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Author(s)	SUZUKI, Morihisa
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Polymetamorphism in the Hida Metamorphic Belt, Central Japan*

By

Morihisa SUZUKI

with 17 Tables and 50 Text-figures

(Received November 17, 1976)

ABSTRACT: On the western part of the Hida metamorphic belt, central Japan, there develop quartzofeldspathic gneiss, basic gneiss and calcareous gneiss, associated with lesser amounts of pelitic gneiss. Various kinds of granite are distributed. Judged from the petrological and mineralogical characters of such metamorphic minerals as pyroxene, amphibole, garnet, feldspar and mica, the metamorphic facies of the area is, in general, the amphibolite facies or lower.

It must be noted, however, that there occur some interesting metamorphites with critical mineral associations suggesting the metamorphic facies of higher grade, probably the granulite facies. It is represented by such rocks as K feldspar-corundum gneiss (K feldspar-corundum-plagioclase-biotite-rutile), eclogitic rock (clinopyroxene-garnet-quartz) and two pyroxene gneiss (orthopyroxene-clinopyroxene-hornblende-garnet-K feldspar-plagioclase-quartz). The so-called "syenitic rock" of the Inishi type, which consists of wollastonite, clinopyroxene and plagioclase, would suggest the same metamorphic condition as that of the granulite facies rocks. Besides those critical mineral assemblages mentioned above, some minerals show the characteristics in chemical composition, which reflect the condition of higher grade metamorphism. Chemical characteristics of hornblende, garnet, plagioclase, scapolite, etc. suggest the granulite facies metamorphism in the area in question. Products of the granulite facies metamorphism are now preserved in the core parts of zoned crystals or zoned aggregates.

Time and spatial relationship between the granulite facies metamorphism and the before-mentioned amphibolite facies metamorphism has been clarified in terms of polymetamorphism. In this concern, special attentions have been paid to the occurrence and mineralogy of a metamorphosed basic dyke, intruded obliquely into the surrounding gneisses.

The role of granites in relation to the process of metamorphism has been summarized. Importance of the so-called "gray-granite" was especially emphasized. It is pointed out that the "gray-granite", at least a part of it, would have been formed by the process of partial melting under the condition of the granulite facies metamorphism. Meanwhile, the Funatsu granite, which had been regarded to be syntectonic and responsible for the granitization and migmatization on a large scale, has been clarified to be the post-kinematic one, playing a role of lubricant against the blocks of metamorphites.

Furthermore, uniqueness of the original rocks of the Hida metamorphites has been discussed, compared with those of the other high T — low P type metamorphic belts in Japan.

Lastly, chronological analysis of the Hida Plateau revealed the presence of the older metamorphism of the granulite facies, the age of which goes back to about 500 m. y.

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* Doctoral thesis (Science) presented to the Hiroshima University in 1976.

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I. INTRODUCTION

A. Previous works

The Hida metamorphic belt has been repeatedly investigated by many petrologists and stratigraphers since the end of the last century. Most of the workers have been concerned with the geology of the Hida metamorphic belt, with special reference to its situation in the geologic development of the Japanese islands (Fig. 1). The most attractive problem has been whether the Hida metamorphic belt was the basement of the Paleozoic geosyncline in Japan.

In the early days of Japanese geology, HARADA (1889) published interesting opinions that the Hida plateau is the basement complex on which Paleozoic systems were accumulated, and that gneisses in the Hida plateau represent the Archaeozoic. On the other hand, OGAWA (1899) argued that the gneisses were formed after the Carboniferous period, based on the evidences that the gneisses lie under the Jurassic series but that they do not appear as pebbles in the conglomerates in any Paleozoic formation.

SATO and NODA (1921) were the first to accomplish the geological map of the Hida gneiss area, namely, the sheet of "Takayama" on the scale of 1/200,000. Afterwards, mainly in publications of the Geological Survey of Japan, the metamorphic rocks of the Hida plateau have been regarded as derived from the Paleozoic sediments.

Afterwards, the age problem of the Hida metamorphic rocks has become one of puz-

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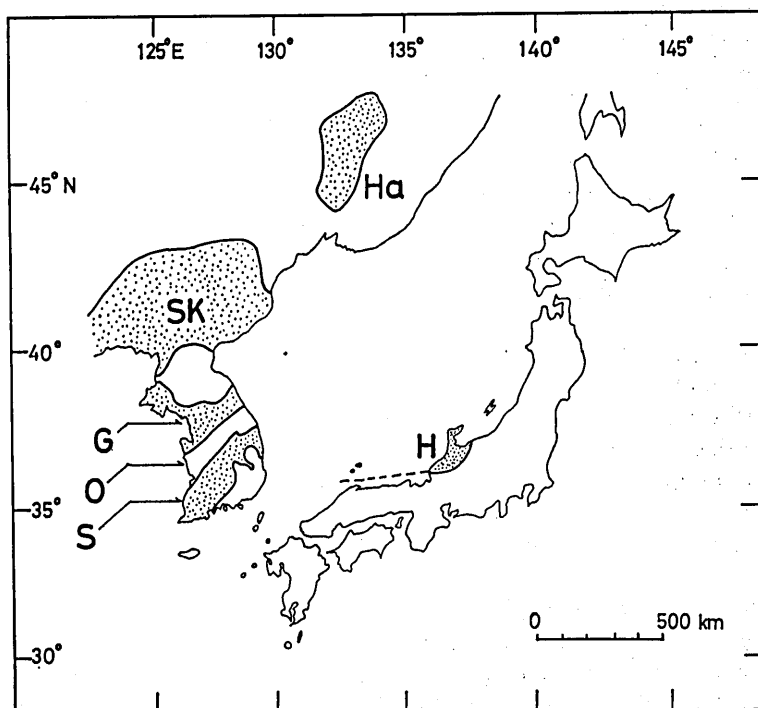


FIG. 1. Basement complex in East Asia.

- Ha: Hanka Massif
- Sk : Sino-Korean Shield
- G : Gyeonggi Massif
- O : Okcheon Belt
- S : Sobaeksan Massif
- H : Hida Massif

zling subjects among Japanese geologists. The representatives of anti-Precambrian theory are T. KOBAYASHI (1941) and NOZAWA (1959). Their views are mainly based on lithologic similarities between the original formations of the Hida gneisses and the Paleozoic ones. On the other hand, FUJIMOTO et al. (1962) H. KOBAYASHI (1958 and 1962) and MINATO et al. (1965) presented the Precambrian-theory. They are of the opinion that the original rocks of the Hida gneisses should not be the Late-Paleozoic but may be the pre-Silurian, probably the Precambrian, in age, because dolomitic limestone, which is predominantly developed in the Hida metamorphic terrain, is rare in sediments of the Late-Carboniferous and the Permian in Japan and no evidences of continuation have been observed from the Paleozoic group to the Hida gneisses. They correlated the gneisses to those of the Matenrei system in North Korea.

Since 1960, the radiometric age has been put forth on the rocks in the Hida belt. The results were summarized by NOZAWA (1968 and 1972) and SHIBATA et al. (1970). MIYASHIRO (1973) noticed the fact that several groups can be discriminated in the radiometric ages of the rocks in the Hida belt, namely, the Precambrian, around 500 m.y.,

320 m.y. and 240 to 180 m.y.. However, the metamorphic events revealed from the studies of metamorphics have not hitherto been correlated with those ages.

As compared with the age problems, detailed geological and petrological studies have been delayed. After the IIInd War, petrological works on the gneisses and granites in the Hida belt have been accumulated. SATO (1968) pointed out that most of the Hida gneisses belong to the epidote-amphibolite and the amphibolite facies, noting the presence of polymetamorphism. SUZUKI and KOJIMA (1970), SUZUKI (1973a, b, and 1974a, b,) and HOSHINO (1971 and 1973) pointed out the existence of metamorphic rocks of the granulite facies in the belt. FUJIIYOSHI (1970) noticed rocks of the two-pyroxene hornfels facies from the Hayatsuki River area, a northeastern part of the Hida belt.

Recently, ADACHI (1971 and 1973), SHIBATA and ADACHI (1972 and 1974) and SHIBATA et al. (1971) pointed out that the pebbles from the Permian Kamiaso conglomerate yield well-defined Precambrian Rb-Sr isochron ages, the oldest of which is 1985 m.y.. According to them, the provenance of the pebbles must have been exposed on the north not far from the present locality of the Kamiaso conglomerate, now occupied by the Hida gneisses.

Consequently, current problems on the Hida metamorphic belt may be summarized as follows:

- 1) mineralogical and petrological characters of the metamorphites
- 2) history and facies of the metamorphism
- 3) radiometric ages of the metamorphic episodes

In this paper, the writer offers detailed geological and petrological descriptions on the metamorphites and granites in the belt and, next, mineralogical characters are shown in detail for each metamorphic mineral. After that are discussed the condition and the history of metamorphism, in which will be shown a polymetamorphic model for the development of the Hida belt.

B. Geologic setting

The so-called "Hida gneisses" are exposed mainly in the Hida plateau, central Japan (Fig. 2). They consist of quartzo-feldspathic gneisses, amphibolites and crystalline limestones closely associated with many kinds of granites. Similar gneissic rocks are also found in the Oki Islands, Shimane Pref., which believed to be the western extension of the Hida belt.

The metamorphic belt in the Hida plateau can be divided into three parts according to lithology and geological structure, namely, from the northwest to the southeast, it is divided as follows: the core part of gneisses complex, the Funatsu granite masses and the Hida marginal belt. The last is composed of high-P-type metamorphic rocks, the age of which has been determined to be about 350 m.y., serpentinite and Paleozoic formations (the Devonian, the Carboniferous and the Permian).

The core part can be further divided into three portions of the eastern, the central and the western. The eastern portion is around the Kurobe River, being composed of gneisses and schists. The schists yield kyanite, andalusite and staurolite. The rock similar to the so-called "leptite" develops. The foliation of metamorphites are trending in N-S. The central portion is around the Kamioka mine area, mainly composed of calcareous and basic gneisses, closely associated with augen-gneiss. The western portion is along

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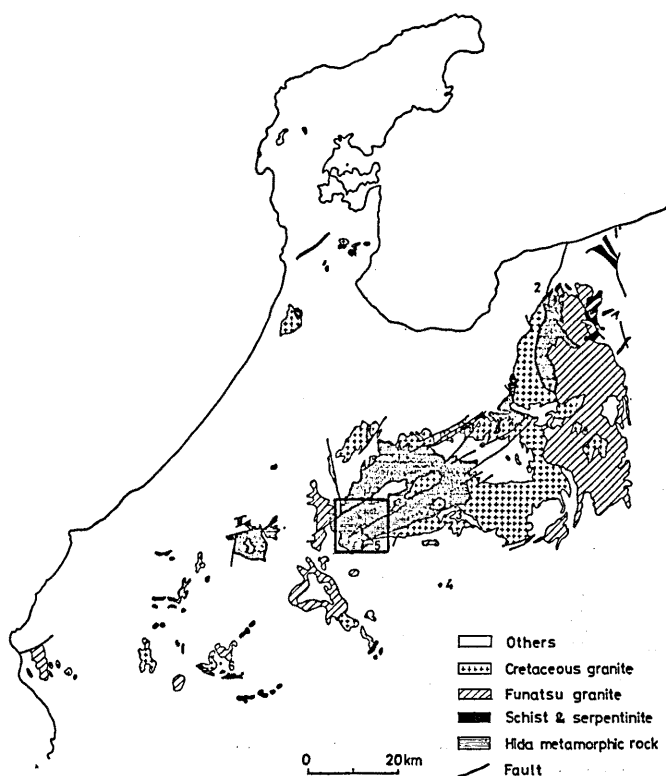


FIG. 2. Distribution of rocks in the Hida Plateau, central Japan (after the Geological Map of Kanazawa, 1: 500000).

The investigated area is shown as a square.

1. Omi, 2. Unazuki, 3. Kamioka, 4. Takayama, 5. Amo, 6. Arashimadake.

the Miya River and Koshimizu area, where various kinds of gneisses are widely distributed. The general trend of the gneisses along the Miya River is E-W, which shows marked contrast to that of the eastern portion. Gneisses in the Arashimadake area, the westernmost part of the Hida plateau, yield staurolite and chloritoid. They may be correlated to the metamorphites around the Unazuki area of the eastern portion.

The area under consideration belong to the western portion, located about 20 km to the northwest of Takayama, Gifu Pref. (Fig. 2).

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II. OUTLINE OF GEOLOGY

The area in question is divided into three blocks of A, B and C from the north to the south by two faults, that is, the Ushikubi fault and the Atotsugawa fault, both trending in WSW-ENE (Fig. 3). Granites and metamorphites are widely distributed in the area. The metamorphites derived from basic and calcareous are predominant. Metapelites are a small share.

The formations younger than the granites and metamorphites are the Jurassic Tetori Series and the Tertiary volcanic rocks. On the southernmost part, K feldspar-porphyrific granite comes in fault contact with the Tetori Series, which is mainly composed of sandstone, shale and conglomerate, yielding plant fossils. The Tertiary volcanics occur as dykes or cover the older rocks.

A. Geological structure

Two distinct faults run across the field, with the trend of WSW-ENE (Fig. 4). The one is the Atotsugawa fault, which is believed active during the late Tertiary (MATSUDA, 1966). According to him, the fault is right-lateral and the displacement amounts to about 3 km in the horizontal direction and its northwest side has been relatively upheaved. The Ushikubi fault has also the same sense of movement. Older faults, running with the trend of N-S, are cut by these younger faults.

The structural elements are observed as follows. As a planer structure, the most predominant one is the distinct gneissosity parallel to the lithologic layering, probably parallel to the original bedding surface. The alternation of leucocratic and melanocratic layers is predominating.

As a linear structure, sometimes the preferred orientation of the longest dimension of prismatic minerals such as amphiboles and micas can be observed.

In the block A, the mesoscopic structure is so complicated as several anticlines and synclines appear repeatedly, more or less disturbed by the intrusion of granitic bodies. The structure in the block B seems comparatively simple; that is, the gneissosity have the trend of E-W throughout the block, dipping gently to the north. While in the block C the orientation of gneissosity is rather complicated; namely, in the eastern half of the block, the gneissosity trends E-W dipping to the south, while it gradually turns to N-S in strike, dipping to E, in the western part.

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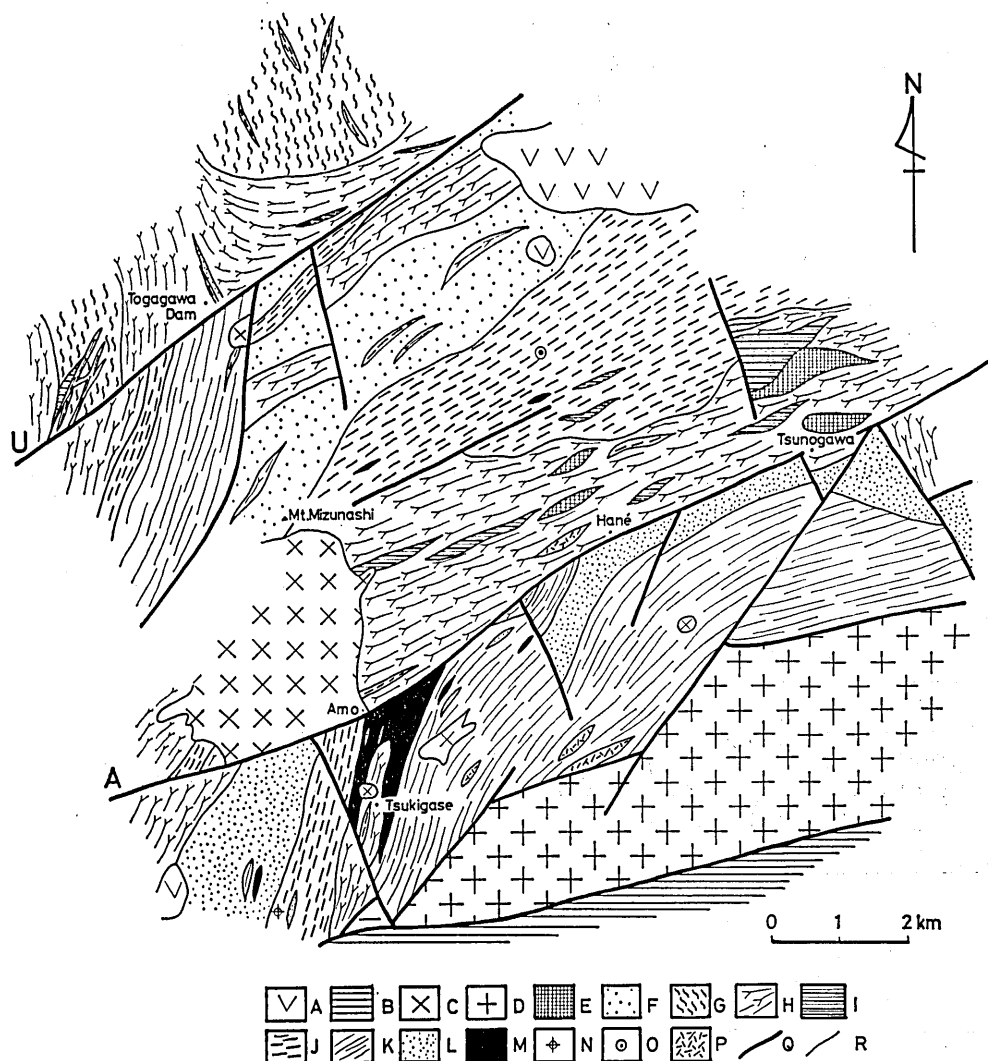


FIG. 3. Geological map of the Odori-River area, southwestern part of the Hida Plateau.

A: Cenozoic volcanic rocks, B: Tetori Series (Mesozoic), C: Funatsu-type granite, D: K feldspar-porphyrific granite, E: Gabbro, F: Migmatitic granite, G: Mylonitized granite, H: Crystalline limestone, I: Lime-silicates gneiss, J: Hornblende-clinopyroxene gneiss, K: Basic migmatite, L: Biotite gneiss, M: Pyroxene gneiss, N: Eclogitic rock, O: K feldspar-corundum gneiss, P: "Syenitic rock" of the Inishi type, Q: Fault (A; Atotsugawa fault, U; Ushikubi fault), R: Boundary line of rocks.

As will be discussed later, the structure of N-S direction would have been resulted from an older phase of metamorphic event, while, that of E-W direction represents the younger one. Therefore, on the field, overlapping of at least two kinds of predominant structure, whose trends are mutually perpendicular can be observed.

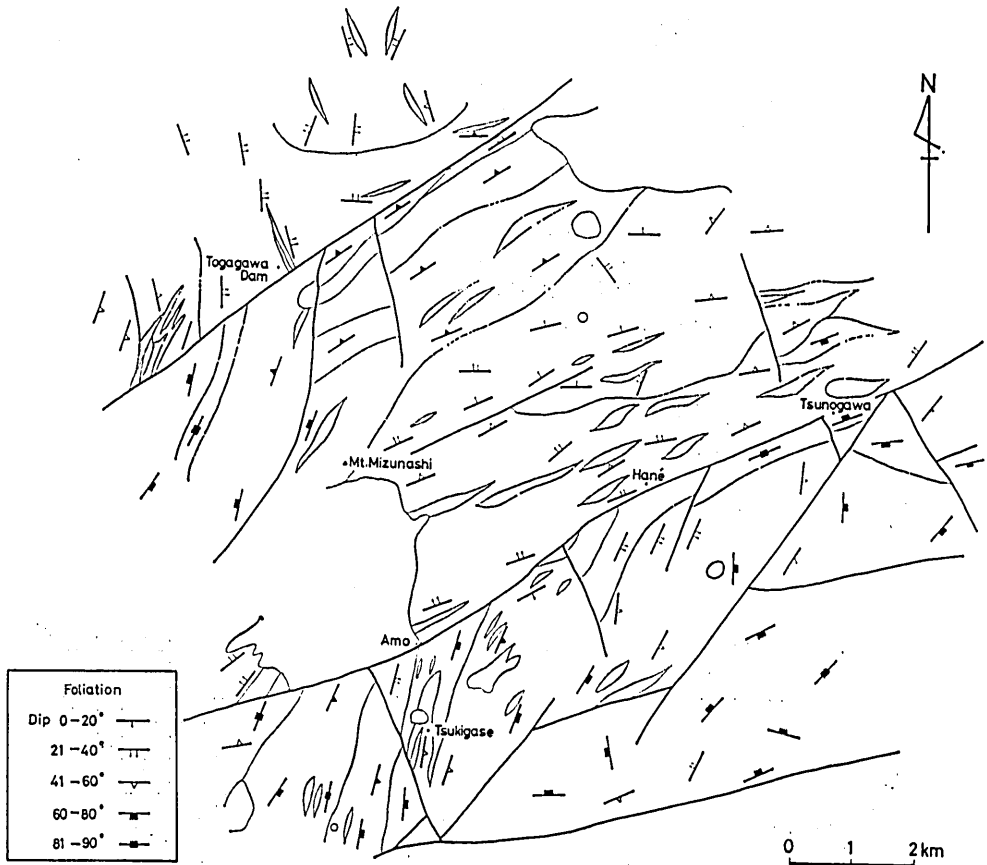


FIG. 4. Tectonic map of the Odori-River area.

B. Distribution of metamorphic rocks and granites

In the block A, crystalline limestone and associated limesilicates gneiss are predominant in metamorphites, while basic gneiss and pelitic gneiss are minor members (Fig. 3). It should be mentioned that more or less mylonitized pinkish granite, structurally discordant with the metamorphics, is widely distributed. The lime-silicates gneiss is characterized by the mineral assemblage of clinopyroxene-hornblende-plagioclase-perthitic orthoclase-quartz-calcite-graphite. The pelitic gneiss has the mineral composition of sillimanite-garnet-plagioclase-microcline-quartz-graphite. The basic gneiss contains no clinopyroxene but green hornblende. In the pinkish granite of mylonitic appearance porphyroblastic plagioclase and perthitic orthoclase are scattered among fine-grained quartzofeldspathic matrix.

Younger dykes of porphyrite and diabase are developed cutting distinctly the gneisses and granite, arranged parallel to the direction NE-SW.

In the block B, hornblende-clinopyroxene gneiss (hornblende-clinopyroxene-K feldspar-plagioclase-quartz) and calcareous gneiss (crystalline limestone and lime-silicates gneiss

with wollastonite, scapolite and diopside) are widely developed. On the northernmost of the block, there are distributed calcareous gneiss and hornblende-clinopyroxene gneiss penetrated by the migmatitic granite. It is characteristic that biotite gneiss of pelitic origin is rarely developed in the block B. It should be noted that K feldspar-corundum gneiss (K feldspar-corundum-plagioclase-biotite-rutile) occurs in the hornblende-clinopyroxene gneiss, forming a large fusiform body of 20 m × 5 m (SUZUKI and KOJIMA, 1970). Pyroxene gneiss (orthopyroxene-clinopyroxene-almandine-brown hornblende-K feldspar-plagioclase-quartz) are also found sporadically in the basic gneiss.

In the block C, basic migmatite (hornblende-biotite-K feldspar-plagioclase-quartz) and a thick bed of some ten meters of pelitic gneiss are developed. It is noted that pyroxene gneiss and eclogitic rock (ferroaugite-almandine-quartz) occur. Their bearing to suggest the specified metamorphic condition has already been discussed by the author (1973a, b, and 1974a, b), that being summarized briefly in the later section.

The so-called "gray-granite", a coarse-grained, pegmatitic granite of small dimension, is distributed throughout the gneiss region in the district. Although it forms a small mass on each outcrop, intruding parallel or obliquely to the gneissosity, total volume of the gray-granite would be enormous because of the high frequency of occurrence. The gray-granite stands in contrast with the younger pinkish granite, the former being abundant of gray K feldspar.

Near the southernmost part of the area in question, porphyritic granite is widely developed. It is characterized by the presence of large crystals of pinkish K feldspar. Hälllefinta-like mylonite and so-called augen gneiss are seen along the contact between the granite and the basic migmatite.

Near Amo, pinkish granite of massive occurrence is distributed. There seems to be no markable thermal effect upon the adjoining gneiss.

III. PETROGRAPHY AND PETROCHEMISTRY

In this chapter, the metamorphites and granites are discussed with reference to their distribution, characters on the scale of hand specimen, mineral assemblage, petrochemical characters and the conditions of their genesis will be discussed.

A. Metamorphic rocks

1. *Pyroxene gneiss*

The rock is rather widely developed in the area of Amo, while it occurs sporadically throughout the area. Its distribution extends along the layer and, although the gneissosity of the rock is not clearly defined, it seems rather harmonic with that of such adjoining gneisses, as hornblende-clinopyroxene gneiss and basic migmatite, both derived from basic rocks. There exists no evidence suggesting structural unconformity between them. Megascopically, the pyroxene gneiss is green to dark green in tint and pinkish garnets are sporadically distributed.

The pyroxene gneiss is characterized by the association of orthopyroxene-clinopyroxene almandinous garnet-hornblende-K feldspar-plagioclase-quartz. The association of orthopyroxene and clinopyroxene is diagnostic for the granulite facies. Orthopyroxene has often been changed to amphibole in retrogressive direction. The mineral will be treated in detail in Chapter IV. The orthopyroxene has the composition of En 90 Fs 10.

The clinopyroxene is plotted in the area of salite and ferrosalite (Fig. 15). Hornblende is characterized by the high content of Ti (Fig. 19). Garnet is rather almandinous: the content of pyrope molecule changes widely from 0.5 to 17.7 mol. percent. Zoning in garnet crystals will be treated in the later section. Chemical composition of plagioclase changes from andesine to labradorite. Only one specimen contains low Ab content of 8.6 mol. percent. Orthoclase solubility in plagioclase is as low as near 1.0 mol. percent. K feldspar shows low values of triclinicity (0.519–0.738). The orthoclase mol. percent is around 90. Ordering in K feldspar is, in general, closely related with the mode of change of physical condition during metamorphism. The above-mentioned low values of triclinicity are unique and in striking contrast to the higher values of K feldspar from adjoining gneisses. Graphite and apatite are commonly observed. Retrograde minerals are as follows; that is, bluish-green (Z-axial colour) hornblende replacing orthopyroxene, clinopyroxene and brown hornblende from the margin of the grain, epidote, chlorite, biotite, titanite and prehnite.

Relating components are SiO_2 , Al_2O_3 , total Fe-oxides, MgO, MnO, CaO, K_2O and Na_2O . After the mineralogical phase rule, therefore, seven phases can coexist stably in the seven components system. A sample of the pyroxene gneiss collected at Korobuchi near Amo was chemically analysed, the result being shown in Table 1. It is noteworthy that the chemical composition of the rock is roughly correspond to that of the graywacke (PETTIJOHN et al., 1972) as shown in Fig. 5. It seems that the pyroxene gneiss has been derived from somewhat calcareous psammitic rock under the metamorphic condition of the granulite facies.

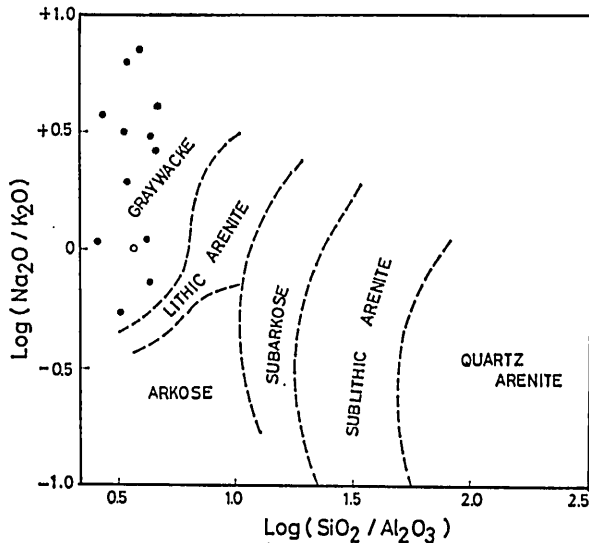


FIG. 5. $\text{SiO}_2/\text{Al}_2\text{O}_3$ versus $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios of pyroxene gneiss. Dashed lines are the boundary lines of sandstone after PETTIJOHN et al. (1972). Open circle: Pyroxene gneiss, solid circles: quartzo-feldspathic gneiss from the Odori-River area after Nozawa et al. (1975).

