Chemical compositions and Sr, Nd isotope ratios of gabbroic xenoliths in calc-alkali andesites of Naeba and Torikabuto volcanoes, North Fossa Magna, central Japan

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Gabbroic, doleritic and basaltic xenoliths found in calc-alkali andesites of Naeba and Torikabuto volcanoes are geochemically divided into three groups. Gabbro A of the group 1 from Naeba is rich in MgO and Ni, poor in alkalis, and shows depleted REE pattern resembling those of Ichinomegata (Sp. No. 2232) and Hakone (HKG1, HKG2) volcanoes. On the basis the REE pattern and high Al^{IV} contents in clinopyroxenes, gabbro A is interpreted to have been cumulate from a primary magma generated by partial melting of upper mantle. From REE pattern, gabbros of the group 2 from Ichinomegata (Sp. No. 2218) may have derived from low alkali tholeiite magma which have been formed by removal of material such as the group 1 gabbro at shallow depth. Doleritic and basaltic xenoliths of the group 3 from Naeba, gabbroic xenoliths from Torikabuto and Umikawa are poorer in MgO and richer in alkalis than those of the group 1 and show enriched pattern in REE resembling that of high alkali tholeiite and contain clinopyroxenes having low Al^{IV} . Therefore, these rocks are considered to be differentiates of high alkali tholeiite magma at shallow depth.

On $\epsilon Nd-^{87}Sr/^{86}Sr$ diagram, isotope data of gabbro A of the group 1 plot near those of andesites from Asama and Myoko volcanoes of the North Fossa Magna. It is interpreted that these rocks have derived from the same mantle source as the Asama and Myoko volcanoes which are richer in incompatible elements than those of MORB.

Introduction

Ultramafic and mafic xenoliths included in alkali basalts of NW Japan provide valuable information for upper mantle-lower crust materials as well as on the fractional crystallization of magma at deep depth. Gabbroic xenoliths included in calc-alkali andesites from the North Fossa Magna are also reported (Yamazaki *et al.*, 1966, Takeshita and Oji, 1968).

One of us (M.S.) reported petrology of

gabbroic xenoliths in the Pliocene calc-alkali andesites of the Arakurayama and Umikawa areas of the North Fossa Magna (Shimazu *et al.*, 1979, Shuto *et al.*, 1988). Most gabbroic xenoliths are cumulates, and some of them are considered to have derived from lower crust. Gabbroic xenoliths are also found from Quaternary volcanoes such as Yatsugatake in the North Fossa Magna (Kawachi, 1976), Hakone (Fujimaki, 1982) and Izu-Oshima (Aoki and Kuno, 1972) of the South Fossa Magna, and Ichinomegata of NE Japan (Aoki, 1971).

Recently gabbroic xenoliths have been found in calc-alkali andesites of Naeba and Torikabuto volcanoes (Igarashi *et al.*, 1984).

We intend to present petrographical and geochemical data on the gabbroic xenoliths from the last two volcanoes and discuss the origin of the gabbroic xenoliths in comparison with the gabbroic xenoliths from the other areas.

Geological setting

Naeba volcano is a middle Pleistocene stratovolcano (Fig. 1). The volcano suffered

solfatatic alteration and an erosion caldera is formed in the middle stream of Iwogawa, but original lava flow surfaces are preserved in the northern part and in the neighborhood of the summit (Naeba-san).

The volcanic activity of Naeba volcano is divided into four stages. The first stage volcanic products are distributed in the western part and consist mainly of andesitic pyroclastic rocks with minor lavas. The second stage andesite lavas are widely distributed in the northwestern part forming a gentle sloped surface in and to the south of Tsunan. The lavas

Table 1. Major and minor element compositions of basic xenoliths and their host andesite from Naeba and Torikabuto volcanoes, and other areas

