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Garnet-bearing granitoids within the Kiyosaki Granodiorite pluton in the Ryoke Belt, central Japan

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三河地方領家帯の清崎花崗閃緑岩中の含ざくろ石花崗岩質岩

沓掛俊夫*

(Abstract)

Garnet-bearing granitoids occur within the microdioritic enclave of the Kiyosaki Granodiorite in the Ryoke Belt, central Japan. These rocks comprise the ferrous minerals, such as ferropargasite, almandine-rich garnet and annite, and are high in Fe/Mg ratio and also in Zr and REE contents. These should not be the granitization products of meta-mafic rocks as suggested by Koide (1958), but magmatic rocks, representing a magmatic activity somewhat different from and prior to the major Ryoke granitoid magmatism.

Introduction

Within the Kiyosaki Granodiorite in the Ryoke Belt, central Japan, there occur medium-grained garnet-bearing biotite granite and hornblende-biotite tonalite, associated with the microdioritic enclaves (Koide, 1958). These rocks characterized by garnet, were regarded by Koide (1958) to be the products of granitization of the metadiabasic rocks. From the Mitsuhashi Granite in the Toyone-mura area, I have already described the similar rocks to these granitoids, and suggested of their metasomatic origin (Kutsukake, 1993). Here, I will present the petrography and whole-rock chemistry of these and their related rocks and also mineral chemistry of the major minerals, mentioning the condition of crystallization and petrogenetic implications of these rocks.

Geological outline and mode of occurrence

Kiyosaki Granodiorite pluton (5 km × 4 km) is a representative of the Older Ryoke granitoids in central Japan (Ryoke Research Group, 1972). It was emplaced within the Ryoke metamorphic rocks and intruded by the Mitsuhashi Granite to the southwest (Fig. 1). Geology, petrography and geochemistry of the Kiyosaki Granodiorite have already been reported (Kutsukake, 2001).

There occurs a microdioritic enclave, some tens meters in scale, in the northern portion of this pluton. Within this microdioritic enclave, a garnet-bearing biotite granodiorite, which has been regarded to be the granitization products of meta-mafic rocks by Koide (1958), is seen as a lenticular body with a width less than 1.5 m. This body is trending N80° E. Although the contact between the microdiorite and granitoids is usually sharp (Fig. 2), an aplitic lithology is sometimes intercalated (Fig. 3).

The medium-grained garnet-bearing biotite granodiorite is somewhat foliated and the mafic-lich schlieren-like layers of several centimeter in width are developed (Fig. 2). The main lithology is a garnet-bearing biotite granodiorite, whereas the mafic-rich schlieren is a garnet-bearing hornblende-biotite tonalite. Garnets are unevenly distributed,

