K-Ar Ages of Andesites from Two Volcanic Arrays in Western Chugoku, Southwest Japan

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The volcanic front in the Southwest Japan Arc formed relative to the subducting Philippine Sea Plate. In the west Chugoku district, the volcanic front changes direction from E-W to NNE-SSW. Twenty-two Quaternary lava domes in this area can be topographically classified into two arrays (East and West arrays) based on the degree of dissection. K-Ar age results show that domes of the East array formed earlier (0.6-0.3 Ma) than those of the West array (0.2 Ma-recent). The two arrays in different ages may result from the migration of volcanic front caused by westward migration of the PSP slab.

1. Introduction

The volcanic front of the Southwest Japan arc (Aramaki and Ui, 1982) consists of two differently oriented segments in Chugoku and Kyushu-Nansei Islands (Fig. 1). Active volcanoes along the volcanic front in the Kyushu-Nansei Islands result from subduction of the Philippine Sea Plate (PSP) (Kamata and Kodama, 1999), which is represented by a seismic plane, reaching to 120 km depth (Fig. 1). In contrast, the intermediate lava domes along the volcanic front in the Chugoku segment preserve no record of historical eruptions, and no deep earthquakes occur beneath them. However recent studies of seismic tomography revealed that an aseismic part of the PSP exists beneath the area (Hirahara, 1981; Zhao et al., 2000). Zhao et al. (2000) concluded that the volcanic front in Chugoku also formed relative to the subducting PSP slab. In this paper, we examine the degree of erosion of intermediate lava domes distributed in the west Chugoku district, where the volcanic front changes direction from E-W to NNE-SSW (Fig. 1), and propose that the domes are classified into eastern and western arrays. We also present K-Ar ages for them. The results show that the eastern array volcanoes were formed considerably earlier than those in the western array.

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2. Geology and Geomorphology

Basement rocks to the Quaternary lava domes in the west Chugoku district consist mainly of Permian sedimentary and metamorphic rocks and Cretaceous felsic welded tuff (Geological Survey of Japan, 1978). The twenty-two Quaternary lava domes found in this area can be classified topographically into less dissected and dissected (Fig. 2). The former have flat tops surrounded by relatively smooth and circular contour lines (Fig. 3). Most slopes range from 31° to 33°, which is close to the
angle of repose of talus deposits. This geomorphology of the domes suggests that they preserve the original shape accompanied by a talus apron. They are concentrated in the western half and form a NE-SW trending volcanic array (West array). The West array consists of Nabe-yama (also referred to as Shima, locality number 1 in Fig. 2; 610 m above sea level), Chikura-yama (2; 622 m), Koaono-yama (3; 684 m), Aono-yama (4; 908 m), Ryuboshi-yama (5; 534 m) and Kumoi-mine (7; 523 m), and Nosaka-yama (8; 640 m)—which form a single dome respectively—and an unnamed 420 m peak (6; 420 m), Taiin-san (9; 594 m), Otsubo-yama (10; 636 m), Kannon-yama (11; 497 m), and an unnamed 416 m peak (12; 416 m). They have been called the Aono-yama Volcano Group by Taneda and Yamaguchi (1950). Of these domes, Aono-yama (4) is the largest, with a basal diameter of 2000 m and a dome height of 520 m, and Nabe-yama (1) is the smallest, with a basal diameter of 430 m and a dome height of 80 m (basal diameters and heights are from Table 1 in Moriya, 1978). Choja-bara Volcano, located 20 km southwest of the Aono-yama Group (13 in Fig. 2), is composed of basaltic andesite and forms a less dissected flat hill. Large valleys west of Chikurayama and north of Aono-yama (Fig. 3) are consistent with either explosive or gravitational collapse of the dome.

In contrast, domes which have a number of deeply-incised valleys and pointed tops (Fig. 4) are distributed in the eastern half of the district (Fig. 2). They show a greater degree of dissection compared to the domes in the West array and trend in a NNE-SSW direction over 40 km (East array). Constituent volcanoes of the East array include Tobinoko-yama (locality number 14 in Fig. 2; 604 m above sea level), Mottaga-dake (15; 891 m), Maru-yama (16; 648 m), an unnamed 835 m peak (17; 835 m), Kinpo-san (18; 790 m), Shiroi-dake (19; 660 m), Sengoku-dake (20; 630 m), Shikuma-dake (21; 504 m), and Dake-yama (22; 364 m). Of these domes, Mottaga-dake (15) is the largest, with a basal diameter of 2500 m and a dome height of 395 m, and the unnamed 835 m peak (17) is the smallest, with a basal diameter of 675 m and a dome height of 160 m (basal diameters and heights were calculated following Moriya, 1978).

