Note on the Graphite-Free Corundum-K feldspar Gneiss in the Hida Metamorphic Belt, Central Japan

By

Tetsuya OSAKABE and Morihisa SUZUKI

with 4 Tables, 3 Text-figures and 1 Plate

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ABSTRACT: The association of corundum-K feldspar in a graphite-free rock is newly found in the western portion of the Hida Metamorphic Belt, central Japan. The equilibrium assemblage of the rock is corundum-K feldspar-plagioclase-biotite-apatite-zircon-ore with no graphite. Ore minerals are characterized by the abundance of rutile and by the absence of ilmenite and/or magnetite. Corundum and K feldspar had been in direct contact with each other before the formation of kelyphitic rims of muscovite aggregates around corundum crystals. The association of corundum-K feldspar in the graphite-free system must suggest the formation by the breakdown of muscovite under the condition when P_{H_2O} is not so low. Therefore, the breakdown must occur more or less near the maximum temperature expected. The metamorphic conditions have been estimated by the stable associations of zincian spinel-garnet-biotite-sillimanite-K feldspar-plagioclase and clinopyroxene-garnet in the metamorphites from the area to be around 700°C and 6 kb, which are not inconsistent with the condition deduced from the association now discussed.

CONTENTS

I. INTRODUCTION

The metamorphic association of corundum and K feldspar has been considered to be the breakdown product of muscovite and has the significance for the determination of petrogenetic conditions. Since the first report by SUZUKI and KOJIMA (1970) from Hane valley, about 7.5 km northeast of the discussed area, the association has been found from some localities in the Hida Metamorphic Belt, such as Toga (INAZUKI, 1979), Wada River (ASAMI, 1979, 1982 and personal communication) and Oki Islands (HOSHINO, 1979) areas. It must be noted that the association of corundum-K feldsper so far reported is always found in the graphite-bearing rock.

As stated by BANNO (1980), the presence of graphite in the system must reduce the upper stability temperature of muscovite. Namely, if the fluid phase is in equilibrium with graphite, CO_2 will be produced by the reaction of graphite with oxygen. As a result, P_{H_2O} can be reduced to the lower value than the maximum one. Therefore, the association of corundum-K feldspar in the graphite-bearing system can be produced under lower temperature condition than that in the graphite-free system.

The junior author, T. OSAKABE, has found out a graphite-free corundum-K feldspar gneiss at Tsukigase, Odori River area, Gifu Prefecture. In this paper, the authors intend to describe the rock comparing with the samples already reported from the Hida Metamorphic Belt and to give the key to estimate the metamorphic conditions and history in the area.

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II. GENERAL GEOLOGY

The studied area is situated in the western portion of the Hida Metamorphic Belt, central Japan. In the area, various kinds of metamorphic and granitic rocks are widely distributed (Fig. 1). As the geological outline of the area has already been shown (SUZUKI and OSAKABE, 1982), only the summarizing note will be given here.

The metamorphic rocks in the area have been derived from basic, calcareous and pelitic equivalents. Among them, basic gneiss is most predominantly developed, having the stable association of intermediate plagioclase, quartz, brown hornblende, clinopyroxene (salite), K feldspar, graphite and/or almandinous garnet. Basic gneiss is sometimes changed gradually to basic migmatite, especially near the contact to Tsukigase-type granite mentioned below. It shows metatectic appearance, being composed of plagioclase, quartz, biotite, brown to greenish brown hornblende, K feldspar and/or almandinous garnet. Metamorphites of calcareous rock origin are also widely distributed. They can be divided into at least two categories of lime-silicate gneiss and crystalline limestone. The former is always associated and concordant with the latter. The main constituent minerals of the lime-silicate gneiss are intermediate to calcic plagioclase, quartz, K feldspar, clinopyroxene (salite and ferrosalite), sphene and graphite. Ca-rich garnet, scapolite, biotite and hornblende are often associated. Crystalline limestone is calcitic with lesser amounts of clinopyroxene, wollastonite, phlogopite and graphite. Pelitic gneiss is, as a usual case in the Hida Metamorphic Belt, rather minor member among the metamorphites. It is composed of plagioclase, quartz, K feldspar, biotite, almandinous garnet, graphite and ilmenite. When the aluminous silicate mineral is associated, it is always sillimanite. Hornblende is sometimes associated with the above assemblage.

