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Impact of hornblende crystallization for the genesis of calc-alkalic andesites

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Abstract—Hornblende gabbros, including hornblendite or hornblende megacrysts, often enclosed in calc-alkalic andesites, are common along the Japan Sea coast of northeastern Japan. The andesites, in turn, are closely associated with high–alumina basalts.

Hornblende gabbros consist of plagioclase, hornblende, clinopyroxene, olivine, orthopyroxene, magnetite and apatite. The first two minerals are essential constituents, with modal plagioclase contents ranging from 15 to 55 volume percent and hornblende from 30–60 volume percent,—rarely reaching 90 volume percent in hornblendite. Magnetite is an intercumulus phase, with a modal abundance reaching 7 volume percent. These phases occur as cumulus minerals, poikilitically enclosing clinopyroxene and magnetite. Most hornblende is pargasitic with a small portion of tschermakite. Clinopyroxene is high in Al_2O_3, being consistent with a suggestion that clinopyroxene crystallized at high pressure.

Experimental studies in the system basalt-water indicate that hornblende and plagioclase will crystallize from a wet magma in the pressure range 7–10 kbar at temperatures near 1000°C. At these pressures and temperatures hornblende and plagioclase will sink to form cumulate hornblende and plagioclase.

It is suggested that calc-alkalic andesite magma may be formed by separation of about 40 percent of a hornblende gabbro mineral assemblage from a proposed hydrous, parental high–alumina basalt magma near the base of the crust in the island arcs. Extensive hornblende gabbros, or metamorphic rocks derived from them, may, therefore, be expected to underlie calc-alkalic andesites. Such a model is consistent with the structure of the lower crust in northeastern Japan from seismological observations.

INTRODUCTION

THE GENESIS of calc-alkalic andesite, commonly occurring in island arcs and along continental margins, is one of the most important problems in igneous petrology. YODER and TILLEY (1962), in an experimental study of liquidus phase relations of tholeiitic and related basalts at high water pressure, found that hornblende has a wide pressure-temperature stability field, and sometimes is stable near the liquidus. This study revived the importance of hornblende fractionation [originally postulated by BOWEN (1928)] in the evolution of igneous rocks. Based mainly on experimental studies in hydrous synthetic and natural basalt systems, hornblende fractionation has been considered an important factor in the genesis of calc-alkalic andesites (*e.g.*, GREEN and RINGWOOD, 1968; HOLLOWAY and BURNHAM, 1972; ALLEN *et al.*, 1975; ALLEN and BOETTCHER, 1978; CAWTHORN and O'HARA, 1976).

Hornblende gabbro inclusions, or hornblende megacrysts in calc-alkalic andesite and high–alumina basalt, are common in the Fossa Magna region in central Japan (TAKESHITA, 1974, 1975). Hornblende gabbro closely associated with calc-alkalic andesite has also been reported from numerous other localities in Japan and in other island arcs (*e.g.*, SATO *et al.*, 1975; SHIMAZU *et al.*, 1979; KUNO and AOKI, 1970; ARCULUS and WILLS, 1980). The purpose of this report is to describe the petrology and geochemistry of these rocks, and to discuss possible origins of calc-alkalic andesites in light of these data.

OCCURRENCE OF HORNBLENDE GABBRO INCLUSIONS

In the Green Tuff region (Figure 1) there are several localities along the Japan Sea coast of northeastern Japan where hornblende gabbros, including hornblendite and hornblende megacrysts, are closely associated with calc-alkalic andesites.

(1) Shigarami

Felsic volcanic rocks, andesites of both the calc-alkalic and tholeiitic series, and high–alumina basalt of Miocene to early Pleistocene age occur in this district (TAKESHITA, 1974, 1975).

Andesites. Calc-alkalic augite-hypersthene andesites are predominant in the Shigarami district.

