10. EXSOLUTION TEXTURE IN COEXISTING AMPHIBOLES FROM TANZAWA TONALITE COMPLEX, TANZAWA MOUNTAINLAND, CENTRAL JAPAN

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Abstract

Coexisting amphiboles, hornblende and cummingtonite pairs in tonalite igneous rocks frcm Tanzawa Mountainland, Central Japan have been examined by optical, X-ray and electron microprobe techniques. It is demonstrated that the hornblende and cummingtonite pair has very fine exsolution lamellae respectively of hornblende from cummingtonite host or of cummingtonite from hornblende host. The exsolved phases of the two amphiboles appear as lamellae oriented parallel to ($\bar{1}01$) and (100) of the host.

Host hornblende and the exsolution lamellae of cummingtonite and hornblende have space group symmetry $C\,2/m$, but host cummingtonite has space group symmetry $P\,2_1/m$.

These coexisting amphibole pairs were formed as primary igenous phases, and with subsequent cooling the lamellae were expelled due to unmixing.

Introduction

Primary occurence of Ca-poor amphibole, such as cummingtonite and anthopyllite, has been a matter of discussion when it is associated with Ca-rich amphiboles in metamorphic or igneous rocks. Two cases in which the two amphiboles coexist are recognized, one of them is in a physical contact and the other is in a parallel intergrowth. The former assemblage has been interpreted to be in equilibrium and in the latter case, two different interpretations have been made either, unmixing or secondary replacement.

ASKLUND, BROWN and SMITH (1962) reported coarsely intergrown amphiboles in amphibolite from Skothagen, Sweden which include very fine lamellae parallel to (001); colorless lamellae in hornblende, and green lamellae in cummingtonite. They suggested that the coarse intergrowth of cummingtonite

and hornblende is primary, whereas the fine lamellae parallel to (001) represent exsolution analogous to that in the pyroxenes. After this investigation, reports on exsolution textures in amphibole were published by many investigators. (VERMON (1962), BINNS (1965), BORIANI and MINUTTI (1965), CALLEGARI (1966) JAFFE, ROBINSON and KLEIN (1968), ROSS, SMITH and ASHTON (1968), ROSS, PAPIKE and WEIBLEN (1968), ROBINSON, JAFFE, KLEIN and ROSS (1969), WOENSDREGT and HARTMAN (1969), ROBINSON, JAFFE, ROSS and KLEIN (1971), CEOUDKURI (1972). ROSS, PAPIKE and SHAW (1969) described the intergrowth textures of amphiboles observed in specimens from thirteen localities, and explained all the intergrowth textures of amphiboles by unmixing, and moreover explained amphibole phase relations by analogy of pyroxene phase relations.

However, these studies of exsolution in amphibole dealt with only the amphibole from metamorphic rocks except the amphibole from gabbro, the Moxie pluton,

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Marine (Ross, Papike and Shaw (1969)).

The present work deals with the coexistence of the two amphiboles of igneous origin, in tonalite and diorite from the Tanzawa Mountainland, central Japan. Cummingtonite from Tanzawa Mountainland was first described by Iwao (1937), but lamellae in the cummingtonite and the hornblende had not been noticed, until Kojima (1952) described very fine lamellar structure in the two amphiboles as polysynthetic twinning on (100) and parting on (001). He interpreted the parallel intergrowth of the amphiboles as replacement of hornblende by cummingtonite. The purpose of the present study is to describe the exsolution textures of hornblende and cummingtonite in tonalite and diorite from Tanzawa Mountainland, and to show that the association of the two amphiboles is explained as crystallized under a cotectic condition.

General Geology

The Tanzawa tonalite complex intrudes into the Tanzawa group, Neogene tertiary formation (lower to middle Miocene). This is one of the largest plutonic mass of the Neogene plutonic rocks exposed in the *Green Tuff* region in Japan. The plutonic complex is exposed in the area about 20×5 km with E-W elongation and is composed of ten rock types which are as follows (Takita (1974)):

1) Otakisawa type—fine grained cummingtonite hornblende diorite.

2) Kumakizawa type—medium grained two pyroxene hornblende quartz diorite.

3) Yushin type—coarse to medium grained porphyritic hornblende biotite tonalite.

4) Azegamaru type—medium grained hornblende diorite — hornblende biotite tonalite.

5) Hakoneyazawa type—gneissose biotite hornblende tonalite.

6) Itagoyazawa type—fine to medium grained hornblende biotite quartz diorite porphyrite.

7) Yokisawa type—fine grained hornblende biotite tonalite porphyrite.

8) Jizozawa type—medium grained biotite hornblende tonalite.

9) Mominokisawa type—coarse to medium grained cummingtonite biotite trondhjemite.

10) Fujimi type—fine grained biotite trondhjemite.

Most of the plutonic complex is occupied by the Kumakizawa, the Yushin and the Azegamaru types. Other rock types exist as small bodies. According to the sequence of intrusion, these ten rock types can be divided into the following four groups; I 1), 2), II 3), 4), III 5), 6), 7), 8), 9) and IV 10).

