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TWO KINDS OF GARNET AMPHIBOLITES IN THE MOMOSE-MIZUNASHI DISTRICT, HIDA METAMORPIC BELT, CENTRAL JAPAN

by

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(with 9 text-figures and 5 tables)

Abstract

The mode of occurrence and chemical composition of garnet amphibolite in the Momose-Mizunashi district of the Hida Metamorphic Belt are described. The masses of garnet ampibolite form thin fusiform bodies whose occurrence is concordant with surrounding pelitic and basic gneisses. Formation of garnets is inferred to depend on chemical speciality of the original rocks such as high $\Sigma FeO/MgO$ and low CaO/Al_2O_3 ratio. They are classified into two kinds of garnet amphibolite according to CaO content in garnet, i.e., one comparatively low in the CaO content, and the other rather high in the CaO content. The occurrence of Ca-rich almandine amphibolite seems to imply that the metamorphic condition in the Momose-Mizunashi district belongs to slightly higher pressure type than most prevailing metamorphic conditions in the Hida Metamorphic Belt.

Introduction

The Hida Metamorphic Belt, which is composed mainly of rocks of amphibolite facies, has been one of the representative metamorphic belts of low-pressure type in Japan (Miyashiro, 1973). However, for the reason of probable poly-metamorphic episodes, other types of metamorphic rocks have also been reported from the Belt, for example, eclogitic rock in the Tsukigase area (Suzuki, 1973) and intermediate-pressure type metamorphic rocks in the Unazuki area (Ishioka, 1949). The author also discriminated a contact effect by small granitic bodies of a later stage from the regional metamorphic rocks in the Momose-Mizunashi district (Inazuki, 1980a). Due to complexity of the metamorphic history and the variety of original rocks, many kinds of metamorphic rocks have been reported in the Hida Belt as compared with those in other metamorphic belt in Japan.

Recently, the author has found two kinds of garnet amphibolite in the Momose-Mizunashi district. In this paper, the author describes these occurrences and discusses shortly their geneses, as occurrence of garnet amphibolite from the Hida Metamorphic Belt has never been described.

Mode of Occurrence

The Momose-Mizunashi area is situated in the northwestern part of the Hida Metamorphic Belt. In this area, various kinds of metamorphic rocks, such as calcareous gneiss (crystalline limestone and calc-siliceous gneiss with grossular, epidote, and plagioclase), biotite gneiss (biotite – plagioclase - quartz ± almandine ± sillimanite ± muscovite), and hornblende gneiss (hornblende – plagioclase ± clinopyroxene ± quartz), are widely

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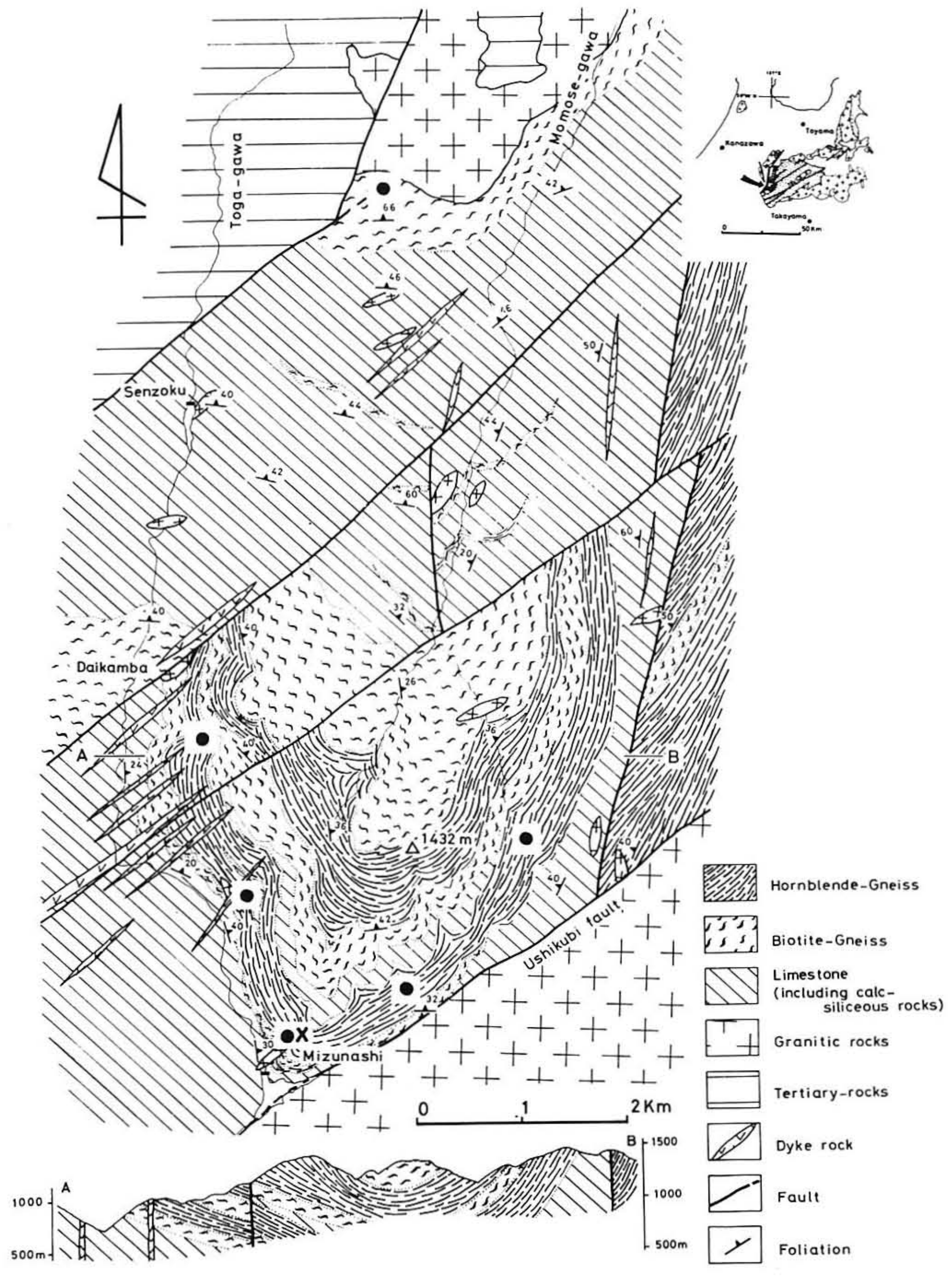