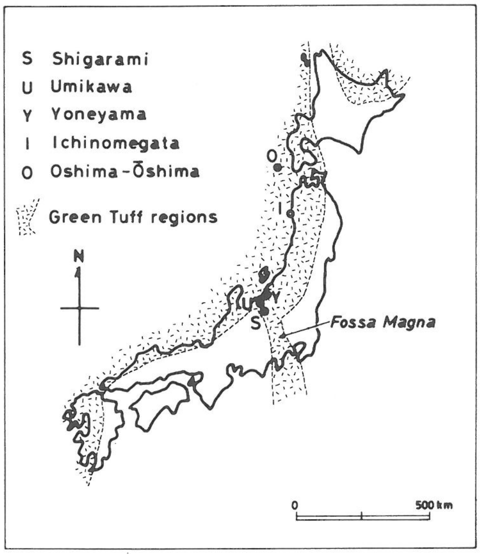

FIG. 1. Localities of hornblende gabbroic inclusions in northeastern Japan.

Their SiO_2 content ranges from 50 to 59 weight percent. Plagioclase phenocrysts range from labradorite to bytownite, sometimes to anorthite. Augite and hypersthene are abundant and hornblende is sometimes present. Magnetite also occurs as phenocrysts. The groundmass, pilotaxitic to hyalophilitic in texture, consists of andesine-labradorite laths and prismatic crystals of hypersthene and rare clinopyroxene. In the leucocratic portions, anhedral anorthoclase and quartz poikilitically enclose plagioclase laths, pyroxene rods and magnetite grains.

Tholeiitic augite-hypersthene andesites are less common. The phenocrysts in these rocks are the same as in calc-alkalic andesite, but the groundmass is composed of plagioclase laths and pigeonite. Hypersthene, when present, is always sandwiched between pigeonite or subcalcic augite (YAGI and YAGI, 1958).

High-alumina basalt. The phenocrysts are plagioclase, olivine, augite and rare orthopyroxene and hornblende. The plagioclase is bytownite with anorthite cores, surrounded by labradorite-andesine rims. Augite is abundant in calcium-rich basalts, but is rare in magnesium-rich ones. The ground–mass consists of labradorite laths, augite, subcalcic augite or pigeonite together with small amounts of olivine without reaction rims. Magnetite is confined to the groundmass.

Hornblende gabbro inclusions. The calc-alkalic andesites carry inclusions of hornblende gabbro or hornblendite as well as hornblende megacrysts (YAMAZAKI *et al.*, 1966; TAKESHITA and OJI, 1968; TAKESHITA, 1974). The texture of the hornblende gabbro is medium (0.5–1.0 mm) to coarse-grained (2.0–7.0 mm grain size), and is essentially a plagioclase (An_{85}–An_{95}) cumulate (WAGER *et al.*, 1960). The plagioclase occurs as rectangular, euhedral, chemically homogeneous crystals, rarely containing globular magnetite grains. Long prismatic hornblende shows subhedral form against plagioclase. Hornblende-rich gabbro, containing more than 50 volume percent hornblende, is, therefore, regarded as plagioclase-hornblende cumulate in which euhedral to subhedral hornblende poikilitically encloses clinopyroxene. Most magnetite grains are subhedral to anhedral, occurring as an intercumulus phase.

The modal abundance of hornblende ranges from 30 to 60 volume percent in hornblende gabbro and may reach 95 volume percent in hornblendite. In contrast to phenocrystic hornblende, the hornblende in the gabbros is generally homogeneous with only a weak zoning in some subhedral grains. Anorthite and hornblende megacrysts in the andesites are homogeneous in composition and structure except for a thin labradorite rim on plagioclase.

(2) *Yoneyama and Umikawa districts*

The Yoneyama district to the northeast, and the Umikawa district to the northwest of the Shirigama district (Figure 1) have mostly Pliocene volcanics, ranging from olivine-augite high–alumina basalt to pyroxene andesites and biotite–hornblende andesites for the calc-alkalic series. The pyroxene andesites are the most common (SATO *et al.*, 1975; SHIMAZU *et al.*, 1979).

In the Yoneyama district, olivine-augite or hornblende-bearing olivine-augite high alumina basalt occurs. Although such basalts have not been found in the Umikawa district, basaltic andesite is present. Calc-alkalic andesite is common in both districts.

