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PRELIMINARY STUDY ON TRACE ELEMENT GEOCHEMISTRY OF METABASITES AROUND SYOWA STATION AND THE ADJACENT AREAS

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Abstract: Trace element geochemistry of basic metamorphic rocks around Syowa Station and the adjacent areas is presented. The rocks have a wide range of bulk chemical composition. As migration of some major elements such as K_2O is considerable during high-grade metamorphism, the estimation of original rock series is difficult. Trace element chemistry shows migration of some incompatible elements such as K, Ba and F. The MORB and primordial mantle normalized patterns of less incompatible elements show that most of the rocks have the nature similar to MORB and that a discordant dyke intruded after the regional metamorphism is similar to those of within-plate basalts and/or continental alkali basalts.

1. Introduction

Basic metamorphic rocks within metasedimentary rocks of the granulite to upper-amphibolite facies are widely distributed around Lützow-Holm Bay and along the Prince Olav Coast. Most of them are regarded as basic igneous rocks in origin. Their modes of occurrence in relation to the surrounding rocks are as follows; concordant layers, lenticular blocks, and discordant dykes intruded into them. For the purpose of elucidation of the history of tectonic setting and crustal development of East Antarctica, it is important to estimate the original igneous rock series of them. Their primary chemical compositions and mineral assemblages are uncertain because of strong deformation, recrystallization and chemical change during high-grade metamorphism. However, the behaviors of some immobile trace elements combined with major elements may be useful for inferring their original rock series. In this paper, a preliminary report on the trace element geochemistry of metabasites of the area will be given for the discussion on the tectonic setting of East Antarctica. Basic rocks used in the present study exclude the "normatively" ultramafic rocks (normative olivine+pyroxene+ilmenite $>70\%$) and unambiguous calc-silicate rocks.

2. Geological and Petrological Outline of the Studied Area

The Late Proterozoic metamorphic rocks of the granulite and upper-amphibolite facies, exposed around Lützow-Holm Bay and along the Prince Olav Coast, are called

