PETROLOGICAL STUDY ON THE OJIKA GABBROIC COMPLEX, KITAKAMI MOUNTAINS, NORTHEAST JAPAN

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Abstract The Ojika gabbroic complex is one of the Mesozoic plutonic masses in the Kitakami mountains. It is exposed at the central part of the Ojika Peninsula, southern Kitakami mountains, intruding the Jurassic formations of the Ojika Group. The complex is composed of seven rock types which are grouped into two large groups such as I; gabbroic series (clinopyroxenite, porphyritic clinopyroxene gabbro, olivine two pyroxene gabbro, two pyroxene gabbro) and II; quartz diorite series (pyroxene hornblende diorite, quartz diorite).

The complex was formed by the magmatic intrusions of four stages. The magma of each stage is represented by those of porphyritic clinopyroxene gabbro, clinopyroxene hornblende gabbro, two pyroxene gabbro and quartz diorite, respectively. Fractional crystallization played the main role to form each rock type.

At the first stage intrusion, only clinopyroxene existed as solid phase in the magma reservoir under water-undersaturated condition of $P \approx 10$ kb, $T > 950^\circ\text{C}$. At the second stage intrusion, clinopyroxene, plagioclase, olivine, orthopyroxene and titanomagnetite existed as solid phase in the magma reservoir. The temperature was about 950°C . At the third stage intrusion, clinopyroxene, plagioclase, orthopyroxene and titanomagnetite existed stably in the magma reservoir. The temperature was about 900°C . At the fourth stage intrusion, plagioclase and titanomagnetite existed stably in the magma reservoir under the condition of relatively higher water-vapor pressure and lower temperature than those of the previous stages. During or after the emplacement, the magma at this stage was contaminated partly by the gabbroic rocks already intruded, resulted in the formation of pyroxene hornblende diorite associated with quartz diorite.

The chemical compositions of the Ojika gabbroic complex are characterized by low alkali content and high Al content, showing the trend of calc-alkaline rock series after DALY (1914).

Introduction

The Kitakami mountains consist mainly of the Paleozoic and Mesozoic sediments and many plutonic masses intruding them. The Mesozoic plutonic masses except for ultrabasic rock masses have been classified, on the basis of petrological characters, into the masses of six zones and further into two subzones (KATADA *et al.*, 1971, 1974).

The present author considers, however, that these plutonic masses should be classified into

the following three types, because they differs one another in the original magma type. The detailed discussion will be made elsewhere.

Type I : Composed mainly of granodioritic to adamellite rocks with or without small amount of gabbroic rocks and more extensively exposed compared with the other two types. The Type I masses occur in the Zones I, II, V and VIa of KATADA *et al.* (1974).

Type II : Composed of a large amount of gabbroic rocks associated with acidic rocks such as quartz diorite, and characterized by low K_2O , though monzonitic rock is sometimes associated with them. The Type II masses occur in the Zones III and IVb of KATADA *et al.* (1974).

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Type III : Contains a large amount of gabbroic rocks characterized by high K_2O . The Type III masses occur in the Zone IV of KATADA *et al.* (1974).

Of the Type I masses, the Tono mass (SUZUKI, 1954), Hitokabe mass (KANISAWA, 1969), Kinkasan mass (SENDO & UEDA, 1963; KATO & TANAKA, 1973) and Tanohata mass (ISHII *et al.*, 1956) have been investigated. Of the Type II masses, the Orikabe mass (ISHIJIMA & KATO, 1971; KATO, 1972), Tabashine mass (SHIMAZU, 1955 ; KATO, 1974) and Ojika mass (IGI *et al.*, 1974) have been investigated. Of the Type III masses, the Ichinohe mass (ONUKI & TIBA, 1964) and Himekami mass (MASUDA *et al.*, 1965) have been investigated.

To elucidate the origins and mutual relationships of these three types, the present author has investigated several masses. In the present paper, the petrography and crystallization history of the Ojika mass will be described. The petrography of the S-mass, which is one of the satellitic masses of the Ojika mass, has already been reported (KUBO, 1976).

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Geological setting

The oldest rocks in the Ojika Peninsula are the Mesozoic sedimentary and volcanic

rocks. The Mesozoic system is composed of the Inai and Ojika Groups, and the Yamadori Formation (Triassic, Jurassic, and Cretaceous in age, respectively) (TAKIZAWA *et al.*, 1974). The Ojika gabbroic complex with several satellitic masses is intruded into the Ojika group. Before and after the emplacement of these igneous masses, innumerable thin porphyrite dikes were intruded. (Fig. 1).

Geological outlines of the Ojika gabbroic complex and its satellitic masses

The term "Ojika gabbroic complex" refers to the igneous masses exposed near the Mt. Okusayama, intruding the Ojika Group at the middle part of the Ojika Peninsula. The satellitic masses of the Ojika gabbroic complex are exposed at the Aji-shima islet, being named the N- and S-masses (Fig. 1).

The Ojika gabbroic complex consists of several small masses (Figs 2,3). As a whole it shows an outline elongated in the direction of NNE-SSW. This direction is nearly parallel to the strikes of the surrounding Mesozoic sediments and dikes. The internal structure of the mass (foliation and lineation) indicates that the major part of the mass inclines steeply eastward or almost vertically, while a small clinopyroxenite mass inclines gently eastward.

The complex comprises seven petrographic types of rocks, which are grouped into two series, namely, I: gabbro series (clinopyroxenite, porphyritic clinopyroxene gabbro, olivine two pyroxene gabbro, clinopyroxene hornblende gabbro, two pyroxene gabbro) and II: quartz diorite series (pyroxene hornblende diorite, quartz diorite).

These two series are distinguished from each other by the characteristics of plagioclase, that is, the plagioclase in the former is generally unzoned and has a higher An content (An80-90), whereas the plagioclase in the latter is lower in An content (An36-64) and remarkably zoned. The modal compositions of each rock type are listed in Table 1. The localities of samples used for modal and chemical analyses are shown in Fig. 4.

The sedimentary wall rocks are metamorphosed to two mica hornfels in several tens

Fig. 1. Geological sketch map of the southern half of Ojika peninsula (modified from TAKIZAWA *et al.*, 1974).

1: Plutonic rocks. The studied mass occupies the central part of the peninsula. 2: Yamadori Formation. 3—5: Ojika Group (3, Ayukawa Formation 4, Oginohama Formation 5, Tsukinoura Formation). 6: Inai group. 7: Fault. 8: Syncline-axis. 9: Anticline-axis. O: Mt. Okusayama.

of meter from the contact. The rocks locally contain sillimanite, cordierite or andalusite. The structural disturbance of the wall rocks is not clearly noticed. Most of the porphyrite dikes are metamorphosed. They contain metamorphic biotite and amphibole. Some of the dikes are intruded into the rocks of gabbroic series. The quartz diorite contains the dike rocks as xenolith.