Hornblende gabbroic inclusions. The calc-alkalic andesites in the Yoneyama and Umikawa districts often contain hornblende gabbro inclusions as well as hornblende and diopside megacrysts, and rarely anorthite, up to 8 cm in size. The gabbro consists principally of hornblende (6–47 volume percent) and plagioclase, with varying amounts of augite, olivine, magnetite and rare hypersthene. As in the gabbros from the Shigarami district, fine-grained patches of basalt occur in hornblende gabbro from the Umikawa district (SHIMAZU *et al.*, 1979).

(3) *Ichinomegata*

Ichinomegata in northeastern Honshu (Figure 1) is well known for the occurrence of various ultramafic and mafic inclusions. These inclusions are garnet lherzolite, spinel lherzolite, websterite, amphibolite, hornblende gabbro, hornblendite and various crustal rocks (KUNO and AOKI, 1970; AOKI, 1971; TANAKA and AOKI, 1981; AOKI and FUJIMAKI, 1982; FUKUYAMA, 1985; TAKAHASHI, 1986). AOKI (1971) considered that hornblende gabbro, hornblendite, and amphibolite form the greater part of the lower crust in this region.

Among mafic inclusions, hornblende gabbro with 30–60 volume percent hornblende, is the most common. Modal plagioclase contents are usually less than 10 percent in hornblendite, but reaches 50 volume percent in the gabbro. Cumulus olivine and clinopyroxene, surrounded by intercumulus, poikilitic hornblende, are described by AOKI (1971) in one type of hornblendite. This hornblendite resembles the coarse–grained, hornblende-rich gabbros from the Shigarami district. The mineral assemblages of the hornblende gabbro at Ichinomegata are the same as in the other districts.

(4) Oshima-Oshima Volcano

Oshima-Oshima is an insular volcano off the Japan Sea coast of Hokkaido (Figure 1) with about 30 percent calc-alkalic andesite and about 70 percent alkalic basalt among the lavas and pyroclastics. The alkalic basalts are augite-olivine basalts with phenocrysts of plagioclase, olivine and augite in a groundmass of plagioclase, anorthoclase, fine-grained clinopyroxene, olivine and magnetite. Calc-alkalic andesites comprise olivine-pyroxene andesite, hornblende-pyroxene andesite and biotite–hornblende-bearing pyroxene andesite. Both andesites and basalts are intimately associated; for example, in the 1741–1742 eruption pyroclastics changed from calc-alkalic andesite pumice to olivine basalt scoria.

Most andesites and some basalts contain ultramfic and mafic inclusions such as dunite, wehrlite, olivine-clinopyroxenite, hornblendite and hornblende gabbro. Hornblende gabbro is predominant and consists mainly of hornblende and plagioclase, with variable amounts of olivine, clinopyroxene, orthopyroxene, magnetite and apatite.

PETROCHEMISTRY OF VOLCANIC ROCKS

(1) High–alumina basalts

Bulk chemical compositions of several high–alumina basalts from the Shigarami and Yoneyama districts (SATO *et al.*, 1975), and alkali basalt from Oshima-Oshima (YAMAMOTO, 1984) show that the Al_2O_3 contents are always high, especially in the Yoneyama basalts. There may also be an increase in K_2O/Na_2O from the volcanic front toward the Japan Sea coast (KUNO, 1960; KAWANO *et al.*, 1961).

(2) Calc-alkalic andesites

The calc-alkalic andesites from Shigarami (TAKESHITA, 1975), Yoneyama (SATO *et al.*, 1975) and Oshima-Oshima (YAMAMOTO, 1984) are characterized by their higher Al_2O_3 and alkalies compared with aphanitic andesite of the hypersthenic rock series (KUNO, 1950) and are also rather poor in MgO and CaO.

