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K-Ar Ages of Unzen Volcano in Kyushu, Japan

—With Some Aspects of Geology of Mayu-Yama—

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Abstract

Unzen volcano, a large composite volcano of andesite to dacite, is located at the central part of Shimabara Peninsula, Kyushu, Japan. Mayu-yama, a dacite composite dome in Unzen volcano, is situated isolated at the eastern foot of Unzen volcano. In 1792, the eastern slope of Mayu-yama collapsed and a large debris avalanche caused a big "Tsunami" which killed ca. 15,000 people around Shimabara Bay (OHTA, 1984). The growth history of Unzen volcano is briefly subdivided into four stages, i. e., Pre-Myoken-dake, Myoken-dake, Fugen-dake and historic eruption stage. The reliable K-Ar ages of the rocks from each stage are consistent with the stage subdivision of Unzen volcano. The geomorphologic features and K-Ar ages of the rocks from Mayu-yama are consistent with a conclusion that the main part and the basal part of Mayu-yama were formed in the Fugen-dake stage and in the Pre-Myoken-dake stage, respectively. The collapse of the upper part of Mayu-yama was probably controlled by the old and hard rocks at its base. This is significant for the magnitude of the next collapse which may occur in the future.

Key Words : Geology, K-Ar age, Unzen volcano, Mayu-yama

Introduction

Unzen volcano, a large composite volcano, is located at the central part of Shimabara Peninsula, Kyushu, Japan (Fig. 1). The main part of the Unzen volcano is composed of several lava domes and thick lava flows of andesite to dacite. The main peak, Fugen-dake, erupted in the summit area on November 17, 1990, after 198 years of dormancy.

Mayu-yama, a dacite composite dome of Unzen volcano, is situated isolated at the eastern foot of Unzen volcano. In 1792, the eastern slope of Mayu-yama collapsed and a large scale debris avalanche rushed into Shimabara Bay. This debris avalanche caused the big "Tsunami" which killed about 15,000 people around Shimabara Bay (OHTA, 1984). This catastrophe was the biggest volcanic disaster in Japan.

We have been studying the geology to clarify the growth history of Unzen volcano (WATANABE et al., 1991a, b). In this paper we intend to give some K-Ar ages for volcanic rocks of Unzen volcano, and to discuss some aspects of geology and the collapse of Mayu-yama in 1792.

Previous Works on Geology of Unzen Volcano

The brief geology and petrography of Unzen volcano were clarified by OGAWA and HOMMA

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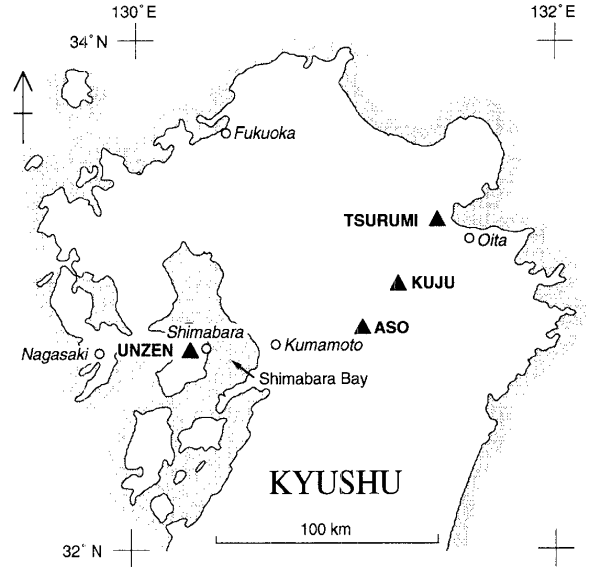

Fig. 1. Location of Unzen volcano. Solid triangles: Active volcanoes in Central Kyushu.

(1926), HOMMA (1936) and SENDO et al. (1967). OHTA (1984, 1987) summarized the geology and gave a geologic map taking into consideration the growth history of Unzen volcano. On the other hand, SUGIYAMA et al. (1986) and MIYACHI and OHTA(1985) gave some fission track ages for the volcanic rocks described by FUJINO and YAMASAKI (1975) (Table 2). TANAKA and NAKADA(1988) and TAKAHASHI (1989) independently made geologic maps of Unzen volcano. However, the results of these studies are not always consistent with each other.