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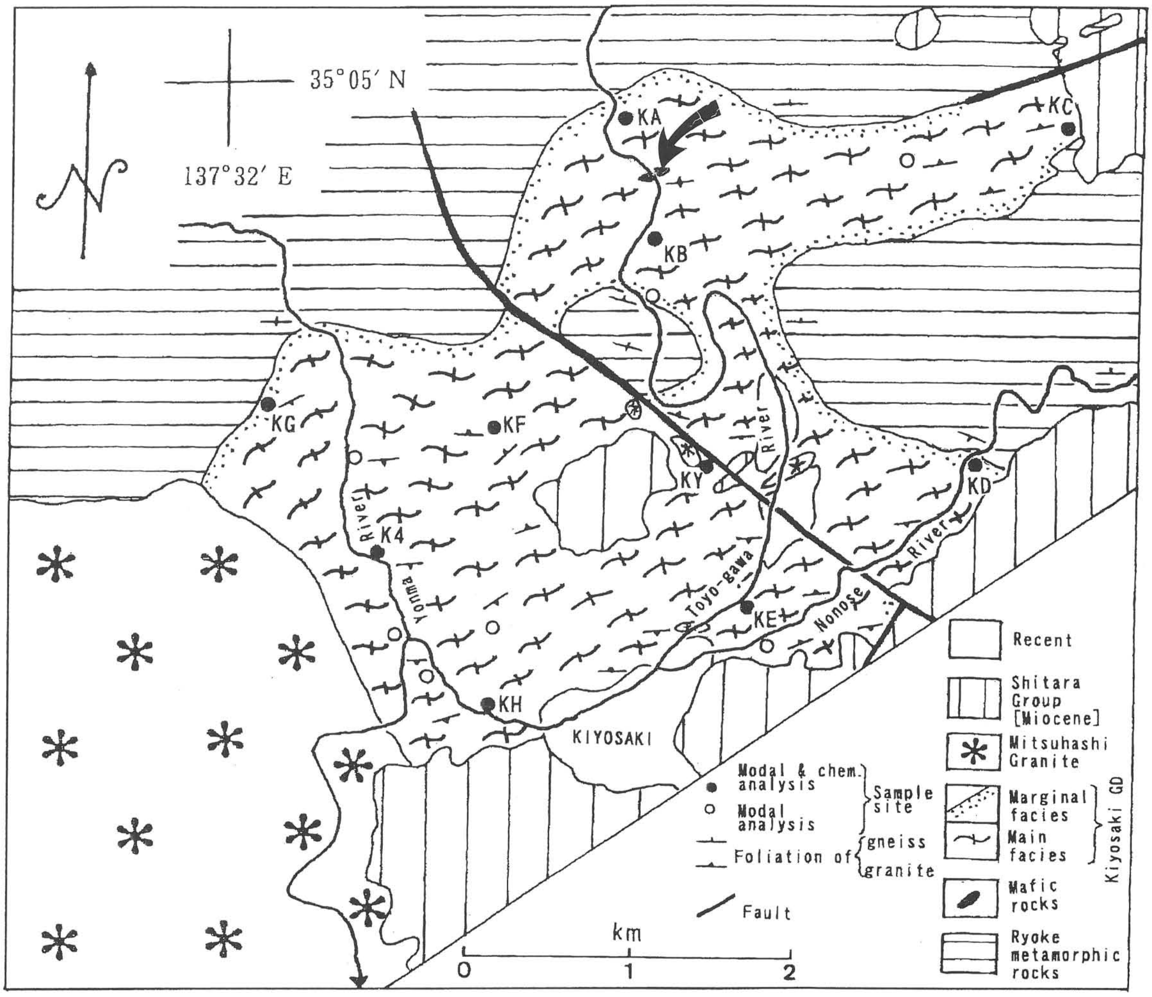

Fig. 1. Geological map of the Kiyosaki Granodiorite pluton (Kutsukake, 2001). Allow indicates the studied enclave.

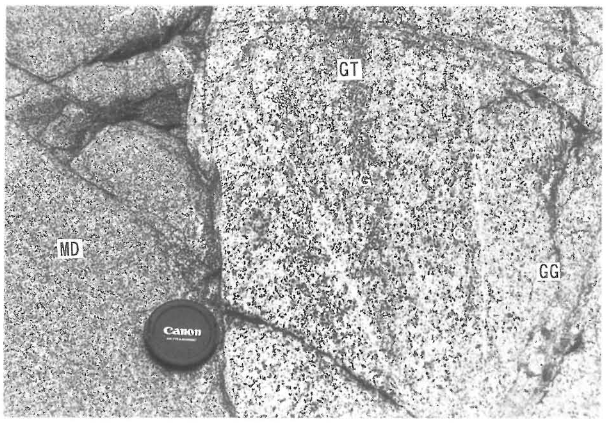

Fig. 2. Photograph showing the field-relationships among the garnet-bearing granodiorite (GG), garnet-bearing tonalite (GT) and microdiorite (MD). G indicates the garnet aggregates.

and sometimes they form clots of several individuals in both the granodiorite and tonalitic schlieren (Fig. 2).

