NOTES ON PETROGRAPHY AND ROCK-FORMING MINERALOGY (11) GREEN BIOTITE IN SANBAGAWA BASIC SCHISTS IN THE KANTO MOUNTAINS, JAPAN

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In the northeastern part of the Kanto Mountains, central Japan, in basic schists, green biotite widely occurs in a lower-grade part where garnet is common in pelitic and psammitic schists, while brown biotite is present in a higher-grade part where brown biotite commonly occurs in them.

Comparing with brown biotite from higher-grade part of the Sanbagawa metamorphic terrain in this area and central Shioku, green biotite in lower-grade part of this area contains lower Al_2O_3 and higher Fe_2O_3 , and slightly lower TiO_2 .

On the basis of the paragenetic relation of the green biotite-bearing assemblages, the occurrence of green biotite is explained by high Fe_2O_3 , $(\text{FeO} + \text{MgO})$, and low Al_2O_3 contents of the host rocks. Brown biotite in basic schists in a higher-grade part is formed by the following reaction;

green biotite + (Fe, Mg-rich) chlorite + epidote + albite + quartz = brown bitite + hornblende + (Al-rich)chlorite + magnetite + H_2O .

This reaction enlarges the stability field of biotite, and in a higher-grade part, brown biotite-bearing assemblages widely occurs in the common basic schists.

INTRODUCTION

Green biotite widely occurs in the low-grade basic schists of the Sanbagawa metamorphic terrain in the Kanto Mountains (Tanaka and Fukuda, 1974; Toriumi, 1975; Suzuki, 1977; Sakai, 1980). It occurs at the grade lower than the biotite zone where brown biotite occurs commonly in pelitic and psammitic schists.

The paragenetic relation and chemistry of green biotite were studied in the eastern part of Onishi-machi, Gunma prefecture, to elucidate its stability field in relation to the chemical environments and physical conditions. The following intends to describe the mode of occurrence of green biotite along

with discussing its genesis.

MODE OF OCCURRENCE

The study area is situated in the east of Onishi-machi, Gunma prefecture (Fig. 1). It can be divided into three metamorphic zones I, II and III that are defined by the paragenesis of pelitic and psammitic schists (Sakai, 1980). Zone I is the chlorite zone, zone II the garnet zone and zone III is the biotite zone in the sense of Higashino (1975). Green biotite occurs in basic schists in zone II and in a lower-grade part of zone III accompanied by chlorite, actinolite and epidote (Fig. 1 and Fig. 2). In a higher-grade part of zone III, all biotites in basic schists are brown colored.

Fig. 1. Metamorphic zone map and sample localities of green biotite-bearing basic schists in the east of Onishi-machi, Kanto Mountains.

Minerals	Chlorite zone	Garnet zone	Biotite zone
Na-amphibole			
Pumpellyite	-----		
Actinolite			
Hornblende			
Epidote			
Biotite			
Muscovite			
Chlorite			
Albite			
Calcite			
Quartz			
Sphene			
Apatite	-----		
Hematite	-----		
Magnetite			
Pyrite			
Chalcopyrite	-----		

Fig. 2. Schematic stability of metamorphic minerals in basic schists in the study area.

In zone II, the mineral assemblages of the green biotite-bearing basic schists are as follows: quartz and albite are always associated, and accessory minerals are sphene, apatite, calcite, pyrite and chalcopyrite;

II-1) chlorite + actinolite + epidote + green biotite + magnetite,

II-2) chlorite + actinolite + epidote + green biotite + magnetite + hematite,

II-3) chlorite + actinolite + epidote + green biotite + muscovite.

The assemblage II-1 is the most common. The assemblages II-2 and II-3 are rare. Most of green biotites occur in contact with chlorite and muscovite, and their basal planes are elongated parallel to the schistosity plane, but in the magnetite-bearing assemblages, some green biotites are in contact with euhedral magnetite.

The optical properties of the green biotite in zone II are as follows:

axial color X=colorless-pale yellow, Y=Z=dark green; refractive index $\beta=1.636\pm 0.001$; optical angle $2V_x=0^\circ$.