K-Ar Age Determinations for Volcanic Rocks

Rock samples to be dated were collected from the entire area with regard to the growth history of Unzen volcano (Fig. 2). The analysis of K and Ar and calculation of ages were carried out by the methods of NAGAO et al. (1984), NAGAO and ITAYA (1988) and ITAYA et al. (1991).

The rock samples were crushed and the phenocrystic minerals were separated by an isodynamic separator. The size fraction of 60 to 80 mesh of groundmass was used for age determination. A portion of the 60 to 80 mesh fraction was ground using an agate mortar, and the resulting powder was analyzed for potassium.

The potassium analysis was carried out by flame photometry using a 2,000 ppm Cs buffer. The decomposition of powder sample for analysis by flame photometry was achieved with HF and HNO_3. Potassium content was determined from an average of two runs of measurement. Relative error of analyses could be attained within 2%.

Argon was analyzed on a 15 cm radius sector type mass spectrometer with a single collector system by an isotopic dilution method using an argon 38 spike. Calibration error of the argon 38 spike is within about 1% (ITAYA et al., 1991).

Localities of the analyzed samples and the results of K-Ar age determinations are shown in Fig. 2 and Tables 1, 2, respectively. Some samples are too young for age to be determined by the isotopic dilution method. Consequently, reliability of K-Ar age of some rocks is not enough, but some results were considered to be reliable because of insignificant contamination by atmospheric

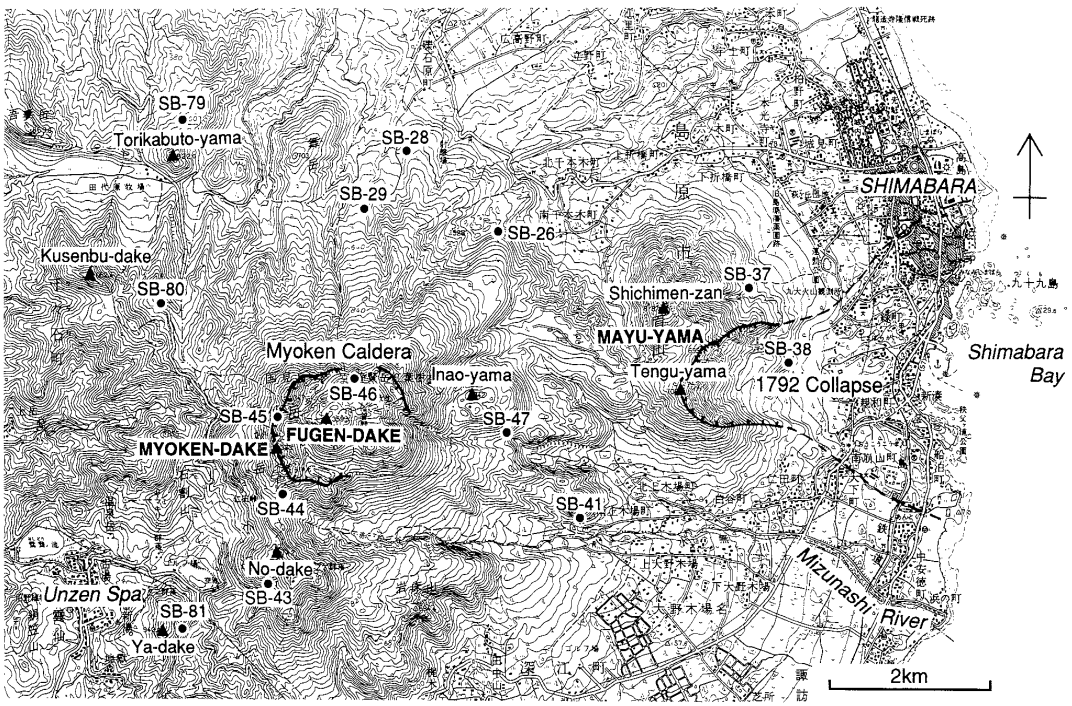

Fig. 2. Sample localities for K-Ar age determination of Unzen volcano. Numbers are consistent with those in Table 1. HO-1 is located outside of this map. Base map : 1 : 50,000 "Shimabara" published by Geographical Survey Institute.

argon.