Text-fig. 1 Geological map of the Momose-Mizunashi district, Hida Metamorphic Belt, Toyama Prefecture. Solid circle: sample locality of "grossular-almandine garnet" amphibolite. Cross: sample locality of Ca-rich almandine amphibolite.

distributed (Text-figure 1). The metamorphic grade is generally of the amphibolite facies (Inazuki, 1980a,b).

The garnet amphibolite is dark green in color and shows a gneissic structure with some red spots of garnet. The amphibolite forms a fusiform body about 20 x 40 cm maximum wides, whose long axis is almost parallel to the gneissosity (Text-figure 2). Some of them occurs as a thin layer which is concordant with the other pelitic and basic gneisses (Text-figure 1). They are classified into two kinds of garnet amphibolite on the basis of the CaO content in garnet, i.e., one comparatively low in the CaO content, and the other rather high in the CaO content (Table 1), and of the shape of amphibole, i.e., one comparatively slender needle, the other stout prism. The both kinds of garnet have high CaO content compared with normal almandine, whose grossular component attains as much as 54 mol% (Table 1). The author calls the former garnet as Ca-rich almandine (No. 1-3 in Table 1) and the latter "grossular-almandine garnet" (No. 4-10 in Table 1). "Grossular-almandine garnet" is common type of garnet in garnet amphibolite in this area. Only at one locality two kinds of garnet amphibolites occur together (see Text-figure 1). It is possible, however, to discriminate two kinds of garnet amphibolites to each other, because of the difference of the shapes of amphibole.

Mineral assemblage of the Ca-rich almandine amphibolite is essentially:

Garnet – hornblende – plagioclase (An 50-94) – quartz – ilmenite (Text-figure 3a).
Clinopyroxene does not occur in the Ca-rich almandine amphibolite. Chlorite and sericite also occur as products of retrogressive metamorphism in some minor parts. Garnet occurs as xenoblastic crystals, ranging from 0.1 to 0.4 mm in diameter. Hornblende is hypidioblastic and greenish-brown to green in Z′-axial color. Plagioclase occurs as an allotriomorphic equent

Text-fig. 2 Polished specimen of garnet amphibolite (No. 4M129).
G: porphyroblast of garnet.

