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Sr/Ca-Ba/Ca systematics of Quaternary volcanoes in Toshima, Udonejima, Niijima and Kōzushima, the Izu Islands, Japan*

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Ca, Sr and Ba contents in various volcanic rocks (basalts, andesites, rhyolites and their cognate inclusions) from Quaternary volcanoes in Toshima, Udonejima, Niijima and Kōzushima, the Izu Islands, Japan, have been determined by an ICP-OES method.

Basalts and andesites from Toshima and Niijima make two different series of Sr/Ca-Ba/Ca systematics (SB systematics), indicating that there exist two different primary magmas derived from a common mantle peridotite with different degrees of partial melting. The various series of SB systematics of volcanoes in the Izu Islands so far obtained, suggest that the common mantle peridotite has a chondritic composition in terms of Sr/Ca and Ba/Ca ratios.

The various series of SB systematics defined by basalt-andesite-dacite series in the Izu Islands converge into a rhyolitic composition of Jinaijima type. The silicic rock may be an end product of a crystal fractionation process, and might have formed a thin crust under the Niijima and Kōzushima region. The majority of rhyolites which characterize the volcanoes of Niijima and Kōzushima display quite different SB systematics, suggesting that the rhyolites are formed by remelting of a thin crust, and substraction of Na-rich plagioclase from the silicic magma. The rhyolite volcanism may be triggered by the heat of basaltic magma intruded under the thin crust, as indicated by the presence of cognate inclusions with basaltic composition in the rhyolites.

INTRODUCTION

We are investigating arc volcanism in the Izu Islands, Japan, on the basis of a Sr/Ca-Ba/Ca diagram (ONUMA, 1981). The diagram enables us to visualize both partial melting of mantle materials and crystal fractionation in a magma chamber beneath any given volcano. Therefore, a regional variation in the degree of partial melting of mantle materials can be revealed by various series of Sr/Ca-Ba/Ca systematics (SB systematics for short hereafter) defined by sets of volcanic rocks from respective volcanoes and volcano groups situated in the region.

In previous papers (ONUMA *et al.*, 1981; HIRANO *et al.*, 1982), we have reported the SB systematics of volcanoes in Ōshima, Miyakejima, Mikurajima, Ōnoharajima and Inambajima. The first three lie on the volcanic front and the last two behind it (Fig. 1). The volcanoes forming these islands are classified into four groups on the basis of four different series of SB systematics. The differences are considered to reflect mainly different degrees of partial melting of mantle materials, while the parallelism between the four series is considered to indicate similar crystal fractionation processes in "magma chambers" of the respective volcanoes.

In this paper, we report SB systematics of volcanoes and volcano groups constituting Toshima, Udonejima, Niijima and Kōzushima lying on the distinct submarine ridges obliquely disposed to the Izu-Ogasawara Trench. The purpose of this report is to examine:—(a)

