Jour. Sci. Hiroshima Univ., Ser. C, Vol. 10, No. 2, 193-197 (1995)

# 1994 Multi-site Broadband Seismic Observation at Sakurajima Volcano, Japan

By

Kayoko TSURUGA, Satoru HONDA, Kiyoshi YOMOGIDA
Hisao ITO, Takao OHMINATO, Takao EGUCHI and Eisuke FUJITA

*with 6 Figures*

(received November 16, 1994)

ABSTRACT: Broadband observation of volcanic earthquakes has been recently conducted at many volcanoes. At the Sakurajima Volcano in Japan, one of the most active volcanoes all over the world, we conducted two broadband seismic observations successfully in last three years. However, they left some problems in terms of the number of observation sites and recording systems. This paper reports the outline of our third observation using three broadband seismometers (Streckeisen STS-II) with continuous recording at the Sakurajima Volcano from February 18 to March 28, 1994. This observation is distinguished from the previous two by the three stations operating continuously over the entire period. Although the Sakurajima Volcano had very low seismic activities during this observation period, we observed some kinds of volcanic earthquake, A-type and B-type earthquakes and volcanic tremors, particularly one series of interesting clone events.

CONTENTS



## I. INTRODUCTION

The Sakurajima Volcano, located near the southwest end of Japan, is one of the most active volcanoes all over the world. Volcanic and seismic phenomena at the Sakurajima Volcano have been observed and studied since 1910's. The main subjects of seismic studies are the relationship between volcanic earthquakes and volcanic activities (Kamo, 1978; Ishihara *et al.*, 1989) and the characteristics of volcanic earthquakes or tremors (e.g., Kakuta *et al.*, 1979; Kamo *et al.*, 1977; Iguchi, 1985). In those studies, analog recordings using classical seismometers with the natural period of about 1 sec (e.g., Kamo *et al.*, 1977; Iguchi, 1985, 1944; Ishihara *et al*, 1989) were mainly employed, and seismic observations in the volcano have been limited to a narrow frequency range (> 1 ~ 2 Hz).

In recent global as well as regional seismology, STS-II broadband seismometers are widely applied to monitor various kinds of seismic activity. This seismometer has a flat and stable velocity response for the broad frequency range of 1/120 to 50 Hz and three components are recorded. It is designed for portable installation at a limited space and very useful for observations in a short recording period.

Broadband seismic observation of the earthquakes at the Sakurajima Volcano just started in 1991 by using only one Streckeisen STS-II seismometer and a Teledyne Geotech PDAS-100 recorder (Kawakatsu *et al*, 1992) and followed by a multi-site quasi-continuous observation by using four STS-II and Colombia DTC-8000 or PDAS-100 recorders (Ohminato *et al.*, 1993). These two observation systems revealed a major problem to be improved at each time as follows: (1) observation site was only one although data were partially recorded continuously (Kawakatsu *et al*, 1992), and (2) data were recorded by all the four stations only in a part of the whole observation period (Ohminato *et al*, 1993).

We therefore attempted to improve the above problems by conducting multi-site continuous observation at the Sakurajima Volcano this time. In this paper, we report the outline of our third broadband seismic observation of the Sakurajima at three sites.

## II. BROADBAND SEISMIC OBSERVATION

We conducted the broadband seismic observation of volcanic earthquakes at the Sakurajima Volcano from

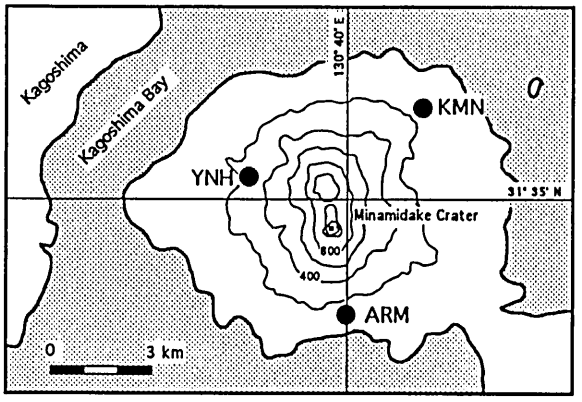


Fig.1 Locations of three observation sites: Yunohira (YNH), Arimura (ARM) and Koumen (KMN).