Based upon the observation of paragenetic relationship of the metamorphites described above, the common metamorphic condition now observed in the area is amphibolite facies. As already mentioned (SUZUKI, 1977 and SUZUKI and OSAKABE, 1982), however, there occur some peculiar kinds of metamorphic rocks with the association suggesting the formation under higher grade condition than that mentioned above. Among them, zincian spinel-bearing gneiss is significant. It has the stable association of garnet ($Alm_{76-82}Pyr_{11-17}Spes_{3-4}Gros_{3-5}$), biotite (with 2–3 wt% of TiO_2), spinel ($He_{40-62}Ga_{27-54}$

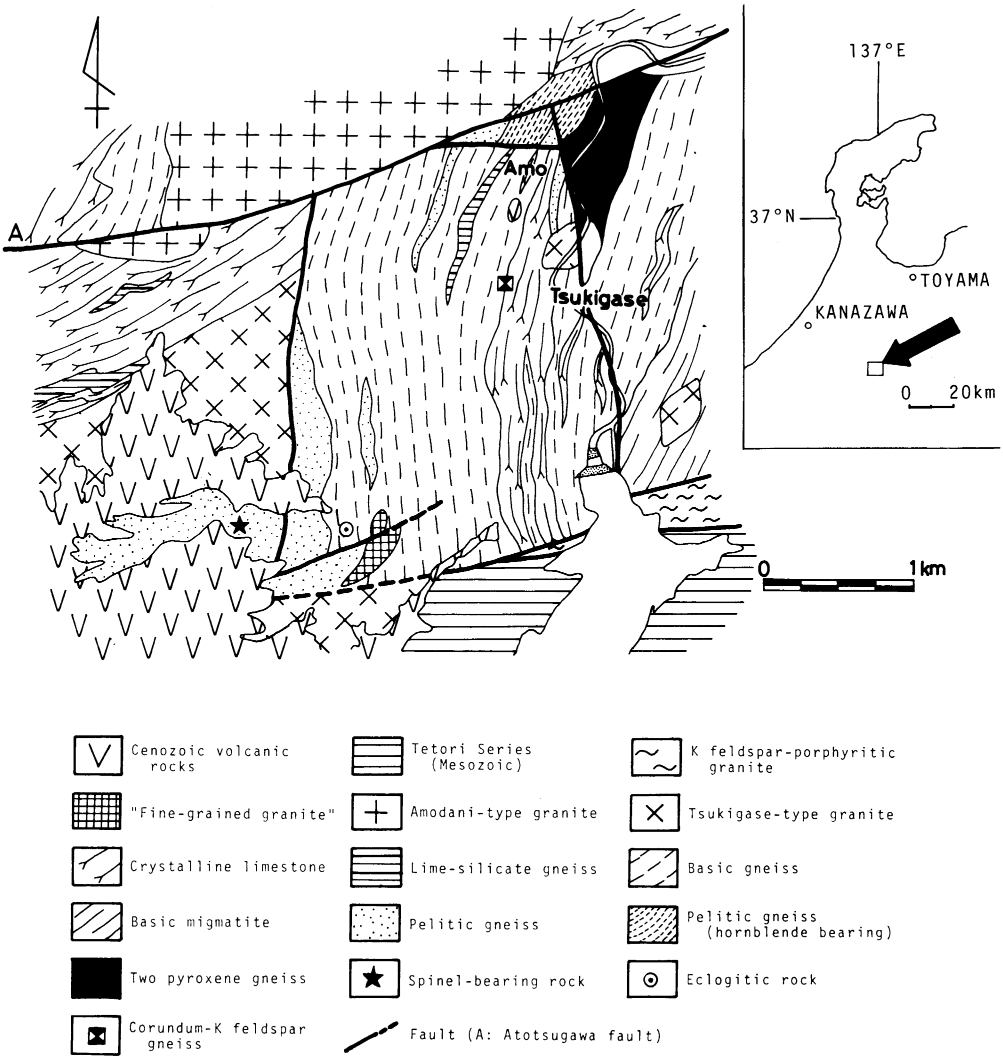

FIG. 1. Location and geological map of the Tsukigase area, southwestern part of the Hida Plateau.