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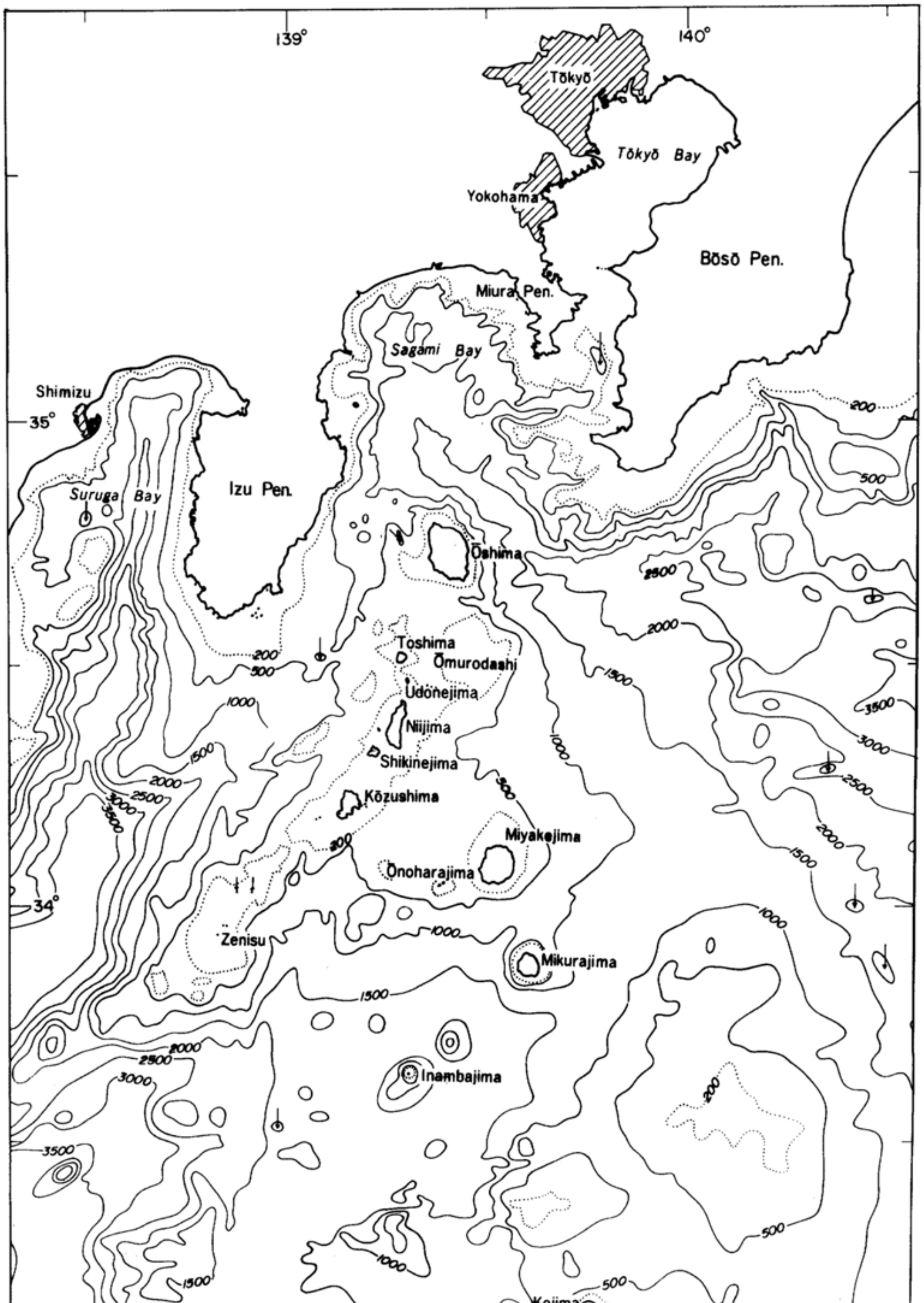

Fig. 1. Locality map of the Izu Islands. Based on Ocean Sounding Chart G1406 and G1506 published by Maritime Safety Agency, Japan, in 1974, and prepared by Messrs. Ken-ichi Tanaka and Yoshiro Masai.

magmatic processes in volcanoes lying behind the volcanic front, which is aligned parallel to, and about 200 km west of the Izu-Ogasawara Trench are the same or not; and (b) whether magmatic processes along and behind the volcanic front are the same or not. In particular, the origin of rhyolites which characterize the islands of Niijima and Kōzushima will be discussed in detail.

Geological Setting

The geology and petrology of Toshima, Udonejima, Niijima, Kōzushima and associated small volcanic islets have been studied by one of us (N.I.) and a part of the study has already been published (Isshiki, 1978). Brief descriptions on the volcanoes and volcano groups forming these islands are given below according to the previous publications (Tsuya, 1929; 1938) and our unpublished data.