In a lower-grade part of zone III, the mineral assemblages of the green biotite-bearing basic schists are as follows: again quartz and albite are always present, and accessory minerals are sphene, apatite, calcite, pyrite and chalcopyrite.

- III-1) chlorite+actinolite+epidote+green biotite+magnetite,
 III-2) chlorite+actinolite+epidote+green biotite+hornblende,
 III-3) chlorite+actinolite+epidote+green biotite+muscovite,
 III-4) chlorite+actinolite+epidote+green biotite+muscovite+hornblende,
 III-5) chlorite+actinolite+epidote+green biotite+muscovite+magnetite.

The assemblages III-1 and III-2 are common. The assemblages III-3, III-4 and III-5 are uncommon. Some of green biotites form the aggregates with muscovite and chlorite.

The optical properties of the green biotite in a lower-grade part of zone III are similar to those in zone II.

In a higher-grade part of zone III, green biotite is absent and brown biotite-bearing assemblages are common. Brown biotite-bearing assemblages in a lower-grade and higher-grade part of zone III are as follows: quartz and albite are always associated, and the accessory minerals are similar to the green biotite-bearing assemblages.

lower-grade part of zone III:

- III-6) chlorite+actinolite+epidote+brown biotite,
 III-7) chlorite+actinolite+epidote+brown biotite+hornblende,
 III-8) chlorite+actinolite+epidote+brown biotite+hornblende+magnetite,
 III-9) chlorite+actinolite+epidote+brown biotite+hornblende+muscovite.

higher-grade part of zone III:

- III-10) chlorite+actinolite+epidote+brown biotite+muscovite,
 III-11) chlorite+actinolite+epidote+brown biotite+hornblende+muscovite.

CHEMISTRY OF GREEN BIOTITE

The chemical composition of green biotite in a basic schist in a lower-grade part of zone III is shown in Table 1. It was analyzed by the electron-probe micro-analyzer, model JAX-5A of the Geological Survey of Japan following the procedure described by Okumura and Soya (1976). Fe_2O_3 and FeO were determined by the

Table 1. Chemical compositions of green biotite and chlorite in a basic schist from a lower-grade part of zone III (Sample No. CS78040513)

Mineral	green biotite***	chlorite****
SiO_2	37.98	26.77
TiO_2	1.33	0.07
Al_2O_3	16.48	21.21
Fe_2O_3	3.61	
FeO	13.78	20.60 (FeO*)
MnO	0.20	0.28
MgO	13.63	20.59
CaO	0.02	0.02
K_2O	9.74	0.08
Na_2O	0.12	0.05
H_2O^{**}	4.03	12.39
Total	100.92	102.06
O =	22.0	27.0
Si	5.589	5.185
Ti	0.147	0.010
Al^{IV}	2.411	2.815
Al^{VI}	0.447	2.027
Fe^{3+}	0.399	
Fe^{2+}	1.695	3.335
Mn	0.025	0.045
Mg	2.987	5.941
Ca	0.005	0.005
K	1.828	0.019
Na	0.036	0.019
OH	4.000	16.000
Total	19.569	35.401

FeO* means total iron as FeO. H_2O^{**} was determined by stoichiometry. green biotite*** is average of three grains. chlorite**** is average of two grains.

wet chemical analysis in the Chiba University.

Suzuki (1977) described that green biotite is compositionally not different from brown biotite in the western part of the Kanto Mountains except for MgO and Al_2O_3 contents. However, the TiO_2 content (1.37 wt%) of green biotite in the study area and that (1.32 wt %) of Suzuki (1977) are slightly lower than that (1.28–2.06 wt%) of brown biotite in the Sanbagawa schists in central Shikoku (Banno, 1964; Higashino, 1975). The Al_2O_3 contents of green biotites (Suzuki, 1977; this paper) are lower than those of the brown biotites from a higher-grade part in the respective terrain. The Fe_2O_3 content (3.61 wt%) of green biotite is higher than that (0.27–1.07 wt %) of brown biotites of biotite zone in central Shikoku except one sample, which contains 4.03 wt. per cent of Fe_2O_3 (Banno, 1964). Greenish tint of green biotite in the study area is due to high $\text{Fe}_2\text{O}_3/(\text{Fe}_2\text{O}_3 + \text{FeO})$ ratio as shown by Hayama (1959).