Sp_{6-12}), sillimanite, K feldspar ($Or_{87-89}Ab_{9-11}An_{1-3}$), quartz, graphite, ilmenite, apatite, zircon and/or plagioclase ($An_{31}Ab_{68}Or_{1}$). The rock has been considered to be derived from some kind of pelitic equivalent under higher temperature condition (SUZUKI and OSAKABE, op. cit.). Next representative of the higher grade rocks is pyroxene gneiss with the stable association of orthopyroxene and clinopyroxene, but the former mineral has often been retrogressively altered to amphiboles. The eclogitic rock of the clinopyroxene-garnet is also found in the area, the petrogenetic significance of which has been shown by one of the present authors (SUZUKI, 1973). Above-mentioned peculiar kinds of rocks have undergone intense retrogressive metamorphism to result in showing the association containing hydrous phases at the expense of anhydrous ones. It can be inferred that above-mentioned interesting rocks had been formed during the higher grade and older metamorphism than that prevailing on a large scale. The rock now concerned will be described along the line that it can belong to the metamorphites of the higher grade (OSAKABE and SUZUKI, 1982).

Granitic rocks in the area can be divided at least into the following six types: that is, gray granite, Inishi-type granite, Tsukigase-type granite, "fine-grained granite", Amodani-type granite and K feldspar porphyritic granite. The former two are developed only in the gneisses as a small-scaled sheet and dyke, therefore, the distribution of them are not shown in Fig. 1. The former four types of granites show more or less distinct gneissose structure concordant to that of surrounding gneisses. The latter two are rather massive and/or partly mylonitic.

III. MODE OF OCCURRENCE

The corundum-K feldspar gneiss has been found about 300 m west of Tsukigase (Fig. 1). The rock is rather leucocratic in contrast to the grayish appearance of the sample from Hane valley, which is characterized by the abundance of graphite. The rock in question occurs along the boundary between crystalline limestone and basic gneiss as a lenticular body of several meters wide. Although the direct contact to the surroundings can not be observed, it appears to be underlain by the crystalline limestone. It shows weakly developed gneissose structure, which is harmonic not only with the long axis of the rock body but with that of the environmental gneisses of N–S trend dipping steeply to the east. It seems that there are no evidences to suggest the effects of thermal metamorphism by the igneous masses and of tectonic disturbance by faults in the vicinity.

IV. PETROGRAPHY

The rock under consideration is weakly foliated with the scattering of porphyroblastic corundum crystals of right pinkish tint. The mineral assemblage of the specimen would be divided into at least two paragenetic groups, each representing independent metamorphic condition of different metamorphic stage.

The essential metamorphic assemblage formed during the main stage is corundum-K feldspar-plagioclase-biotite-rutile-apatite-zircon-ore minerals. As ore minerals have now been intensely altered to lepidocrocite, essential mineral can not be identified. However, the lacking of graphite, ilmenite and/or magnetite can not be doubtful. Muscovite, epidote, tourmaline, titanite and prehnite must be produced during later stage of metamorphisms, which can further been divided into some substages.

The modal composition of the rock is shown in Table 1, where the compositions of samples from Hane and Toga areas of the Hida Metamorphic Belt are also given for reference. It is remarkable from the table that the sample now discussed is characterized by the abundance of K feldspar and muscovite and by the poverty of plagioclase among the Hida samples. It is further significant that opaque minerals of the samples are characterized by graphite, ilmenite and/or magnetite, except for the rock from Tsukigase.