(3) Hornblende gabbros

The hornblende gabbros from the Shigarami (TAKESHITA, 1975), Yoneyama (SHIMAZU *et al.*, 1979), Umikawa (SHIMAZU *et al.*, 1979) and Ichinomegata (AOKI, 1971) districts exhibit generally low silica contents, ranging from 35 to 47 weight percent, whereas FeO*/(FeO* + MgO) is fairly high and ranges from 0.335 to 0.796. Normative nepheline is always present, except in an orthopyroxene-clinopyroxene hornblende gabbro from Umikawa (SHIMAZU *et al.*, 1979). In one case from Ichinomegata (AOKI, 1971), there is leucite in the norm. Diopside and magnetite contents are always high. These features are similar to those of hornblende gabbro from the Lesser Antilles (LEWIS, 1973a, b; ARCULUS and WILLS, 1980).

It is noted that in the FeO*o–MgO–(Na_2O + K_2O) diagram (Figure 2) hornblende gabbros associated with the calc-alkalic andesites in the Shigarami district fall near the extension of the tie-lines connecting calc-alkaline andesites with high–alumina basalts. These gabbros do fall within the tholeiite field.

Hornblende. All hornblende analyses (TAKESHITA, 1975; YAMAZAKI *et al.*, 1966; SHIMAZU *et al.*, 1979; ONUKI, 1965; YAMAMOTO, 1984) are compositionally similar with low SiO_2 and high concentrations of Al_2O_3 and Fe_2O_3. The TiO_2 content is low (less than 2.5 weight percent).

The hornblende compositions are plotted in the Al^{IV}-(Al^{VI} + Fe^{3+} + Ti) and Al^{IV}-(Na + K) diagrams (Figure 3) used by DEER *et al.* (1963). The pargasite contents range from 40 to 90 percent, and tschermakite from 10 to 30 percent, with less than 10 percent of the edenite molecule.

Clinopyroxene, present as an accessory mineral, has generally high Al_2O_3 and low Na_2O and TiO_2, and thus exhibit high concentrations of the tschermak's molecule (4–12 mol percent). The Ca-tschermak's molecule has a wide high-pressure sta-

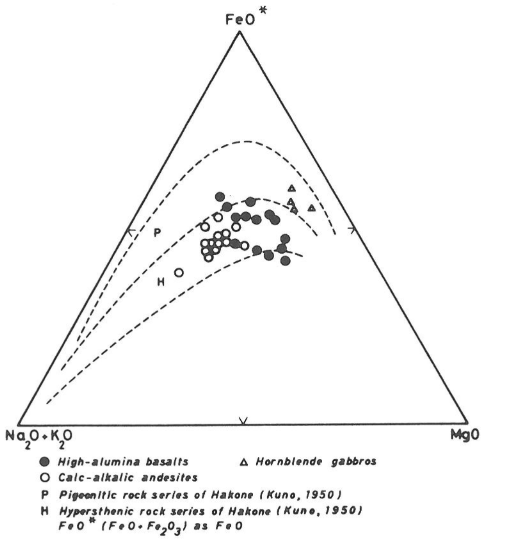

FIG. 2. Plots of high–alumina basalts, calc-alkalic andesites and hornblende gabbros in the MgO–FeO*–(Na_2O + K_2O) diagram. Data from KUNO (1950), SATO *et al.* (1975), YAMAMOTO (1984), TAKESHITA (1974, 1975), SHIMAZU *et al.* (1979), AOKI (1971).

bility field (HAYS, 1966) with increasing tschermak's molecule content with increasing pressure (KUSHIRO and YODER, 1966; KHANUKHOVA *et al.*, 1976). Therefore, it is probable that clinopyroxene crystallization took place at high pressure.

Magnetite consists mainly of FeO and Fe_2O_3, with variable amounts of Al_2O_3, TiO_2, MnO and MgO. An electron microprobe analysis of an intercumulus magnetite showed (weight percent); TiO_2 = 7.59, Al_2O_3 = 9.00, Cr_2O_3 = 0.16, FeO* = 70.10, MnO = 0.33, and MgO = 7.53 (T. UENO, personal communication).