(1) *Toshima volcano* Toshima is situated between 34°30.5′-34°31.7′N. and 139°16.2′-139°17.8′E. and on a small submarine ridge extending from Ōshima towards the southwest. It is composed of three geologic units: main stratovolcano, volcaniclastic deposits and lava flows of parasitic craters. The main stratovolcano forms the bulk of the volcano and consists of many superposed basalt lava flows of aa type, with associated scoriaceous ash layers, cut by radial dikes of the same petrographic character. Most of the dikes trend in a northwest-southeast direction. The volcaniclastic deposits comprise mafic pyroclastic fall, rhyolite ash fall, mudflow and detrital deposits, and their weathered products. Of these, the rhyolite ash falls may have been supplied from rhyolite volcanoes on Niijima, Shikinejima and Kozushima or elsewhere in the sea to the south. The lava flows of parasitic craters are andesite and are found at the upper levels of the volcaniclastic deposits. One of the lava flows is considered to be younger than 8,000 years old and older than 4,000 years old, on the basis of the ^{14}C dating and archeological evidence. The basalts of the main stratovolcano contain phenocyrsts of plagioclase, olivine and augite, and microphenocrysts of orthopyroxene intergrown in parallel with clinopyroxene in a groundmass consisting of plagioclase, clinopyroxene, iron ore, felsic mesostasis, cristobalite and a few orthopyroxene grains intergrown in parallel with clinopyroxene. The andesites of parasitic craters contain phenocyrsts of plagioclase and olivine in a groundmass of plagioclase, clinopyroxene, iron ore, felsic mesostasis, cristobalite and small number of orthopyroxene crystals intergrown in parallel with clinopyroxene. Xenocrysts of plagioclase, quartz and possible amphibole or biotite which is now completely changed to a clinopyroxene aggregate are sporadically seen. They may have been derived from granitic crustal rocks beneath the volcano.

(2) *Udonejima volcano* Udonejima is situated at about 34°28′N. and 139°18′E. and is a small dissected stratovolcano 1.3 km long and 0.5 km wide. It consists of basalt lava flows of aa type, scoria fall deposits and associated radial dikes, most of which trend in a northwest-southeast direction. The basalts of the volcano always contain phenocrysts of olivine, sometimes with augite and plagioclase, in a groundmass consisting of plagioclase, clinopyroxene, iron ore, felsic mesostasis with apatite needles, and cristobalite, associated with or without orthopyroxene.

(3) *A group of monogenetic volcanoes in Niijima and the adjacent islets* Niijima is situated between 34°19.6′-34°25.7′N. and 139°14.7′-139°17.7′E. and on a small submarine ridge extending from Ōmurodashi towards the southwest. Niijima and the adjacent islets are composed of fourteen rhyolitic, one or two andesitic and one basaltic volcano. Assemblages of mafic silicate phenocrysts of the rhyolites are: hornblende-cummingtonite-hypersthene, cummingtonite, cummingtonite-biotite and biotite. Plagioclase, quartz, magnetite and ilmenite are ubiquitous as phenocrysts in a glassy or cryptocrystalline groundmass. The rhyolites

sometimes contain cognate inclusions of basaltic chemistry. They are oval or irregular in shape. The andesites contain phenocrysts of plagioclase, augite, bronzite-hypersthene and magnetite in a fine-grained, partly glassy groundmass. The basalt contains a few phenocrysts of olivine, plagioclase and magnetite also in a fine-grained, partly glassy groundmass.

(4) *A group of monogenetic volcanoes in Kōzushima and the adjacent islets* Kōzushima is situated between 34°10.9′-34°14.4′N. and 139°7.3′-139°10.7′E. and on the same small submarine ridge on which Niijima lies. Kōzushima and the adjacent islets are composed of eighteen rhyolitic volcanoes of similar dimensions to those of Niijima. Hypersthene rhyolite, cummingtonite rhyolite and biotite rhyolite are found in them, but the last one is most predominant. Plagioclase, quartz, magnetite and ilmenite are ubiquitous as phenocrysts. Cognate inclusions of basaltic chemistry are contained especially in the hypersthene rhyolite.

EXPERIMENTAL

All the samples employed in this work were collected by one of the authors (N.I.). The sampling localities are summarized in Table 1.