February 18 to March 28, 1994. We used Streckeisen STS-I seismometers and Teledyne Geotech PDAS-100 recorders with a hard disk of hundreds megabytes simultaneously at three sites : Yunohira (YNH), Arimura (ARM) and Koumen (KMN) (Fig. 1). All the data were recorded continuously with the sampling rate of 50 Hz and pre-amp gain of 10 or 100. They were digitized by a 16 bits A/D converter and finally stored in six CD-ROMs.

The recording sites, YNH, ARM and KMN, are located at the distances of about 2.7, 2.7 and 4.3 km from the recent active Minamidake crater, and the elevations are about 370, 90 and 120 m, respectively. These are common with our previous two observations (Kawakatsu *et al*, 1992; Ohminato *et al*, 1993). The geology of each site is different: YNH is on the An-ei Lava and the Yunohira Pumice Cone, ARM on the An-ei Lava, and KMN on the Minamidake Lava and Pyroclastics (Fukuyama *et al.*, 1981).

Volcanic earthquakes are usually classified into four types: A-type, B-type and explosive earthquakes and volcanic tremors. In this paper, we adopted the following definitions used in the previous study (Tsuruga *et al.*, submitted). *A-type earthquakes* resemble a standard tectonic one in which P and S waves can be clearly identified, *B-type earthquakes* are microearthquakes in which P and S waves cannot be identified as clearly as that of A-type, and *explosive earthquakes* are often followed by summit explosions. *Volcanic tremors* are continuous vibrations for several seconds to minutes without any distinguished phases.

Figure 2 shows the daily frequencies of A-type, B-type and explosive earthquakes and the total duration time (minutes) of volcanic tremors reported by the Kagoshima Meteorological Observatory of JMA in February and March , 1994. A-type, B-type and explosive earthquakes were recorded 3, 88 and 0 times, respectively, and the total duration of volcanic tremors amounted to about 2 minutes during our observation period. The volcanic activities (e.g., visual monitoring of summit crater) were very low in this period, so as the seismic activities in contrast to before and after the period. A-type earthquakes generally occur at the first stage of volcanic eruptive cycle, followed by B-type

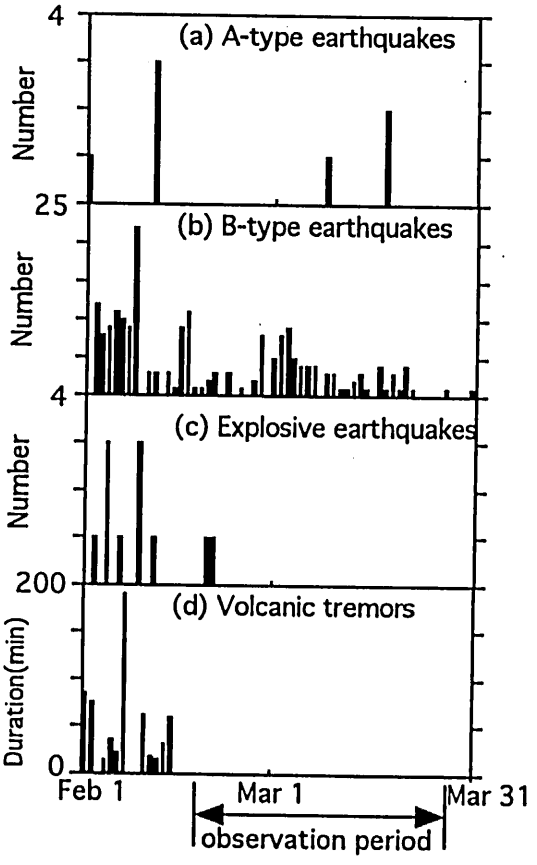


Fig.2 Daily volcanic activities of the Sakurajima Volcano from February 1 to March 31, 1994. Total number of A-type earthquakes (a), B-type earthquakes (b) and explosive earthquakes (c) and total duration time of volcanic tremors (d).