3. K-Ar ages
3-1 Samples
Samples for K-Ar dating were taken from summit outcrops or slopes of lava domes wherever possible, or from large lava blocks (> 100 cm in diameter) on dome aprons where there was no outcrop. In the case of Choja-bara volcano, the dated sample is an essential block (ca. 15 cm long) from a pyroclastic unit (possibly a pyroclastic surge deposit). Sample localities are given in Table 1, and some are marked on Figs. 3 and 4. All samples from both the West and East arrays contain hornblende and plagioclase phenocrysts, in a groundmass consisting of hornblende, plagioclase, and iron oxide, quartz, and interstitial glass or micro- to crypto-crystalline material.
Biotite and pyroxene are rare as either phenocrysts or groundmass. Hornblende is usually brown, and partially or completely opacitized.

3-2 Analytical procedures

Samples were crushed and sieved to obtain 60 (250 μm) to 100 mesh (150 μm) fractions. Magnetic minerals and phenocrysts were removed from the fractions using a hand magnet and an isodynamic separator. The groundmass fraction was used for K and Ar analysis. In three samples (WSHh, KMlh, SREh), hornblende phenocrysts were concentrated to over 99% purity using an isodynamic separator. A modified-VG5400 mass spectrometer was used for Ar analysis by isotope dilution at the Institute for Study of the Earth’s Interior, Okayama University. Some samples were also analyzed by the sensitivity method (Itaya and Nagao, 1988; Matsumoto et al., 1989) using another modified-VG5400 system, which is permanently free from the $^{38}$Ar spike. Analytical procedures and precision of these systems have been discussed by Nagao et al. (1991; 1996). K analyses were performed at Osaka City University using flame photometry following the method described by Nagao et al. (1984).

3-3 Results

Analytical results for twelve samples are listed in Table 1. Five samples showing a large air contamination (>96%) were further analyzed by the
Fig. 4. Geomorphology of some domes of the East array.
Number shows location of domes in Fig. 2. X: sampling locality. broken line: estimated base line of domes.
1 : 25,000 Digital Map (Yamaguchi), Geographical Survey Institute (2001) is used.
### Table 1. K-Ar age results by the isotope dilution method.

<table>
<thead>
<tr>
<th>sample name</th>
<th>dome</th>
<th>sampling locality</th>
<th>A No.</th>
<th>Longitude</th>
<th>Latitude</th>
<th>K (wt%)</th>
<th>Weight (g)</th>
<th>( ^{40}\text{Ar}/^{39}\text{Ar} )</th>
<th>( ^{39}\text{Ar} ) (STP/10(^{18}))</th>
<th>Air Frac. (%)</th>
<th>K-Ar age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CKY</td>
<td>Chikusa- Yama</td>
<td>W 2 34° 28.42'N 131° 49.21'E</td>
<td>1.519±0.046</td>
<td>0.70649</td>
<td>297.0±0.2</td>
<td>43.6±0.44</td>
<td>0.561±0.243</td>
<td>99.68</td>
<td>0.085±0.041</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AON</td>
<td>Aono- yama</td>
<td>W 4 34° 27.32'S 131° 48.00'E</td>
<td>1.094±0.036</td>
<td>0.71636</td>
<td>305.6±0.2</td>
<td>68.37±0.079</td>
<td>0.669±0.038</td>
<td>96.85</td>
<td>0.157±0.010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KMI</td>
<td>Kumo- mine</td>
<td>W 7 34° 28.35'N 131° 44.57'E</td>
<td>1.732±0.052</td>
<td>0.69520</td>
<td>295.6±0.2</td>
<td>142.1±1.4</td>
<td>1.282±1.190</td>
<td>100.12</td>
<td>0.190±0.177</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHB</td>
<td>Chojabara</td>
<td>W 13 34° 18.23.47'N 131° 40.08'E</td>
<td>1.235±0.037</td>
<td>0.72161</td>
<td>315.4±0.3</td>
<td>4.014±0.055</td>
<td>0.792±0.022</td>
<td>93.82</td>
<td>0.185±0.008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTD</td>
<td>Mottagadake</td>
<td>E 15 34° 21.49.6'N 131° 52.30'E</td>
<td>1.099±0.033</td>
<td>0.72186</td>
<td>378.8±1.0</td>
<td>3.156±0.049</td>
<td>2.622±0.033</td>
<td>78.12</td>
<td>0.614±0.020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRE</td>
<td>835m peak</td>
<td>E 17 34° 14.58.1'N 131° 48.30'E</td>
<td>1.859±0.056</td>
<td>0.51120</td>
<td>304.3±0.3</td>
<td>30.37±0.32</td>
<td>2.565±0.227</td>
<td>97.23</td>
<td>0.355±0.033</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TKP</td>
<td>Kinpo-san</td>
<td>E 18 34° 11.0.5'N 131° 50.17'E</td>
<td>2.014±0.016</td>
<td>0.50480</td>
<td>550.9±14.</td>
<td>1.328±0.088</td>
<td>3.401±0.044</td>
<td>53.63</td>
<td>0.434±0.006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SGD</td>
<td>Sengoku-dake</td>
<td>E 20 34° 11.09.6'N 131° 45.59'E</td>
<td>1.903±0.057</td>
<td>0.50300</td>
<td>299.9±0.3</td>
<td>81.25±0.82</td>
<td>3.385±0.440</td>
<td>98.81</td>
<td>0.458±0.061</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKD</td>
<td>Shihumadake</td>
<td>E 21 34° 05.19.2'N 131° 48.12'E</td>
<td>1.752±0.053</td>
<td>0.73101</td>
<td>335.5±0.3</td>
<td>7.607±0.086</td>
<td>3.029±0.059</td>
<td>88.21</td>
<td>0.445±0.015</td>
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<td></td>
</tr>
<tr>
<td>WSH (A)</td>
<td>420m peak</td>
<td>W 6 34° 28.30.5'N 131° 45.45'E</td>
<td>0.477±0.014</td>
<td>0.81531</td>
<td>390.4±0.8</td>
<td>4.061±0.053</td>
<td>3.848±0.045</td>
<td>75.82</td>
<td>2.077±0.066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KMk (B)</td>
<td>Kumo-mine</td>
<td>W 7 34° 28.35.4'N 131° 44.57.7'E</td>
<td>0.817±0.019</td>
<td>0.94004</td>
<td>293.3±0.3</td>
<td>31.98±0.32</td>
<td>0.845±0.148</td>
<td>99.21</td>
<td>0.352±0.062</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRE (B)</td>
<td>835m peak</td>
<td>E 17 34° 14.58.1'N 131° 48.30'E</td>
<td>0.674±0.020</td>
<td>0.83922</td>
<td>342.5±0.3</td>
<td>9.032±0.097</td>
<td>4.228±0.071</td>
<td>89.40</td>
<td>1.615±0.055</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