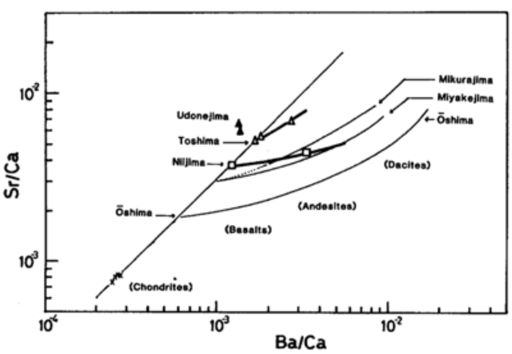

Fig. 2. SB systematics of basalt-andesite series of Toshima, Udonejima and Niijima situated behind the volcanic front. (△: Toshima, ▲: Udonejima, □: Niijima) Three series of SB systematics defined by Ōshima, Miyakejima, Mikurajima volcanoes situated on the volcanic front (HIRANO et al., 1982) are shown for comparison.

The specimens in Table 1 are arranged in chronological order based on stratigraphy of each volcanic island.

The analytical procedure used is inductively coupled plasma-optical emission spectrometry (HIRANO *et al.*, 1980; ONUMA *et al.*, 1981).

RESULTS AND DISCUSSION

The results obtained in this work are listed in Table 2. Sr/Ca *vs.* Ba/Ca plots for basalts and andesites from Toshima, Udonejima and Niijima are shown in Fig. 2 together with those of Ōshima, Miyakejima and Mikurajima for comparison. SB systematics defined by rhyolites from Niijima, Kōzushima and the adjacent islets is shown in Fig. 3.

(1) *SB systematics in volcanoes on the volcanic front parallel to the Izu-Ogasawara Trench*
Figure 4 shows a Sr/Ca-Ba/Ca diagram (SB diagram) reported in the previous paper (HIRANO *et al.*, 1982) for volcanoes of the volcanic front parallel to the Izu-Ogasawara Trench. Various volcanic rocks (basalts, andesites and dacites) from volcanoes of Ōshima, Miyakejima and Mikurajima make three different series of SB systematics.

Each of the trends of a given SB plot displayed by a volcano represents the evolution path of a primary magma by plagioclase-clino-

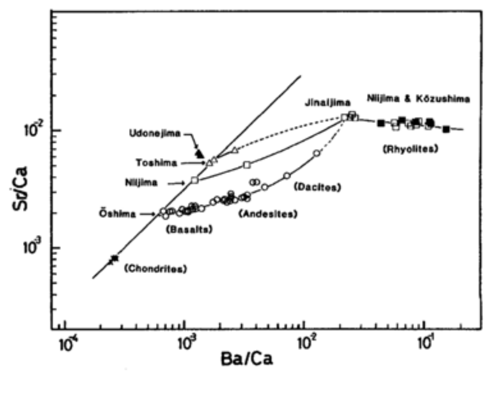

Fig. 3. SB systematics of rhyolites of Niijima and Kōzushima situated behind the volcanic front. (□: Niijima, ■: Kōzushima)

