STAUROLITE-BEARING CORDIERITE-SILLIMANITE GNEISS FROM THE TOGA AREA IN THE HIDA METAMORPHIC TERRANE, CENTRAL JAPAN

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Abstract

Staurolite was found in the cordierite-sillimanite gneiss from the Toga area, the northern central part of the Hida metamorphic terrane. The metamorphic rocks consist mainly of the following three: (1) biotite gneisses often with sillimanite, cordierite, garnet and andalusite, (2) marble and banded limestone with or without garnet, wollastonite and clinopyroxene, and (3) biotite-hornblende gneiss; they occur as a block largely enclosed with a biotite adamellite-granodiorite intrusion.

The staurolite-bearing gneiss prevails considerably within the metapelites in this area, although the modal amount of staurolite is small. Staurolite, exhibiting almost constant optics throughout the specimens, is intimately associated with quartz, plagioclase, biotite, sillimanite, cordierite, ilmenite and magnetite, and often with garnet and/or andalusite; peculiar textures suggestive of disequilibrium relations between staurolite and the other constituents are not observable. It is also notable that muscovite is absent or scarce and potassium feldspar is lacking in the staurolite-bearing gneiss.

Chemical analyses of three staurolite-bearing gneisses, two with garnet and the other without garnet, and a cordierite-sillimanite gneiss without staurolite are presented; they show a characteristic deficiency in K_2O . The staurolite-bearing gneisses are lower in the

$MgO/MgO+FeO-Fe_2O_3$ molecular ratio than the staurolite-free gneiss, and the staurolite-bearing gneisses with relatively high manganese content carry garnet rich in spessartine, suggesting that the manganese is concentrated in garnet.

Based on the mineral association and the petrochemical characters, it seems likely that the assemblage staurolite-cordierite-sillimanite is of the highest grade in the staurolite-bearing rocks formed under the intermediate pressure condition comparable to the Buchan-type metamorphism.

The geologic meanings of the staurolite-bearing gneiss with respect to the Hida metamorphism is also discussed.

Introduction

It was more than a quarter of a century ago that ISHIOKA (1949) first documented an occurrence of staurolite schist from the Kurobe-gawa area in the Hida metamorphic terrane. Another occurrence of staurolite-bearing rocks in this terrane, however, had been unknown up to the time when ASAMI (1972) found a staurolite-bearing schist in the Arashimadake area, southwestern Hida plateau. Subsequently to these works, we found staurolite in a cordierite-sillimanite gneiss in the Toga area*** (ASAMI and ADACHI, 1974), where metamorphic rocks of pelitic composition are widely developed. The presence of staurolite has not been suspected up to this time,

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*** Although this area has popularly been called the Kōshimizu district, the time-honored name would not be used in this paper because Kōshimizu is now a ghost town.

because this metamorphic area is characterized by sillimanite gneiss and cordierite-sillimanite gneiss (KOBAYASHI, 1954).

Staurolite has been regarded as one of the index minerals in the regionally metamorphosed pelitic rocks formed under the intermediate P-T conditions; recently such conditions have been also experimentally analyzed with respect to geologically conceived reactions involving staurolite (RICHARDSON, 1968; HOSCHEK, 1969; GANGULY, 1972).

In the Hida metamorphic terrane, it is known that most parts are occupied with high-grade gneisses, migmatites and associated granitic rocks. The characteristics of the Hida metamorphism are still obscure, although considerable studies on the metamorphic complex have been made up to now. A new occurrence of staurolite in association with cordierite and sillimanite in the Toga area will give us key evidence to enlarge our knowledge on the Hida metamorphism.

We here describe a staurolite-bearing gneiss and related rocks, and briefly discuss some geological meanings chiefly from the petrographic standpoint. Detailed petrology and mineralogy under study will be reported in the near future.

General geology

The Toga area, about 30 km southwest of Toyama city, occupies the northern central part of the Hida metamorphic terrane. The geologic map of this area is shown in Figure 1. The metamorphic rocks form a north-south elongated block (about 5×2 km) which is largely enclosed with a massive to feebly foliated, medium-grained biotite adamellite-granodiorite intrusion, called the Funatsu-type granite (FUJII *et al.*, 1970). Tertiary sediments consisting mainly of tuff breccia cover unconformably these basement rocks here and there. Thermal effect of the granitic mass on the metamorphic rocks is generally inconspicuous as far as observed in the field and under the microscope.

Macroscopically the metamorphic rocks are grouped in three rock types; pelitic gneisses, crystalline limestone and basic gneisses. They occur as thick layers apparently from several

tens to several hundreds meters, thin interbedded layers of a few meters being occasionally developed. Gneissose structure of the metamorphics generally shows the northwest-southeast trends in the western side of a fault running north-south in the central part of the mapped area and the northeast-southwest trends in the eastern side of the fault. Generally the gneissose structure inclines steeply toward the north.

As shown in the geologic map (Fig. 1), there can be found three thick layers of pelitic gneisses, in all of which the staurolite-bearing gneiss was found. The pelitic gneisses are commonly dark gray, ill-foliated, fine- to medium-grained biotite gneisses often with garnet and sillimanite. Accompanied by the pelitic gneisses, cummingtonite gneiss, a description of which was given by KOBAYASHI (1954), occurs rarely as thin layers.

Crystalline limestone is composed mainly of white to light gray, massive, medium- to coarse-grained calcite marble with a subordinate amount of banded limestone. Thin layers and lens-like bodies of skarn, calc-silicate gneiss and amphibolite are occasionally intercalated in marble. Small lenses of calcsilicate gneiss are also found in pelitic gneisses.