and volcanic tremors and finally ending with explosive earthquakes (Kamo, 1978). We can call our observation periods a low volcanic activity stage, that is, "calm period". Despite the small number of recorded events, our data may show some characters of volcanic earthquakes in a calm period, compared with the data of our previous two observations in "active periods".

## III. BROADBAND DATA

In this chapter, we show the three types of volcanic seismic events, A-type and B-type earthquakes and volcanic tremors, recorded during our observation period.

Figure 3 shows (a) broadband velocity seismograms and (b) spectral amplitude of A-type earthquakes in the vertical component at three sites. The number in each seismogram represents the maximum peak-to-peak amplitude with velocity unit ($1 \times 10^{-8}$ m/sec). The maximum peak-to-peak amplitudes are about $2.4 \times 10^{-4}$, $9.2 \times 10^{-5}$ and $4.1 \times 10^{-5}$ m/sec at YNH, ARM and KMN, respectively. A-type earthquakes occurred at the depth of about 4 ~ 16 km under the sea level and related to magma intrusion into the deep structure (e.g., Nishi, 1978; Kamo, 1978).

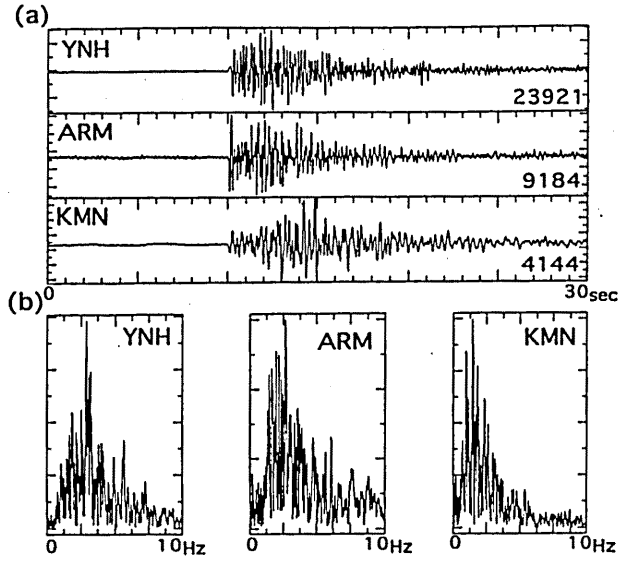


Fig.3 (a) Velocity seismogram and (b) spectral amplitude of an A-type earthquake at 16:34 on March 18, 1994 in the vertical component at YNH, ARM and KMN. The number of each plot represents the maximum peak-to-peak amplitude with velocity unit of $1x10^{-8}$ m/sec.