	A	B	C	And	T1	T2	G6	G5	2218	HKG2	HKG2
SiO ₂	43.43	57.03	53.92	60.69	52.39	54.76	45.06	44.36	46.61	44.38	44.97
TiO ₂	0.24	0.79	0.91	0.77	0.76	0.87	1.10	1.05	0.92	0.18	1.04
Al ₂ O ₃	18.46	16.81	17.46	16.45	17.19	19.25	16.78	22.38	15.42	26.13	21.63
FeO	11.96	9.14	10.25	7.63	10.69	8.80	10.85	6.13	10.88	5.99	11.37
MnO	0.18	0.18	0.20	0.16	0.17	0.15	0.18	0.10	0.30	0.09	0.16
MgO	14.90	4.12	5.06	3.69	5.74	3.48	11.39	9.68	13.97	8.60	5.04
CaO	9.90	8.44	9.20	6.24	10.43	8.39	12.12	13.36	10.44	13.96	14.50
Na ₂ O	0.82	2.32	2.09	2.35	1.95	3.32	2.17	2.11	1.31	0.64	1.20
K ₂ O	0.09	1.01	0.75	1.86	0.87	0.76	0.36	0.80	0.10	-	0.06
P ₂ O ₅	0.02	0.16	0.17	0.14	0.15	0.21	-	0.01	0.05	0.02	0.02
Total	100.00	100.00	100.01	99.98	100.34	99.99	100.01	99.98	100.00	99.99	99.99
MgO/FeO	1.25	0.45	0.49	0.48	0.54	0.40	1.05	1.58	1.28	1.44	0.44
Rb	1.1	20.3	17.5	47.7	18.9		3.5		1.8	0.2	0.6
Sr	256	352	288	270	218		508		305	74	128
Nb	3.1	3.6	2.1	-			3.3		0.7		
Zr	14.5	64.5	51.3	113.6			27.6		25.5		
Y	4.4	23.1	31.4	41.5			22.7		11.4		
Ni	122.1	11.5	18.9	12.7			75.1		213.0		
Co	95.0	89.0	63.0				55.0				
Sc	11.0	35.0	39.0				73.0				
La	0.81	8.14	6.50	7.60	6.73		2.02		1.33	0.67	0.51
Sm	0.47	3.00	2.90	3.58	2.32		2.23		1.32	0.36	0.54
Eu	0.10	0.80	0.60	0.72	0.85		0.70		0.649	0.181	0.310
Yb	0.41	1.94	1.38	1.39	1.40		1.73		1.10	-	-
Lu	0.06	0.26	0.35	0.35	-		0.19		0.159	0.056	0.110

A, B and C, gabbroic xenoliths from Naeba volcano; And, andesite from Naeba volcano; T1 and T2, gabbroic xenoliths from Torikabuto volcano (This study); G5 and G6, gabbroic xenoliths from Umikawa (Shimazu *et al.*, 1979, minor elements: new analyses); 2218, gabbroic xenolith from Ichinomegata volcano (Tanaka and Aoki, 1981); HKG1 and HKG2, gabbroic xenoliths from Hakone volcano (Fujimaki, 1982).

Fig. 1. Geological map of an area between Naeba and Torikabuto volcanoes.

1, locality of analyzed gabbroic xenoliths; 2, Miocene formations; 3, Pliocene volcanic rocks; 4, Shikumi volcanic rocks of early Pleistocene age; 5, Uonuma Group of Pliocene to Pleistocene age; 6, volcanic rocks of Torikabuto volcano; 7, volcanic rocks of Torikabuto main lava; 8-11, volcanic rocks of Naeba volcano; 8, first stage rocks; 9, second stage rocks; 10, third stage rocks; 11, fourth stage rocks; 12, Holocene sediments (river terrace and lake deposits).

are characterized by 30 m high well developed columnar joints. The third stage products are largely mud flow deposits and are widely distributed in the northern part with minor lavas which form flat surface at Komatsubara. The fourth stage products are mostly andesite lavas

distributed in the eastern and southern sides of the summit showing flat topography.

The first stage rocks are olivine-augite-hypersthene andesite ($\text{SiO}_2 \sim 64\%$), the second stage hypersthene-augite andesite (SiO_2 59 ~62%), the third stage olivine-augite-hypersth-

ene andesite ($\text{SiO}_2 \sim 59\%$), and the fourth stage hypersthene-augite andesite ($\text{SiO}_2 \sim 58\%$), respectively.

Gabbroic, doleritic and basaltic xenoliths appear in the andesitic rocks of the fourth stages. Many gabbroic xenoliths were collected from surface exposure along a road (about 1,200 m in altitude) situated in upper stream of the Kamagawa, where these xenoliths are included in hypersthene-augite andesite lavas underlain by mud flow deposits of the third stage. The andesite is a blocky

lava with an autobrecciated basal part showing irregular columnar joints of about 20 m high.