Petrography

1. Microdiorite (MD)

This rock is dark greenish, fine-grained and massive rock. It is composed mainly of plagioclase, biotite, hornblende and quartz. Modally this rock is properly called tonalite. Under the microscope, it exhibits an equigranular texture. Plagioclase, andesine, is subhedral and anhedral. Zoning is not distinct, and sometimes sericitized calcic core is seen. Mafic minerals are usually scattered and sometimes biotite (Z=dark brown; γ =1.656) forms clots of several individuals by alone and/or together with hornblende (Z=green with brownish tint; α =1.657, γ =

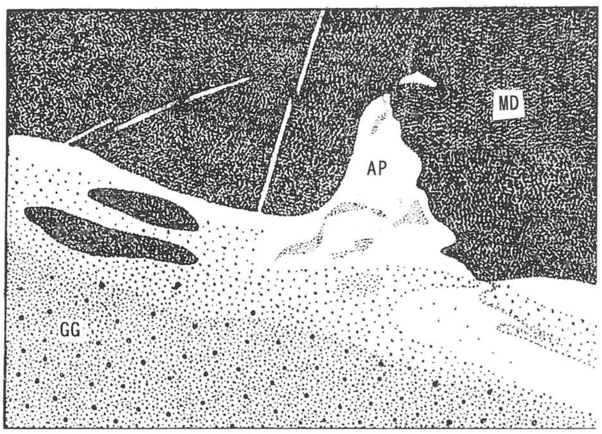

Fig. 3. Contact between the garnet-bearing granodiorite (GG) and microdiorite (MD). Along the contact an aplite (AP) is developed (Koide, 1958; Fig. 84).

1.682; 2Vx=70°; Koide, 1958). Apatite is only as accessory mineral and secondary titanite replaces both the biotite and hornblende.

2. Garnet-bearing biotite granodiorite (GG)

This rock is medium-grained and moderately foliated. Under the microscope, it exhibits anhedral and granular texture. It is composed mainly of plagioclase, alkali feldspar, quartz and biotite with sporadic garnet. Larger plagioclase shows zoning. Myrmekite is developed along the boundary between alkali feldspar. Alkali feldspar fills the interstices between other minerals. It shows faint tweed texture. Biotite (Z=dark reddish brown) occurs both as discrete flake and in aggregate. Garnet is irregular-shaped and ragged crystals, however, it is euhedral against biotite.

3. Garnet-bearing hornblende-biotite tonalite (GT)

This rock occurs as schlieren within the above-mentioned granodiorite. It is a mesocratic and moderately foliated rock. The texture is almost the same as the above-mentioned granodiorite. It is composed mainly of plagioclase, quartz, biotite, hornblende and garnet with a little amount of alkali feldspar.

Garnet occurs as porphyroblastic and/or skeletal crystals associated with biotite. It develops cutting across the cleavage of biotite, and this mode of occurrence suggests its replacement of the latter. It includes ameba-like quartz and plagioclase crystals. Hornblende (Z=grass green) is discrete crystal and /or associated with biotite (Z=deep reddish brown). Chemistry and optics of the major minerals will be described in the mineral chemistry section.

Euhedral and zoned allanite, acicular apatite, long prismatic zircon and tiny pyrite are common accessories.

Whole-rock chemistry

Chemical analyses for major- and trace-elements of the representative rocks are shown in Table 1, together with the analysis of a granodiorite of the Kiyosaki Granodiorite (Kutsukake, 2001), for comparison. The garnet-bearing biotite granodiorite (GG) has almost the same SiO_2 content as the host Kiyosaki Granodiorite (KB), however it has far higher Fe/Mg ratio (FeO_T/MgO=14.8) than the latter (2.9). The garnet-bearing hornblende-biotite tonalite (GT) also has very high Fe/Mg ratio (15.1). Usually the garnet-bearing granitoids in the Ryoke Belt have higher Fe/Mg ratios than those without garnet (Kutsukake, 1993, 1997a). For other major-elements, the garnet-bearing granitoids do not show any distinctive characteristics except for their slightly high Mn content.