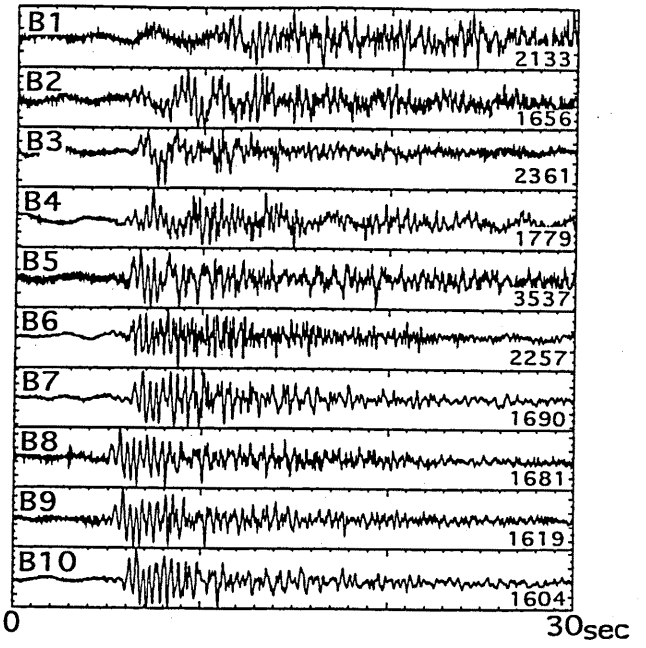


Fig.4 Velocity seismograms of B-type earthquakes: B1 - B5 events were recorded at 1:17, 1:20, 1:57, 3:25 and 20:45 on February 27, 1994, and B6 - B10 events at 5:29, 20:40, 21:30, 22:05 and 23:27 on March 3, 1994, respectively.