Early Pleistocene Torikabuto stratovolcano is situated to the west of Naeba volcano. Torikabuto volcano consists of Maekura lava, Takayamazawa pyroclastic rock, Onizawa pyroclastic rock, Uenohara welded tuff, Nunoiwa lava and Torikabuto main lava in ascending order. The Torikabuto main lava is subdivided into the Takizawa, Oneyama, Shirakura-yama, and Summit lavas. In the eastern side of the Nakatsugawa, the Uenohara welded

Fig. 2. $\text{MgO-FeO-(Na}_2\text{O+K}_2\text{O)}$ diagram for basic xenoliths in the rocks of Naeba volcano (A, B, C), Torikabuto volcano (T1, T2), Ichinomegata volcano (Sp. No. 2218, 2233) (Aoki, 1971), Hakone volcano (HKG1, HKG2) (Fujimaki, 1982) and Umikawa area (G5, G6) (Shimazu *et al.*, 1979). Small solid circles, volcanic rocks of Naeba volcano.; G, gabbroic xenoliths; V, Volcanic rocks.

P and H are pigeonitic and hypersthene rock series, respectively.

tuff is underlain by the second stage lava of Naeba volcano. The volcanic rocks of Torikabuto volcano are mostly andesite, while the Onizawa pyroclastic rock is dacitic composition. Both belong to calc-alkali rock series, but some andesites of the Torikabuto main lava are tholeiitic. Many of the andesitic rocks contain phenocrysts of hypersthene and augite, and some contain either olivine or hornblende phenocrysts in addition. Biotite phenocrysts appear in some rocks having hornblende phenocryst. A number of hornblende-augite gabbroic xenoliths are included in hypersthene-augite andesite of the Summit lava and basaltic xenoliths occur in many lavas of the Torikabuto main lava.

Chemical compositions of the rocks from Naeba and Torikabuto volcanoes and other areas are plotted in a MFA diagram (Fig. 2). The rocks of the first and second stages and most of the fourth stage of Naeba volcano belong to calc-alkali rock series, but some fourth stage rocks to tholeiitic rock series.

Petrography of gabbroic, doleritic and basaltic xenoliths

The xenoliths consisting of gabbro, dolerite and basalt from Naeba volcano are fine-grained and show yellowish gray color. They are mostly 2 to 3 cm in size (rarely up to 10 cm). The gabbroic xenoliths are petrographically classified into the following three types;

- gabbro A olivine-bronzite-salite gabbro
- gabbro B bronzite-salite gabbro
- gabbro C hornblende-two pyroxene gabbro

Gabbro A is a granular aggregate of anhedral olivine, plagioclase, and small amounts of bronzite and salite. Gabbro B consists of subhedral to anhedral bronzite, salite and subhedral plagioclase. Gabbro C consists of subhedral hornblende, clino- and orthopyroxene, and euhedral plagioclase including anthophyllite

needles of metamorphic origin.

Dolerite consists of subhedral plagioclase, anhedral bronzite and augite, and shows doleritic texture. Basalt is composed of subhedral olivine, clinopyroxene and hypersthene phenocrysts with groundmass consisting of clinopyroxene, lath-shaped plagioclase and glass. Olivines are altered, but have rims of fresh clinopyroxenes. Orthopyroxenes show brownish tint and are intergrown with clinopyroxenes.

Plagioclases in gabbro A are slightly zoned (An_{88-92}), while plagioclases in dolerite show different extents of zoning of An_{89-78} , An_{83-79} and An_{98-68} , and attain An_{49} in the outermost part.