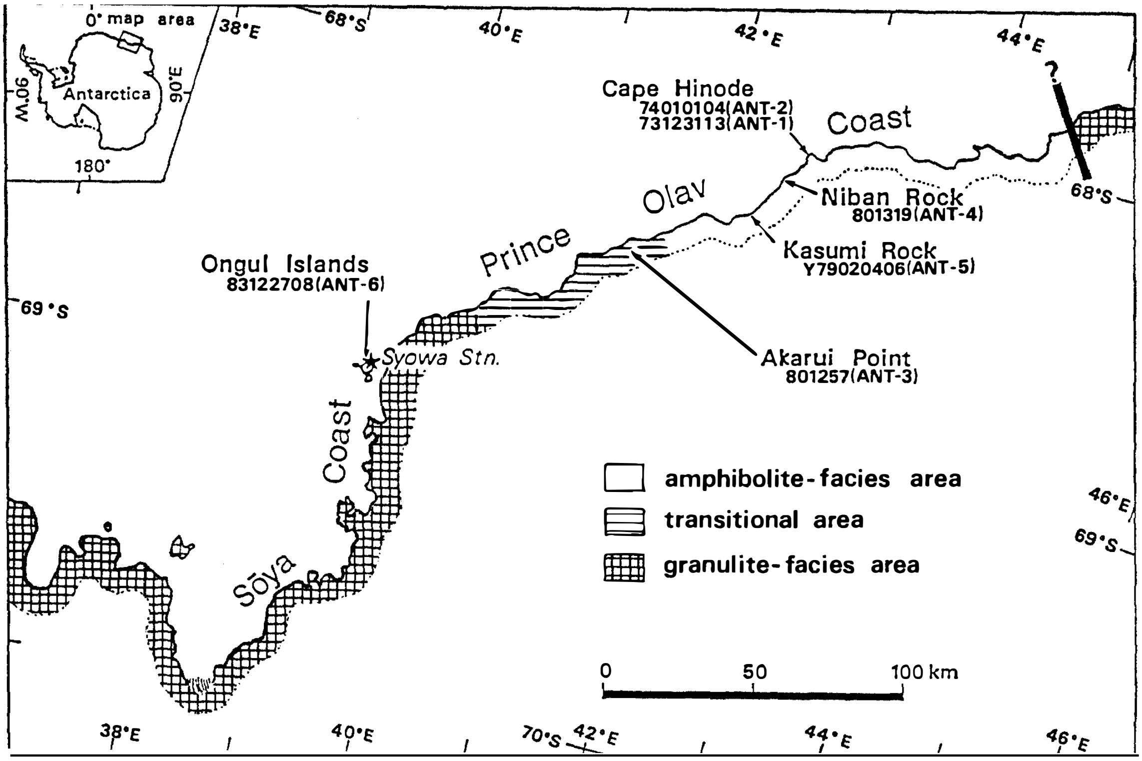

Fig. 1. Map showing metamorphic facies of the Lützow-Holm Bay and Prince Olav Coast regions and sampling locations. Division of the metamorphic facies is according to Hiroi *et al. (1983a).*

the Lützow-Holm Complex (Hiroi *et al.*, 1986). According to Hiroi *et al.* (1983a, b), metamorphic rocks around Syowa Station are characterized by the medium-pressure type progressive metamorphism from east to west and divided into three areas of different metamorphic facies (Fig. 1). The eastern part of the Prince Olav Coast, including Cape Hinode, Niban Rock and Kasumi Rock, is an amphibolite facies area. Its western part, with Tenmondai Rock, Naga-iwa and Akarui Point, is a transitional area from the amphibolite facies to the granulite facies. The Lützow-Holm Bay region belongs to the granulite facies.

3. Trace Element Geochemistry

Six typical metabasites from various localities were selected carefully on the basis of field occurrence, microscopic observation and major element chemistry. Sample locations are shown in Fig. 1. Trace elements of them were analyzed by means of instrumental photon activation analyses using a linear accelerator of Tohoku University (Yoshida *et al.*, 1986), Ba and F were analyzed by means of flameless atomic absorption method and selective ion electrode method, respectively (Ishikawa and Kanisawa, 1986; Kanisawa, 1978). The analytical results with major elements are shown in Table 1.

Incompatible element patterns of the analyzed rocks normalized by tholeiitic MORB and primordial mantle are shown in Figs. 2 and 3. Tholeiitic MORB nor-

Table 1. Major and trace element chemistry of metabasites.

	ANT-1	ANT-2	ANT-3	ANT-4	ANT-5	ANT-6
SiO_2	50.56	47.02	46.10	49.76	44.58	48.33
TiO_2	1.81	2.44	1.57	1.32	1.83	0.61
Al_2O_3	12.93	14.76	15.82	14.81	14.36	14.69
Fe_2O_3	5.85	7.01	4.11	3.45	3.48	1.34
FeO	7.60	6.33	8.41	6.98	9.54	7.23
MnO	0.21	0.18	0.24	0.23	0.19	0.17
MgO	6.09	5.67	6.98	7.19	8.65	9.65
CaO	9.38	8.29	9.79	11.16	11.02	12.15
Na_2O	3.09	3.50	3.50	2.93	2.60	2.71
K_2O	0.95	1.20	1.17	0.90	1.54	1.28
H_2O+	1.40	1.61	1.91	1.36	2.03	1.58
H_2O-	0.16	0.39	0.16	0.04	0.03	0.14
P_2O_5	0.24	1.34	0.24	0.13	0.11	0.12
Total	100.27	99.74	100.00	100.26	99.96	100.00
ppm						
Ba*	152	846	90	53	39	35
Ce	25.1	61.8	87.5	9.5	14.5	11.2
Co	39.2	42.1	39.1	43.0	55.9	42.6
Cr	51.8	26.5	119	74.7	360	404
Cs	0.30	1.53	0.78	0.36	0.18	—
F**	680	985	803	735	1670	6012
Nb	7.2	8.6	23.1	2.7	7.0	2.1
Ni	24.9	53.4	29.0	59.3	166	108
Rb	1.5	7.1	12.0	2.5	8.8	7.5
Sc	35.2	25.7	44.2	37.2	34.5	17.7
Sr	230	956	237	272	133	314
Y	42.6	40.0	117	20.0	20.7	13.2
Zn	37	77	45	110	79	62
Zr	116	209	49.8	68.0	82.3	33.6

*; Flameless atomic absorption method.