Basic gneisses consist mainly of dark green, medium-grained biotite-hornblende gneiss and minorly of hornblende gneiss which have feldspathic bands alternating with hornblende-rich ones. Locally there are thin layers of fine-grained biotite-hornblende gneiss in pelitic gneisses, and are thin layers and small lenses of medium-grained amphibolite in biotite-hornblende gneiss and marble. Garnet amphibolite is rarely found as thin layers, associated with cummingtonite gneiss.

Petrography

1. Outline of the metamorphic rocks

(A) Pelitic gneisses

Pelitic gneisses, along with calcareous rocks, make up a substantial part of metamorphic rocks in the Toga area. They consist mainly of garnet-biotite gneiss, biotite gneiss and staurolite-bearing cordierite-sillimanite-biotite gneiss with or without garnet and andalusite, and minorly of garnet-sillimanite-biotite gneiss,

Fig. 1. Geologic map of the Toga area.

cordierite-sillimanite-biotite gneiss, cordierite-garnet-biotite gneiss, cordierite-biotite gneiss, staurolite-bearing garnet-biotite gneiss, quartz-feldspathic garnet-biotite gneiss and garnet-cummingtonite-biotite gneiss. There is a rare occurrence of graphite-muscovite-corundum-potassium feldspar-plagioclase-biotite gneiss*.

In these gneisses except for the corundum gneiss, quartz and plagioclase are ubiquitous

* A gneiss with similar assemblage was also reported from the Odori-gawa area of the Hida terrane (SUZUKI and KOJIMA, 1970).

constituents, and ilmenite, magnetite, graphite, rutile, zircon and apatite are found as accessories. Generally plagioclase is calcic oligoclase although the mineral in cummingtonite gneiss is more calcic. Brown to greenish brown variety of biotite is common. Garnet is usually found as rounded porphyroblast. In some specimens sillimanite occurs as large bundle. Cordierite is allotriomorphic, non-porphyroblastic crystal in which twinning is rare. Andalusite is sometimes found in the sillimanite-bearing gneisses. Graphite predominates in some garnet-biotite gneiss.

Tabular muscovite is rarely present in association with biotite in the pelitic rocks exclusive of the garnet-cummingtonite-biotite gneiss. Minute grains of green spinel are rarely enclosed within large porphyroblasts of sillimanite. Either garnet or biotite is sometimes lacking in cummingtonite gneiss. Potassium feldspar is very rare in the pelitic gneisses; it has been found only in three specimens of such gneisses as garnet-sillimanite-biotite gneiss, quartzo-feldspathic garnet-biotite gneiss and corundum-biotite gneiss.

Detailed description of the staurolite-bearing gneiss will be given later.

(B) Crystalline limestone and related rocks

Dominant calcareous rock is calcite marble, which sometimes has a small amount of graphite, clinopyroxene or wollastonite. The mineral associations of banded limestone and calc-silicate rock developed in marble are: wollastonite-quartz-clinopyroxene, wollastonite-clinopyroxene-calcite, garnet-wollastonite-clinopyroxene-quartz, clinopyroxene-garnet-plagioclase-epidote and plagioclase-clinopyroxene-quartz. Calc-silicate lens encountered in pelitic gneisses consists of quartz, garnet, epidote and calcite. These rocks often include a small quantity of sphene.

(C) Basic gneisses

Biotite-hornblende gneiss and minor hornblende gneiss, amphibolite and garnet amphibolite make up metabasites in this area. Biotite-hornblende gneiss, hornblende gneiss and amphibolite are characterized by the assemblage of green hornblende-plagioclase-brown biotite-quartz, and contain accessory sphene, apatite, magnetite and rarely epidote. Plagioclase is usually andesine. Some amphibolites in marble carry clinopyroxene. Garnet amphibolite is composed of green hornblende, quartz, plagioclase and porphyroblastic garnet, occasionally with epidote or cummingtonite.

2. Staurolite-bearing gneiss

The rock is light gray to dark brownish gray in color and shows gneissic structure (Plate I-A). It occurs as layers concordant with the other pelitic gneisses; localities of the staurolite-bearing gneiss are shown in Figure 1. In many cases it is garnetiferous.

Gneissose texture is stressed by sub-parallel alignment of sillimanite prisms or bundles and of biotite flakes in the matrix composed of feebly elongated plagioclase, quartz and cordierite.

Mineral assemblages in the staurolite-bearing gneiss can be divided into the following three. Minerals are arranged approximately in order of decreasing abundance, and the minerals not always present are parenthesized.

- (1) Quartz-plagioclase-biotite-garnet-sillimanite-cordierite-staurolite (-andalusite, -muscovite)
- (2) Quartz-plagioclase-biotite-sillimanite-cordierite-staurolite (-andalusite, -muscovite)
- (3) Quartz-plagioclase-biotite-garnet-staurolite (-graphite)

Ilmenite, magnetite, zircon and apatite are common accessories, while rutile and tourmaline are rather rare. The first assemblage is the most common and the third one is rare. In the gneiss with the third rare assemblage, a very small amount of staurolite is found only as minute poikilitic inclusions in garnet porphyroblasts. The following description is of the rocks with the former two assemblages.

Optical and X-ray data for the main constituent minerals in eight staurolite-bearing gneisses, (1)—(8), together with a staurolite-free sillimanite-cordierite gneiss, (9), are listed in Table 1.

