Sr/Ca-Ba/Ca systematics of Quaternary volcanoes in Toshima, Udoneyjima, Nijima and Közushima, the Izu Islands, Japan*

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(Received January 7, 1982: Accepted April 25, 1982)

Ca, Sr and Ba contents in various volcanic rocks (basalts, andesites, rhyolites and their cognate inclusions) from Quaternary volcanoes in Toshima, Udoneyjima, Niijima and Közushima, 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 Közushima region. The majority of rhyolites which characterize the volcanoes of Niijima and Közushima 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 Oshima, Miyakejima, Mikurajima, Önoharajima 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, Udoneyjima, Niijima and Közushima lying on the distinct submarine ridges obliquely disposed to the Izu-Ogasawara Trench. The purpose of this report is to examine:—(a)

* Contribution No. 2379, Geological Survey of Japan.
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 Kozushima will be discussed in detail.

**GEOLOGICAL SETTING**

The geology and petrology of Toshima, Udonejima, Niijima, Kozushima and associated small volcanic islets have been studied by one of us (N.I.) and a part of the study has already been published (Ishiki, 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 14C dating and archeological evidence. The basalts of the main stratovolcano contain phenocrysts 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 phenocrysts 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 withapatite 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 Kozushima and the adjacent islets Kozushima 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. Kozushima 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. 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, Kozushima 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-

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**Fig. 2.** SB systematics of basalt-andesite series of Toshima, Udomejima and Niijima situated behind the volcanic front. (∆: Toshima, ◆: Udomejima, ○: 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.

**Fig. 3.** SB systematics of rhyolites of Niijima and Kozushima situated behind the volcanic front. (○: Niijima, □: Kozushima)
Table 1. Sampling localities