The bulk chemical compositions of the samples from Tsukigase and Hane valley are shown in Table 2. Both are notably rich in Al_2O_3 and total alkalies, while poor in MgO and FeO. The former sample shows the characteristics of higher contents of Al_2O_3 and

TABLE 1. MODAL COMPOSITIONS OF THE CORUNDUM-K FELDSPAR GNEISS IN THE HIDA METAMORPHIC BELT.

Locality	Tsukigase	Hane	Toga (INAZUKI, 1979)			
Sample No.	T–1	H–1	730530			
			A	B	C	D
Quartz	—	—	1.8	tr.	—	—
Plagioclase	4.2	65.5	57.9	79.3	20.2	31.9
K feldspar	52.0	7.8	tr.	1.7	18.1	19.3
Biotite	5.1	2.5	19.5	tr.	33.7	tr.
Muscovite	34.9	14.9	14.5	15.6	11.8	15.8
Corundum	2.6	3.7	0.1	0.3	12.6	2.4
Sillimanite	—	—	—	—	—	tr.
Andalusite	—	—	—	—	tr.	15.9
Rutile	0.4	0.7	—	—	—	—
Opaque	tr.	4.3	0.5	0.7	1.8	10.9
Others	0.8	0.6	5.7	2.4	1.8	3.8
Total	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 2. BULK CHEMICAL COMPOSITIONS OF THE CORUNDUM-K FELDSPAR GNEISS

Locality	Tsukigase	Hane (SUZUKI, 1977)
SiO_2	50.0	54.55
TiO_2	1.47	0.28
Al_2O_3	30.7	27.57
Fe_2O_3	2.90*	0.93
FeO		1.51
MnO	0.14	0.02
MgO	2.90	0.72
CaO	2.10	1.53
Na_2O	1.52	4.21
K_2O	7.46	6.15
$H_2O(+)$	n.d.	1.60
$H_2O(-)$	n.d.	0.38
P_2O_5	n.d.	0.09
C	n.d.	0.49
Total	99.2	100.03
$\frac{Al_2O_3**}{Na_2O+K_2O+CaO}$	2.77	1.69
$\frac{K_2O**}{Na_2O+K_2O}$	0.83	0.49

* Total Fe as FeO

** Mole ratio

MgO, while lower of Na_2O and SiO_2.

Under the microscope, porphyroblastic corundum crystals are scattered in the granoblastic feldspathic matrix. The largest crystal reaches to 2 cm in the long diameter. The chemical composition of corundum is given in Table 3, showing that it contains a little amounts of iron component. The corundum crystal is always mantled by two-layered kelyphitic rims of right greenish muscovites. Namely, corundum is directly surrounded by very fine-grained (less than 0.05 mm) muscovite aggregate, which is further surrounded by coarser-grained (0.1 to 0.7 mm) muscovite of euhedral shape (Plate 1). The chemical compositions of muscovites of each layer are shown in Table 3, showing the

TABLE 3. REPRESENTATIVE CHEMICAL COMPOSITIONS OF THE MAIN CONSTITUENT MINERALS OF THE CORUNDUM-K FELDSPAR GNEISS IN THE HIDA METAMORPHIC BELT.