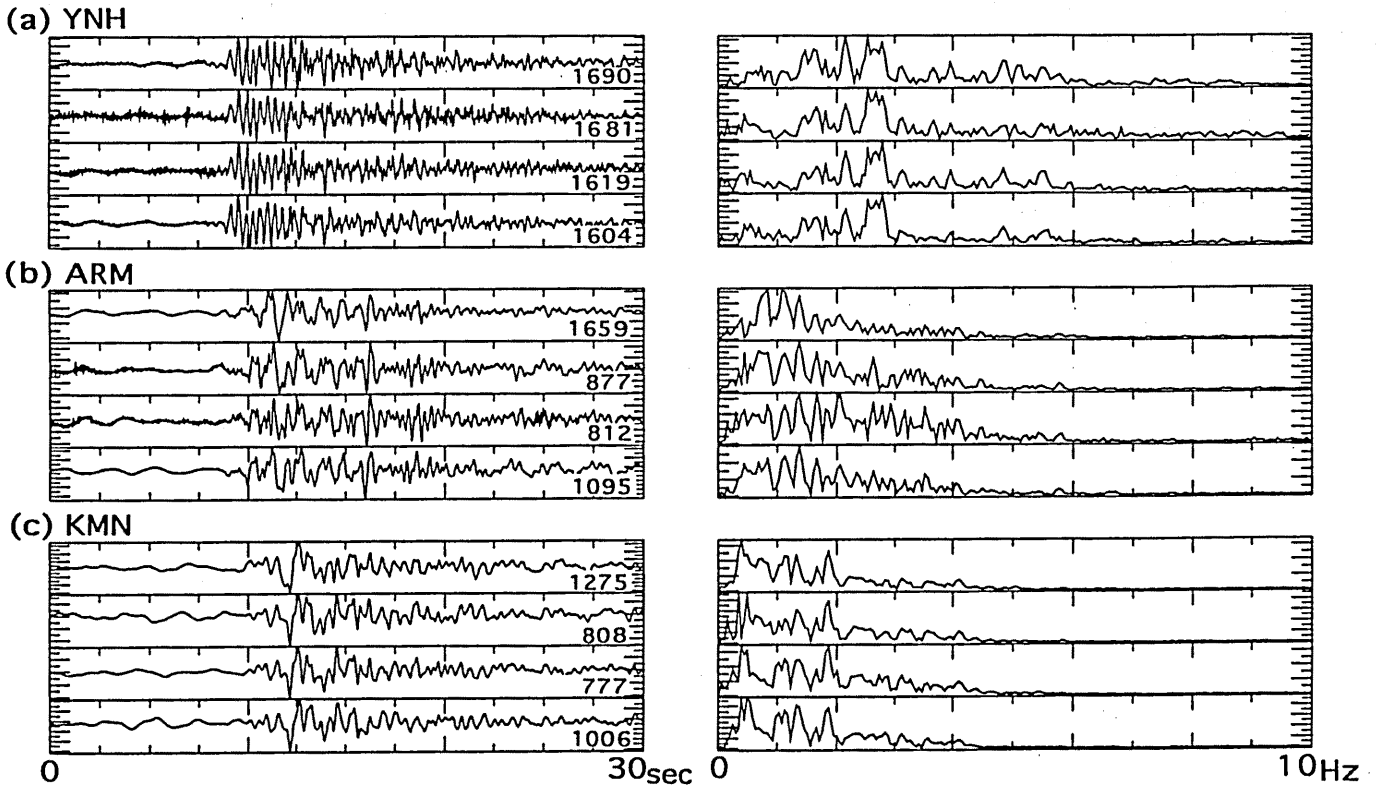


Fig.5 Velocity seismograms and spectral of clone events of B-type earthquake at three sites, (a) YNH, (b) ARM and (c) KMN.

We also recorded various kinds of B-type earthquakes at YNH on February 27 and March 3, 1994, as shown in Fig. 4. It is clear that the events on March 3 (B6 to B10 events) are very similar each other in both waveform and spectra (Fig. 5). We call them "*clone*" events. Such clone events can be observed at the other sites, ARM and KMN. Since some kinds of volcanic earthquakes seem to share the common hypocenter, we can consider that clone events are the products of the same source mechanism and the same effect of propagating path. Common spectral peaks among several sites should be mainly affected by source characteristics in contrast to the others affected strongly by site and/or path characteristics. We can find major common spectral peaks at two frequency ranges of 1.1~1.2 and 1.6~1.7 Hz. On the other hand, some spectral peaks in both lower (< about 1.0 Hz) and higher (e.g., 2~3 Hz) frequency ranges are quit different among the sites and they may be mainly affected by site characteristics. The relative site effects at each site can be therefore eliminated using such clone events in a future study. Kawakatsu *et al.* (1992) also reported similar events recorded at KMN and suggested that these later phases may inform us about the structure beneath the Sakurajima edifice.

In our observation period, few volcanic tremors were recorded. Figure 6 shows (a) original waveforms, (b) spectra and (c) bandpassed (0.6 ~ 10 Hz) waveforms in the vertical component recorded at three sites at 18:15 on March 9, 1994. Volcanic tremors occur frequently in a high volcanic activity period before explosions when swarms of B-type earthquakes become also active (e.g., Kamo *et al*, 1977; Tsuruga *et al*, submitted). Since it was a calm period, volcanic tremors were recorded for less than 2 minutes.

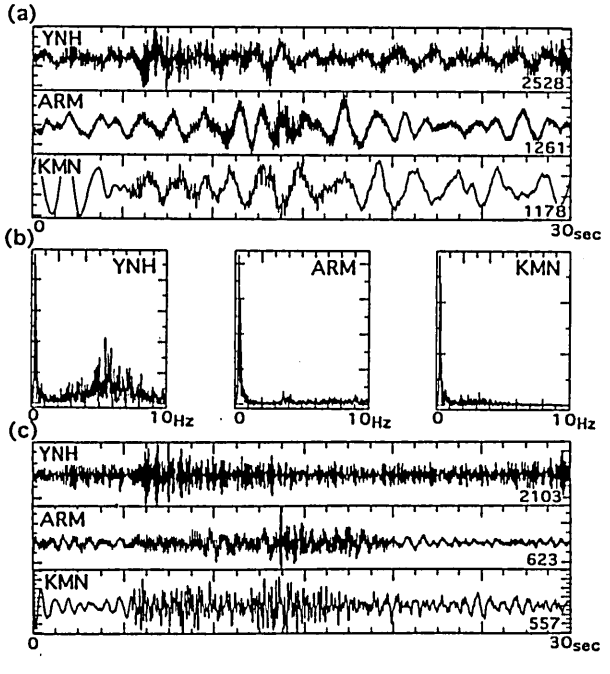


Fig.6 Velocity seismograms (a), spectra (b) and band-passed (0.6 ~ 10 Hz) waveforms (c) of volcanic tremors in the vertical component recorded at three sites at 18:15 on March 9, 1994.