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TABLE 1. CHEMICAL COMPOSITION AND C. I. P. W. NORM OF THE PYROXENE GNEISS (ANALYST: M. SUZUKI).

TABLE 2. CHEMICAL COMPOSITION AND C. I. P. W. NORM OF THE ECLOGITIC ROCK (ANALYST: A. MINAMI).

TABLE 3. CHEMICAL COMPOSITION AND C. I. P. W. NORM OF THE POTASSIUM FELDSPAR — CORUNDUM GNEISS (ANALYST: K. ISHIBASHI).

TABLE 1		TABLE 2		TABLE 3	
specimen	P-5	specimen	E	specimen	K
SiO ₂	59.06	SiO ₂	53.77	SiO ₂	54.55
TiO ₂	1.94	TiO ₂	0.74	TiO ₂	0.28
Al ₂ O ₃	13.43	Al ₂ O ₃	10.23	Al ₂ O ₃	27.57
Fe ₂ O ₃	1.44	Fe ₂ O ₃	1.92	Fe ₂ O ₃	0.93
FeO	5.03	FeO	17.51	FeO	1.51
MnO	0.02	MnO	2.36	MnO	0.01 ₃
MgO	1.34	MgO	2.45	MgO	0.71
CaO	9.52	CaO	8.70	CaO	1.53
Na ₂ O	2.65	Na ₂ O	0.23	Na ₂ O	4.21
K ₂ O	2.63	K ₂ O	0.12	K ₂ O	6.15
H ₂ O(-)	0.23	H ₂ O(-)	0.17	H ₂ O(-)	0.38
H ₂ O(+)	0.64*	H ₂ O(+)	2.00*	H ₂ O(+)	1.60
		P ₂ O ₅	0.49	P ₂ O ₅	0.09 ₁
				C	0.49
Total	100.10	Total	100.69	Total	100.12 ₀
Q	17.93	Q	18.59	Q	1.72
c	—	c	—	c	11.36
or	15.51	or	0.67	or	36.36
ab	22.37	ab	1.94	ab	35.58
an	16.96	an	26.49	an	7.09
nc	—	nc	—	nc	—
wo	7.76	wo	5.77	wo	—
di en	3.06	di en	0.96	di en	—
fs	4.78	fs	5.29	fs	—
cn	0.28	en	5.16	en	1.77
hy fs	0.44	hy fs	28.39	hy fs	1.57
fo	—	fo	—	fo	—
ol fa	—	ol fa	—	ol fa	—
mt	2.06	mt	2.76	mt	1.35
hm	—	hm	—	hm	—
il	3.68	il	1.40	il	0.52
ap	4.70	ap	1.14	ap	0.20

* Determined by ignition loss

* Determined by ignition loss

2. *Eclogitic rock*

The rock in question has already been described by the present author (1973b). The rock, characterized by the association of garnet-clinopyroxene-quartz, has been found in the valley of Tsukigase (Fig. 3).

It was named the eclogitic rock. It forms a fusiform body of 2 m × 4 m on the outcrop, the long axis of which seems to be parallel to the gneissosity of the country rocks, trending N-S with easterly steep dip. The contact between the rock in question and the surrounding gneiss can be clearly observed, showing gradual change as stated below (Fig. 6).

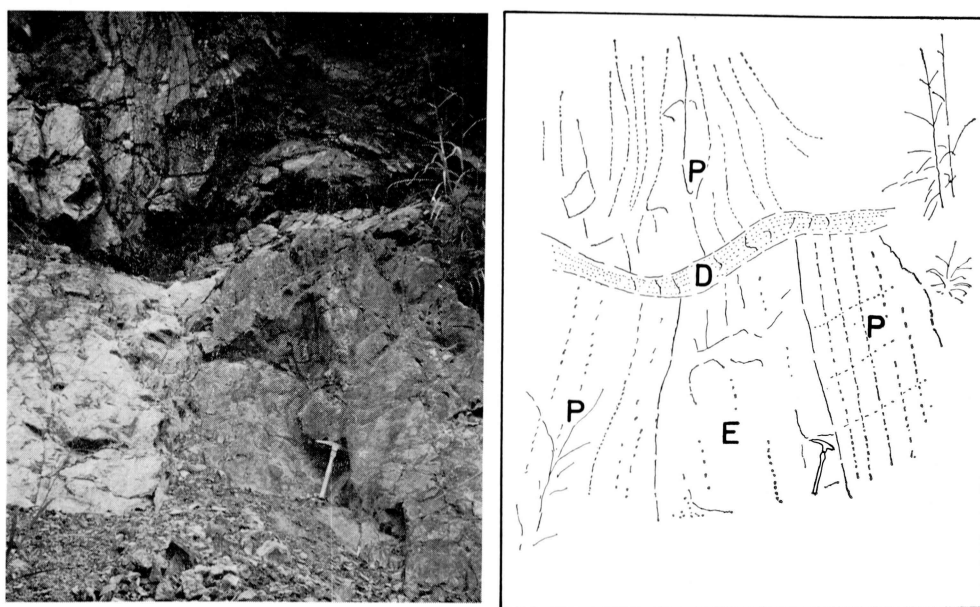


FIG. 6. Mode of occurrence of the eclogitic rock at Tsukigase. The rock (E) is enclosed in surrounding paragneiss (P). A metamorphosed basic dyke (D) appears cutting across the gneissosity.

The eclogitic rock is massive, showing a marked contrast to the surrounding basic and pelitic gneisses having distinct foliation or compositional banding. The change of mineral assemblage from the pelitic rock toward the eclogitic rock is gradual, characterized as follows;

- assemblage characterized by the paragenesis of almandinous garnet and biotite (pelitic gneiss)
- ↓
- addition of hornblende
- ↓
- appearance of clinopyroxene
- ↓
- assemblage of garnet-clinopyroxene-quartz without hydrous phases (eclogitic rock)

It is noteworthy that a basic dyke has been intruded across the gneissosity of the country rocks and that it itself shows distinct foliation structure characterized by the parallel

arrangement of amphiboles. Chemical composition of the amphibole suggest the metamorphic condition of the amphibolite facies (Figs. 18 and 19).

The average modal composition of the rock is as follows; quartz 33.5, garnet 32.4, clinopyroxene 19.3, hornblende 8.4, ore 2.6, biotite 1.9, epidote 1.5, graphite 0.1, tourmaline 0.1 and titanite+rutile 0.1 in volume percent. Judged from the texture and occurrence of minerals, the essential constituents formed during the main metamorphic phase may be garnet, clinopyroxene, quartz, graphite and rutile (and/or biotite). Hornblende can be regarded as a product of later metamorphic phase, as it occurs along the margin of pyroxene grains. Epidote, tourmaline, titanite, pyrrhotite and ilmenite may be hystergene. The chemical composition and CIPW norm of the eclogitic rock are given in Table 2. It must be mentioned that total iron is very high (Fig. 7). The chemical composition suggests that the eclogitic rock in question may be derived from a rock of unusual chemical composition, if assumed the isochemical metamorphisms.

In view of the mineralogical character, particularly in respect to the distribution relation of Fe and Mg between garnet and clinopyroxene, the eclogitic rock have been formed under a high grade metamorphism, presumably that of the granulite facies (SUZUKI, 1973b).

In this connection, the presence of metamorphosed basic dyke at the outcrop of the eclogitic rock is significant. As already mentioned, amphiboles in the dyke show preferred orientation, having chemical composition to suggest the formation under the amphibolite facies metamorphism. Judged from the field occurrence, it may be inferred that the basic dyke was intruded after the formation of the surrounding gneisses and before the formation of amphibole in the dyke under the metamorphic condition of the amphibolite facies. The bearing of the metamorphic basic dyke will be discussed in Chapter VII-B.

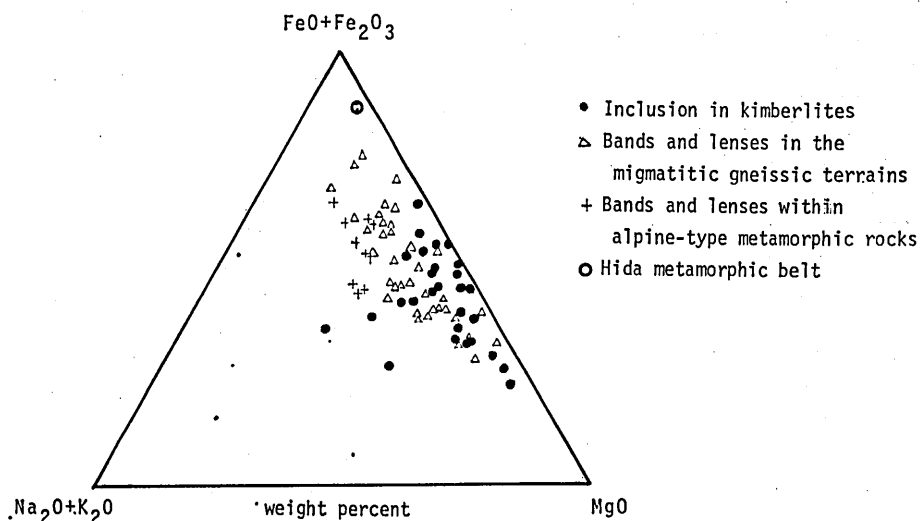


FIG. 7. AFM diagram in weight percent of the eclogitic rock from the area and some eclogites cited from COLEMAN et al. (1965).

Solid circle: eclogitic rock from the Hida metamorphic belt, open circles: Group A eclogites, triangles: Group B eclogites, crosses: Group C eclogites.

3. *K feldspar — corundum gneiss*

The rock in question, characterized by stable association of K feldspar and corundum, occurs along the Hané valley in the block B, the locality being about 1000 m above sea level. It is enclosed in the hornblende-clinopyroxene gneiss, forming a large fusiform body of 20 m × 5 m. The very contact between the rock and the surrounding gneiss cannot be observed. The gneissosity of these gneisses is harmonic with each other, and the long axis of the fusiform body seems parallel to the gneissosity of the surrounding gneiss.

The rock in question is grayish in colour with distinct foliation. Corundum has a pinky tint (so-called ruby variety), forming megacrysts of fusiform, the largest of which attains to 4 cm. The corundum crystals are arranged with their long axes on the foliation surface, showing no linear tendency. It includes rutile. The corundum is now surrounded by muscovite aggregates (kelyphitic rim).

The essential metamorphic mineral assemblage is corundum-K feldspar-plagioclase-biotite-rutile-graphite-apatite-zircon-ore. Hysterogene minerals are titanite, epidote, chrolite and prehnite. Titanite occurs replacing the crystal of rutile from the margin or along the fracture.

Corundum has a pinkish tint, with refractive indices: $\varepsilon=1.759\pm 0.001$ and $\omega=1.769\pm 0.002$. K feldspar is usually microcline or string perthite, with $2 V_x=77^\circ-88^\circ$. The triclinicity ranges from 0.913 to 0.925. Chemical composition of the representative is Or 86.0 Ab 12.1 An 1.9. Plagioclase is $2 V_z=83^\circ-87^\circ$, An=19-21 in molecular percent after the X-ray determination. Biotite is brown, with $TiO_2=2.45$ in weight percent.

Muscovite is formed at the expense of corundum. Two types can be discriminated in retrogressive muscovite. The one is very fine-grained, surrounding directly the core corundum, while another is coarse-grained, coexisting with graphite, around the outer margin of the corundum porphyroblast. Although chemical composition of these two types of muscovite do not differ perceptibly, the coarse type (b in Fig. 41) seems to be richer in total Fe oxides and poorer in Al_2O_3 than the fine type (a in Fig. 41), while the paragonite molecule is quite similar between them.

The bulk chemical composition of the rock, shown in Table 3, indicates that the rock is notably rich in Al_2O_3 and total alkalis, while poor in FeO and MgO. Averaged chemical compositions of pelites from the area and the Hida metamorphic belt, Precambrian slate, Paleozoic slate from Japan and some aluminous sedimentary rocks are given in Table 4. Fig. 8 shows the relation of Al_2O_3 against total alkalis. Fig. 9 is the AFM diagram for samples given in Table 4. From these figures, it can be said that the K feldspar-corundum gneiss in question is rather peculiar in chemical composition, especially with respect to its richness of alkalis. As discussed in the later chapter, the surrounding gneiss (hornblende-clinopyroxene gneiss) is interpreted to have been derived from some basic volcanics and graywacke, judged from its fabric and chemical composition. It may be assumed that the K feldspar-corundum gneiss in question has also been derived from a kind of volcanic rock. In Table 5 chemical composition of some alkali volcanic rocks is shown. The relation of alkali- Al_2O_3 and the AKF diagram for samples in Table 5 are shown in Figs. 8 and 9, along with the K feldspar-corundum gneiss. As can be read from the figures, the chemical composition of the K feldspar-corundum

Polymetamorphism in the Hida Metamorphic Belt, Central Japan

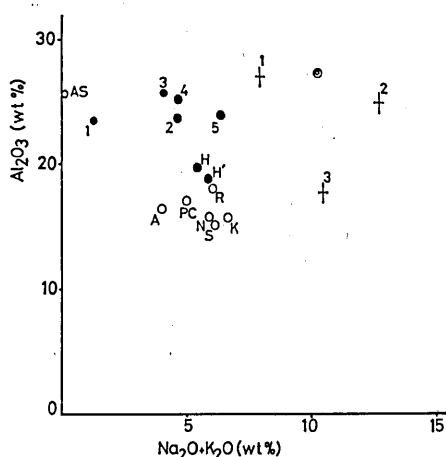


FIG. 8. Al_2O_3 plots of pelites and alkali volcanic rocks against total alkalis. Double circle: K feldspar-corundum gneiss, solid circles: Hida metapelites, open circles: pelites from other than the Hida metamorphic belt, crosses: alkali volcanic rocks. Abbreviations for circles as the symbols in Table 4 and for crosses as those in Table 5.

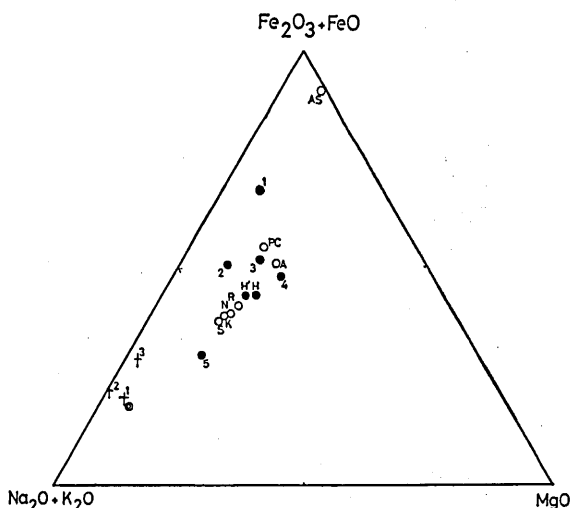


FIG. 9. AFM plots for pelites and alkali volcanic rocks. Double circle: K feldspar-corundum gneiss, solid circle: Hida metapelites, open circles: pelites from other than the Hida metamorphic belt, crosses: alkali volcanic rocks. Abbreviations as in Fig. 8.

gneiss is rather similar to that of alkali volcanic rocks.

It can therefore be said that the rock concerned has been derived from some alkali volcanic rocks, probably akin to trachytic-kelatophyric series (SUZUKI, 1973a). This fact is very significant in considering the origin and development of the Hida metamorphic belt.

The paragenesis of K feldspar and corundum is very useful in determining P-T condition of the metamorphism. TILLEY (1924) published a famous classical report on the metamorphic rocks in the Comrie area in Scotland, where the Carn Chois diorite pluton has been intruded into the phyllites and slates of the Dalradian series, and a zoned contact aureole exists. From aluminous and silica-deficient hornfels following associations were reported:

- 1) K feldspar-corundum-cordierite-biotite-andalusite
- 2) K feldspar-corundum-cordierite-biotite
- 3) K feldspar-corundum-cordierite-biotite-spinel-plagioclase

In Japan, there are a few reports on the coexistence of corundum with K feldspar. HASEGAWA (1955) found out the assemblage of corundum-K feldspar-sillimanite-plagioclase-cordierite-spinel in thermally metamorphosed by granodiorite, at Okita, Kitakami Mountain land, northeast Japan. In the Abukuma metamorphic terrain, the association of corundum-K feldspar-plagioclase-andalusite-muscovite-biotite was detected

TABLE 4. CHEMICAL COMPOSITIONS AND

symbols	1	2	3	4	5	H	H'
SiO ₂	60.58	57.24	53.85	50.50	57.32	57.75	59.08
TiO ₂	1.09	0.77	0.97	1.00	1.08	0.83	0.71
Al ₂ O ₃	23.64	23.81	25.81	25.27	23.92	19.84	18.78
Fe ₂ O ₃	0.21	0.34	1.24	0.41	0.06	1.00	0.91
FeO	3.16	5.60	5.13	6.83	3.16	5.21	5.52
MnO	0.11	0.14	0.17	0.13	0.04	0.11	0.13
MgO	0.40	1.04	1.95	3.33	1.69	2.60	2.41
CaO	0.14	5.40	3.82	6.63	4.66	4.65	4.16
Na ₂ O	0.52	3.88	2.85	3.15	4.39	3.08	2.76
K ₂ O	0.75	0.89	1.26	1.59	1.98	2.40	3.15
H ₂ O(-)	0.53	0.24	0.37	0.48	0.33	0.28	0.22
H ₂ O(+)	6.31	0.86	1.71	1.50	0.93	1.75	1.88
P ₂ O ₅	—	0.28	0.16	0.23	0.30	0.12	0.19
C	—	—	—	—	—	—	—
CO ₂	—	—	—	—	—	—	—
S	—	0.14	0.46	0.04	0.02	—	—
Total	97.44	100.31	99.39	100.61	99.55	99.62	99.90
Q	52.04	14.84	18.56	2.61	10.67	13.70	15.11
c	21.74	7.22	13.14	6.78	6.71	3.96	3.65
or	4.39	5.23	7.45	9.40	11.68	14.18	18.63
ab	4.35	32.75	24.05	26.62	37.10	25.99	23.32
an	0.67	25.21	18.04	31.55	21.38	22.41	19.54
nc	—	—	—	—	—	—	—
di	{ wo	—	—	—	—	—	—
	{ en	—	—	—	—	—	—
	{ fs	—	—	—	—	—	—
hy	{ en	0.99	2.59	4.87	8.32	4.22	6.02
	{ fs	4.01	8.96	7.09	10.78	4.04	8.45
ol	{ fo	—	—	—	—	—	—
	{ fa	—	—	—	—	—	—
mt		0.30	0.49	1.79	0.58	0.07	1.34
hm		—	—	—	—	—	—
il		2.07	1.46	1.84	1.88	2.04	1.34
ap		—	0.64	0.37	0.54	0.71	0.44

1. Aluminous metapelites from Senno-tani (NOZAWA et al., 1960). 2. Aluminous metapelites (ditto). H. Averaged composition of the metapelites from the Hida Metamorphic Belt, of metapelites from the studied area, tabulated in Table 8. AS. Carboniferous aluminous America (NANZ, 1953). K. Averaged composition of Precambrian metapelites of the ern part and eastern half of the central part in Abukuma Plateau (MRYASHIRO and HARA-gatake area. Ryoke Metamorphic Belt (ditto). N. Averaged composition of practically or practically or nearly unmetamorphosed Palaeozoic slates for zone S (ditto).

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C. I. P. W. NORMS OF THE PELITES.

AS	PC	K	A	R	N	S
44.95	56.30	64.09	65.03	62.92	65.31	66.16
0.45	0.77	0.40	0.55	0.71	0.63	0.59
25.95	17.24	15.96	15.53	18.16	15.81	15.37
11.48	3.83	1.93	2.23	1.02	1.83	1.48
1.73	5.09	3.52	4.49	4.64	3.25	3.30
tr.	0.10	1.28	—	0.08	0.08	0.11
1.40	2.54	2.08	2.54	2.37	2.08	1.84
1.50	1.00	1.51	2.73	1.19	0.34	0.49
0.01	1.23	2.31	2.31	2.04	2.09	2.95
0.01	3.79	4.40	1.77	4.01	3.84	3.28
3.87	0.38	2.79	—	0.24	0.61	0.73
8.14	3.31	0.37	2.20	2.37	3.36	2.88
0.08	0.14	0.07	—	0.13	0.10	0.12
—	1.18	—	—	—	0.76	0.67
—	0.84	—	—	—	—	—
—	SO ₃ 0.28	—	—	—	—	—
99.57	98.02	100.71	99.38	99.88	100.09	99.97
39.76	26.74	24.65	32.72	26.94	33.28	31.17
23.36	9.57	4.76	4.85	8.57	7.80	6.32
0.06	22.41	26.02	10.45	23.69	22.68	19.35
0.05	10.38	19.49	19.49	17.24	17.66	24.89
7.01	4.20	7.14	13.54	5.14	1.08	1.75
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
3.49	6.34	5.19	6.34	5.92	5.19	4.59
—	5.08	6.59	5.49	6.65	3.56	4.07
—	—	—	—	—	—	—
—	—	—	—	—	—	—
4.27	5.54	2.78	3.22	1.46	2.64	2.13
8.53	—	—	—	—	—	—
0.85	1.46	0.74	1.03	1.34	1.19	1.11
0.17	0.30	0.13	—	0.30	0.24	0.27

from Nagato-River (SOMA, 1975). 3, 4 and 5. Aluminous metapelites from Wada-River tabulated in Table 8 in this paper and Table 3 (SUZUKI 1975). H'. Averaged composition shale from Fukuji (IGO, 1961). PC. Averaged composition of Precambrian slates in North Kamiaso conglomerate (ADACHI, 1973). A. Averaged composition of metapelites of the south-MURA, 1966). R. Averaged composition of metapelites of the Dando area and Kiso-Koma- or nearly unmetamorphosed Palaeozoic slates for zone N (ditto). S. Averaged composition

TABLE 5. CHEMICAL COMPOSITIONS AND C. I. P. W. NORMS OF THE ALKALI ROCKS.

specimen	1	2	3	specimen	1	2	3
SiO ₂	54.41	53.13	62.63	Q	17.60	—	6.47
TiO ₂	0.54	0.60	0.55	c	14.93	2.98	—
Al ₂ O ₃	27.04	24.87	17.25	or	39.64	42.92	30.69
Fe ₂ O ₃	1.88	2.25	2.13	ab	9.59	19.34	45.12
FeO	0.11	1.40	2.34	an	8.06	13.29	7.73
MnO	—	—	0.21	ne	—	14.97	—
MgO	0.51	tr.	0.40	di	wo	—	—
CaO	2.00	2.68	2.21	en	—	—	0.85
Na ₂ O	1.14	5.56	5.34	fs	—	—	0.29
K ₂ O	6.71	7.26	5.19	hy	en	1.27	—
H ₂ O(-)	3.36	0.36	1.55	fs	—	—	0.70
H ₂ O(+)	—	1.05	—	ol	fo	—	—
P ₂ O ₅	0.08	—	0.20	fa	—	—	—
CO ₂	1.22	—	—	mt	—	2.78	3.09
SO ₃	0.29	—	—	hm	1.87	0.32	—
Total	99.29	99.16	100.00	il	0.23	1.12	1.03
				ap	0.17	—	0.47

1. KERATOPHYRE (JOHANNSEN, 1949). 2. Borolanite (JOHANNSEN, 1949). 3. Trachyte (KUNO, 1964).

in shale rich in aluminium, thermally metamorphosed by gabbro (SHIDO, 1958).

All the examples mentioned are related to the metamorphic condition of the pyroxene hornfels facies. However, the K feldspar-corundum paragenesis of the area concerned is represented in a gneiss, which would be the product of a regional metamorphism of the granulite facies. Details will be discussed in Chapter VI.

4. So-called "syenitic rock of the Inishi type"

This is one of most peculiar types of rocks in the Hida metamorphic belt. The rock is widely, though sporadically, distributed in the area. It is developed especially on the northern part of the area, being closely associated with crystalline limestone and lime-silicates gneiss. It appears rather massive, while sometimes shows noticeable gneissosity defined by parallel arrangement of clinopyroxene and feldspars. The rock is characterized by greenish clinopyroxene dispersed in leucocratic feldspathic matrix.

Clinopyroxene and plagioclase are common. Wollastonite is sometimes associated, forming idiomorphic megacrystals lying on the gneissosity. Titanite is clearly idiomorphic. Quartz is poor, trending to be associated with calcite. Clinopyroxene has been altered to bluish-green amphibole from the margin of grain. Epidote-calcite or prehnite veins penetrate. No graphite is found in the rock, although it is usually associated in the Hida metamorphites. The mineral graphite, which is rather common in the Hida metamorphites except the Inishi type rock and the basic migmatite, suggests reducing environment in metamorphism. Plagioclase is always calcic oligoclase. K feldspar has the composition in the range of Or 92 to Or 96. Perthitic albite has the composition of

Polymetamorphism in the Hida Metamorphic Belt, Central Japan

TABLE 6. CHEMICAL COMPOSITIONS AND C. I. P. W. NORMS OF THE "SYENITIC ROCK" OF THE INISHI TYPE.

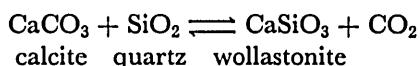
specimen	1	2	3	4	5
SiO ₂	56.02	61.56	58.91	58.34	56.20
TiO ₂	0.85	0.45	0.39	0.83	0.12
Al ₂ O ₃	23.36	20.48	21.58	21.54	22.60
Fe ₂ O ₃	0.63	0.34	1.09	0.63	0.07
FeO	2.00	2.38	2.15	1.77	3.09
MnO	0.02	n. d.	0.06	0.05	0.09
MgO	0.58	0.98	1.04	0.93	1.66
CaO	7.06	3.15	4.02	8.51	9.55
Na ₂ O	6.25	4.22	6.25	6.04	4.53
K ₂ O	0.65	4.10	1.43	0.72	0.96
H ₂ O(-)	0.18	0.38	0.41	0.12	0.22
H ₂ O(+)	2.18	2.21	1.31	0.14	0.37
P ₂ O ₅	0.01	0.02	0.07	n. d.	0.34
Total	99.79	100.27	98.71	99.62	99.81
Q	0.74	11.69	5.99	3.01	3.11
c	—	3.39	2.55	—	—
or	3.84	24.24	8.45	4.23	5.67
ab	52.82	35.63	52.82	51.04	38.25
an	33.72	15.54	10.60	29.50	38.45
ne	—	—	—	—	—
di { wo	0.53	—	—	5.31	2.92
{ en	0.24	—	—	2.32	1.25
{ fs	0.29	—	—	1.45	1.68
hy { en	1.20	2.44	2.59	—	2.89
{ fs	1.48	3.34	2.51	—	3.91
ol { fo	—	—	—	—	—
{ fa	—	—	—	—	—
mt	0.90	0.49	1.58	0.90	0.09
hm	—	—	—	—	—
il	1.61	0.85	0.73	1.57	0.21
ap	—	0.03	0.13	—	0.77

1. Tochibora, Kamioka area (SATO, 1968). 2. Southwest of Inishi Pass, Kamioka area (ditto). 3. East of Maebira, Kamioka area (ditto). 4. Maruyama drift, Kamioka area (KAWAI et al., 1958). 5. Wadagawa (KANO, 1975).

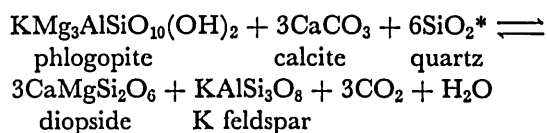
Or 5 Ab 89 An 6. Clinopyroxene is plotted on the join diopside-hedenbergite, almost in the calcic ferrosalite region. Chemical composition of the rock is shown in Table 6. Close association of the rock in question with crystalline limestone may suggest that the rock is more or less related to some kind of calcareous rock. If it is assumed to be igneous in origin, close association with limestone will be difficult to explain, as the "syenitic rock" does not occur with other gneisses. Furthermore, there is no evidence supporting that

it has intruded into limestone. The writer prefers to assume that this type of rock has been developed from sediment relating to calcareous rock.