PHASE RELATION OF GREEN BIOTITE-BEARING BASIC SCHISTS

Chemical system

The chemical components necessary to describe the typical basic schists in the Sanbagawa metamorphic terrain are SiO_2 , Al_2O_3 , Fe_2O_3 , FeO , MgO , CaO , Na_2O , K_2O and H_2O . All green biotite-bearing basic schists contain quartz, albite and epidote, and then SiO_2 , $\text{Ca}_{2.0}\text{Al}_{2.6}\text{Fe}^{3+}_{0.4}\text{Si}_3\text{O}_{12}(\text{OH})$ (average of $\text{Fe}^{3+}/(\text{Fe}^{3+} + \text{Al})$ in this area is 0.15), and $\text{NaAlSi}_3\text{O}_8$ can be regarded as excess components. Consequently, the mineral paragenesis of basic schists in the study area can be discussed in terms of five component system Al_2O_3 - Fe_2O_3 - FeO - MgO - KAlSi_3O_8 .

However, some essential features of the paragenetic relation may be revealed by treating it as a pseudo-quarternary system, in which FeO and MgO are jointly treated as if a single component. Fig. 3 shows the paragenetic relation of such a pseudo-quarternary system with excess of quartz, albite and epidote.

Fig. 3. Paragenetic relation in the pseudo-quarternary system Fe_2O_3 - Al_2O_3 -($\text{FeO} + \text{MgO}$)- KAlSi_3O_8 for the green biotite-bearing basic schists in zone II and a lower-grade part of zone III. Projection is made from quartz, albite, epidote and H_2O . FMO is ($\text{FeO} + \text{MgO}$). G-B means green biotite.

Here, the formulae for chlorite, green biotite and muscovite are assumed as follows:

The maximum Fe_2O_3 content of chlorite from the Bessi district is 3.0 wt per cent, then it may be ignored in crude treatment. The calciferous amphiboles such as actinolite and hornblende are plotted in the negative field in regard to the Al_2O_3 and Fe_2O_3 components.

Four-phase assemblages of green biotite-bearing basic schists

In Fig. 3, the following four-phase regions are distinguished. The parentheses show the observed assemblages of zone II and a lower-grade part of zone III.

1. chlorite+actinolite+green biotite+magnetite (II-1),
2. chlorite+actinolite+green biotite+muscovite (II-3 and III-3),
3. chlorite+hornblende+green biotite+magnetite (III-1),
4. chlorite+actinolite+hornblende+green biotite (III-2),
5. chlorite+green biotite+magnetite+hematite,
6. chlorite+green biotite+muscovite+hematite,
7. actinolite+hornblende+green biotite+magnetite.

These mineral parageneses are compatible with the common mineral assemblages of other rock-types, such as phengite+chlorite+manganian-garnet in pelitic and psammitic schists and chlorite+

actinolite (+epidote) in basic schists in zone II, and chlorite+hornblende (+epidote) in zone III.

Five-phase assemblages of green biotite-bearing basic schists

The five-phase assemblages in the green biotite-bearing basic schists, such as the assemblages II-2, III-4 and III-5, can not be shown in Fig. 3. In the system where FeO and MgO are treated as independent components, however, they are compatible with the four-phase assemblages discussed above.

For example, green biotite-magnetite-bearing five-phase assemblages, such as the assemblages II-2 and III-5 are shown in a tetrahedral diagram, Fig. 4, where chlorite, green biotite, muscovite and hematite are projected from magnetite. The FeO component is plotted at minus infinite distance in this diagram. Green biotite, chlorite and actinolite are plotted in the negative field in regard to the Fe_2O_3 component. In this diagram, green biotite is also plotted in a tetrahedron of chlorite-actinolite-muscovite-hematite, and then the tetrahedron is divided into four volumes. Fig. 4 shows that the following four-phase volumes are distinguished.

1. green biotite+chlorite+actinolite+hematite (II-2),
2. green biotite+chlorite+actinolite+muscovite (III-5),
3. green biotite+chlorite+muscovite+hematite,
4. green biotite+actinolite+muscovite+hematite.