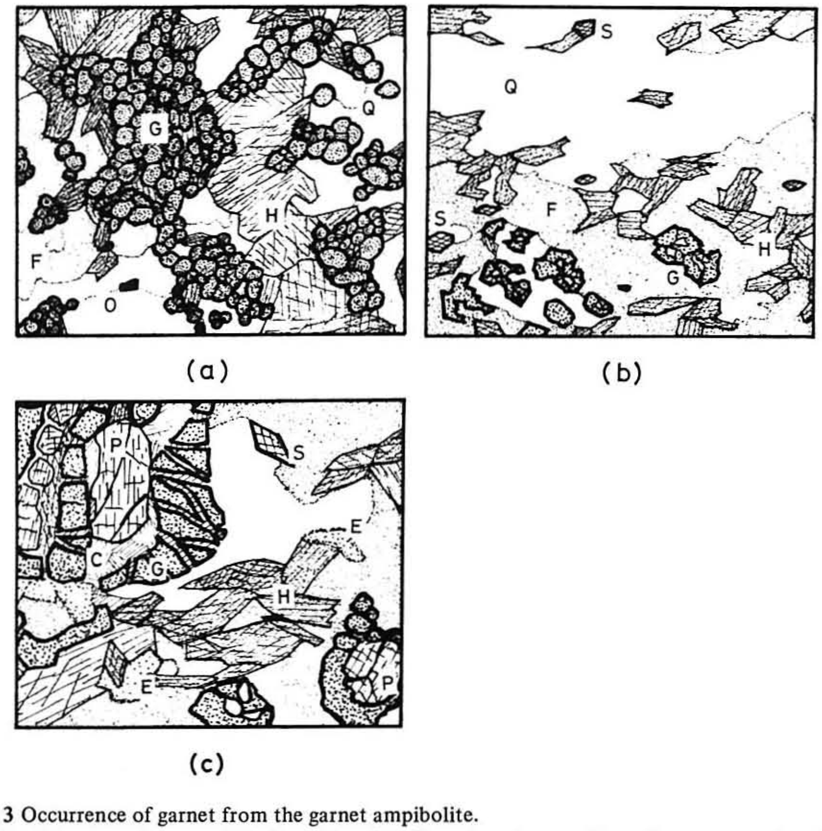
or feebly elongated grain less than 0.8 mm. Its compositional zoning is distinct. The An content of plagioclase normally decreases from the core to margin.

While, mineral assemblages of the "grossular-almandine garnet" amphibolite are the followings (Text-figures 3b, 3c):

(1) Garnet + hornblende + plagioclase (An 88-92) + quartz + ilmenite ± magnetite + sphene

(2) Garnet + clinopyroxene + plagioclase (An 46-92) + quartz ± ilmenite ± magnetite + sphene.

It has been more or less affected by retrogressive effect which produced following mineral assemblage:



Text-fig. 3 Occurrence of garnet from the garnet ampibolite.

(a) Ca-rich almandine amphibolite (No. 6M26); mineral assemblage is garnet – hornblende – plagioclase – quartz – ore.

(b) "Grossular-almandine garnet" amphibolite (No. 4M138); mineral assemblage is garnet – hornblende – plagioclase – quartz – sphene.

(c) Pyroxene-bearing "grossular-almandine garnet" amphibolite (No. 4M84); mineral assemblage is garnet – clinopyroxene – hornblende – actinolite – epidote – plagioclase – quartz – calcite – sphene.

Actinolite, epidote, and calcite occur as retrogressive products in some minor parts. G = garnet, P = clinopyroxene, H = amphibole, E = epidote, F = plagioclase, Q = quartz, O = ore mineral, S = sphene, C = calcite. Long dimension of these figures is approx 2 mm.

Actinolite – epidote – sodic-plagioclase – calcite – pyrite.

Garnet occurs as hypidioblastic and xenoblastic crystals, up to 2 mm and rarely 3 mm across. There are two types of clinopyroxene in shape. One is idioblastic and hypidioblastic crystals, and the other is allotriomorphic and has a higher birefringence than the former. The latter pyroxene is quite rare in the amphibolite, found in only one specimen in a small quantity (No. 3 in Table 4). Blue-greenish actinolite is found at the margin and /or along

