METAMORPHIC HORNBLENDEN FROM AN OUTCROP IN THE HITACHI DISTRICT

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Six hornblendes and their host amphibolites collected from an outcrop in the Hitachi district were studied chemically. The metamorphic grade of the host rocks corresponds to the higher temperature part of the epidote amphibolite facies. There is no regular relation between the alkali contents in the hornblendes and their host rocks. With increasing $\text{Ca}/(\text{Ca} + \text{Na})$ ratio of the host rock, this ratio of the hornblende remains nearly constant, although anorthite molecule in the coexisting plagioclase increases. Thus, the variation of $\text{Ca}/(\text{Ca} + \text{Na})$ ratio of the host rock is mainly reflected on the composition of the plagioclase, but not on that of hornblende.

INTRODUCTION

The metamorphic terrains of the Abukuma plateau are divided into a main part which is called the central Abukuma plateau and the Hitachi district in the southernmost part. In the central Abukuma plateau, Miyashiro (1958) and Shido (1958) studied the metamorphic rocks in detail. Petrologic studies on the metamorphic rocks of the Hitachi district were carried out by Kuroda (1959) and Tagiri (1971). The metamorphic rocks of the Hitachi district are different from those of the central Abukuma plateau; that is, the assemblage sodic plagioclase ($< \text{An}_{30}$)-epidote-common hornblende is well developed in the former (Kuroda, 1959; Tagiri, 1971), whereas this critical assemblage of the epidote amphibolite facies is practically lacking in the latter (Miyashiro, 1958; Shido, 1958). Based on the classification of mineral facies series in regional metamorphism proposed by Miyashiro (1971), the Hitachi metamorphism is regarded as interme-

diated between the andalusite-sillimanite and kyanite-sillimanite types or as the low pressure intermediate group, while the central Abukuma metamorphism is characterized by the andalusite-sillimanite type or relatively high temperature and low pressure type (Tagiri, 1971).

Many investigators have discussed the relationship between the change of compositional range of calciferous amphiboles and the increasing grade of metamorphism. In this discussion the effect of bulk composition to the chemistry of hornblende should be taken into consideration. It is well-known that calciferous amphibole is not hornblende, but tremolite-actinolite is produced by the amphibolite facies metamorphism in the rocks of appropriate composition, e.g. metamorphosed ultramafics and impure limestones.

In this paper the chemistry of the hornblendes and their respective amphibolites collected from an outcrop in the Hitachi

district is described, with some preliminary discussions on the dependence of the hornblende chemistry on the bulk composition.

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Table 1. Chemical compositions of metamorphic rocks

	1 HT-338	2 HT-324	3 HT-335	4 HT-337	5 HT-321	6 HTO-13	7 HT-341
SiO ₂	48.69	58.85	54.02	48.35	68.91	61.38	38.42
TiO ₂	0.81	0.37	1.09	0.38	0.58	0.73	1.20
Al ₂ O ₃	13.72	13.31	15.75	16.03	13.01	15.48	21.75
Fe ₂ O ₃	3.91	2.75	5.89	5.78	2.39	2.69	6.59
FeO	6.28	6.74	6.20	10.26	4.19	4.69	11.52
MnO	0.13	0.18	0.11	0.24	0.31	0.26	0.17
MgO	10.78	6.56	3.89	6.25	2.01	2.09	8.04
CaO	11.62	5.48	10.08	9.20	5.73	4.56	5.14
Na ₂ O	2.24	3.56	1.27	1.27	2.11	5.64	1.51
K ₂ O	0.24	0.15	0.13	0.17	0.18	0.64	0.19
M ₂ O+	1.63	1.55	1.55	1.59	0.70	0.99	5.14
H ₂ O-	0.05	0.10	0.07	0.07	0.03	0.36	0.16
P ₂ O ₅	0.08	0.11	0.15	0.09	0.13	0.19	0.12
Total	100.18	99.71	100.20	99.68	100.28	99.70	99.95
I	74.6	63.1	52.6	51.6	45.5	43.6	53.9
II	66.2	55.7	37.6	41.7	35.8	34.0	43.8
III	64.1	73.1	53.9	66.4	66.1	65.8	66.0
C.I.P.W. Norms							
qz	—	13.32	19.49	6.81	39.07	12.55	0.31
or	1.45	0.89	0.78	1.01	1.06	3.79	1.11
ab	18.93	30.11	10.75	10.74	17.85	47.73	12.79
an	26.68	19.92	36.89	37.53	25.51	15.05	24.74
c	—	—	—	—	—	—	10.00
py {	wo	12.84	2.75	5.09	3.17	0.91	2.71
	en	19.50	16.34	9.69	15.56	5.01	5.20
	fs	4.76	9.83	4.93	13.89	5.33	5.67
ol {	fo	5.15	—	—	—	—	—
	fa	1.90	—	—	—	—	—
il	1.53	0.70	2.06	0.73	1.11	1.38	2.28
mt	5.65	3.98	8.55	8.40	3.47	3.91	9.58
ap	0.20	0.27	0.37	0.20	0.30	0.44	0.30
An %	22-24	14-16	27-30	25-27	20-22	10-13	n.d.