Olivines in gabbro A are Fo_{71-75} , and those in dolerite are Fo_{71-74} . Clinopyroxenes are

Table 2. Chemical compositions of clinopyroxenes in basic xenoliths and phenocryst of an andesite from Naeba volcano

	A	Ba	D	D	And
SiO ₂	48.86	50.54	51.27	52.46	51.52
TiO ₂	1.22	0.02	0.46	0.30	0.33
Al ₂ O ₃	5.43	0.46	1.54	1.47	1.20
FeO	9.82	11.26	12.52	9.23	8.53
MnO	0.04	0.24	0.44	0.57	0.27
MgO	12.87	13.79	13.45	15.08	14.71
CaO	21.51	23.64	19.22	21.56	22.97
Na ₂ O	0.24	0.02	0.23	0.26	0.10
K ₂ O	0.00	0.00	0.01	0.00	0.00
Total	99.99	99.97	99.14	100.93	99.63
(O=6.00)					
Si	1.83	1.93	1.95	1.94	1.93
Al ^{IV}	0.17	-	0.05	0.08	-
Al ^{VI}	0.07	0.02	0.02	0.06	0.01
Ti	0.03	0.00	0.01	0.00	0.01
Fe	0.31	0.36	0.40	0.29	0.28
Mn	0.00	0.01	0.01	0.02	0.01
Mg	0.72	0.78	0.76	0.83	0.82
Ca	0.86	0.96	0.78	0.86	0.92
Na	0.02	0.00	0.02	0.02	0.01
Atom. %					
Ca	46	46	40	43	46
Mg	38	37	39	42	40
Fe	16	17	21	15	14

A, gabbro A; Ba, basaltic xenolith; D, doleritic xenolith; And, hypersthene-augite andesite.

Table 3. Chemical compositions of orthopyroxenes in xenoliths and phenocryst of an andesite from Naeba volcano

	Ba	D	D	And
SiO ₂	49.72	53.03	54.06	51.08
TiO ₂	0.00	0.27	0.19	0.11
Al ₂ O ₃	0.00	2.10	0.65	0.71
FeO	26.55	17.18	20.28	23.53
MnO	0.58	0.72	0.98	0.49
MgO	21.72	23.83	22.71	22.42
CaO	0.88	1.78	1.25	1.17
Na ₂ O	0.41	0.00	0.00	0.00
K ₂ O	0.00	0.02	0.01	0.00
Total	99.86	98.93	100.13	99.51
(O=6)				
Si	1.91	1.95	2.00	1.93
Al ^{IV}	0.01	0.00	0.01	0.03
Ti ^{VI}	0.00	0.09	0.03	0.00
Fe	0.85	0.55	0.63	0.75
Mn	0.02	0.02	0.03	0.02
Mg	1.24	1.31	1.25	1.27
Ca	0.04	0.07	0.05	0.05
Na	0.00	0.00	0.00	0.00
K	0.00	0.00	0.00	0.00
Atom. %				
Ca	0	4	3	2
Mg	45	68	65	48
Fe	55	28	32	50

Ba, D and And are the same as in Table 2.

salite (Table 2) and orthopyroxenes are En₁₈₋₃₉ in gabbros A and B (Table 3).

Al^{IV} contents of the clinopyroxenes in gabbro A are 0.17 and are similar to gabbroic xenoliths (0.13 Sp. No. 2233 and 0.17 Sp. No. 2218) from Ichinomegata volcano (Aoki, 1971), and are higher than those (0.05–0.08) in doleritic xenoliths from Naeba volcano.

As high Al^{IV} contents in clinopyroxene are interpreted to represent crystallization under high pressure conditions (Aoki and Kushiro, 1968), gabbro A may have been formed at deep depth as gabbroic xenoliths of Ichinomegata (Aoki, 1971).

Major and minor chemical compositions of gabbroic xenoliths

XRF analyses of the gabbroic xenoliths

and an andesite from Naeba and gabbroic xenoliths (T1, T2) from Torikabuto volcanoes are shown in Table 1. The analyses from Ichinomegata volcano (2218) (Tanaka and Aoki, 1981; Aoki and Yoshida, 1986), Hakone volcano (HKG1, HKG2) (Fujimaki, 1982) and Umikawa (G5, G6) (Shimazu *et al.*, 1979) are also shown in Table 1 for comparison. The doleritic and basaltic xenoliths were not analyzed because of their small sizes.

Chemical compositions of gabbroic xenoliths along with host andesite from Naeba, gabbroic xenoliths from Torikabuto (T1, T2), Ichinomegata (2218, 2233), Hakone (HKG1, HKG2), and Umikawa (G5, G6) are plotted on a MFA diagram (Fig. 3).