As regards trace elements, Zr is more concentrated in these garnet-bearing rocks than the Kiyosaki Granodiorite. And also Sc and Y contents are slightly higher in these garnet-bearing rocks. Other trace element concentrations are similar for the analyzed four rock-types.

ΣREE contents are 224 ppm for GT and 284 ppm for GG, respectively, and these values are more than twice higher in the Kiyosaki Granodiorite (117 ppm in KB). Chondrite-normalized REE patterns are shown in Fig. 4. The garnet-bearing tonalite (GT) is high for HREE as garnet has large partition coefficients for these elements. Also it exhibits a distinctive negative Eu-anomaly. Three rock-types (MD, GG and GT) show their own REE patterns, different from that of the Kiyosaki Granodiorite. Therefore, these garnet-bearing granitoids could not be derived from the Kiyosaki Granodiorite. The microdiorite shows a flat pattern, indicating the less differentiated and a primitive composition.

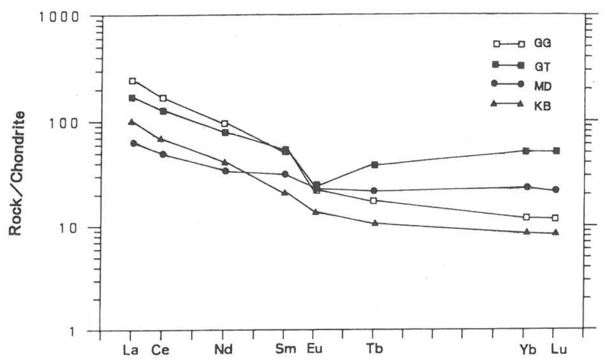

Fig. 4. Chondrite-normalized REE patterns for the rocks. For sample number refer to Table 1.

Mineral chemistry

For the major minerals constituting the garnet-bearing tonalite, the electron-microprobe analyses have been performed. The analyses were made at the Department of Geology, University of Otago, Dunedin, New Zealand.

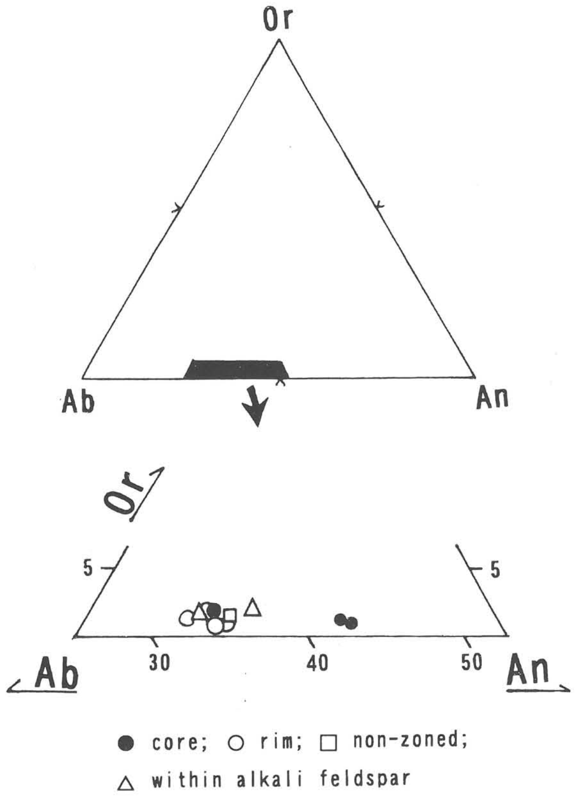

Fig. 5. Or-Ab-An plots of plagioclase in the garnet-bearing tonalite.

Table 1. Major- and trace-element analyses of the rocks.