Staurolite appears in a minor amount as hypidiomorphic to idiomorphic equant or short prismatic crystals, less than 0.5 mm in diameter, associated frequently with biotite, cordierite, quartz and plagioclase, occasionally with sillimanite, garnet, andalusite and ore minerals (Plate I—B, C and Plate II). It is often enclosed in biotite and cordierite, and occasionally intergrown with sillimanite needles. So far as observed, peculiar textural evidence suggestive of reaction relations between staurolite and the other constituents has not been detected. Pleochroism with $X=Y$ =pale yellow and Z =light golden yellow is characteristic. Refractive indices are $\alpha=1.738$ — 1.740 , $\beta=1.744$ — 1.746 and $\gamma=1.750$ — 1.753 . Optic axial angles are almost constant throughout the specimens in a range of 83° to 87° over Z with a dispersion $r>v$. The staurolite

Table 1. Optical and X-ray data for the minerals in eight staurolite-bearing gneisses and a staurolite-free cordierite-sillimanite gneiss from the Toga area.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Staurolite	X = pale yellow Y = pale yellow Z = light golden yellow $\alpha = 1.738$ $\beta = 1.744$ $\gamma = 1.750$ $2V_z = 83^\circ - 85^\circ$ $r > v$	X = pale yellow Y = pale yellow Z = light golden yellow $\alpha = 1.740$ $\beta = 1.745$ $\gamma = 1.752$ $2V_z = 83^\circ - 84^\circ$ $r > v$	X = pale yellow Y = pale yellow Z = light golden yellow $\alpha = 1.740$ $\beta = 1.745$ $\gamma = 1.752$ $2V_z = 84^\circ - 87^\circ$ $r > v$	$\beta = 1.552$ $2V_x = 74^\circ - 76^\circ$	n. d.	X = pale yellow Y = pale yellow Z = light golden yellow $\alpha = 1.740$ $\beta = 1.746$ $\gamma = 1.753$ $2V_z = 83^\circ - 86^\circ$ $r > v$	X = pale yellow Y = pale yellow Z = light golden yellow $\alpha = 1.740$ $\beta = 1.746$ $\gamma = 1.753$ $2V_z = 83^\circ - 85^\circ$ $r > v$	n. d.	—
Cordierite	pinitized	pinitized	pinitized	$\beta = 1.552$ $2V_x = 74^\circ - 76^\circ$	pinitized	$2V_x = 73^\circ - 75^\circ$	$2V_x = 75^\circ - 77^\circ$	$2V_x = 71^\circ - 73^\circ$	$2V_x = 71^\circ - 73^\circ$
Garnet	$n = 1.816$ $a = 11.536 \text{ \AA}$ $4.18 < D < 4.25$ (Al78 Py8 Sp14)	$n = 1.818$ $a = 11.532 \text{ \AA}$ $4.18 < D < 4.25$ (Al82 Py8 Sp10)	$n = 1.817$ $a = 11.534 \text{ \AA}$ $4.18 < D < 4.25$ (Al80 Py8 Sp12)	$n = 1.814$ $a = 11.541 \text{ \AA}$ $4.18 < D < 4.25$ (Al71 Py9 Sp20)	$n = 1.817$ $a = 11.537 \text{ \AA}$ $4.18 < D < 4.25$ (Al79 Py7 Sp14)	—	—	—	—
Sillimanite	$\alpha = 1.657$ $\beta = 1.661$ $\gamma = 1.678$ $2V_z = 24^\circ - 25^\circ$	$\alpha = 1.657$ $\beta = 1.661$ $\gamma = 1.678$ $2V_z = 24^\circ - 25^\circ$	—	n. d.	n. d.	$2V_z = 23^\circ$	$2V_z = 25^\circ$	$2V_z = 24^\circ$	$2V_z = 24^\circ$
Andalusite	$2V_x = 80^\circ$	$2V_x = 81^\circ - 82^\circ$	$2V_x = 81^\circ$	—	n. d.	—	$2V_x = 81^\circ$	—	—
Biotite	X = pale yellow Y = Z = greenish brown $\beta = \gamma = 1.641$	X = pale yellow Y = Z = greenish brown $\beta = \gamma = 1.640$	X = pale yellow Y = Z = greenish brown $\beta = \gamma = 1.643$	X = pale brownish yellow Y = Z = light brown $\beta = \gamma = 1.641$	X = pale brownish yellow Y = Z = brown $\beta = \gamma = 1.648$	X = pale brownish yellow Y = Z = brown $\beta = \gamma = 1.651$	X = pale yellow Y = Z = greenish brown $\beta = \gamma = 1.642$	X = pale brownish yellow Y = Z = greenish brown $\beta = \gamma = 1.643$	X = pale yellow Y = Z = yellowish brown $\beta = \gamma = 1.633$
Plagioclase	$\alpha_{\min} = 1.541$ $\gamma_{\max} = 1.550$ $2V_x = 78^\circ - 85^\circ$ (An 25-26)	$\alpha_{\min} = 1.542$ $\gamma_{\max} = 1.551$ $2V_x = 78^\circ - 85^\circ$ (An 26-27)	$\alpha_{\min} = 1.542$ $\gamma_{\max} = 1.550$ $2V_x = 78^\circ - 86^\circ$ (An 26)	$\alpha_{\min} = 1.541$ $\gamma_{\max} = 1.551$ $2V_x = 78^\circ - 85^\circ$ (An 25-27)	$\alpha_{\min} = 1.540$ $\gamma_{\max} = 1.552$ $2V_x = 79^\circ - 86^\circ$ (An 23-29)	$\alpha_{\min} = 1.539$ $\gamma_{\max} = 1.549$ $2V_x = 77^\circ - 84^\circ$ (An 21-24)	$\alpha_{\min} = 1.541$ $\gamma_{\max} = 1.550$ $2V_x = 75^\circ - 86^\circ$ (An 25-26)	$\alpha_{\min} = 1.539$ $\gamma_{\max} = 1.549$ $2V_x = 77^\circ - 86^\circ$ (An 21-24)	$\alpha_{\min} = 1.540$ $\gamma_{\max} = 1.550$ $2V_x = 76^\circ - 86^\circ$ (An 23-26)