Experimental results on the equilibrium of wollastonite have been accumulated. HARKER and TUTTLE (1956) and GREENWOOD (1962) determined experimentally the equilibrium curve of the reaction:



Temperature of appearance of wollastonite depends on fluid pressure (Pf) and molar fraction of CO₂(X_{CO₂}). If P_f=P_{CO₂}=2 kb, the equilibrium curve of wollastonite is almost coincident with that of muscovite. The equilibrium curve for wollastonite, however, shifts toward the lower temperature side when P_f and X_{CO₂} decrease. It is interesting that phlogopite is contained in the limestone which adjoins the "syenitic rock", while lacking in the latter itself. The following reaction may now be inferred (SATO, 1968):



The reaction is one of dehydration. Retrograde minerals are also found in the rock concerned. Large porphyroblasts composed of calcite and quartz develop, and some of them are traversed by calcite veins. It seems that wollastonite may have been altered to calcite and quartz retrogressively. K feldspar is microcline and seems fresh in appearance. That is the common feature of K feldspar in the Hida metamorphites. Clinopyroxene has been altered from its margin to bluish-green hornblende. In conclusion, the essential metamorphic assemblage of the rock in question is clinopyroxene-K feldspar-plagioclase-wollastonite(-quartz). Although the syenitic rock contains no diagnostic mineral or mineral association of the granulite facies, it is possible that it also formed under the condition of the granulite facies.

5. Biotite gneiss

It is remarkable that in the Hida metamorphic belt pelitic gneiss has a small share among the metamorphites, in contrast to other metamorphic belts in Japan. Occurrence of alumino-silicate minerals is also rare in the belt. Biotite gneiss, derived from pelitic rock, shows various modes of occurrence. The most common is that intercalated within hornblende-clinopyroxene gneiss and basic migmatite, both probably derived from the variety of basic rocks. In the block C of the area, however, there are distributed thick beds of pelitic gneiss. Petrochemical characters and its bearings are already described by the author (1975). In this section petrochemical and petrographical characters of the biotite gneiss would be summarized.

The rock is gneissose, characterized by fine alternation of leucocratic and melanocratic bands. Porphyroblasts of garnet are often developed sporadically, sometimes attaining

* In the limestone are often intercalated a lot of thin siliceous layers, which sometimes appear as boudinages. Therefore, silica would be sufficient during the metamorphic reaction of the limestone.

Polymetamorphism in the Hida Metamorphic Belt, Central Japan

TABLE 7. MODAL ANALYSES OF PELITIC GNEISSES IN THE ODORI RIVER DISTRICT.

	1	2	3	4	5	6	7	8	9	10	11
Quartz	25.7	5.3	22.5	36.3	24.9	27.7	32.2	53.6	16.9	3.1	36.0
Plagioclase	43.5	64.4	47.9	19.6	56.3	24.2	44.5	15.2	55.1	49.7	33.5
K-feldspar	1.9	7.2	3.1	24.1	1.5	21.5	2.7	3.6	0.6	2.9	2.5
Biotite	19.1	14.1	24.4	19.8	16.9	22.7	11.4	16.5	25.2	28.3	17.3
Muscovite	0.7	8.7	—	0.1	tr.	0.6	0.7	—	—	1.8	0.1
Sillimanite	—	—	—	—	—	—	—	—	—	0.3	0.5
Garnet	2.6	0.2	0.4	—	0.3	2.8	4.4	5.7	0.4	7.8	8.0
Titanite	1.5	0.1	—	0.1	0.1	—	0.1	tr.	—	0.1	0.1
Hornblende	—	—	1.7	—	—	—	0.1	5.3	—	—	—
Clinopyroxene	—	—	—	—	—	—	—	—	0.8	—	—
Graphite	2.4	0.1	0.1	—	—	—	3.6	—	0.1	5.7	0.5
Ore	—	—	—	0.1	tr.	0.6	0.3	0.1	1.0	0.4	0.5
Others	2.6	—	—	—	—	—	—	—	—	—	1.1
Total	100.0	100.1	100.1	100.1	100.0	100.1	100.0	100.0	100.1	100.1	100.1

Locality of each specimen is shown in Appendix.

to 2 cm in diameter. Darkness of the grayish colour of the gneiss is due to the amount of biotite. Mineralogical modal composition is shown in Table 7.

K feldspar is microcline to perthitic orthoclase. One of the sample gives the value of triclinicity of 0.888. Plagioclase is very abundant. Anorthite mol. percent of it ranges from 24 to 89, depending not always on the bulk chemical composition. Garnet is always rich in almandine molecule. Detailed description on mineralogical characters and zonal structure of the garnet will be given in the later section. Muscovite is not generally the main constituent, but occurs as the secondary mineral, along with epidote, chlorite and prehnite. Aluminosilicate is rarely found. Only about 3 percent of thin sections of pelitic gneisses contains aluminosilicate, which is always sillimanite. As ore minerals, ilmenite or magnetite is predominant, and pyrite occurs rarely.

Chemical composition of the pelitic gneiss is shown in Table 8. Figs. 10, 11, 12 and 13 show the petrochemical features of the Hida metapelites. It may safely be said that they are higher in CaO, FeO and MgO, while lower in Al-excess compared to pelites of other areas. Judged from the mode of occurrence and petrochemical characters, the metapelites in question may probably be not derived from "miogeosynclinal" rocks of higher maturity, but from those intermingled with basic volcanic materials and graywacke sandstone. The association of K feldspar and sillimanite is generally stable, suggesting the condition of the upper amphibolite facies of higher. Further information will be given in Chapter VI and VII.

6. Hornblende-clinopyroxene gneiss

The rock is widely distributed on the northern part of the area. It is one of the most common rock type in the Hida metamorphic terrain, being characterized by fine alternation of melanocratic layer rich in hornblende and clinopyroxene, and quartzo-feldspathic leucocratic one. Calcareous gneiss, biotite gneiss and pyroxene gneiss are some-

TABLE 8. CHEMICAL COMPOSITIONS AND C. I. P. W. NORMS OF PELITIC GNEISSES

specimen	1	2	3	4	5
SiO ₂	59.91	50.92	60.51	67.76	58.76
TiO ₂	0.61 ₆	0.89 ₄	0.73 ₃	0.43 ₉	0.59 ₈
Al ₂ O ₃	17.61	22.98	17.93	15.44	18.43
Fe ₂ O ₃	1.22	0.77	0.63	0.02	0.44
FeO	4.95	4.88	5.72	3.10	5.58
MnO	0.13 ₃	0.04 ₉	0.08 ₈	0.04 ₆	0.11 ₈
MgO	3.53	1.72	1.86	1.29	2.04
CaO	4.24	6.73	5.52	1.13	5.42
Na ₂ O	2.63	4.51	3.82	2.11	3.76
K ₂ O	1.91	2.52	1.89	7.91	2.23
H ₂ O(-)	0.19	0.21	0.16	0.14	0.22
H ₂ O(+)	2.36	3.38	0.70	0.62	1.90
P ₂ O ₅	0.18 ₇	0.38 ₃	0.24 ₃	0.15 ₇	0.19 ₃
CO ₂	—	0.15	0.03	0.02	—
C	0.38	—	—	—	—
S	—	—	—	—	—
Total	99.86 ₅	100.09 ₅	99.82 ₃	100.18 ₂	99.68 ₉
Q	20.11	—	13.01	19.00	10.09
c	3.89	1.37	0.03	1.67	0.36
or	11.29	14.90	11.18	46.76	13.18
ab	22.22	35.42	32.28	17.82	31.75
an	19.96	31.22	26.05	4.67	25.80
ne	—	1.45	—	—	—
di	wo	—	—	—	—
	en	—	—	—	—
	fs	—	—	—	—
hy	en	8.82	—	4.64	5.09
	fs	7.29	—	8.91	9.09
ol	fo	—	3.00	—	—
	fa	—	5.36	—	—
mt	1.76	1.11	0.90	0.02	0.63
hm	—	—	—	—	—
il	1.17	1.69	1.38	0.82	1.12
ap	0.44	0.87	0.54	0.37	0.44

* This sample contains sulfide, so the iron content is determined in terms of total Fe as FeO.

times intercalated in it.

Characteristic assemblage is hornblende-clinopyroxene-K feldspar-plagioclase-quartz-biotite-graphite-apatite. Garnet is rarely found. Bluish-green hornblende, epidote, chlorite and prehnite occurs as hysterogene minerals. Molecular percent of orthoclase in K feldspar is 92 percent and the measured triclinicity is 0.925. The anorthite molecular percent in plagioclase is 42-52. Or content in plagioclase is somewhat higher. Clinopy-

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IN THE DISTRICT (ANALYSTS: 1 to 10; K. ISHIBASHI, 11; A. MINAMI).

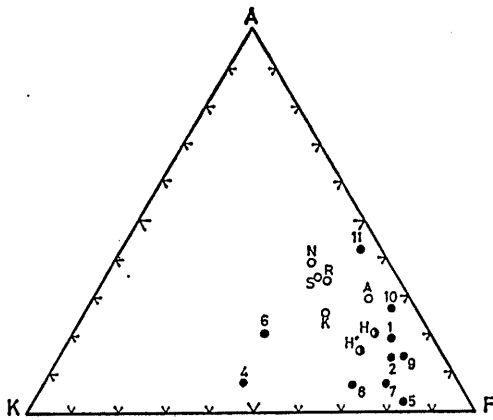
6	7	8	9	10	11
60.11	59.54	68.41	56.41	48.19	59.40
0.64 ₀	0.70 ₈	0.42 ₅	0.55 ₃	0.82 ₄	1.38
17.83	17.47	13.29	19.70	24.99	20.86
2.28	2.50	0.64	1.16	—	0.33
4.54	3.12	4.86	5.85	7.77*	10.38
0.13 ₈	0.14 ₄	0.15 ₉	0.18 ₃	0.22 ₂	0.17
1.22	1.74	1.63	2.54	7.19	1.70
2.63	6.49	4.22	5.56	2.45	1.32
0.97	2.76	0.60	3.67	4.19	1.36
7.52	1.69	3.54	1.63	1.88	1.90
0.45	0.17	0.27	0.19	0.17 ₂	0.25
1.21	3.18	1.62	2.54	1.62	1.58
0.21 ₃	0.17 ₈	0.16 ₂	0.20 ₀	0.15 ₄	0.04
—	—	—	—	—	n. d.
—	0.21	—	—	0.47	n. d.
—	—	—	—	0.08	n. d.
99.74 ₉	99.90 ₀	99.82 ₆	100.18 ₆	100.20 ₀	100.67
16.21	19.96	36.71	9.52	—	31.31
3.73	—	1.12	2.21	11.91	14.23
44.42	9.95	20.91	9.62	11.06	11.23
8.17	23.32	5.03	30.97	35.37	11.48
11.87	30.25	20.02	26.41	11.31	6.37
—	—	—	—	—	—
—	0.38	—	—	—	—
—	0.22	—	—	—	—
—	0.16	—	—	—	—
3.04	4.12	4.07	6.34	7.31	4.24
5.65	2.60	7.97	9.20	5.41	16.79
—	—	—	—	7.46	—
—	—	—	—	6.08	—
3.29	3.62	0.90	1.67	—	0.46
—	—	—	—	—	—
1.20	1.34	0.81	1.03	1.55	2.61
0.47	0.40	0.37	0.47	0.34	0.07

roxene belongs to ferrosalite. Hornblende is generally plotted in the field of green- and brown-hornblende in the higher amphibolite and granulite facies, judged from the atomic percent of Si, Ca, Na and K. Some of the hornblende gives higher content of TiO₂.

Chemical composition is given in Table 9. Among the rocks bound under the name of hornblende-clinopyroxene gneiss, there are wide variation lithologically from more

melanocratic one with richer amount of hornblende to more leucocratic one. Analysed specimens are rather leucocratic ones. It is suggested from the chemical composition that the leucocratic ones might be derived from rocks corresponding to graywacke. It is, however, also conceivable that some of the gneisses must have been derived from some kinds of basic or andesitic rocks. Judged from its fine banding, its original rock may be tuffaceous with fine lamination. On the viewpoint of its mineralogy, the hornblende-clinopyroxene gneiss may have been formed under the metamorphic condition as high as the amphibolite facies. Detailed information on the metamorphic condition will be given in Chapter VI.

FIG. 10. AKF plots of pelites in Japan.



Solid circles: Hida metapelites, the numbers attached to individual symbol refer to the column numbers in Table 8, except for No. 3 which can not be plotted on the diagram because of too lower value of excess alumina, half open circles: averaged composition of Hida metapelites, H; metapelites throughout the Hida meta morphic belt, H'; metapelites from the studied area, open circles: averaged compositions of pelites from Kamiaso conglomerate (K), Abukuma metamorphic belt (A), Ryoke metamorphic belt (R), Paleozoic slates from zone N (N) and from zone S (S). Abbreviations for half open circles and open circles refer to the column symbols in Table 4.

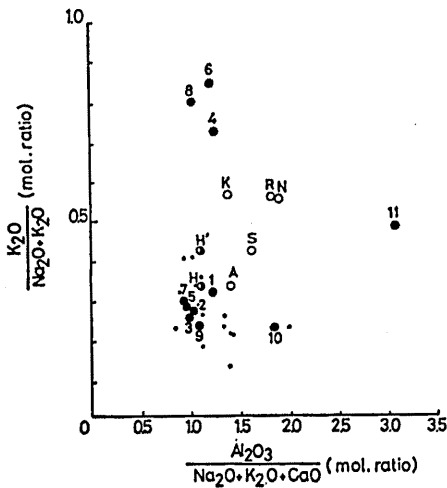


FIG. 11. Alkali ratios and excess alumina of pelites. Abbreviations as in Fig. 10. A sample (No. 1 in Table 4) is omitted because of its exceptionally high value of excess alumina.

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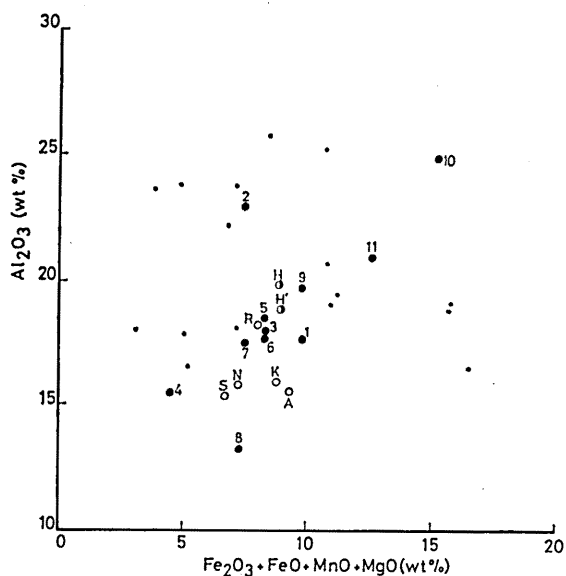


FIG. 12. Al_2O_3 plotted against $Fe_2O_3 + FeO + MnO + MgO$ for pelites. Small solid circles are plots of published data for metapelites from the Hida metamorphic belt, their chemical compositions being shown in SUZUKI (1975, Table 3). Other abbreviations as in Fig. 11.

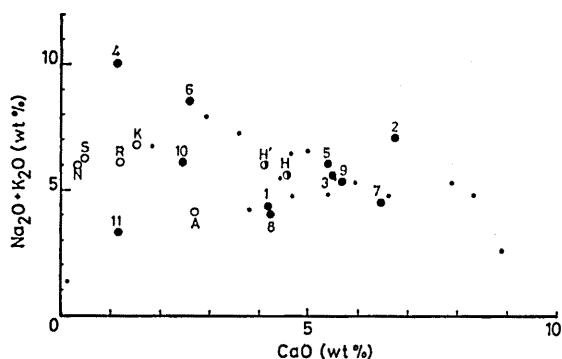


FIG. 13. Total alkalis and CaO contents of pelites. Abbreviations as in Fig. 12.

7. Basic migmatite

The rock is mainly developed on the southern part of the area. The rock in question is coarser-grained than other gneisses. It shows migmatitic appearance, being metatectic or permiating. It is dark-green in colour, due to the abundance of green- to brown-hornblende.

Hornblende, biotite, K feldspar, plagioclase and quartz are the main constituents. Viewed from the relationship between Si and $Ca + Na + K$, hornblende from the basic

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TABLE 9. CHEMICAL COMPOSITIONS AND C. I. P. W. NORMS OF HORNBLENDE GNEISS FROM THE HIDA METAMORPHIC BELT.

specimen	1	2	3	4	5
SiO ₂	62.96	67.67	53.09	52.03	54.90
TiO ₂	0.91	0.82	0.48	1.18	1.08
Al ₂ O ₃	13.61	12.38	17.12	18.89	20.09
Fe ₂ O ₃	0.51	0.23	3.18	2.76	2.65
FeO	4.32	3.93	5.94	5.71	3.85
MnO	0.11	0.08	0.10	0.13	0.04
MgO	1.89	0.75	4.34	4.19	2.03
CaO	11.39	6.10	8.06	7.83	7.43
Na ₂ O	2.50	2.33	4.51	3.92	5.71
K ₂ O	0.34	1.38	1.02	1.57	1.11
H ₂ O(-)			0.20	0.11	0.42
H ₂ O(+)	2.06*	4.65*	1.42	1.97	0.85
P ₂ O ₅	0.14	0.13	0.001	0.000	0.000
Total	100.74	100.45	100.48	100.29	100.16
Q	24.10	34.63	—	—	—
c	—	—	—	—	—
or	2.00	8.12	6.00	9.29	6.56
ab	21.12	19.65	38.09	33.12	48.21
an	24.88	19.24	23.44	29.25	25.88
ne	—	—	—	—	—
di { wo	12.89	4.29	6.90	4.00	4.57
{ en	4.72	1.10	3.88	2.35	2.68
{ fs	6.20	3.42	2.73	1.45	1.66
hy { en	—	0.77	5.54	6.59	1.26
{ fs	—	2.39	3.92	4.09	0.79
ol { fo	—	—	0.99	1.06	0.78
{ fa	—	—	0.78	0.72	0.54
mt	0.72	0.32	4.59	3.99	3.83
hm	—	—	—	—	—
il	1.72	1.55	0.90	2.23	2.04
ap	0.30	0.30	—	—	—

* Determined by ignition loss

1. H-1 (Analyst: S. HIGASHI). 2. H-2 (Analyst: S. HIGASHI). 3. Do, joint between Takahara and Atotsu Rivers, Kamioka area (SATO, 1968). 4. Do, the same place, at a distance of 5 cm from the locality of No. 3 (ditto). 5. Half way between Yoshigawara and Shikama, Kamioka area (ditto).

migmatite is plotted in the area of hornblende of the amphibolite and the granulite facies. Biotite is plotted near the middle between annite and phlogopite in composition. Some biotite contains such high TiO₂ content as about 5 weight percent. The composition of plagioclase ranges from andesine to calcic oligoclase, with higher content of Or molecule.

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TABLE 10. CHEMICAL COMPOSITIONS AND C. I. P. W. NORMS OF THE BASIC MIGMATITE (ANALYST: S. HIGASHI).

specimen	M-1	M-2	specimen	M-1	M-2
SiO ₂	55.06	60.05	Q	2.87	13.84
TiO ₂	1.22	0.78	c	—	—
Al ₂ O ₃	18.67	17.55	or	11.68	7.06
Fe ₂ O ₃	1.97	1.17	ab	34.01	32.96
FeO	5.53	5.03	an	26.99	26.80
MnO	0.15	0.14	ne	—	—
MgO	3.30	2.63	di { wo	3.04	0.37
CaO	7.20	5.77	di { en	1.61	0.18
Na ₂ O	4.03	3.90	di { fs	1.33	0.18
K ₂ O	1.98	1.20	hy { en	6.63	6.39
H ₂ O(-)	0.10	0.15	hy { fs	5.45	7.04
H ₂ O(+)	1.06	2.14	ol { fo	—	—
P ₂ O ₅	0.25	0.17	ol { fa	—	—
Total	100.52	100.68	mt	2.85	1.69
			hm	—	—
			il	2.31	1.47
			ap	0.57	0.37

Both of two samples are from Odori River area.

Or content of K feldspar ranges from 94 to 98 and the triclinicity falls in the range of 0.731 to 0.816. Sometimes occurs almandinous garnet as an essential metamorphic mineral. Hysterogene minerals are bluish-green hornblende, chlorite, epidote and prehnite.

Chemical composition is shown in Table 10. It suggests that the basic migmatite is originated from basic rock. Somewhat higher content of alkalis may owe to the metasomatic addition during migmatization.

8. Crystalline limestone

Calcareous metamorphites are widely developed in the area as in other parts of the Hida metamorphic belt.

Perfectly saccharoidal crystalline limestone contains usually graphite and/or phlogopite. Andradite, clinopyroxene and tremolite are present in lesser amount. It is noticeable that siliceous layers are observed commonly as boudinage in crystalline limestone. Wollastonite is found along the boundary zone between the calcic part and the siliceous layer. Wollastonite is found sometimes as veins cutting markedly the crystalline limestone.

Judged from the chemical composition of the crystalline limestone determined by the X-ray method, it is clear that the composition is rather calcitic. Samples containing a significant amount of dolomite are sometimes found.

9. Lime-silicates gneiss

Lime-silicates gneiss is found closely associated with crystalline limestone. It occurs

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TABLE 11. CHEMICAL COMPOSITIONS AND C. I. P. W. NORMS OF THE LIME-SILICATES GNEISS.

specimen	1	2	3	4
SiO ₂	58.02	68.20	55.43	49.77
TiO ₂	1.14	0.28	0.80	0.20
Al ₂ O ₃	15.80	14.43	16.74	14.26
Fe ₂ O ₃	0.25	0.55	1.99	0.63
FeO	4.21	3.71	2.49	1.90
MnO	0.07	0.10	0.11	0.08
MgO	1.29	0.76	1.76	1.47
CaO	10.89	1.87	14.86	20.09
Na ₂ O	2.51	4.50	1.93	1.25
K ₂ O	2.88	2.95	0.93	1.28
H ₂ O(-)		0.38	0.37	0.35
H ₂ O(+)	2.48*	2.12	0.79	0.67
P ₂ O ₅	0.14	0.10	0.20	0.11
CO ₂	—	—	2.20	8.73
S	—	—	0.10	0.04
Total	99.68	99.86	100.33	100.48
Q	11.37	23.18	14.19	6.40
c	—	0.65	—	—
or	17.01	17.40	5.45	7.56
ab	21.17	37.99	16.30	10.53
an	23.32	8.67	34.25	29.50
ne	—	—	—	—
di { wo	12.50	—	16.00	29.06
{ en	3.22	—	4.39	3.67
{ fs	5.76	—	1.81	2.79
hy { en	—	1.89	—	—
{ fs	—	6.09	—	—
ol { fo	—	—	—	—
{ fa	—	—	—	—
mt	0.35	0.79	2.88	0.90
hm	—	—	—	—
il	2.16	0.52	1.50	0.36
ap	0.30	0.24	0.47	0.24

* Determined by ignition loss

1. L-1 (Analyst: S. HIGASHI). 2. North of Tsudo, Tochibora, Kamioka area (SATO, 1968). 3 and 4. Wada-River (SOMA, 1975).

as the intercalation of fine banding. The rocks included in this category show wide variation in mineral composition. Main constituent minerals are clinopyroxene, plagioclase, K feldspar, quartz and graphite. Garnet, scapolite and biotite are also observed. Bluish-green hornblende, epidote, calcite and prehnite are the secondary minerals. The rock is fine-grained with fine compositional banding.

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Clinopyroxene is always ferrosalite, showing wide range in Mg/Fe ratio. Garnet is almandinous with larger amount of grossular component. Plagioclase shows wide variation in composition ranging from 32 to 75 in An component, although being rather calcic commonly. Scapolite is always associated with plagioclase, showing the chemical composition plotted in the range between mizzonite and meionite.

Chemical composition of the rocks is given in Table 11. It is notable that the rock is calcareous, showing the close connection of the original rock with calcareous sediments. Judged from the equilibrium relation between plagioclase and scapolite, it may well be said that the metamorphic condition of the gneiss concerned ranges from the amphibolite to the granulite facies.

10. *Quartzo-feldspathic gneiss*

Quartzo-feldspathic gneiss of dacitic origin is distributed in the area of Kotani, easternmost of the investigated area. As already discussed by NOZAWA et al. (1975), there remains the texture characteristic in volcanics, having blastoporphyratic plagioclase in quartzo-feldspathic matrix.

Table 12 gives the chemical composition of the rock. It is seen from the table that the rock in question may have been derived from dacitic rock in chemical composition.

TABLE 12. CHEMICAL COMPOSITIONS AND C. I. P. W. NORMS OF THE DACITIC GNEISS.

SiO ₂	67.65	Q	27.00
TiO ₂	0.39	c	1.50
Al ₂ O ₃	15.58	or	8.12
Fe ₂ O ₃	0.96	ab	34.90
FeO	1.58	an	15.79
MnO	0.04	ne	—
MgO	2.60		
CaO	3.30	di	{ wo —
Na ₂ O	4.13		{ en —
K ₂ O	1.38		{ fs —
H ₂ O(—)	1.63	hy	{ en 6.49
H ₂ O(+)	0.30		{ fs 1.54
P ₂ O ₅	0.11	ol	{ fo —
C	0.03		{ fa —
CO ₂	0.04	mt	1.37
S	0.01	hm	—
Fe	0.01	il	0.73
Total	99.72	ap	0.24

Data from NOZAWA et al. (1975).

B. Granites

Granites in the area can be classified into the following three groups; that is, gray-granite, K feldspar-porphyratic granite and the "Funatsu" type granite.

1. *Gray-granite*

The rock is medium- to coarse-grained biotite granite, characterized by its gray colour, and shows weak gneissosity. The mode of occurrence of the granite may be grouped as the following; that is,

- 1) intruded nearly parallel to the gneissosity of adjoining gneiss
- 2) intruded obliquely to the gneissosity of adjoining gneiss
- 3) intruded as dyke-like bodies, pygmatic in appearance

The volume of the gray-granite on each outcrop is very small, but the total amount seems enormous because of high frequency of appearance. The gray colour of the granite shows marked contrast to the pinkish granite, which is younger than the gray-granite. It is very heterogeneous, in some cases pegmatitic or comparatively fine-grained. It is generally porphyritic due to megacrysts of plagioclase and K feldspar, which attain as large as 5 cm in long diameter. It should be noted that there exists no graphite in the gray-granite, in spite of its common presence in adjoining gneisses. Some gray-granites contain hornblende and micas. K feldspar is always microcline with characteristic grille structure. The value of triclinicity ranges from 0.900 to 0.944, and mol. percent of Or 88 to 91. 5 specimens of K feldspar are chemically analysed, the result being plotted near the apex of Or in the Or-Ab-An diagram (Fig. 35). Plagioclase shows wide compositional range from 2 to 44 in An mol. percent, being generally rather acidic.

Modal composition of the typical sample is as follows: quartz 38, plagioclase 35, K feldspar 24, biotite 2 and opaque 1. Bulk chemical composition of the gray-granite from the Hida metamorphic belt is summarized in Table 13. As shown in Fig. 14, they are plotted in the lowest area of the liquidus surface of the system $\text{SiO}_2\text{-Ab-Or-H}_2\text{O}$. The occurrence and petrochemical characters suggest that the gray-granite would have presumably been generated through the partial melting of adjoining gneisses. The partial melting would be related to the older metamorphism of the belt, which have been assumed to be the granulite to amphibolite facies of metamorphism, and the cataclastic or mortar texture of the granite may be attributed to the later phase of deformation and metablastesis.

It must be noticed that the gray-granite is distributed in somewhat limited area on the west of the Hida plateau. The area in which the gray-granite is frequently developed coincides with the polymetamorphic terrain.

2. *K feldspar-porphyritic granite*

This type of rock is distributed on the northernmost and southernmost parts of the investigated area. It is characterized by pinkish tint with porphyritic texture. The long diameter of megacryst of K feldspar attains 5 cm. The porphyritic granite was sheared and have changed to hällflintaic mylonite or augen gneiss, specifically along the margin against the gneisses. It may belong to the so-called Funatsu-type granite after the grouping of predecessors.

The mineral assemblage of the porphyritic granite is K feldspar-plagioclase-quartz. K feldspar is microcline and mol. percent of Or is 86-93 after the X-ray determination. Secondary minerals are chlorite, epidote, calcite and prehnite.