	GT	GG	MD	KB
SiO_2	63.40	69.82	60.79	69.22
TiO_2	0.51	0.36	0.96	0.39
Al_2O_3	16.10	14.80	17.12	15.31
Fe_2O_3	1.62	0.89	1.42	0.21
FeO	7.32	3.92	5.69	2.95
MnO	0.41	0.09	0.16	0.07
MgO	0.58	0.32	1.94	1.08
CaO	4.16	2.77	5.20	3.22
Na_2O	3.23	3.32	3.54	3.65
K_2O	1.52	2.47	1.79	2.90
P_2O_5	0.14	0.09	0.17	0.10
L.O.I.	0.32	0.42	0.56	0.83
Total	99.30	99.26	99.41	99.91

Trace elements (in ppm except for Au and Ir)				
Ag*	<0.4	<0.4	<0.4	-
As	<1	<1	<1	3
Au(ppb)	<1	1	<1	<2
Ba	402	809	744	543
Be	3	3	2	2
Bi*	<5	<5	<5	-
Br	<0.5	<0.5	<0.5	<0.5
Cd*	0.5	0.6	0.7	-
Co	4.0	3.0	12.8	7.3
Cr	<0.5	<0.5	<0.5	9.7
Cs	4.6	3.5	2.8	7.5
Cu*	3	2	3	-
Ga**	25	19	23	17
Hf	16.5	11.2	4.1	4.5
Hg	<1	<1	<1	<1
Ir(ppb)	<2	<2	<2	<2
Mo	<2	<2	<2	<2
Nb**	19	16	12	11
Ni*	<5	<5	<5	-
Pb**	15	13	8	24
Rb	86	96	87	120
S**	180	<50	205	225
Sb	0.1	<0.1	0.1	0.4
Sc	31.9	22.0	18.8	6.7
Se	<0.5	<0.5	<0.5	1.0
Sn**	<5	<5	<5	<5
Sr	244	237	315	215
Ta	1.2	1.4	1.2	0.7
Th	11.1	18.0	5.2	13.2
U	2.0	2.0	1.2	3.0
V	30	21	65	46
W	<1	<1	<1	<1
Y	93	27	48	17
Zn*	134	99	101	-
Zr	950	574	148	158
La	52.8	79.3	20.7	31.9
Ce	100	136	40	54
Nd	46	55	20	24
Sm	10.2	9.80	5.86	3.92
Eu	1.68	1.55	1.49	0.96
Tb	1.8	0.8	1.0	0.5
Yb	9.94	2.20	4.45	1.67
Lu	1.50	0.35	0.65	0.25

Analyses were made by the Activation Laboratories, Ltd., Ontario, Canada.
ICP analysis except for the elements with* AAS and** XRF. —: not determined.
GT. Garnet-bearing hornblende-biotite tonalite; GG. Garnet-bearing biotite granodiorite; MD. Microdiorite; KB. Biotite granodiorite (Kiyosaki Granodiorite; Kutsukake, 2001).

Table 2. Analysis and formula of the garnet.

				Si+Al+Ti+Fe^{+3}=10 [O=24]	
SiO_2	35.80	(0.42)	Si	5.819	6.00
TiO_2	0.07	(0.06)	Al^{IV}	0.181	
Al_2O_3	19.81	(0.26)	Al^{VI}	3.614	4.00
FeO*	29.97	(0.49)	Ti	0.009	
MnO	5.64	(0.34)	Fe^{+3}	0.373	
MgO	0.39	(0.02)	Fe^{+2}	3.886	6.09
CaO	7.67	(0.42)	Mn	0.776	
Na_2O	0.01	(0.02)	Mg	0.092	
K_2O	0.00	(0.01)	Ca	1.336	
			Na	0.003	
Total	99.36		K	0.001	

Mole percent end-members	
Almandine	63.8
Spessartine	12.7
Pyrope	1.5
Andradite	9.4
Grossular	12.6

FeO* denotes total Fe as FeO.
The figures in parentheses indicate the standard deviations.

Table 3. Analysis and formula of the hornblende. 15eNK indicates the cations normalized to 15 excluding Na and K.