No.	1	2	3	4	5	6	7	8	9	10
SiO_2	36.44	37.02	36.47	37.11	37.35	37.07	37.18	38.41	38.26	38.04
TiO_2	–	0.01	0.03	0.04	0.06	–	0.03	0.20	0.04	0.06
Al_2O_3	20.09	20.72	20.40	20.57	20.66	19.64	20.37	19.56	19.22	21.41
Cr_2O_3	0.01	–	–	–	–	0.03	–	0.05	0.06	–
FeO*	29.21	29.12	29.00	24.46	22.34	22.18	21.39	18.98	21.14	17.53
MnO	5.67	5.77	6.36	3.15	5.13	5.38	6.16	6.08	2.94	2.68
MgO	2.04	1.64	1.58	0.93	0.89	0.65	0.46	0.36	0.44	0.19
CaO	5.62	5.80	5.67	13.20	13.91	14.32	14.76	15.34	16.90	21.24
Na_2O	–	0.01	–	–	–	–	0.01	0.01	–	–
Total	99.08	100.09	99.51	99.46	100.34	99.27	100.36	98.99	99.00	101.15
Cation contents to 24 oxygen atoms										
Si	5.936	5.967	5.930	5.945	5.929	5.959	5.915	6.136	6.105	5.908
Al	3.857	3.937	3.909	3.883	3.865	3.721	3.820	3.683	3.615	3.919
Ti		0.001	0.004	0.005	0.007		0.004	0.024	0.005	0.007
Cr	0.001					0.004		0.006	0.008	
Fe^{3+} **	0.206	0.095	0.157	0.167	0.199	0.316	0.262	0.151	0.268	0.166
Fe^{2+}	3.773	3.830	3.786	3.110	2.766	2.666	2.584	2.384	2.553	2.111
Mn	0.782	0.788	0.876	0.427	0.690	0.733	0.830	0.823	0.397	0.353
Mg	0.495	0.394	0.383	0.222	0.211	0.156	0.109	0.086	0.105	0.044
Ca	0.981	1.002	0.988	2.266	2.366	2.466	2.516	2.626	2.889	3.535
Na		0.003					0.003	0.003		
Mol% end members										
Alm.	62.6	63.6	62.8	51.6	45.9	44.3	42.8	40.3	43.0	34.9
And.	5.1	2.4	4.0	4.3	5.1	7.9	6.6	4.4	6.9	4.3
Sp.	13.0	13.1	14.5	7.1	11.4	12.1	13.7	13.9	6.6	5.8
Uv.						0.1		0.2	0.2	
Gr.	11.1	14.3	12.4	33.3	34.1	33.0	35.1	39.8	41.5	54.2
Py.	8.2	6.6	6.3	3.7	3.5	2.6	1.8	1.4	1.8	0.7
Measured physical properties										
a (Å)		11.588				11.673		11.718	11.685	11.773

Table 1 Chemical analyses and physical properties of garnet from basic rocks.
No. 1-3 = 6M26, No. 4 = 4M129, No. 5 = 9M09, No. 6-7 = 4M84, No. 8 = 9M03, No. 9 = 9M10, No. 10 = 4M102.
* total iron calculated as FeO. ** calculated on the basis of Fe^{3+} = 10 – (Si + Ti + Al + Cr).

	1	2	3
	74M113	74M212	74M138
SiO_2	49.44	63.47	50.54
TiO_2	1.10	0.62	1.02
Al_2O_3	18.78	12.82	19.44
Fe_2O_3	0.73	1.64	3.34
FeO	7.31	3.35	5.30
MnO	0.11	0.06	0.14
MgO	5.64	3.95	3.07
CaO	7.52	5.96	7.38
Na_2O	3.57	1.88	3.37
K_2O	1.62	4.16	3.12
P_2O_5	0.20	0.19	0.37
$H_2O(+)$	3.28	0.95	2.51
$H_2O(-)$	0.37	0.48	0.29
Total	99.67	99.53	99.60

Table 2 Bulk chemical composition of amphibolites from the Momose-Mizunashi district.
No. 1: Hornblende – plagioclase – quartz rock. No. 2: Clinopyroxene – hornblende – plagioclase – quartz rock. No. 3: Garnet – hornblende – plagioclase – quartz rock (with minor actinolite – epidote – calcite).

cleavages of clinopyroxene grains. Hornblende is hypidioblastic and greenish-brown to green in Z′-axial color. Plagioclase and quartz are present interstitially. In places epidote and calcite are observed in contact with plagioclase. Pyrite is rarely found at the margin of ilmenite grains.

There are garnet-free amphibolites in the Hida Metamorphic Belt. As compared with bulk chemistry of these amphibolites, appearance of garnet in amphibolite is realized to be definitely controlled by bulk composition (Table 2 and Text-figure 4). It is apparent that the composition of garnet amphibolites (No. 3 in Table 2) is high in ΣFeO and Al_2O_3, and low in MgO and CaO. The composition of clinopyroxene-bearing hornblende gneiss is extremely low in Al_2O_3. No data is available for bulk composition of Ca-rich almandine amphibolite.