In this diagram, green biotite-magnetite-bearing four-phase assemblages II-1 and III-1 belong to these five-phase assemblages, and then these five-paragenetic relations are consistent with the assemblages

Fig. 4. Paragenetic relation of green biotite-bearing basic schists in zone II and a lower grade-part of zone III shown in the five-component system $\text{Fe}_2\text{O}_3\text{-Al}_2\text{O}_3\text{-FeO-MgO-KAlSi}_3\text{O}_8$ with excess magnetite. The projection points for actinolite, green biotite and chlorite are negative in regard to the Fe_2O_3 component. FeO component is plotted at minus infinite distance. "hm"=hematite; "mus"=muscovite; "biot"=green biotite; "chl"=chlorite; "act"=actinolite.

II-1 and III-1. Consequently, all the magnetite-bearing assemblages observed in the study area are compatible with each other.

The green biotite-muscovite-bearing five-phase assemblage, III-4, is also consistent with other green biotite-bearing assemblages in the quarternary system in

which chlorite, actinolite, hornblende, green biotite, hematite and magnetite are projected from muscovite (Fig. 5). Fig. 5 shows the paragenetic relation of a quarternary $\text{Fe}_2\text{O}_3\text{-Al}_2\text{O}_3\text{-FeO-MgO}$ system with excess of quartz, albite, epidote and muscovite. Green biotite is plotted in the negative field in regard to the Al_2O_3 component.

Fig. 5. Paragenetic relation for the green biotite-muscovite-bearing assemblages in the quaternary system Fe_2O_3 - Al_2O_3 - FeO - MgO . Projection is made from quartz, albite, epidote, muscovite and H_2O as excess phases. The projection points for actinolite and hornblende are negative, for other minerals positive in regard to the Fe_2O_3 component.

Hornblende and actinolite are plotted in the negative field in regard to the Al_2O_3 and Fe_2O_3 components as well. The following mineral parageneses are distinguished from this diagram. The observed mineral parageneses in the green biotite-muscovite-bearing basic schists in the study area are shown in parentheses.

1. chlorite + actinolite + hornblende + green biotite (III-4),
2. chlorite + actinolite + magnetite + green biotite.

Green biotite-muscovite-bearing four-phase assemblages II-3 and III-3 belong to five-phase assemblage III-4, and then these green biotite-muscovite-bearing assemblages observed in the study area are compatibly shown in this diagram.

As a results, all the green biotite-bearing assemblages observed in the study area are compatible with each other.

Bulk composition of green biotite-bearing basic schists, and chemical reaction producing brown biotite

From Fig. 3, it is understood that green biotite occur in basic schists with relatively higher Fe_2O_3 and $(\text{FeO} + \text{MgO})$ contents and lower Al_2O_3 content than those of other rock-types in zone II (garnet zone) and a lower-grade part of zone III (biotite zone), and that the mineral is absent from the pyrrhotite and carbonaceous matters-bearing common pelitic schists with low oxygen fugacity. As described previously, in a lower-grade part of zone III, some brown biotites occasionally occur in basic schists. They do not coexist with green biotite and the brown biotite-magnetite-bearing assemblage (III-8) is uncommon. Therefore, brown biotite may occur in basic schists with lower Fe_2O_3 content than that of green biotite-bearing basic schists in a lower-grade part of zone III.

Green biotite disappears and brown biotite becomes more common in a higher-grade part of zone III. As described previously, the Al_2O_3 content of brown biotite in a higher-grade part is higher, while the Fe_2O_3 content is lower than in green biotite. Mather (1970) has indicated that muscovite shows an increase in the amount of the Al_2O_3 component and a decrease in the $(\text{FeO} + \text{MgO})$ component as metamorphic grade increases in Dalradian. Ernst et al. (1970) and Otsuki (1980) have also shown that the Al_2O_3 content in chlorite and muscovite increases with increasing metamorphic temperature in the Sanbagwa metamorphic terrain. Consequently, in a higher-grade part of zone III, the formation of brown biotite may be explained by the following reaction;