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TABLE 13. CHEMICAL COMPOSITIONS AND C. I. P. W. NORMS OF THE GRAY-GRANITE.

specimen	1	2	3	4	5	6	7	8	
SiO ₂	75.22	73.61	72.66	72.94	71.65	73.86	73.10	70.32	
TiO ₂	0.03	0.03	0.11	0.31	0.31	0.15	0.02	0.15	
Al ₂ O ₃	13.94	14.31	14.26	15.39	15.09	14.84	14.63	15.01	
Fe ₂ O ₃	0.19	0.22	0.30	0.05	0.17	0.12	0.46	0.44	
FeO	0.29	0.31	0.73	1.12	1.01	0.73	0.93	1.13	
MnO	0.01	0.01	0.02	0.01	0.04	0.03	nil	nil	
MgO	0.06	0.16	0.08	0.24	0.43	0.17	0.16	0.83	
CaO	2.69	2.12	2.39	4.64	2.80	1.75	3.54	2.67	
Na ₂ O	3.39	2.73	3.89	4.24	3.32	3.16	3.33	3.00	
K ₂ O	3.50	5.59	4.08	0.28	3.68	4.00	3.65	4.35	
H ₂ O(-)	—	—	—	0.09	0.13	0.24	0.08	0.27	
H ₂ O(+)	0.60*	0.54*	0.80*	0.82	0.88	0.80	0.08	1.61	
P ₂ O ₅	0.01	0.01	0.02	nil	tr.	0.01	0.04	0.02	
S	0.04	0.02	0.01	—	—	—	—	—	
Total	99.94	99.62	99.35	100.13	99.51	99.86	100.25	99.80	
Q	36.35	31.51	29.35	36.52	31.10	35.75	32.16	28.71	
c	—	—	—	—	0.55	2.12	—	0.54	
or	20.68	33.03	24.13	1.61	21.74	23.63	21.57	25.69	
ab	28.61	23.06	32.85	35.79	28.03	26.67	28.14	25.31	
an	12.45	10.23	9.37	22.13	13.87	8.67	14.15	13.15	
nc	—	—	—	—	—	—	—	—	
di	{ wo	0.36	0.10	0.99	0.36	—	—	1.35	—
	{ cn	0.10	0.05	0.17	0.10	—	—	0.33	—
	{ fs	0.28	0.05	0.90	0.28	—	—	1.10	—
hy	{ cn	0.04	0.34	0.02	0.49	1.07	0.42	0.06	2.07
	{ fs	0.08	0.32	0.05	1.24	1.28	1.06	0.21	1.47
ol	{ fo	—	—	—	—	—	—	—	—
	{ fa	—	—	—	—	—	—	—	—
mt	0.26	0.30	0.42	0.07	0.23	0.16	0.65	0.63	
hm	—	—	—	—	—	—	—	—	
il	0.05	0.05	0.20	0.58	0.58	0.27	0.03	0.27	
ap	—	—	0.03	—	—	—	0.07	0.03	

* Determined by ignition loss

1 and 2. Kubusu-River (KANO, 1975). 3. Nozumi-River (ditto). 4, 5 and 6. Oonagatani-River (AOKI, 1964). 7. Futatsuya, Kamioka area (SATO, 1968). 8. Tochibora, Kamioka area (ditto).

3. *Funatsu-type granite*

Granitic rocks with pinkish tint are often found in the area. It is massive with medium-grained texture. The mineral assemblage of the rock is generally quartz-K feldspar-plagioclase-biotite. Hornblende is sometimes associated. Prehnite veins often traverse the granite, but epidote, calcite and chlorite, which are common in other granites men-

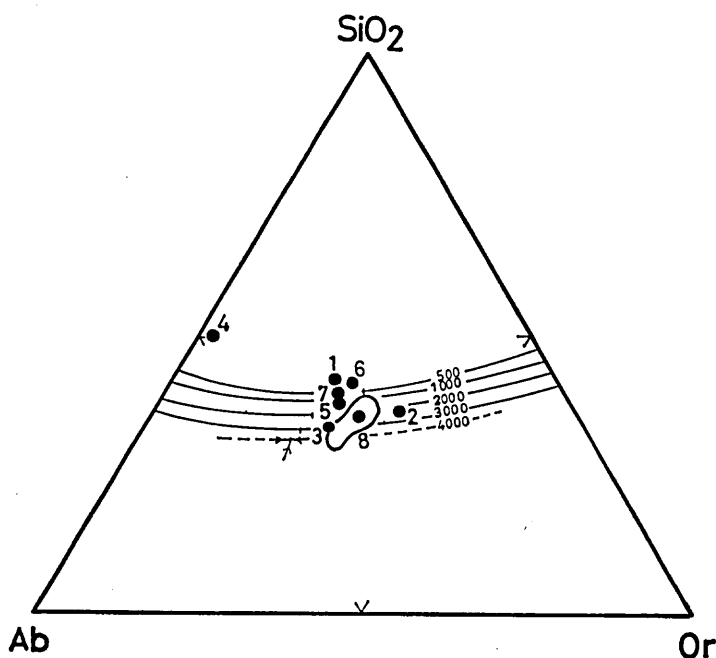


FIG. 14. Q-Ab-Or plots of gray-granite.

tioned above, are usually absent. No remarkable effect of thermal metamorphism cannot widely be observed in surrounding gneisses. Basic intrusives such as gabbro and diorite are also found. Gabbro is always intruded into the gneisses, clearly cutting the gneissosity. It is composed of plagioclase-clinopyroxene-hornblende \pm biotite. Sometimes it shows pegmatitic appearance, characterized by large crystals of hornblende and clinopyroxene. Diorite shows wide variation in mineral association. Some yield quartz, while others clinopyroxene.

Basic rocks mentioned above seem genetically related to the activity of the Funatsu-type granites.

IV. MINERALOGY

Gneisses and granites of the area concerned are composed of such kinds of essential constituents as follows: pyroxenes (orthopyroxene and clinopyroxene), calcic amphiboles, garnets (pyralspite and calcium garnet), micas (biotite and muscovite), feldspars (K feldspar and plagioclase), corundum, wollastonite, scapolite, olivine, titanite, rutile, apatite, quartz, ore and graphite. In this chapter, chemical characters of the minerals will be described in order to clarify genetical conditions of the rocks.

Almost all of the minerals have been analysed by means of JEOL X-ray microprobe analyzer (JXA-5A), having a take-off angle of 40° , in the Institute of Geology and Mineralogy, Hiroshima University. The analyses are done by using a polished thin sections, coated with carbon simulataneously with standards. As the standards are used natural and synthetic oxides and silicates such as SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , MnO ,

MgO, CaSiO₃, Albite (from Amelia) and Adularia (from Gotthard). Na-K-Mg, Si-Ca-Fe and Al-Ti-Mn have been analysed simultaneously, by using the spectrographic crystals of PET and RAP. The standards were checked after every 60 minutes in order to minimize any errors resulting from beam drifting. Operation conditions are 15 kV accelerating voltage, 0.01-0.02 microamperes sample current and about 2-3 microns spot size. The integration times are 10 seconds for all elements. Weight percent of the oxides have been calculated by using the correlation procedures of BENCE and ALBEE (1968), employing the alpha factor by NAKAMURA and KUSHIRO (1970).

All the analytical data of minerals are shown in appendix of the Doctor thesis of the present author in the Hiroshima University.

A. Pyroxenes

Pyroxenes are present in such metamorphites as hornblende-clinopyroxene gneiss, lime-silicates gneiss, the so-called "syenitic rock of the Inishi type" and pyroxene gneiss. Among them, pyroxene gneiss contains orthopyroxene associated with clinopyroxene, while the rest only clinopyroxene.

1. Orthopyroxene

Orthopyroxene in association with clinopyroxene, produced by the dehydration reaction of hornblende, is a critical mineral to mark the beginning of the granulite facies. The amount of orthopyroxene is very small among the main constituents of the pyroxene gneiss, and furthermore, most of orthopyroxene has been altered to hornblende retrogressively. The axial colour of the mineral is as follows; that is, X: pale-red, Y: pale-yellow, Z: pale-green and the axial angle $2V_z$ is 85°. The chemical composition is assumed from the optical data to be En₉₀Fs₁₀.

2. Clinopyroxene

Clinopyroxene occurs in pyroxene gneiss, eclogitic rock, "syenitic rock of the Inishi type", hornblende-clinopyroxene gneiss and lime-silicates gneiss.

Chemical composition of clinopyroxene depends closely on the chemical composition of host rock. For example, calcic varieties of the clinopyroxene are usually found in the "syenitic rock of the Inishi type" and lime-silicates gneiss, both being believed to have been originated from calcareous rocks. While, clinopyroxenes with comparatively lower CaO contents occur in pyroxene gneiss, eclogitic rock and hornblende-clinopyroxene gneiss, especially in the former two. Those gneisses are believed to have been derived from rather basic rocks. Some specimens have been analysed by means of the step scan method with the interval of 20 microns in order to check the chemical zonation in individual grain. Figs 15 and 16 show parts of the Ca-Mg-(Fe+Mn) diagram of clinopyroxenes. Almost all of them are plotted in the area of salite and ferrosalite, except some of them, specifically from eclogitic rock and pyroxene gneiss, plotted in the augite field. Specimens from metamorphic rocks of calcareous rocks origin are plotted in more calcic field than the diopside-hedenbergite join (Fig. 16).

In metabasites or calcareous metabasites, clinopyroxene is believed to begin to occur at the upper threshold of the amphibolite facies at the expense of calcic hornblende and quartz. Therefore, the metabasite containing clinopyroxene may have been formed under the metamorphic condition of the amphibolite facies or higher. It is said that,

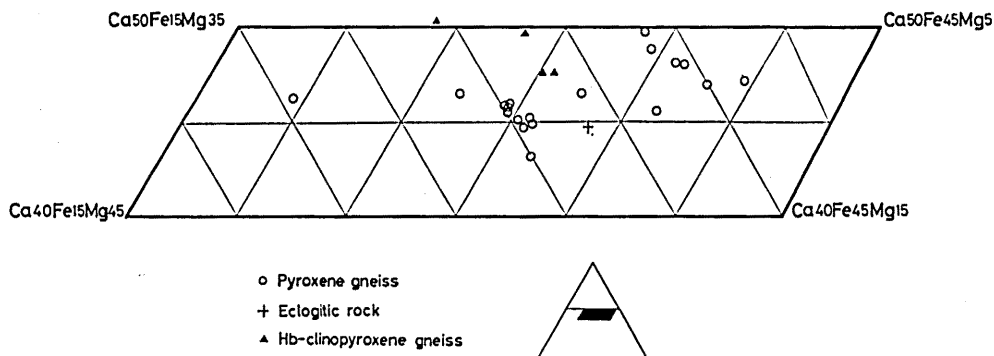


FIG. 15. Tentative Ca-Mg-Fe plots of clinopyroxene from pyroxene gneiss, eclogitic rock and hornblende-clinopyroxene gneiss.

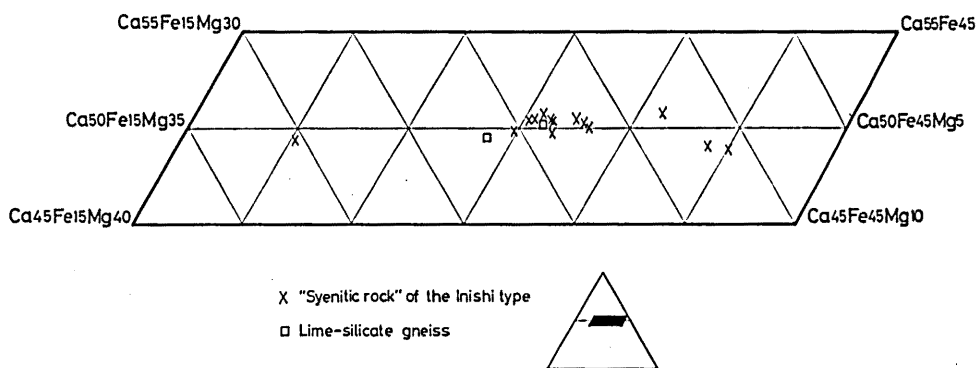


FIG. 16. Tentative Ca-Mg-Fe plots of clinopyroxene from calcareous gneisses.

in metabasites of the amphibolite facies, clinopyroxene is usually salite, whereas in those from granulite facies augite. Although rock specimens grouped under the name of pyroxene gneiss are more calcic than usual basic rocks, as discussed in the previous chapter, some clinopyroxenes from them are plotted in the field of augite. It is consistent with the fact that the pyroxene gneiss shows the critical association of clinopyroxene and orthopyroxene. All are concerned, the pyroxene gneiss should represent the metamorphic rock of the granulite facies. Judged from the mineral association and the chemical character of clinopyroxene, hornblende-clinopyroxene gneiss may have been metamorphosed under the condition of the amphibolite facies. Calcareous rocks, both "syenitic rock" and the lime-silicates gneiss, give no mineralogical informations from clinopyroxene directly suggesting the metamorphic condition. Clinopyroxene is ferrosalite in the eclogitic rock, the metamorphic condition of which will be discussed in a later chapter, where it may be suggested that the rock has been formed under the condition of the granulite facies.

Zonal structure of clinopyroxene has been checked by using two specimens of the pyroxene gneiss and the "syenitic rock". Concerning to major components, they show no remarkable zonal patterns.

B. Amphiboles

Amphiboles are distributed throughout the area in question in wide varieties of rocks; that is, amphiboles are usually found in pyroxene gneiss, hornblende-clinopyroxene gneiss and basic migmatite. Calcareous gneiss, lime-silicates gneiss and "syenitic rock of the Inishi type", also contain amphiboles, and in biotite gneiss and gray-granite they can be found. A metamorphosed basic dyke from Tsukigase also contains them.

Calcic amphiboles are classified into two groups: the actinolite group and the hornblende on the basis of the degree of Tschermak substitution ($\text{Mg, Fe}^{+2}\text{Si} \rightleftharpoons \text{Al Al}$) (MIYASHIRO, 1973). It is said that, together with the increase of the degree of Tschermak substitution, the colour for Z changes from pale-green to bluish-green. With further rise in temperature Tschermak molecule in hornblende is broken down into cummingtonite molecule, that resulting in the change of colour from bluish-green to green and brown. The colour for Z of amphibole is variable in this area, and the predominant is brown or greenish-brown. In almost all the cases, brownish hornblende is mantled with colourless to pale-greenish amphiboles.

The compositional change of calcic amphiboles with rising temperature was described in detail in the central Abukuma Plateau and Broken Hill (MIYASHIRO, 1958, SHIDO, 1958 and BINNS, 1965). As mentioned above, the colour of calcic amphiboles changes, reflecting the compositional change, from pale-green (actinolite) to green and brown through bluish-green (hornblende) as shown in Fig. 17. Most of amphiboles from the investigated area are plotted in the area C of the upper amphibolite and the granulite facies hornblende as shown in Fig. 18. Some specimens from calcareous gneiss and those mantling brownish hornblende in basic gneiss can be grouped into actinolite.

Meanwhile, LEAKE (1965) and RAASE (1974) emphasized that the TiO_2 content in amphibole trends to increase with rising temperature. Fig. 19 shows the Ti contents on the basis of 23 (O), of amphiboles from various kinds of gneisses and granites. After RAASE, the metamorphic hornblende generally concentrates Ti in itself reflecting the metamorphic condition as follows:

greenschist-amphibolite transition facies:	smaller than 0.08
lower grade amphibolite facies	: 0.08-0.14
upper grade amphibolite facies	: 0.14-0.22
hornblende granulite facies	: 0.22-0.33

Increase in Ti content in amphibole with rising temperature may happen to compensate the decrease in octahedral Al resulting from the breakdown of Tschermak molecule in hornblende.

Pyroxene gneiss, with critical association of orthopyroxene and clinopyroxene, contains hornblende having high values of Ti, the highest of which attain 0.289 ($\text{TiO}_2=2.42$ weight percent, specimen 4). Hornblende from hornblende-clinopyroxene gneiss and basic migmatite gives the Ti content suggesting the condition of the upper amphibolite to the granulite facies of metamorphism.

The metamorphosed basic dyke (specimen D) contains greenish-brown hornblende with Ti value of 0.07, suggesting the greenschist to lower grade amphibolite facies (Fig. 19). In Fig. 18, however, it is plotted on the field of the boundary zone between bluish-green hornblende in the low amphibolite facies and green- and brown-hornblende in the high amphibolite to the granulite facies. All are concerned, the metamorphic grade

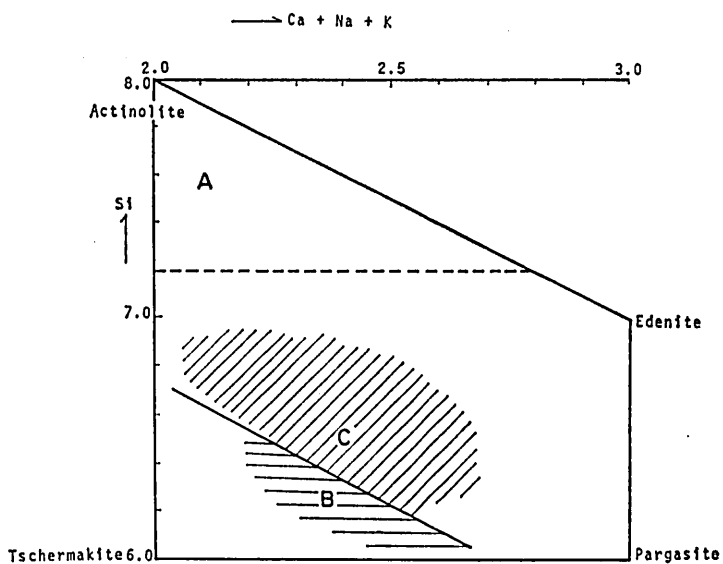


FIG. 17. Calcic amphiboles in metabasites (MIYASHIRO, 1973).
 A: actinolite field, B: blue-green hornblende field,
 C: field of green and brown hornblendes in the high
 amphibolite and granulite facies.

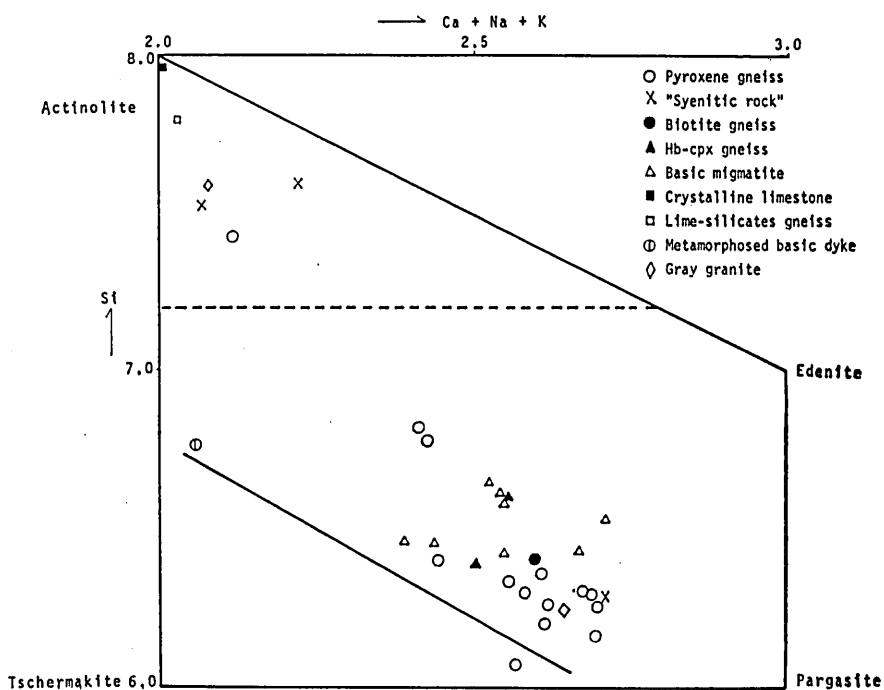


FIG. 18. Calcic amphiboles from various kinds of Hida metamorphites.

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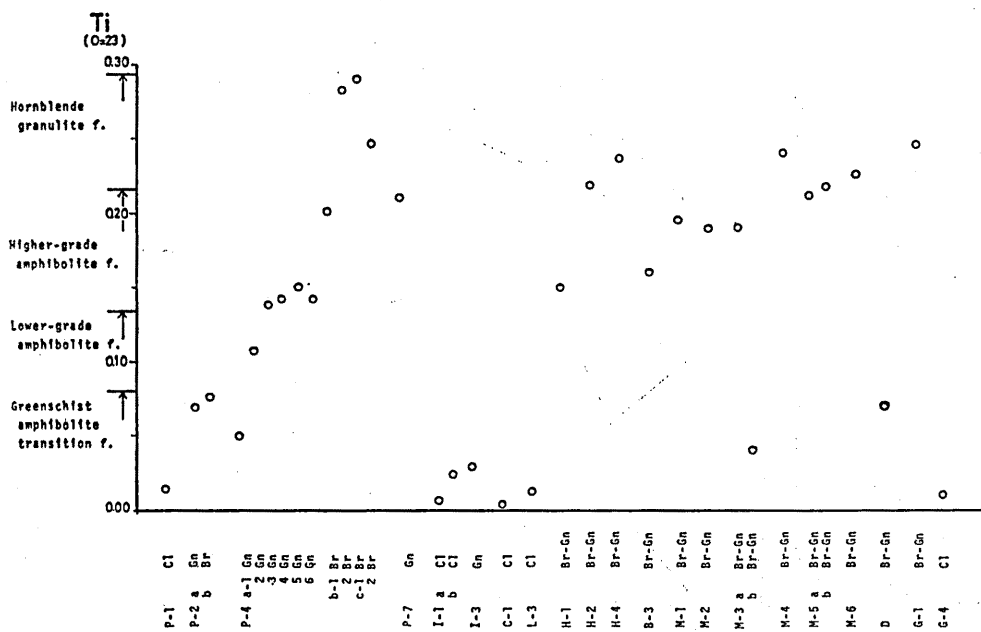


FIG. 19. Ti-contents in amphiboles from various kinds of Hida metamorphites.

P: pyroxene gneiss, I: "syenitic rock" of the Inshi type, C: crystalline limestone, L: lime-silicates gneiss, H: hornblende-clinopyroxene gneiss, B: biotite gneiss, M: basic migmatite, D: metamorphosed basic dyke, G: gray granite.

suggested by the amphibole of the basic dyke is regarded to be that of the amphibolite facies. The bearing of the amphibole in the basic dyke will be discussed later (see Chapter VII).

A specimen from pyroxene gneiss has been analysed to clarify the chemical zonation. It is seen from Fig. 20 that the Ti content is richer in the core part, although distinct zonal pattern concerning to other major elements cannot be observed.

C. Garnet

Garnet is one of the most essential constituents in the metamorphic rocks of the area. Pyroxene gneiss and biotite gneiss usually contain garnet, while hornblende-clinopyroxene gneiss, basic migmatite and lime-silicates gneiss also sometimes contain it. Crystalline limestone sometimes bears grandite garnet with pinkish to reddish tint. Pyrospite garnet always shows distinct zoning, discussions on the bearing of which will be given later.

Pyroxene gneiss usually contains garnet, composition of which is almandinous showing wide range in the contents of CaO, MgO and MnO. Figs. 21 and 22 visualize the chemical variation in terms of Ca, Mg, Fe and Mn atoms, showing distinct zonation.

Garnet from eclogitic rock is analyzed to give the molecular constitution of $Alm_{60}And_2Gros_{24}Pyr_{10}Spes_4$. As the garnet in the eclogitic rock does not appear as euhedral crystals, the zonal structure could not be checked.

Biotite gneiss contains almost always garnet, associated with biotite, K feldspar, plagi-

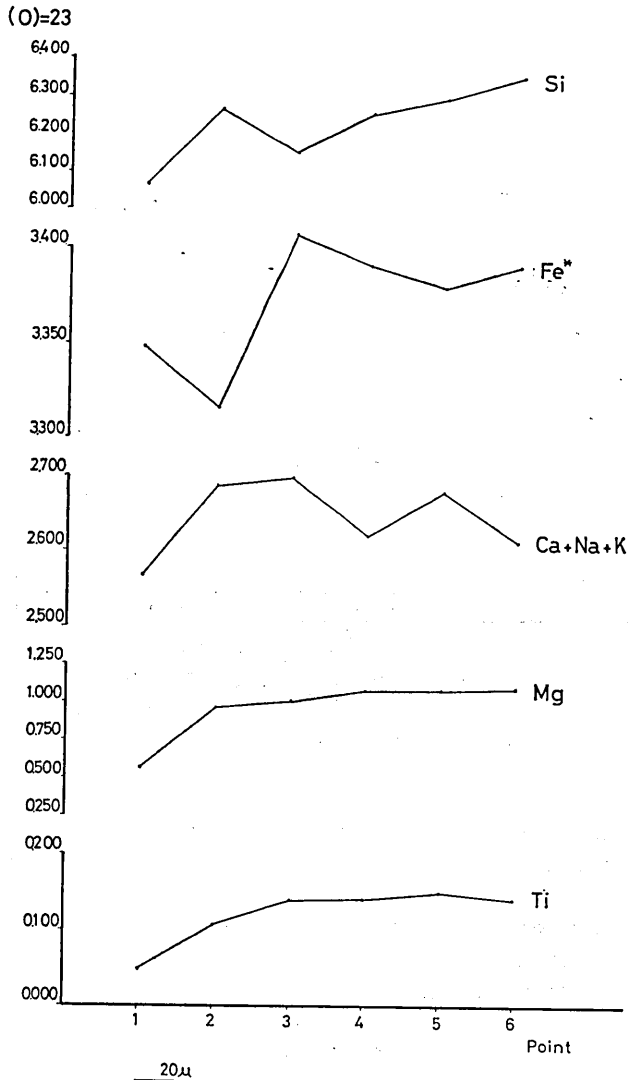


FIG. 20. Chemical zonation in hornblende from the pyroxene gneiss (Specimen No. P-4).

clase and/or sillimanite. It is also almandinous. Because the chemical composition of garnet shows close relationship to the bulk chemical composition as mentioned later, the ratio between Ca, Mg, Fe and Mn is variable in relation with the bulk composition of the host rock. Figs. 23 and 24 show the composition of garnet in terms of the relation between the major elements. Zonal structure is very distinct.

It is rather rare that such basic and calcareous gneisses as hornblende-clinopyroxene gneiss, basic migmatite and lime-silicates gneiss contain garnet. Chemical composition of the garnets are shown in Figs. 25 and 26 to give the relation between major components.

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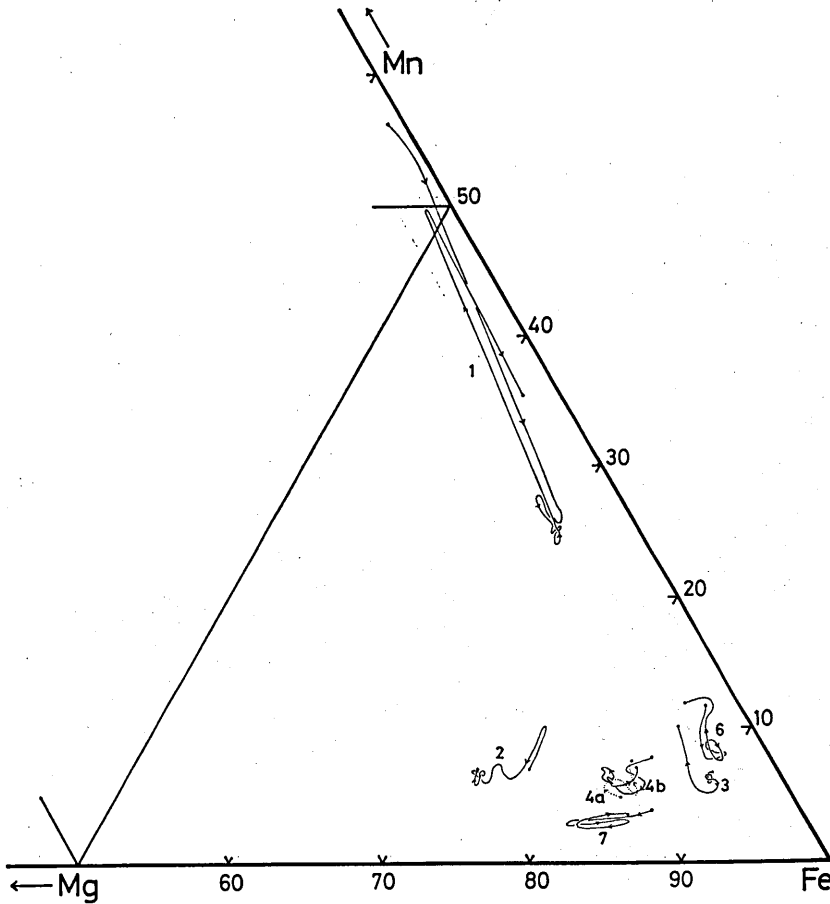


FIG. 21. Triangular plot of zoned garnets from pyroxene gneiss based on atomic percent of Mn, Mg and Fe.