Description of Host Rocks of Amphiboles used in this study

a) *Otakisawa type*—cummingtonite hornblende diorite:

The Otakisawa type is one of the earliest groups of the plutonic complex and occurs as a large xenolith like mass within the tonalite mass of Azegamaru type. Iwao (1937) and Kojima (1952) described this rock as hornblende microgabbro or gabbroic diorite inclusion in hornblende quartz diorite (tonalite). The rock of this type is fine to medium grained, massive rock, dark in color and shows dioritic texture with large poikilitic hornblende (up to 2.0 mm) and large plagioclase (up to 1.6 mm) or rarely shows granoblastic texture under the microscope. The constituent minerals are plagioclase, hornblende, and cummingtonite. Biotite and quartz which is less abundant, often fills the interstices among other minerals. Opaque minerals, apatite and sphene occur as accessory minerals.

Table 1a. Optical properties of main constituent minerals of the rock specimens.

			Azegamaru type		Otakisawa type	
			81008–b	81307–a	N–157a	N–166
Plagioclase	An %	core	44	65–48	67	68
		rim	30–28	35	47	61
Hornblende	axial color	X	very pale yellow	pale yellow	pale yellow	pale yellow
		Y	green with brownish tint	brownish deep green	brownish green	green with brownish tint
		Z	pale bluish green	greenish brown	pale brownish green	brownish green
	2Vz		71°, 73°	69°–73°	77°	71°
	index γ		1.674	1.680	1.676	1.677
Cummingto-nite	2Vx		85°	87°	75°	79°
	index γ		1.669	1.670	1.666	1.669
Biotie	axial color	X	pale yellow	pale yellow	alter to chlorite	pale yellow
		Y=Z	brown	deep brown		reddish brown
	index γ		1.640	1.642		1.652

Table 1b. Modal composition of the rock specimens.

Rock type	Azegamaru type		Otakisawa type	
Sample No.	81008–b	81307–a	N–157a	N–166
Plagioclase	53.6%	53.3	61.5	66.1
Quartz	37.3	19.1	0.0	0.0
Biotite	6.7	3.6	0.0	1.5
Hornblende	0.6	17.9	20.1	20.7
Cumming-tonite	0.4	2.8	12.7	7.0
Opaque	1.1	2.8	5.0	4.7
Others*	0.3	0.5	0.7	0.0
Total	100.0	100.0	100.0	100.0
Color index	8.7	27.6	37.8	33.9

* Sphene, apatite, zeolite

b) *Azegamaru type*—biotite hornblende tonalite:

The tonalite mass of the Azegamaru type is exposed largely in the complex. This tonalite mass exhibits change of distinct facies from hornblende quartz diorite to
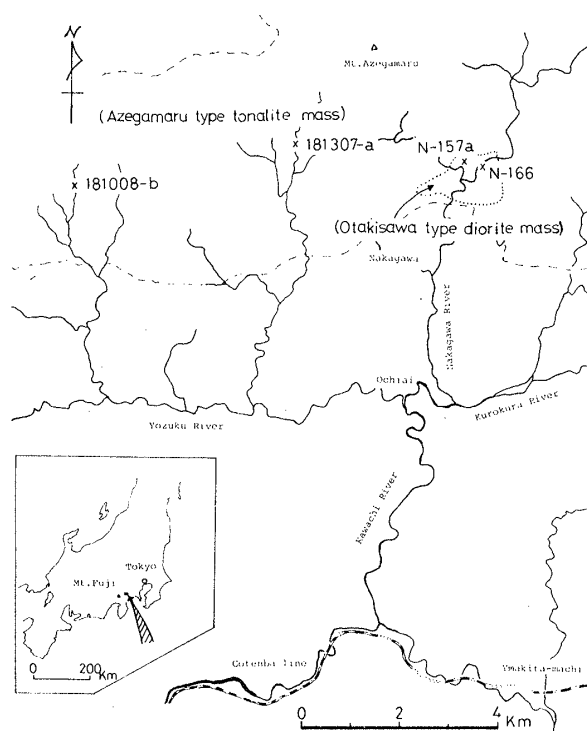

Fig. 1. Map showing location of rock specimens.

hornblende biotite tonalite. The typical facies is medium grained massive rock with hornblende and plagioclase. Under the microscope, it shows hypidiomorphic granular texture and sometimes poikilitic texture by large crystals of hornblende (up to 5 mm). The main constituents are plagioclase, quartz, hornblende, biotite and cummingtonite. Rhombic and monoclinic pyroxenes, and potassium feldspars are rare. Accessory minerals are opaque minerals, apatite, zircon and sphene. Chlorite, clinozoisite, prehnite, sericite and calcite are secondary minerals.

The modal compositions and optical properties of minerals in the rock specimens used are shown in Table 1, and these rock specimens were collected from the localities shown in Figure 1.