			Formula (15eNK)	
SiO_2	38.44	(1.12)	Si	6.294
TiO_2	0.96	(0.09)	Al^{IV}	1.706
Al_2O_3	11.48	(0.76)	Sum T	8.000
FeO*	29.06	(0.82)	Al^{VI}	0.509
MnO	0.60	(0.02)	Ti	0.118
MgO	1.70	(0.13)	Fe^{+3}	0.317
CaO	10.80	(0.46)	Mg	0.415
Na_2O	1.13	(0.05)	Fe^{+2}	3.641
K_2O	1.47	(0.10)	Sum C	5.000
			Fe^{+2}	0.021
Total	95.64		Mn	0.084
			Ca	1.895
			Sum B	2.000
			Na	0.358
			K	0.307
			Sum A	0.665
			Total	15.665

FeO* denotes toal Fe as FeO.

1. Plagioclase

Ten analyses are plotted onto the Or-Ab-An triangle (Fig. 5). The most calcic core composition ranges from An32 to An43. They are mostly sodic andesine. They fall within the compositional range estimated optically by Koide (1958). Or content is less than 2 mole percent. The maximum minor element contents are as follows: TiO_2=0.04; FeO=0.21; MnO=0.04 and MgO=0.03wt. %, respectively.

2. Garnet

Average of 10 analyses is shown in Table 2. An estimate of the Fe^{+3} content of a garnet analysis may be obtained by recalculating on the basis of Si+Al+Ti+Fe^{+3}=10 per formula unit (Kutsukake, 1993). Cations total nearly 16 (Table 2), indicating this recalculation to be not unreasonable. This garnet has ca. 64% almandine component. Mn and Ca are also important: 13% mole percent is spessartine and 13% mole percent is grossular.

The refractive index (R.I.) determined by Koide (1958) is n=1.803.

3. Hornblende

Average of 7 analyses is given in Table 3. To estimate Fe^{+3} content, formula was calculated on the basis of ΣCa=15 excluding Na and K (Stout, 1972). This recalculation of minimum Fe^{+3} seems reasonable, as the Fe^{+3}/Fe^{+2} of the host rock is low ($\approx$0.2). Plotting onto the classification diagram of calcic amphiboles by Leake *et al.* (1997), this hornblende falls in the ferropargasite field (Fig. 6). According to Koide (1958), this hornblende gives α=1.700 and 2Vx=49°.

4. Biotite

Average of ten analyses is given in Table 4. This biotite is fairly Fe-rich and moderate in Ti content. The structural formula was calculated as if all iron is ferrous on the basis 22(O). This biotite is close to annite end member. R. I.: α=1.608 and γ=1.680 (Koide, 1958).

5. Pyrite

Opaque minerals are mostly pyrite. Three analyses of pyrite have been averaged. It gives a formula of $Fe \cdot (As_{0.005}, S_{1.956})_{1.961}$.

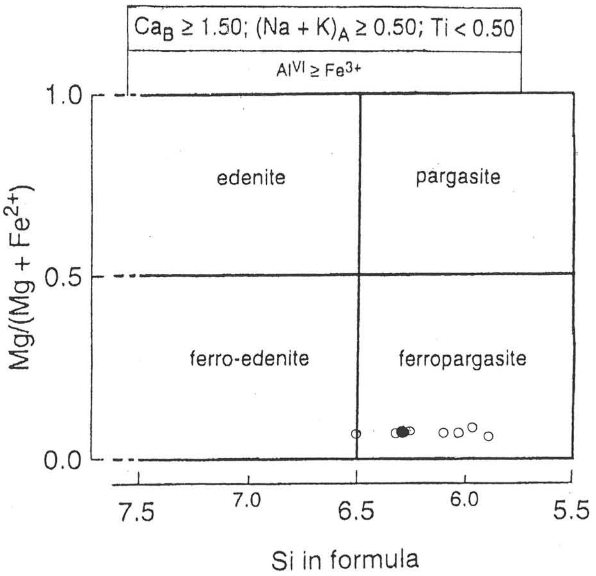

Fig. 6. Plot of hornblende in the garnet-bearing tonalite onto the classification diagram of calcic amphiboles (Leake *et al.*, 1997). Solid circle indicates the average value.