decay constants \( \lambda = 0.581\times 10^{-10}/y, \beta = 4.962\times 10^{-10}/y \) and \( ^{40}K/K = 0.0001167 \) (Steiger and Jäger, 1977).

(*) hornblende phenocryst sample. A: division of arrays, W: West array, E: East array. No.: location number of dome shown in Fig. 2.

\( ^{40}\text{Ar}/^{39}\text{Ar} \): radiogenic \( ^{40}\text{Ar} \). Air Frac.: initially trapped atmospheric \( ^{40}\text{Ar} \) (%) in all \( ^{40}\text{Ar} \) in sample. Errors of K is 3%. Other errors are 1 \( \sigma \).

### Table 2. K-Ar age results by the sensitivity method.

<table>
<thead>
<tr>
<th>sample name</th>
<th>dome</th>
<th>K (wt%)</th>
<th>Weight (g)</th>
<th>( ^{39}\text{Ar}/^{38}\text{Ar} ) (present-day)</th>
<th>( ^{39}\text{Ar} ) (STP/10(^{18}))</th>
<th>Air Frac. (%)</th>
<th>K-Ar Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CKY</td>
<td>Chikusa- yama</td>
<td>1.519±0.046</td>
<td>0.4507</td>
<td>0.1879±0.00048</td>
<td>297.7±0.18</td>
<td>43.2±2.2</td>
<td>0.740±0.080</td>
</tr>
<tr>
<td>AON</td>
<td>Aono- yama</td>
<td>1.094±0.036</td>
<td>0.46444</td>
<td>0.1875±0.0051</td>
<td>304.72±0.17</td>
<td>6.87±0.35</td>
<td>0.599±0.033</td>
</tr>
<tr>
<td>KMI</td>
<td>Kumo- mine</td>
<td>1.732±0.052</td>
<td>0.46289</td>
<td>0.1878±0.00051</td>
<td>295.72±0.19</td>
<td>134.7±8.7</td>
<td>-0.38±0.26</td>
</tr>
<tr>
<td>SRE</td>
<td>835m peak</td>
<td>1.859±0.056</td>
<td>0.46576</td>
<td>0.1881±0.00053</td>
<td>305.23±0.24</td>
<td>29.3±1.5</td>
<td>2.70±0.15</td>
</tr>
<tr>
<td>SGD</td>
<td>Sengoku- dake</td>
<td>1.903±0.067</td>
<td>0.46655</td>
<td>0.1879±0.00082</td>
<td>301.44±0.19</td>
<td>74.5±3.7</td>
<td>4.05±0.25</td>
</tr>
</tbody>
</table>

decay constants \( \lambda = 0.581\times 10^{-10}/y, \beta = 4.962\times 10^{-10}/y \) and \( ^{40}K/K = 0.0001167 \) (Steiger and Jäger, 1977).