It follows from these figures that the composition is almandinous, with the pyrope molecule ranges from 6.5 to 9.0 percent. Zonal structure of garnet in lime-silicates gneiss can be checked. Figs. 27, 28 and 29 show the pattern of the zonal structure of garnets from various kinds of metamorphites. The analysis was usually carried out by the step-scan method, sometimes by the manual scanning.

The pattern of the zonal structure of garnet can be summarized as follows:

- 1) From the core towards the fringe, the content of MnO is generally decreased and afterwards increased rapidly towards the outermost part. Generally speaking, MnO content is poorer in the core part than in the rim part.
- 2) Zonal pattern concerned to MgO content shows opposite tendency to that of MnO.
- 3) FeO profile is consistent with that of MnO.

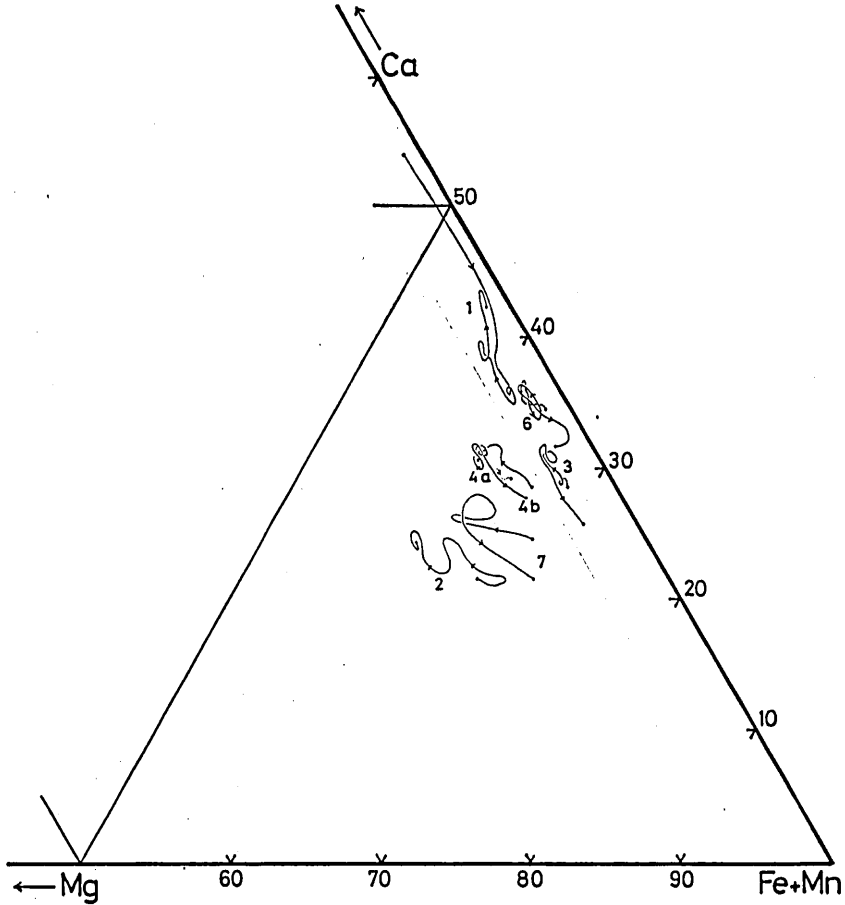


FIG. 22. Triangular plot of zoned garnets from pyroxene gneiss based on atomic percent of Ca, Mg and Fe+Mn.

4) CaO profile is consistent with that of MgO.

5) As a consequence of MnO distribution, zonal pattern does not take the simple "V"-like or the so-called bell-shaped patterns; that is, near the central part they take a normal "V"-like pattern, while, near the rim part, an inverted "V"-like pattern. In other words, zonal profile of MnO is a complicatedly mixed type of the "normal" and "reverse" types.

Progressive change of MnO content of garnet in metapelites has been discussed on the basis of two kinds of models of crystallization representing either complete fractionation or complete equilibrium. The former has been demonstrated by HOLLISTER (1966) and ATHERTON (1968). According to them, the progressive decrease of MnO content can be

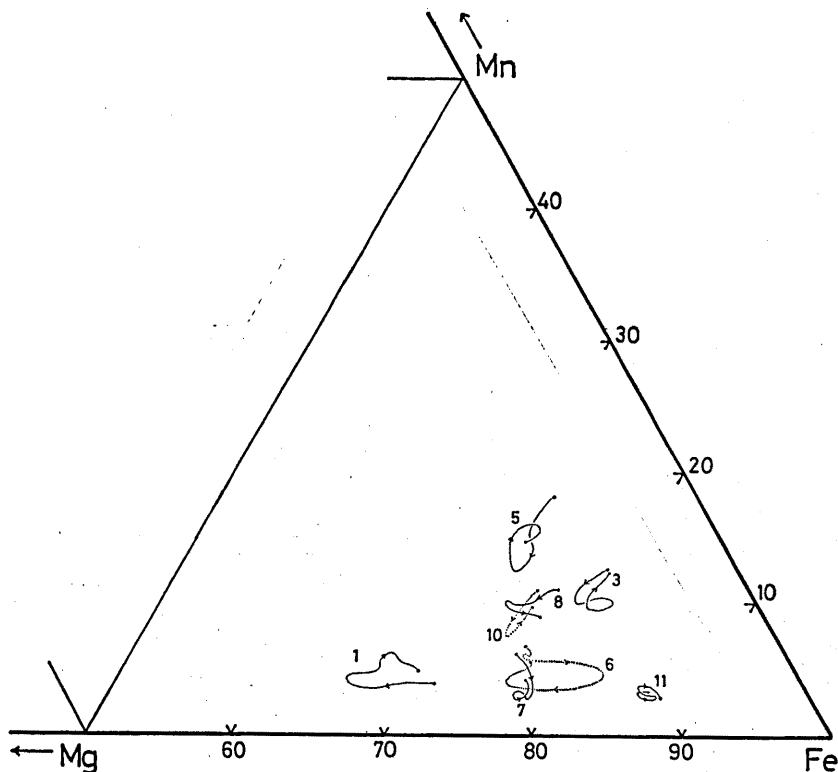


FIG. 23. Triangular plot of zoned garnets from biotite gneiss based on atomic percent of Mn, Mg and Fe.

explained in terms of a simple segregation model or by the Rayleigh fractionation. The latter model has been advanced by MIYASHIRO and SHIDO (1973). In this model garnet crystals are assumed to be always homogeneous and to have been in equilibrium with the associated minerals. The MnO content of garnet as a function of the weight fraction, calculated to follow the two models mentioned above respectively, are similar, as indicated by MIYASHIRO and SHIDO (1973). Consequently, the progressive decrease of MnO content of garnet may have been resulted from gradual increase in the amount of garnet in metapelites.

As concerned to the specimens from the area in question, the characteristic "bell"-shaped patterns observed in the central part in each grain can be explained by the fractionation model. That is, the decrease in MnO content may have resulted from the increase in the amount of garnet crystals with rising temperature. While, the normal "V"-like profile in the periphery can be explained by the effect of another metamorphic event. Namely, garnet formed under the condition of progressive metamorphic process has been broken down to form MnO-rich fringe. Therefore, polymetamorphic develop-

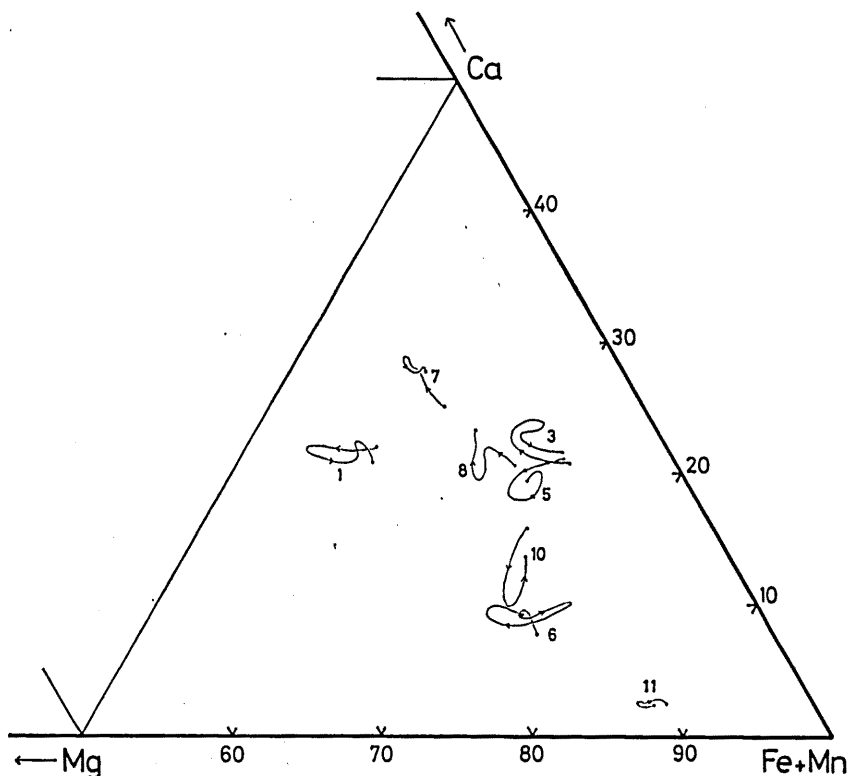


FIG. 24. Triangular plot of zoned garnets from biotite gneiss based on atomic percent of Ca, Mg and Fe+Mn.

ment should be assumed in the area. All are concerned, zonal profile in the central part of the grain shows progressive metamorphic reaction, and the reverse type at the periphery represents the reaction during the later stage metamorphism.

The influence of bulk chemical composition on the garnet composition can be explained in metapelites. As shown by STURT (1962), chemical composition of garnet and metamorphic grade are closely related. The higher the grade becomes, the more increasing the concentration of Mg and Fe, in contrast to the decreasing Mn and Ca amounts. When the composition of garnets is plotted on the STURT's diagram (Fig. 30), the points are scattered in a area of wide range from the biotite grade to the granulite facies. As the rocks have been metamorphosed under the condition of the amphibolite and/or the granulite facies, as mentioned already, the wide scattering of points would be explained by the effect of the bulk rock composition of the host rocks. The correlation of composition between garnet (both of rim and core parts) and the host rock is shown in Table 14. It should be noted that close relationship can be detected in the amounts of FeO and CaO.

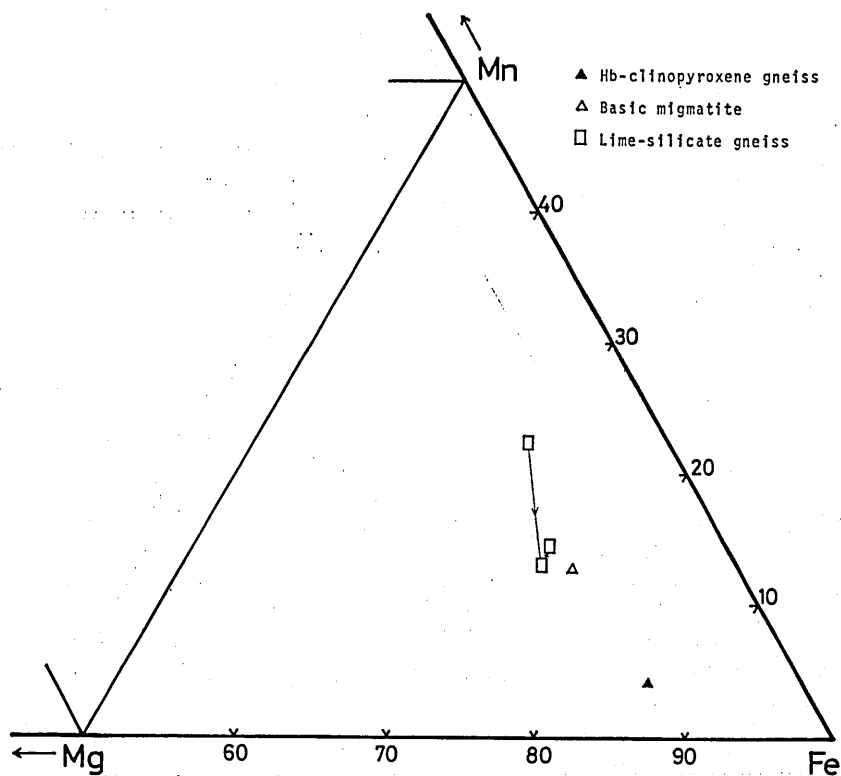


FIG. 25. Triangular plot of zoned garnets from hornblende-clinopyroxene gneiss, basic migmatite and lime-silicates gneiss based on atomic percent of Mn, Mg and Fe.

On the other hand, no clear correlation is detected in the contents of MnO and MgO. Next, the contents of FeO, MgO, MnO and CaO of garnet have been plotted against those of the host rock (Fig. 31). In this figure, the above-mentioned correlation is shown more clearly.

In conclusion, among the major components of garnet, CaO and FeO are directly influenced by the bulk composition, while, the amounts of MnO and MgO do not clearly reflect it. It may be reasonable to think that the amounts of MgO and MnO in garnet depend on the condition of metamorphism.

Accordingly, when wide compositional range exists as in the case of metapelites of the Hida metamorphic belts, the STURT's diagram seems inadequate in order to clarify the metamorphic condition. The diagram presented by SAXENE (1968), partly revised by KARAKIDA (1974) may be more effective (Fig. 32). It suggests the condition of the granulite and the amphibolite facies.

It is noticeable that garnets from metapelites intercalated with pyroxene gneiss (specimens B-1 and -7) show higher content of Mg, that suggesting the condition of the granulite

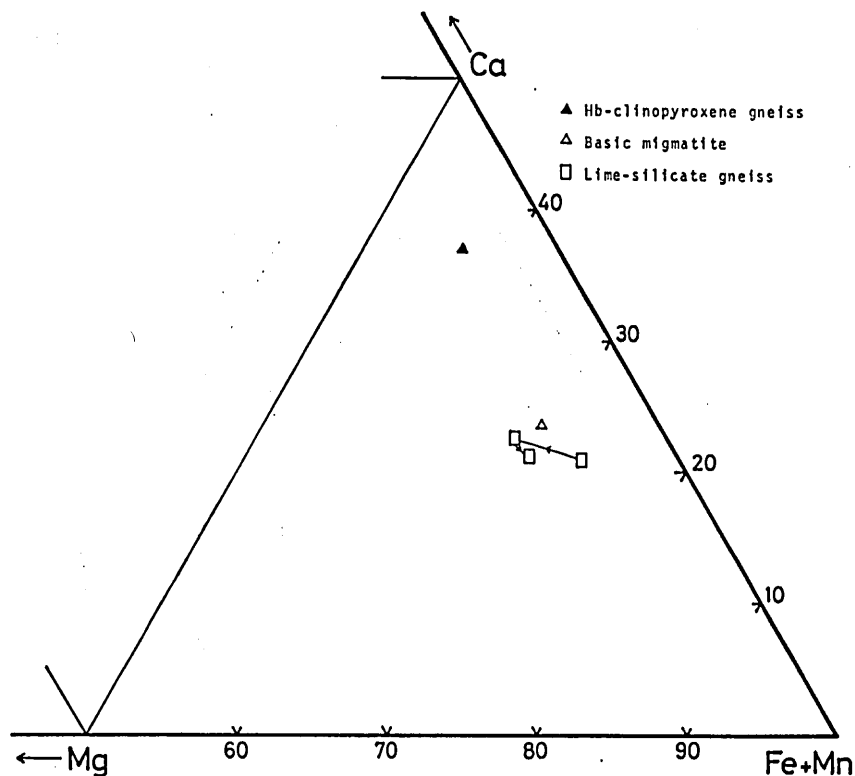


FIG. 26. Triangular plot of zoned garnets from hornblende-clinopyroxene gneiss, basic migmatite and lime-silicates gneiss based on atomic percent of Ca, Mg and Fe+Mn.

facies. It is not possible, however, to discuss from Fig. 32-B the metamorphic condition of garnets from basic and calcareous gneisses.

D. Micas

1. Biotite

Biotite is abundant in pelitic gneiss, as well as in basic migmatite. K feldspar-corundum gneiss, pyroxene gneiss and gray-granite also contain it as a major component.

Megascopically, in all gneisses examined, axial colour of "fresh" biotite is brown to reddish brown. In the common cases, biotite is altered to chlorite from the margin or along the cleavage of each grain. It is not so rare that biotite is altered to prehnite. Consequently, it is usually impossible to check the gradual change of the chemical composition from the rim to the core in each grain.

Some of the biotite flakes from above-mentioned gneisses and granite are chemically analysed. Fig. 33 shows the Mg-Fe-Mn triangular diagram for biotite. It is clear in

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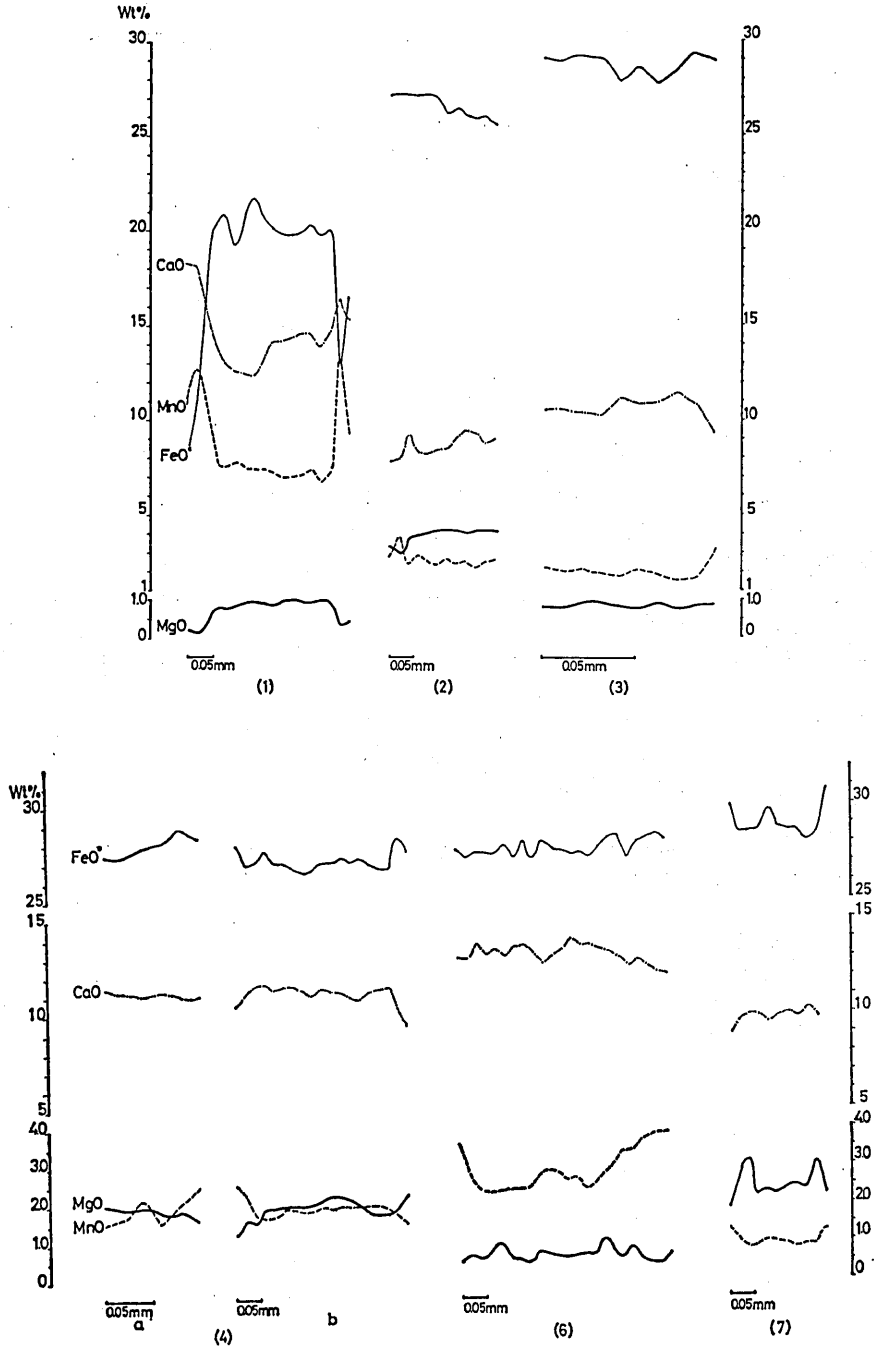


FIG. 27. Zonal profiles of garnets from pyroxene gneiss. Analyses are made traversed across the diameter of each grain.

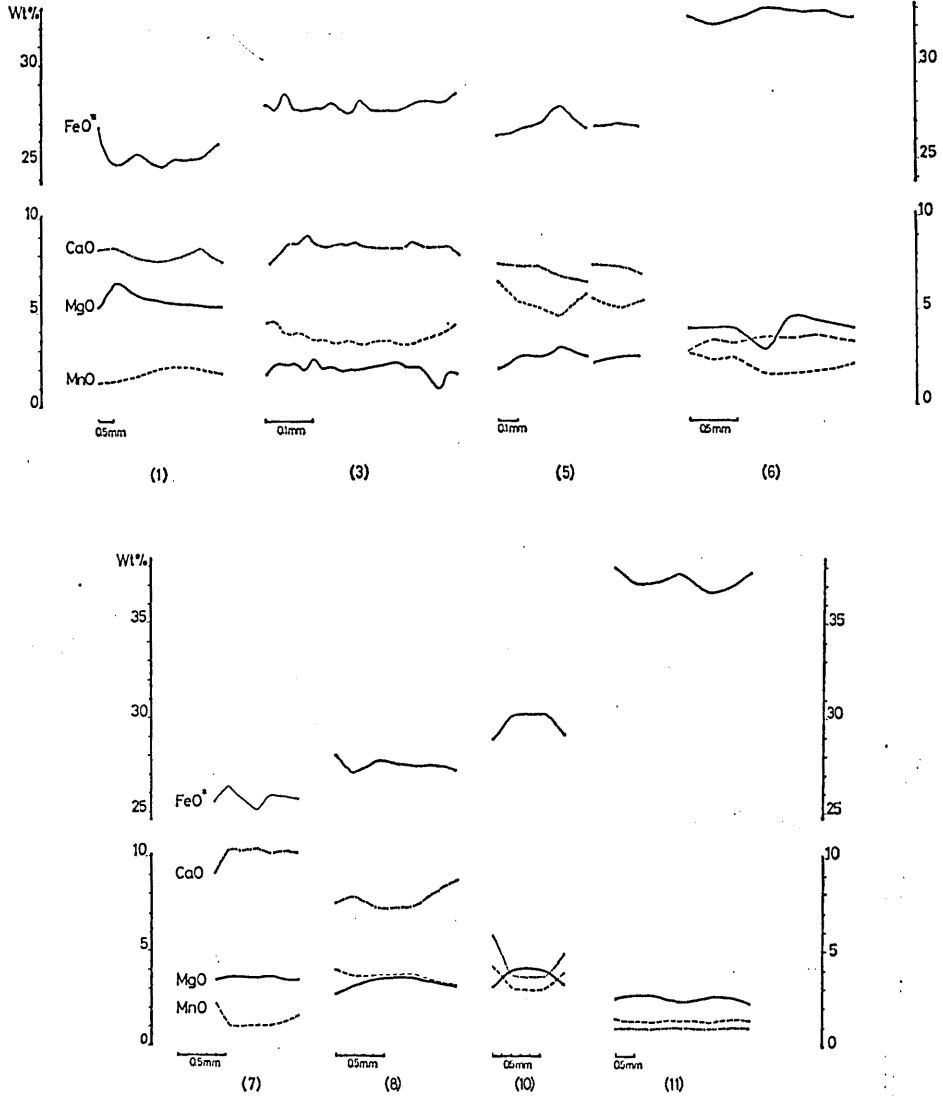


FIG. 28. Zonal profiles of garnets from biotite gneiss.
Analyses are made traversed across the diameter of each grain.

the figure that biotite from pelitic gneiss is rather poorer in Mg content than that from other rock types. TiO_2 contents in biotite is variable, the highest value of which reaches to around 5 weight percent. It is seen from the Fig. 34 that biotite composition is ranged in annite molecule from ca. 50 to 80 percent.

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FIG. 29. Zonal profiles of garnet from lime-silicates gneiss. Analyses are made traversed across the diameter of a grain.

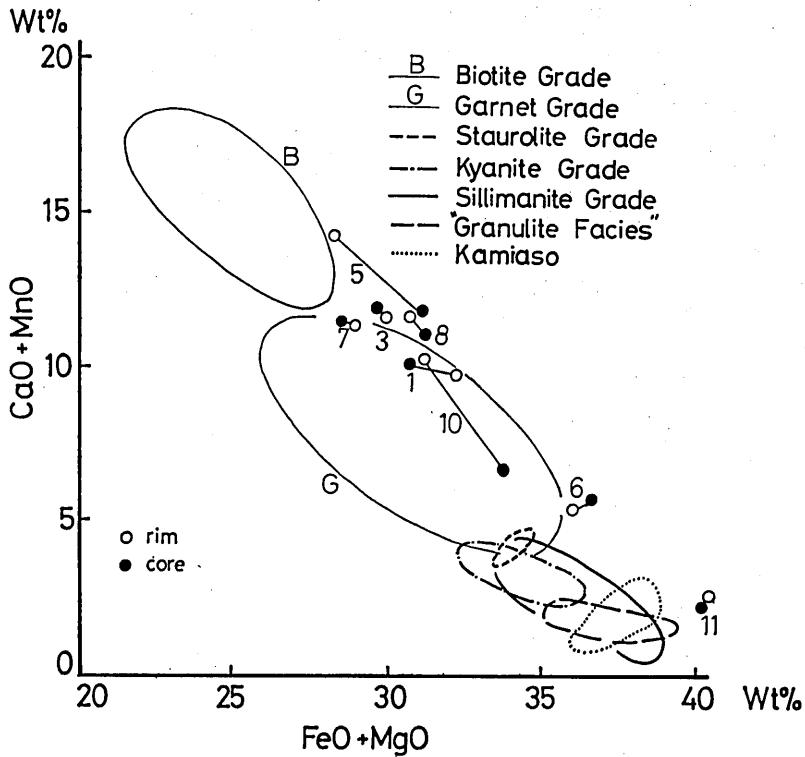
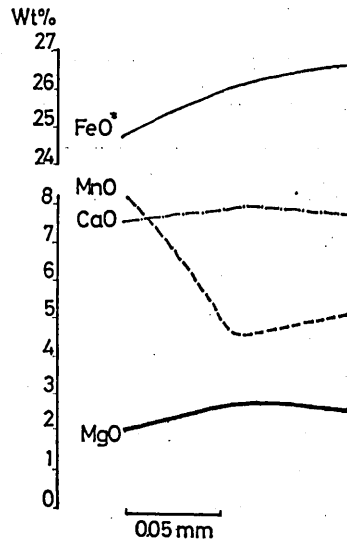


FIG. 30. Plot of garnets from biotite gneiss on STURR's diagram (1962) of (CaO+MnO) — (FeO+MgO) in weight percent.

TABLE 14. COEFFICIENTS CORRELATION BETWEEN GARNET AND HOST ROCK IN META-PELITES.