Optical Studies

Amphibole specimens used in this study are listed in Table 2. Green hornblende from the Otakisawa type diorite (N–157a, N–166) coexisting with cummingtonite contains very thin lamellae, approximately 10^{-4} cm thick or less, of colorless amphibole oriented parallel to ($\bar{1}01$). The lamellae oriented parallel to (100) of hornblende cannot be detected, but striations parallel to c-axis are clearly

recognized under the microscope.

Cummingtonite from the Otakisawa type diorite (N–157a, N–166) is commonly coexisting with hornblende. In many cases, the two amphiboles have common crystallographic axis, but the boundary between the two amphiboles is irregular. Sometimes hornblende is fringed by the narrow rims of cummingtonite and in some cases, a grain of cummingtonite has a narrow rim of hornblende.

These cummingtonites have very thin lamellae of hornblende, about 10^{-4} cm thick or less, oriented parallel to ($\bar{1}01$) and occasionally to (100). However, because of the variable abundance, thickness and distribution of lamellae, in some grains the lamellae textures are not detected clearly under the microscope.

A typical coexisting amphiboles and their lamellae structure (specimen N–157a) are shown in Figure 2.

Green hornblende from the Azegamaru type tonalite (81008–b, 81307–a) contains very thin lamellae of colorless amphibole oriented parallel to ($\bar{1}01$) of the host, but (100) lamellae can not be observed, and only striations oriented to (100) are detectable. Some hornblendes are fringed by narrow rims of blue green hornblendes.

Cummingtonites from the Azegamaru type

Table 2. Amphibole specimens used in this study

| Sample No.	Specimen	Host rock	Rock specimen Sample No.
1	hornblende	hornblende diorite Otakisawa type	N–157a
2	cummingtonite		
3	hornblende	hornblende diorite Otakisawa type	N–166
4	cummingtonite		
5	hornblende	hornblende biotite tonalite Azegamaru type	81008–b
6	cummingtonite		
7	hornblende	hornblende biotite tonalite Azegamaru type	81307–a
8	cummingtonite		
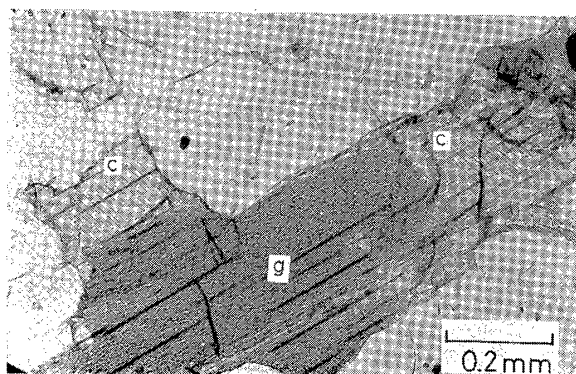
Fig. 2. Photomicrograph of coexisting amphiboles with lamellae. Specimen: Otakisawa type N–157a. Uncrossed polarizers.

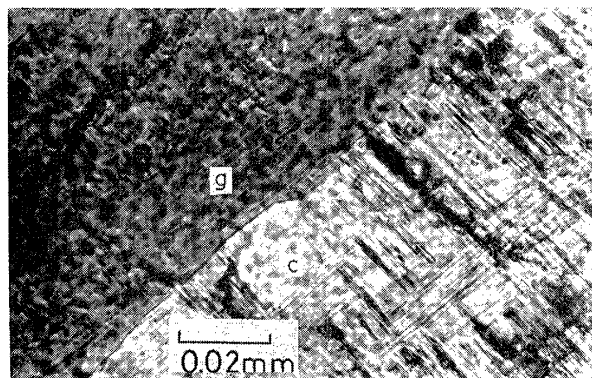tonalite coexist with hornblende, and in many cases, these two amphiboles show parallel

Fig. 3. Photomicrograph of coexisting amphiboles with lamellae. Specimen: Azegamaru type 81008–b. Uncrossed polarizers.

intergrowth but the boundaries between the two amphiboles are irregular. Very thin lamellae which is parallel to ($\bar{1}01$) of the host, and (100) striations are recognized in these cummingtonites.

Microphotograph of the two amphiboles from the tonalite of the Azegamaru type (81008–b) is shown in Figure 3.

Single Crystal X-ray Studies

Four hornblende and cummingtonite pairs which are listed in Table 2 have been examined by single crystal X-ray techniques. Unit cell data from Buerger precession X-ray single crystal photograph are given in Table 3.

Table 3. Cell dimensions of cummingtonite, two exsolved hornblende (cummingtonite host), hornblende and two exsolved cummingtonite (hornblende host) in diorite and tonalite.