Locality	Tsukigase				Hane			Toga (INAZUKI, 1979)	
Minerals*	Cor	Mu(f)	Mu(c)	Biot	Mu(f)	Mu(c)	Biot	Cor	Mu
SiO_2	0.04	45.8	45.9	36.3	46.3	46.9	34.7	0.10	45.9
TiO_2	0.05	0.09	0.47	2.25	0.05	0.18	2.64	0.25	1.04
Al_2O_3	99.4	36.0	33.6	19.2	36.1	32.5	18.6	99.8	36.6
FeO**	0.73	1.12	2.77	14.6	0.50	1.51	20.2	0.27	1.19
MnO	0.06	0.08	0.10	0.23	0.03	0.02	0.38	0.01	0.04
MgO	0.03	0.38	1.19	13.8	0.26	1.03	9.30	0.01	0.40
CaO	0.03	0.03	0.01	0.03	0.08	0.03	0.07	0.01	0.01
Na_2O	0.01	0.24	0.22	0.13	0.28	0.27	0.09	0.00	0.48
K_2O	0.01	11.0	10.2	9.65	11.0	11.5	9.54	0.00	10.2
Cr_2O_3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.00	0.02
Total	100.4	94.7	94.5	96.2	94.6	93.9	95.5	100.5	95.8
				Cations on the basis of 22 Oxygens					
Si		6.137	6.201	5.359	6.191	6.371	5.316		6.058
Al		5.683	5.354	3.334	5.677	5.204	3.365		5.680
Ti		0.009	0.048	0.249	0.006	0.018	0.304		0.103
Fe		0.125	0.313	1.799	0.056	0.171	2.583		0.132
Mn		0.009	0.012	0.029	0.003	0.002	0.050		0.005
Mg		0.075	0.240	3.203	0.053	0.209	2.122		0.079
Ca		0.004	0.002	0.005	0.012	0.005	0.011		0.002
Na		0.063	0.057	0.038	0.073	0.070	0.028		0.122
K		1.878	1.753	1.816	1.870	1.991	1.865		1.724
Cr		—	—	—	—	—	—		0.002
		K feldspar	Plagioclase		K feldspar		Plagioclase	K feldspar	
Or		86.7–86.8	1.0– 1.1		86.0		1.4	84.6–94.1	
Ab		12.0–12.2	59.2–62.7		12.1		77.2	4.9–15.1	
An		1.1– 1.2	36.2–39.8		1.9		21.4	0.3– 1.0	

* Abbreviations of minerals are as follows: Cor; corundum, Mu; muscovite, Biot; biotite, (f) and (c) mean fine-grained and coarse-grained, respectively.

** Total Fe as FeO

distinct difference with each other. The same texture and chemical difference are observed also in the Hane sample (Plate 1 and Table 3). The significance of the chemical descrepancy will be discussed in the following chapter.

K feldspar is usually euhedral, showing microcline-grille structure and/or perthitic texture. It is not unreasonable to consider that K feldspar was in direct contact with corundum before the formation of the kelyphitic rims described above. The chemical composition of K feldspar is around $Or_{86.8}Ab_{12.1}An_{1.1}$ and is very similar to that of the sample from Hane valley (Table 3).

Plagioclase is lesser in amount than K feldspar. The composition is in the range of $An_{36.2-39.8}Ab_{59.2-62.7}Or_{1.0-1.1}$, which is more calcic than that of Hane sample.

Biotite is parallely orientated on the gneissosity plane, the composition being given in Table 3. The content of TiO_2 is reaching to as high as 2 wt%. X_{Fe} (Fe/Fe+Mg) is around 0.37. The ratio is rather lower comparing with that of Hane sample (0.55).

Ore minerals are characterized by the abundance of rutile and brownish mineral. The former is always altered to titanite along its margin or fractures in it. The latter is characterized by the strong pleochroic orange-red to brown, and the total Fe as FeO is around 73 wt%, therefore, the mineral can be identified to lepidocrocite. It may be the altered product of original ore minerals which can not be determined. No graphite and ilmenite are found.

V. Metamorphic Conditions of the Discussed Area

To estimate the metamorphic conditions of the area now concerned, it is significant to pay attention not only to the mineral associations but to the chemical characteristics of main constituent minerals.

The significant associations found in metamorphites are corundum-K feldspar now concerned, clinopyroxene-garnet in eclogitic rock, two pyroxene association in pyroxene gneiss and zincian spinel-sillimanite-garnet-biotite-K feldspar-plagioclase in some kind of pelitic equivalents. As described above, the association of corundum and K feldspar is found in the graphite-free system, therefore, it is not unreasonable to consider that the association has been formed as a result of breakdown reaction of muscovite under the condition of higher value of P_{H_2O}, then of more or less near the highermost temperature expected as in the case of muscovite+quartz reaction (Fig. 2).