Table 4. Analysis and formula of the biotite.

			[O=22]		
SiO_2	32.00	(0.56)	Si	5.485	8.00
TiO_2	2.71	(0.28)	Al^{IV}	2.515	
Al_2O_3	14.74	(0.61)	Al^{VI}	0.463	5.71
FeO*	31.94	(0.95)	Ti	0.349	
MnO	0.32	(0.07)	Fe	4.577	
MgO	2.18	(0.14)	Mn	0.046	
CaO	0.01	(0.02)	Mg	0.279	
Na_2O	0.06	(0.02)	Ca	0.002	1.92
K_2O	8.69	(0.29)	Na	0.021	
			K	1.901	
Total	92.65				

FeO* denotes total Fe as FeO.

Discussion

The metamorphosed mafic rocks bearing ferrous minerals have been found from the Ryoke Belt (Yoshizawa, 1952). Also the occurrence of ferrous minerals has been known in the granitized metabasites incorporated in the Ryoke granitoids (Iwao, 1937, 1940). I reported the tonalitic rocks bearing the ferrous minerals and including a number of REE minerals from the Mitsuhashi Granite in the Toyone-mura area (Kutsukake, 1993). The mineralogy of these rocks is quite similar to that of the garnet-bearing granitoids of this study.

The crystallization of almandine-rich garnet in the granitoids requires the low oxygen fugacity conditions (Calk and Dodge, 1986; Liggett, 1990; Kutsukake, 1997a), and also the presence of ferropargasite indicates high-temperature crystallization. As a matter of fact, the amphibole-plagioclase geothermometer (Blundy and Holland, 1990) yields the temperature as high as 815℃ for GT, using the hornblende analysis in Table 3 and the rim composition (An32) of plagioclase (assuming P=0.45GPa; Kutsukake, 1997b). This estimated temperature is well above the solidus of tonalite (Stern *et al.*, 1975), indicating the magmatic crystallization of this granitoid.

The texture of the microdiorite (MD) also suggests its magmatic crystallization, on the contrary to Koide's (1958) interpretation of its metamorphic recrystallization. Koide (1958) regarded these garnet-bearing granitoids to be the products of "granitization characterized by garnet" of metamafic rocks. However, the temperature of crystallization estimated above favors the liquidus rather than subsolidus crystallization for these garnet-bearing granitoids.

Whole-rock major- and trace-element chemistry indicates the different origin of these rocks from the host Kiyosaki Granodiorite. As mentioned above, the mafic and intermediate rocks with high Fe/Mg ratios and their associated garnet-bearing granitoids have been found as enclosed by the Ryoke granitoids from several localities. These rocks would represent a somewhat different magmatic activity from and prior to the main Ryoke granitoid magmatism.

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（要　旨）

沓掛俊夫：三河地方領家帯の清崎花崗閃緑岩中の含ざくろ石花崗岩質岩.

清崎花崗閃緑岩体中の微閃緑岩質包有岩に貫入する中粒花崗閃緑岩（幅1.5m）は，シュリーレン状のトーナル岩質の部分とともにざくろ石を含む．トーナル岩は，ざくろ石の他にフェロパーガス閃石とアンナイト質の黒雲母を含む．これらのざくろ石を含む岩石は，非常に高いFe/Mg比とZr, Sc, YやREEの高い含有量をもっている．推定される形成条件からみて，これらは従来考えられていたように苦鉄質岩の花崗岩化作用の産物ではなく，火成岩と考えられる．他地域からも報告されている領家花崗岩中に包有される鉄に富む苦鉄質岩類やそれに伴う含ざくろ石花崗岩質岩は，主要な領家花崗岩類の活動に先行するマグマ活動の産物である可能性が高い．