Sample No.	Amphibole	a (Å)	b (Å)	c (Å)	β	V (Å³)
	hornblende	9.84	18.1	5.31	104°54′	916
1	exsolved cummingtonite on ($\bar{1}01$)	9.51	18.1	5.32	102°15′	898
	exsolved cummingtonite on (100)	9.53	18.1	5.31	102°10′	898
	cummingtonite	9.50	18.1	5.31	102°11′	892
2	exsolved hornblende on ($\bar{1}01$)	9.82	18.1	5.33	105°08′	914
	exsolved hornblende on (100)	9.83	18.1	5.31	104°51′	913
	hornblende	9.83	18.04	5.31	104°50′	909.7
3	exsolved cummingtonite on ($\bar{1}01$)	9.50	18.04	5.31	102°03′	891.3
	exsolved cummingtonite on (100)	9.50	18.04	5.31	102°20′	889.3
	cummingtonite	9.51	18.10	5.31	102°15′	892.8
4	exsolved hornblende on ($\bar{1}01$)	9.82	18.10	5.32	105°07′	912.6
	exsolved hornblende on (100)	9.83	18.10	5.32	104°44′	914.5
	hornblende	9.82	18.09	5.30	104°34′	910.4
5	exsolved cummingtonite on ($\bar{1}01$)	9.52	18.09	5.32	102°10′	895.8
	exsolved cummingtonite on (100)	9.56	18.09	5.30	102°02′	895.8
	cummingtonite	9.52	18.11	5.32	102°03′	896.7
6	exsolved hornblende on ($\bar{1}01$)	9.84	18.11	5.32	104°44′	916.1
	exsolved hornblende on (100)	9.85	18.11	5.33	104°48′	918.9
	hornblende	9.82	18.06	5.31	104°44′	911.4
7	exsolved cummingtonite on ($\bar{1}01$)	9.51	18.06	5.31	102°12′	891.5
	exsolved cummingtonite on (100)	9.55	18.06	5.30	102°18′	893.0
	cummingtonite	9.52	18.2	5.32	102°08′	896
8	exsolved hornblende on ($\bar{1}01$)	9.86	18.2	5.31	104°49′,	916
	exsolved hornblende on (100)	9.83	19.2	5.32	104°22	917

Single crystal photographs of hornblendes from the diorite (Otakisawa type) illustrate three sets of spots as shown in Figure 4a. One of these three sets is the stronger reflection of hornblende host phase, and other two sets are due to lamellae phases. One of reflections of lamellar phases corresponds to ($\bar{1}01$) lamellae and the other to (100) striations. No reflection violating the diffraction symmetry $2/mC-/-$is found in the sets of reflections from host phase and lamellae phases. Accordingly, the hornblende host and two lamellae phases have space group $C2/m$ respectively. By evaluating unit cell parameters, space group and relative intensities of diffraction pattern, two sets of lamellae were decided to be cummingtonite phase. Presuming from intensities of reflections owing to lamellae, the volume contents of two sets of lamellae are approximately equal. From the crystallographic relationship between the hornblende host and the thin lamellae of cummingtonite, it is clear that the b-axis of host is in common with those of the ($\bar{1}01$) lamellae and the (100) lamellae. The direction of the a-axis of the ($\bar{1}01$)

lamellae coincides with that of the hornblende host, and the direction of the c-axis of the (100) lamellae coincides with that of the host. Figure 4b demonstrates the violation of $C2/m$ symmetry expected for cummingtonite, although the reflections violating the $C2/m$ space group symmetry are very weak and clearly diffuse along to a^* direction, and slightly diffuse along to b^* direction but do not diffuse along to c^* direction, whereas the reflections obeying the $C2/m$ space group are strong and sharp. The reflections showing this are 304, 10$\bar{4}$, 70$\bar{4}$, 502 and 30$\bar{2}$ on the ($h0l$) precession photograph.

ROSS, PAPIKE and SHAW (1969) classified cummingtonites into two types, i.e. one has $P2_1/m$ space group symmetry as "primitive" cummingtonite in allusion to the primitive lattice, and the other with $C2/m$ space group symmetry designated "C-centered" cummingtonites. The cummingtonite host phase from the Otakisawa type diorite is "primitive" cummingtonite showing $P2_1/m$ symmetry.

It is comfirmed by X-ray single crystal photographs that the very thin lamellae oriented parallel to ($\bar{1}01$) of the cumming-
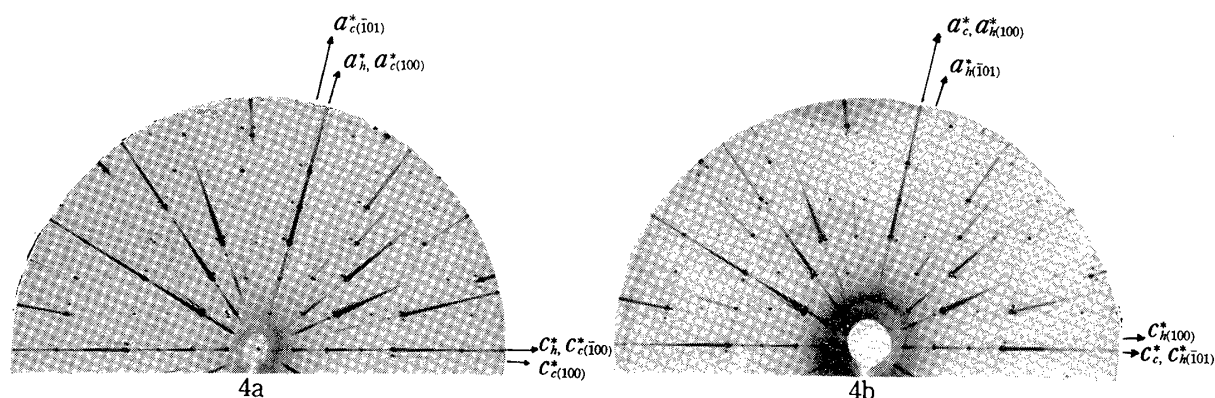