The N-mass exposed at the northern shore of the Aji-shima islet is a nearly vertical dike-like body 100 m wide. It is composed of quartz gabbro and rhythmic layering is developed in two-thirds of the mass.

The S-mass in the Aji-shima islet is exposed along the southern coast as a stock-like body with a dimension of about 800×250 m. It is composed of six rock types varying from quartz

Fig. 2. Geological map of the Ojika gabbroic complex.

1: Quartz diorite. 2: Pyroxene hornblende diorite. 3: Two pyroxene gabbro. 4: Clinopyroxene hornblende gabbro. 5: Olivine two pyroxene gabbro. 6: Porphyritic clinopyroxene gabbro. 7: Clinopyroxenite. 8: Porphyrite. 9: Mesozoic sediments. 10: Fault.

Fig. 3. Geological cross section.

1: Quartz diorite. 2: Pyroxene hornblende diorite. 3: Two pyroxene gabbro. 4: Clinopyroxene hornblende gabbro. 5: Porphyritic clinopyroxene gabbro. 6: Porphyrite. 7: Mesozoic sediments.

Table 1. Modal compositions of rocks from the Ojika gabbroic complex.

No.	Pl	Qz	K-f	Opx	Cpx	Hb	Bi	Ore	Ol*	S.M.	O.M.	C.I.	Points
1	39.0				46.1	5.9				9.0	0.09	61.0	5491
2	57.8			0.2	22.8	6.1	0.3	5.8	6.1*	0.7	0.04	42.1	7163
3	72.7	1.6			5.9	11.5	0.9	2.8		4.3		24.5	4258
4	69.2			20.0	4.0			6.8				30.8	4578
5	51.0			6.8	0.7	34.3		6.9		0.3	0.16	48.9	5127
6	59.6			11.5	10.2	7.3		11.2			0.19	40.2	5142
7	53.6	4.5		2.6	1.6	31.4	1.8	1.9	2.3**	0.1	0.14	41.7	5557
8	52.6	6.6				31.8		1.6	1.1**	5.9	0.26	40.0	5258
9	57.0	2.1	0.1		0.2	33.5	1.5	1.5	1.6**	2.6		40.6	5659
10	75.9	8.7				10.0	0.5	1.3		3.6	0.05	15.4	5470
11	48.8	7.3	0.5			37.1	1.2	1.4		3.5	0.26	43.1	5106
12	56.7	18.7	0.1			17.7	5.2	1.4		0.1	0.05	24.2	4216
13	51.7	15.8	1.0			20.1	0.3	0.1		9.7	1.23	30.0	5812
14	56.8	27.6	1.5					0.4		12.7	1.04	13.5	6760

1: Porphyritic clinopyroxene gabbro (7441901). 2: Olivine two pyroxene gabbro (7441904). 3: Clinopyroxene hornblende gabbro (7412601). 4: Two pyroxene gabbro (7372309). 5: Hornblende two pyroxene gabbro vein in two pyroxene gabbro (7372308). 6: Two pyroxene gabbro xenolith in pyroxene hornblende diorite (7372603). 7: Pyroxene hornblende diorite near two pyroxene gabbro (7372305). 8: Pyroxene hornblende diorite near quartz diorite (7372608). 9—12: Quartz diorite (7372301, 7372405, 7372008, 7371811). 13, 14: Quartz diorite cropped out to the east of Kukunari-hama (7412706, 7412710). S. M.: Secondary minerals such as chlorite, actinolitic amphibole or epidote. O. M.: Other minerals such as apatite, sphene or calcite. C. I.: Color index.

gabbro to granodiorite. Unusual layered structure is developed in this mass, the structure and origin of which were reported in the previous paper (KUBO, 1976).

Description of rocks

Gabbro series

Clinopyroxenite

This rock is coarse-grained and homogeneous, being composed of clinopyroxene and hornblende. Clinopyroxene is coarse-grained subhedral and homogeneous, and contains small patches of brown hornblende. It is frequently uralitized. Colorless to pale green actinolitic amphibole and chlorite occur at

the margin of clinopyroxene.

Porphyritic clinopyroxene gabbro

This rock is characterized by sporadic, coarse grained clinopyroxene. It is composed mainly of plagioclase, clinopyroxene and hornblende, accompanied with secondary minerals such as actinolitic amphibole, chlorite, calcite and epidote. Clinopyroxene is euhedral to subhedral, and generally has oscillatory zoning. Plagioclase is euhedral to subhedral, and is fairly homogeneous, rarely having narrow sodic rim. Hornblende is brownish and occurs as patches in clinopyroxene or as interstitial crystal.

Fig. 4. Localities of samples listed in Tables 1, 2 and 3.

Olivine two pyroxene gabbro

This rock is medium to fine-grained, and is composed mainly of plagioclase, olivine, clinopyroxene, orthopyroxene and ore minerals. Hornblende, biotite and quartz are contained as accessories, accompanied with secondary minerals such as actinolitic amphibole or chlorite. Plagioclase is euhedral to subhedral and homogeneous. Olivine is subhedral and fairly homogeneous (Fo 69.8–71.5%). Clinopyroxene is coarse-grained, subhedral, and weakly zoned. It contains fine-grained plagioclase, olivine, ore minerals and patchy brown hornblende. The marginal parts of olivine

and clinopyroxene enclose plagioclase. Orthopyroxene is fine-grained and subhedral. Magnetite with ilmenite lamellae and chalcopyrite are recognized as interstitial crystals. Minute grains of spinel (less than 2 μm) are found at the periphery of ilmenite lamellae. Small amount of brown hornblende, biotite and quartz occur in the interstices.

Clinopyroxene hornblende gabbro

This rock is medium-grained, having locally well-developed foliation. It is composed mainly of plagioclase, clinopyroxene, hornblende and ore minerals. Quartz and biotite are contained as accessories. Plagioclase is euhedral to subhedral and homogeneous. Clinopyroxene and brown hornblende have an ophitic texture with plagioclase. Clinopyroxene and brown hornblende decrease in amount toward the southern part of the mass, subhedral green hornblende increasing instead of them. Anhedral ore minerals similar to those in olivine two pyroxene gabbro occur in small amount. They are accompanied by biotite.