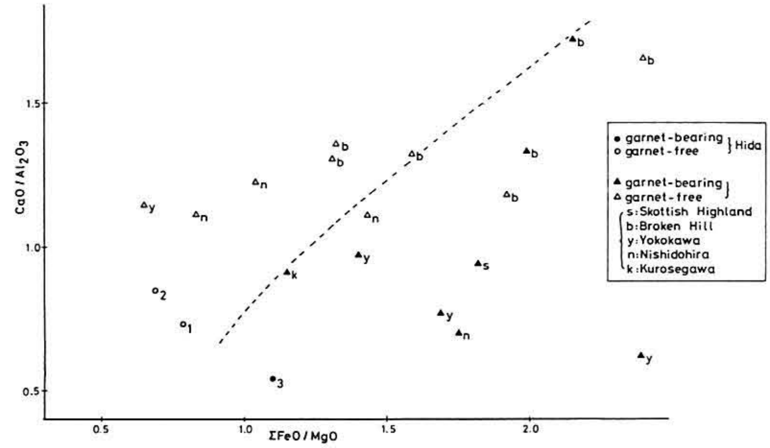
Mineral Chemistry

Electron microprobe analyses were made on some specimens of garnet, pyroxene, and amphibole, using a JXA-5A electronprobe microanalyzer at Niigata University and JXA-5 at Akita University. Recalculation of garnet formula was made by assuming that the amout of Fe required to fill the M(1)-M(3) sites is Fe^{3+}, i.e. $Fe^{3+} = 10 - (Si + Ti + Al + Cr)$.

The results of analyses of garnet form the Momose-Mizunashi district are given Tables 1 and 3. The unit cell dimentions are also determined by X-ray diffractometer. Analyses of garnets in pelitic and calc-siliceous gneiss are listed in Table 3 for comparison with the data from the amphibolite. The CaO content of the garnet ranges from 0.92 to 36.62 wt%. Compositional zoning are observed. The CaO content increases from the core to margin. This is conpensated by decrease in FeO. MgO tends to decrease toward the margin.

Variation of unit cell demensions is controlled mainly by the grossular component (Text-figure 5). This regularity seems to give a proof for the effectiveness of the recalculation of garnet formula mentioned before.

Text-figure 6 shows the relationship between Mg, Fe^{2+} , and (Ca + Mn) of the garnets



Text-fig. 4 Plots of CaO/Al_2O_3 and $\Sigma FeO/MgO$ mol ratio of the bulk composition from the Hida districts and the other metamorphic terrane. The numbers attached individual symbols (1-3) refer to the column numbers in Table 2.
s: Scottish Highland (Wiseman, 1934) b: Broken Hill (Binns, 1965) y: Yokokawa (Kanisawa, 1969) n: Nishidohira (Tagiri, 1973) k: Kurosegawa (Karakida, et al., 1979)

from various areas. The Fe/(Ca + Mn) ratio from the area studied has the wide compositional range and shows a similar variation pattern to the garnets either from Kurosegawa (Karakida *et al.*, 1979) or from Broken Hill (Binns, 1965). The MgO content tends to, however, be lower than that from the Kurosegawa amphibolite. The Ca-rich almandine attaining up to 63 mol% in almandine component is rich in pyrope components (up to 8.2 mol%). The chemical composition of this garnet is very similar to that from "eclogitic rock" at Tsukigase in the Hida Metamorphic Belt (Suzuki, 1973). The grossular component in the "grossular-almandine garnet" increases from the core to margin. Such a compositional variation trend is contrary to those of the amphibolites from the Broken Hill district (Binns, 1965). Considering from this negative trend, It is inferred that the grossular component in Ca-rich almandine increases as retrogressive metamorphism proceeds.

After their chemical composition, the majority of the clinopyroxene is salite to ferrosalite (No. 1 and 2 in Table 4), and rarely ferroaugite (No. 3 in Table 4).

Twnety-two calcic amphiboles were analyzed from the garnet-bearing amphibolites, and eleven calcic amphiboles were also analyzed from garnet-free amphibolites (Text-figures 7 and 8). The majority of the amphibole from the garnet-bearing amphibolite is ferroan pargasite to ferro-pargasitic hornblende, but seven amphiboles are ferro-tschermakitic hornblende to ferro-hornblende (Table 5). The amphiboles from garnet-free amphibolite are ferroan pargasitic hornblende to ferro-edenitic hornblende (Leake, 1978).