\( ^{40}\text{Ar}/^{39}\text{Ar} \): radiogenic \( ^{40}\text{Ar} \). Air Frac.: initially trapped atmospheric \( ^{40}\text{Ar} \) (%) in all 40Ar in sample. Errors of K is 3%. Other errors are 1 \( \sigma \).
sensitivity method to test the mass fractionation of initially trapped atmospheric argon (Table 2). As measured $^{38}\text{Ar}/^{36}\text{Ar}$ ratios are consistent with that of air ($^{38}\text{Ar}/^{36}\text{Ar} = 186$; Nier, 1950), a mass fractionation correction was not required. The ages obtained by both methods are consistent with each other within error. In the case of KMI, the present $^{40}\text{Ar}/^{36}\text{Ar}$ ratio, which was measured to a high degree of accuracy, is similar to that of air ($^{40}\text{Ar}/^{36}\text{Ar} = 296$). Even if a $2\sigma$ error in $^{40}\text{Ar}/^{36}\text{Ar}$ ratio (Table 2) is postulated, the upper age limit is 0.019 Ma. It is likely that KMI is at least younger than several 10 ka and is the youngest of the measured samples. The K-Ar ages of hornblende phenocrysts (SREh and KMIh) are unexpectedly older than the groundmass ages of the same samples (SRE, KMI), suggesting the presence of significant amounts of excess Ar in these hornblende phenocrysts. These results confirm that groundmass analysis is highly recommended for determining the eruption ages of young volcanic rocks (Itaya and Nagao, 1988). Consequently, the eruption age of the unnamed 420 m peak (6 in Figs. 2 and 3) is equivocal, it may be considerably younger than the K-Ar age of the hornblende phenocrysts (WSHh, 2.08 Ma).

4. Discussion and Conclusions

The K-Ar age data obtained by this study (Table 1 and Fig. 2) are consistent with the dissection state of the lava domes. The West array comprises younger lava domes ($<0.2$ Ma), whereas the East array domes are older (0.3 to 0.6 Ma). Kamata et al. (1988) reported six K-Ar ages from the West array and three from the East array. Some of their results for the West array are consistent with the data presented here (Aono-yama north; 0.23±0.01 Ma; Choja-bara, Kumoi-mine, and Nabe-yama; <0.2 Ma), but others are considerably older (Nosaka-yama; 0.46±0.05 Ma, Chikura Pass, near Chikurayama; 1.28±0.06 Ma). The flat top and smooth contoured topography of Nosaka-yama (3 in Fig. 3) is similar to other domes of the West array. Our sample CKY from Chikura-yama (2 in Fig. 3) was taken from a lava flow, which dammed up a valley cut into basement. Although there is a large valley in the western half of Chikura-yama, the smooth and quasi-circular contours of the eastern half (Fig. 3) suggest a less-dissected geomorphology similar to other domes of the West array. Kamata et al. (1988) reported three K-Ar ages between 0.6 and 1 Ma from the East array (Sengoku-dake; 1.00±0.05 Ma, Kinpo-san; 0.6±0.2 Ma, Shikuma-dake; 0.70±0.08 Ma). There are differences in the age results presented here and those of Kamata et al. (1988), although some domes might be composite domes formed over a lengthy period of time. However, both sets of data show that most of the domes from the East array are older than those of the West array.

Based on our results, it is likely that volcanic activity began at about 0.6 Ma and formed the East array domes until 0.3 Ma. Volcanism shifted to the west at about 0.2 Ma and continued until at least several 10 Ka, forming the West array. The orientations of two arrays make angles with the direction of the maximum horizontal compressional stress in Chugoku area in present, $\alpha_{Hmax}=$WNW to ESE (Tsukahara and Kobayashi, 1991), against along which some monogenetic volcano groups in the area elongate (Nakamura, 1977). Alternatively two arrays belong to the volcanic front, which are located at the northward extension of the volcanic front in Kyushu-Nansei Islands and the western end of that in Chugoku district. Therefore the formation of the two arrays of different ages might be due to a migration of the volcanic front in the west Chugoku district, and be related to westward migration of the PSP slab beneath the area.

Acknowledgments

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References


Geographical Survey Institute (2001) 1:25,000 Digital Map (Yamaguchi). Geographical Survey Institute, Japan.


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(Editorial handling Hikaru Iwamori)