Table 1. Sampling localities

Sample	Locality	Reference
Toshima volcano		
NI70053001	The lowermost lava flow near Nazukata on the eastern coast	ISSHIKI (1978)
NI70052903	A lava flow exposed on the sea-cliff near Ōne on the northwestern coast	ISSHIKI (1978)
NI70060606	A lava flow exposed on the sea-cliff a little west of a landing place at Maehama on the northern coast	ISSHIKI (1978)
Udonejima volcano		
NI70053101	A dike exposed at the east-southeastern tip	
NI70053109	A dike exposed at the west-northwestern tip	
Niijima		
(1) Jinaijima volcano		
NI73052502	Dome lava exposed on Nadara Rock 300m south-southeast of the southern tip of Jinaijima	
NI73052503	Dome lava exposed on Nadara Rock 300m south-southeast of the southern tip of Jinaijima	
NI73052504	Dome lava exposed on Natsuhada Rock 50m west of the northwestern tip of Jinaijima	
NI73052505	Dome lava exposed at Kirema of Jinaijima	
(2) Habushiiso volcano		
NI71060807	Dome lava exposed at a roadcut near Habushiiso	
(3) Shimawakezawa pyroclastic rock		
NI73030307	Essential lapilli exposed on the right bank of Shimawakezawa on the western coast	
(4) Niijimayama volcano		
NI71053101	Dome lava exposed at Okunoiso north of Wakagō-Maehama	
(5) Miyatsukayama volcano		
NI73030607a	Dome lava exposed on the eastern wall of Miyatsukayama in the middle of Niijima	
NI73030607b	A cognate inclusion in dome lava exposed on the eastern wall of Miyatsukayama in the middle of Niijima	
(6) Wakagō volcano		
NI71053103	A bomb in the base surge deposit exposed at the northern end of Wakagō-Maehama	
(7) Atchiyama volcano		
NI75052401	Dome lava exposed on the northern flank of Atchiyama	
NI71060103	Dome lava exposed at the southern end of Awaiura on the eastern coast	
NI71060104	A cognate inclusion in dome lava exposed at the southern end of Awaiura on the eastern coast	
(8) Mukaiyama volcano		
NI71061203	Dome lava exposed on a roadcut east of Tangoyama	
Kōzushima		
(1) Membō volcano		
NI60072503	Dome lava exposed on the sea-cliff near Kōzushima lighthouse at the southwestern tip	
NI60072504	A cognate inclusion in dome lava exposed on the sea-cliff near Kōzushima lighthouse at the southwestern tip	
NI60072214	A cognate inclusion in dome lava exposed on the western sea-cliff of Miura Bay	
(2) Nagahama volcano		
NI76053102	A lava flow exposed at the northern end of Maehama	
(3) Sanukayama volcano		
FT501	Glassy part of dome lava exposed at the east-northeastern end of Takō Bay	
NI60072102	Lithic part of dome lava exposed at the east-northeastern end of Takō Bay	
(4) Takōdoyama volcano		
NI76052706	Dome lava exposed on a roadcut on the eastern flank of Takōdoyama	
(5) Tenjōsan volcano		
NI60072406	Dome lava exposed near a trail about 300m north of Fudōson on Tenjōsan	

Table 2. Ca, Sr and Ba contents and Sr/Ca, Ba/Ca ratios of volcanic rocks of Toshima, Udonejima, Niijima and Kōzushima, the Izu Islands, Japan