(1) MA 73081210, 250 m south of Takanuma. (2) MA 72070307-2, 600 m south of Takanuma. (3) MA 72070306 B, 750 m south of Takanuma. (4) MA 73081313-1, 600 m northwest of Sorei. (5) MA 72070310 A, 600 m northwest of Sorei. (6) MA 73081217-2, 500 m south of Takanuma. (7) MA 73081213-2, 350 m south of Takanuma. (8) MA 73081207, 150 m south of Takanuma. (9) MA 72070311, 750 m south of Takanuma.

Table 2. X-ray powder diffraction data for staurolite in staurolite-garnet-cordierite-sillimanite-andalusite-biotite gneiss (MA 72070306, south of Takanuma).

2θ FeK α , obs.	d obs. $\text{\AA}$	I	hkl
13.37°	8.31 $\text{\AA}$	40	020
15.67	7.10	50	110
26.96	4.153	40	040
31.60	3.555	50	220
36.89	3.059	30	150
37.53	3.009	100	221
39.98	2.832	20	002
40.89	2.771	90	060
42.13	2.693	90	151
44.61	2.550	40	241
47.58	2.400	100	132
48.20	2.371	70	330
48.53	2.355	50	311
50.60	2.265	20	260
54.66	2.108	40	171
58.61	1.978	60	062
58.96	1.967	40	400
77.85	1.541	20	282
79.47	1.514	70	530
79.70	1.511	50	511
86.37	1.414	20	004
87.84	1.396	50	462
88.69	1.385	10	0,12,0

has also been identified by X-ray powder method, the result of which is shown in Table 2. Twinned crystals of staurolite are occasionally seen.

Cordierite, in many cases, has partially or entirely been altered to colorless to yellowish pseudomorphous pinitite. It is allotriomorphic, somewhat elongated approximately parallel to the gneissosity, and usually ranges from 0.5 to 2.0 mm in size and rarely more than 3 mm. Small poikilitic inclusions of quartz, sillimanite, biotite, garnet, staurolite and iron ore are present. Clear cordierite which survived pinitization shows refractive index (β) of 1.552 and constant optic axial angles of 71° — 77° over X.

Sillimanite appears in two forms; the one is long needles or stumpy prisms ($\alpha=1.657$, $\beta=1.661$, $\gamma=1.678$, $2V_z=23^\circ$ — 25°) up to 6 mm in length and the other is fibrolitic aggregates. Commonly both forms of sillimanite are intimately associated with each other.

Sillimanite is intergrown often with biotite and cordierite and rarely with andalusite and staurolite.

Andalusite, showing $2V_x=80^\circ$ — 82° , occurs as allotriomorphic poikiloblasts with quartz inclusions. It is sometimes intergrown with sillimanite needles.

Almandinous garnet ($n=1.814$ — 1.818 , $a=11.532$ — 11.541 $\text{\AA}$, $4.18 < D < 4.25$) tends to form hypidiomorphic porphyroblasts up to 8 mm in diameter and often encloses poikilitically minute grains of quartz, iron ore and biotite. Compositions estimated from its physical properties, using the diagram of WINCHEL (1958), are: almandine 71—82, pyrope 7—9, spessartine 10—20.

Biotite flakes, 0.5 to 2.5 mm in diameter, show axial color of $Y=Z$ =greenish brown to brown. Refractive index ($\beta \doteq \gamma$) lies in a narrow range from 1.640 to 1.651, the value in the cordierite-sillimanite gneiss without staurolite being relatively low (1.633).

Quartz and plagioclase occur as allotriomorphic equant or feebly elongated grains less than 3 mm. Polysynthetically twinned plagioclase is commonly present. Generally zoning is inconspicuous. Refractive indices of plagioclase are in a narrow range of $\alpha_{\min}=1.539$ to 1.542 and $\gamma_{\max}=1.549$ to 1.552, giving An 21—29, but optic axial angles vary between smaller ones (75° — 79°) and larger ones (84° — 86°).

Flaky muscovite, 0.5 to 2.0 mm in diameter, sometimes occurs in a small amount, associated intimately with biotite.

Tiny crystals of spinel are rarely found in cordierite, sillimanite and magnetite.

Mode and chemistry

Modes of eight representative specimens of the staurolite-bearing gneiss, together with one of staurolite-free cordierite-sillimanite gneiss, are presented in Table 3. Among them the former five contain garnet but the rest lacks it.

The amount of staurolite is generally small, at most 2.4 percent, while quartz, plagioclase, biotite, cordierite, sillimanite and garnet are predominant. Muscovite is absent or scarce and potassium feldspar is lacking, suggesting

Table 3. Modal analyses of staurolite-bearing gneisses and a staurolite-free gneiss from the Toga area.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Staurolite	2.4	1.1	0.7	0.1	0.1	0.9	0.7	tr.	---
Cordierite	15.7*	1.5*	17.4*	9.6	2.3*	13.9	13.8*	10.8	12.2
Garnet	8.8	9.1	9.9	2.3	0.2	---	---	---	---
Sillimanite	5.1	1.4	2.3	0.7	0.4	6.5	2.2	10.3	6.4
Andalusite	0.7	0.7	3.0	---	0.4	---	1.9	---	---
Biotite	16.9	21.5	9.7	22.4	24.6	8.9	18.7	3.8	8.7
Muscovite	---	---	---	1.2	1.3	---	0.2	0.3	1.3
Plagioclase	10.5	35.0	17.4	23.3	24.8	26.7	20.0	26.3	30.1
Quartz	38.0	27.8	37.9	38.6	43.9	37.1	38.9	46.0	37.3
Iron ore	1.9	1.6	1.7	1.8	1.6	5.0	3.2	2.5	3.9
Others	tr.	0.2	tr.	tr.	0.3	0.9	0.2	tr.	tr.
Total	100.0	99.9	100.0	100.0	99.9	99.9	99.8	100.0	99.9

* Almost pinitized

Rock numbers refer to those in Table 1.

