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9. ZONED HORNBLENDES AND ASSOCIATED CUMMINGTONITES FROM THE NUMABUKURO PLUTONIC MASS, KITAKAMI MOUNTAINS, JAPAN

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Introduction

Exsolution textures of calciferous amphiboles and cummingtonite in plutonic rocks described from the Tanzawa Mountains (TOMITA *et al.*, 1971) have been regarded as rare examples in Japan. Moreover, TOMITA *et al.* (1972) have reported that the exsolution lamellae of hornblende-cummingtonite are widely distributed in the same area.

Chemical composition of zoned hornblendes was reported by ONUKI and KATO (1971) from the Tabito gabbroic complex in the Abukuma Plateau.

In the present study, chemistry of hornblende-cummingtonite parallel growth, their exsolution texture and strongly zoned hornblende, all from the Numabukuro quartz diorite mass in the Kitakami Mountains are described.

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Description of Host Rocks

The Numabukuro plutonic mass is situated

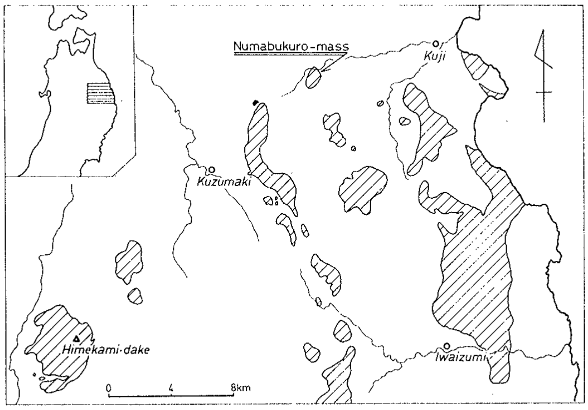

Fig. 1. Locality of the Numabukuro mass. Shaded areas are granites.

to the west of Kuji City, Northern Kitakami Mountains (Fig. 1). KATADA *et al.* (1971) divided granitic rocks of the Kitakami Mountains into six zones from their petrographical and chemical natures. The Numabukuro mass belongs to zone C which is composed of various small plutonic bodies ranging from olivine-pyroxene gabbro to biotite-hornblende granodiorite. The Numabukuro mass is a circular body of about 2 km in diameter and consists of biotite-cummingtonite quartz diorite, sometimes containing clinopyroxene. The hornblende shows strong zonal structure varying from greenish brown core to deep bluish rim. Its optical axial angles vary from $2V_x=80°$ to $56°$. Cummingtonite is frequently associated with zoned hornblende. Their mutual relation is very complicated, showing exsolution relation or irregular coexistence in one crystal. but always having b-axis (=Y-axis) in common with each other. Exsolution

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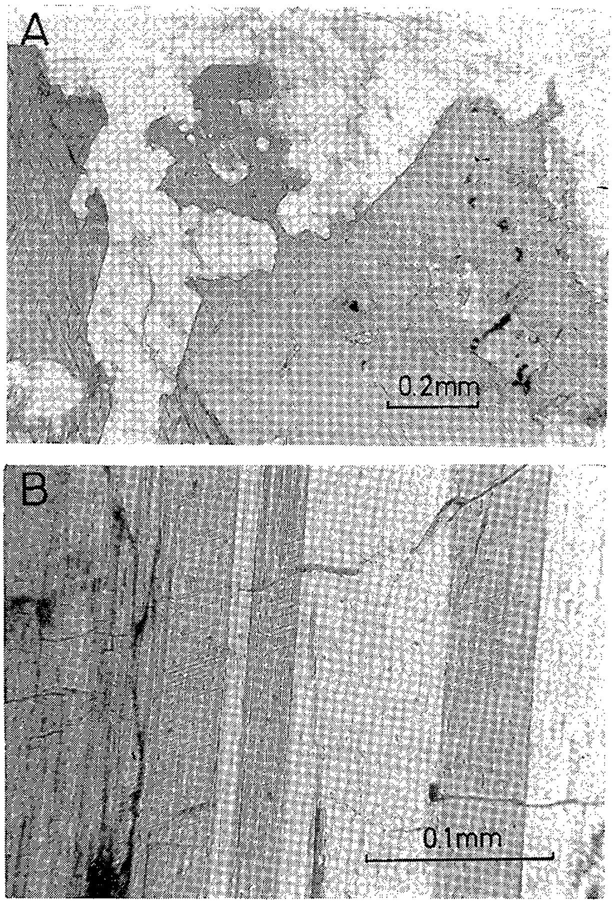