Fig. 6. Fe_2O_3 - Al_2O_3 -($\text{FeO}+\text{MgO}$)- KAlSi_3O_8 pseudo-quarternary diagram showing the enlargement of the stability field of the biotite-bearing assemblages with increasing metamorphic temperature. Projection points for actinolite and hornblende are negative in regard to the Fe_2O_3 component. FMO is ($\text{FeO}+\text{MgO}$). G-B and B-B denote green biotite and brown biotite, respectively.

part of zone III)
 =brown biotite+hornblende+(Al-rich)
 chlorite+magnetite+ H_2O (higher-grade
 part of zone III).

Fig. 6 shows that the reaction enlarges the stability field of biotite in a higher-grade part of zone III. In this diagram, in a higher-grade part of zone III, the stability field of biotite in basic schists is larger than in a lower-grade part of zone III, and then brown biotite widely occurs in basic schists with relatively lower Fe_2O_3 and higher Al_2O_3 of the host rocks.

CONCLUSIONS

On the basis of the paragenetic relation of the biotite-bearing basic schists and chemical composition of the green biotite, the following conclusions are drawn. (1) Green biotite occurs in basic schists with relatively higher Fe_2O_3 and ($\text{FeO}+\text{MgO}$) contents and lower Al_2O_3 content. Therefore, it is absent from common pelitic schists with low oxygen fugacity in the Sanbagawa metamorphic terrain.

(2) Brown biotite in basic schists is formed by the following reaction;

The stability field of biotite-bearing assemblages enlarges with elevating temperature by this reaction. Consequently, brown biotite-bearing assemblages are more common in a higher-grade part, as we observed in field.

ACKNOWLEDGEMENTS

The author wishes to express my sincere thanks to Prof. S. Banno, Kyoto University, for his critical reading of this manuscript as well as his constructive criticism and stimulating discussion. He would especially like to thank Prof. M. Yamazaki, Kanazawa University and Prof. K. Kanehira, Chiba University, for their critical reading. His thanks are also due to Mr. K. Takai, Chiba University, for the wet chemical analysis, and to Mr. T. Higashino, Hakusan

Nature Conservation Center, for his kind advice and continuous encouragements. The electron-probe micro-analysis of green biotite and chlorite is carried out with EPMA of the Geological Survey of Japan by Mr. M. Imaizumi, now at Sumitomo Consultant Ltd. Thanks are also due to Mr. K. Okumura, Geological Survey of Japan, for the convenience of the micro-probe analysis.

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岩石学造岩鉱物学ノート (11) 関東山地三波川塩基性片岩中の緑色黒雲母

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関東山地北東部に分布する三波川変成帯のザクロ石帯から黒雲母帯の低温部では、塩基性片岩中に緑色黒雲母が出現する。この緑色黒雲母の組成と、鉱物共生関係を調べることにより、その生成条件を考察した。

マイクロプローブと湿式の分析により、緑色黒雲母はより高変成度の岩石中に産する褐色黒雲母と比べて、 TiO_2 にわずかに乏しく、比較的高い Fe_2O_3 量と低い Al_2O_3 量を含むことがわかった。このことは、緑色黒雲母の濃緑色の軸色が高い $\text{Fe}_2\text{O}_3/(\text{Fe}_2\text{O}_3+\text{FeO})$ 比に依存することを示す。 $\text{Fe}_2\text{O}_3-\text{Al}_2\text{O}_3-(\text{FeO}+\text{MgO})-\text{KAlSi}_3\text{O}_8$ の擬4成分系に投影した共生関係は、緑色黒雲母が、 Fe_2O_3 と $(\text{FeO}+\text{MgO})$ に富み、 Al_2O_3 に乏しい塩基性片岩中に出現し、普通の泥質片岩中には出現し得ないことを示す。より高温では、緑色黒雲母+緑泥石+緑レン石+曹長石+石英=褐色黒雲母+ホルンブレンド+磁鉄鉱+緑泥石+水の反応が生じ、黒雲母の安定領域が拡大され、褐色黒雲母のみが出現する。

Onishi : 鬼石

Jushi : 出牛