**; Selective ion-electrode method.

—; not determined.

ANT-1; 73123113 (Cape Hinode), ANT-2; 74010104 (Cape Hinode), ANT-3; 801257 (Akarui Point), ANT-4; 801319 (Niban Rock), ANT-5; Y79020406 (Kasumi Rock), ANT-6; 83122708 (East Ongul Island).

malize patterns were drawn in order to produce smooth and readily comparable patterns according to PEARCE (1983); a normalizing factor of the typical tholeiitic MORB presented by PEARCE (1983) has been used, and the elements have been ordered according to their petrogenetic properties. In the primodial mantle normalized pattern (Fig. 3), the order is based on SUN *et al.* (1979) in which it was demonstrated that average "typical" MORB have a regular pattern of relative depletion, so the elements are arranged in the order of an increase in incompatibility with the most incompatible elements on the left.

Brief descriptions of analyzed rocks and the features of their patterns are as follows:

ANT-1, No. 73123113: Clinopyroxene-bearing biotite amphibolite. Loc. Cape

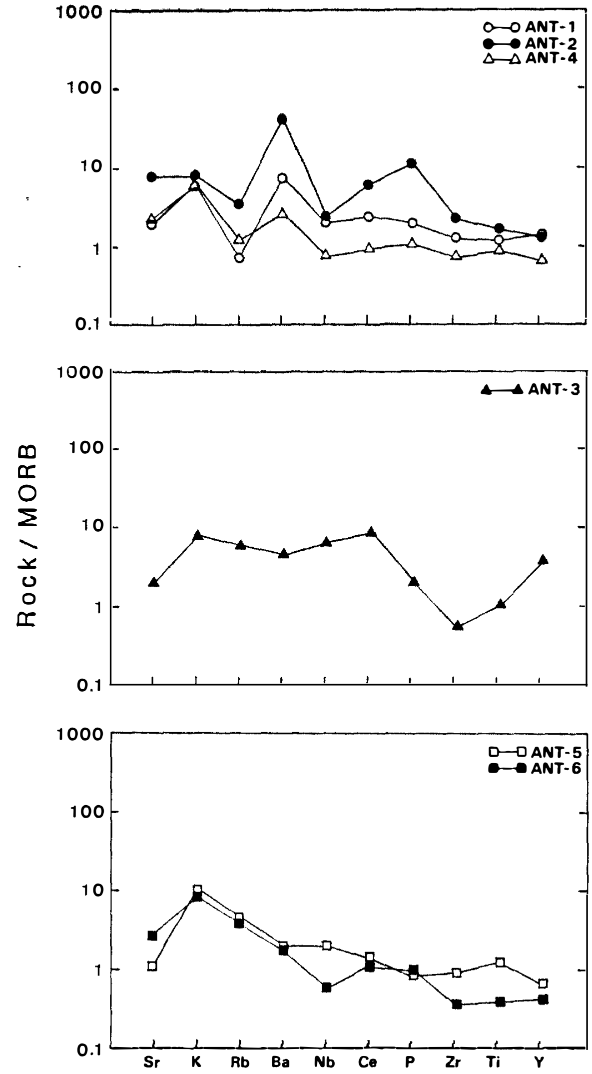

Fig. 2. *Geochemical patterns for basic metamorphic rocks normalized by "tholeiitic MORB."*