Table 4. Chemical compositions of staurolite-bearing gneisses and a staurolite-free gneiss from the Toga area.

	(1)	(4)	(6)	(9)
SiO ₂	58.16	59.01	56.57	53.74
TiO ₂	1.09	1.16	0.96	1.67
Al ₂ O ₃	18.26	17.23	19.93	21.88
Fe ₂ O ₃	2.16	3.81	2.53	5.69
FeO	7.23	6.34	5.17	5.77
MnO	0.26	0.23	0.06	0.08
MgO	2.08	2.06	0.98	2.09
CaO	1.82	2.29	3.22	2.19
Na ₂ O	2.89	3.74	5.60	3.81
K ₂ O	1.78	1.94	1.74	1.10
P ₂ O ₅	0.05	0.05	0.05	0.04
H ₂ O(+)*	3.32	1.46	2.60	1.38
H ₂ O(-)	0.52	0.25	0.35	0.24
Total	99.62	99.57	99.76	99.68
$\frac{\text{MgO}}{\text{MgO}+\text{FeO}-\text{Fe}_2\text{O}_3}^{**}$	0.38	0.45	0.31	0.54

* Ignition loss   ** Molecular ratio

(Analyst: M. Asami)

(1) and (4) Staurolite-bearing gneiss with garnet.

(6) staurolite-bearing gneiss without garnet.

(9) cordierite-sillimanite gneiss without staurolite.

Rock numbers refer to those in Tables 1 and 3.

that potash is almost exhausted in biotite. The amount of plagioclase is rather large compared with that of common metapelite.

Chemical compositions of three staurolite-bearing gneisses, of which two specimens carry garnet and one lacks it, and of a cordierite-sillimanite gneiss without staurolite are given in Table 4.

Compositions of these rocks show characters of normal pelite, though they have higher contents of alumina, total iron, lime and soda and lower contents of silica and potash than those of the average pelitic rock (SHAW, 1956) and the average Paleozoic slate in Japan (MIYASHIRO and HARAMURA, 1962).

These compositions are plotted on the AKF diagram (Fig. 2). Figure 2 shows that the staurolite-bearing rocks, (1), (4) and (6), are not so excess in alumina for rocks containing the aluminum silicate. The gneisses analyzed are characteristically located on the AF side of the sillimanite-biotite join, while the average pelitic rocks on the AK side; the gneisses in the Toga area seem deficient in K₂O. This is in harmony with the fact that

Fig. 2. AKF diagram for staurolite-bearing gneisses, (1), (4) and (6), and a staurolite-free gneiss, (9), from the Toga area. Compositions of average pelitic rock, Av. 1, (SHAW, 1956) and average Paleozoic slate in Japan, Av. 2, (MIYASHIRO and HARAMURA, 1962) are also plotted. Rock numbers refer to those in Table 4.

the potassium mineral in these gneisses is exclusively biotite as stated previously; muscovite is rare or absent and potassium feldspar is absent.

Chemical compositions of the four gneisses and the average pelitic rocks are also presented on the AFM diagram (Fig. 3). The staurolite-bearing gneisses are not necessarily higher in alumina content compared with the average pelitic rocks. Nevertheless, they contain abundant sillimanite.

As shown in Table 4, the molecular ratios $\text{MgO}/\text{MgO} + \text{FeO} - \text{Fe}_2\text{O}_3$ in the staurolite-bearing gneisses (0.31–0.45) are lower than those in the staurolite-free gneiss (0.54) and the average pelitic rocks (0.60–0.62). The staurolite-bearing gneiss, (6), lacks garnet in spite of fairly lower value in the $\text{MgO}/\text{MgO} + \text{FeO} - \text{Fe}_2\text{O}_3$ ratio than those of the other two staurolite-bearing gneisses with garnet, (1) and (4). However, both the gneisses with garnet differ distinctly in high manganese content (0.26 and 0.23% respectively) from the garnet-free staurolite-bearing one (0.06%) and also the cordierite-sillimanite gneiss, (9), (0.08%). Most of manganese in the rocks

Fig. 3. AFM diagram for staurolite-bearing gneisses, (1), (4) and (6), and a staurolite-free gneiss, (9), from the Toga area and average pelitic rocks, Av. 1 and Av. 2.

$A = \text{Al}_2\text{O}_3 - (\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$, $F = \text{FeO} - \text{Fe}_2\text{O}_3$ and $M = \text{MgO}$ in molecular ratio.

may be concentrated in garnet, this being consistent with an appreciable amount of manganese in garnet, as suggested by its physical properties (Table 1). It seems plausible that the difference in mineral assemblage of these gneisses is chiefly ascribed to the differences in the $\text{MgO}/\text{MgO} + \text{FeO} - \text{Fe}_2\text{O}_3$ ratio and manganese content of the rocks.