I: $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Mn})$, II: $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3} + \text{Mn})$, III: $\text{Fe}^{+2} \times 100 / (\text{Fe}^{+2} + \text{Fe}^{+3})$.

Analyst: H. Onuki

PETROGRAPHY AND PETROCHEMISTRY

All the samples used in this study were collected from a restricted portion (about 20 meters wide) of a quarry (50 meters wide and 5~15 meters high) about 1.2 kilometers east of Machiya in the Hitachi district. This outcrop is quite heterogeneous and comprises amphibolites of various compositions derived from tuffs, tuffaceous sediments and lavas. The metamorphic grade of these rocks corresponds to the higher temperature part of the epidote amphibolite facies.

The mineral assemblages of the seven rocks studied are as follow:

Specimen No. HT-338; plagioclase-hornblende-cummingtonite-chlorite-epidote-sphene.

Sp. No. HT-324; plagioclase-quartz-hornblende-cummingtonite-chlorite.

Sp. No. HT-335; plagioclase-quartz-hornblende-cummingtonite-epidote.

Sp. No. HT-337; plagioclase-hornblende-cummingtonite-chlorite-sphene.

Sp. No. HT-321; quartz-plagioclase-hornblende-cummingtonite-chlorite-biotite.

Sp. No. HTO-13; quartz-plagioclase-hornblende-cummingtonite-chlorite-sphene.

Sp. No. HT-341; chlorite-cummingtonite-plagioclase-hornblende-sphene.

All of them include apatite and oxide minerals, mainly magnetite and rarely hematite. The magnetite-hematite association is found in two specimens (HT-324 and HT-321), but all the hematites may not be primary. The hornblende-cummingtonite association is always observed and is the most characteristic mineralogical feature of the rocks studied.

In the central Abukuma plateau cummingtonite does not occur in the lower temperature part but in the intermediate and higher temperature parts of the amphi-

bolite facies. On the contrary, cummingtonite appears in the higher temperature part of the epidote amphibolite facies in the Hitachi district. Thus, this mineral is found in the Hitachi district at a temperature lower than in the central Abukuma plateau.

Hornblendes in all the samples are the blue-green variety (Miyashiro, 1958; Shido, 1958). Cummingtonite is found mostly in the marginal part of the hornblende crystals, and rarely as independent grains. The boundary between hornblende and cummingtonite is discrete, with Becke line. The exsolution lamellae of cummingtonite in hornblende and those of hornblende in cummingtonite are not microscopically observed.

The chemical compositions of the rocks studied are shown in Table 1, together with their C.I.P.W. norms and anorthite molecular per cent of their plagioclases inferred from refractive indices α and γ . The chemical composition of a peculiar rock (HT-341), unusually rich in chlorite, is also

Figure 1. FeO and Fe_2O_3 contents of the basic metamorphic rocks from the Hitachi and central Abukuma districts.

The lines show $\text{FeO}/\text{Fe}_2\text{O}_3=2:1$ and $1:1$ by weight.

- 1: The Hitachi metamorphic rocks (this study).
- 2: Rocks of the A zone of the central Abukuma district (Miyashiro, 1958).
- 3: Rocks of the B zone of the central Abukuma district (Miyashiro, 1958).

given in Table 1 for reference. These chemical compositions except HT-341 are arranged in the order of decreasing $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Mn})$ ratio.