Two pyroxene gabbro

This rock is fine-grained, homogeneous and is characterized by adcumulus texture (WAGER *et al.*, 1960). It is composed mainly of plagioclase, clinopyroxene, orthopyroxene and ore minerals. The former three minerals show well-developed preferred orientation. Clinopyroxene and orthopyroxene are euhedral to subhedral and homogeneous. Rarely, these pyroxenes are accompanied by very small amount of brown hornblende. Magnetite containing lamellae or blebs of ilmenite and small amount of pyrite occur in the interstices.

Quartz diorite series

Quartz diorite

This rock is medium-grained, leucocratic. It is composed mainly of plagioclase, quartz, hornblende, biotite and ore minerals. Cummingtonite, K-feldspar, clinopyroxene, apatite and zircon are contained as accessories. Plagioclase is euhedral to subhedral and remarkably zoned. Quartz is interstitial and has weak wavy extinction. Green hornblende and biotite are subhedral to anhedral. Magnetite contains ilmenite and hematite as lamellae or blebs. Small amount of chalcopyrite is also

recognized. These ore minerals are fine-grained. They occur as rounded grains included in hornblende or biotite crystals, whereas they are anhedral in the interstices. Rarely, clinopyroxene is enclosed in hornblende as relic. Cummingtonite and hornblende occur together in some single amphibole crystals.

Pyroxene hornblende diorite

This rock is medium-grained, leucocratic, resembling to quartz diorite megascopically. It is composed mainly of plagioclase, quartz, hornblende and ore minerals with or without clinopyroxene, orthopyroxene, cummingtonite and biotite. Plagioclase is euhedral to subhedral and fairly homogeneous, though irregularly heterogeneous crystals and remarkably zoned crystals are sometimes present. Pyroxenes are enclosed in hornblende as relic mineral or occur as euhedral to subhedral isolated crystals. In the latter case, the composition, shape and size of pyroxenes are similar to those in the gabbroic rocks, suggesting that the pyroxenes in this rock type were derived from the gabbroic rocks. Other characters of this rock type resemble to those of quartz diorite.

Minor rock type

Fine-grained porphyritic clinopyroxene gabbro

A block of this rock is found at the valley, to the west of clinopyroxenite mass. The rock is porphyritic with clinopyroxene and plagioclase phenocrysts. The clinopyroxene phenocrysts are 1–8 mm across, 6 mm average, and euhedral. It is free from inclusion and homogeneous except at the marginal part where weak oscillatory zoning is observed. The plagioclase phenocrysts are 0.5–1 mm long and euhedral. It is fairly homogeneous with or without normally-zoned narrow rim. Penetration twin is frequently observed.

The matrix is composed of fine-grained plagioclase, clinopyroxene, hornblende, pale greenish amphibole, biotite and ore minerals. The plagioclase is acicular in shape. Most of clinopyroxene is altered to secondary amphibole. The hornblende is subhedral and greenish brown. Minute biotite occurs in very small amount.

Based on the microscopic observations described above, this rock is considered to be

a chilled facies of porphyritic clinopyroxene gabbro.

Xenolith

Porphyritic clinopyroxene gabbro xenolith included in two pyroxene gabbro

This rock occurs as angular xenolith (less than 0.5 m across) within the two pyroxene gabbro which cropped out at the road cutting to the eastern side of Mt. Okusayama.

It consists of porphyritic clinopyroxene and fine-grained plagioclase, clinopyroxene, orthopyroxene, ore minerals, hornblende and biotite. The coarse-grained clinopyroxene is euhedral (1–15 mm across), the interior of which is irregularly replaced by plagioclase, hornblende, clinopyroxene, orthopyroxene, ore minerals and biotite. Minute acicular magnetite is enclosed in the porphyritic clinopyroxene, forming the concentric circles (Fig. 10). Most of fine-granular clinopyroxene lack this magnetite inclusion. Hornblende is brown and occurs in the interstices. It shows sometimes ophitic texture, partly hemming the coarse-grained clinopyroxene. Orthopyroxene occurs as fine granular crystal. Plagioclase is subhedral and homogeneous. Medium- (1 mm long) and fine-grained (less than 0.1 mm long) crystals exist. The medium-grained crystals frequently show penetration twin. Biotite is fine-grained and occurs in coarse-grained clinopyroxene in small amount. Magnetite with ilmenite lamellae occur as rounded crystals and as anhedral crystals. Minor amount of pyrite and chalcopyrite are also recognized.

Relationship among the rock types

Quartz diorite is intruded into porphyritic clinopyroxene gabbro, clinopyroxene hornblende gabbro and two pyroxene gabbro, and contains blocks of these rocks as xenoliths. These gabbroic rocks are thermally metamorphosed near the contact with quartz diorite. Pyroxene hornblende diorite changes gradually into quartz diorite.

Clinopyroxene hornblende gabbro contains porphyritic clinopyroxene gabbro as xenolith. Two pyroxene gabbro contains clinopyroxenite and porphyritic clinopyroxene gabbro as

Fig. 5. Schematic diagram showing the intrusive relations.

The rock at the point of an arrow is intruded by the rock at the root of the arrow. The dashed line indicates that the two rocks change gradually.

xenoliths.

Clinopyroxenite contacts with porphyritic clinopyroxene gabbro. Narrow transitional zone dipping steeply eastward is present between the two rocks. Within 20 meter from the boundary, porphyritic clinopyroxene gabbro contains larger amount of clinopyroxene than the other parts, and the layered structure due to the alternation of clinopyroxenitic and gabbroic parts is partly developed. The orientation of the layered structure is N 12–45° E, 40–45° S. The relations mentioned above are shown schematically in Fig. 5.

Olivine two pyroxene gabbro is surrounded by clinopyroxene hornblende gabbro. Though the contact between these rocks is not observed, gradual change between these two rocks is suggested. That is, foliations develop in both rocks have almost the same orientations, and chemical compositions of clinopyroxene and plagioclase in both rocks are similar.

As will be described later, clinopyroxene hornblende gabbro and two pyroxene gabbro differ distinctly in mineral assemblage and chemical compositions of minerals. Therefore, these rocks are not considered to have been differentiated *in situ* from a common magma after emplacement. Thus, these rocks are considered to have intruded in different stages.

After all, four stages of magmatic intrusion are distinguished. The magma of each stage may be represented by porphyritic clinopyroxene gabbro, clinopyroxene hornblende gabbro, two

pyroxene gabbro and quartz diorite, respectively*.