Gabbro A is rich in MgO and poor in alkalis, and plots close to those from Ichinomegata, Hakone and Umikawa on the diagram, whereas gabbros B, C, T1 and T2 are rich in FeO* and alkalis and plot near some of the andesites from Naeba volcano.

On MgO/FeO*-oxides diagrams (Fig. 4), gabbro A is rich in MgO, poor in alkalis and is similar to that of the gabbros (Sp. No. 2218) from Ichinomegata. Chemical compositions of gabbros B, C and gabbros T1 and T2 from Torikabuto are poor in MgO and rich in alkalis. MgO and alkali contents of the gabbros from the Umikawa and Arakurayama are intermediate between gabbro A and gabbros B, C. The above three types of gabbros are discriminated by minor element content such as Ni, Rb, Zr and Y (Table 1).

Rare earth element contents of gabbroic xenoliths and andesite

Rare earth element (REE) contents were measured by instrumental neutron activation analysis (INAA) following the method of Masuda *et al.* (1973). Sm and Nd of gabbro A and gabbro (G6) were measured by the mass spectrometric stable isotope dilution method.

Fig. 3. MgO/FeO^* -oxides (%) diagrams for gabbroic xenoliths. Symbols are the same as in Fig. 2.

REE contents of gabbroic xenoliths and andesite from Naeba and gabbroic xenoliths from Torikabuto, Ichinomegata, Hakone and Umi-kawa are given in Table 1. Chondrite (Leedey)-normalized REE patterns of the xenoliths and GSJ rock reference samples (Ando *et al.*, 1987) are shown in Fig. 4. Although the REE abundances of gabbro A is higher than those of lherzolite xenoliths (Tanaka and Aoki, 1981), it is more depleted in REE than gabbros B and C and are similar to that of gabbro from Ichinomegata (Sp. No. 2233) (Tanaka and Aoki, 1981) and Hakone (HKG1, HKG2) (Fujimaki, 1982).

The REE pattern of gabbro A shows negative Eu anomaly in contrast to positive Eu

anomalies of gabbros from Ichinomegata and Hakone volcanoes and those of gabbros B, C and host andesite show negative Eu anomalies. The REE patterns of gabbro (G6) and gabbro (Sp. No. 2218) from Ichinomegata are similar to that of dolerite, but the REE pattern of dolerite shows positive Eu anomaly. Difference of Eu anomaly probably depend on the extent of plagioclase accumulation.

On the basis of differences of the REE patterns, the gabbroic xenoliths are divided into the following three groups;

- Group 1: depletion of REE,
gabbro A, 2233, HKG1, HKG2
- Group 2: enrichment of REE, depletion of LREE

Fig. 4. Chondrite Leedeey-normalized REE patterns of gabbroic xenoliths.

Solid circles (A, B, C), gabbroic xenoliths from Naeba volcano; Small solid circle (And), andesite from Naeba volcano; Solid square (D), doleritic xenolith from Naeba volcano; Open square (T1), gabbroic xenolith from Torikabuto volcano; Open stars (2218, 2233), gabbroic xenoliths from Ichinomegata volcano (Tanaka and Aoki, 1979); Solid stars (HKG1, HKG2), gabbroic xenoliths from Hakone volcano (Fujimaki, 1982); Open circle (G6), gabbroic xenolith from Umikawa area.

LT and HT are low alkali tholeiite (JB-2) and high alkali tholeiite (JB-3), respectively (Ando *et al.*, 1987).

2218

Group 3: enrichment of REE, slightly
enrichment of LREE
gabbro B, C, T1, G6, basalt,
dolerite, andesite

This grouping does not always correspond with that by major elements. The REE patterns of the group 1 gabbros are lower than those of the group 2 and are similar to considerably enriched spinel lherzolite (Sp. No. 3) from Ichinomegata (Tanaka and Aoki, 1981), but are slightly higher than it. On the other hand, the REE patterns of the group 2 gabbros are similar to that of low alkali tholeiite (JB-2), but are slightly lower than it.

On the basis of differences of the above REE patterns, the group 1 gabbros are considered to be cumulate from a primary magma generated by partial melting of spinel lherzolite. Low alkali tholeiite magma is interpreted to have been formed by removal of gabbroic material such as the group 1 from the primary magma at the lower crust.