Fig. 2. A: Zoned hornblende of the Numabukuro mass. (open nicol) Deep grey part of hornblende crystals is bluish, and light grey part is brownish. B: Hornblende lamellae parallel to (001) in cummingtonite host. Twinning plane is parallel to (100). (crossed nicols)

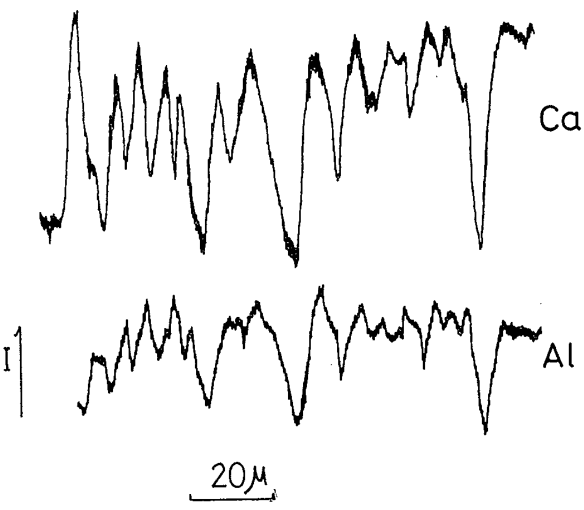

Fig. 3. Electron-microprobe scans for Ca and Al in a hornblende grain having exsolution lamellae of cummingtonite. Intense Ca and Al peaks represent hornblende part.

lamellae are parallel to (001) plane of the host crystal (Fig. 2).

Electron microprobe scan on the typical hornblende crystals containing exsolution lamellae of cummingtonite shows that hornblende host is rich in Ca and Al, whereas cummingtonite lamellae are poor in Ca and Al (Fig. 3).

Associated plagioclase has also a wide compositional range from An_{87} in the core, to An_{38} in the rim, with a distinct gap around An_{70}.

Chemistry of Zoned Hornblende and Associated Cummingtonite

Zoned hornblende and cummingtonite were analysed by means of JEOL (JAX–5) X-ray microanalyser in the Akita University. Analytical results are shown in Table 1.

From these data, it is clear that the brownish core of hornblende is rich in Si and Mg, whereas the bluish rim is rich in Al and Fe. Na+K is nearly constant. TiO_2 slightly decreases from core to rim. The greenish hornblende has an intermediate composition between the two. The most remarkable change is Mg/Mg+Fe ratio ranging from 0.67 to 0.25. Cummingtonite associated with the brown hornblende is also rich in Mg and poor in Al, whereas that associated with the bluish hornblende is poor in Fe and slightly rich in Al.

Chemical variations of zoned hornblende are shown in Fig. 4, with those of the Tabito gabbroic complex (ONUKI and KATO, 1971) and metamorphic rocks of Feather Falls (KLEIN, 1969). Al^{IV} of hornblendes increases and Mg/Mg+Fe ratio of them decreases from core to rim both in the Numabukuro and Feather Falls hornblendes, but Al^{IV} decreases, and Mg/Mg+Fe is nearly constant in the Tabito hornblende. Na+K is nearly constant in the sequence of the Numabukuro hornblende, but increases in the Feather Falls

Table 1. Electron-probe analyses of amphiboles.