Sample	Rock type	Ca (ppm)	Sr (ppm)	Ba (ppm)	Sr/Ca	Ba/Ca
Toshima volcano						
NI70053001	Augite-olivine basalt	72,600	400	131	5.51×10^{-3}	1.80×10^{-3}
NI70052903	Olivine-augite basalt	73,500	383	121	5.21×10^{-3}	1.65×10^{-3}
NI70060606	Olivine andesite	60,900	414	165	6.80×10^{-3}	2.71×10^{-3}
Udonejima volcano						
NI70053101	Augite-olivine basalt	72,900	474	98.8	6.50×10^{-3}	1.36×10^{-3}
NI70053109	Olivine-augite basalt	74,700	444	103	5.94×10^{-3}	1.38×10^{-3}
Niijima						
(1) Jinaijima volcano						
NI73052502	Rhyolite (lithic)	16,500	210	365	1.27×10^{-2}	2.21×10^{-2}
NI73052503	Hypersthene-cummingtonite-hornblende rhyolite (glassy)	15,100	194	406	1.28×10^{-2}	2.69×10^{-2}
NI73052504	Rhyolite (lithic)	15,400	196	377	1.27×10^{-2}	2.45×10^{-2}
NI73052505	Biotite- and augite-bearing hypersthene-cummingtonite-hornblende rhyolite	15,300	200	392	1.31×10^{-2}	2.56×10^{-2}
(2) Habushiiso volcano						
NI71060807	Biotite-bearing cummingtonite rhyolite	8,710	98.5	509	1.13×10^{-2}	5.84×10^{-2}
(3) Shimawakezawa pyroclastic rock						
NI73030307	Bronzite-augite andesite	46,800	235	158	5.02×10^{-3}	3.38×10^{-3}
(4) Niijimayama volcano						
NI71053101	Hypersthene- and cummingtonite-bearing biotite rhyolite	6,010	70.9	557	1.18×10^{-2}	9.27×10^{-2}
(5) Miyatsukayama volcano						
NI73030607a	Biotite rhyolite	5,510	58.0	602	1.05×10^{-2}	1.09×10^{-1}
NI73030607b	Cognate inclusion in biotite rhyolite	73,600	262	103	3.56×10^{-3}	1.40×10^{-3}
(6) Wakagō volcano						
NI71053103	Olivine basalt	72,300	275	88.1	3.80×10^{-3}	1.22×10^{-3}
(7) Atchiyama volcano						
NI75052401	Biotite rhyolite	7,260	79.8	547	1.10×10^{-2}	7.53×10^{-2}
NI71060103	Biotite rhyolite	6,920	74.9	545	1.08×10^{-2}	7.88×10^{-2}
NI71060104	Cognate inclusion in biotite rhyolite	74,700	246	91.2	3.29×10^{-3}	1.22×10^{-3}
(8) Mukaiyama volcano						
NI71061203	Biotite rhyolite	6,470	71.1	565	1.10×10^{-2}	8.73×10^{-2}
Kōzushima						
(1) Membō volcano						
NI60072503	Hypersthene rhyolite	11,400	126	497	1.11×10^{-2}	4.36×10^{-2}
NI60072504	Cognate inclusion in hypersthene rhyolite	58,200	413	45.2	7.10×10^{-3}	7.77×10^{-4}
NI60072214	Cognate inclusion in hypersthene rhyolite	60,900	408	194	6.70×10^{-3}	3.19×10^{-3}
(2) Nagahama volcano						
NI76053102	Cummingtonite rhyolite	8,110	97.3	541	1.20×10^{-2}	6.67×10^{-2}
(3) Sanukayama volcano						
FT501	Biotite rhyolite (obsidian)	5,390	59.8	601	1.11×10^{-2}	1.12×10^{-1}
NI60072102	Rhyolite	5,480	61.7	614	1.13×10^{-2}	1.12×10^{-1}
(4) Takōdoyama volcano						
NI76052706	Biotite rhyolite	6,640	73.3	583	1.10×10^{-2}	8.78×10^{-2}
(5) Tenjōsan volcano						
NI60072406	Biotite rhyolite	3,970	39.7	600	1.00×10^{-2}	1.51×10^{-1}

pyroxene crystallization within a "magma chamber". The slope of an SB plot is controlled by the plagioclase/clinopyroxene ratio of cumulates. The parallelism of these series of SB plots suggests a general similarity of plagioclase-clinopyroxene crystallization process in the respective "magma chambers".

The line with slope of 45° through chondritic Sr/Ca and Ba/Ca ratios is a hypothetical partial melting line (ONUMA *et al.*, 1981). The chondritic meteorites, as is well known, show non-volatile elemental abundances representative of the solar system. The non-volatile elements such as Ca, Sr and Ba are expected not to be fractionated during the accretion process of planetary materials on a growing planet, and subsequent metal-silicate fractionation processes within the planet. Therefore, we employed Sr/Ca and Ba/Ca ratios of chondritic meteorites as those of a hypothetical terrestrial mantle material.

If mantle peridotite beneath these volcanoes has the same Sr/Ca and Ba/Ca ratios as those of chondritic meteorites, primary magmas derived from the mantle with different degrees of partial melting are considered to lie on the line. As shown in Fig. 4, these three series of SB systematics start from the hypothetical partial melting line. We defined the intersection of SB systematics given by a volcano and the hypothetical partial melting line as the SB index. The larger SB index corresponds to a smaller degree of partial melting and vice versa.