K-Ar Ages and Geology of Unzen Volcano

In this paper, the growth history of Unzen volcano is briefly subdivided into four stages mainly by characteristic features in geomorphologic development. They are Pre-Myoken-dake stage, Myoken-dake stage, Fugen-dake stage and historic eruption stage, in ascending order. Each of the stages can probably be subdivided.

The volcanoes in the Pre-Myoken-dake stage are composed of many old dissected volcanoes around Myoken-dake. They are Taka-dake, Kusenbu-dake, Torikabuto-yama and others. Six reliable K-Ar ages from the volcanic rocks in this stage were measured about 0.26±0.02Ma to 0.08±0.02 Ma (Table 1).

The Myoken-dake, which has a small southeast-opened caldera embracing the Fugen-dake, is one of the main peaks of the caldera rim in this stage. The name of Myoken caldera was given by OHTA (1984). The K-Ar age of 0.04±0.02Ma is the only reliable age from rocks in this stage.

The Fugen-dake stage is the period from the formation of the Myoken caldera to the development of the main body of Fugen-dake in prehistoric age. The 0.02±0.01 Ma of K-Ar age was obtained from the main part of Mayu-yama.

NISHIMURA(1982) reported that the Myoken caldera was formed by a large collapse of Myoken-dake like the 1980 eruption of Mt. St. Helens. The age of the caldera formation was estimated at about 4,000 years ago by TAKAHASHI (1989), or younger than Akahoya Ash (6.3 ka ; MACHIDA and ARAI, 1978) by KOBAYASHI and OZEKI (1991). However, we believe that the age of

Table 1. Samples for K-Ar age determinations from Unzen volcano.

No.	Unit (Stage)	Rock Name	Locality		Sample Number
1	Kureishibaru PF. (Fugen-dake)	cpx-opx-bg qz-bi-hb An	Kenshu Center SW Shimabara City	32°46′45″N 130°17′59″E	SB-29
2	Fugen-dake-lave (Fugen-dake)	qz-cpx-bg opx-bi-hb An	Kazaana E Shimabara City	32°45′39″N 130°17′53″E	SB-46
3	Mayu-yama lava (Fugen-dake)	opx-bg qz-bi-hb Da	Shichimenzan E Shimabara City	32°46′14″N 130°21′03″E	SB-37
4	Inao-yama lava (Fugen-dake)	ol-cpx-opx-qz-bg bi -hb Da	Inao-yama Shimabara City	32°45′21″N 130°19′09″E	SB-47
5	Senbugi lava (Myoken-dake)	cpx-opx-bg qz-bi-hb Da	Yaki-yama S Shimabara City	32°46′36″N 130°19′01″E	SB-26
6	Myoken-dake lava (Myoken-dake)	cpx-qz-bg opx-bi-hb An	Myoken-dake N Obama Town	32°45′26″N 130°17′24″E	SB-45
7	Myoken-dake lava (Myoken-dake)	opx-bi-bg qz-hb An	Nita-toge NE Obama Town	32°44′54″N 130°17′19″E	SB-44
8	No-dake lava (Pre-Myoken-dake)	opx-qz-bg bi-hb An	No-dake SW Obama Town	32°44′20″N 130°17′12″E	SB-43
9	Mayu-yama Basal lava (Pre-Myoken-dake)	cpx-opx-qz-bg bi-hb An	Tengu-yama E Shimabara City	32°45′45″N 130°21′22″E	SB-38
10	Koba lava (Pre-Myoken-dake)	opx-bg qz-bi-hb Da	Minami-kamikoba W Shimabara City	32°44′39″N 130°19′44″E	SB-41
11	Kusenbu-dake lava (Pre-Myoken-dake)	opx-qz-bi-bg cpx-hb An	Kusenbu-dake E Kunimi Town	32°46′08″N 130°16′21″E	SB-80
12	Torikabuto-yama lava (Pre-Myoken-dake)	bi-qz-opx-bg hb An	Torikabuto-yama N Kunimi Town	32°47′18″N 130°16′31″E	SB-79
13	Ya-dake lava (Pre-Myoken-dake)	bi-bg opx-cpx-hb An	Ya-dake Obama Town	32°44′01″N 130°16′32″E	SB-81
14	Saruba-yama-lava (Pre-Myoken-dake)	qz-hb An	Saruba-yama Obama Town	32°45′55″N 130°11′58″E	HO-1
15	Kenshu Center lava (Pre-Myoken-dake)	opx-bg cpx-bi-hb Da	Kenshu Center SW Shimabara City	32°47′07″N 130°18′18″E	SB-28