Fig. 4a. Precession photograph of the $h0l$ net of sample 3 (rock specimen N–166). The strong set of reflection marked by axes a_h^* and c_h^* is due to host hornblende. One of the weaker sets marked by axes $a^*_{c(\bar{1}01)}$ and $c^*_{c(\bar{1}01)}$ is due to the ($\bar{1}01$) lamellae of cummingtonite, the other sets marked by axes $a^*_{c(100)}$ and $c^*_{c(100)}$ is due to the (100) lamellae of cummingtonite. Mok α radiation, 100 hr. exposure.

Fig. 4b. Precession photograph of the $h0l$ net of sample 4 (rock specimen N–166). The strong set of reflection marked by axes a_c^* and c_c^* is due to host cummingtonite. One of the weaker sets marked by axes $a^*_{h(\bar{1}01)}$ and $c^*_{h(\bar{1}01)}$ is due to the ($\bar{1}01$) lamellae of hornblende, the other set marked by axes $a^*_{h(100)}$ and $c^*_{h(100)}$ is due to the (100) lamellae of hornblende. Mok α radiation, 97 hr. exposure.
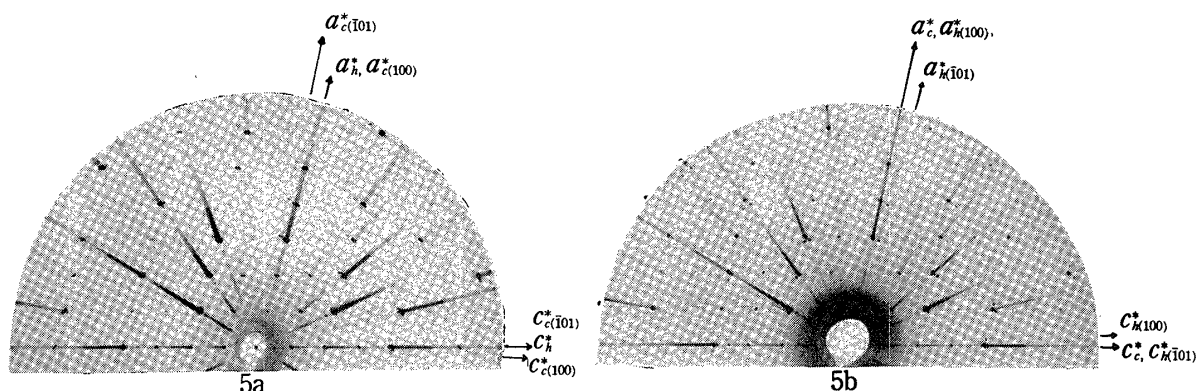
Fig. 5a. Precession photograph of the $h0l$ net of sample 5 (rock specimen 81008–b). The strong set of reflection marked by axes a_h^* and c_h^* is due to host hornblende. One of the weaker sets marked by axes $a_{c(\bar{1}01)}^*$ and $c_{c(\bar{1}01)}^*$ is due to the $(\bar{1}01)$ lamellae of cummingtonite, the other set marked by axes $a_{c(100)}^*$ and $c_{c(100)}^*$ is due to the (100) lamellae of cummingtonite. Mok α radiation, 102 hr. exposure.

Fig. 5b. Precession photograph of the $h0l$ net of sample 6 (rock specimen 81008–b). The strong set of reflection marked by axes a_c^* and c_c^* is due to host cummingtonite. One of the weaker sets marked by axes $a_{h(\bar{1}01)}^*$ and $c_{h(\bar{1}01)}^*$ is due to the $(\bar{1}01)$ lamellae of hornblende, the other set marked by axes $a_{h(100)}^*$ and $c_{h(100)}^*$ is due to the (100) lamellae of hornblende. Mok α radiation, 80 hr. exposure.

tonite are the hornblende phases which have space group $C2/m$ symmetry. The volume content of the $(\bar{1}01)$ cummingtonite lamellae phase is approximately the same as that of the (100) hornblende lamellae.