As clearly shown in Table 1, the bulk chemistry has a wide range from basic to

acidic, but all the rocks, except HT-338, are oversaturated with silica in normative composition. These rocks are characterized generally by the high ferric/ferrous iron ratio. The analysed rocks of the epidote amphibolite facies of the Hitachi district

Table 2. Chemical compositions of hornblendes

	1 HT-338H	2 HT-324H	3 HT-335H	4 HT-337H	5 HT-321H	6 HTO-13
SiO ₂	47.14	48.41	42.98	43.79	43.94	45.11
TiO ₂	0.69	0.30	0.98	0.27	0.56	0.58
Al ₂ O ₃	9.40	7.73	14.74	14.40	13.62	11.04
Fe ₂ O ₃	4.86	3.11	5.03	4.74	6.76	5.68
FeO	7.95	12.71	11.75	14.22	13.23	15.75
MnO	0.24	0.31	0.12	0.27	0.41	0.40
MgO	14.02	13.05	9.73	9.24	7.27	7.21
CaO	12.31	11.15	11.11	11.09	10.91	10.30
Na ₂ O	1.17	1.19	1.39	1.20	1.40	1.28
K ₂ O	0.14	0.13	0.12	0.18	0.29	0.34
H ₂ O ⁺	2.01	1.96	1.93	1.85	1.85	1.92
H ₂ O ⁻	0.09	0.04	0.14	tr.	0.04	0.19
Total	100.08	100.09	99.97	100.25	100.28	99.80
Atomic ratios (<i>O</i> = 23)						
Si	6.783	7.048	6.297	6.316	6.485	6.750
Al ^{IV}	1.217	0.952	1.703	1.684	1.515	1.250
Al ^{VI}	0.383	0.374	0.841	0.817	0.849	0.693
Ti	0.074	0.033	0.107	0.030	0.062	0.065
Fe ⁺³	0.525	0.341	0.553	0.524	0.747	0.637
Fe ⁺²	0.953	1.547	1.436	1.749	1.627	1.964
Mn	0.029	0.038	0.015	0.034	0.051	0.050
Mg	3.025	2.831	2.141	2.024	1.609	1.618
Ca	1.897	1.738	1.746	1.753	1.725	1.651
Na	0.326	0.336	0.394	0.344	0.400	0.370
K	0.025	0.024	0.023	0.034	0.055	0.065
Total	15.237	15.264	15.256	15.331	15.125	15.113
H ₂ O	0.964	0.952	0.943	0.910	0.910	0.957
I	75.5	64.1	59.6	53.4	48.9	44.5
II	66.7	59.5	51.6	47.0	39.9	34.2
III	64.5	81.9	72.2	76.9	69.1	75.5
γ	1.662	1.666	1.678	1.685	1.685	1.688
2V _x	67~80°	64~80°	46~66°	60~66°	45~73°	60~67°

I: $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Mn})$. II: $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3} + \text{Mn})$. III: $\text{Fe}^{+2} \times 100 / (\text{Fe}^{+2} + \text{Fe}^{+3})$.

Analyst: H. Onuki

have lower $\text{FeO}/\text{Fe}_2\text{O}_3$ ratios than those in zone A (the greenschist facies) and in zone B (the lower temperature part of the amphibolite facies) of the central Abukuma plateau. Namely, most of the metamorphic rocks treated in the Hitachi district fall in the field between the lines of $\text{FeO}/\text{Fe}_2\text{O}_3 = 2/1$ and $1/1$ by weight, while the metamorphic rocks in the central Abukuma plateau are plotted in the field where the $\text{FeO}/\text{Fe}_2\text{O}_3$ ratio is higher than $2/1$ (Fig. 1). Thus, the metamorphic rocks in the Hitachi district and in the central Abukuma plateau have been formed under different oxygen partial pressures. This feature is important to interpret the different nature of the metamorphic rocks in these two districts.

CHEMICAL COMPOSITION OF HORNBL- ENDES

The chemical compositions of the hornblendes together with their atomic ratios on the anhydrous basis of $\text{O}=23$ and physical data are listed in Table 2. Si

has a range from 6.32 to 7.05 and Al^{IV} varies from 0.90 to 1.70. The total of Al^{IV} , Fe^{+3} and Ti ranges from 0.75 to 1.66 and Ca from 1.65 to 1.90. The content of $(\text{Na}+\text{K})$ shows a narrow range from 0.33 to 0.46.