## IV. SUMMARY

We conducted broadband continuous observation by using STS-II seismometers at three sites of the Sakurajima Volcano from February 18 to March 28, 1994. Although the Sakurajima Volcano had very low seismic activities during this observation period, recorded seismic events are of various characters. Dominant spectral peaks of each event exist in wide frequency ranges from 0.1 to more than 10 Hz. In volcanic areas, such a broadband multi-site observation is very useful for many kinds of earthquakes whose spectral dominant peaks are over a broadband frequency range.

## Acknowledgments

We appreciate the cooperation of Kagoshima University, the Kagoshima Meteorological Observatory of the Japan Meteorological Agency and the town of Sakurajima for offering three temporary observation sites in this study. We also thank Takamoto Okudaira for the help with making pictures.

## References

Fukuyama, H. and Ono, K., 1981. Geological map of Sakurajima Volcano. *Geol. Surv. Japan.***

Iguchi, M., 1985. Analysis of volcanic "Shallow Earthquakes" observed near the active crater. *Bull. Volcanol. Soc. Japan, Ser.2*, 30: 1-10.*

Iguchi, M., 1994. A vertical expansion source model or the mechanisms of earthquakes originated in the magma conduit of an andesitic volcano: Sakurajima, Japan. *Bull. Volcanol. Soc. Japan, Ser.2*,39: 49-67.

Ishihara, K. and Iguchi, M., 1989. The relationship between micro-earthquake swarms and volcanic activity at Sakurajima Volcano. *Ann. Disast. Prev. Res. Inst., Kyoto Univ*, 32B-1: 223-229.*

Kakuta, T. and Nonaka, Y., 1979. Spectra of volcanic earthquakes related to the eruptions of Sakura-jima Volcano in February, 1975. *Bull. Volcanol. Soc. Japan, Ser.2*, 24: 213-222.*

Kamo, K., 1978. Some phenomena before the summit eruptions at Sakura-zima Volcano. *Bull. Volcanol. Soc. Japan, Ser.2*, 23: 53-64.*

Kamo, K., Furusawa, T. and Akamatsu, J., 1977. Some natures of volcanic micro-tremors at the Sakura-jima Volcano. *Bull. Volcanol. Soc. Japan, Ser.2*, 22: 41-58*

Kawakatsu, H., Ohminato, T., Ito, H., Kuwahara, Y., Kato, T., Tsuruga, K., Honda S. and Yomogida, K., 1992. Broadband seismic observation at the Sakurajima Volcano, Japan. *Geophys. Res. Lett.*, 19: 1959-1962.

Nishi, K. 1978. On the focal mechanism of volcanic earthquakes in Sakurajima Volcano. *Ann. Disast. Prev. Res. Inst., Kyoto Univ*, 21B-1: 145-152.*

Ohminato, T., Ito, H., Kuwahara, Y., Kawakatsu, H., Kato, T., Tsuruga, K., Honda, S., Yomogida, K. and Goto, K., 1993. Observation at Sakurajima Volcano, Japan. *Abstract, Seis. Soc. Japan*, 2: 205.*

Tsuruga, K., Yomogida, K., Honda, S., Ito H. and Ohminato, T. (submitted). Spatial and temporal variations of volcanic earthquakes at Sakurajima Volcano, Japan. *J. Volcanol. Geotherm. Res.*

* : in Japanese with English abstract
** : in Japanese

Kayoko TSURUGA, Satoru HONDA and Kiyoshi YOMOGIDA: Department of Earth and Planetary Systems Science, Hiroshima University, Higashi-Hiroshima 724, Japan

Hisao ITO and Takao OHMINATO:
Geological Survey of Japan, Tsukuba 305, Japan

Takao EGUCHI and Eisuke FUJITA:
National Research Institute for Earth Science and Disaster Prevention, Tsukuba 305, Japan