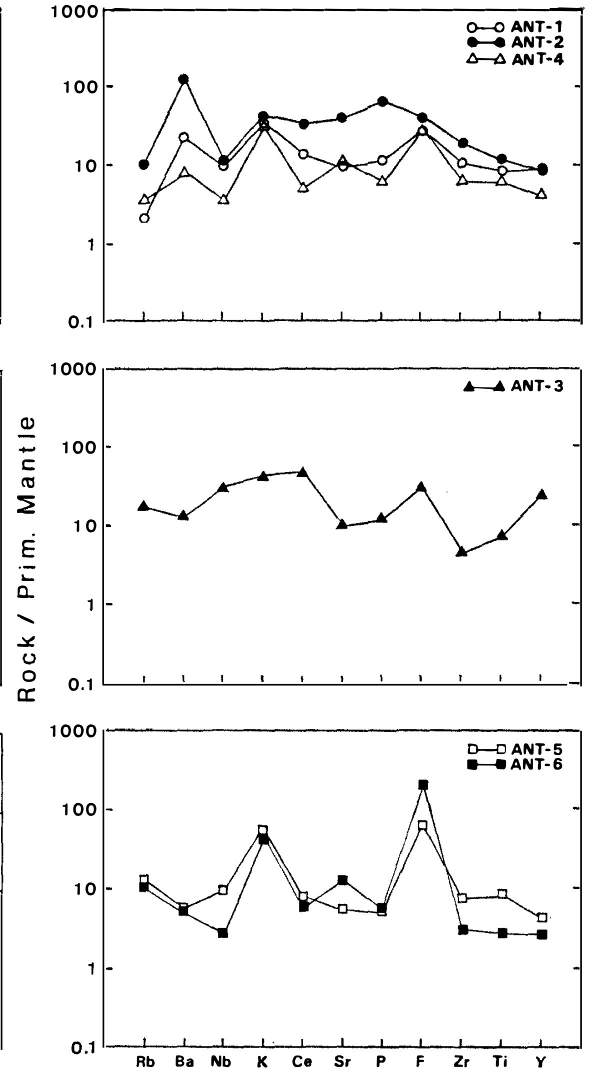

Fig. 3. *Same as Fig. 2 but for "primordial mantle."*

Hinode.

The rock occurs concordantly intercalating with garnet-bearing biotite gneiss and belongs to the amphibolite facies (Yanai and Ishikawa, 1978; Kanisawa *et al.*, 1979; Kanisawa and Yanai, 1983). Constituent minerals are greenish-brown hornblende, plagioclase, small amounts of dark brown biotite, quartz, and trace amounts of clinopyroxene and iron-oxides. Major element chemistry shows the characteristics of Q- and hy-normative. MORB normalized pattern is flat in high field strength elements (HFS; Ti, Zr and Nb), Y, Ce and P. Positive anomalies of K and Ba and negative one of Rb are conspicuous. Primordial mantle normalized pattern shows strong positive anomalies of F, K and Ba and depletion in Rb.

ANT-2, No. 74010104: Biotite amphibolite. Loc. Cape Hinode.

It occurs as a discordant dyke intruded into biotite gneiss. It suffered amphibolite-facies metamorphism (Yanai and Ishikawa, 1978; Kanisawa and Yanai, 1983). Constituent minerals are green hornblende, dark brown biotite, quartz, plagioclase, and small amounts of apatite and iron-oxides. Primary plagioclase phenocrysts (An_{48-35}) of igneous origin are common. The intrusion of the rock might have taken place after the main regional metamorphism of the Late Proterozoic and before the contact metamorphism by the intrusion of Early Paleozoic granites (HIROI *et al.*, 1983 a, b; HIROI and SHIRAISHI, 1986). Major element chemistry shows the nature of Q- and hy-normative. MORB normalized pattern shows the irregular shape enriched in P and especially in Ba, and depleted in Nb. Primordial mantle normalized pattern shows a convex smooth curve in the range of less incompatible elements. However, the pattern is strongly depleted in Nb and Rb, and enriched in Ba.

ANT-3, No. 801257: Biotite-bearing clinopyroxene amphibolite. Loc. Akarui Point.