Petrochemistry

Ten rock samples from the Ojika gabbroic complex were chemically analyzed. Six samples were taken from the main rock types and the other four from the minor rock types. The results are listed with C.I.P.W. norms in Table 2.

The contents of oxides are plotted against differentiation index (Fig. 6). In this variation diagram, each oxide of the main rock types (Nos. 1–6) is plotted on the trend shown by a curve which has inflexion in the vicinity of No. 3, although such inflexion is not recognized for alkali oxides. The D. I. value increases in the order of intrusion. This fact suggests that each rock type was differentiated from a common original magma. The Ojika gabbroic complex might have been formed from a certain basic original magma, which differentiated at some deeper level and intruded into the present level successively in four stages of the differentiation.

As mentioned previously, phenocrysts of clinopyroxene and plagioclase exist in the chilled facies of porphyritic clinopyroxene gabbro. This indicates that crystals of clinopyroxene and plagioclase were suspended in the intruding magma of the first stage. In some places, clinopyroxenite (cumulate) was observed to grade into porphyritic clinopyroxene gabbro. Porphyritic clinopyroxene gabbro (specimen No. 2) taken near the contact between clinopyroxenite and porphyritic clinopyroxene gabbro is somewhat enriched in cumulus clinopyroxene. Therefore, the composition of magma at the first stage intrusion is not represented by No. 2.

Nos. 7, 8 and 9 are porphyritic clinopyroxene gabbros which are included in or intruded by other rocks. They are similar in chemical

* There is no evidence indicating the order of intrusion between clinopyroxene hornblende gabbro and two pyroxene gabbro. It is assumed tentatively in this paper that clinopyroxene hornblende gabbro intruded earlier than two pyroxene gabbro.

Fig. 6. Variation diagram.

Sample numbers correspond to those in Table 2. Pentagram: Evaluated chemical composition of liquid fraction of the magma at the first stage intrusion.

composition one another except for alkalis. The rocks of Nos. 8 and 9 are intruded by quartz diorite and contain some amount of hornblende and biotite as secondary products. High alkali content for the rocks of Nos. 8 and 9 is probably ascribed to metasomatism due to the intrusion of quartz diorite. As mentioned previously, the rock of No. 7 (porphyritic clinopyroxene gabbro xenolith in two pyroxene gabbro) is suffered from recrystallization but lacks secondary hornblende and biotite. Thus, No. 7 may be considered to be

most alike to the chemical composition of magma at the first stage of intrusion. The liquid fraction of this magma is evaluated by subtracting the core part of clinopyroxene from the bulk composition, and is shown by a pentagram in Figs. 6 and 7 and listed in Table 2.

As clinopyroxene is the only solid phase formed in the magma reservoir at deeper level before plagioclase appears, the liquid fraction of the magma should decrease in Si, Ca and Mg and increase in Al, Ti and Fe as fractional crystallization proceeds until plagioclase and titanomagnetite appear. The composition of the solid fraction plus minor interstitial liquid at the stage when these two minerals started to crystallize may be represented by No. 3.

After this stage, namely after the second stage intrusion, the composition of liquid fraction in the magma reservoir at deeper level would have followed the trend similar to that shown by a straight line in the variation diagram, which is shown by shaded zone in the same diagram (Fig. 6).

The ferromagnesian and alkaline components are plotted in the AFM diagram, together with those of the N- and S-masses (Fig. 7). The plots are nearly on the trend of calc-alkaline rock series after DALY (1914).

Mineralogy of clinopyroxene and plagioclase

Clinopyroxene

Clinopyroxene is found from all the rock types of the Ojika gabbroic complex. The compositions are shown in Fig. 8 with coexisting orthopyroxene and olivine. The clinopyroxene from clinopyroxenite and porphyritic clinopyroxene gabbro are free from inclusion and similar in shape and size (5–10 mm across). Similar clinopyroxene is also contained in olivine two pyroxene gabbro, though it encloses fine-grained plagioclase and olivine. Equidimensional euhedral crystals of clinopyroxene in these three rock types show compositional zoning*.

* The term "normal" and "reverse" zonings of mafic minerals mean respectively the increase and decrease of Fe/Mg ratio from core to margin of crystal.

Fig. 7. AFM diagram.

Sample numbers correspond to those in Table 2. Crosses represent the samples from the N- and S-masses of the Aji-shima islet.

Pentagram: Evaluated chemical composition of liquid fraction of the magma at the first stage intrusion.

The clinopyroxene in clinopyroxenite is poor in Fe and normally zoned weakly. The clinopyroxene in porphyritic clinopyroxene gabbro has Fe-poor core and oscillatory-zoned mantle (Fig. 9). The core is normally zoned weakly. The composition of the core is the same as that of the clinopyroxene in clinopyroxenite. The mantle is considerably richer in Fe than the core.

The clinopyroxene in olivine two pyroxene gabbro is oscillatory-zoned. The average composition is the same as that of the margin of clinopyroxene in porphyritic clinopyroxene gabbro. The margin of coarse-grained crystals is similar in composition to that of interstitial or ophitic crystals in clinopyroxene hornblende gabbro, though the latter is slightly enriched in Fe.

The clinopyroxene in two pyroxene gabbro is rectangular and euhedral (0.5–2 mm long) and is homogeneous in composition. It includes fine granular plagioclase and magnetite.

In pyroxene hornblende diorite and quartz diorite, clinopyroxene occurs as relic mineral within hornblende and rarely as subhedral

Table 2. Chemical compositions and C.I.P.W. norms of rocks from the Ojika gabbroic complex.