<table>
<thead>
<tr>
<th>Sample Locality</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td><strong>Toshima volcano</strong></td>
<td></td>
</tr>
<tr>
<td>NI70053001 The lowermost lava flow near Nazukata on the eastern coast</td>
<td>ISSHIKI (1978)</td>
</tr>
<tr>
<td>NI70052903 A lava flow exposed on the sea-cliff near Ōne on the northwestern coast</td>
<td>ISSHIKI (1978)</td>
</tr>
<tr>
<td>NI70060606 A lava flow exposed on the sea-cliff a little west of a landing place at Maehama on the northern coast</td>
<td>ISSHIKI (1978)</td>
</tr>
<tr>
<td><strong>Udonejima volcano</strong></td>
<td></td>
</tr>
<tr>
<td>NI70053101 A dike exposed at the east-southeastern tip</td>
<td></td>
</tr>
<tr>
<td>NI70053109 A dike exposed at the west-northwestern tip</td>
<td></td>
</tr>
<tr>
<td><strong>Niijima</strong></td>
<td></td>
</tr>
<tr>
<td>(1) Jinajijima volcano</td>
<td></td>
</tr>
<tr>
<td>NI73052502 Dome lava exposed on Nadara Rock 300m south-southeast of the southern tip of Jinajijima</td>
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</tr>
<tr>
<td>NI73052503 Dome lava exposed on Nadara Rock 300m south-southeast of the southern tip of Jinajijima</td>
<td></td>
</tr>
<tr>
<td>NI73052504 Dome lava exposed on Natsuha Rock 50m west of the northwestern tip of Jinajijima</td>
<td></td>
</tr>
<tr>
<td>NI73052505 Dome lava exposed at Kirema of Jinajijima</td>
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</tr>
<tr>
<td>(2) Habushiiho volcano</td>
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<tr>
<td>NI71060807 Dome lava exposed at a roadcut near Habushiiho</td>
<td></td>
</tr>
<tr>
<td>(3) Shimawakezawa pyroclastic rock</td>
<td></td>
</tr>
<tr>
<td>NI73030307 Essential lapilli exposed on the right bank of Shimawakezawa on the western coast</td>
<td></td>
</tr>
<tr>
<td>(4) Niijimayama volcano</td>
<td></td>
</tr>
<tr>
<td>NI71053101 Dome lava exposed at Okunoiso north of Wakagō-Maehama</td>
<td></td>
</tr>
<tr>
<td>(5) Miyatsukayama volcano</td>
<td></td>
</tr>
<tr>
<td>NI73030607a Dome lava exposed on the eastern wall of Miyatsukayama in the middle of Niijima</td>
<td></td>
</tr>
<tr>
<td>NI73030607b A cognate inclusion in dome lava exposed on the eastern wall of Miyatsukayama in the middle of Niijima</td>
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<tr>
<td>(6) Wakago volcano</td>
<td></td>
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<tr>
<td>NI71053103 A bomb in the base surge deposit exposed at the northern end of Wakagō-Maehama</td>
<td></td>
</tr>
<tr>
<td>(7) Atchiyama volcano</td>
<td></td>
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<tr>
<td>NI75052401 Dome lava exposed on the northern flank of Atchiyama</td>
<td></td>
</tr>
<tr>
<td>NI71061013 Dome lava exposed at the southern end of Awaiura on the east coast</td>
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<tr>
<td>NI71061014 A cognate inclusion in dome lava exposed at the southern end of Awaiura on the east coast</td>
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<td>(8) Mukaiyama volcano</td>
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<td>NI71061203 Dome lava exposed on a roadcut east of Tangoyama</td>
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<td><strong>Kōzushima</strong></td>
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<td>(1) Membo volcano</td>
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<tr>
<td>NI60072503 Dome lava exposed on the sea-cliff near Kōrushima light-house at the southwestern tip</td>
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<tr>
<td>NI60072504 A cognate inclusion in dome lava exposed on the sea-cliff near Kōzushima lighthouse at the southwestern tip</td>
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<tr>
<td>NI60072214 A cognate inclusion in dome lava exposed on the western sea-cliff of Miura Bay</td>
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<td>(2) Nagahama volcano</td>
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<tr>
<td>NI76053102 A lava flow exposed at the northern end of Maehama</td>
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<td>(3) Sanukayama volcano</td>
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<tr>
<td>FT501 Glassy part of dome lava exposed at the east-northeastern end of Takō Bay</td>
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<tr>
<td>NI60072102 Lithic part of dome lava exposed at the east-northeastern end of Takō Bay</td>
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<td>(4) Takōdoyama volcano</td>
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<tr>
<td>NI76052706 Dome lava exposed on a roadcut on the eastern flank of Takōdoyama</td>
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<td>(5) Tenjōsan volcano</td>
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<tr>
<td>NI60072406 Dome lava exposed near a trail about 300m north of Fujōson on Tenjōsan</td>
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</table>
Table 2. Ca, Sr and Ba contents and Sr/Ca, Ba/Ca ratios of volcanic rocks of Toshima, Udomejima, Niijima and Kozushima, the Izu Islands, Japan