Discussion

1. Metamorphic grade

The staurolite-bearing gneiss prevails considerably within the sillimanite-grade metapelites in the Toga area, although the modal content of staurolite is commonly small. It has normal chemical compositions of pelite and always contains plagioclase, quartz, biotite, sillimanite, cordierite and staurolite, and often garnet and/or andalusite as the essential constituents. Peculiar textures suggesting disequilibrium relations between the minerals have not been observed. The presence or absence of staurolite and garnet in the sillimanite-bearing gneisses in this area may be ascribed chiefly to the differences in the $\text{MgO}/\text{MgO} + \text{FeO} - \text{Fe}_2\text{O}_3$ ratio and manganese content of the rocks respectively.

In the medium-grade metapelites, staurolite is commonly associated with kyanite and almandine. This association is characteristic of the Barrovian-type metamorphic regions, where the upper stability limit of staurolite lies within the kyanite field, indicating relatively high pressure condition. Staurolite also appears to occur in association with cordierite-andalusite or sillimanite. The assemblage of staurolite-cordierite-andalusite characterizes the Buchan-type metamorphic rocks, as reported from the southeastern Scottish Highlands (READ, 1952), the central Pyrenees (ZWART, 1962), and the northern Appalachians (OSBERG, 1971). In these regions staurolite disappears within the andalusite-cordierite zone with increase in the metamorphic grade before sillimanite appears. The assemblage of staurolite-sillimanite, generally lacking cordierite, is well developed in metamorphics of the northern Appalachians (BILLINGS, 1937; GREEN, 1963; THOMPSON, 1957; GUIDOTTI, 1968) and of the northern Michigan (JAMES, 1955). In this type of metamorphism this assemblage is characteristic in the lower sillimanite zone, and staurolite is no longer stable in the upper sillimanite zone (GUIDOTTI, 1968); the upper stability limit of staurolite lies in the sillimanite field. The difference between such two types of the amphibolite facies metamorphism as described above may be attributed mainly to the difference of the prevailing rock pressure during the metamorphism. If staurolite disappears according mainly to the reaction with muscovite and the following reaction is applicable (e.g. HOSCHEK, 1969):

the former Buchan-type metamorphism represents a rather lower pressure condition than the latter (Fig. 4). Therefore, in the medium-grade of the amphibolite facies, development of the staurolite-cordierite-andalusite assemblage may be favorable to a lower pressure environment in comparison with that of the staurolite-sillimanite assemblage.

In view of the above two staurolite-bearing associations, the assemblage of the staurolite-bearing gneiss in the Toga area is similar to that in the Buchan-type metamorphic region, although the Al_2SiO_5 mineral in the former case is chiefly sillimanite instead of andalusite. It is conceivable that the pressure condition during the metamorphism in this area may be comparable to that of the Buchan-type metamorphism, but the staurolite-cordierite-sillimanite assemblage may suggest a somewhat restricted stability field of staurolite under the higher temperature condition than that of the Buchan-type, as will be discussed below.

The staurolite-bearing gneiss usually contains abundant sillimanite in spite of its being not so excess in alumina. This evidence indicates an intimate connection of sillimanite with biotite, which intersects the staurolite-muscovite join in the AKF diagram (Fig. 2). This is represented by the following reaction:

As noted by CHINNER (1965), HOSCHEK (1969) and GUIDOTTI (1970), the reaction is of prograde. If the rocks contain abundant muscovite, an assemblage of muscovite-sillimanite-biotite must be favored in the higher grade part as a result of disappearance of staurolite. In this case the rocks may have compositions plotted in the field left side of the sillimanite-biotite join on the AKF diagram. However, the staurolite-bearing gneisses now concerned fall in the field right side of the sillimanite-biotite join; they may well be regarded as gneisses showing an assemblage of staurolite-sillimanite-biotite. This is compatible with the fact that staurolite-bearing rocks free from sillimanite are seldom present in the Toga area, that the modal amount of staurolite is usually small and that muscovite is absent or scarce and potassium feldspar is lacking. According to HOSCHEK (1969), it is known that the above reaction (I) takes place at lower temperatures than the reactions:

Fig. 4. Presumed P-T conditions of metamorphism; (1) Buchan-type metamorphic regions, where staurolite disappears within the andalusite field, (2) northern Appalachians and northern Michigan, where it disappears within the sillimanite field, and dotted field, Toga area. Curves shown are (I) HOSCHEK (1969), (II) RICHARDSON (1968), (III) EVANS (1965) and (IV) RICHARDSON *et al.* (1969). Abbreviations: Al, Al-silicate; Bi, biotite; Ga, garnet; Kf, K-feldspar; Mu, muscovite; Qu, quartz; St, staurolite.

and

under the lower pressure conditions. Thus the staurolite-cordierite-sillimanite-biotite assemblage* found in this area indicates a restricted range of P-T conditions and may be an example suggesting the highest grade in the pelitic rocks containing staurolite (Fig. 4). In the gneisses with relatively high manganese content, garnet appears as

* Similar assemblages involving staurolite-cordierite-sillimanite have been reported from Idaho (HIETANEN, 1968) and from the Udokan-Stanovoy zone (KORIKOVSKII, 1970).

Fig. 5. Map showing localities of staurolite-bearing rocks in the Hida metamorphic terrane: A, Arashimadake area; K, Kurobe-gawa area; T, Toga area.

an additional mineral.