	1	2	3	4	5	6	7	8	9	10	11
SiO ₂	49.12	46.16	41.60	47.27	50.22	56.26	46.50	45.59	48.35	42.54	45.88
TiO ₂	0.27	0.18	0.81	0.68	0.57	0.41	0.73	0.84	0.88	0.96	0.81
Al ₂ O ₃	4.02	16.45	19.76	20.81	20.19	20.87	15.63	16.73	20.73	20.62	17.20
Fe ₂ O ₃	1.63	1.25	5.20	4.07	3.13	2.17	3.70	3.69	4.18	4.86	4.19
FeO	4.80	5.25	7.33	6.76	5.61	2.99	7.61	7.68	5.96	7.02	7.92
MnO	0.14	0.13	0.17	0.30	0.21	0.12	0.21	0.30	0.19	0.16	0.22
MgO	16.36	10.86	8.11	5.67	5.77	2.93	9.96	8.37	5.33	7.84	9.20
CaO	20.88	15.40	14.30	11.61	10.50	8.49	13.73	13.86	10.39	13.09	12.71
Na ₂ O	0.27	0.55	0.74	1.99	2.15	3.52	1.24	1.87	2.56	1.48	1.35
K ₂ O	0.06	0.14	0.08	0.09	0.29	0.21	0.08	0.37	0.91	0.17	0.09
H ₂ O +	2.33	2.89	0.93	tr	1.01	1.20	0.17	0.29	0.42	0.93	0.42
H ₂ O -	0.24	0.18	0.18	0.14	0.27	0.24	0.21	0.15	0.20	0.26	0.42
Total	100.12	99.44	99.21	99.39	99.92	99.41	99.77	99.74	100.10	99.93	99.99
Q	-	-	-	0.54	3.78	10.98	-	-	-	-	-
Or	-	0.56	0.56	0.56	1.67	1.67	0.56	2.22	5.56	1.11	0.56
Ab	-	4.72	6.29	16.77	18.34	29.87	10.48	12.97	21.48	10.87	11.53
Ne	-	-	-	-	-	-	-	1.49	-	0.92	-
An	-	41.98	50.32	47.54	44.58	40.31	36.70	36.14	42.26	48.93	40.59
Di {	-	14.38	8.58	3.83	3.25	0.81	12.76	13.46	3.94	6.73	9.40
En {	-	10.00	5.70	2.30	2.00	0.50	8.40	8.50	2.50	4.50	5.50
Fs {	-	3.17	2.24	1.32	1.06	0.26	3.43	4.09	1.19	1.72	3.43
Hy {	-	8.50	1.50	11.90	12.40	6.80	8.70	-	7.90	-	6.70
Fs {	-	2.64	0.66	7.13	6.07	3.04	3.17	-	3.83	-	4.36
Ol {	-	6.09	9.17	-	-	-	6.09	8.68	2.03	10.57	7.56
Fa {	-	2.14	3.98	-	-	-	2.75	4.69	1.12	4.59	3.88
Mt	-	1.86	7.66	5.80	4.64	3.25	5.34	5.34	6.03	6.96	3.71
Il	-	0.30	1.52	1.37	1.06	0.76	1.37	1.67	1.67	1.82	1.52
D.I.	1.58	5.28	6.85	17.87	23.79	42.52	11.04	16.68	27.04	12.90	12.09

1: Clinopyroxenite (7372704). 2: Porphyritic clinopyroxene gabbro (7441901). 3: Olivine two pyroxene gabbro (7441904). 4: Two pyroxene gabbro (7372309). 5: Pyroxene hornblende diorite (7372608). 6: Quartz diorite (7371811). 7: Porphyritic clinopyroxene gabbro xenolith in two pyroxene gabbro (7372310). 8: Porphyritic clinopyroxene gabbro intruded by quartz diorite (7372302). 9: Fine-grained porphyritic clinopyroxene gabbro intruded by quartz diorite (7441702). 10: Hornblende two pyroxene gabbro vein in two pyroxene gabbro (7372308). 11: Evaluated chemical composition of liquid fraction of the magma at the first stage intrusion.

Fig. 8. Compositions of pyroxenes plotted on the Ca-Mg-Fe diagram.

- (1) solid circle: clinopyroxenite. open circle: porphyritic clinopyroxene gabbro.
 (2) solid circle: olivine two pyroxene gabbro (Coexisting olivine is plotted below). open circle: clinopyroxene hornblende gabbro. (3) solid circle: two pyroxene gabbro. open circle: hornblende two pyroxene gabbro. (4) solid circle: quartz diorite. open circle: pyroxene hornblende diorite. (5) solid circle: fine-grained porphyritic clinopyroxene gabbro intruded by quartz diorite. open circle: two pyroxene gabbro xenolith in pyroxene hornblende diorite. triangle: porphyritic clinopyroxene gabbro xenolith in two pyroxene gabbro.

isolated crystal. The composition of relic clinopyroxene is somewhat different from those in the gabbroic rocks.

Crystallization process of clinopyroxene

Based on the field evidence, it is concluded that the clinopyroxenite is a cumulate formed at the present or somewhat deeper levels, the latter case being more probable as shown below. As plagioclase phenocryst exists in the chilled facies of porphyritic clinopyroxene gabbro, though in small amount, the intruding magma might have suspended small amount of plagioclase together with abundant clinopyroxene crystals. From such a magma, clinopyroxene cumulate free from plagioclase cannot be formed in such a small magma chamber as in the present case. Clinopyroxenite was probably formed as a cumulate at deeper level.

The morphological and compositional similarity indicates that the clinopyroxene in clinopyroxenite and the core part of clinopyroxene in porphyritic clinopyroxene gabbro were formed under the same condition. Their crystallization must have been accomplished before the emplacement of magma into the present level and before plagioclase have started to crystallize. The oscillatory-zoned mantle of clinopyroxene in porphyritic clinopyroxene gabbro might have crystallized mainly during the emplacement, because such a mantle exists also in the chilled facies of porphyritic clinopyroxene gabbro.

pyroxene gabbro.

The abrupt increase in Fe/Mg ratio at the boundary between core and mantle may be ascribed to a rapid drop in temperature on the occasion of the uprise of magma.

The reverse zoning in Ca-rich pyroxene, which is not accompanied by Ca-poor pyroxene, has been attributed to the rise in P_{H_2O} , f_{O_2} or temperature (HEWINGE, 1974; OSHIMA, 1975). In the present case, the mantle is reversely zoned with superimposed oscillations (Fig. 9). The reverse zoning of the mantle may be ascribed to the rise in P_{H_2O} and f_{O_2} , because, for such a small magma chamber as in the present case, the rise in P_{H_2O} may be expected during the fractional crystallization. The weak oscillations may reflect the turbulence of magma flow during emplacement.

The coarse-grained clinopyroxene in olivine two pyroxene gabbro might have been formed by the addition of more Fe-rich component by *in situ* crystallization to such clinopyroxene crystals as represented by those in porphyritic clinopyroxene gabbro.

The clinopyroxene in two pyroxene gabbro is rectangular and differs in its shape and composition from the coarse-grained equidimensional clinopyroxene represented by that in porphyritic clinopyroxene gabbro. The clinopyroxene in two pyroxene gabbro shows dis-

Fig. 9. Compositional zoning of clinopyroxene in porphyritic clinopyroxene gabbro.

Analyses within a single grain are shown by the same symbol. Arrows are drawn from core to margin. Microprobe step scanings by Mg- and Fe-K α across a clinopyroxene crystal are shown at the lower left. The compositions of points A, B and C are represented by open circle with dot.

tinct preferred orientation, having euhedral shape and compositional homogeneity. This indicates that the pyroxene was formed before the emplacement to the present level.