Discussion and Geological Significance

The formation of the "grossular-almandine garnet" is inferred to be related to the characteristics of chemistry of the original rocks such as high $\Sigma FeO/MgO$ and low CaO/Al_2O_3 ratio (Text-figure 4, and Inazuki, 1980b). Appearence of clinopyroxene seems to depend on

No.	1	2	3	4
SiO_2	36.83	36.76	38.71	39.12
TiO_2	0.01	–	0.98	0.04
Al_2O_3	20.73	21.72	17.18	21.46
Cr_2O_3	0.03	–	–	–
FeO*	37.45	35.25	7.95	2.10
MnO	0.95	4.14	0.35	0.11
MgO	2.62	1.79	0.06	0.09
CaO	0.92	1.18	34.40	36.62
Na_2O	–	–	–	–
Total	99.54	100.84	99.63	99.54
Cation contents to 24 oxygen atoms				
Si	5.995	5.928	5.965	5.935
Al	3.977	4.127	3.120	3.837
Ti	0.001		0.114	0.005
Cr	0.004			
Fe^{3+} **	0.023		0.802	0.223
Fe^{2+}	5.075	4.754	0.222	0.043
Mn	0.131	0.565	0.046	0.014
Mg	0.636	0.430	0.014	0.020
Ca	0.160	0.204	5.679	5.953
Na				
Mol% end members				
Alm.	84.5	79.9	3.7	0.7
And.	0.6		23.0	5.7
Sp.	2.2	9.5	0.8	0.2
Uv.	0.1			
Gr.	2.0	3.4	72.2	93.1
Py.	10.6	7.2	0.2	0.3
Measured physical properties				
a (Å)	11.523	11.527	11.904	11.849

Table 3 Chemical analyses and physical properties of garnet from pelitic (No. 1-2) and calc-siliceous rocks (No. 3-4).
No. 1 = 4M127, No. 2 = 4M165, No. 3 = 5M73, No. 4 = 4M124.

the bulk chemistry of the original rock. The paragenetic relation of "grossular-almandine garnet" amphibolite have not been reported in the Hida Metamorphic Belt (Text-figure 9b). Ackermand *et el.* (1972) consider that there is complete solid solution between almandine and grossular, at least under condition of greenschist to low-temperature amphibolite facies of regional metamorphism of the Tauern area in Austria. It is difficult to increase accuracy for bulk chemical analysis of Ca-rich almandine amphibolite. For this reason, the mechanism of the two kinds of garnet amphibolite is not yet elucidated.

The occurrence of Ca-rich almandine amphibolite gives an important information to understand the metamorphism in the Hida Belt. The paragenetic relation of Ca-rich almandine amphibolite is shown in Text-figure 9a. According to Miyashiro (1973), epidote amphibolites and amphibolites commonly contain almandine garnet with 6-10 wt% CaO in

No.	1	2	3
SiO_2	51.47	50.88	52.58
TiO_2	0.08	0.02	0.03
Al_2O_3	0.26	0.48	1.55
Cr_2O_3	0.01	–	–
FeO*	14.94	19.41	21.10
MnO	0.71	1.36	0.54
MgO	9.39	5.53	11.37
CaO	23.74	22.08	12.21
Na_2O	–	0.19	–
Total	100.60	99.95	99.38
Si	1.979	2.007	2.021
Al	0.012	0.022	0.070
Ti	0.002		0.001
Cr			
Fe^{2+}	0.480	0.640	0.678
Mn	0.023	0.045	0.018
Mg	0.538	0.325	0.651
Ca	0.978	0.933	0.503
Na		0.014	
Fe	24.1	33.7	37.0
Mg	26.9	17.1	35.5
Ca	49.0	49.2	27.5

Table 4 Chemical compositions and atomic proportion (O = 6) of clinopyroxene from the garnet amphibolite.
No. 1 = 9M06, No. 2 = 9M03, No. 3 = 9M06.
* total iron calculated as FeO.

medium- and high-pressure metamorphism, and high rock-pressure would favour the formation of Ca-rich almandine in metabasites. If ferroaugite had been equilibrium with Ca-rich almandine prior to the formation of the "grossular-almandine garnet" and salite to ferrosalite, this assemblage is similar to that from "eclogitic rock" at Tsukigase in the Hida Metamorphic Belt (Suzuki, 1973). Assuming that the assemblage of Ca-rich almandine and ferroaugite is formed under higher rock-pressure, the following interpretation is possible that rocks in the Momose-Mizunashi district have once undergone some metamorphism of high rock-pressure type.