PF : pyroclastic flow deposit, An : andesite, Da : dacite, hb : hornblende, bi : biotite, qz : quartz, opx : orthopyroxene, cpx : clinopyroxene, ol : olivine, bg : bearing.

the caldera formation is older than about 6,300 years ago because some eruption products in the Fugen-dake stage are covered by the Akahoya-Ash from Kikai caldera (WATANABE et al., 1991a, b).

This stage is too young to be determined by K-Ar testing, so no reliable K-Ar ages with the exception of the Mayu-yama have been obtained. However, the Myoken-dake and the Fugen-dake stages were clearly defined from the different characteristic features of geomorphologic development.

The historic eruption stage is defined as the period of the recorded activities of Fugen-dake. In this stage, three remarkable eruptions of Fugen-dake were documented in 1663-1664, 1792, and 1990 to present.

Table 2. K-Ar ages and some published FT ages for volcanic rocks from Unzen volcano.

No.	Unit (Stage)	Material analysed	K (wt.%)	Rad. Ar (10^{-6}ccSTP/g)	Age(Ma) [Non.Rad.Ar(%)]	FT Age (Ma)
1	Kureishibaru PF. (Fugen-dake)	gm	2.411 ±0.048	$^{40}Ar/^{36}Ar=292.2$		
2	Fugen-dake-lave (Fugen-dake)	gm	2.690 ±0.054	$^{40}Ar/^{36}Ar=294.8$		
3	Mayu-yama lava (Fugen-dake)	gm	2.802 ±0.056	0.20+0.13	**0.02±0.01 [96.7]**	0.07±0.02[1] 0.09±0.04[2] 0.10±0.05[2]
4	Inao-yama lava (Fugen-dake)	gm	3.106 ±0.062	$^{40}Ar/^{36}Ar=295.0$		
5	Senbugi lava (Myoken-dake)	gm	2.454 ±0.049	0.2+1.1	(0.03±0.12) [99.6]	
6	Myoken-dake lava (Myoken-dake)	gm	2.449 ±0.049	0.35+0.16	**0.04±0.02 [96.8]**	
7	Myoken-dake lava (Myoken-dake)	gm	2.411 ±0.048	1.2+1.7	(0.13±0.19) [98.6]	
8	No-dake lava (Pre-Myoken-dake)	gm	2.504 ±0.050	0.81+0.14	**0.08±0.02 [88.7]**	0.06±0.03[1]
9	Mayu-yama Basal lava (Pre-Myoken-dake)	gm	2.705 ±0.054	1.80+0.15	**0.17±0.02 [77.2]**	
10	Koba lava (Pre-Myoken-dake)	gm	2.569 ±0.051	0.43+0.54	(0.04±0.05) [98.4]	
11	Kusenbu-dake lava (Pre-Myoken-dake)	gm	2.346 ±0.047	1.85+0.11	**0.20±0.01 [73.5]**	0.17±0.06[1] 0.13±0.09[2]
12	Torikabuto-yama lava (Pre-Myoken-dake)	gm	1.934 ±0.039	1.60+0.10	**0.21±0.01 [77.1]**	
13	Ya-dake lava (Pre-Myoken-dake)	gm	2.557 ±0.051	2.36+0.11	**0.24±0.01 [69.0]**	0.26±0.04[1]
14	Saruba-yama-lava (Pre-Myoken-dake)	gm	2.966 ±0.059	2.97+0.28	**0.26±0.02 [85.0]**	0.19±0.03[1] 0.17±0.06[2]
15	Kenshu Center lava (Pre-Myoken-dake)	gm	2.771 ±0.055	14.3+7.8	**1.33±0.73 [96.3]**	