2. Distribution of staurolite-bearing rocks in the Hida metamorphic terrane

Staurolite-bearing rocks have hitherto been known from the two areas in the Hida metamorphic terrane: (1) the Kurobe-gawa area in the northeastern part, and (2) the Arashimadake area in the southwestern part of the terrane. Unlike the Toga area, both areas lie on the "outer" parts of the Hida terrane (Fig. 5). The metamorphic rocks of the Kurobe-gawa area include kyanite-andalusite-staurolite-almandine phyllite, muscovite-biotite-almandine-staurolite schist, blastoporphyrific leptyte, and almandine-plagioclase amphibolite which are indicative of the staurolite-kyanite subfacies of the amphibolite facies (ISHIOKA, 1949; ISHIOKA and SUWA, 1954; 1956). Staurolite usually occurs as large poikilitic porphyroblasts. On the other hand, the metamorphic rocks of the Arashimadake

area are composed largely of biotite-hornblende gneiss and crystalline limestone, with a subordinate amount of pelitic and quartzofeldspathic schists. Staurolite is present as minute grains associated with garnet, sillimanite, andalusite, biotite, plagioclase and quartz. An occurrence of sillimanite-muscovite-biotite schist suggests that the metamorphic rocks belong to those of the lower sillimanite grade of the amphibolite facies. It is notable that chloritoid was formed in some pelitic schists during the later stage of the metamorphism (ASAMI, 1970; 1972).

As outlined above, it is noteworthy that such staurolite-bearing rocks have been found not only on the "outer" parts but also in the "inner" part of the Hida metamorphic terrane (Fig. 5), although the rocks in the Kurobe-gawa, the Arashimadake and the Toga areas appear to show some different metamorphic grade from each other.

In the central part of the Hida metamorphic terrane, there occur gneisses of such assemblages as sillimanite-potassium feldspar-garnet-biotite-plagioclase-quartz (e.g. SUZUKI, 1973; SUWA *et al.*, 1973), orthopyroxene-clinopyroxene-hornblende-almandine-potassium feldspar-plagioclase-quartz (SUZUKI and KOJIMA, 1970) and so on. Undoubtedly the metamorphic grade of the gneisses in the central part is higher than that recognized in the Toga, the Kurobe-gawa and the Arashimadake areas. Such petrological characters of rocks in the Hida terrane will provide some basic information on the Hida metamorphism. In this respect, the staurolite-cordierite-sillimanite gneiss found in the Toga area, the inner part of the Hida terrane, are of much importance.

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References

- ASAMI, M., 1970 : Hida metamorphic rocks in the Arashimadake area, Fukui Prefecture, Japan. *J. Geol. Soc. Japan*, **76**, 98—99 (in Japanese).
- ASAMI, M., 1972 : Chloritoid in the Hida metamorphic rocks of the Arashimadake area, Fukui Prefecture, Japan. *Abst. Program, 1972 Annual Meet. Geol. Soc. Japan*, 256 (in Japanese).
- ASAMI, M. and ADACHI, M., 1974 : Staurolite-cordierite-bearing gneiss from the Toga area in the Hida metamorphic terrane. *Abst. Program, 1974 Annual Meet. Geol. Soc. Japan*, 315 (in Japanese).
- BILLINGS, M. P., 1937 : Regional metamorphism of the Littleton-Moosilauke area, New Hampshire. *Bull. Geol. Soc. Am.*, **48**, 463—566.
- CHINNER, G. A., 1965 : The kyanite isograd in Glen Clova, Angus, Scotland. *Mineral. Mag.*, **34**, 132—143.
- EVANS, B. W., 1965 : Application of a reaction-rate method to the breakdown equilibria of muscovite and muscovite plus quartz. *Am. J. Sci.*, **263**, 647—667.
- FUJII, S., SOMA, T., KONDO, Y., OGAWA, K., SAKAMOTO, S. and ASANO, H. 1970 : Geological map of Toyama Prefecture and its explanatory text, scale 1 : 150,000. Toyama Prefecture (in Japanese).
- GANGULY, J., 1972 : Staurolite stability and related parageneses: theory, experiments, and applications. *J. Petrol.*, **13**, 335—365.
- GREEN, J. C., 1963 : High-level metamorphism of pelitic rocks in northern New Hampshire. *Am. Min.*, **48**, 991—1023.
- GUIDOTTI, C. V., 1968 : Prograde muscovite pseudomorphs after staurolite in the Rangeley-Oquossoc area, Maine. *Am. Min.*, **53**, 1368—1376.
- GUIDOTTI, C. V., 1970 : The mineralogy and petrology of the transition from the lower to