<table>
<thead>
<tr>
<th>Sample</th>
<th>Rock type</th>
<th>Ca (ppm)</th>
<th>Sr (ppm)</th>
<th>Ba (ppm)</th>
<th>Sr/Ca</th>
<th>Ba/Ca</th>
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<td>NI70053001</td>
<td>Augite-olivine basalt</td>
<td>72,600</td>
<td>400</td>
<td>131</td>
<td>5.51 x 10^-3</td>
<td>1.80 x 10^-3</td>
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<tr>
<td>NI70052903</td>
<td>Olivine-augite basalt</td>
<td>73,500</td>
<td>383</td>
<td>121</td>
<td>5.21 x 10^-3</td>
<td>1.65 x 10^-3</td>
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<tr>
<td>NI70060606</td>
<td>Olivine andesite</td>
<td>60,900</td>
<td>414</td>
<td>165</td>
<td>6.80 x 10^-3</td>
<td>2.71 x 10^-3</td>
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<td>NI70053101</td>
<td>Augite-olivine basalt</td>
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<td>98.8</td>
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<td>NI70053109</td>
<td>Olivine-augite basalt</td>
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<td>Rhyolite (lithic)</td>
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<td>Hypersthene-cummingtonite-hornblende rhyolite (glassy)</td>
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<td>406</td>
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<td>Biotite- and augite-bearing</td>
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<td>NI71060807</td>
<td>Biotite-bearing cummingtonite rhyolite</td>
<td>8,710</td>
<td>98.5</td>
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<td>1.13 x 10^-2</td>
<td>5.84 x 10^-2</td>
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<td>NI73030307</td>
<td>Bronzite-augite andesite</td>
<td>46,800</td>
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<td>NI71053101</td>
<td>Hypersthene- and cummingtonite-</td>
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<td>70.9</td>
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<td>NI73030607a</td>
<td>Biotite rhyolite</td>
<td>5,510</td>
<td>58.0</td>
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<td>Cognate inclusion in biotite rhyolite</td>
<td>73,600</td>
<td>262</td>
<td>103</td>
<td>3.56 x 10^-3</td>
<td>1.40 x 10^-3</td>
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<td>NI71053103</td>
<td>Olivine basalt</td>
<td>72,300</td>
<td>275</td>
<td>88.1</td>
<td>3.80 x 10^-3</td>
<td>1.22 x 10^-3</td>
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<td>NI75052401</td>
<td>Biotite rhyolite</td>
<td>7,260</td>
<td>79.8</td>
<td>547</td>
<td>1.10 x 10^-2</td>
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<td>NI71060103</td>
<td>Biotite rhyolite</td>
<td>6,920</td>
<td>74.9</td>
<td>545</td>
<td>1.08 x 10^-2</td>
<td>7.88 x 10^-2</td>
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<td>NI71060104</td>
<td>Cognate inclusion in biotite rhyolite</td>
<td>74,700</td>
<td>246</td>
<td>91.2</td>
<td>3.29 x 10^-3</td>
<td>1.22 x 10^-3</td>
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<td>(8) Mukaiyama volcano</td>
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<td>NI71061203</td>
<td>Biotite rhyolite</td>
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<tr>
<td><strong>Kozushima</strong></td>
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<td>(1) Membo volcano</td>
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<td>NI60072503</td>
<td>Hypersthene rhyolite</td>
<td>11,400</td>
<td>126</td>
<td>497</td>
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<td>Cognate inclusion in hypersthene rhyolite</td>
<td>58,200</td>
<td>413</td>
<td>45.2</td>
<td>7.10 x 10^-3</td>
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<td>194</td>
<td>6.70 x 10^-3</td>
<td>3.19 x 10^-3</td>
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<td>(2) Nagahama volcano</td>
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<td>NI76053102</td>
<td>Cummingtonite rhyolite</td>
<td>8,110</td>
<td>97.3</td>
<td>541</td>
<td>1.20 x 10^-2</td>
<td>6.67 x 10^-2</td>
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<td>(3) Sanukayama volcano</td>
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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 Oshima 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 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 Oshima 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 Oshima, 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 crystallization. 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
proposed model that the rhyolites are derived from Jinajima 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 Kozushima. 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 Jinajima type silicic rocks, and have triggered remelting of the crust. Although any basaltic lava is not exposed on the surface of Kozushima, the cognate inclusions in rhyolite from Kozushima are also considered to be relics of basaltic melts which have initiated remelting of the thin crust of Jinajima type composition.

Acknowledgments—The work was supported in part by Grant-in-Aid for Scientific Research, No. 504112 and No. 56110005 from the Ministry of Education, Science and Culture, Japan.

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

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<th>Olivine basalt</th>
<th>Cognate inclusion</th>
<th>Cognate inclusion</th>
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<td>Miyatsukayama volcano</td>
<td>Atchiyama volcano</td>
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REFERENCES