According to the nomenclatures proposed by Deer *et al.* (1963), Miyashiro (1965) and Leake (1968), the analysed amphiboles are all "hornblendes". The most characteristic feature in the chemistry of these hornblendes is high content of Fe^{+3} . Like their host rocks, the $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Mn})$ and $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3} + \text{Mn})$ ratios of the hornblendes have relatively wide ranges from 44.5 to 75.5 and from 34.2 to 66.7, respectively.

Shido (1958) proposed a procedure for the calculation of these components the chemical composition of hornblendes by a number of theoretical end members. Onuki (1967) made a slight modification on Shido's method. Table 3 shows the results calculated by Onuki's method together with $\text{Al}^{\text{VI}}/\text{Fe}^{+3}$ and also Mg/Fe^{+2} ratios. These calculations are, however, useful only for

Table 3. Molecular proportions of hornblendes

	1 HT-338H	2 HT-324H	3 HT-335H	4 HT-337H	5 HT-321H	6 HTO-13H
Tiam'	148	66	214	60	124	130
Cum	—	660	372	800	—	108
Ca-cum	18	—	—	—	88	—
Ca-ed'	—	—	—	—	—	—
Ed'	238	264	256	331	125	113
Rieb	456	384	644	188	1320	1288
Gl	—	—	—	—	—	—
$\text{Fe}^{+3}\text{Ts}'$	658	392	627	763	667	504
AlTs'	640	602	1345	1306	1358	1106
Tr	5842	5632	4542	4552	4318	4751
Total	8000	8000	8000	8000	8000	8000
$\text{Al}^{\text{VI}}/\text{Fe}^{+3}$	0.73	1.10	1.52	1.56	1.14	1.09
Na/K	13.0	14.0	17.1	10.1	7.36	5.74
Mg/Fe^{+2}	3.17	1.83	1.49	1.16	0.99	0.82

comparison of the gross chemical features of hornblende.

Judging from two equations noted below, Shido (1958) pointed out that hornblendes in silica-undersaturated rocks tend to have higher contents of alkalis than those in oversaturated rocks.

But the hornblendes under consideration do not clearly show such a tendency. Namely, the contents of alkalis in the hornblendes from quartz-free rocks (HT-338 and HT-341) are less than those in other hornblendes associated with quartz. For example, in the hornblende, HT-341H, which is found in the most basic rock, has very low alkali contents; i.e., Na_2O and K_2O are 1.25 and 0.18 weight per cent, respectively (complete analysis has not been carried out). Probably the above-mentioned two reactions have progressed incompletely in the present district.

It is also noteworthy that Ca decreases from 1.90 to 1.65 with decreasing $\text{Mg}/(\text{Mg} + \text{Fe}^{+2} + \text{Mn})$ ratio. As the causes for the decrease of Ca in hornblende, the cummingtonite ($\text{NaAl} \rightleftharpoons \text{CaMg}$), glaucophane-riebeckite (NaAl or $\text{NaFe}^{+3} \rightleftharpoons \text{CaMg}$) and richterite ($\text{Na} \rightleftharpoons \text{Ca}$) substitutions can be considered. Considering first cummingtonite substitution, we can not find clearly any correlation between Ca and $(\text{Mg} + \text{Fe}^{+2} + \text{Mn})$ or between Ca and Mg/Fe^{+2} ratios. This substitution, therefore, is not so important

for lowering Ca in these hornblendes. Next, alkalis are not well correlative to Al^{VI} , but tend to increase with increasing Fe^{+3} (Fig. 2). Thus, it may be pointed out that the

Figure 2. $(\text{Na} + \text{K}) - \text{Fe}^{+3}$ and $(\text{Na} + \text{K}) - (\text{Fe}^{+3} + \text{Al}^{\text{VI}})$ relations of hornblendes.

riebeckite substitution is more effective in these hornblendes. The estimation of the role of richterite substitution in hornblende is almost impossible at present. After the allotment of the atomic numbers calculated on anhydrous or hydrous basis to (Z), (Y, X), (W) and (A) of hornblende structural sites, the role of the richterite substitution may be estimated on the basis of distribution of the alkalis and other atoms, though just expediently. Besides the following relation would be considered.