Origin of minute acicular magnetite in coarse-grained clinopyroxene

Part of the porphyritic clinopyroxene gabbro is metamorphosed by quartz diorite intrusion. Porphyritic clinopyroxene gabbro occurs also as xenolith in two pyroxene gabbro. Coarse-grained clinopyroxene in such a metamorphosed porphyritic clinopyroxene gabbro contains abundant minute and acicular magnetite (1–2 μ m across, several μ m in length). This magnetite lies along [001] or [100] of the host clinopyroxene, 2Vz of which is 48–52°. The minute magnetite grains are distributed in zones of host clinopyroxene as shown in Fig. 10. This pattern seems to correspond to the compositional zoning of the host clino-

Fig. 10. Photomicrograph of clinopyroxene in porphyritic clinopyroxene gabbro xenolith included in two pyroxene gabbro (open nicol).

pyroxene.

A thermal experiment conducted by INOMATA revealed that the magnetite inclusion disappeared under the condition of P=1 atm,

Fig. 11. An compositions of plagioclase.

$f_{O_2} = 10^{-13}$ atm, 1100–1250°C, for 2.5 hours.

Oriented magnetite inclusions in pyroxene have been reported from several regions (RUCKMICK & NOBLE, 1959; ONUKI & TIBA, 1964; GIBB, 1973; INOMATA & KUBO, 1974; YOKOYAMA, 1975). Generally these magnetite inclusions are considered to be exsolution lamellae.

The characteristic occurrence and the result of experiment suggest that the magnetite inclusions in metamorphosed clinopyroxene is exsolution product from host clinopyroxene.

The coarse-grained clinopyroxene studied is low in Ti:Al ratio (less than 1:4). This suggests a possibility for the existence of Fe^{3+} in the pyroxene (BOYD, 1971). Ca-rich clinopyroxene can contain some amount of Fe_2O_3 especially at high temperatures (HUCKENHOLZ *et al.*, 1969). If the clinopyroxene containing considerable amount of Fe_2O_3 is kept for a long time at certain temperatures somewhat lower than the solidus temperature, insoluble Fe^{3+} will be extracted as magnetite.

In the present case, the minute and acicular magnetite must have been extracted during the stage of recrystallization of host rock. Perhaps, the clinopyroxene in porphyritic clinopyroxene gabbro might have crystallized under relatively high oxidizing condition and con-

tained considerable amount of Fe^{3+} .

Plagioclase

The plagioclase in porphyritic clinopyroxene gabbro is fine-grained and euhedral to subhedral (0.4–1.6 mm long). It is homogeneous in composition (An 92.5–93.5), but the outermost part is generally a little more sodic (1–2%). Narrow sodic rim (An 78.5) rarely develops at the boundaries with later-crystallized minerals such as biotite or hornblende.

The plagioclase in olivine two pyroxene gabbro is euhedral to subhedral (0.4–2.5 mm long), showing weak preferred orientation. Fine-grained plagioclase crystals are sometimes enclosed in coarse-grained clinopyroxene. They are homogeneous, though a little more calcic at the margin (major part An 87–90, margin An 88–92). Coarse-grained plagioclase crystals tend to be euhedral and to have oscillatory zoning.

The plagioclase in clinopyroxene hornblende gabbro is euhedral to subhedral (0.4–4 mm long), locally showing preferred orientation. It is homogeneous (An 84–91), though narrow sodic rim (An 61) develops frequently at the boundaries with quartz and with hornblende.

The plagioclase in two pyroxene gabbro is fine-grained and subhedral (0.2–2 mm long),

Fig. 12. Sketch of plagioclase in quartz diorite and microprobe scanings by Ca- and Na-K α for the same grains.

showing preferred orientation. It is homogeneous (An 81–85). Fine-grained plagioclase crystals are sometimes enclosed in coarse-grained clinopyroxene.

The plagioclase in hornblende two pyroxene gabbro vein is similar in microscopic feature and composition to that in two pyroxene gabbro.

The plagioclase in pyroxene hornblende diorite is euhedral to subhedral (0.2–2 mm long), showing preferred orientation. Some of the plagioclase crystals are zoned with such a characteristic pattern as that observed commonly in quartz diorite (Fig. 12). The others are, however, normally zoned or unzoned. Generally, weak and irregular compositional inhomogeneity within a single crystal is noticed.

The plagioclase in quartz diorite is euhedral to subhedral (0.2–2 mm long), showing weak preferred orientation. It is zoned with characteristic pattern as shown in Fig. 12. Some fine-grained crystals show simple reverse zoning. The data analyzed by EPMA are shown in Fig. 11.

Crystallization process of plagioclase in the gabbroic rocks

As mentioned previously, the plagioclase in porphyritic clinopyroxene gabbro started to crystallize during the uprise of magma to the

present position from magma reservoir at a certain deeper level. The intruding magma might have cooled rapidly by encountering the wall rock at shallower depth. The rapid drop in temperature of magma might have caused the supersaturation for plagioclase. This resulted in the crystallization of fine-grained, homogeneous plagioclase. Somewhat sodic rim might have crystallized later from small amount of interstitial liquid.

The plagioclase in olivine two pyroxene gabbro and clinopyroxene hornblende gabbro is homogeneous, with or without sodic rim. The homogeneity of the main part of plagioclase indicates the crystallization under equilibrium condition, or crystallization from continuously refreshing liquid around the growing crystals as the case with the crystal-growth in magmatic flow at constant temperature. The former possibility is discarded on the basis of the existence of weak oscillatory zoning. The development of preferred orientation of plagioclase shows the existence of magmatic flow during the crystallization of plagioclase. This fact is in accordance with the latter possibility.

Crystal-growth in magmatic flow at constant temperature may be realized in fairly large magma reservoir. Then it may be considered that the crystallization of this ho-

ogeneous plagioclase at least in the olivine two pyroxene gabbro proceeded at the magma reservoir from which the magma of the first stage intrusion was transported, not at the magma chamber at shallow level.

Two pyroxene gabbro shows adcumulus texture and has relatively well-sorted grain-size and well-developed preferred orientation of plagioclase. These facts indicate that the plagioclase crystals in this rock type were transported to the place where the rock finally consolidated with other primocrysts such as pyroxenes or ore minerals. The adcumulus growth of each mineral might have proceeded during or after the accumulation of primocrysts. The plagioclase is considered to have started to crystallize in the magma reservoir, from which the magma of the second stage intrusion was transported. The gradational change of An % of plagioclase correlating with the sequence of the intrusion of host rock supports the above idea.