The Fe/Mg ratios among hornblende, clinopyroxene and orthopyroxene in the gabbros of the Shigarami district are displayed in Figure 4 with hornblende showing higher Fe/Mg than the co–existing minerals. Similar relations among hornblende, clinopyroxene, orthopyroxene, olivine and glasses have been observed in experimental run products from basalt-H_2O systems (HOLLOWAY and BURNHAM, 1972; ALLEN *et al.*, 1975).

GENESIS OF HORNBLENDE GABBROS

It is inferred from the textural and compositional relations that the crystallization sequence in the gabbros was olivine, clinopyroxene, plagioclase, hornblende and magnetite. It is noted that hornblende is not an early crystallizing phase. In view of the high water contents required to stabilize hornblende on or near the liquidus of mafic magmas (*e.g.*, YODER and TILLEY, 1962; HOLLOWAY and BURNHAM, 1972; ALLEN *et al.*, 1975; ALLEN and BOETTCHER, 1978), it is suggested that the parental magma for the calc-alkalic andesites did not have very high water contents. Thus, it is suggested that the magma from which hornblende crystallized had

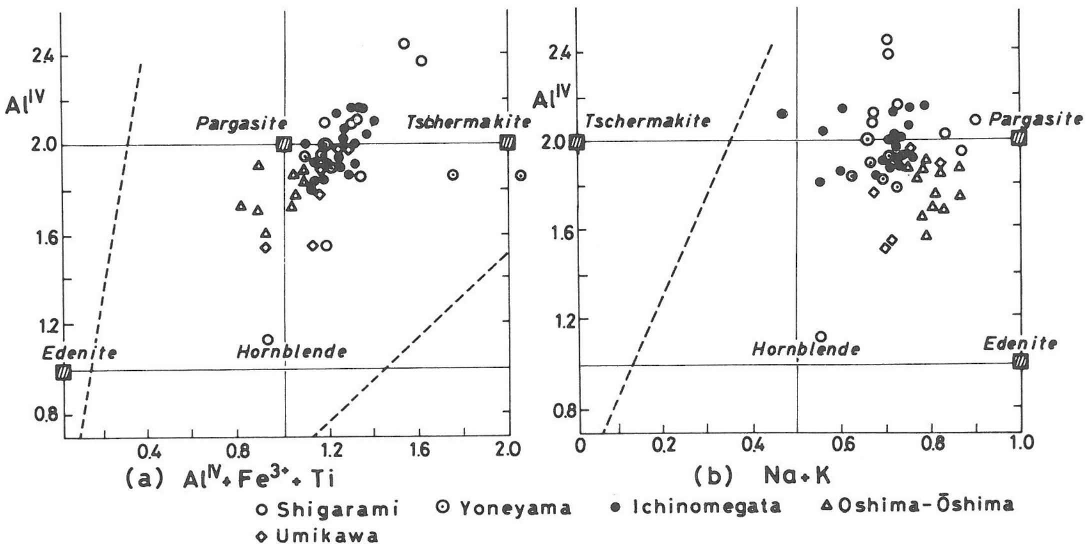

FIG. 3. Hornblende compositions in Al^{IV}-(Al^{VI} + Fe^{3+} + Ti) and Al^{IV}-(Na + K) diagrams. Data from TAKESHITA (1975), AOKI (1971), YAMAZAKI *et al.* (1966), SHIMAZU *et al.* (1979), ONUKI (1965), YAMAMOTO (1984). Symbols as in Figure 4.

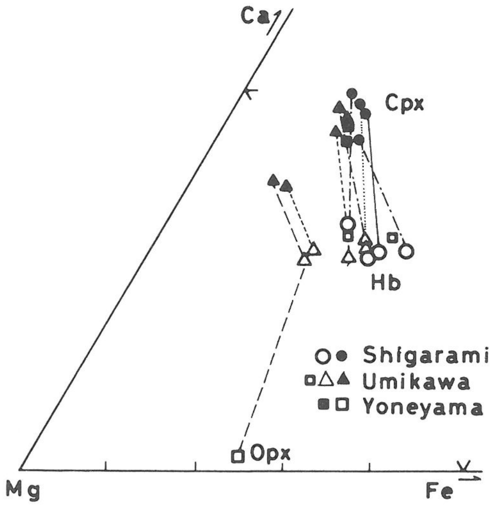

FIG. 4. Clinopyroxene, hornblende and orthopyroxene compositions from the Shigarami, Umikawa and Yoenyama districts. Data sources as in Figure 3.

undergone some fractionation of anhydrous phases (point B in Figure 5). Most likely, the early crystallizing phases were olivine and anorthite (see also discussion below) to shift the liquid composition along the line from cpx-pl toward point B at which point hornblende began crystallizing and driving the liquid from B toward c (Figure 5).