- upper sillimanite zone in the Oquossoc area, Maine. *J. Petrol.*, **11**, 227—336.
- HIETANEN, A., 1968 : Metamorphic environment of anorthosite in the Boehls Butte area, Idaho. *N. Y. State Mus. Sci. Serv., Mem.* **13**, 371—386.
- HOSCHEK, G., 1969 : The stability of staurolite and chloritoid and their significance in metamorphism of pelitic rocks. *Cont. Mineral. Petrol.*, **22**, 208—232.
- ISHIOKA, K., 1949 : Staurolite and kyanite near Unazuki in the lower Kurobe-gawa area. *J. Geol. Soc. Japan*, **55**, 156 (in Japanese).
- ISHIOKA, K. and SUWA, K., 1954 : Fabric of hornblende in a schistose amphibolite from the Kurobe-gawa area, central Japan. *J. Earth Sci. Nagoya Univ.*, **2**, 191—199.
- ISHIOKA, K. and SUWA, K., 1956 : Metasomatic development of staurolite schist from rhyolite in the Kurobe-gawa area, central Japan. *J. Earth Sci. Nagoya Univ.*, **4**, 123—140.
- JAMES, H. L., 1955 : Zones of regional metamorphism in the Precambrian of northern Michigan. *Bull. Geol. Soc. Am.*, **66**, 1455—1488.
- KOBAYASHI, H., 1954 : On the cummingtonite-plagioclase rock of the Kōshimizu district, Toyama Prefecture, Japan. *J. Fac. Sci. Hokkaido Univ., Ser. IV*, **8**, 407—418.
- KORIKOVSKII, S. P., 1970 : Staurolite in cordierite-sillimanite schists of the Udokan series and the upper limit of the staurolite facies in andalusite-sillimanite complexes. *Akad. Nauk SSSR Doklady*, **191**, 429—432.
- MİYASHIRO, A. and HARAMURA, H., 1962 : Chemical composition of Paleozoic slate, IV. *J. Geol. Soc. Japan*, **68**, 75—82 (in Japanese with English abstract).
- OSBERG, P. H., 1971 : An equilibrium model for Buchan-type metamorphic rocks, south-central Maine. *Am. Min.*, **56**, 570—586.
- READ, H. H., 1952 : Metamorphism and migmatization in the Ythan Vally, Aberdeenshire. *Trans. Edin. Geol. Soc.*, **15**, 265—279.
- RICHARDSON, S. W., 1968 : Staurolite stability in part of the system Fe-Al-Si-O-H. *J. Petrol.*, **9**, 467—488.
- RICHARDSON, S. W., BELL, P. M., and GILBERT, M. C., 1969 : Experimental determination of kyanite-andalusite and andalusite-sillimanite equilibria; aluminum silicate triple point. *Am. J. Sci.*, **258**, 259—272.
- SHAW, D. M., 1956 : Geochemistry of pelitic rocks, Part III. *Bull. Geol. Soc. Am.*, **67**, 919—934.
- SUWA, K., SHIOZAKI, H. SOMA, T., ASAMI, M., KANO, T. and HOSHINO, M., 1973 : Hida metamorphic rocks and plutonic rocks of the Wada-gawa and Oguchi-gawa areas, Toyama Prefecture, Japan. *Abst. Program, 1973 Annual Meet. Geol. Soc. Japan*, 217 (in Japanese)
- SUZUKI, M., 1973 : An occurrence of “eclogitic rock” in the Hida metamorphic belt. *J. Japan. Assoc. Min. Pet. Econ. Geol.*, **68**, 372—382.
- SUZUKI, M. and KOJIMA, G., 1970 : On the association of potassium feldspar and corundum found in the Hida metamorphic belt. *J. Japan. Assoc. Min. Pet. Econ. Geol.*, **63**, 266—274.
- THOMPSON, J. B., 1957 : The graphical analysis of mineral assemblages in pelitic schists. *Am. Min.*, **42**, 842—858.
- WINCHEL, H., 1958 : The composition and physical properties of garnet. *Am. Min.*, **43**, 595—600.
- ZWART, H. J., 1962 : On the determination of polymetamorphic mineral associations, and its application to the Bosost area (central Pyrenees). *Geol. Rundsch.*, **52**, 38—65.

飛驒帯・利賀地域の含十字石・堇青石・珪線石片麻岩

浅見 正雄・足立 守

(要 旨)

富山県利賀地域の飛驒変成岩類の中から含十字石片麻岩を見出し、それを記載した。十字石は石英、斜長石、黒雲母、珪線石、堇青石、チタン鉄鉱、磁鉄鉱と密接に伴う。しばしばざくろ石や紅柱石も伴う。白雲母は含まれないか、あってもわずかである。

含十字石片麻岩 3 個と十字石を欠く堇青石珪線石片麻岩 1 個を化学分析した結果、これらは K_2O 含有量が低いのが特徴であること、含十字石片麻岩は十字石を欠くものより $MgO/MgO+FeO-Fe_2O_3$ (モル比) が低いこと、そして MnO 含有量の比較的高い含十字石片麻岩はざくろ石を含むことが明らかになった。

十字石を伴う鉱物組合せと岩石化学的性質の検討から、本地域の十字石-堇青石-珪線石の組合せは含十字石岩においては最も高い変成度を示すものと考えられる。

飛驒変成作用に関して、この含十字石片麻岩の地質学的意味についても触れた。

地 名			
Arashimadake	荒島岳	Sōrei	草嶺
Kōshimizu	高清水	Takamine	高峰
Kurobe-gawa	黒部川	Takanuma	高沼
Momose-gawa	百瀬川	Toga	利賀
Odori-gawa	小鳥川	Toyama	富山

Explanation of Plats

Plate I

- A. Staurolite-bearing garnet-cordierite-sillimanite-biotite gneiss (MA73081217-3). Gneissic structure is stressed by sub-parallel alignment of biotite flakes and sillimanite needles. Garnet porphyroblasts are scattered.
- B. Photomicrograph of staurolite-bearing gneiss (MA73081213-2). A hypidiomorphic grain of staurolite intergrown with prismatic sillimanite and enclosed in cordierite. Biotite and iron ore are also found in contact with staurolite. One nicol.
- C. Ditto. Crossed nicols.

Plate II

- A. Photomicrograph of staurolite-bearing gneiss (MA 72070306B-1). Well-defined crystals of staurolite largely enclosed in biotite. Pinitized cordierite is present around tabular biotite. One nicol.
- B. Ditto (MA 72070306 B-9).
Prismatic staurolite closely associated with biotite flakes and sillimanite needles. One nicol.
- C. Ditto (MA 72070306 B-8).
Hypidiomorphic staurolite surrounded by porphyroblastic garnet, cordierite, sillimanite and biotite. One nicol.
- D. Ditto (MA 72070306 B-6)
A small grain of staurolite found near poikiloblastic andalusite. Note acicular sillimanite within andalusite. One nicol.

All the photomicrographs are same in scale.