As the association of corundum-K feldspar in the Hane valley has been found in the graphite-bearing rock, the formation condition can be rather lower temperature than that now concerned. Moreover, the values of X_{Fe} in biotite in the samples from Tsukigase and Hane are different with each other as mentioned before. The lower value of the former may suggest the higher oxidation condition depending on the absence of graphite. In other words, biotite may be oxidized to form iron oxides to result in reducing of X_{Fe} value.

As for the association of clinopyroxene-garnet in the eclogitic rock, found about 2 km west of the outcrop of the rock now discussed, metamorphic temperature is estimated to be in the range of 720 to 740°C (Suzuki, 1977).

The association of orthopyroxene-clinopyroxene is also important, but the temperature estimation based on the pair has not yet been given successfully because of the intense retrogressive alteration of orthopyroxene to amphiboles.

TABLE 4. P AND T FROM GARNET-BIOTITE-PLAGIOCLASE-SILLIMANITE IN THE ZINCIAN SPINEL-BEARING ROCK, TSUKIGASE*.

	Fe/Mg		T°C**	Mole Fractions (X)				Activity Coefficient (γ)***		P kb****
				garnet			plag	garnet	plag	
	garnet	biotite		Gr	Alm	Pyr	An	Gr	An	
rim	4.8438	1.3450	693	0.0504	0.7658	0.1581	0.314	1.1512	1.4698	6.2
core	4.5787		712	0.0471	0.7596	0.1659	0.314	1.1537	1.4354	6.3

* Chemical compositions of minerals were given in SUZUKI and OSAKABE (1982)
** Calculated from THOMPSON (1976)
*** Calculated from NEWTON and HASELTON (1981)
**** Calculated from GHENT (1976)

Zincian spinel-bearing metamorphites, found in the area about 2.5 km west of the rock under consideration, will be discussed here to estimate the metamorphic conditions in the area, the result being given in Table 4. The temperature is calculated using the garnet-biotite geothermometer of an empirical relation based upon natural occurrences calibrated by the mineralogical data (THOMPSON, 1976), to give the result of around 700°C. The pressure can be estimated by the equilibrium relationship between garnet-plagioclase association with sillimanite and quartz (GHENT, 1976). In the calculation, the activity coefficient of grossular in garnet (γ_{Gr}) is calculated as follows (NEWTON, 1978):

$$RT \ln \gamma_1 = W_{1-2}X_2^2 + W_{1-3}X_3^2 + (W_{1-2} + W_{1-3} - W_{2-3})X_2X_3$$

where W_{1-2} is interaction parameter for components 1 and 2, etc, and X_2 is the molar fraction of the component 2, and so on. Following the equation by NEWTON and HASELTON (1981), the interaction parameters are calculated as follows:

$$W_{Ca-Mg} = 3300 - 1.5\ T(°K)$$

$$W_{Ca-Fe} = W_{Mg-Fe} = 0$$

Thus, the value of γ_{Gr} becomes:

$$RT \ln \gamma_{Gr} = (3300 - 1.5\ T)\ (X_{Mg}^2 + X_{Mg}X_{Fe})$$

The activity of anorthite in plagioclase is calculated by the following equation by NEWTON and HASELTON (op. cit.):

$$\alpha_{An} = \frac{X_{An}(1+X_{An})^2}{4} \exp \frac{(1-X_{An})^2}{RT}(2050 + 9392\,X_{An})$$

Calculated pressure is, then, as high as 6 kb. Zonal structure of garnet seems to be undistinct, the results being not so different between the estimation from garnet-rim and that from core.

Based on the estimated conditions given above and on the equilibrium relationship between corundum and K feldspar in the graphite-free system, the metamorphic conditions of the area, as a whole, must attain to be 700°C and 6 kb during the peak of the main stage of metamorphism (Fig. 2). The condition seems to be consistent with that estimated in the other portion of the Hida Metamorphic Belt (SUZUKI et al., 1982).

