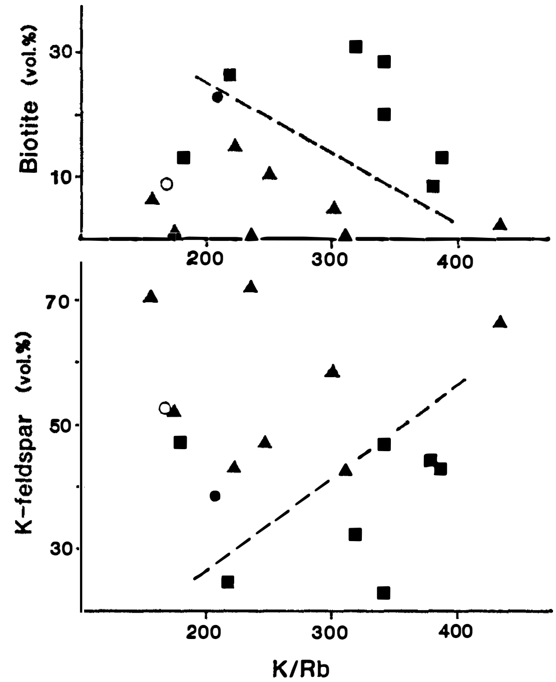

Fig. 6. Relationships between modal biotite and K/Rb, and between modal K-feldspar and K/Rb. Broken line shows the approximate boundary between the plots of the clinopyroxene quartz monzo-syenite and those of the clinopyroxene syenite.

Zr concentrations in the syenitic rocks (Table 2) exceed the average value of granitic rocks (around 200 ppm) but are much lower than those of agpaitic syenites (occasionally 1% level) elsewhere in the world (ERLANK *et al.*, 1978). The Zr content of the clinopyroxene quartz monzo-syenite and the clinopyroxene syenite is probably reflected not only by zircon but also by sphene.

Although the Th content is highly variable, average compositions of U and Th in the syenitic rocks are similar to the average crust (U=2.45 ppm and Th=10.3 ppm) (SHAW, 1967) (Table 2). High Th/U ratio (over 10 in many cases) is frequently reported from the granulite-facies rocks of intermediate to acid compositions (LAMBERT and HEIER, 1968; SIGHINOLFI and SAKAI, 1977; BARBEY and CUNEY, 1982). Th/U ratios in the syenitic rocks are incompatible with those of the granulite facies rocks, but are close to the average crust, especially in the two-pyroxene syenite.

5. Concluding Remarks

The syenitic rocks which are classified on the basis of the field occurrence and petrography are chemically examined.

1) In comparison with the intrusive charnockitoids elsewhere in East Antarctica, the two-pyroxene syenite with charnockitic features has higher Mg/Mg+Fe ratios and K_2O contents. The Rb, Th and U contents and K/Rb, Th/U ratios of the two-pyroxene syenite are not consistent with those of the typical granulite-facies rocks, but are close to the crustal averages.

2) The clinopyroxene quartz monzo-syenite which is a later intrusive than the two-pyroxene syenite may not be a magmatitic differentiate from the latter because both the rock types overlap extensively on the major elements variation diagrams, and the relationships of K/Rb and Rb/Sr ratios between them are incompatible with those in ordinary plutonic rocks.

3) Although the spatial relation between the clinopyroxene quartz monzo-syenite and the clinopyroxene syenite is not clear, it is possible that they may be genetically related because of their petrochemical similarity in both the major and trace elements.

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Appendix

Analyses and CIPW norms of the syenitic rocks from the Yamato Mountains.

