43. On Biotites in Thermally Metamorphosed Slates from Senmaya, Iwate Prefecture, Japan

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This paper presents the result of the writer's study on biotites from contact metamorphic zone near Senmaya, Iwate Prefecture, northeast Honsyû, with special reference to the relationship between the chemical compositions and optical properties of the mineral.

Modes of Occurrence

The rocks from which the biotites were separated for analyses belong to the inner zone of the contact aureole around the Senmaya quartz-diorite mass (Fig. 1). They were derived from Palaeozoic clay-slate which is exposed widely in southern Kitakami plateau. In hand specimens, the thermally metamorphosed rocks are compact, dark brownish, and remarkably schistose. Microscopically they are granoblastic, with component minerals ranging from 0.2 to 0.4 mm. in diameter. The mineral assemblages of the rocks are listed in Table I.

Table I

Mineral assemblages of the rocks

Specimen No. 1	Essential: quartz, plagioclase ($Ab_{76}An_{24}$), cordierite ($\beta=1.558$), biotite, muscovite Accessory: andalusite (relics), apatite, graphite, greenish tourmaline
Specimen No. 2	Essential: quartz, plagioclase ($Ab_{73}An_{27}$), cordierite ($\beta=1.555$), biotite, muscovite Accessory: apatite, zircon, graphite, greenish tourmaline
Specimen No. 3	Essential: quartz, plagioclase ($Ab_{70}An_{30}$), cordierite ($\beta=1.553$), biotite Accessory: apatite, zircon, graphite, tourmaline
Specimen No. 4	Essential: quartz, plagioclase ($Ab_{55}An_{45}$), cordierite ($\beta=1.550$), biotite, anthophyllite ($r=1.679$) Accessory: apatite, graphite, dark greenish tourmaline

Biotites constitute as much as 30% of the host rock in specimen No. 3, and about 20% in the others. It generally occurs as rounded granules, 0.2–0.4 mm. in diameter. It tends to be closely as-

- Quartz-diorite mass
- Palaeozoic formations
- Contact aureole

Fig. 1. Map showing the localities of the host rocks of the analyzed biotites. Crosses show the points from which the specimens No. 1–No. 4 were collected.

sociated with muscovite, cordierite, and anthophyllite, but not with plagioclase and quartz. The biotite forms rims around muscovite crystals in specimen Nos. 1 and 2, and is penetrated by prisms of anthophyllite in No. 4. Small biotite granules are scattered sporadically within cordierite crystals in all specimens. In Nos. 1 and 2, the biotite is subjected to incipient chloritization along the margin of the crystals and cleavage traces.

Separation of Biotites

Biotites for chemical analyses were separated from their host rocks in the following way. About 10 kilograms of each host rock were pulverized by a jaw-crusher and passed through a 200-mesh screen. After completely washed by distilled water, biotites were concentrated by means of electromagnetic separator and then by hand tapping. The material thus obtained was about 20–30 grams and contained biotites as much as 90%. Furthermore, by using bromoform (Nos. 1, 2, and 3) or Thoulet solution (No. 4), the biotites were concentrated up to 99%. Finally they were purified by Crelici solution. Thus 2–3 grams of the biotites, practically free from impurities, were obtained.

Optical Properties and Chemical Compositions

The optical properties and chemical compositions of the Senmaya biotites are shown in Tables II and III. The refractive indices were determined by the immersion method using Na-light, and optical

Table II
Optical properties of the biotites

Specimen number	α	γ	$\gamma - \alpha$	$2V$
1	1.622	1.657	0.035	2°
2	1.618	1.652	0.034	3°
3	1.610	1.645	0.035	5°
4	1.604	1.641	0.037	2°

Specimen number	Pleochroism	Absorption
1	X ...nearly colourless, Y and Z ...dark brownish red	$X \ll Y < Z$
2	X ...pale greenish yellow, Y and Z ...dark brownish red	$X \ll Y < Z$
3	X ...pale greenish yellow, Y and Z ...dark brownish red	$X \ll Y < Z$
4	X ...pale brownish yellow, Y and Z ...dark reddish brown	$X \ll Y < Z$

angles from the conoscopic observations. The chemical analyses were made by the writer, being assisted by T. Hata, J. Ossaka, and T. Tandhaphongse.

Table III
Chemical compositions of the biotites

Specimen number	1	2	3	4 *)
SiO ₂	31.57	33.70	34.82	35.08
TiO ₂	3.05	3.74	2.79	2.59
Al ₂ O ₃	20.79	20.59	21.41	20.26
Fe ₂ O ₃	0.42	0.63	0.66	0.60
FeO	24.77	21.24	18.87	18.88
MnO	0.19	0.25	0.23	0.16
MgO	6.62	6.44	9.02	10.63
CaO	—	0.57	0.23	—
Na ₂ O	0.47	1.07	0.31	0.18
K ₂ O	9.11	8.09	8.23	8.28
H ₂ O(+)	3.89	3.85	3.85	4.02
H ₂ O(—)	0.09	0.05	0.13	0.11
F	0.08	0.06	0.05	0.06
Total	101.05	100.28	100.60	100.85

*) In his previous paper (Yamada, 1943), the writer has already reported the result of the chemical analyses of this biotite, except the weight percentage of F.

From Table III the atomic ratios of the biotites were calculated on the basis of Berman's formula $W(X,Y)_{2-3}Z_4O_{10}(OH,F)_2$ (Berman, 1937), with the results given in Table IV.