The rock occurs as a concordant thin layer grading into biotite-hornblende gneiss (YANAI *et al.*, 1984). Metamorphic grade is transitional from the amphibolite to the granulite facies (HIROI *et al.*, 1983a, b). Constituent minerals are greenish-brown hornblende, plagioclase with small amounts of biotite, clinopyroxene and iron-oxides. Strong gneissose structure with felsic and mafic bands is conspicuous. Partly quartz pools of lenticular or irregular shape and greenish amphiboles around them are observed, suggesting local metasomatism. Major element chemistry shows the nature of ne-normative. MORB normalized pattern shows an irregular shape compared with that of normal igneous rocks, that is, it is flat from K to Ce and enriched in them, and depleted in Zr. Primordial mantle normalized pattern shows also an irregular shape enriched in Nb, K, Ce, F and Y, and relatively depleted in Sr, P, Zr and Ti.

ANT-4, No. 801319: Biotite-bearing clinopyroxene amphibolite. Loc. Niban Rock.

It occurs as a concordant thin layer intercalated with biotite gneiss. Metamorphic grade is of the amphibolite facies (HIROI *et al.*, 1983a, b; KIZAKI *et al.*, 1983). Constituent minerals are green hornblende and hypidiomorphic plagioclase with small amounts of green biotite and sphene. It shows granoblastic and slightly gneissose texture. Major element chemistry shows the nature of ol- and hy-normative. MORB normalized pattern is nearly flat and unity in large ion lithophile elements (LIL; Rb, K, Th, Ba and Sr), Y, Ce and P, and increases slightly with increasing incompatibility and positive anomalies of K and Ba. Primordial mantle normalized pattern shows positive anomalies of K and F.

ANT-5, No. Y79020406: Clinopyroxene-biotite amphibolite. Loc. Kasumi Rock.

The rock occurs as a concordant thin layer in biotite gneiss. Metamorphic grade is of the upper amphibolite facies (NISHIDA *et al.*, 1984; HIROI *et al.*, 1983b). It consists of greenish-brown hornblende, hypidiomorphic plagioclase, biotite with trace amounts of sphene and iron-oxides. The rock shows granoblastic texture with parallel arrangement of hornblende and biotite. Major element chemistry has the nature of ne-normative. MORB normalized pattern shows a nearly flat shape and unity in HFS elements, Y, Ce and P, and slight enrichment in elements with increasing incompatibility, and shows positive K anomaly. Primordial mantle normalized pattern shows strong positive anomalies of K and F.

ANT-6, No. 83122708: Biotite-clinopyroxene amphibolite. Loc. East Ongul Island.

This rock occurs as a rounded block of 25 cm in diameter in pyroxene gneiss.

Metamorphic grade is of the granulite facies. It shows granoblastic texture with remarkable and parallel arrangement of brown hornblende and pale brown biotite. Major element chemistry shows ne-normative. MORB normalized pattern is rich in LIL elements as compared with HFS elements, and shows negative anomaly of Nb, and depleted in Zr, Ti and Y. Primordial mantle normalized pattern shows strong positive anomalies of K and F, and slight enrichment in Rb and Sr, and depletion in Nb.

4. Migration of Elements during High-Grade Metamorphism

For the purpose of discrimination of a possible tectonic setting of the area, characterization of original rock type of metabasites is of particular importance. However, the arguments on the migration of elements during metamorphism cannot be avoided. The nature of major elements of the metabasites mentioned above does not take into account the element migration during metamorphism. Therefore the estimation of original rock series of metabasites from major element chemistry must be made with some caution. Many studies of compositional migration during high-grade metamorphism have been made (*e.g.* MUECKE *et al.*, 1979; CLOUGH and FIELD, 1980; ROLLINSON and WINDLEY, 1980; WEAVER and TARNEY, 1981; SHERATON, 1985). The results from these studies show the significant migration of LIL elements, but other HFS and less incompatible elements (Nb, La, Ce, P, Zr, Ti and Y) are not significantly affected by high-grade metamorphism. Therefore, the abundance of these immobile elements is useful in the characterization of original magma type of metabasites. In the MORB normalized pattern, mobile LIL elements are arranged in the left hand side, whereas less incompatible and less mobile Nb, Ce, P, Zr, Ti and Y are arranged in the right hand side. Therefore, it is possible to discriminate the rock types of metabasites by comparing the right hand side patterns of each rock with those of typical rocks.