	1	2	3	4	5	6	7	8	9	10	11	12
(wt %)												
SiO_2	53.81	55.06	55.28	55.31	55.58	56.93	58.03	58.25	59.33	60.15	61.82	62.32
TiO_2	1.01	1.13	1.14	0.79	0.71	1.14	0.97	1.20	0.74	0.69	0.75	1.07
Al_2O_3	13.35	13.42	13.00	11.60	14.44	14.48	14.36	14.93	15.63	14.54	15.32	14.16
Fe_2O_3	1.29	2.05	2.07	1.70	1.29	1.32	1.94	1.54	1.54	1.03	1.15	0.92
FeO	5.00	5.40	5.01	6.04	4.32	4.17	4.12	3.78	2.62	2.44	3.41	3.40
MnO	0.13	0.11	0.10	0.14	0.06	0.09	0.10	0.06	0.04	0.04	0.08	0.05
MgO	7.37	6.67	6.18	6.54	5.55	4.41	5.88	4.79	3.22	3.63	2.75	3.12
CaO	6.04	6.12	5.77	6.56	5.85	4.47	5.11	4.31	4.09	6.10	3.18	2.97
Na_2O	2.94	2.66	2.94	2.55	3.76	3.40	2.52	2.04	3.72	3.23	3.67	4.17
K_2O	6.20	6.29	5.97	6.13	5.83	6.78	6.08	8.40	7.37	7.22	6.50	5.53
P_2O_5	1.03	1.16	0.89	1.06	0.81	0.67	0.75	0.12	0.67	0.62	0.40	1.36
$H_2O(+)$	0.54	0.89	0.48	0.59	0.55	0.82	0.38	0.46	0.20	tr.	0.51	0.33
$H_2O(-)$	0.33	0.14	0.67	0.83	0.41	0.24	0.68	0.03	0.37	0.39	0.27	0.12
CO_2			0.20	0.46					0.22	0.19		
Total	99.04	101.10	99.70	100.30	99.16	98.92	100.92	99.91	99.76	100.27	99.81	99.52
Q							2.71			0.66	5.41	8.48
or	36.64	37.17	35.28	36.23	34.45	40.07	35.93	49.64	43.55	42.67	38.41	32.68
ab	20.31	22.51	24.88	21.58	26.75	28.77	21.32	17.26	31.48	27.33	31.05	35.29
an	4.92	6.10	4.64	2.10	5.30	4.22	9.91	6.77	4.18	3.85	6.13	3.59
ne	2.48				2.75							
di wo	7.65	6.97	7.59	9.82	7.69	5.67	4.40	5.77	4.90	9.34	2.94	0.95
en	5.17	4.63	5.10	6.05	5.04	3.67	3.08	4.02	3.45	6.64	1.73	0.59
fs	1.89	1.83	1.92	3.21	2.12	1.62	0.95	1.28	1.03	1.88	1.06	0.29
hyp en		2.59	3.93	3.92		11.57	6.44	2.54	1.48	2.41	5.12	7.18
fs		1.02	1.48	2.08		3.59	2.05	0.76	0.65	0.68	3.16	3.52
ol fo	9.24	6.58	4.46	4.43	6.16		1.03	1.42	4.09			
fa	3.71	2.86	1.85	2.59	2.85		0.36	0.47	1.99			
mt	1.87	2.97	3.00	2.46	1.87	2.81	2.23	2.23	1.91	1.49	1.67	1.33
il	1.92	2.15	2.17	1.50	1.35	1.84	2.28	1.41	2.17	1.31	1.42	2.03
ap	2.39	2.69	2.06	2.46	1.88	1.74	0.28	1.55	1.55	1.44	0.93	3.15
Rb(ppm)	269	251				281			333		323	
Sr	908	856				932			741		742	
Th	5.5	12.1			3.5		13.3				27.0	36.1
U	3.4	3.8			1.5		3.5				5.8	5.0
Zr	160	293				267			598		435	

Appendix (continued).