Single crystal photographs of hornblendes from the Azegamaru type tonalite illustrate three sets of spots as shown by the hornblende from the Otakisawa type diorite (Fig. 5a). These X-ray photographs (81008–b, 81307–a) confirm that $(\bar{1}01)$ lamellae are cummingtonite phase, and also (100) striations are lamellae of cummingtonite, and the volume contents of the $(\bar{1}01)$ lamellae are larger than that of the (100) lamellae.

X-ray single crystal photographs of cummingtonites from the Azegamaru type tonalite demonstrate that the host phase of the cummingtonite has a space group $P2_1/m$ symmetry, furthermore, the reflection spot with $h+k=2n+1$, is weaker than that of the cummingtonite from the Otakisawa type diorite, and clearly diffuses along to a^* direction and slightly diffuses along to b^* direction, but does not diffuse along to c^* direction (Fig. 5b). Except for the stronger set of spots from

the X-ray single crystal photographs of the cummingtonite, two sets of spots remain. One of these, of which a^* and b^* directions are in common with the host phase, coresponds to $(\bar{1}01)$ lamellae of hornblende phase, and the other, of which c^* and b^* direction are in common with host phase, coresponds to (100) lamellae of hornblende phase. Volume content of the $(\bar{1}01)$ lamellae are larger than that of the (100) lamellae.

Judging from the result of X-ray analyses, it is clear that the very thin lamellae in the cummingtonite and hornblende pair are formed by exsolution.

Chemical Compositions

Chemical analyses were made with electron microprobe analyzer, Japan Electron Optic Laboratories, JXA–5 instrument, because it was difficult to separate pure samples of only one amphibole discarding another. Even by the probe analysis, it was impossible to avoid exsolution lamellae. Therefore, the area analyzed was so large that the probe analysis might represent the chemical composition

K. TOMITA, Y. YAMAGUCHI and R. TAKITA

Table 4.   Chemical composition of hornblende and cummingtonite.

Sample No.	1	2	3	4	5	6	7	8
SiO$_2$	45.25	54.54	49.10	55.25	51.13	54.58	48.62	51.38
TiO$_2$	0.97	0.23	0.95	0.27	0.38	0.30	0.87	0.30
Al$_2$O$_3$	7.76	2.05	7.65	2.22	6.51	1.99	7.20	2.46
FeO	12.60	17.14	12.97	17.70	13.13	18.19	14.53	19.33
MnO	0.36	0.76	0.34	0.77	0.92	1.98	0.58	1.12
MgO	14.52	19.46	14.43	19.04	14.32	17.44	13.94	17.52
CaO	10.23	1.90	10.20	2.21	10.78	2.34	10.40	2.26
Na$_2$O	0.89	0.20	0.94	0.22	0.72	0.24	0.82	0.24
K$_2$O	0.20	0.04	0.18	0.04	0.61	0.05	0.24	0.05
Total	92.78	96.33	96.75	97.73	98.05	97.12	97.18	94.65

1. hornblende   2. cummingtonite   3. hornblende   4. cummingtonite   5. hornblende   6. cummingtonite
7. hornblende   8. cummingtonite   (analyst T. MARUYAMA)

Table 5.   Chemical formulas* of hornblende and cummingtonite.

Specimen No.	Crystal	horn-blende 1	cumming-tonite 2	horn-blende 3	cumming-tonite 4	horn-blende 5	cumming-tonite 6	horn-blende 7	cumming-tonite 8
T(1), T(2) Σ (8.00)	Si	6.94	7.88	7.16	7.88	7.36	7.91	7.13	7.70
	Al	1.06	0.12	0.84	0.12	0.64	0.09	0.87	0.30
R^{2+}	Fe	1.62	2.07	1.58	2.11	1.58	2.20	1.78	2.42
	Mn	0.05	0.09	0.04	0.09	0.11	0.24	0.07	0.14
	Mg	3.32	4.19	3.14	4.05	3.07	3.77	3.05	3.91
	Σ	4.99	6.35	4.76	6.25	4.76	6.21	4.90	6.47
M(1) M(2) M(3) Σ (5.00)	R^{2+}	4.58	4.74	4.42	4.72	4.49	4.71	4.53	4.83
	Al	0.31	0.23	0.47	0.25	0.47	0.25	0.38	0.13
	Ti	0.11	0.03	0.11	0.03	0.04	0.04	0.09	0.04
M(4)	R^{2+}	0.41	1.61	0.34	1.53	0.27	1.50	0.37	1.64
	Ca	1.68	0.29	1.59	0.34	1.66	0.36	1.63	0.36
	Na	0	0.06	0.07	0.06	0.07	0.06	0	0
	K	0	0	0	0	0	0	0	0
A	Na	0.26	0	0.19	0	0.13	0	0.24	0.04
	K	0.04	0	0.04	0	0.02	0	0.04	0
$\dfrac{100Ca}{Ca+Mg+Fe+Mn}$		25.18	4.36	25.03	5.15	25.85	5.47	24.96	5.27
$\dfrac{100Mg}{Ca+Mg+Fe+Mn}$		49.77	63.10	49.94	61.45	47.81	57.38	46.70	57.24
$\dfrac{100Mg}{Mg+Fe+Mn}$		66.50	65.98	65.96	64.80	64.5	60.70	62.2	60.43
FeO/MgO		0.49	0.49	0.50	0.52	0.51	0.58	0.58	0.59

* Formulas are calculated on the basis of 23 oxygens.

preceding exsolution phenomena. Corrections were made using the correction procedures of BENCE and ALBEE (1968). The results of analyses are given in Table 4. The atomic ratios of amphiboles analyzed were calculated on the basis of 23 oxygen anions exclusive of those combined with hydrogen as given in Table 5.