Host rock	Garnet						
	SiO ₂	TiO ₂	Al ₂ O ₃	FeO*	MnO	MgO	CaO
core							
SiO ₂	-0.150	0.425	-0.328	-0.149	0.068	-0.176	0.334
TiO ₂	-0.225	-0.407	-0.401	0.755	-0.462	-0.362	-0.658
Al ₂ O ₃	-0.030	-0.553	0.134	0.401	-0.120	0.026	-0.548
FeO*	-0.452	-0.344	-0.556	0.785	-0.208	-0.501	-0.702
MnO	0.080	-0.858	0.533	0.381	-0.188	0.310	-0.573
MgO	0.196	-0.530	0.560	-0.094	0.136	0.505	-0.203
CaO	0.411	0.782	0.087	-0.850	0.252	0.042	0.960
rim							
SiO ₂	-0.137	0.149	-0.296	-0.029	-0.100	-0.046	0.146
TiO ₂	-0.173	-0.221	-0.430	0.791	-0.418	-0.186	-0.712
Al ₂ O ₃	-0.021	-0.244	0.073	0.297	0.014	-0.056	-0.378
FeO*	-0.270	-0.105	-0.652	0.804	-0.228	-0.337	-0.737
MnO	-0.243	-0.699	0.397	0.305	-0.163	0.173	-0.346
MgO	0.113	-0.298	0.446	-0.173	0.103	0.172	0.111
CaO	0.668	0.727	0.276	-0.848	0.327	-0.168	0.871

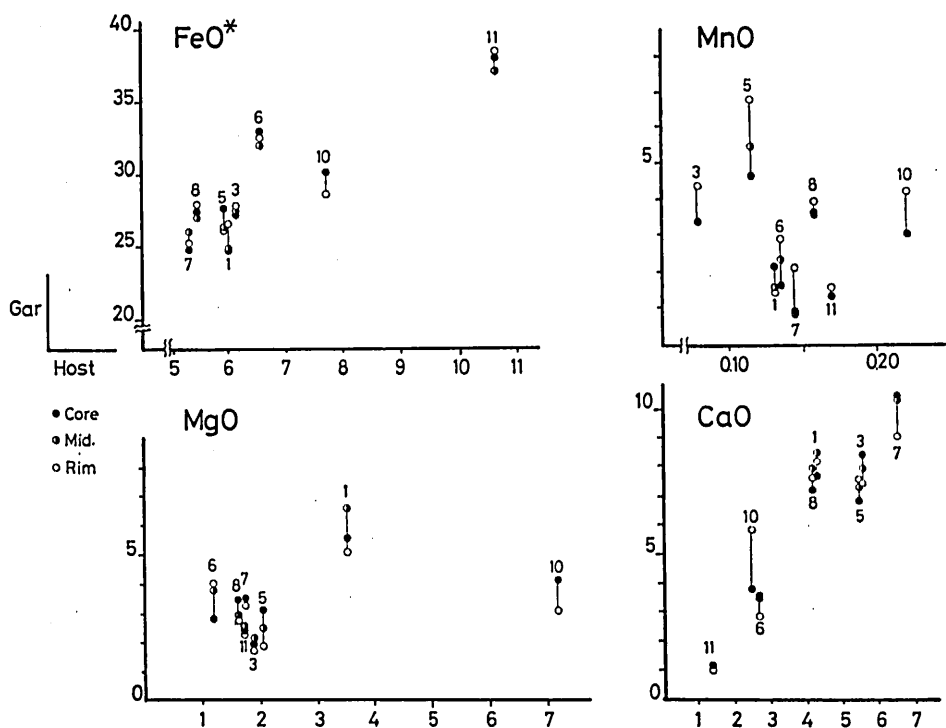


FIG. 31. The relationship between the composition of garnet and the bulk chemical composition of biotite gneiss.

Polymetamorphism in the Hida Metamorphic Belt, Central Japan

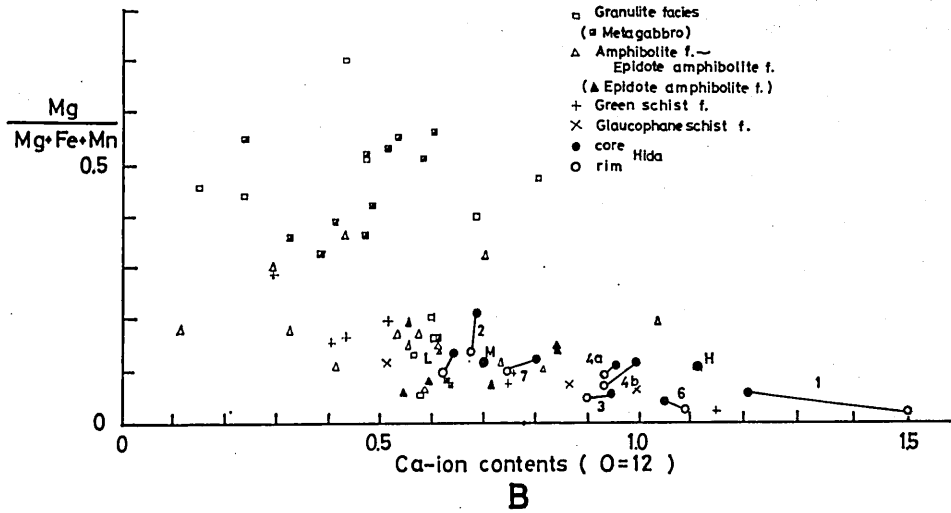
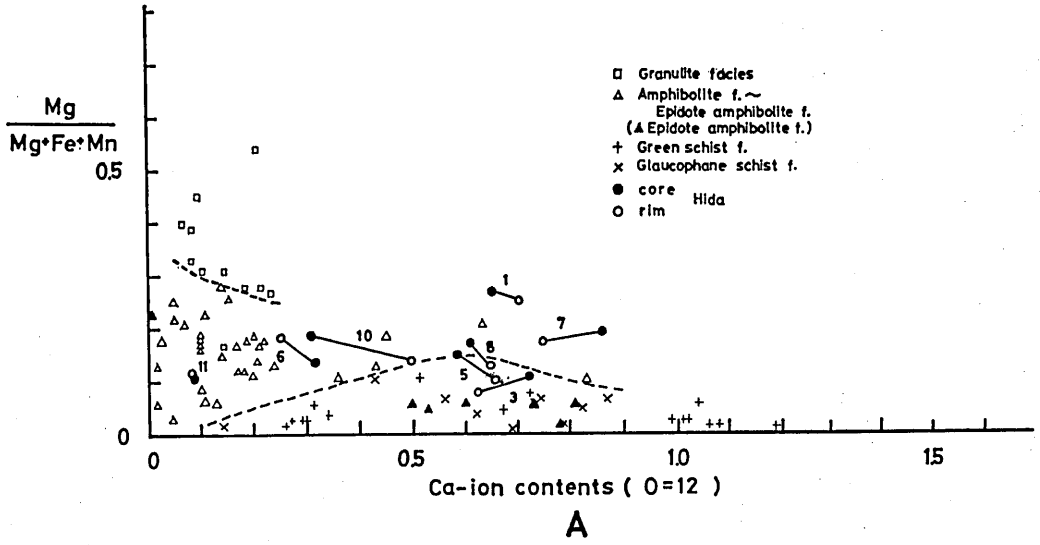


FIG. 32. Composition of garnet as related to the metamorphic grade.
 A: pelitic gneiss, B: basic gneiss.

In the figure B, garnets in calcareous gneiss from the studied area are also plotted.

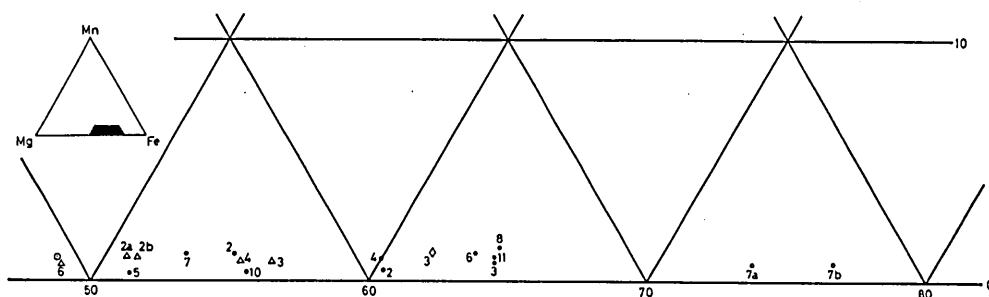


FIG. 33. Plot of biotite on Mn-Mg-Fe triangle.
 Double circle: K feldspar corundum gneiss, open circles: pyroxene gneiss, solid circles: biotite gneiss, open triangles: basic migmatite, diamond: gray granite.

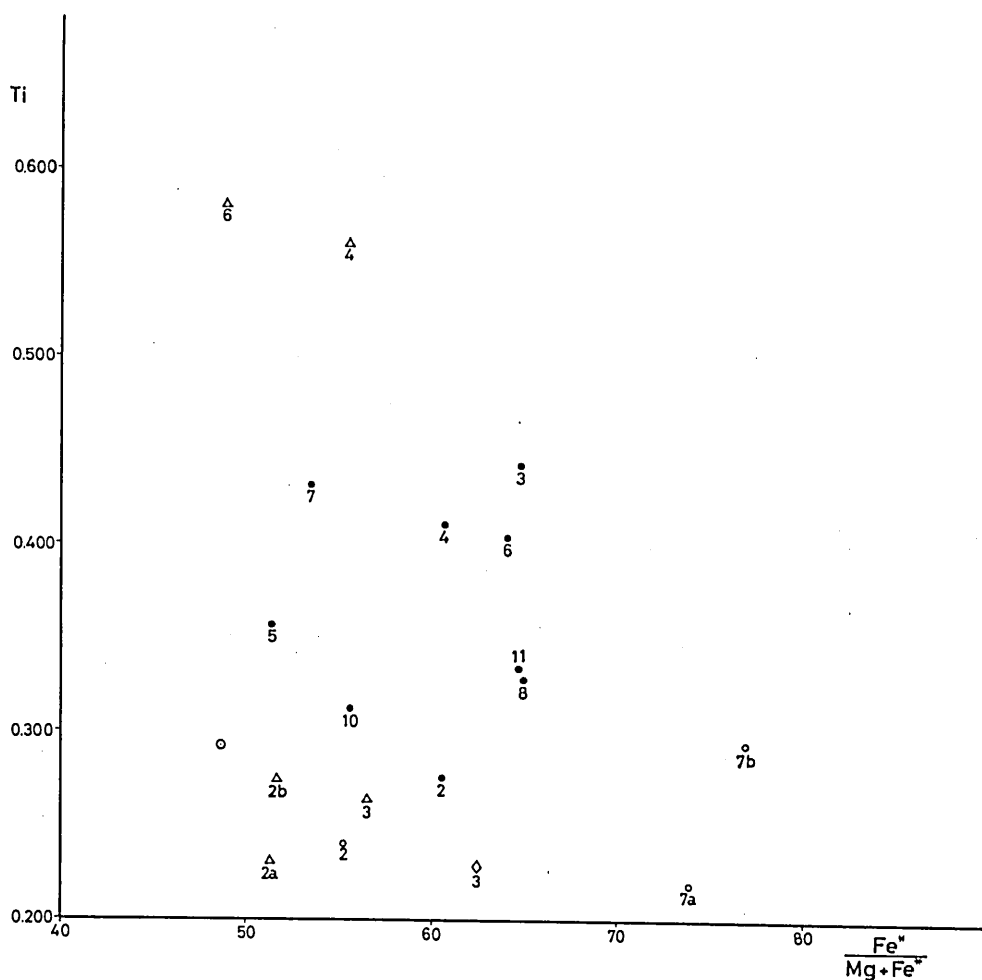


FIG. 34. Plot of biotite on the diagram of Ti (on basis of 23 O) versus $\text{Fe}^*/(\text{Fe}^* + \text{Mg})$. Abbreviations are as in Fig. 33.

2. *Muscovite*

Muscovite is present in K feldspar-corundum gneiss, biotite gneiss and gray granite.

In K feldspar-corundum gneiss muscovite occurs both as fine-grained aggregates mantling corundum crystal (a in Fig. 41) and as euhedral crystals (b in Fig. 41). The chemical composition of them is quite similar, being poorer in paragonite molecule. Metamorphic grade suggested by the muscovite composition corresponds to the amphibolite facies, fine-grained aggregates being reflecting the higher grade of metamorphism than euhedral crystals (Fig. 41).

In pelitic gneiss, muscovite is essentially unstable. It appears as fine-grained aggregates, probably the pseudomorph after aluminum silicate, affected by retrogressive metamorphism.

E. Feldspars

1. *K feldspar*

K feldspar is one of the commonest constituents in gneiss and granites. Although associated plagioclase is more or less saussuritized, the K feldspar is fresh in appearance. Most of K feldspars are microcline with characteristic grille structure. Sometimes the perthitic structure is found. Obliquity of it ranges from 0.52 to 0.95. In table 15 are summarized analysed feldspars. Or-Ab-An diagrams for the K feldspar are shown in Fig. 35. It can be noted that the plots are concentrated in a certain area, that is, Ab solubility in K feldspar is limited in the range of 3.9 to 12.2 molecular percent, mostly around 8.0.

TABLE 15. SUMMARY OF THE COMPOSITIONS OF FELDSPARS FROM VARIOUS KINDS OF GNEISSES AND GRANITE (ANALYST: M. SUZUKI).

specimen	feldspar	grain	Or	mole % Ab	An	analytical method*
P-1	Pl	a	1.0	50.6	48.4	2
		b	—	53.1	46.9	1
		c	—	53.6	46.4	1
		d	—	46.1	53.9	1
P-2	Pl	a	—	42.0	58.0	1
		b	—	42.8	57.2	1
		c	—	43.3	56.7	1
		d	—	39.8	60.2	1
		e	—	42.1	57.9	1
P-3	Pl		1.4	90.0	8.6	2
P-4	Pl	a	8.1	65.8	26.0	3
		b	0.8	53.9	45.3	2
		c	0.9	59.5	39.6	2
	Kf		95.5	3.9	0.5	2
P-5	Pl	a	—	48.1	51.9	1
		b	—	64.9	35.1	1
P-6	Pl	a	1.1	45.3	53.6	3
		b	—	47.4	52.6	1

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TABLE 15. (Continued)

specimen	feldspar	grain	Or	mole % Ab	An	analytical method
P-7	Pl		1.1	60.0	38.9	3
K	Pl		1.4	77.2	21.4	3
	Kf		86.0	12.1	1.9	3
I-1	Pl	a	1.7	70.3	28.1	2
		b	—	71.8	28.2	1
		c	—	70.1	29.9	1
		d	—	75.4	24.6	1
I-2	Pl	a	1.3	73.3	25.4	3
		b	0.8	75.7	23.5	3
		c	—	74.1	25.9	1
		d	—	75.3	24.7	1
I-3	Kf		95.9	3.9	0.2	2
	Pl	a	1.7	72.9	25.4	3
		b	—	74.1	25.9	1
		c	—	71.3	28.7	1
	Kf	a	92.2	7.5	0.3	3
I-4	Pl	b**	5.2	88.9	5.9	2
		a	0.8	67.0	32.2	3
		b	—	67.2	32.8	1
B-1	Pl	c	—	67.0	33.0	1
			—	47.9	52.1	1
			—	90.9	8.1	0.9
B-2	Pl		—	59.6	40.4	1
	Kf		91.5	7.7	0.7	3
B-3	Pl	a	1.8	58.8	39.5	2
		b	—	62.0	38.0	1
		c	—	61.7	38.3	1
		d	—	60.7	39.3	1
B-4	Pl		—	60.9	39.1	1
B-5	Pl		—	55.2	44.8	1
B-6	Pl		—	14.3	85.7	1
	Kf		89.7	9.4	1.0	3
B-7	Pl		—	52.3	47.7	1
B-8	Pl		—	11.1	88.9	1
	Kf		92.3	6.8	0.9	3
B-9	Pl		—	56.8	43.2	1
	Kf		95.9	3.6	0.5	3
B-10	Pl		—	54.3	45.7	1
B-11	Pl		—	76.1	23.9	1
H-1	Pl		14.0	33.6	52.4	2
	Kf		92.3	7.4	0.3	2
H-2	Pl		8.7	46.4	44.8	3

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TABLE 15. (Continued)

specimen	feldspar	grain	Or	mole % Ab	An	analytical method
H-3	Pl		—	54.2	45.8	1
H-4	Pl		—	58.4	41.6	1
H-5	Pl		6.5	49.5	44.0	2
M-1	Pl		2.4	62.5	35.1	3
M-2	Pl		1.1	62.3	36.6	3
M-3	Pl	a	15.8	71.9	12.3	2
		b	0.6	66.5	32.9	2
		c	—	67.9	32.1	1
M-4	Pl		2.7	60.0	37.3	3
M-5	Pl	a	—	72.2	27.8	1
		b	15.5	83.0	1.5	2
	Kf		93.9	5.7	0.4	2
M-6	Pl	a	2.2	62.2	35.6	3
		b	3.3	58.7	38.0	3
L-1	Pl	a	1.9	22.9	75.2	2
		b	0.5	26.8	72.7	2
L-2	Pl	a	1.4	26.6	72.0	2
		b	1.2	66.7	32.1	2
		c	—	56.5	43.5	1
L-3	Pl		0.8	24.2	75.0	3
G-1	Pl	a	1.2	60.6	38.2	2
		b	—	61.4	38.6	1
		c	—	60.9	39.1	1
	Kf		92.5	7.3	0.2	2
G-2	Pl	a	1.0	94.3	4.7	3
		b	—	98.0	2.0	1
		c	—	98.1	1.9	1
	Kf	a***	92.6	7.1	0.3	3
		b****	90.6	9.1	0.3	2
G-3	Pl	a	4.8	92.1	3.1	2
		b	—	97.5	2.5	1
		c	—	55.7	44.3	1
	Kf		92.0	8.0	0.0	2
G-4	Pl	a	0.9	82.7	16.4	2
		b	13.6	65.1	21.3	2
		c	—	92.3	7.7	1
	Kf		90.7	8.9	0.4	3

* 1: relative intensity of Ca 2: relative intensities of K, Na and Ca 3: perfect analysis

** perthitic part in potassium feldspar

*** microcline

**** perthite

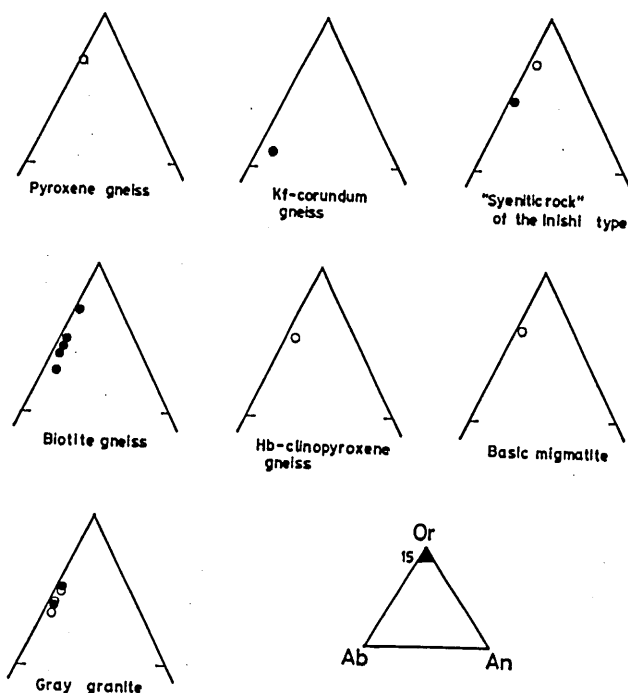


FIG. 35. Plots of the composition of K feldspar on Or-Ab-An diagram.
Open circles: determined by the relative intensity of K, Na and Ca, solid circles:
determined by the perfect analyses.

Judged from above-mentioned properties, along with its "fresh" appearance, micro-clinization during the course of metamorphism can be assumed.

2. Plagioclase

Plagioclase shows polysynthetic twinning after the albite-law. Zonal structure is rare. Sometimes develops grain-boundary-albite, showing marked discontinuity against the core. The core often shows saussuritization. In the gray-granite sometimes is found antiperthitic structure. The results of chemical analyses of plagioclase are summarized in Table 15. Fig. 36 shows the Or-Ab-An plots of them.

It is probable that the rock type and the composition of plagioclase is closely related. As already mentioned by the author (1975), metapelites of the area have been characterized by higher contents in CaO, FeO and MgO and lower in excess Al than usual pelites. Under the condition of the amphibolite facies, the metapelites have given rise to characteristic mineralogy. For example, increase in bulk CaO content is directly reflected in the chemical property of constituent minerals. Plagioclase is one of phases which accommodate calcium. Fig. 37 shows the relation between the modal percent of plagioclase and bulk chemical composition. It seems from the figure that the relationship is rather linear, except for specimens 7 and 8, both containing hornblende.

Next, in Fig. 38 is shown the relation between anorthite content of plagioclase and CaO

Polymetamorphism in the Hida Metamorphic Belt, Central Japan

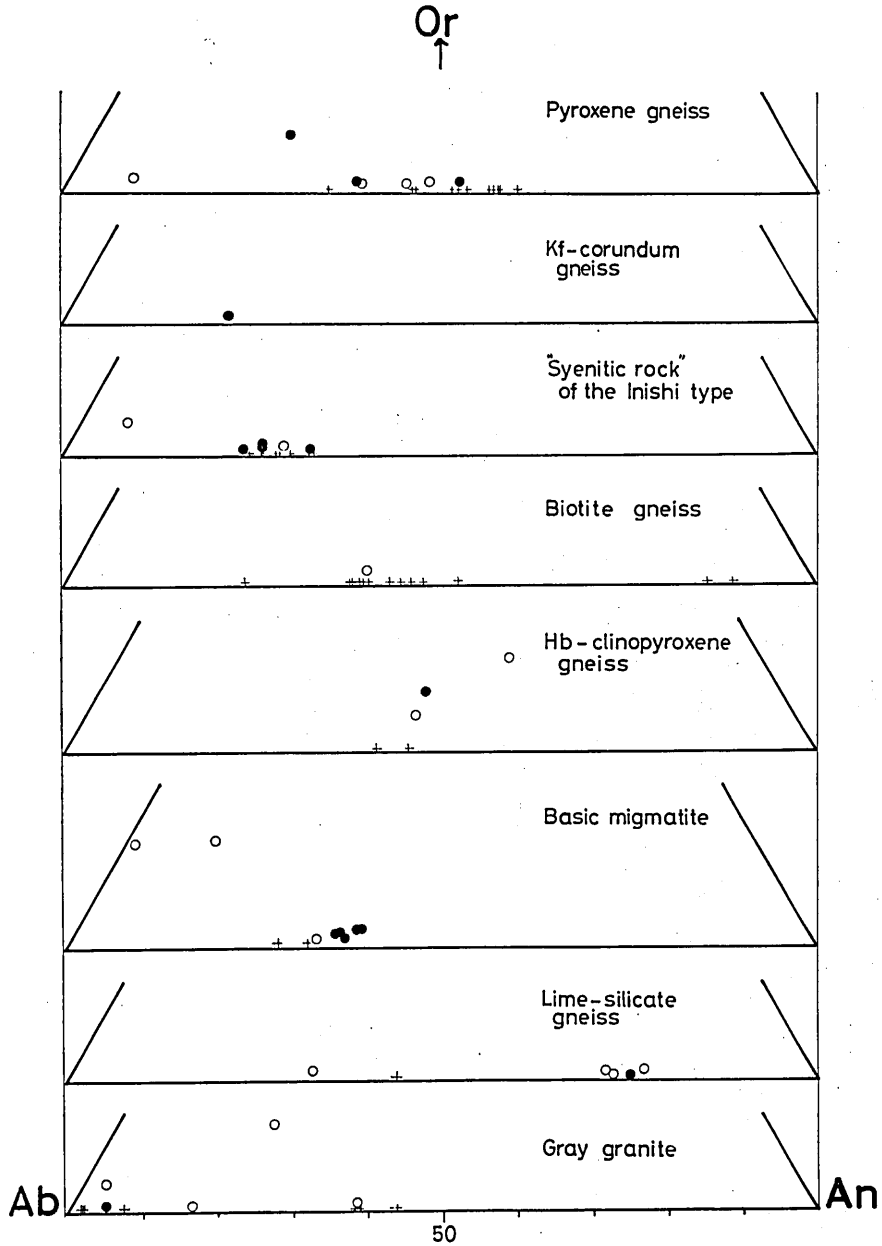


Fig. 36. Plots of the composition of plagioclase on Or-Ab-An diagram.
Crosses: determined by the relative intensity of Ca. Other abbreviations as in Fig. 35.

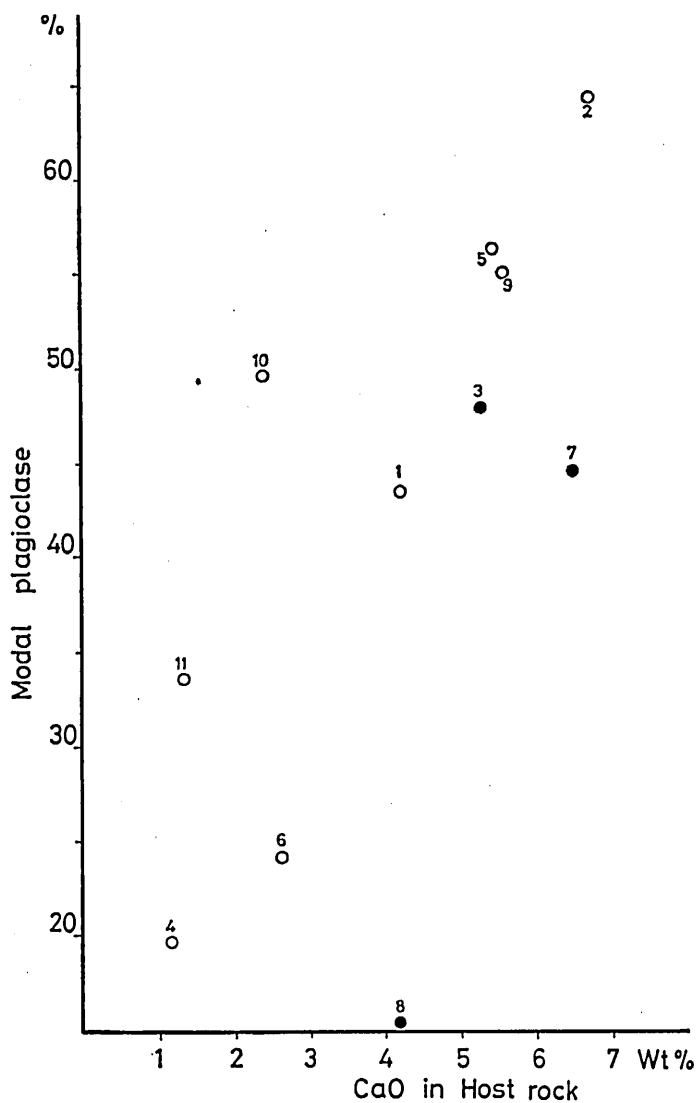


FIG. 37. The relation between modal percent of plagioclase and bulk chemistry of metapelites. Open circles: metapelites lacking of hornblende, solid circles: metapelites with hornblende. The numbers attached to individual symbols refer to the columner numbers in Table 8.

content of the host rock. It is noteworthy that the anorthite percent of plagioclase does not reflect directly the CaO content of host rock, except for the specimens 6 and 8, both having low values of alkalis. It may be that the composition of plagioclase reflects essentially the metamorphic condition (GUIDOTTI, 1970).

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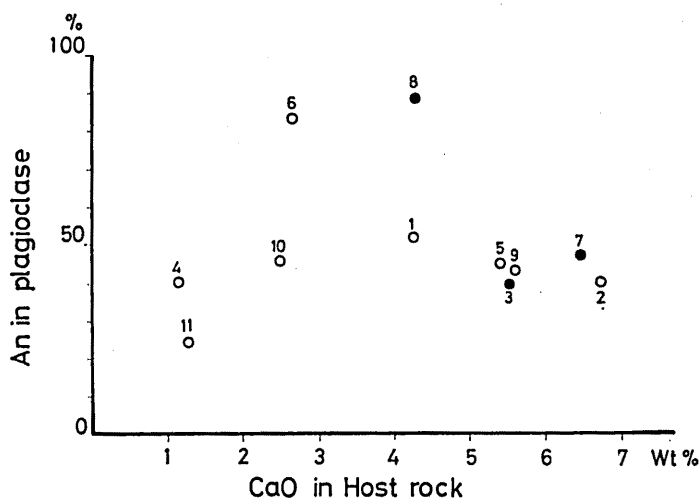


FIG. 38. The relation between the composition of plagioclase and bulk rock chemistry of metapelites.