	13	14	15	16	17	18	19	20	21	22
(wt %)										
SiO_2	49.46	50.05	51.66	52.52	54.78	57.64	59.44	59.78	59.82	61.30
TiO_2	1.35	1.52	1.60	1.63	1.60	1.10	1.42	1.49	0.78	1.16
Al_2O_3	12.33	13.01	15.31	15.13	16.18	16.32	15.12	14.49	14.91	15.28
Fe_2O_3	2.23	1.94	1.68	0.99	1.02	1.32	0.83	2.16	0.43	1.10
FeO	6.31	5.80	5.75	6.52	5.42	4.90	4.48	3.84	4.23	3.61
MnO	0.15	0.13	0.11	0.10	0.09	0.09	0.08	0.07	0.08	0.08
MgO	8.23	7.75	5.27	5.48	3.71	3.86	2.90	2.74	3.63	2.15
CaO	7.85	7.51	6.03	6.02	4.45	4.19	3.87	3.42	3.94	3.27
Na_2O	1.93	2.43	3.22	3.57	3.64	3.23	3.77	3.49	3.51	3.82
K_2O	6.81	6.22	6.12	5.22	6.59	4.99	5.82	6.47	6.40	6.05
P_2O_5	1.45	1.68	1.36	1.20	0.96	0.88	0.78	0.84	0.53	0.59
$H_2O(+)$	0.86	0.86	1.01	0.88	0.85	0.60	0.56	1.10	0.67	0.71
$H_2O(-)$	0.13	0.24	0.18	0.35	0.23	0.49	0.29	0.15	0.27	0.27
CO_2								0.02		
Total	99.09	99.14	99.30	99.61	99.52	99.61	99.36	100.06	99.20	99.39
Q						4.65	3.89	5.79	1.87	6.81
or	40.25	36.76	36.17	30.85	38.95	29.49	34.39	38.24	37.82	35.75
ab	3.64	10.97	19.03	23.43	26.63	27.33	31.90	29.53	29.70	32.32
an	4.87	6.22	9.25	9.84	8.35	15.04	7.14	4.76	6.02	6.68
ne	6.87	5.20	4.45	3.67	2.26					
c						0.09				
di wo	10.27	8.38	4.92	3.67	3.11		2.01	2.80	4.20	2.38
en	6.89	5.71	3.06	5.09	1.74		1.61	1.83	2.38	1.31
fs	2.62	2.01	1.57	2.97	1.25		1.19	0.79	1.65	0.97
hyp en						9.61	5.62	5.00	6.67	4.04
fs						6.26	4.16	2.15	4.62	2.98
ol fo	9.54	9.52	7.06	7.49	5.26					
fa	4.00	3.69	3.99	5.23	4.16					
mt	3.23	2.81	2.44	1.44	1.48	1.91	1.20	3.13	0.62	1.59
il	2.56	2.89	3.04	3.10	3.04	2.09	2.70	2.83	1.48	2.20
ap	3.36	3.38	3.15	2.78	2.22	2.04	1.81	1.95	1.48	2.20
Rb(ppm)	177	142	149	127	148	190	125		293	132
Sr	1620	2380	2080	1540	1910	1530	1760		815	1550
Th	2.5	3.1	1.6	3.2	4.9	19.6	7.1		18.1	6.5
U	0.6	0.7	0.5	1.2	1.7	5.6	2.1		6.9	2.8
Zr	328	326	448	465	647	544	460		300	484

Appendix (continued).

	23	24	25	26	27	28	29	30	31	32	33	34
(wt %)												
SiO_2	51.72	56.60	57.69	58.08	58.09	58.30	58.75	62.28	61.64	63.33	63.80	64.25
TiO_2	1.68	0.80	0.80	1.00	0.76	1.00	0.96	0.90	0.77	0.74	0.59	1.00
Al_2O_3	12.62	14.19	14.18	15.38	15.67	14.71	15.26	14.13	14.72	14.46	15.87	15.05
Fe_2O_3	1.96	1.51	3.13	1.85	1.99	1.64	2.23	1.55	2.66	1.43	2.08	2.25
FeO	4.47	3.37	3.02	3.21	3.64	3.66	3.06	2.52	2.89	2.63	1.41	2.14
MnO	0.11	0.08	0.06	0.04	0.06	0.08	0.05	0.07	0.03	0.03	0.03	0.04
MgO	6.10	5.40	3.47	3.39	3.50	3.75	2.85	2.35	1.99	2.59	0.96	1.14
CaO	6.46	5.65	4.69	4.65	4.42	4.38	3.93	3.10	2.81	3.10	2.25	1.94
Na_2O	2.57	3.65	3.78	3.98	3.70	3.62	4.40	3.83	4.36	3.56	4.16	4.28
K_2O	7.63	6.54	7.62	7.23	6.87	7.01	7.36	6.91	7.04	6.94	7.29	6.74
P_2O_5	1.77	0.85	0.76	0.72	0.58	0.65	0.57	0.55	0.35	0.56	0.21	0.35
$H_2O(+)$	0.80	0.44	0.40	0.36	0.56	0.93	0.22	0.77	0.35	0.24	0.19	0.38
$H_2O(-)$	0.18	0.32	0.20	0.40	0.20	0.23	0.34	0.20	0.33	0.18	0.27	0.10
Total	98.07	99.76	99.80	100.29	100.04	99.96	99.98	99.16	99.94	99.79	99.11	99.66
Q								5.23	3.03	7.90	7.51	9.61
or	45.09	38.05	45.08	42.05	40.62	41.43	43.41	40.84	41.60	41.01	42.85	40.07
ab	11.78	25.86	25.69	28.84	31.46	30.63	30.93	32.41	36.52	30.12	35.13	36.18
an	0.36	3.02	1.39	2.78	5.84	3.18	0.28	0.95		2.98	3.34	1.95
ne	5.40	2.72	2.56				3.41					
di wo	8.40	8.12	7.78	6.50	5.23	5.97	6.50	4.52	4.87	3.65	2.90	2.09
en	6.04	5.61	5.62	4.52	3.31	3.92	4.52	3.10	3.22	2.44	2.41	1.61
fs	1.60	1.85	1.45	1.45	1.38	1.62	1.45	1.06	1.29	0.94		0.26
hyp en								2.75	1.73	4.01		1.20
fs								0.93	0.70	1.54		0.26
ol fo	6.41	5.49	6.51	2.74	3.66	2.49	1.83					
fa	1.87	1.99	2.11	1.02	1.83	1.14	0.71					
mt	2.84	2.19	3.94	2.78	2.78	2.38	3.24	2.25				3.24
il	3.19	1.52	1.52	1.97	1.52	1.90	1.82	1.71	1.46	1.41	1.06	1.97
ap	4.10	1.97	1.68	1.68	1.35	1.51	1.35	1.27	0.81	1.30	0.34	0.67
Rb(ppm)	219	204	287	200	362	299	260	202	335	233	194	129
Sr	2530	2360	2040	1400	1010	896	1560	1770	905	1630	1820	1250
Th	9.7							11.2				
U	3.1							6.0				
Zr	290	579	398	352	443	382	537	548	670	560	819	733