Interpretation of the zoning of plagioclase in quartz diorite

The zonal structure of plagioclase in quartz diorite is shown in Fig. 12. The crystallization process of this zoned plagioclase can be interpreted as follows.

i) Nucleation and crystallization in the magma reservoir under relatively static and H_2O -undersaturated condition (A—B in Fig. 13): At this stage, plagioclase P_1 crystallized from liquid L_1 at temperature T_1 .

ii) Crystallization during the uprise of magma (B—C in Fig. 13): Rapid reduction in pressure on the occasion of uprise of magma may shift the liquidus and solidus curves downward. Thus, plagioclase P_1 became unstable and partly resorbed by liquid and the Ca content in the liquid was increased. At temperature T_2 , plagioclase P_2 crystallized from liquid L_2 .

iii) Crystallization after the emplacement of magma into the present level (C—D in Fig. 13): Most parts of gabbroic rocks are not metamorphosed. Therefore, when quartz diorite magma intruded, the gabbroic rocks may not have been so much cooled yet. If the temperature of the gabbroic rocks at this stage was T_3 , quartz diorite magma may have

Fig. 13. Idealized zoning pattern of plagioclase in quartz diorite and melting relations in the plagioclase.

been cooled rapidly till the temperature became T_3 , and then cooled slowly. When slow cooling initiated, plagioclase P_3 crystallized at temperature T_3 around the more calcic plagioclase. At the same time, nucleation of plagioclase occurred, resulting in the formation of fine-grained plagioclase crystals. Plagioclase between P_2 and P_3 is almost completely lacking. This may be ascribed to the resorption during slow cooling.

P_{H_2O} was increased gradually due to the crystallization of anhydrous minerals. The crystallization was going on under the condition of increasing P_{H_2O} and the composition of plagioclase changed gradually from P_3 to P_4 .

It is a matter of course that the interpretation mentioned above is not a unique one, but it may be a quite probable one. The coarse-grained inhomogeneous plagioclase in

Table 3. Equilibration temperatures for several rock types.

Ol two px gabbro (7441904)	952°C
Two px gabbro (7372309)	898°
Hb two px gabbro (7372308)	832°
Porphyritic cpx gabbro xenolith in two px gabbro (7372310)	904°
Two px gabbro xenolith in px hb diorite (7372603)	867°
Quartz gabbro in the S-mass	931°

pyroxene hornblende diorite was derived probably from the gabbroic rocks nearby.

Equilibration temperatures for several rock types

The temperatures at later stages of the crystallization of several rock types were evaluated using the iron-magnesium exchange relation of Cpx-Opx pair (WOOD & BANNO, 1973). The following aspects are noticed from the data listed in Table 3.

i) The crystallization temperature of hornblende two pyroxene gabbro vein in two pyroxene gabbro is somewhat lower than that of the host two pyroxene gabbro. This is ascribed to the lowering of solidus temperature of this rock by addition of water-vapor.

ii) The equilibration temperature of equigranular matrix part of porphyritic clinopyroxene gabbro xenolith is almost equal to that of host two pyroxene gabbro. The similarities in crystallization temperature and mineral composition between the matrix part of the xenolith and the host two pyroxene gabbro suggest that the matrix part was partially melted at the stage of its reconstruction.

iii) The crystallization temperature of olivine two pyroxene gabbro is almost equal to that of the quartz gabbro in the S-mass at the Aji-shima islet. The crystallization temperature of quartz gabbro corresponds to that of the lower part of magma chamber in the present level (KUBO, 1976). It suggests that the Ojika gabbroic complex and the S-mass had nearly the same temperature, or the former had somewhat higher temperature at the early stage of their emplacement.

Origin of some minor rock types

Porphyritic clinopyroxene gabbro xenolith in two pyroxene gabbro

This rock is similar in porphyritic texture to the porphyritic clinopyroxene gabbro occurring at the northeastern end of the Ojika gabbroic complex. The fine-grained recrystallized matrix part differs, however, from the porphyritic clinopyroxene gabbro in mineral assemblage. Microscopically confirmed minerals which existed before the recrystallization are clinopyroxene and plagioclase. Thus, the xenolith is considered to have derived from a rock similar to the porphyritic clinopyroxene gabbro.

The amount of clinopyroxene of the xenolith is less than that of the porphyritic clinopyroxene gabbro enriched in clinopyroxene. The xenolith have probably derived from porphyritic clinopyroxene gabbro not enriched in clinopyroxene.

If the mineral assemblage of this xenolith is interpreted to have been formed by recrystallization without major exchange of chemical components with surrounding magma, the chemical composition of this rock would represent that of the magma at the first stage intrusion.

The process of recrystallization of this rock is interpreted as follows.

i) When this rock was captured by the magma, its mineral assemblage was clinopyroxene + plagioclase.

ii) Under the water-undersaturated condition of $P=1.5-2$ kb (estimation of this value is described in the next section) and $T \approx 900^\circ\text{C}$, the fine-grained matrix melted partly. The composition of the melt was probably situated in Di-En-SiO₂ field near the Di-En join in the postulated Di-Fo-SiO₂ system.

iii) The above melt would have consolidated rapidly and under disequilibrium condition, due to the rapid cooling of surrounding magma after emplacement.

iv) Clinopyroxene, orthopyroxene, titanomagnetite and plagioclase were formed from the melt. The fractionated residual liquid

Fig. 14. Crystallization model for the Ojika gabbroic complex.

Heavy line indicates the crystallization of specific minerals. The lower half of the diagram shows the crystallization process in the magma reservoir at the lower crust, and the upper half shows the process after the emplacement of magma into the upper crust, about 5 km in depth.

must have been enriched in Si and Ca. Therefore, the minor amount of residual liquid might have been squeezed out or small scale chemical exchange with surrounding magma might have occurred.

Hornblende two pyroxene gabbro

This rock occurs as thin veins in the two pyroxene gabbro which contacts with pyroxene hornblende diorite. Plagioclase lies parallel to the walls of the vein.

This rock was formed probably in the following process. Water-vapor was added at the later stage of consolidation of two pyroxene gabbro, and the rock was partly melted and intruded into the portion of already-solidified two pyroxene gabbro. The origin of water-vapor may be ascribed to the quartz diorite magma. Under the condition of higher vapor pressure and lower temperature, hornblende crystallized stably and most of the already-existed clinopyroxene were replaced by hornblende and the composition of relic clinopyroxene was altered.