Thus, the difference in SB indices of three different series of SB systematics suggests different degrees of partial melting of mantle peridotite. The degree of partial melting is larger in the volcanoes of Ōshima than in Miyakejima or Mikurajima volcano. The important fact indicated in Fig. 4 is that mantle peridotite beneath these volcanoes has Sr/Ca and Ba/Ca ratios similar to chondritic values.

(2) *Basalts and andesites from volcanoes behind the volcanic front* Figure 2 shows Sr/Ca *vs.* Ba/Ca plots of basalts and andesites from Toshima, Udonejima and Niijima. These volcanic

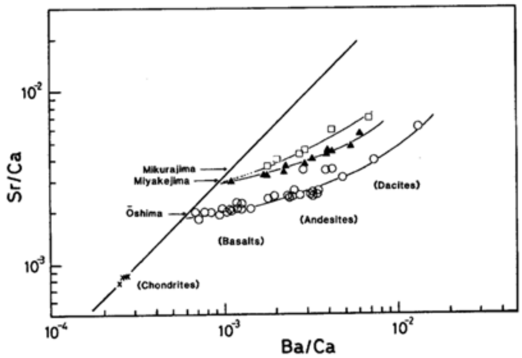

Fig. 4. Comparison of SB systematics of volcanoes situated on the volcanic front parallel to the Izu-Ogasawara Trench. (○: Ōshima, ▲: Miyakejima, □: Mikurajima)
The line with slope of 45° through chondritic Sr/Ca and Ba/Ca ratios is a hypothetical partial melting line. Data are from ONUMA *et al., (1981) and* HIRANO *et al., (1982).*

islands are aligned obliquely to the Izu-Ogasawara Trench and behind the volcanic front (Fig. 1).

Basalts and andesite of Toshima volcano define an SB trend situated above that of Mikurajima, as shown in Fig. 2. The parallelism between the Toshima trend, and those of Mikurajima, Miyakejima and Ōshima indicates similar crystal fractionation process in the respective "magma chambers", while the larger SB index for Toshima suggests a smaller (or the smallest in this region) degree of partial melting of mantle peridotite with chondritic Sr/Ca and Ba/Ca ratios.

Basalt and andesite of Niijima define a different series of SB systematics with a gentle slope. The gentle slope suggests that the plagioclase/clinopyroxene ratio in crystal fractionation processes in the "magma chambers" of Niijima is larger than for the other volcanoes considered here. The SB index (or degree of partial melting of mantle peridotite) of Niijima is smaller (or larger in degree) than that of Toshima volcano, and larger (or smaller in degree) than those of Ōshima, Miyakejima and Mikurajima volcanoes.

Both basalts from Toshima and Niijima lie on the hypothetical partial melting line, suggesting that the mantle peridotite beneath these volcanoes has the same Sr/Ca and Ba/Ca ratios as chondritic ratios. On the other hand, basalts from Udonejima volcano do not lie on the line, and plot slightly to the left. If we assume that Sr/Ca and Ba/Ca ratios of mantle peridotite in the Izu Island region are the same as chondritic ratios, as strongly indicated by Figs. 2 and 4, the exceptional basalts from Udonejima volcano are considered not to be a primary magma, but to be a slightly different melt. The exceptional basalts might be enriched in small amounts of cumulus plagioclase, since Sr/Ca and Ba/Ca ratios of plagioclase are similar to and smaller than those of coexisting magma, respectively.

Thus, mantle peridotite beneath the Izu Island region appears to have chondritic Sr/Ca and Ba/Ca ratios. The SB indices of the volcanoes lying on the volcanic front are smaller than those of volcanoes lying behind the front. In the case of volcanoes of Ōshima, Miyakejima and Mikurajima on the front, the SB index increases from Ōshima to Miyakejima and Mikurajima, in spite of the similar distance from the Izu-Ogasawara Trench. On the other hand, in the case of volcanoes of Ōshima, Toshima and Niijima extending oblique to the Izu-Ogasawara Trench, the SB index increases from Ōshima to Toshima, then decreases from Toshima to Niijima.