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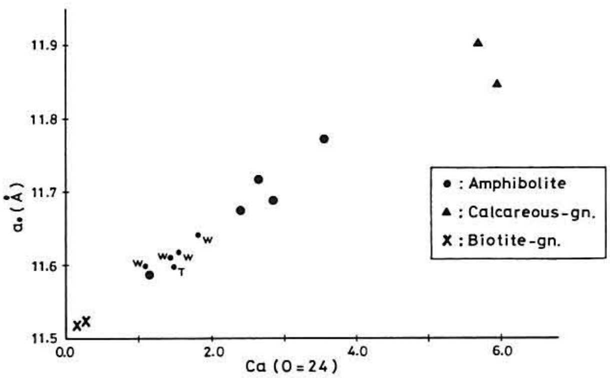
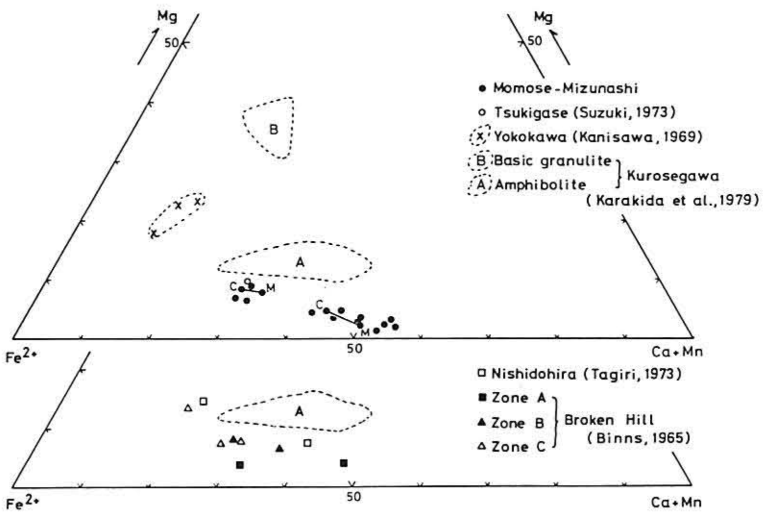
Table 5 Representative analyses and atomic proportion (0 = 23) of hornblende from garnet-bearing amphibolite (No. 1-5) and garnet-free amphibolite (No. 6).
No. 1 = 6M26, No. 2 = 4M84, No. 3 = 9M06, No. 4 = 4M138, No. 5 = 9M10, No. 6 = 4M70.
* total iron calculated as FeO.

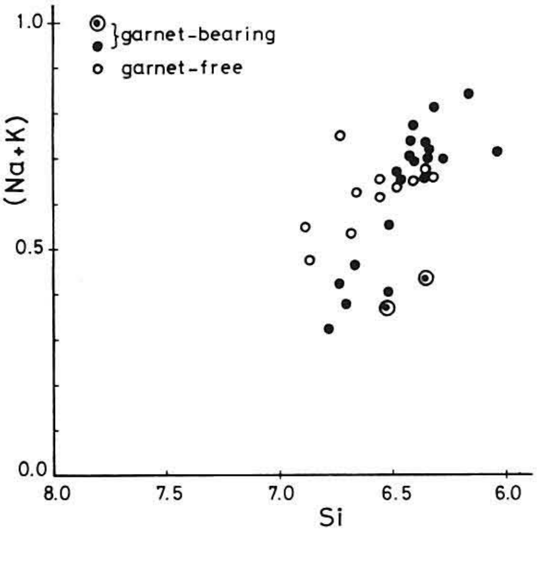
No.	1	2	3	4	5	6
SiO_2	42.27	42.20	44.38	39.29	39.56	41.31
TiO_2	0.80	0.43	0.28	1.02	0.87	0.95
Al_2O_3	13.89	12.39	11.92	12.00	11.92	13.06
Cr_2O_3	–	0.05	0.03	0.76	–	–
FeO*	20.32	22.96	23.51	22.16	25.33	19.50
MnO	0.39	0.58	0.40	0.34	0.44	0.27
MgO	7.51	5.73	4.94	6.81	3.76	7.95
CaO	11.77	11.20	11.49	11.68	11.70	11.51
Na_2O	1.16	1.02	0.86	1.75	1.27	1.45
K_2O	0.49	0.51	0.86	1.50	1.55	1.16
Total	98.60	97.07	98.66	97.31	96.39	97.16
Si	6.360	6.533	6.744	6.174	6.345	6.334
Al^{IV}	1.640	1.467	1.256	1.826	1.655	1.666
Al^{VI}	0.823	0.794	0.879	0.396	0.597	0.694
Ti	0.091	0.050	0.032	0.121	0.105	0.110
Cr		0.006	0.003	0.041		
Fe^{2+}	2.557	2.973	2.988	2.912	3.397	2.500
Mn	0.050	0.076	0.051	0.046	0.060	0.035
Mg	1.685	1.323	1.120	1.594	0.899	1.817
Ca	1.897	1.858	1.871	1.967	2.011	1.891
Na	0.338	0.306	0.254	0.532	0.395	0.431
K	0.094	0.101	0.167	0.301	0.317	0.227