Specimen No.	71060912					71060913				
	A			B		C		D	E	F
Grain	brownish core	bluish rim	cummingtonite assoc. with bluish rim	brownish core	bluish rim	brownish core	bluish rim	brownish core	green horn-blende	cumm. assoc. with bluish rim
SiO_2	49.3	44.4	51.8	49.3	45.5	49.3	43.4	49.3	49.1	56.1
TiO_2	1.0	0.7	0.1	0.9	1.2	1.6	0.7	1.5	1.2	0.1
Al_2O_3	9.7	11.2	3.1	6.9	9.6	6.3	10.9	6.6	7.2	0.6
FeO	12.2	24.4	31.8	12.0	22.9	13.4	24.5	13.3	17.9	16.3
MnO	0.4	0.8	1.5	0.5	0.8	0.4	0.5	0.5	0.5	1.0
MgO	13.3	4.7	7.6	13.6	5.1	13.1	5.3	13.0	12.3	20.4
CaO	10.9	10.1	1.5	10.7	9.7	9.8	9.7	9.9	8.6	0.5
Na_2O	1.5	1.1	0.4	1.3	1.1	1.1	1.3	1.1	1.0	0.1
K_2O	0.2	0.0	0.0	0.2	0.5	0.3	0.4	0.3	0.2	0.0
Total	98.5	97.4	97.8	95.4	96.4	95.3	96.7	95.5	98.0	95.1
	Numbers of ions on the basis of O=23									
Si	7.05	6.83	7.93	7.28	7.03	7.31	6.75	7.30	7.21	8.11
Al^{IV}	0.95	1.17	0.07	0.72	0.97	0.69	1.25	0.70	0.79	—
Al^{VI}	0.68	0.86	0.49	0.48	0.77	0.41	0.75	0.45	0.45	0.10
Ti	0.11	0.08	0.01	0.10	0.14	0.18	0.08	0.17	0.13	—
Fe^{+2}	1.45	3.13	4.06	1.48	2.95	1.66	3.18	1.64	2.19	1.96
Mn	0.05	0.10	0.19	0.06	0.10	0.05	0.07	0.06	0.06	0.12
Mg	2.85	1.08	1.75	3.01	1.18	2.92	1.24	2.89	2.71	4.41
Ca	1.67	1.66	0.25	1.69	1.61	1.56	1.62	1.57	1.35	0.08
Na	0.42	0.33	0.12	0.37	0.33	0.32	0.39	0.31	0.28	0.03
K	0.04	—	—	0.04	0.10	0.06	0.08	0.06	0.04	—

hornblende, and decreases in the Tabito hornblende with crystallization. Chemical changes from the core to the rim of zoned hornblende in the Numabukuro mass are very similar to those of Feather Falls, but are opposite to those of the Tabito complex.

Ca-Mg-Fe ratios of coexisting hornblendes and cummingtonites are shown in Fig. 5.

Consideration

Generally, stability field of amphiboles with higher Al content and Mg/Fe ratio is extended to higher temperature side, whereas that of amphiboles poor in Al and Mg is limited to lower temperature region (BOYD, 1959, ERNST, 1966, GILBERT, 1966). Both the hornblendes and the cummingtonites of the Numabukuro mass decrease in Mg/Mg+Fe ratio, but increase in Al^{IV} and also Al^{VI} from the core to the rim. Thus, in the crystallization process of the Numabukuro magma, chemical change of hornblende depends not only on falling temperature, but on the abrupt change of coexisting plagioclase around An_{70}, which may be due to an abrupt decrease of P_{H_2O}. Excess Al from plagioclase may have entered into hornblende. Among natural iron-rich calcic amphiboles, ferropargasite which is thought to be produced at extremely low oxygen fugacities is very rare, but hastingsite containing a significant amount of Fe^{+3} is common (GILBERT, 1966). The bluish hornblende of present study may also contain a considerable amount of Fe^{+3}.