The difference between hornblende gabbro and hornblendite may be related to whether or not plagioclase sinks in the magma. FUJII and KUSHIRO (1977) found that plagioclase of any composition will float in anhydrous basaltic melt at pressures higher than about 5 kbar, whereas in the pressure range 1–5 kbar, plagioclase more calcic than An_{90} will sink. Recently, KUSHIRO (1987) found that plagioclase more calcic than An_{60} would sink in a basaltic melt with 1.5 weight percent H_2O at pressures corresponding to those at the base of the crust. Therefore, plagioclase may sink in the basalt magma together with hornblende and magnetite, sometimes also clinopyroxene, resulting in the formation of hornblende gabbro. If plagioclase does not sink, hornblendite, instead of hornblende gabbro, will be formed, giving rise to gradational facies between the two types of rocks.

From the available experimental data and mineral assemblages in the gabbros, AOKI (1971) suggested that hornblende gabbro and hornblendite of Ichinomegata were formed at about 7–9 kbar near 1000°C, corresponding to a depth of 25–30 km, whereas SHIMAZU *et al.* (1979) estimated the pressure and temperature of crystallization of gabbros with the mineral assemblage olivine–clinopyroxene-plagioclase-hornblende from the Umikawa district to be about 10 kbar and 1000°C, respectively (about 30 km depth). In both models, the basalt magma was hydrated, with total pressure greater than water pressure. It appears, therefore, that the crystallization of these gabbroic inclusions occurred near the base of the crust in northeastern Japan.

ORIGIN OF CALC-ALKALIC ANDESITE MAGMA

The relationship of hornblende fractionation in high–alumina basalt magma to the formation of calc-alkalic andesite will be considered next,—first for the Shigarami district. The composition of a suggested parental high–alumina basalt magma B (No. 1; Table 1), a representative calc-alkalic andesite (No. 3, sample 66862; Table 1), hornblende gabbro HG (No. 2; Table 1), clinopyroxene (No. 7; Table 1) and hornblende (No. 8; Table 1) from the Shigarami district are shown.

Plagioclase and hornblende are present in the gabbro inclusions in nearly equal proportions, and the proportions of inclusions in the magma are estimated to be less than 50 percent of the total amount of material. We choose 40 percent for the amount to be subtracted from the parental magma. Liquid compositions a, b and c (Figure 5) can be

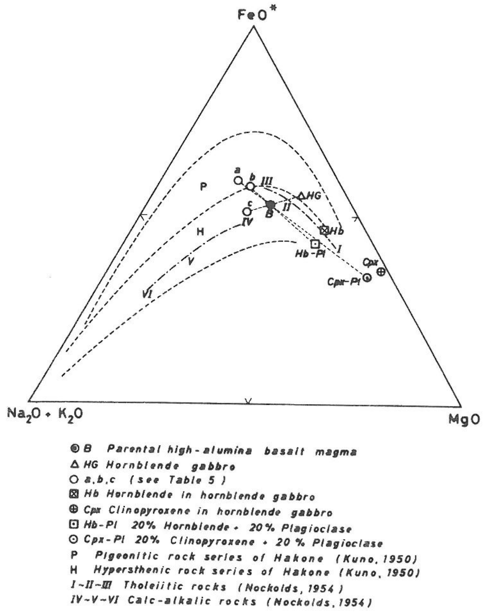

FIG. 5. High–alumina basalt, hornblende gabbro, hornblende, clinopyroxene and residual compositions (from Table 1).