Crystallization history of the Ojika gabbroic complex

The Ojika gabbroic complex is considered to have been formed by the magmatic intrusions of four stages. These intrusive masses seem to have been derived from a common magma reservoir at some deeper level and their mineralogical and chemical variations are well elucidated by the process of fractional crystallization in the magma reservoir.

The depth of emplacement of the Ojika gabbroic complex is evaluated from the thickness of sedimentary wall rocks. The complex is emplaced near the boundary between the Inai group and the Ojika group, the thickness of the latter being about 3 km. The Yamadori formation, the thickness of which is more than 1.6 km, is partly suffered from the thermal effect by the complex. After all, the Ojika gabbroic complex is considered to have emplaced at the depth of about 5 km, where the load pressure is about 1.5–2 kb.

It may be probable that the magma reservoir where the fractional crystallization proceeded was situated in certain portion of the

Fig. 15. Di-Fo-SiO₂ diagram. Heavy line with arrow shows the course of liquid fraction during differentiation.

lower crust. If this is the case, the magma reservoir was under the pressure condition near 10 kb.

At the first stage intrusion, only the clinopyroxene existed as solid phase in the magma reservoir under water-undersaturated condition of $P \approx 10$ kb, $T > 950^\circ\text{C}$. The chemical composition of clinopyroxene is represented by that in clinopyroxenite.

Before or during the uprise of magma, suspended grains were concentrated by certain mechanical process such as flow differentiation (KOMAR, 1972; KUBO, 1976) or by crystal sinking resulting in the formation of clinopyroxenite.

Plagioclase started to crystallize during the emplacement and porphyritic clinopyroxene gabbro was formed in close association with the clinopyroxenite.

At the second stage intrusion, clinopyroxene, plagioclase, olivine, orthopyroxene and titanomagnetite existed as solid phases in the magma reservoir. The temperature was about 950°C . In the magma chamber at shallower depth, a part relatively enriched in solid fraction formed olivine two pyroxene gabbro. In the other part, crystallization proceeded under the condition of gradually increasing water-vapor pressure and rapidly decreasing temperature, resulting in the formation of clinopyroxene hornblende gabbro.

At the third stage intrusion, clinopyroxene, plagioclase, orthopyroxene and titanomagnetite existed stably in the magma reservoir. The temperature was about 900°C .

The two pyroxene gabbro is the product of this stage and is constituted by well-sorted pyroxenes and plagioclase, which show adcumulus texture. These facts indicate that the intruding magma of this stage was derived mainly from the liquid fraction in the magma reservoir, and during the uprise pyroxenes and plagioclase started to crystallize almost simultaneously. The adcumulus growth of these crystals may be ascribed to the crystal-growth from continuously refreshed melt during uprise.

In any case, the magma at this stage is under relatively dry condition, considering the lack of hydrous minerals in its products.

At the fourth stage intrusion, plagioclase and titanomagnetite existed stably in the magma reservoir under the condition of relatively higher water-vapor pressure and lower temperature than those of the previous stages.

During or after the emplacement, the magma was contaminated partly by the gabbroic rocks already intruded. At this stage, some of the gabbros had not been cooled completely yet and remobilized, having resulted in the formation of pyroxene hornblende diorite associated with quartz diorite.

The process mentioned above is schematically shown in Fig. 14. The path of liquid fraction in the magma reservoir is shown also schematically in the Di-Fo-SiO₂ diagram (Fig. 15). That is, the composition of magma at the first stage intrusion must be in the stippled area in the diagram, and that of the liquid fraction is shown by the point **a**. From this

liquid, clinopyroxene and plagioclase were formed, though the latter mineral is not shown in this diagram, and the liquid moved toward the point **b**. When the liquid arrived at the point **b**, olivine started to crystallize. At point **c**, orthopyroxene appeared, which might be followed by titanomagnetite. The magma of this stage corresponds to the second stage intrusion.

The third stage intrusion was taken place before the liquid arrived at the point **d**. The liquid of the fourth stage intrusion is not shown in this diagram.

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北上山地，牡鹿斑れい岩体の岩石学的研究

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(要 旨)

南部北上山地，牡鹿半島に露出する牡鹿斑れい岩体は，ジュラ系を貫ぬく小岩体で，次の7岩相が区別される。

1) clinopyroxenite, 2) porphyritic clinopyroxene gabbro, 3) olivine two pyroxene gabbro, 4) clinopyroxene hornblende gabbro, 5) two pyroxene gabbro, 6) pyroxene hornblende diorite, 7) quartz diorite.

これらは斜長石の性質に基づいて斑れい岩系岩相(1~5)と石英閃緑岩系岩相(6, 7)に大別される。すなわち，後者中の斜長石は特有の累帯構造を有し，前者中の均質な斜長石とは明瞭に区別される。

野外の貫入関係から，本岩体は4回のマグマ進入により形成されたと結論される。前3回の進入で斑れい岩系岩相が，最後の進入で石英閃緑岩系岩相が形成された。岩体の固結深度は，堆積岩の層厚から判断して約5kmと推定される。マグマの温度は輝石温度計により推定された。

本岩体の形成過程は以下のとおりである。地殻下部のマグマ溜り中でまず単斜輝石が晶出し，950°C以上の温度で第1回目のマグマの上昇進入が起き，clinopyroxenite と porphyritic clinopyroxene gabbro を形成した。マグマ溜り中では，斜長石，かんらん石，斜方輝石，チ

タノマグネタイトの順に晶出し，約950°Cの温度で第2回目のマグマの上昇進入が起き，olivine two pyroxene gabbro と clinopyroxene hornblende gabbro を形成した。マグマ溜り中の液相部が局部的に上昇進入し(第3回目のマグマの進入)，two pyroxene gabbro が次に形成された。この時の温度は約900°Cであった。深部のマグマ溜り中では次第に温度が下がり P_{H_2O} が上昇してきた。輝石にかわって普通角閃石が晶出しはじめる段階で第4回目のマグマの進入が起き，quartz diorite が形成された。進入の際マグマは未冷却の斑れい岩を一部混成し，その境界部に pyroxene hornblende diorite を形成した。本岩体の母体マグマは，その最初の進入時において，液相部の組成がアルミナに富みアルカリに乏しい玄武岩質のものであったと考えられる。

(地 名)

Aji-shima	網地島
Ayukawa	鮎川
Kukunari	十八成
Ohara-hama	大原浜
Okusayama	大草山
Tomari	泊
Tashiro-jima	田代島
Yagawa	谷川