On the other hand, the REE patterns of the group 3 xenoliths are similar to that of high alkali tholeiite (JB-3), indicating that the group 3 gabbros are originated from high alkali tholeiite magma; the group 2 xenoliths from low alkali tholeiite magma at shallow depth, because clinopyroxenes in these rocks are poor-

er in Al^{IV} contents than those of the group 1. The origin of basaltic and doleritic xenoliths from Naeba is also interpreted to have the same origin as the group 3 xenoliths whose host andesite may be differentiate of high alkali tholeiite magma.

Sr and Nd isotope chemistry of gabbroic xenoliths

$^{87}Sr/^{86}Sr$ ratios for two gabbros and four andesites and $^{143}Nd/^{144}Nd$ ratios for one gabbro and one andesite were measured following the procedure described by Kagami *et al.* (1982, 1987, 1989).

$^{87}Sr/^{86}Sr$ ratios were normalized to $^{86}Sr/^{88}Sr = 0.1194$ and $^{143}Nd/^{144}Nd$ ratios to $^{146}Nd/^{144}Nd = 0.7219$. The blanks for the whole procedures were 0.07 ng Rb, 0.50 ng Sr, 0.03 ng Sm and 0.39 ng Nd. $^{87}Sr/^{86}Sr$ ratios for NBS987 measured was $0.710254 \pm 0.00001(2\sigma)$, duplicated analysis). $^{143}Nd/^{144}Nd$ ratio for JB-1a (GSJ rock reference sample) during the course of this study is 0.512784 (Kagami *et al.*, 1989). The mean measurement errors of $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$ ratios for each sample were 0.0023% and 0.0032% at the 2σ level, respectively. Age corrections were not applied because the samples are younger than 3 Ma.

The analytical results are shown in Table

4. The data are plotted in the ϵNd - $^{87}Sr/^{86}Sr$

diagram (Fig. 5). Data of gabbro G5, G6 and G7 from Umikawa (Shuto *et al.*, 1988), an icelandite from Shikumi to the west of study area (Shimazu *et al.*, 1981), and volcanic rocks of NE Japan are also plotted in Fig. 5. Gabbro A plots in the margin of the mantle array (DePaolo, 1988) and on the lower $^{87}Sr/^{86}Sr$ side and higher ϵNd side of the Bulk Earth value. Gabbro (G5) also plots in the mantle array and on the slightly smaller ϵNd side than gabbro A, while gabbro (G7) on the higher $^{87}Sr/^{86}Sr$ than gabbro (G5); gabbro (G6) plots on the higher $^{87}Sr/^{86}Sr$ side than the Bulk Earth value. Gabbros (G5, G6 and G7) are plotted within a narrow range of ϵNd with some variations of $^{87}Sr/^{86}Sr$.

Such arrangement may result from secondary contamination in the mantle (Shuto *et al.*, 1988). However, gabbro A, gabbros (G5, G7) in or near the mantle array are considered to have derived from the mantle source without any secondary contamination.

An icelandite from Shikumi and andesites from Asama volcano (Nohda and Wasserburg, 1981) plot on the higher ϵNd side and outside of the mantle array. Andesite from Myoko volcano (Nohda and Wasserburg, 1981) plots on slightly outside of the mantle array. Data of Kampu, Moriyoshiyama and Hachimantai volcanoes of NE Japan (Nohda and Wasserburg,

Table 4. Sr and Nd isotope data

	Rb (ppm)	Sr (ppm)	$^{87}Sr/^{86}Sr$	Sm (ppm)	Nd (ppm)	$^{143}Nd/^{144}Nd$	ϵNd
A	1.1	266	0.70391	0.49	1.27	0.51284	+4.2
T2	18.9	218	0.70405				
And	7.1	236	0.70395				
S	23.7	229	0.70400	3.94	14.44	0.51295	+6.1
G-5	16.4	393	0.70389	1.92	5.14	0.51278	+2.8
G-6	4.5	534	0.70485	2.57	7.38	0.51279	+3.1

A, gabbro A from Naeba volcano; T2, gabbroic xenolith from Torikabuto volcano; And, andesite from Naeba volcano; S, icelandite from Shikumi area; G5 and G6, gabbroic xenoliths from Umikawa area (Shuto *et al.*, 1988).