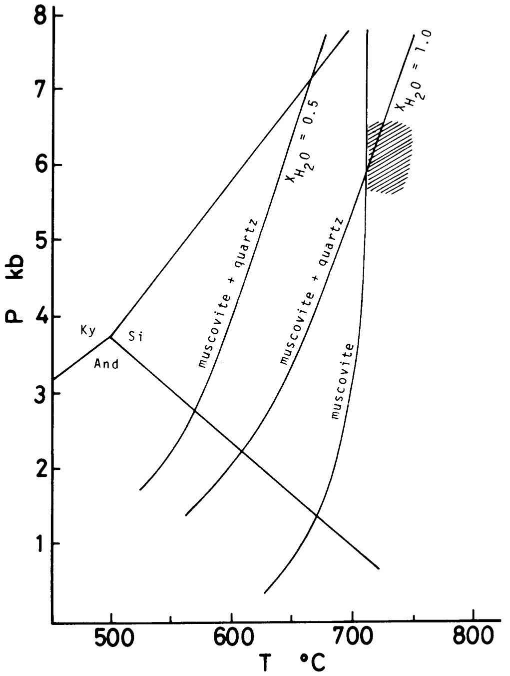

Fig. 2. The metamorphic conditions inferred for the main stage of metamorphism lie within the shaded area. Al_2SiO_5 curves from HOLDAWAY (1971), muscovite + quartz curves from KERRICK (1972) and muscovite breakdown curve from VELDE (1966).

It is remarkable that the metamorphic minerals of the area have been brokendown by retrogressive reactions on the regional scale. For example, pyroxenes have been altered to amphiboles, sillimanite to muscovite and so on. Garnets in various kinds of metamorphites often show distinct reverse zoning (SUZUKI, 1977).

In the sample now discussed, as described before, corundum crystals are surrounded by two-layered kelyphitic rims of muscovite aggregates. Both in the samples from Tsukigase and from Hane, fine-grained muscovites directly surrounding around corundum crystals are rich in Al_2O_3 (35.3–36.1 wt%) and poor in total iron (0.50–1.34 wt%), while the Al_2O_3 and total iron contents of euhedral muscovites in the outer kelyphitic rim are in the ranges of 32.5–34.0 wt% and 1.51–2.77 wt%, respectively. The representative chemical compositions of muscovites are shown in Table 3. Fig. 3 gives the relationship between the compositions of muscovites in metapelites and the metamorphic grade (MIYASHIRO, 1973). The compositions of fine-grained muscovite correspond to those in higher grade amphibolite facies rocks. Meanwhile, euhedral muscovite of coarse-

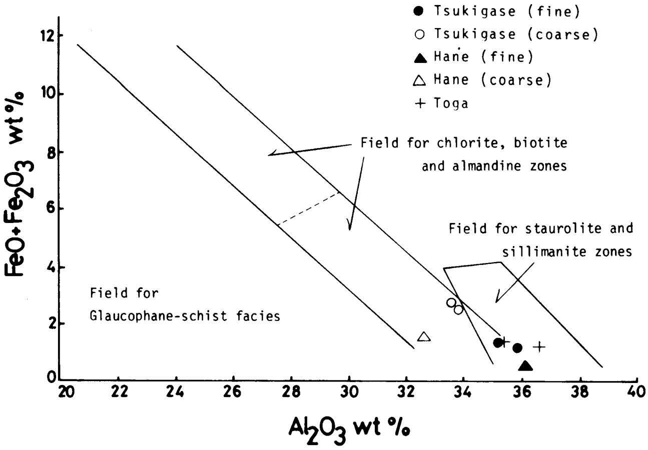

FIG. 3. Chemical compositions of muscovites. Both in the specimens from Tsukigase and Hane, fine-grained muscovites (fine) constitute the inner kelyphitic rim directly surrounding corundum, while coarse-grained ones (coarse) the outer rim of euhedral aggregate. The data of Toga from INAZUKI (1979).

grained shows the compositional range corresponding to that formed under the lower condition than the almandine zone. Judged from the texture, it may well be said that euhedral muscovites of outer rim have been grown after the formation of fine-grained inner rim.