The MORB normalized patterns of metabasites may be divided into two groups; ANT-1, -2, -4 and ANT-5, -6. ANT-3 is excluded from the above two groups. The former three show positive Ba and K anomalies in both MORB and primordial mantle normalized patterns, whereas the latter two show strong positive K and Rb anomalies and depletion in Sr and other less incompatible and HFS elements in MORB normalized pattern. In the primordial mantle normalized patterns of the latter two rocks, strong positive anomalies in K and F, and slightly positive anomaly in Rb are recognized. ANT-3 shows an abnormal pattern for less incompatible elements, especially is rich in Y and depleted in Zr. Although one explanation for such an abnormal pattern of ANT-3 is that the rock is derived from a cumulate consisting of some special phases, the major element chemistry does not show any cumulative evidence. The occurrence of quartz pool and greenish amphiboles in the rock suggests the later metasomatic alteration for another possible interpretation. ANT-1 shows a MORB-like pattern from the behavior of HFS and less incompatible elements, except K, Ba and P anomalies. The pattern of ANT-2 is similar to "within-plate basalts", or "continental alkali basalts" having positive Ba and P anomalies (YOSHIDA and AOKI, 1986). It is obvious that the addition of Ba, K and F took place in ANT-1,

-2 and -4, whereas the addition of K and F, but without addition of Ba is distinct in ANT-5 and -6. Addition of F is also distinct in ANT-3. Enrichment of both K and F represents the existence of some metasomatism with H_2O-rich fluid which plays a role of the carrier of them. If it is possible to be regarded that Ba, K and F have been enriched during the high-grade metamorphism, the pattern of ANT-1 is similar to that of typical tholeiitic MORB (Yoshida *et al.*, 1986) showing gradual depletion from HFS to LIL elements with increasing incompatibility. The patterns of the right-hand side of ANT-5 and -6 are similar to that of typical tholeiitic MORB or nearly to "active continental margin basalt", though the latter is slightly depleted in Zr, Ti, Y and Nb (Pearce, 1983). Hiroi *et al.* (1986) considered that the ultramafic rocks in the Lützow-Holm Complex were tectonically fractured and emplaced in the metasedimentary rocks, and that these rocks were derived from the presently missing part (ocean floor) between the adjacent Lützow-Holm and Yamato-Belgica Complexes, judging from their mode of occurrences. Some metabasites occurring as lenticular or rounded blocks and having the MORB-like pattern also might have been derived from the missing ocean floor. The rock of ANT-2 showing the pattern similar to that of within-plate basalt or continental alkali basalt is thought to be the post regional metamorphic igneous activity, because the rock occurs as a discordant dyke and contains relic phenocrysts of plagioclase as evidence of weak metamorphism.

5. Summary

Trace element geochemistry of basic metamorphic rocks around Syowa Station and adjacent areas is presented. The rocks have a wide range of bulk composition. Some rocks show the nature of ne-normative, and others are Q- and hy-normative. Since degree of migration of some major elements may be not so small, the evaluation of original rock series from major element chemistry is difficult. Trace element chemistry suggests migration of some incompatible elements such as K, Ba and F. The behaviors of some LIL and less incompatible elements (Nb, Ce, P, Zr, Ti and Y) are thought to have been immobile during high-grade metamorphism, and show that most of the rocks have the nature of MORB-like rocks, and one example of the discordant dyke from Cape Hinode intruded after the main regional metamorphism shows the nature of within-plate basalt or continental alkali basalt.

Although the data presented here are insufficient, the comparison with the trace element patterns of high-grade metamorphic rocks normalized by MORB and primordial mantle is useful for characterization of the original rock types.

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