Appendix (continued).

No.	Sample No.	Specimen name*	Analyst or reference**
1	Y80A537	Two-pyroxene-biotite syenite	1)
2	Y80A34A	Two-pyroxene-biotite mela-syenite	1)
3	YC238	K-feldspar porphyritic two-pyroxene-biotite syenite	a)
4	YA301	Two-pyroxene-biotite syenite	a)
5	73120606	K-feldspar porphyritic two-pyroxene-biotite syenite	b)
6	A79120102	K-feldspar porphyritic two-pyroxene-biotite syenite	1)
7	74121803	K-feldspar porphyritic two-pyroxene-biotite synetie	c)
8	73120203	Two-pyroxene-biotite syenite	2)
9	YE54	K-feldspar porphyritic two-pyroxene-biotite syenite	a)
10	YF87	K-feldspar porphyritic two-pyroxene-biotite syenite	a)
11	Y80A556	K-feldspar porphyritic two-pyroxene quartz-syenite	1)
12	73120208	K-feldspar porphyritic biotite-hornblende quartz-syenite	2)
13	Y80A41	Clinopyroxene-biotite mela-alkali-feldspar syenite	1)
14	Y80A59A	Clinopyroxene-biotite mela-alkali-feldspar syenite	1)
15	Y80A100	Clinopyroxene-biotite syenite	1)
16	Y80A540	Clinopyroxene-biotite monzonite	1)
17	Y80A544	Clinopyroxene-biotite quartz-monzonite	1)
18	Y80A122	Clinopyroxene-biotite quartz-monzonite	1)
19	Y80A557	Clinopyroxene-biotite quartz-syenite	1)
20	YA292	Hornblende-biotite quartz-syenite	a)
21	Y80A520	Clinopyroxene-biotite quartz-syenite	1)
22	Y80A501B	Biotite-hornblende quartz-syenite	1)
23	K79112909	Hornblende-biotite mela-syenite	1)
24	73120802	Clinopyroxene-hornblende mela-syenite	b)
25	73120304	Clinopyroxene-biotite syenite	b)
26	73120601	Biotite-clinopyroxene syenite	b)
27	73120402	Clinopyroxene-biotite-hornblende syenite	b)
28	N79120112	Biotite-hornblende quartz-syenite	1)
29	73120510	Clinopyroxene-hornblende syenite	b)
30	K79112910	Biotite-hornblende quartz-syenite	1)
31	73120406	Hornblende quartz-syenite	b)
32	73120303	Clinopyroxene-hornblende-biotite quartz-syenite	b)
33	73120904A	Clinopyroxene leuco-quartz-syenite	b)
34	73120905	Hornblende-biotite leuco-quartz-syenite	b)

* Nomenclature after the IUGS Subcommission (1973).

** Analyst or reference for major elements

1): Japan Chemical Analysis Center, 2): Environmental Research Center,
a): Kizaki (1964), b): Shiraishi (1977), c): Yanai *et al.* (1982).

Analyst for trace elements: H. Kanaya.