Table IV
Atomic ratios of the biotites

Specimen number	1	2	3	4
O ⁻²	2000	2000	2000	2000
Z { Si ⁺⁴	490	515	517	521
{ Al ⁺³	310	285	283	279
Y { Al ⁺³	63	86	91	76
{ Fe ⁺³	5	7	7	7
{ Ti ⁺⁴	35	43	31	29
X { Fe ⁺²	321	271	234	234
{ Mg ⁺²	153	147	199	235
{ Mn ⁺²	3	3	2	2
W { Ca ⁺²	—	9	4	5
{ Na ⁺	12	27	8	—
{ K ⁺	180	153	156	157
{ OH ⁻	404	329	381	389
{ F ⁻	4	3	2	3

Discussions

The following discussions are based on Tables II, III, and IV.

- 1) In the Senmaya biotites, the number of Al^{+3} atoms in Z group, which varies from 279 to 310, is larger than that in any other biotites so far known. In the igneous biotites, it is usually between 210 and 250. The number of Al^{+3} atoms in Y group varies from 63 to 81 and is larger than that in biotites from igneous rocks.
- 2) As to the number of Fe^{+2} atoms (212–321) and that of Ti^{+4} atoms (29–43), the Senmaya biotites do not differ much from biotites in granitic rocks and gneisses. While, the number of Fe^{+3} atoms of the Senmaya biotites is about 7, markedly smaller than that in biotites from granitic rocks (Fig. 2).

Fig. 2. Diagram showing the relation between the numbers of Fe^{+2} and Fe^{+3} atoms in biotites of various occurrences. Biotites from granitic rocks are plotted in the area A, while biotites from gneisses, in the area B. Open circles denote the biotites from Senmaya and a solid circle denotes a biotite in thermally metamorphosed slate from Karakasa (Tsuboi, 1938, p. 129). Note that circles are located at the extreme left of this diagram.

Fig. 3. Diagram showing the relation between the number of Fe^{+2} atoms and r in biotites of various occurrences. Symbols are same as in Fig. 2. Note that circles fall close to a curve $a-a'$. The pairs of points connected by dotted lines represent biotites with the same $\text{Fe}^{+2} + \text{Fe}^{+3}$ contents. Point 4' denotes a biotite from Senmaya quartz-diorite (unpublished data). Point 2' denotes a biotite in granite from Isikawayama (Tsuboi, 1938, p. 128).

- 3) The number of atoms in W group is the largest in igneous micas (nearly 200), intermediate in the Senmaya biotites (194–162), and the smallest in katamorphic micas such as sericite, illite, etc. (120–150). Thus the number of atoms in W group appears to be a measure of the temperature of formation of the micas.
- 4) The number of F^- atoms in the Senmaya biotites is markedly smaller (2–4) than that of igneous biotites^{**)} .
- 5) From Figs. 2 and 3 it follows that: (i) In biotites with the

^{**)} For example, the number of F^- is 10 or more in biotites from Senmaya quartz-diorite.

same Fe^{+2} content, the value of γ increases with the content of Fe^{+3} . (ii) In biotites with the same Fe^{+3} content, the value of γ increases with the content of Fe^{+2} . (iii) The effect of Fe^{+3} is greater than that of Fe^{+2} in raising the value of γ , in accordance with Heinrich's remark (Heinrich, 1946). The dotted lines in Fig. 3 illustrate the relation between the Fe^{+2} content and γ in a series of biotites whose $\text{Fe}^{+2} + \text{Fe}^{+3}$ contents are constant. (iv) Rather low value of γ of the Senmaya biotites may be taken as due to the poverty of Fe^{+3} relative to Fe^{+2} , but not due to the poverty of $\text{Fe}^{+2} + \text{Fe}^{+3}$.

6) As is shown in Table II, the amount of double refraction ($\gamma - \alpha$) of the Senmaya biotites varies from 0.035 to 0.037. While, ($\gamma - \alpha$) of biotites varies from 0.040 to 0.050 in gneisses, and from 0.050 to 0.070 in granitic rocks. The Fe^{+3} content, on the other hand, is 5-7 in the Senmaya biotites, 8-15 in biotites from gneisses, and 12-50 in biotites from granitic rocks. This fact shows that Fe^{+3} content in biotites gives a remarkable effect on raising the amount of double refraction.

7) The pleochroism of the Senmaya biotites is noteworthy. The axial colours for Y and Z are reddish, characteristic of biotites from thermally metamorphosed slates. It has been suspected that the colour of biotites is affected most strongly by their Fe^{+3} and Ti^{+4} contents and less so by Fe^{+2} . In a series of biotites with such high Ti^{+4} contents as 25-45,*** the axial colours for Y and Z are known to vary from black to brown as their Fe^{+3} contents decrease, and are dark red when the number of Fe^{+3} becomes less than 10. Then the reddish axial colours appear to be due to the ionic colour of Ti^{+4} . This colour effect of Ti^{+4} may be especially remarkable when the colour effect of Fe^{+3} is not too great. The rather high Ti^{+4} and low Fe^{+3} contents of the Senmaya biotites probably explain their characteristic pleochroism.

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*** In biotites with low Ti^{+4} contents, such as those occurring in nepheline-syenites, ultrabasic rocks, etc. (Heinrich, 1946; Miyashiro, 1947), the colour varies from pale to dark green as the content of Fe^{+3} increases. Then the greenish colour appears to be due to the ionic colour of Fe^{+3} .

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