Analyst: T. Itaya. The contants used in the calculation were from Steiger and Jäger (1977).
[1] **Sugiyama** *et al.* (1986), [2] Miyachi and Ohta (1985), PF: pyroclastic flow deposit, gm: grandmass.
Other FT dating: Azuma-dake: 0.18±0.06[1], Taka-dake: 0.20±0.05[1]/0.19±0.07[2], Kinugasa-yama: 0.23±0.06[1]: Takaiwa-yama: 0.24±0.06[1], Tatsuishi Formation: 0.25±0.05/0.28±0.05[1]/0.30±0.09[2]

Geology of Mayu-yama

Mayu-yama, a dacite composite dome, is situated isolated at the eastern foot of the Unzen volcano. Consequently, it is very difficult to confirm the relationship between the Mayu-yama and other volcanic bodies of Unzen volcano.

The Mayu-yama is probably composed of two domes, Shichimen-zan in the north and Tengu-yama in the south. The interior of Mayu-yama volcano is mainly composed of partly brecciated dacite lava and pyroclastics formed probably by pyroclastic flow and talus deposits

during the growth of the dome. Consequently, the Mayu-yama volcano is considered to be very brittle and unstable. In the 1792 eruption, a collapse of the eastern part of the Tengu-yama coincided with a big earthquake which occurred just under the Shimabara area (OHTA, 1984).

The topographic features of Mayu-yama are not simple but have some geomorphologically discordant parts near its base within the main part of the dome. There are a remarkable terrace at the floor of the collapsed part and some small isolated mounds and terraces near the foot of the dome (Fig.2). We call them collectively the basal part of Mayu-yama in this paper. The rocks named the "Mayu-yama basal lava" from the terrace at the floor of the collapsed part are different in assemblage and quantity of phenocrystic minerals from that of the main part of Mayu-yama.

From these facts, we conclude that the basal part of Mayu-yama is composed of ruins of older volcanoes than the main part of Mayu-yama. Thus we determined the K-Ar age of each rock to confirm our geological interpretation. The ages of the Mayu-yama basal lava (sample number SB-38) and the main part (sample number SB-37) of the Mayu-yama have been determined to be about 0.17 ± 0.02Ma and 0.02 ± 0.01Ma, respectively. Moreover, these ages are reliable because of less contamination from atmospheric argon and small deviation. Consequently, these K-Ar ages suggest that the main part and the basal part of Mayu-yama were formed in the Fugen-dake stage and in the Pre-Myoken-dake stage, respectively.

The difference in geomorphologic features, rock types and K-Ar ages leads us to conclude that the basal part of Mayu-yama was produced in the Pre-Myoken-dake stage. The existence of older rocks is very important for understanding the mechanism of collapse of Mayu-yama in 1792, i. e., the upper main part of Mayu-yama collapsed selectively and left the hard rocks of its basal part. Furthermore, the boundary between the upper main part and the basal part of Mayu-yama might play a role in the "slip plane" of collapse. This may be an indicator for the magnitude of the next collapse.

Conclusions

1) The growth history of Unzen Volcano is subdivided into four stages, i. e., Pre-Myoken-dake, Myoken-dake, Fugen-dake and historic eruption stage, in ascending order.

2) The reliable K-Ar ages for the rocks from each stage are consistent with the subdivision of growth history of Unzen volcano.

3) The differences in geomorphologic features, rock types, and K-Ar ages of the rocks from Mayu-yama lead us to conclude that the main part and the basal part of Mayu-yama were formed in the Fugen-dake stage and in the Pre-Myoken-dake stage, respectively.

4) The collapse of the upper part of Mayu-yama in 1792 was probably controlled by the existence of the hard and older rocks at the base of Mayu-yama. This is indicative of the magnitude of subsequent collapse which may occur in the future.

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