No reliable method for the estimation of the role of richterite substitution has been established.

Taken as a whole, the positive correlation between alkalis and Fe^{+3} in the hornblendes suggests a significant role of the

riebeckite substitution in these hornblendes. This substitution should also have a great effect on the decrease of Ca in them.

The $\text{Fe}^{+3}/(\text{Fe}^{+2} + \text{Fe}^{+3})$ ratio in these hornblendes varies in a wide range of 0.18 to 0.35 just like in their host rocks, although the samples were collected from an extremely narrow area. This may suggest the irregular distribution of the oxygen partial pressure within the rocks and the low mobility of oxygen during metamorphism.

CHEMICAL COMPOSITIONS OF SOME COEXISTING MINERALS

Hornblendes always coexist with cummingtonite in the rocks studied. Two analyses of cummingtonite and their atomic ratios on the anhydrous basis of $\text{O}=23$ are given in Table 4. The two cummingtonites are lower in the $\text{Mg} \times 100/(\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3})$

+Mn) ratio and richer in MnO and TiO_2 than those of the coexisting hornblendes.

It is generally noticed that cummingtonite occurs commonly in the metamorphic terrains characterized by relatively high temperature and low pressure metamorphism, but is usually absent in the terrains of relatively low temperature and high pressure metamorphism (Shido, 1958). If this is true, the prevailing occurrence of cummingtonite characterizes the Hitachi metamorphism.

Concerning the formation of cummingtonite, Shido (1958) suggested the following equation:

Table 4. Chemical analyses of cummingtonites

Wt. %			Atomic ratios (O=32)		
	1 HT-324C	2 HT-337C		1 HT-324C	2 HT-337C
SiO ₂	52.02	49.80	Si	7.510	7.309
TiO ₂	0.41	0.33	Al ^{IV}	0.490	0.691
Al ₂ O ₃	3.67	4.15	Al ^{VI}	0.134	0.026
Fe ₂ O ₃	4.38	5.97	Ti	0.044	0.036
FeO	18.54	20.20	Fe ⁺³	0.474	0.657
MnO	0.53	0.64	Fe ⁺²	2.236	2.471
MgO	17.22	15.80	Mn	0.065	0.079
CaO	1.68	1.28	Mg	3.729	3.558
Na ₂ O	0.12	0.12	Ca	0.260	0.202
K ₂ O	0.02	0.02	Na	0.033	0.033
H ₂ O+	1.69	1.79	K	0.003	0.004
H ₂ O-	0.01	0.04	Total	14.979	15.066
Total	100.29	100.14	H ₂ O	0.813	0.876
$\text{Mg} \times 100/(\text{Mg} + \text{Fe}^{+2} + \text{Mn})$				61.8	57.7
$\text{Mg} \times 100/(\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3} + \text{Mn})$				57.3	52.0
$\text{Fe}^{+2} \times 100/(\text{Fe}^{+2} + \text{Fe}^{+3})$				82.5	79.0

1: Cummingtonite (HT-324). 2: Cummingtonite (HT-337).

Analyst: H. Onuki

As the total volume of the solid phases on the left-hand side of the equation is smaller than that on the right-hand side, the occurrence of cummingtonite is favoured by lower rock pressures and higher temperatures. The analysed hornblendes from the metamorphic rocks belonging to the epidote amphibolite facies of the Hitachi district are more tschermakitic in composition than those from the metamorphic rocks corresponding to the lower temperature part of the amphibolite facies (zone B, Shido, 1958; Shido and Miyashiro, 1959) in the central Abukuma plateau. The appearance of cummingtonite may have started at lower temperature in the metamorphic rocks of the Hitachi district compared with those of the central Abukuma plateau. Probably above-noted reaction (1) is effective only in the central Abukuma plateau, but the cummingtonite in the Hitachi district should have formed in different way, possibly through the following equations:

Table 5. Chemical analyses of chlorite and magnetite

Wt. %			Atomic Ratios		
			0 = 14		0 = 32
	1	2		1	2
	HT-341Ch	HT-341M		HT-341Ch	HT-341M
SiO ₂	26.25	0.37	Si	2.636	0.114
TiO ₂	0.21	1.11	Al ^{IV}	1.364	} 0.092
Al ₂ O ₃	22.57	0.25	Al ^{VI}	1.307	
Fe ₂ O ₃	3.47	67.35	Ti	0.016	0.256
FeO	18.34	30.39	Fe ⁺³	0.262	15.547
MnO	0.23	0.02	Fe ⁺²	1.540	7.795
MgO	18.15	tr.	Mn	0.019	0.006
CaO	0.10	tr.	Mg	2.715	—
Na ₂ O	0.12	n.d.	Ca	0.011	—
K ₂ O	0.02	n.d.	Na	0.023	—
H ₂ O ₊	10.35	} 0.16	K	0.002	—
H ₂ O ₋	0.15		Total	9.895	23.810
Total	99.94	99.65	H ₂ O	3.465	—

1: Chlorite (HT-341). 2: Magnetite (HT-341).

Analyst: H. Onuki

restricted physical conditions of the same or nearly the same to the Hitachi metamorphism, because at much higher rock pressures the assemblage anorthite-cumingtonite will be replaced by the assemblage involving garnet as suggested by Shido (1958).

Chemical compositions of chlorite and magnetite from HT-341 are shown in Table 5. This chlorite is not oxidized and is termed orthochlorite. Since the $(\text{Fe}^{+2} + \text{Fe}^{+3})/(\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3})$ ratio and Si atom calculated on the anhydrous basis of $\text{O}=14$ are 0.38 and 5.3, respectively, the mineral is defined as ripidolite (Deer *et al.*, 1962). The ratio $\text{TiO}_2:\text{Fe}_2\text{O}_3:\text{FeO}$ in the magnetite is 1.12:68.13:30.75 in weight per cent and 1.64:49.12:49.26 in molecular per cent.

THE RELATION BETWEEN CHEMICAL COMPOSITIONS ON HORNBLENDES AND THE HOST ROCKS

Since hornblendes can contain almost all rock-forming elements as the components, their chemical composition is variable in a wide range, with extremely diverse isomorphous substitution. Since hornblendes, in nature, can be formed in metamorphic rocks of various compositions, it is not easy to analyse the relation in chemistry between the hornblendes and their host rocks. First the relatively minor components will be examined.

It is clear that TiO_2 content in the hornblende is always lower than in the host rocks. So, these rocks must include one or more other minerals which are richer in TiO_2 than coexisting hornblendes. As titanium-bearing minerals, sphene and magnetite are present in these rocks, but the TiO_2 content of magnetite in this metamorphic grade may not exceed greatly that of the coexisting hornblende, judging from the composi-

tion of magnetite in HT-341.

As shown in Fig. 3, the TiO_2 contents in the hornblendes increase with increasing TiO_2 contents of the host rocks, though always within the range less than 1 weight per cent TiO_2 in the hornblendes. The maximum solubility of TiO_2 in hornblende is determined by the temperature-pressure condition of metamorphism. The HT-335H shows the highest content of TiO_2 (0.98 weight per cent) among the analysed hornblendes. Its host rock has an excess TiO_2 represented by the presence of sphene. Probably the maximum content of TiO_2 in hornblende is about 1 weight per cent under this metamorphic grade.

The MnO content of the hornblende is always higher than that of its host rock (Fig. 3).

Figure 3. MnO and TiO_2 contents of hornblendes and their host rocks.

Although the K_2O contents are quite small in these hornblendes and also in their host rocks, the correlation of K_2O between them appears to be positive in the available data. There is no regular relation between Na or $(\text{Na} + \text{K})$ contents in the hornblendes and those in their host rocks (Fig. 4). The maximum of the alkali contents in hornblendes can change depending on the rock chemistry only within the

limits determined by the metamorphic condition.

The $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Mn})$ ratios in the hornblendes increase sympathetically

Figure 4. (Na+K) contents of hornblendes and their host rocks.

Open circles: Hornblendes not associated with quartz.

Closed circles: Hornblendes associated with quartz.

Figure 5. $\text{Mg}/(\text{Mg} + \text{Fe}^{+2} + \text{Mn})$ ratios of hornblendes and their host rocks.