Table 1. Comparison of compositions of residua after separation of hornblende-free cumulate, hornblende-bearing cumulate and hornblende gabbro from the high-alumina basalt magma

$$B(100\%) - Cpx(20\%) - Pl\,An_{90}(20\%) \rightarrow a(60\%)$$

$$B(100\%) - Hb(20\%) - Pl\,An_{90}(20\%) \rightarrow b(60\%)$$

$$B(100\%) - HG(40\%) \rightarrow c(60\%)$$

Number	1	2	3	4	5	6	7	8
Symbol	B	HG		a	b	c	Cpx	Hb
Weight percent								
SiO_2	48.57	43.40	54.31	49.93	51.69	52.06	48.26	43.22
TiO_2	0.94	1.19	0.93	1.30	1.04	0.77	0.82	1.58
Al_2O_3	20.42	21.25	19.15	20.41	18.29	19.88	6.22	12.59
Fe_2O_3	3.95	4.74	3.91	—	—	3.43	—	—
FeO	5.62	6.12	3.58	12.84*	10.87*	5.29	7.63*	13.55*
MnO	0.16	0.16	0.11	0.27	0.21	0.16	—	0.10
MgO	5.07	6.60	3.62	3.91	3.85	4.05	13.63	13.90
CaO	11.64	14.20	9.42	5.68	9.33	9.94	23.18	12.14
Na_2O	2.37	1.65	2.77	3.59	2.96	2.85	0.26	2.16
K_2O	0.97	0.38	1.94	1.63	1.38	1.36	—	0.76
P_2O_5	0.24	0.31	0.25	0.40	0.31	0.19	—	—
Total	99.95	100.00	99.99	100.00	99.96	99.98	100.00	100.00
MgO	28.8	34.7	23.4	17.8	20.2	24.3	63.3	45.8
FeO*	52.2	54.6	46.0	58.4	57.0	50.4	35.5	44.6
$Na_2 + K_2O$	19.0	10.7	30.5	23.8	22.8	25.3	1.2	9.6

Norm Compositions		1	2	3	6	Atomic Ratios	7	8
Q		—	—	7.31	3.04		O = 6	O = 23
Or		5.73	2.25	11.49	8.06	Si	1.802	6.258
Ab		20.12	10.82	23.46	24.10	Al^{IV}	0.198	1.742
An		42.12	49.39	33.94	37.36	Al^{IV}	0.076	0.403
Ne		—	1.68	—	—	Ti	0.023	0.172
Di	Wo	5.95	8.05	4.72	4.55	Fe^{3+}	—	—
	En	3.81	5.51	3.44	2.72	Fe^{2+}	0.238	1.635
	Fs	1.71	1.89	0.83	1.58	Mn	—	0.012
Hy	En	7.67	—	5.60	7.41	Mg	0.764	3.019
	Fs	3.50	—	1.18	4.30	Ca	0.928	1.884
Ol	Fo	0.82	7.69	—	—	Na	0.019	0.606
	Fa	0.42	2.90	—	—	K	—	0.141
Mt		5.73	6.87	5.67	4.96			
Il		1.78	2.26	1.76	1.46			
Ap		0.57	0.67	0.61	0.44			

* Total iron represented as FeO
1 (B): Average of four analyses of lime-rich high-alumina basalts from Shigarami (TAKESHITA, 1975)
2 (HG): Average of four analyses of hornblende gabbros from Shigarami (TAKESHITA, 1975; SHIMAZU *et al.*, 1979)
3: Calc-alkalic andesite, No. 66862 from Shigarami (TAKESHITA, 1975)
7 (Cpx): Average of three analyses of clinopyroxene in clinopyroxene hornblende gabbro from Shigarami (SHIMAZU *et al.*, 1979)
8 (Hb): Average of five analyses of hornblende in the hornblende gabbro from Shigarami (SHIMAZU *et al.*, 1979)