Abbreviations as in Fig. 37.

F. Others

Other essential metamorphic minerals are scapolite, titanite, corundum, wollastonite, olivine and graphite. Brief comments will be given on some of these minerals in the following.

1. *Scapolite*

Scapolite is sometimes found in the lime-silicates gneiss. As discussed by HIETENEN (1967) and HAUGHTON (1971), scapolite is generally more calcic than the coexisting plagioclase in the metamorphic assemblage, and at higher temperature such as of the granulite facies, the Ca content in scapolite compared with that of plagioclase may decrease or maintain relatively constant value. As a result, the value of anorthite mole percent in plagioclase can exceed the meionite content in scapolite. In the area concerned, two specimens (L-1 and -2) of the lime-silicates gneiss have the following coexisting relation between the two phases: namely, meionite 72.3 mole percent-anorthite 74.9 mole percent and meionite 71.6-anorthite 73.0. In fig. 39 are given the correlation between the mole percent of anorthite versus that of meionite in coexisting plagioclase and scapolite. It should be noted in the figure that, under the lower grade metamorphism, the value of meionite percent exceed that of anorthite percent, points being plotted above the 45° line. The points of the specimens from the area, however, are plotted on or below the line.

It is not unreasonable, judged from the coexisting relation between the plagioclase and the scapolite, to consider that the metamorphic condition under which the scapolite-bearing lime-silicates gneiss has been formed is as high as the granulite facies.

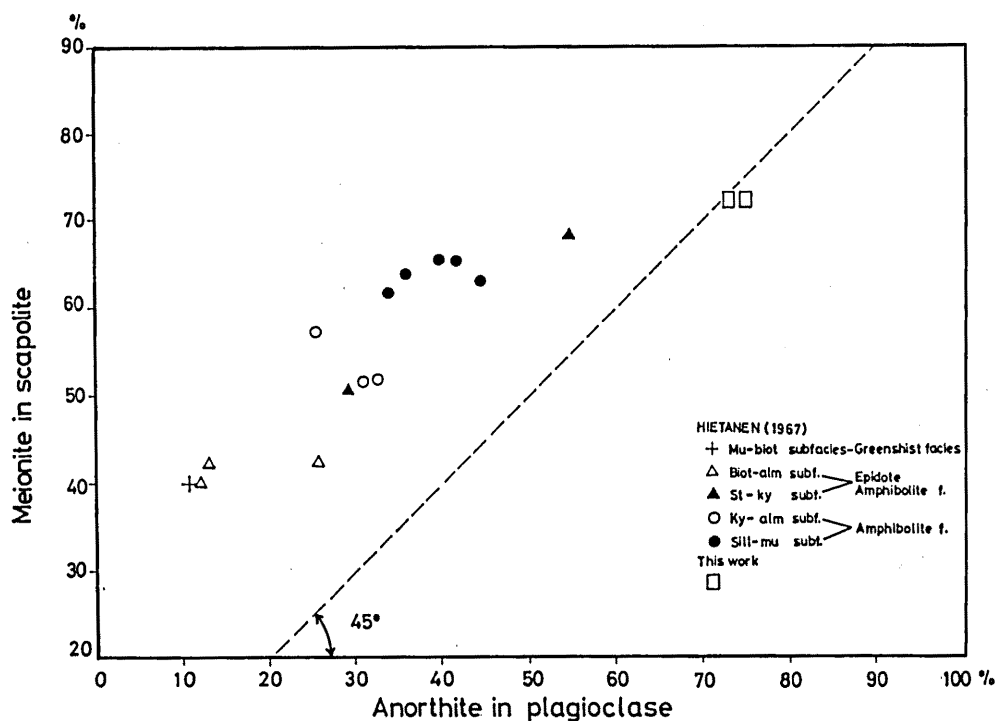


FIG. 39. Mole percent anorthite versus mole percent meionite in coexisting plagioclase and scapolite as related to the metamorphic grade.

2. Titanite

Titanite is found in all the kind of gneisses and granites in the area. Specifically, in the "syenitic rock of the Inishi type" large idiomorphic crystals of titanite develop, the largest of which reaches a few cm in the long diameter. Characteristic brown colour is observed with the naked eye. Major components of it are as follows: $\text{SiO}_2=31.16$, $\text{TiO}_2=37.48$, $\text{Al}_2\text{O}_3=1.67$, Total Fe as $\text{FeO}=0.52$ and $\text{CaO}=28.04$ in weight percent.

V. CHARACTERISTICS OF ORIGINAL ROCKS OF THE HIDA METAMORPHICS

As mentioned already, the most predominant gneisses of the area in question are those derived from graywacke sandstones and calcareous rocks and basic gneisses. Pelitic gneiss has a small share in metamorphites. Such tendency is common throughout the Hida metamorphic belt.

Previously, the present author (1975) discussed the chemical abnormality of the original rock of biotite gneiss derived from pelitic rock. Pelitic gneisses from the southwestern part of the belt are characterized by comparatively high contents of CaO , FeO and MgO , showing lower values of alkali ratios and alumina excess (Figs. 10 to 13). Occasional occurrence of hornblende and/or clinopyroxene, in contrast to the scarcity of Al-silicate minerals in metapelites can be explained by the peculiarity of bulk chemical

composition. He has suggested that the original rocks of the metapelites may not have been derived from miogeosynclinal sediments with higher maturity, but from those intermingled with basic ones of volcanic provenance. That is one of the most distinguished character of the Hida metamorphic belt compared to other metamorphic belts of similar types in Japan.

Next, basic gneisses show the following characteristics. As mentioned in Chapter III, they are rather calcareous as compared with ordinary basaltic rocks, presumably suggesting the possibility of mechanical intermingling with calcareous rock.

It should be noted that there are found some kinds of gneisses derived from alkali volcanic rocks. The representatives are K feldspar-corundum gneiss and biotite quartzofeldspathic gneiss. The former may have been derived from a trachytic rock, and the latter from a dacitic rock. As for the K feldspar-corundum gneiss, the detailed petrographic characters have been described already (Chapter III, A.3).

Lime-silicates gneisses are usually associated with crystalline limestone bearing olivine and clinopyroxene. Apparently pure saccharoidal limestone is more or less dolomitic.

As for the figures of sedimentary aspect of the original rocks, comments will be summarized as follows:

- 1) The original rocks are rich in calcareous rocks and graywacke sandstone, associated with basic rocks, in contrast to a small share of pelitic rock.
- 2) The pelitic rock may have been accumulated in the environments where basic volcanic rock was intermingled.
- 3) Some kinds of acid to alkali rocks have been inserted.
- 4) Calcareous rock is rather dolomitic.

All are concerned, the sedimentary basin of the original rocks of the Hida metamorphics is an unstable one, where many kinds of sediments were intermingled.

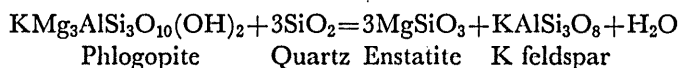
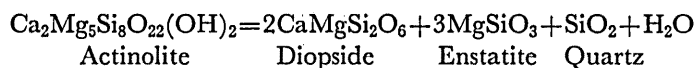
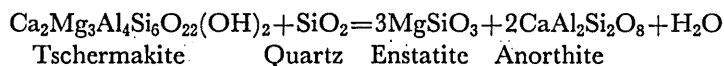
The figure of premetamorphic sedimentation is quite different from other metamorphic terrains in Japan.

VI. METAMORPHISM

On the basis of preceding description on petrological and mineralogical properties of the gneisses of the area in question, the character of the metamorphism will be discussed in the following.

As discussed in the previous sections, the granulite facies metamorphism can be assumed to have occurred, although the rocks of the amphibolite facies are ubiquitously distributed.

The granulite facies, which is firstly advocated by *ESKOLA* (1929), is characterized by the predominance of anhydrous minerals. Following reactions, which may mark the boundary zone between the amphibolite and the granulite facies, progress through the wide range of temperature.



Special attention will be paid in this paper on the granulite facies condition in the area studied, in connection with time and spatial relationship to the lower grade metamorphism.

A. Critical mineral assemblage

In the area studied, pelitic gneiss has critical assemblage of pyralspite, biotite, K feldspar and/or sillimanite. Muscovite is not stable. In metabasites, clinopyroxene and hornblende are commonly associated stably. Such mineral association suggests that the metamorphic condition is not lower than the amphibolite facies. In addition, following parageneses of specific character are also found.

1. *K feldspar — corundum*

The assemblage constitutes the K feldspar-corundum gneiss. Although the corundum crystals have been altered to muscovite from the margin, it can safely be assumed that corundum and K feldspar had been stably associated in the original gneiss before the retrogressive formation of muscovite.

For the following equation of the breakdown of muscovite,

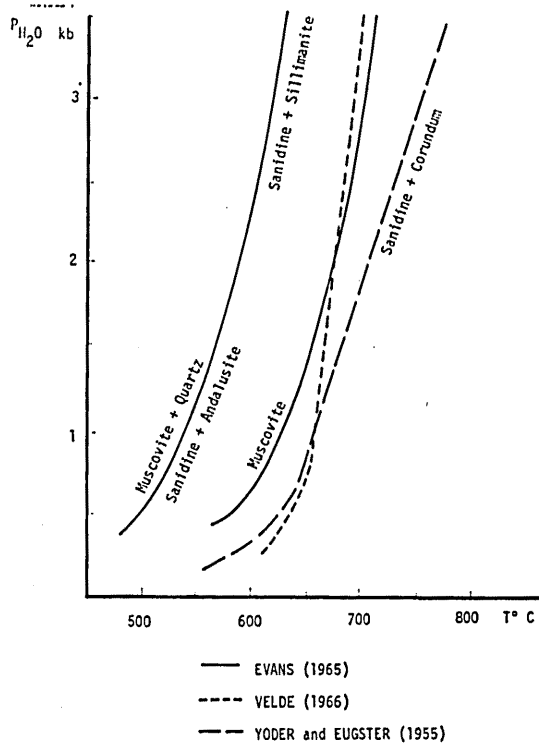
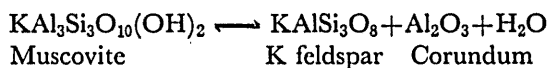


FIG. 40. Equilibrium diagram for the decomposition of muscovite.

TURNER (1968) gave the value of dP/dT at 700°C and 2kb, calculated from the thermochemical data, as 28 bars/deg. While, experimentally determined curves show following values of inclination: 20 b/ $^{\circ}\text{C}$ by YODER and EUGSTER (1955), 25 b/ $^{\circ}\text{C}$ by EVANS (1965) and 50 b/ $^{\circ}\text{C}$ by VELDE (1966) (Fig. 40).

Apparently, the EVANS' curve is most coincident with that calculated. According to the EVANS's curve, the decomposition temperature is at $P_{\text{H}_2\text{O}}=P_s=3$ kb about 700°C and at $P_{\text{H}_2\text{O}}=P_s=1$ kb about 640°C . Recent result by CHATTERJEE and JOHANNES (1974) shows the decomposition temperature as 675°C under $P_{\text{H}_2\text{O}}=3$ kb.

In some of the metamorphic terrains of the granulite facies, the temperature of metamorphism was estimated as follows: in Adirondack Mountains, it is $550\text{--}625^{\circ}\text{C}$ (BUDDINGTON, 1963) deduced from the composition of iron-oxide pairs and in Broken Hill $600\text{--}700^{\circ}\text{C}$ from the composition of coexisting magnetite-ilmenite pairs (BUDDINGTON and LINDSLAY, 1964).

Judged from these data, it can be inferred that the K feldspar-corundum association in question have formed under the metamorphic condition of the granulite facies.

As mentioned above, the corundum crystals are surrounded by kelyphitic rims of white mica, the composition of which is plotted in Fig. 41. The composition corresponds to those in metapelites of the amphibolite facies.

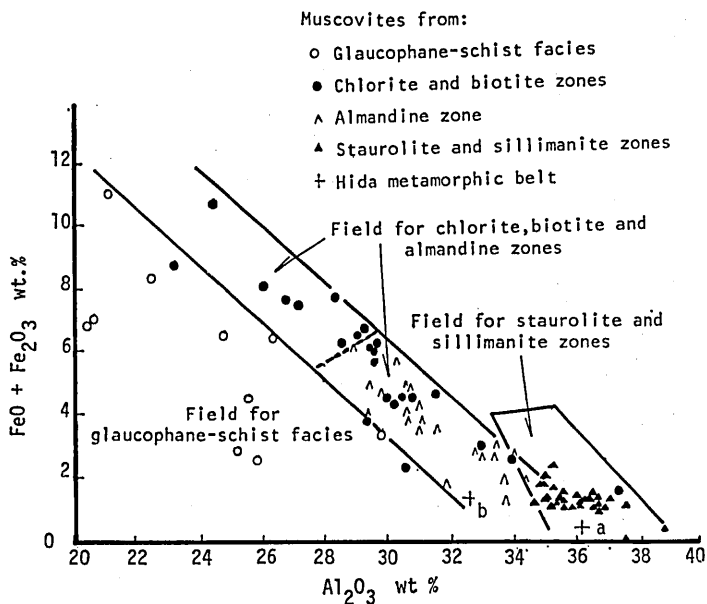


FIG. 41. Composition of muscovite (after MIYASHIRO, 1973).
Crosses muscovite from K feldspar-corundum gneiss, a; fine grain mantling corundum crystal, b; euhedral crystal.

2. Ferroaugite-almandine-quartz

The assemblage constitutes a kind of eclogitic rock found at Tsukigase. Mode of occurrence and petrographic properties of the rock were described in a former paper (SUZUKI, 1973b). Therefore, mineralogical characters will be described here.

Distribution relations of several major cations between coexisting garnet and clinopyroxene have been discussed by many authors. BANNO (1970) defined the apparent Fe-Mg distribution coefficient between garnet and clinopyroxene, $K'_{\text{Fe-Mg}}^{\text{ga-cpx}}$, as follows:

$$K'_{\text{Fe-Mg}}^{\text{ga-cpx}} = \left(\frac{X_{\text{Fe}}}{X_{\text{Mg}}} \right)_{\text{ga}} / \left(\frac{X_{\text{Fe}}}{X_{\text{Mg}}} \right)_{\text{cpx}}$$

where $(X_{\text{Fe}})_{\text{ga}}$ etc. denote the mole fraction of Fe in garnet etc., saying that the apparent distribution coefficient is closely reflecting physical conditions of the rock formation. According to this definition, the value of K' of the association in the rock concerned is 4.3.

Fig. 42 gives the relationship between K' and Fe/(Fe+Mg) ratio of garnet from eclogites. The value of K' of the eclogitic rock in question is rather low in comparison with the average of the pair from the metamorphic rocks of the amphibolite facies. It is also clear that the value is higher than those of eclogite included in kimberlites and basalts. From the figure it can be said that the relationship between K' and garnet composition in the rock concerned is similar to those of eclogites from the metamorphic terrains of the granulite facies.

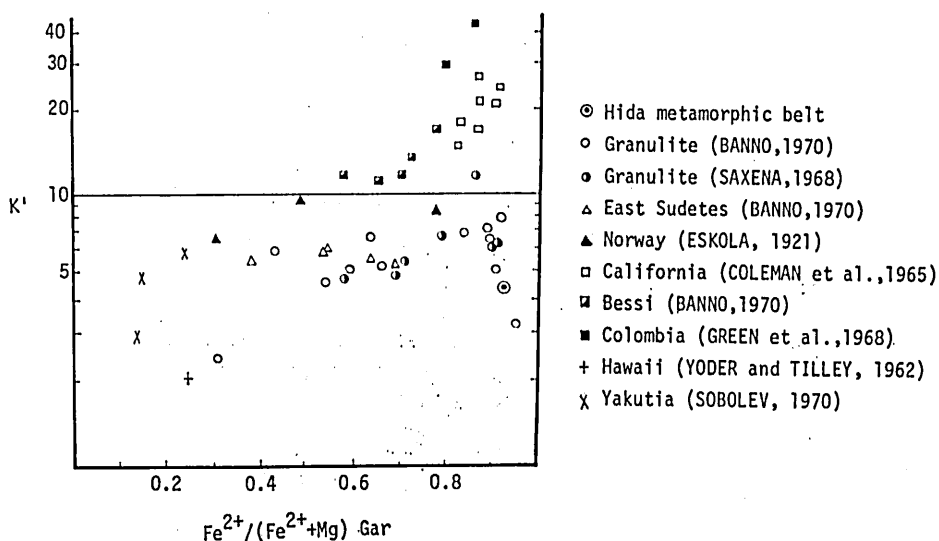


FIG. 42. The relation between K' and $\text{Fe}^{2+}/(\text{Fe}^{2+}+\text{Mg})$ ratio of garnet for various coexisting garnet-clinopyroxene pairs from eclogites and granulites.

Recently, from the experimental results on the equilibrium of garnet-clinopyroxene pair, RÅHEIM and GREEN (1974) presented the equation determining uniquely the temperature of equilibrium of natural eclogites of more or less basaltic composition, where $K_{\text{Fe}}^{\text{ga-cpx}}$ is known with estimated pressure. If we follow the equation, the metamorphic temperature of the eclogitic rock in question will be as follows, provided the bulk composition is limited in the range of $6.2 < \frac{\text{Mg}}{\text{Mg}+\text{Fe}^{2+}} < 8.5$; that is, under 3 kb 724°C, 4 kb 731°C and 5 kb 739°C. These values are consistent with the granulite facies.

Judged from the field occurrence, there is no tectonic discontinuity between the eclogitic rock in question and the surroundings which are characterized by the mineral parageneses of the amphibolite facies. Therefore, it is probable that the rock has ever been placed under the condition of the amphibolite facies.

In this connection, it should be noted that, in the main part of the Hida Plateau, kyanite has not so far been reported, while sillimanite is sporadically distributed. The fact suggests the moderate or lower pressure condition of the metamorphism.

Having those facts in mind, the following history of development may possibly be set forth in relation to the genesis of the eclogitic rock. That is, it can be inferred that the eclogitic rock had been formed under a higher grade condition than the amphibolite facies which prevailed on a regional scale. In other words, the area in question would represent that of polymetamorphism, the rock in question being a relic of the older phase metamorphism of the granulite facies.

In this connection, the metamorphosed basic dyke offers a key. As mentioned before, the basic dyke, which cut across the gneissosity of the surrounding gneiss, has been metamorphosed to take the foliation defined by parallel arrangement of hornblende. The chemical composition of the hornblende have the character of those formed under the condition of the amphibolite facies (Fig. 18 and 19). Accordingly, it should be concluded that the granulite facies metamorphism of the older phase has been overlaid with the younger metamorphic phase of the amphibolite facies.

GREEN and RINGWOOD (1967) showed experimentally the possibility of formation of eclogitic assemblage from basaltic ones under the condition inherent to the crust. While BANNO (1965 and 1966) suggested that the assemblage of Fe-rich clinopyroxene, almandinous garnet and quartz is stable under the condition of the granulite facies so long as the ratio of $\text{FeO}/(\text{FeO}+\text{MgO})$ of the bulk chemical composition is maintained

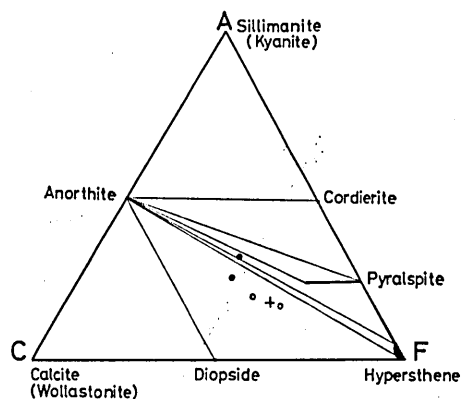


FIG. 43. ACF diagram for the granulite facies with excess SiO_2 .
Solid circles: Madras (HOWIE and SUBRAMANIAM, 1957), open circles: Adirondack (BUDDINGTON, 1952), cross: Hida metamorphic belt.

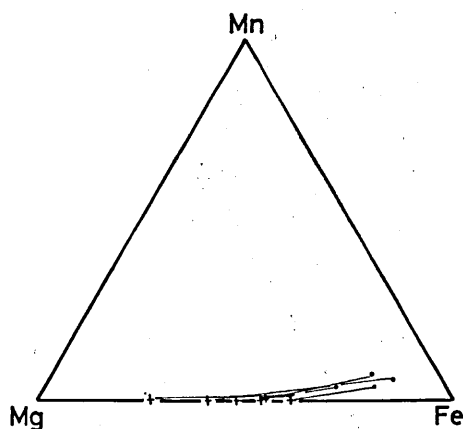


FIG. 44. Tie-lines of coexisting biotite (cross) and garnet (circle) of granulites in Bohemian massif (after MATĚJOVSKÁ, 1970).

high. In the granulite facies terrains such as Madras (HOWIE and SUBRAMANIAN, 1957) and Adirondack (BUDDINGTON, 1952) (Fig. 43), the five-phase assemblage of orthopyroxene-clinopyroxene-garnet-plagioclase-quartz was described from the rocks rich in FeO, and if the composition of the rock becomes much richer in FeO, stable association of clinopyroxene (ferroaugite)-garnet (almandine)-quartz would be expected in the granulite facies.

3. *Orthopyroxene-clinopyroxene*

As many authors discussed (MUELLER, 1960, KRETZ, 1961 and HOWIE, 1965), when orthopyroxene coexists with calcic clinopyroxene in metabasites, the partition of Mg and Fe' between these two phases is related to the condition of rock genesis. In the area concerned, orthopyroxene occurs in small amounts in company with clinopyroxene in pyroxene gneiss. Usually, however, orthopyroxene has already been altered to hornblende from the margin or along the cleavage. Therefore, it has not been succeeded to decide the metamorphic condition from the distribution of elements among the coexisting phases.

4. *Garnet-biotite*

The association of garnet with biotite in metapelites is mineralogically interesting. It has been said that the gradient of the tie-line of garnet and biotite in Mn-Mg-Fe triangle may reflect the P-T condition (MIYASHIRO, 1953 and KANO and KURODA, 1973). In general, the lower the metamorphic grade declines, the steeper the tie-line becomes. In the Abukuma Plateau, KANO and KURODA demonstrated that the tie-lines from the area II show gentler slope than in the area I. The area II was believed to be the region of polymetamorphism. In the Bohemian granulites (MATĚJOVSKÁ, 1970), the tie-lines are remarkably of gentle inclination (Fig. 44).

In Fig. 45 are shown the tie-lines of coexisting biotite and garnet from the area concerned. It is clear that their gradients are relatively of lower values. It is moreover

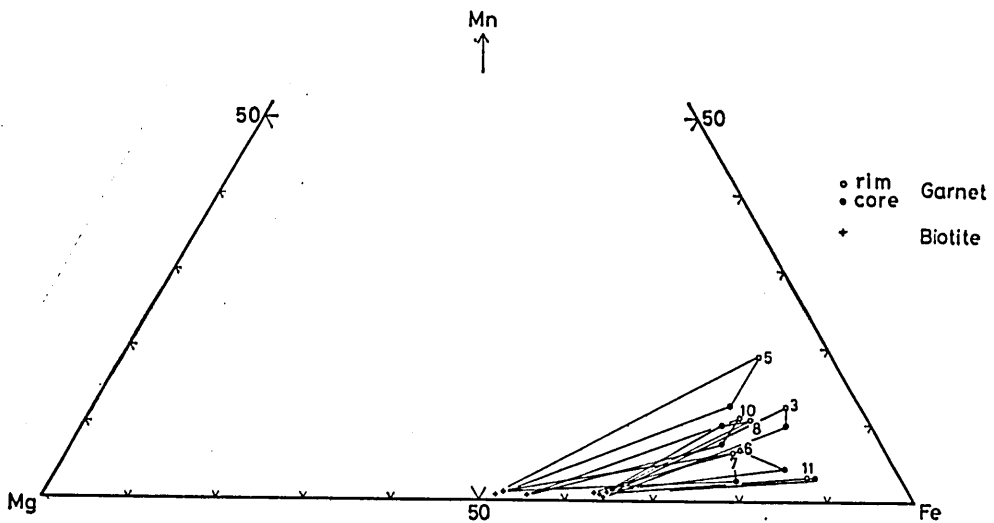


FIG. 45. Tie-lines of coexisting biotites and garnets of biotite gneiss.

interesting that, in general, the inclination of the tie-lines between biotite and the core part of garnet are gentler than those between biotite and the fringe of garnet crystal. It is probable, therefore, that the lower grade metamorphism may have happen after the older phase of higher grade one.

The distribution relation of major elements between coexisting biotite and garnet is also important. KANO and KURODA considered the apparent partition coefficients among the coexisting phases from the following three equations:

$$(Fe^{2+})_{gar} + (Mg^{2+})_{biot} = (Mg^{2+})_{gar} + (Fe^{2+})_{biot}$$

$$(Mn^{2+})_{gar} + (Fe^{2+})_{biot} = (Fe^{2+})_{gar} + (Mn^{2+})_{biot}$$

$$(Mn^{2+})_{gar} + (Mg^{2+})_{biot} = (Mg^{2+})_{gar} + (Mn^{2+})_{biot}$$

Following KANO and KURODA, the apparent distribution coefficient K' has been calculated as shown in Table 16. The results are also presented in Figs. 46 to 48. The values for Fe/Mg become smaller at the core part than at the marginal part of each garnet

TABLE 16. APPARENT PARTITION COEFFICIENTS FOR THE PAIR OF COEXISTING GARNET AND BIOTITE IN BIOTITE GNEISS.

specimen		3	5	6	7	8	10	11
Fe/Mg	core	4.34	4.57	3.54	3.46	2.39	3.29	4.70
	rim	4.99	7.22	2.53	3.71	3.16	4.22	4.59
Mn/Fe	core	10.50	24.86	2.94	1.45	6.14	14.57	2.44
	rim	13.25	36.71	4.89	4.26	6.55	21.43	2.50
Mn/Mg	core	43.96	116.10	10.24	6.57	14.61	48.20	11.44
	rim	64.14	271.24	12.21	15.43	20.73	91.09	11.58

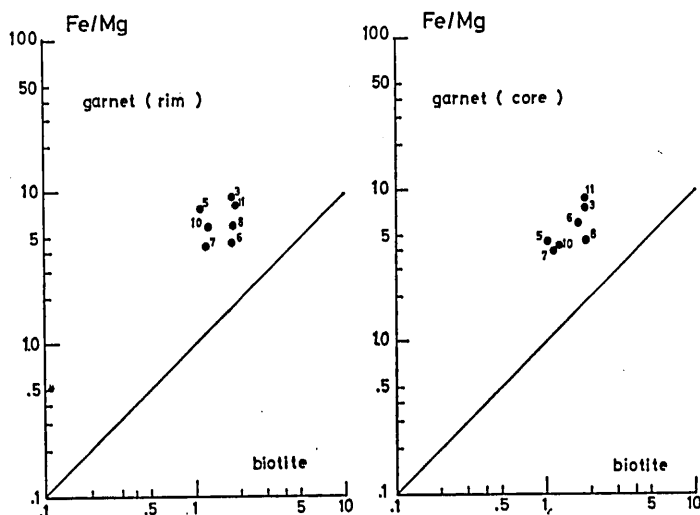


FIG. 46. Fe/Mg relation between garnet and biotite of biotite gneiss.