Cations occupying M 4 site of the hornblendes analyzed are Ca and small divalent cations (Mg, Fe, Mn ions) and negligible alkali ions. The amount of alkali ions occupying A site is approximately constant. Ca/(Ca+Na+K) ratio of hornblende analyzed shows constant value and the value of Al/Ca ratio is between 0.68–0.86.

The alkali ion contents of cummingtonites analyzed are negligible and Al ion contents per formula unit is between 0.34 to 0.43. Therefore, the relationship of chemical composition between the hornblende and cummingtonite is able to be represented by the Ca, Mg and Fe ion contents.

The four hornblendes contain 0.27 to 0.41 atoms of small divalent cations such as Mg, Fe and Mn ions substituting for Ca ions in the M 4 sites, so that exsolution of cummingtonite is able to occur. The four cummingtonites contain 0.35 to 0.42 atoms of Ca ions substituting for small divalent cations such as Mg, Fe, and Mn ions in the M 4 sites, and consequentely exsolution of hornblende is also expected.

The distribution of Mg, Fe(total)+Mn and Ca between coexisting hornblende and cummingtonite is shown graphically in the system $Ca_2Mg_5Si_8O_{22}(OH)_2$-$Ca_2Fe_5Si_8O_{22}(OH)_2$-$Mg_7Si_8O_{22}(OH)_2$-$Fe_7Si_8O_{22}(OH)_2$ (Fig. 6) (KLEIN (1968), ROSS, PAPIKE and WEIBLEN (1968)). In this Figure 6, four of the amphibole pairs are shown with tielines. It was pointed out by ROBINSON and JAFFE (1969) that in the probe analyses of coexisting

hornblende and cummingtonite the high total Fe in the hornblende is probably due to high Fe^{3+} in hornblende, and therefore this together with probably low Fe^{3+} in cummingtonite results in the peculiar tieline orientation. They described that cummingtonite had about the same FeO/MgO ratio as the hornblende in the wet analysis.

Based on probe analyses of the hornblende and cummingtonite pairs used in this study, these amphibole pairs have about the same FeO/MgO ratio: Strictly speaking, cummingtonite has a little larger FeO/MgO ratio than that of coexisting hornblende (see Table 4).

Consequently, the $Ca:Mg:Fe^{2+}$ ratio and $Mg/(Mg+Fe^{2+}+Mn)$ ratio of amphibole pairs may be represented by the ratio Ca: Mg:Fe(total) and 100 Mg/Mg+Fe(total) +Mn, respectively. The hornblende has a higher Mg/Mg+Fe ratio than the coexisting cummingtonite as shown table 4. Fig. 6 shows the tielines do not to corss each other; i.e. Fe content of hornblende increases with increasing Fe in the coexisting cummingtonite.
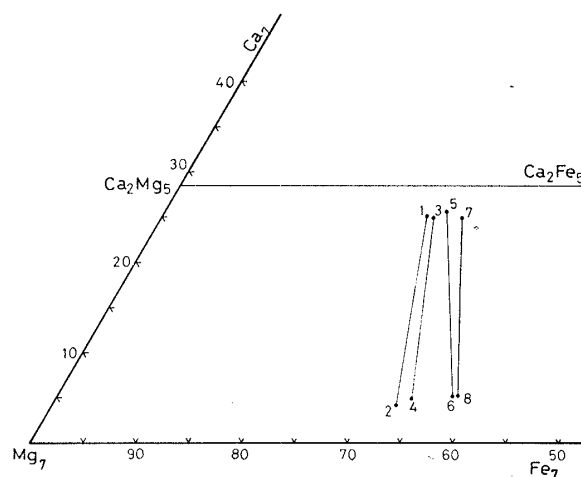

Fig. 6. Distribution of Mg, Fe(total) and Ca between the cummingtonite and hornblende pairs in diorite (Otakisawa type) and tonalite (Azegamaru type). Numbers indicate the sample No. shown in Table 2.

Discussion

Chemical composition of host and lamellae phase of the amphibole pair examined cannot be directly determined on account of the exsolution texture which exhibits very thin lamellae repeating at a narrow interval.