obtained by subtracting 40 percent of clinopyroxene (20 percent) + plagioclase (An_{90}; 20 percent), hornblende (20 percent) + plagioclase (20 percent) and hornblende gabbro (40 percent), respectively. In Figure 5, *a* plots in the tholeiite field, *c* in the calc-alkalic field and *b* on the boundary between those two fields. The results indicate that hornblende fractionation from high-alumina basalt will tend to shift the residual liquid compositions along the calc-alkalic trend. Magnetite, which may reach modal abundances of 7 percent in some gabbros, can also play an important role in the fractionation processes (OSBORN, 1959). Magnetite fractionation alone, however, drives the residual liquid away from the FeO* apex toward the MgO–(Na_2O + K_2O) side. This trend differs from the calc-alkalic trend represented by the shift of liquid compositions from *b* to *c* in Figure 5. Therefore, silicate minerals, *e.g.*, hornblende, must crystallize together with magnetite in order for the residual liquids to follow the calc-alkalic trend.

TAKESHITA and OJI (1968) concluded that calc-alkalic andesites were formed as residua after separation of hornblende gabbro from high alumina basalt. In the Oshima-Oshima volcano, YAMAMOTO *et al.* (1977) and YAMAMOTO (1984) suggested that amphibole fractionation (hornblende and hornblende gabbro) in basalt magma is an important factor for the genesis of calc-alkalic andesites. SHIMAZU *et al.* (1979), however, recognized implicitly the same possibility for the Umikawa district, though conclusive evidence was lacking.

Diverse opinions have been proposed for the Ichinomegata district. KATSUI *et al.* (1979), from the observation that the host rocks of mafic and ultramafic inclusions are pumiceous calc-alkalic andesite, were lead to the conclusion that calc-alkalic andesite may have been derived primarily by partial melting of upper mantle peridotite under hydrous conditions as suggested by KUSHIRO (1969, 1972, 1974), MYSEN and BOETTCHER (1975) and YODER (1969). AOKI and FUJIMAKI (1982) ruled out the possibility of production of andesite magma through amphibole fractionation from basalt magma on the basis of similar REE patterns and concentrations in the basalts and calc-alkalic andesites. Instead, they suggested that andesite and basalt in the Ichinomegata district could have been formed by nearly the same degree of partial melting of mantle peridotite at depths of 40–60 km with different activities of water.

TAKAHASHI (1986) proposed a two-stage melting process. Basalt magma was generated by partial melting in an ascending diapir. The heat supplied by the invading basalt magma might cause partial melting of hornblende gabbros or amphibolites near the crust/mantle boundary to form calc-alkalic andesite. Although most investigators have interpreted the hornblende gabbros or hornblende-rich rocks as cumulates from hydrous basaltic magma, TAKAHASHI (1986) suggested that they could be residues after extraction of calc-alkalic magma from basaltic materials.

In our calculations (Table 1; see also Figure 5) the production of calc-alkalic andesite magma from parental high–alumina basalt would leave about 40 percent hornblende gabbro. Whether or not such large amounts of hornblende gabbro exist in the deep portion of the Japanese crust remains a subject of discussion. AOKI (1971) considered that hornblende gabbro and related mafic rocks form the main part of the lower crust from which the inclusion in the Ichinomegata extrusives were derived. In the Paleogene volcanic rocks of northern Caucasus, ZAKARIADZE and LORDKIPANDZE (1971) showed that calc-alkalic andesites and dacites are underlain by extensive hornblende gabbros or related rocks in the lower crust. From the prevalent occurrence of inclusions of hornblende gabbro, amphibolite and granulite rocks in the Cenozoic volcanic rocks from the west San-in region in southwestern Japan, MURAMAKI (1975) concluded that these rocks form the lower crust in that part of Japan.

CONCLUSIONS

(1). Inclusions of hornblende gabbro or hornblendite frequently observed in the calc-alkalic andesite and associated rocks along the Japan Sea coast in northeastern Japan are considered to represent the cumulates from the parental hydrated basalt magma.

(2). Calc-alkalic andesite magma was formed by separation of hornblende gabbro or hornblendite from the parental high–alumina basalt.

(3). The presence of large amounts of hornblende gabbro and related mafic rocks in the lower crust in northeastern Japan is consistent with crustal models derived from seismic data.

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