Figure 6. $\text{Mg}/(\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3} + \text{Mn})$ ratios of hornblendes and their host rocks.

to those of their host rocks (Fig. 5). The $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3} + \text{Mn})$ ratios of the hornblendes and their host rocks show also the same tendency except HT-335 (Fig. 6). Thus, the $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Mn})$ and $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3} + \text{Mn})$ ratios in the hornblendes appear to be almost entirely controlled by these ratios in the host rocks.

PLAGIOCLASE-HORNBLENDE EQUILIBRIUM

The relation between the compositions of plagioclase and hornblende is a key to clarify the relation between the bulk composition of the rocks and hornblende chemistry. Leake (1965), in his study on this relation, concluded that the $\text{Ca}/(\text{Ca} + \text{Na})$ and Al/Si ratios in both plagioclase and coexisting hornblende change systematically with increase in the grade of metamorphism, though the rock chemistry is also important. The rocks studied here were formed under nearly the same metamorphic grade and have plagioclases and hornblendes only as sodium-containing minerals. Therefore, the plagioclase-hornblende relation should be examined.

The $\text{Ca}/(\text{Ca} + \text{Na})$ ratio of the hornblendes is nearly constant with a very narrow range from 0.79 to 0.84, while this ratio of their host rocks varies from 0.29 to 0.80, and that of plagioclases from 0.11 to 0.29. With increasing $\text{Ca}/(\text{Ca} + \text{Na})$ ratio of the host rock, therefore, anorthite molecule in the plagioclase increases but the ratio $\text{Ca}/(\text{Ca} + \text{Na})$ of the coexisting hornblende remains nearly constant (Fig. 7). In other words, the $\text{Ca}/(\text{Ca} + \text{Na})$ ratio of the hornblendes do not vary significantly with the change of this ratio in the host rocks, whereas the ratio of the associated plagioclases varies sensitively within the

Figure 7. Relationship among $\text{Ca}/(\text{Ca}+\text{Na})$ ratios of the hornblende, the coexisting plagioclase and the host rock.

HT- and HTO- prefixes have been omitted from the sample numbers.

limit determined by the physical conditions of metamorphism. The change of the anorthite content in plagioclase is accompanied by the change of the Al/Si ratio of the mineral. There seem to be no systematic variation in the Al/Si ratio among the hornblendes, plagioclases and their host rocks.

The variation of $\text{Ca}/(\text{Ca}+\text{Na})$ ratio of the host rocks is, therefore, mainly reflected on the changing composition of the plagioclases, but not that of hornblendes.

The maximum $\text{Ca}/(\text{Ca}+\text{Na})$ ratio in both plagioclase and coexisting hornblende in metamorphic rocks would be determined by the metamorphic grade and may vary with increasing grade of metamorphism, but the variation of the ratio in each mineral may differ in different types of metamorphism. If this concept is true, the conclusion noted above may be not

correct in all cases, but only in the higher temperature part of the epidote amphibolite facies in the Hitachi district. Further studies are needed to elucidate the nature of the equilibrium between these two minerals.

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日立地方，同一露頭からの変成ホルンブレンド

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阿武隈山地，日立地方の同一露頭から6個の角閃岩類を選び，ホルンブレンドを分離し，化学分析を行なった。この露頭は緑れん石角閃岩相の高温部に相当する。岩石の記載，ホルンブレンドの化学的性質などを述べたのち，岩石とホルンブレンドの間の化学的関係を， TiO_2 , MnO ，アルカリ， $\text{Mg} \times 100 / (\text{Mg} + \text{Fe}^{+2} + \text{Mn})$ などについて調べた。岩石中のアルカリ量の多少はホルンブレンドのアルカリ量に殆んど関係がないこと，岩石の $\text{Ca}/(\text{Ca} + \text{Na})$ 比が著しく変化してもホルンブレンドの同比は殆んど不変で，共生する斜長石の $\text{Ca}/(\text{Ca} + \text{Na})$ 比が変化するにすぎないことなどが解った。なお参考の為，ホルンブレンドと共存するカミングトン閃石2個，緑泥石に著しく富んだ岩石ならびにこの岩石中の緑泥石と磁鉄鉱の化学組成をも示した。