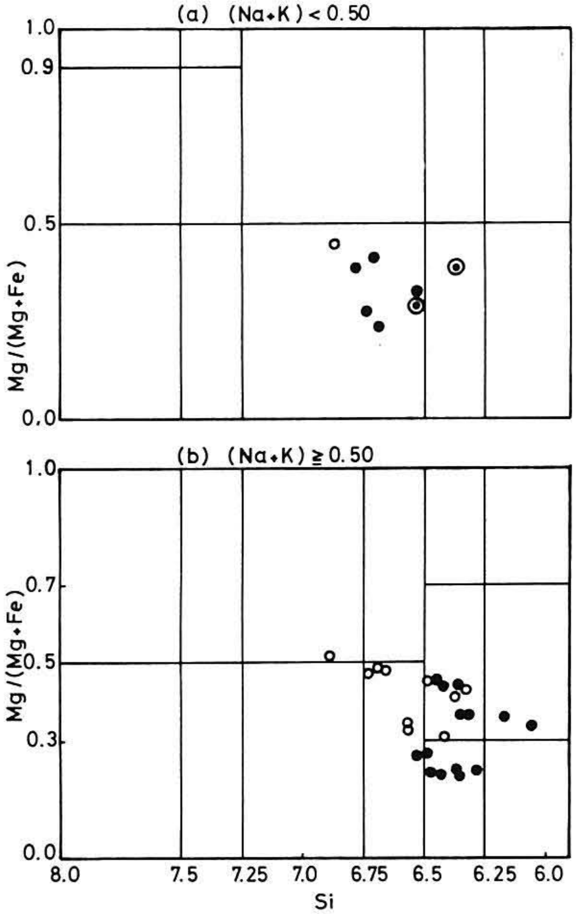
Text-fig. 5 Dependence of cell dimensions upon grossular content in garnets.
Large solid circle; garnet from amphibolite in this studied area. Small solid circle: garnet from the other districts, W = Broken Hill (Binns, 1965), T = Tsukigase (Suzuki, 1973). Cross: garnet from biotite gneiss in this area. Solid triangle: garnet from calcareous gneiss in this area.



Text-fig. 6 Relationship between the Mg, Fe^{2+}, and (Ca + Mn) of garnets from different areas.



Text-fig. 7 Si – (Na + K) diagram of calcic amphiboles.
Double circle: amphibole from Ca-rich almandine amphibolite. Solid circle: amphibole from "grossular-almandine garnet" amphibolite. Open circle: amphibole from garnet-free amphibolite.



Text-fig. 8 Diagram showing composition of calcic amphiboles. Classification by Leake (1978). Symboles are the same as in Text-figure 7.

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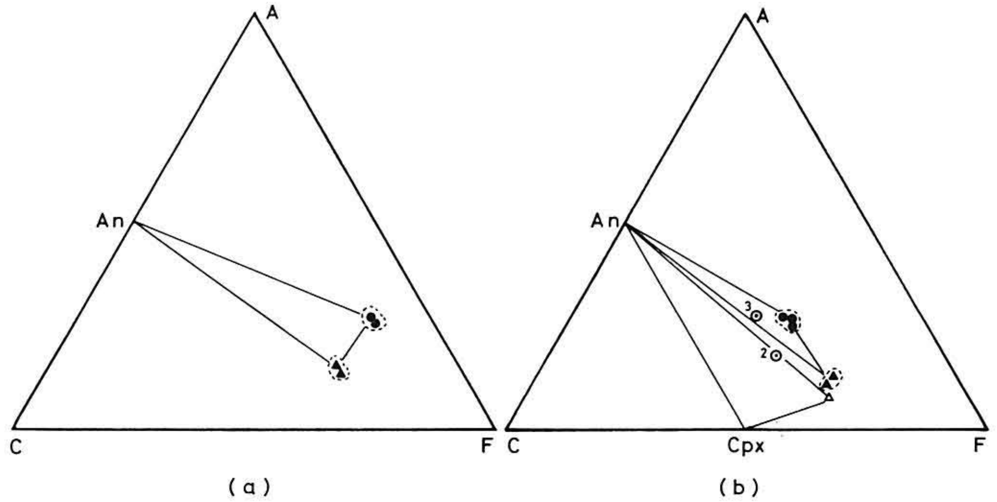

Text-fig. 9 ACF-diagram for the rocks and their minerals at the Momose-Mizunashi district.
Double circle: chemical composition of rock. Solid circle: garnet. Triangle: hornblende.
(a) is Ca-rich almandine amphibolite.
(b) is "grossular-almandine garnet" amphibolite and garnet-free clinopyroxene amphibolite. Numbers (2 and 3) correspond with those in Table 2. Solid symboles is sample No. 3 in Table 2. Open symboles is sample No. 2 in Table 2.

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