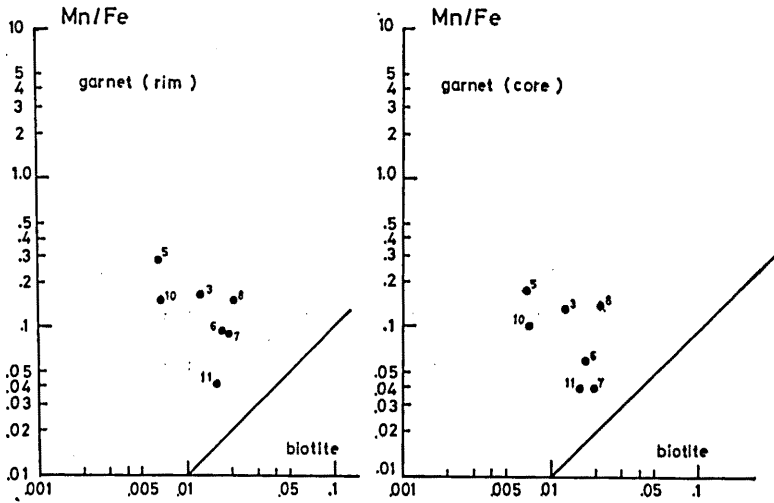


FIG. 47. Mn/Fe relation between garnet and biotite of biotite gneiss.

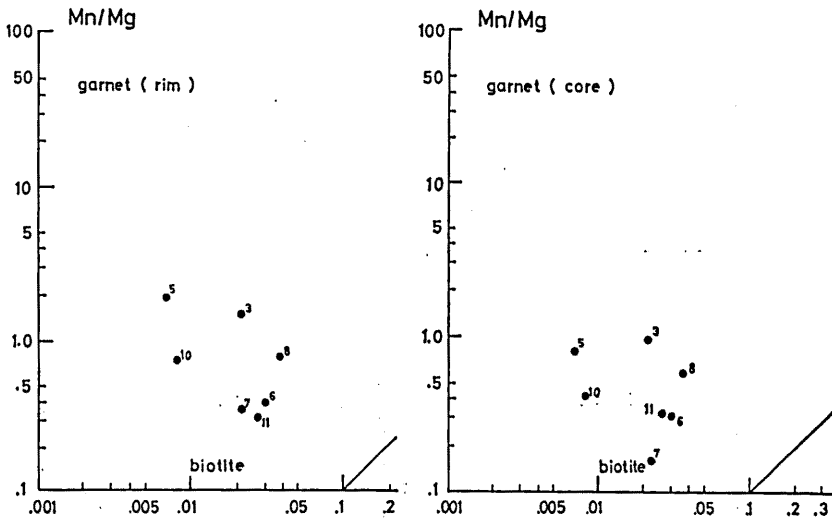


FIG. 48. Mn/Mg relation between garnet and biotite of biotite gneiss.

grain. As for the reactions of Mn/Fe and Mn/Mg, the plots are scattered in comparatively wide area. Also in these cases, the apparent distribution coefficients increase from the core part of garnet to the fringe part.

Although not certain, it may be that the partition coefficient becomes large with decreasing temperature. All are concerned, the distribution relation of major elements among the coexisting biotite and garnet in metapelites would suggest the existence of metamorphism as high as the granulite facies.

5. *K feldspar-sillimanite*

The reaction in which muscovite reacts with quartz to form K feldspar and sillimanite in metapelites is one of most important key in determining the metamorphic condition. The lower boundary of the assemblage of K feldspar and sillimanite on the map is situated on the transition zone between the granulite and the amphibolite facies in the Appalachian (THOMPSON and NORTON, 1968). While, it appears within the amphibolite facies in the Ryoke metamorphic belt, central Japan (ONO, 1969). Therefore, it seems that the association in question is stable above the upper amphibolite facies. In the area under consideration, the association of K feldspar and sillimanite is stably observed in metapelite, although muscovite has been formed retrogressively.

6. *Scapolite-plagioclase*

In lime-silicates gneiss, calcic plagioclase coexists with scapolite. As already mentioned, the An value in plagioclase exceeds the Mcionite value in coexisting scapolite (Fig. 39). The metamorphic condition has been suggested from the facts to be as high as the granulite facies.

B. Mineralogical characteristics

Some of metamorphic minerals reflect sensitively the metamorphic condition on their composition. Several representative examples will be enumerated.

1. *Amphiboles*

As shown in Chapter IV-B, based on the chemical composition of hornblende, the metamorphic condition in the area can be graded up as high as the granulite facies. The specimens with zonal structure of amphiboles have suggested the history of retrogressive metamorphic process from the granulite facies to the amphibolite facies and lower.

It is also noteworthy that the metamorphosed basic dyke has hornblende with the composition suggesting the formation under the amphibolite facies. Hornblendes are always mantled with colourless amphiboles, with high values in Si content, plotted in the actinolite field (Fig. 18). These may be the latest stage metamorphic products.

2. *Garnet*

In the area concerned, the composition of garnets in metapelites suggests the formation condition of amphibolite to granulite facies, while that of garnets in calcareous and basic gneiss does not distinctly reflect the metamorphic condition.

It is also note that garnets with distinct zonal structure have higher content of MnO in the periphery part, in contrast to the lower content of MgO, than the core part. This indicates the complicated metamorphic history in the area, from higher grade metamorphism to the lower.

3. *Plagioclase*

Anorthite mole percent in plagioclase from various kinds of gneisses in the studied area is, in general, higher than that in the metamorphites from the amphibolite facies terrains in the world (BUDDINGTON, 1963), suggesting the metamorphic condition under at least high amphibolite facies, perhaps as high as the granulite facies.

C. Metamorphic condition

Summarizing above descriptions, the condition of metamorphism of the terrain under consideration can be inferred as follows.

It should be emphasized that there are observed some critical mineral assemblage of the granulite facies of metamorphism. For example, K feldspar-corundum gneiss, pyroxene gneiss and eclogitic rock can be mentioned. Moreover, mineralogical characters of such minerals as hornblende, garnet and plagioclase suggest also the granulite facies. In addition hornblende and garnet show distinct zoning, suggesting a complex history of metamorphism. The core part of the crystals has, in general, chemical composition suggesting higher grade metamorphic condition than the rim part.

From these facts in mind, the metamorphism of the Hida belt under consideration can be divided into at least two phases, the one of the granulite facies and another of the amphibolite facies. The essential problem is how the time and spatial relationships between the two metamorphic phases are. The problem will be discussed in detail in the following chapter.

It should also be noted that the gneisses show more or less migmatitic appearance.

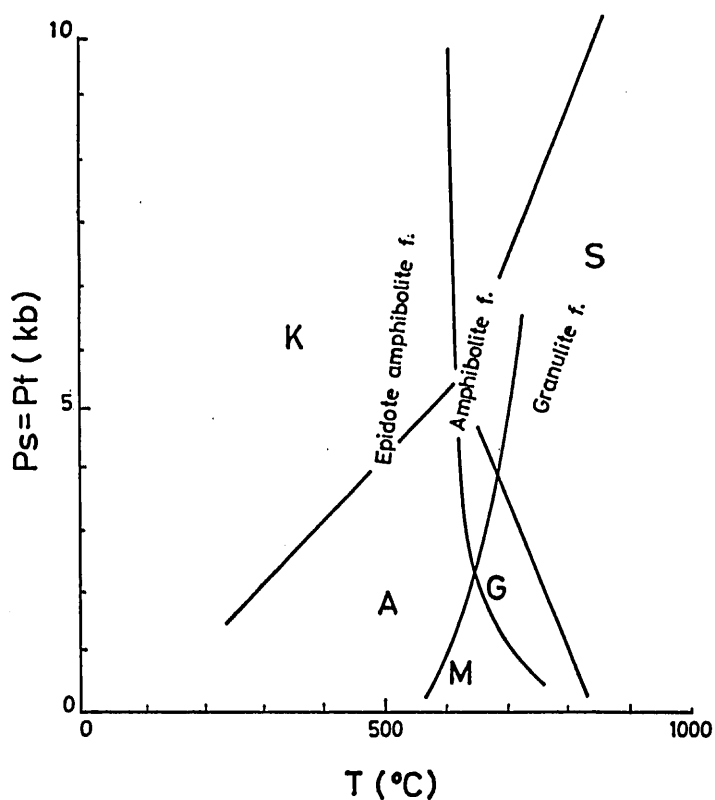


FIG. 49. Temperature and pressure of metamorphic facies of the Hida metamorphic belt. Abbreviations are as follows: K; kyanite, S; sillimanite, A; andalusite, G; beginning of melting of granite, M; decomposition curve of muscovite.

Leucocratic bands develop widely and frequently throughout the area in question. It suggests the presence of the metamorphic condition of as high as the upper temperature side of the melting curve of granitic composition (Fig. 49).

VII. TIME AND SPATIAL RELATIONSHIP BETWEEN THE METAMORPHISM OF THE GRANULITE FACIES AND THAT OF THE AMPHIBOLITE FACIES

A. Time relationship

In the Hida metamorphic belt under consideration, metamorphic rocks suggesting the granulite facies occur forming so to speak "islands" in the "sea" of the amphibolite facies metamorphites. In Japan, rocks of the granulite facies have hitherto been reported from a few localities in the Hida metamorphic belt including the Oki islands and the Kurosegawa tectonic belt.

Two cases can be discriminated about the relation of the amphibolite facies and the granulite facies metamorphisms, that is,

- 1) progressive change from the amphibolite facies to the granulite facies (such as in Adirondack and Broken Hill).
- 2) overlapping of two phases of metamorphism, namely, polymetamorphism (such as in Ceylon).

In Adirondack Mountains, progressive changes in mineral assemblage from the amphibolite facies to the granulite facies are observed and it is possible to draw isograds (BUDDINGTON, 1963 and 1965). They are marked in the order of increasing grade by 1) disappearance of titanite in amphibolite, 2) appearance of abundant diopside in amphibolite and disappearance of muscovite to almandine plus K feldspar and 3) appearance of hypersthene marking the entrance into the granulite facies. On the other hand, in the Central Highlands of Ceylon, COORAY (1961 and 1962) postulates two major Archean phases of metamorphism. The earlier one, of the granulite facies, is preserved almost undisturbed in the Highlands series. The bordering zone of Vijayan migmatitic gneiss is, however, interpreted as products of the second regional metamorphism, which is suggested from the mineral assemblage of the amphibolite facies. Therefore, the overlapping of two phases of metamorphism has been inferred. Recently, the same author (1972) also suggests local heterogeneity with respect to P_{H_2O} , resulting in close association of the amphibolite facies metamorphites and charnockite.

In the case of the studied area, the possibility of progressive metamorphism from the granulite to the amphibolite facies would be denied, because no isograds can be drawn and there seems to exist no such a simple thermal structure that the amphibolite facies rocks progressively grade into the granulite facies ones. Accordingly, it should be assumed that the earlier metamorphic rocks of the granulite facies have been locally preserved among the rocks of the amphibolite facies of the later metamorphic phase.

Summarizing the petrographical and mineralogical data described above, following points should be noticed.

- 1) Such gneisses as pyroxene gneiss, K feldspar-corundum gneiss and eclogitic rock show critical mineral associations for the granulite facies metamorphism. These gneisses occur conformably to the surrounding gneisses on the outcrop. In addition, it is remarkable that some of these granulite facies rocks have exceptionally peculiar chemical composition among the Hida metamorphites. The granulite facies rocks have underwent

intense retrogressive metamorphism to result in the association containing hydrous phases at the expense of anhydrous ones.

2) The retrogressive change is observed ubiquitously over the area concerned. Brownish hornblendes have always been altered to green and pale green amphiboles from the margin or along the cleavage. The core part of some hornblende crystals have the chemical composition consistent with the granulite facies. These facts also indicate the retrogressive transformation. Likewise, garnet shows distinct zoning, the core part being higher in MgO than the rim part. This fact would also suggest the presence of higher grade metamorphism before the rim part has been changed retrogressively.

3) In most gneisses, K feldspar is now represented by microcline with clear appearance. It is noted that its chemical composition shows a narrow range throughout various kinds of gneisses.

Now, it should be considered what the time and spatial relationships are between the metamorphism of the granulite facies and that of the amphibolite facies. Concerning to that, the metamorphosed basic dyke would furnish a key to solve the problem.

B. Meaning of the metamorphosed basic dyke

A metamorphosed basic dyke occurs by the eclogitic rock at the Tsukigase area. The basic dyke, about 30 cm in width, has intruded across the gneissosity (Fig. 6). The dyke has its own foliation characterized by the parallel arrangement of hornblende, suggesting the metamorphism of the dyke under the condition of the amphibolite facies. In addition, the hornblende of the dyke would correspond to the hornblende mantle around clinopyroxene in the surrounding gneisses and the eclogitic rock. Furthermore, the hornblende both from the basic dyke and the surrounding gneiss have been mantled by pale-green to colourless amphiboles. Consequently, the following history can be conceived as to the metamorphosed dyke: that is,

- 1) intrusion across the gneissosity,
- 2) metamorphic recrystallization under the amphibolite facies on a regional scale, and
- 3) formation of pale-green to colourless amphiboles.

Therefore, the dyke must have been intruded after the formation of regional gneissosity and before the metamorphism of the amphibolite facies. In other words, the area in question represents a region of polymetamorphism, the metamorphic grade of the older phase being of the granulite facies, while the younger the amphibolite facies. Foliation of the basic dyke is generally E-W, while that of the surrounding gneisses, including the eclogitic rock, is N-S, the former being the earlier and the latter the later.

In this connection, special attention should be paid on the "gray-granite". It is characteristically distributed through the Hida metamorphic belt, especially in the western part, occurring not as large bodies but frequently as small sheet- or dyke-like masses, concordantly as well as discordantly with respect to the gneissosity. Some of them show foliation characterised by the arrangement of biotite, which is parallel to the surrounding gneissosity. It may have formed during the later phase of metamorphism. The author believes that the gray-granite, if not all, but at least in part, is the anatectic product in the granulite facies metamorphism. The variety of gray-granite, intruded obliquely to the gneissosity, may represent the reactivation in the later phase.

Lastly, it must also be mentioned that such hysterogene minerals as chlorite, epidote, calcite and pale-green to colourless amphiboles are widely distributed. Prehnite veins

Polymetamorphism in the Hida Metamorphic Belt, Central Japan

also found. Most of them suggest the alteration under the condition of the greenschist facies. Geological specification of this phase of alteration cannot be determined.

C. Metamorphic history

The metamorphic history of the region in question will be summarized as follows. As the oldest phase of metamorphism, that including the granulite facies metamorphism can be discriminated, during which the following critical minerals were produced; that is, orthopyroxene-clinopyroxene-brown hornblende (pyroxene gneiss), K feldspar-corundum, clinopyroxene-almandine-quartz (eclogitic rock), sillimanite-garnet-Kfeldspar-plagioclase-biotite (pelitic gneiss), scapolite-plagioclase (lime-silicates gneiss), hornblende-clinopyroxene-plagioclase (basic gneiss), wollastonite-clinopyroxene-plagioclase ("syenitic rock of the Inishi type) etc..

Most of the gray-granites, which are distributed ubiquitously, may have been produced as the result of partial melting from the gneisses.

Afterwards, the metamorphism up to the amphibolite facies took place. Pyroxenes have been altered to hornblende, orthoclase to microcline and the assemblages K feldspar-corundum and sillimanite-K feldspar to muscovite. Minerals also have changed their composition to those stable in the amphibolite facies. Some minerals formed by the first metamorphism escaped the later alteration. Basic dyke intruded after the first metamorphic phase has been metamorphosed to show foliation. Migmatization is also believed to have occurred during the second metamorphism. Remobilization of a part of the gray-granite is assumed.

There are distributed two types of granitic rocks of post-kinematic character, the one being porphyritic and another the so-called "Funatsu type". The former is also incorporated in the "Funatsu type" granite by some authors. The porphyritic granite is partly deformed to mylonite, including augen gneiss. The "Funatsu type" granite in a narrow sense is massive in appearance, and seems to have been intruded later than the porphyritic granite. Mylonitic features are hardly observed. These granites would have related to block movement of the Hida belt.

D. Chronology of the Hida metamorphism

One of the most attractive themes on the Hida metamorphic belt is the age problem. The problem has been approached from two standpoints; that is, the geological relationship between the gneisses and the Paleozoic formations and the absolute age determination.

As for the former problem, there is the opinion that gneisses have metamorphosed from Paleozoic formations in the Mesozoic age (T. KOBAYASHI, 1941). NOZAWA (1959) have a view that the Hida gneisses have been formed closely related to the igneous activity of the Funatsu granite in the early Mesozoic.

On the other hand, the view that they were formed in the Precambrian are maintained by many investigators (FUJIMOTO et al., 1962, H. KANO, 1973 and MINATO et al., 1965). A basis of this argument is that the Paleozoic Group to the south of the Hida belt becomes thinner and changes its character gradually to neritic one towards the Hida belt. The controversy has been summarized by SUWA (1972).

With this problem in mind, the Hida belt can be divided into three units, i.e., eastern, central and western areas.

The eastern area is unique in its original rock species, metamorphic facies and the type of metamorphism in comparison. For example, there occur leptite-like rocks derived from acidic volcanics. A vast amount crystalline limestone is also distributed. The metamorphism is somewhat higher pressure type, as suggested by the presence of kyanite and staurolite. On the other hand, in the central and western areas lower pressure type metamorphites develop. Metamorphites of the eastern area show some similarity to those of the Arashima-dake area, where staurolite stably exists (ASAMI and ADACHI, 1973). It must be noted that the eastern area as well as Arashima-dake area are situated along the "outer (southern) side" of the Hida gneiss belt, where the Funatsu granite has been intruded.

Next, the data of absolute age determination will be discussed. Since 1960, absolute

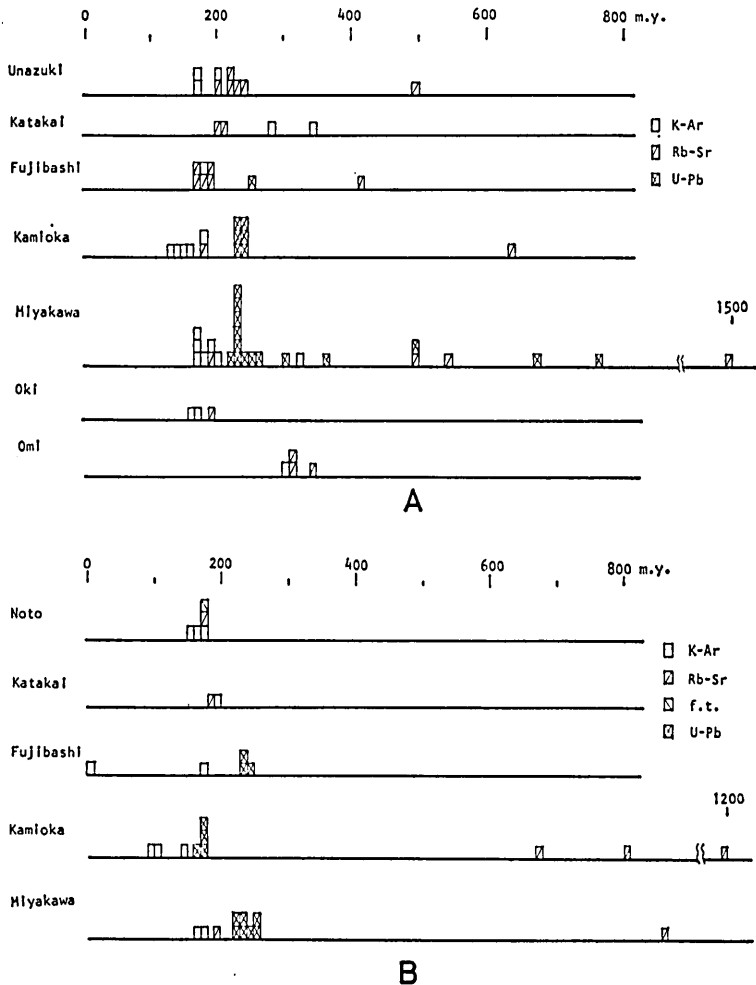


Fig. 50. Histograms of isotopic ages of Hida metamorphites (A) and granites (G). Data are mainly based on NOZAWA (1968 and 1972) and SHIBATA et al. (1970). f. t. means fission track method.

Polymetamorphism in the Hida Metamorphic Belt, Central Japan

age determination on the basis of radioisotope ratios has progressed on Hida gneisses and granites. The results were summarized by NOZAWA (1968 and 1972) and SHIBATA et al. (1970). Based on their works, Fig. 50 gives the histograms of isotopic ages of the metamorphites and granites of the Hida belts, including the Omi area in the so-called Hida marginal belt. It is shown that ages are scattered in a wide range from 100 to 1500 m.y.. Precambrian events, if present, may be represented by such ages as about 1500 m.y. (YAMAGUCHI, 1967) for metamorphites and a Rb-Sr age of about 1200 m.y. (SATO et al., 1967) for the granite. There are four age clusters around 500 m.y. (Ordovician), 320 m.y. (Carboniferous), 240 m.y. (Permian) and 180 m.y. (Jurassic). Among them the youngest cluster is most distinct and widely distributed throughout the Hida terrain. That would indicate the phase of metamorphism, with which associated the Funatsu granite. It may be noted that older ages, both of metamorphites and of granites, are clustered mainly on the western area of the belt.

It should be mentioned that the age of a gneiss from Amo shows peculiarities. According to YAMAGUCHI (1967), the gneiss has the mineral association of graphite-garnet-hornblende-diopside and its Rb-Sr isochrone age is 490 m.y., while Pb_{207} - Pb_{208} age of the detrital zircon is 1493 m.y.. Judged from the locality and petrographical character of the gneiss mentioned by him, it should coincide with the pyroxene gneiss after the present author, formed by the older granulite facies metamorphism, modified by the later amphibolite facies one. Therefore, it can be conceivable that the age of the granulite facies metamorphism is not so younger than at least 500 m.y.*. Furthermore, it is also possible that the age of 500 m.y. represents a mixed age, and that the older phase of metamorphism would go back to the Precambrian. In this connection, it should be noted that ADACHI (1971 and 1973) and SHIBATA et al. (1971, 1972 and 1974) have measured the age of pebbles of metamorphites and granites in the Permian (to Triassic) Kamiaso conglomerate with the result of Rb-Sr isochrone ages, the oldest representatives of which are 1985 and 1820 m.y.. According to them, the rocks can be correlatable to the Matenrei and Nangnim systems in North Korea, and the provenance of the pebbles is believed to have been situated to the north not far from the present site of the Kamiaso conglomerate, which is now cropped out about 80 km south of the southern border of the Hida belt.

The problem about the age of newer metamorphism of the amphibolite facies has been rather confused as to the relation between the regional nature of the metamorphism and the intrusion of the so-called Funatsu granites. According to the present author, there seems to exist no direct relationship between the grade of metamorphism including migmatization and the distribution of the Funatsu granites. The Funatsu granites may not be the type of syntectonic granite to cause migmatization on a large scale but the post-kinematic type, intruded along with block movement, locally giving the thermal effect. Therefore, it is also possible to correlate the age of the amphibolite facies metamorphism with the age cluster of 300 m.y.*, than with that of the Funatsu plutonism of around

* The age of 500 m. y. is a significant one in the Hida terrain. YAMAGUCHI et al. (1968) gives 496 m. y. (Rb-Sr age) for the "leptite", and concluded that this age shows the eruptive event of the original acidic volcanics.

* The age is very close to that of the Omi schists in the Hida marginal belt. The amphibolite facies metamorphism of low pressure type of the Hida belt proper may form a pair with the higher pressure type of metamorphism in the Hida marginal belt.

180 m.y.. If this can be allowed, the mineral age of muscovite around the corundum megacryst in K feldspar-corundum gneiss, which was newly determined by Dr. Ken SHIBATA to give the K-Ar age of 183 m.y., can be regarded as representing the later retrogressive metamorphism. Determinations of age on some specimens from the area in question have been made (SHIBATA and SUZUKI, in prep.), but the data are too complicated to interpret the meaning. All are concerned, the metamorphic history in the Hida metamorphic belt is summarized as in Table 17.

Precambrian rocks are widely developed in the eastern part of the Asian continent, especially in North China and Korea. Because of the deficiency in detailed geological data of the Asian continent and the Japanese Islands, it is not easy to settle the geologic relationship between them. There could exist, however, some possibilities to consider that Precambrian continent exists, which is possibly now hidden under the present Japanese Islands and the Japan Sea.

TABLE 17. METAMORPHIC HISTORY IN THE HIDA METAMORPHIC BELT.

100 m.y.	Mylonitization		
200	Greenschist facies metamorphism	Activity of Funatsu granite	
300	Amphibolite facies metamorphism and migmatization		Medium-high P metamorphism in Omi
400		Intrusion of basic dyke	
500	Granulite facies metamorphism	Formation of gray granite	Acidic volcanism in Unazuki
	Sedimentation of original rocks		

VIII. CONCLUSION

In this paper, metamorphic and granitic rocks in the Hida metamorphic belt in Central Japan have been described with the following results:

1) On the southwest of the belt, quartzo-feldspathic, calcareous, basic, psammitic and pelitic gneisses are widely distributed. These rocks have been described petrographically.

2) Chemical characters of main metamorphic minerals, such as pyroxenes, amphiboles, garnets, feldspars and micas etc., have been analysed by using EPMA.

3) Judged from the chemical characters of minerals, the distribution relation of characteristic mineral pairs and the critical mineral associations, the metamorphic rocks of the area are revealed to have suffered two types of metamorphism, the one being of the granulite facies, another of the amphibolite facies.

4) The time and spatial relationships of the granulite facies metamorphism and the amphibolite facies one have been discussed. The presence of polymetamorphism has been clarified.

5) By summarization of the data of radiometric ages of the Hida metamorphic and granitic rocks, each metamorphic phase has been correlated to the cluster on the histograms of determined ages. The granulite facies metamorphism would not be younger than at least 500 m.y..

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INSTITUTE OF GEOLOGY AND MINERALOGY
 FACULTY OF SCIENCE, HIROSHIMA UNIVERSITY
 HIROSHIMA, JAPAN

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APPENDIX 1: SAMPLE NUMBERS AND LOCALITIES OF STUDIED SPECIMENS.

Symbol	Sample No.	Locality	Symbol	Sample No.	Locality
Pyroxene gneiss			Hörnblende-clinopyroxene gneiss		
P-1	67V0709	Hane-Valley	H-1	69X7-5	Idani
P-2	67V0602	Hane	H-2	69X6-3	Hayashi-Valley
P-3	67V1903	Genda-Valley	H-3	68V04	Hane-Valley
P-4	67V2201	Aramachi	H-4	68V25	Shinmyo
P-5	67VII0402	Kurobuchi	H-5	67V1616	Jyogashima-Valley
P-6	68VII3105	Tsukigase	H-6	70VI6-3	Amo
P-7	68VII3112	Tsukigase	Basic migmatite		
Eclogitic rock			M-1	71X8-10	Kamiasagara-Valley
E	69X4-9	Tsukigase	M-2	67V1819	Kamiasagara-Valley
Potassium feldspar — corundum gneiss			M-3	67V1929	Genda-Valley
K	67X0802	Hane-Valley	M-4	71IX8-12	Southeast of Tsukigase
“Syenitic rock” of the Inishi type			M-5	70IX8-3	Shimoodori Dam
I-1	67V0808	Jyogashima-Valley	M-6	71IX9-4	Ho
I-2	67V1824	Kamiasagara-Valley	Crystalline limestone		
I-3	67V1928	Genda-Valley	C-1	72VII0402	Hane-Valley
I-4	67V0515	Ho	C-2	71VI0118	Jyogashima-Valley
Biotite gneiss			Lime-silicate gneiss		
B-1	67V2408	Amo	L-1	68V08	Hane-Valley
B-2	67V1922	Genda-Valley	L-2	67V1710	Kara-Valley
B-3	67IV2902	Omukari	L-3	67V2334	Kurobuchi
B-4	67V0601	Hane	Metamorphic basic dyke		
B-5	67V1811	Kamiasagara-Valley	D	72X3-15	Tsukigase
B-6	67V2701	Shimoasagara-Valley	Gray granite		
B-7	67V2335	Kurobuchi	G-1	68V12	Hane-Valley
B-8	67VII1802	Shinmyo	G-2	68V03	Hane-Valley
B-9	69X0402	Tsukigase	G-3	67V1414	Jyogashima-Valley
B-10	70X0609	West of Amo	G-4	67V1507	Kara-Valley
B-11	71IX1112	Mizunashi			

APPENDIX 2: LOCALITY MAP OF STUDIED SPECIMENS.