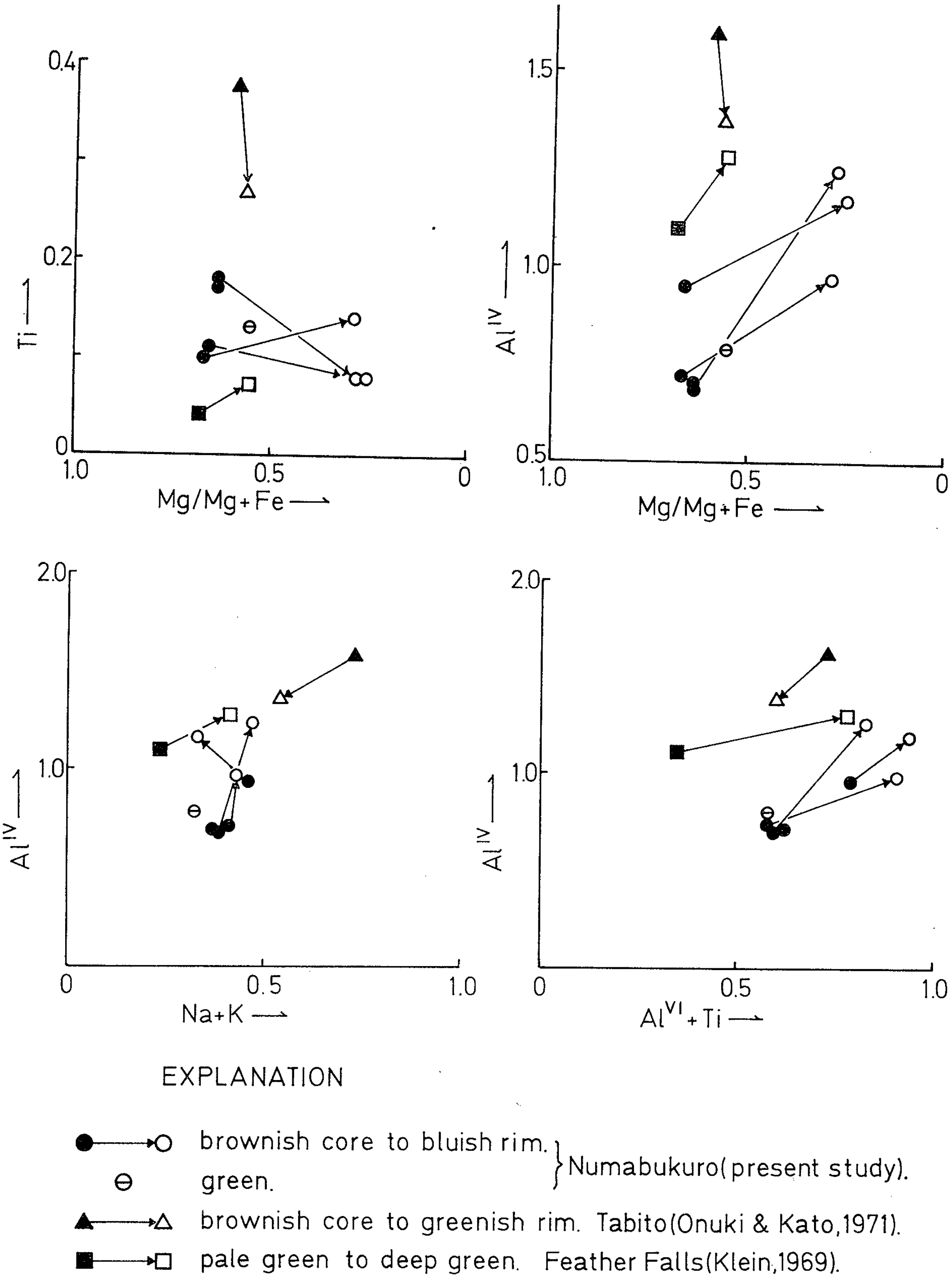

Fig. 4. Chemical variation of zoned hornblendes. Arrow shows trend from core to rim.

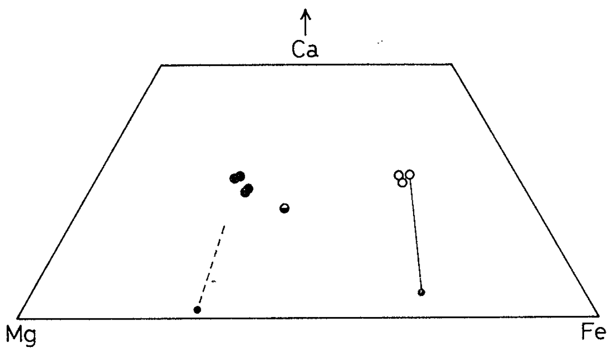

Fig. 5. Ca-Mg-Fe ratios of coexisting hornblendes and cummingtonites of the Numabukuro mass.
Solid circle: Brownish hornblende
Half solid circle: Greenish hornblende
Open circle: brownish hornblende
Small solid circle: cummingtonite
Tie line indicates coexisting pair. Cummingtonite associated with brownish hornblende is indicated by dotted line.

Substitutions of Al⇌Fe^{+3} and $(Mg, Fe^{+2})\cdot Si$ ⇌Al·Al or Al·Fe^{+3} in amphibole structure may also play an important role in their stability range, but it seems likely that these substitutions may depend on the composition and Fe^{+3}/Fe^{+2} ratio of coexisting ferromagnesian minerals, as well as f_{O_2} and temperature. Future study is expected to clarify the role of aluminum in calciferous amphiboles.

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北上山地，沼袋深成岩体中の累帯構造を示す普通角閃石および共存するカミングトン閃石

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（要　　旨）

北部北上山地の久慈市西方に分布する沼袋石英閃緑岩体中には，いちじるしい累帯構造を示す普通角閃石と，それに密接に伴なわれるカミングトン閃石が存在する．両者の関係は複雑で，お互に離溶関係を示すこともあり，平行連晶をなすこともある．マイクロプローブ分析により結晶粒の中心部の褐色普通角閃石は Mg にとみ Al に乏しく，周辺部の青緑色普通角閃石に向って Fe と Al にとむようになる．褐色普通角閃石と共存するカミングトン閃石はやはり Mg にとみ，青緑色普通角閃石と共存するものは Fe にとむ．

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Tabito	田　人
Kuji	久　慈