KLEIN (1967) demonstrated that the a, b, c, β and $asin\beta$ parameters in all of cummingtonite-grunerite series vary linearly with composition, and he estabilshed the equation representative of the relation between cell dimension or cell volume and the composition. In order to evaluate the mole fraction of $Fe_7Si_8O_{22}(OH)_2$ $(= X_{Fe})$ of the cummingtonite host examined in this study, KLEIN's equations were used. Compositions derived from cell dimensions of the cummingtonite (N–166, 81008–b) determined by single crystal X-ray data and cell volumes calculated are shown as follows,

	$V(Å^3)$	X_{Fe} calcu- rated	X_{Fe} probe analyses
Cummingtonite (N–166)	893	32 %	34.1 %
Cummingtonite (81008–b)	896.7	40 %	39.3 %

MORIMOTO and TOKONAMI (1969) deduced that the exsolved augites in pigeonite retain lattice distortion by orientation effects in pigeonite and cell dimensions corrected for the lattice distortions represent their composition satisfactorily, and they demonstrated that the exsolved augite parallel to (001) has the same cell dimensions corrected for lattice distortions as that parallel to (100), therefore compositions of two exsolved augites are identical. Thus it seems certain that if composition of the exsolved amphiboles in amphibole host are invariable, their unit cell volume remains constant even when the lattice is distorted. Making a comparison between cell volume of amphibole lamellae

contained in an amphible crystal and that of host coexisting with its crystal, the cummingtonite lamellae in the hornblende host have approximately the same unit cell volume as the coexisting host cummingtonite, and the hornblende lamellae as well (see Table 3). Conseuqently, it may be concluded that the composition of the cummingtonite lamellae are consistent with the coexisting host cummingtonite, and that of the hornblende lamellae as well.

On the genesis of coexisting hornblende and cummingtonite in tonalite and diorite from Tanzawa Mountainland, KOJIMA (1952) explained that at the later stage of solidification of quartz diorite magma, as a result of excessive separation of hornblende and calcic feldspars, the residual solution was richer in aluminium, magnesium, iron, alkali and silicon, than in calcium, and so the residual solution reacted on the already crystallized hornblende and plagioclase feldspars, resulting in the formation of cummingtonite.

As mentioned in previous sections and the above discussion, the two amphiboles examined in this study form hypidiomorphic or poikilitic crystals, and also the two amphiboles frequently occur as parallel intergrowth. The cummingtonites have lamellae phase of the hornblende, and the hornblends have lamellae phase of the cummingtonite. These textures could be interpreted as due to exsolution of two phases by unmixing.

Consequently hornblende and cummingtonite in the tonalite and diorite, may have occured as primary crystallized minerals from diorite magma. With subsequent cooling, the cummingtonites exsolved hornblende lamellae and hornblendes exsolved cummingtonite lamellae. Either during or after exsolution, portions of the hornblende might have reacted with residual liquids, and so formed the rim of blue green hornblende,

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丹沢トーナル岩複合岩体中の角閃石の離溶組織

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（要　　旨）

変成岩中で共存する緑色角閃石とカミングトン閃石中に離溶組織が存在することについては，すでに多くの報告がある．しかし火成岩中で共存する緑色角閃石とカミングトン閃石中に離溶組織が存在するという報告は1例だけである．

丹沢トーナル岩複合岩体中に共存する緑色角閃石とカミングトン閃石には普遍的にラメラ組織が見い出される．このラメラは約 1μ の巾で，母相の（100）面と（$\bar{1}01$）面（結晶軸を体心格子としてとれば，（001）面）にほぼ平行に存在する．この複合岩体の主体をなす唯ケ丸型トーナル岩と，早期に貫入した大滝沢型閃緑岩中に共存する緑色角閃石とカミングトン閃石8ケについて，プレセッション法によるX線単結晶回折及びX線マイクロアナライザーによる化学分析を行なった．その結果，緑色角閃石にはカミングトン閃石が，（100）面及び（$\bar{1}01$）面に平行な離溶相として存在し，カミングトン閃石には，緑色角閃石が（100）面及び（$\bar{1}01$）面に平行な離溶相として存在する．離溶相の組成を，単位胞の体積から推定すれば，緑色角閃石中の離溶相のカミングトン閃石は，共存するカミングトン閃石の母体の組成とほぼ一致する．またカミングトン閃石中の離溶相の緑色角閃石は，共存する緑色角閃石の母体の組成とほぼ同じである．また緑色角閃石とカミングトン閃石の組成を検討すると，共存する両角閃石の Fe/Mg 比はほぼ一定である．

以上のことから，共存する両角閃石は比較的高温条件で初生鉱物として生成し，その後のゆっくりした冷却過程で，緑色角閃石は，カミングトン閃石を，カミングトン閃石は，緑色角閃石をそれぞれ離溶したと推定される．

	地	名		
Tanzawa	丹　　沢	Itagoyazawa	板小屋沢
Otakisawa	大 滝 沢	Yokisawa	用 木 沢
Kumakizawa	熊 木 沢	Jizôzawa	地 蔵 沢
Azegamaru	唯 ケ 丸	Mominokisawa	モミの木沢
Hakoneyazawa	箱根屋沢	Fujimi	富 士 見