Although the associations of corundum and K feldspar from Hane and Tsukigase may be formed under the different condition of oxidation with each other, the retrogradic condition and history of the association seems to be quite similar. It can be inferred that the corundum-K feldspar association of the Odori River area has been suffered by the retrogradic metamorphism of two stages, one being higher grade of amphibolite facies and earlier, while another lower grade and later. In this connection, it must be noted that the K-Ar age of muscovite from Hane sample, although the separation of each aggregate of two-layered rims has not been tried, was given to be 183 ± 6 Ma (SUZUKI, 1977). It suggests that the retrogradic metamorphism, at least its latest stage, is closely associated with the activity of Funatsu granites.

In the Odori River area, there occur several kinds of metamorphic rocks as fusiform bodies, which suggest the formation during higher grade and older metamorphism than that during which ubiquitously developed metamorphic associations were formed. Some associations in the former must partly be escaped from the metamorphisms of the latter. The corundum-K feldspar association now described must belong to the members of escaped one.

SUZUKI (1977) has concluded that in the Hida Metamorphic Belt, at least in the western portion, the main metamorphism has been succeeded by two stages of retrogradic metamorphism, the older one being amphibolite facies and the younger one the greenschist facies closely connected with the activity of Funatsu granites. The metamorphic history suggested by the rock now discussed is not inconsistent with above conclusion.

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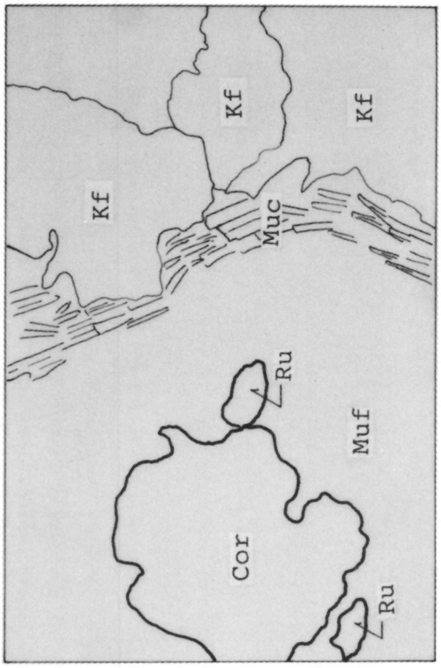
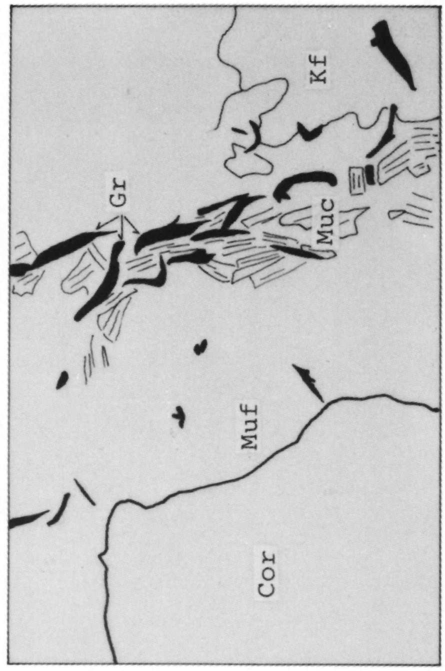
Tetsuya Osakabe and Morihisa Suzuki
Institute of Geology and Mineralogy,
Faculty of Science, Hiroshima University,
Hiroshima, 730 Japan

EXPLANATION OF PLATE I

Photomicrographs of corundum-K feldspar gneiss in the Hida Metamorphic Belt. Crossed nicols, scale bars = 0.5 mm. Two-layered kelyphitic rims of muscovites are observed between corundum (Cor) and K feldspar (Kf). Fine-grained muscovite (Muf) in direct contact with corundum is surrounded by coarse-grained muscovite (Muc).

Upper: Sample from Tsukigase, Rutile (Ru) is abundant but lacking of graphite.
Lower: Sample from Hane. Graphite (Gr) is often associated.


Kf
Kf
Kf
Muc
Ru
Muf
Cor
Ru


Kf
Gr
Muc
Muf
Cor