Fig. 5. ϵ_{Nd} vs. $^{87}\text{Sr}/^{86}\text{Sr}$ diagram for gabbroic xenoliths and volcanic rocks.

Solid circle (A), gabbro A from Naeba volcano; Solid circle (S), icelandite from Shikumi area; Open circles (G5, G6, G7), gabbroic xenoliths from Umikawa (Shuto *et al.*, 1988); Open square (My), andesite from Myoko volcano, small circles (K, Mo, H): andesite from Kampu, Moriyo-shiyama and Hachimantai volcanoes, respectively (Nohda and Wasserburg, 1981). Field (AS) is for andesites from Asama volcano (Nohda and Wasserburg, 1981), and field (HK) is for andesites from Hokkaido on the Kurile arc (Ikeda *et al.*, 1990).

1981) along with those from Hokkaido on the Kurile arc (Ikeda *et al.*, 1990) are also shown in Fig. 5.

Based on these data, gabbro A and gabbro (G7) are concluded to have derived from the mantle source which has similar isotopic signatures with andesites of Asama and Myoko volcanoes. The Sr isotopic composition of the mantle source is presumably more radiogenic than those of MORB and that of Kampu volcano, but is very close to those of most of volcanoes of NE Japan arc and some volcanoes of the Kurile arc.

$^{87}\text{Sr}/^{86}\text{Sr}$ data of gabbro (T2) and andesite from Naeba volcano are 0.70405 and 0.70391, respectively, and show a narrow range which

resembles those of gabbro A and icelandite.

Summary

On the basis of pyroxene compositions, major chemical compositions, and REE patterns, the origins of the gabbroic, doleritic and basaltic xenoliths from Naeba and Torikabuto are summarized as follows.

1. Gabbro A of the group 1 is probably cumulate from a primary magma generated by partial melting of upper mantle, because of its depleted REE pattern and high Al^{IV} contents in clinopyroxenes.
2. Group 2 gabbros have slightly lower REE pattern than that of low alkali tholeiite and may have derived from low alkali tholeiite magma which have been formed by removal of

material such as the group 1 gabbro at shallow depth.

3. Gabbros B,C of the group 3, doleritic and basaltic xenoliths have similar REE patterns to that of a high alkali tholeiite (JB-3), suggesting that these xenoliths are differentiated from high alkali tholeiite magma at shallow depth. Host calc-alkali andesite of gabbroic xenoliths may also be the same origin.

4. Based on Sr and Nd isotope data, gabbro A of the group 1 is concluded to have derived from the mantle source having similar isotope signature with andesite of Asama and Myoko volcanoes, which is rich in incompatible elements as compared to MORB.

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北部フォッサマグナ、苗場、鳥甲火山のカルクアルカリ安山岩中のはんれい岩ゼノリスの化学成分と Sr, Nd 同位体比

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苗場、鳥甲火山のカルクアルカリ安山岩中のはんれい岩、ドレライト、玄武岩ゼノリスは地球化学的に大きく3つのグループに分けられる。第1のグループの苗場のはんれい岩Aは、MgO, Niに富み、アルカリに乏しく、一ノ目湯(2232)、箱根(HKG1, KHG2)のはんれい岩ゼノリスと似て、REEに乏しいパターンを示す。このことと単斜輝石の高いAl^{IV}含量に基づくと、このはんれい岩Aは上部マントルの部分熔融により生成された初成マグマからの沈積相と考えられる。第2のグループの海川、一ノ目湯のはんれい岩はREEパターンから、第一のグループのような物質が取り除かれることにより生じた低アルカリソレアイトマグマから由来したものであろう。第3のグループの苗場のドレライト、玄武岩ゼノリス、鳥甲のはんれい岩ゼノリスは第1のグループよりMgOに乏しく、アルカリに富み、高アルカリソレアイトのそれに似たREEに富んだパターンを示し、Al^{IV}に乏しい単斜輝石を含むことから浅所での高アルカリソレアイトマグマの分化物と考えられる。

第1のグループのはんれい岩Aの同位体は $\epsilon\text{Nd-}^{87}\text{Sr}/^{86}\text{Sr}$ ダイアグラム上では、MORBよりインコンパチブル元素に富んだ北部フォッサマグナの浅間、妙高火山のそれに近く、それらとおなじマントル物質から由来したことを示している。