(3) *Rhyolites from volcanoes of Niijima and Kōzushima* The presence of rhyolites in Niijima, Shikinejima and Kōzushima characterizes arc volcanism in the Izu Islands. Figure 3 shows the SB systematics defined by rhyolites from Niijima and Kōzushima.

As shown in Fig. 3, both rhyolites from Niijima and Kōzushima are situated at positions of the largest Sr/Ca ratios with limited variation, and of the largest Ba/Ca ratios with large variation defining a quite different series of SB trend with a slightly negative slope. It is interesting that Ōshima SB systematics defined by basalt-andesite-dacite series, Niijima SB systematics and Toshima SB systematics defined by basalt-andesite series, all converge into the left end of the rhyolite SB systematics. The rhyolites located at the left end are from Jinaijima, so here we call them the rhyolites of Jinaijima type. Problems which we have to solve are: (a) convergence of SB systematics defined by the basalt-andesite-dacite and basalt-andesite series, (b) origin of quite different SB systematics defined by the rhyolite series.

The convergence of SB systematics defined by the basalt-andesite-dacite and basalt-andesite series into Jinaijima type rhyolites suggests that the rhyolites may be end products derived from crystal fractionation process operated in "magma chambers". The convergence also suggests that various primary magmas with different degrees of partial melting of mantle peridotite evolve through basalt-andesite-dacite path into a rhyolite with composition of Jinaijima type, regardless of the initial compositions of primary magmas. However, at present, we cannot explain the reason why primary magmas with different chemical compositions converge into a unique rhyolite by crystal fractionation processes.

The unique SB systematics defined by rhyolites from Niijima and Kōzushima might be explained by the following two mechanisms: (a) partial melting of Jinaijima type silicic rocks and Na-rich plagioclase left as residual solid, or (b) total melting of Jinaijima type silicic rocks followed by Na-rich plagioclase crystallization. Removal of Na-rich plagioclase from a given melt causes great increase of Ba/Ca ratio with slight decrease of Sr/Ca ratio in evolved melts. Therefore, we can expect such unique SB systematics with a gentle negative slope by removal of Na-rich plagioclase from melts. Jinaijima rhyolites are considered to be melts derived from an end product of crystal fractionation process by total melting, and the other rhyolites might have been derived from Jinaijima type silicic rocks by removal of Na-rich plagioclase through remelting process.

(4) *Cognate inclusions of basaltic composition in Niijima and Kōzushima rhyolites* If the

Table 3. Comparison of chemical compositions of olivine basalt and cognate inclusions in biotite rhyolites in Niijima Islands (in ppm)

	Olivine basalt Wakagō volcano (NI71053103)	Cognate inclusion Miyatsukayama volcano (NI73030607b)	Cognate inclusion Atchiyama volcano (NI71060104)
Al	91,300	92,700	88,300
Ca	72,300	73,600	74,700
Fe	93,700	82,200	95,500
K	3,960	4,030	3,800
Mg	31,200	32,000	30,700
Mn	1,670	1,710	1,660
Na	18,800	17,900	17,000
P	930	790	790
Ti	6,510	5,600	6,510
Ba	88.1	103	91.2
Sc	44.0	40.7	50.3
Sr	275	262	246
V	400	326	459
Y	22.2	23.2	22.5

proposed model that the rhyolites are derived from Jinaijima type silicic rocks by remelting is correct, we have to answer a question how to melt the silicic rocks or thin crust which might be seated at a shallow depth beneath Niijima and Kōzushima. Cognate inclusions in rhyolites from these islands are considered to be a clue to the problem.

The cognate inclusions in rhyolite from Niijima have compositions very similar to that of basalt of Niijima, as shown in Table 3. The similarity suggests that the cognate inclusions might be relics of basaltic melts which have intruded under the thin crust made of Jinaijima type silicic rocks, and have triggered remelting of the crust. Although any basaltic lava is not exposed on the surface of Kōzushima, the cognate inclusions in rhyolite from Kōzushima are also considered to be relics of basaltic melts which have initiated remelting of the thin crust of Jinaijima type composition.

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