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Long-term variation of the shallow tremor sources at Aso Volcano from 1999 to 2003

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ABSTRACT

In order to investigate the continuous volcanic tremor of Aso Volcano in Japan, we performed a series of temporary short-period seismic array observations near the Nakadake first crater (the active crater) during five years from 1999 to 2003. We deployed in all of the temporary observations a seismic array at the same location about 700 m west of the active crater, in order to investigate long-term changes in the tremor activity. In 1999 and 2003, another array was simultaneously deployed at a different location 700 m north of the crater to help locate the tremor sources. We developed a frequency domain semblance method and applied it to the waveform data of the frequency range where the continuous tremor is dominant (3–6 Hz). We measured arrival azimuths and slownesses of the continuous tremor signals as functions of frequency, which are then used to locate the epicenters of the tremor signals corresponding to the principal peaks of the power spectra.

For the observations in 1999 and 2002, the continuous tremor amplitudes are relatively small, and the slowness of the tremor signal observed at the west array takes a local minimum (0.5 to 0.6 s/km) near the frequency (~4.7 Hz for 1999 and ~4.8 Hz for 2002) which corresponds to the highest spectral peak. This implies that body waves dominate the tremor signals at the west array around the frequency. The tremor epicenters corresponding to 4.7 Hz for the observation in 1999 are located at the west rim of the currently active crater. While the surface crater activity of Aso remains low and the tremor activity is not clearly linked with the surface activity until early 2003, a close link between the tremor and crater activity appears in the middle of 2003, when a small phreatic eruption occurred a month before the array observation (July 10, 2003). Tremor signals of the observation in 2003 show a large spectral peak (4.2 Hz) where the slowness measured for the west array is very large (1.1 s/km), clearly suggesting that surface waves are dominant. The epicenter is again located at the western rim of the active crater. We interpret these observations as follows: in 1999 and 2002 when the surface activities of Aso were low, the continuous tremor excitation was deep and inactive. In the middle of 2003 when Aso Volcano became active with a series of phreatic eruptions a shallower tremor source was activated, possibly masking the deeper sources. This shallowing of the dominant tremor source could be due to the increase in the volcanic gas flow rate triggered by the phreatic eruptions.

1. Introduction

1.1. Activity of volcanic tremor

Seismic events observed at active volcanos can be classified as volcano tectonic earthquakes or as non-tectonic events. In this study we focus on"volcanic tremor" or simply "tremor", one of the non-tectonic volcanic signals, whose characteristic is its continuous occurrence. Seismic waves of volcanic tremor sometimes show one or more sharp spectral peaks which are typically interpreted as the results of resonance of underground resonators such as conduits, fluid-filled cracks (Chouet, 1986), and bubble clouds ascending in the conduit (Chouet et al., 1997). Examples include the tremors of Soufriere Hills (Neuberg et al., 2000), Sakurajima (Maryanto et al., 2008), Kilauea (Almendros et al., 2001), Deception Island (Ibanez et al., 2000), Pavlof (Garces et al., 2000), and Satsuma-Iwojima (Ohminato, 2006). A different class of physical model to explain the generation of continuous tremor is offered by Julian (1994). According to his model, non-linear oscillation of flow inside a vertical crack connecting two reservoirs generates continuous signals whose spectral feature changes with time. Iwamura and Kaneshima (2005) propose a steam/water mixture flow model for the generation of long period continuous tremor.

Features of volcanic tremor at an active volcano often change with time, reflecting changes in surface activity. Falsaperla et al. (2002)

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observed at Etna that the amplitudes of LP events and tremor fluctuate with changes in the surface activity of the volcano, though they focus on the LP events without intensively investigating the tremor. Jousset et al. (2003) observed low-frequency volcanic earthquakes and tremor at the Soufriere Hills volcano in Montserrat. The time interval between two consecutive low-frequency earthquakes often decreases preceding a dome collapse or an explosion, when the individual low-frequency earthquakes eventually merge to form a continuous tremor. At the Sakurajima volcano, the types of earthquake and tremor change depending on the position of the magma ascending through the conduit. Although there are many observations of the changes in features of volcanic tremor concomitant with changes in other

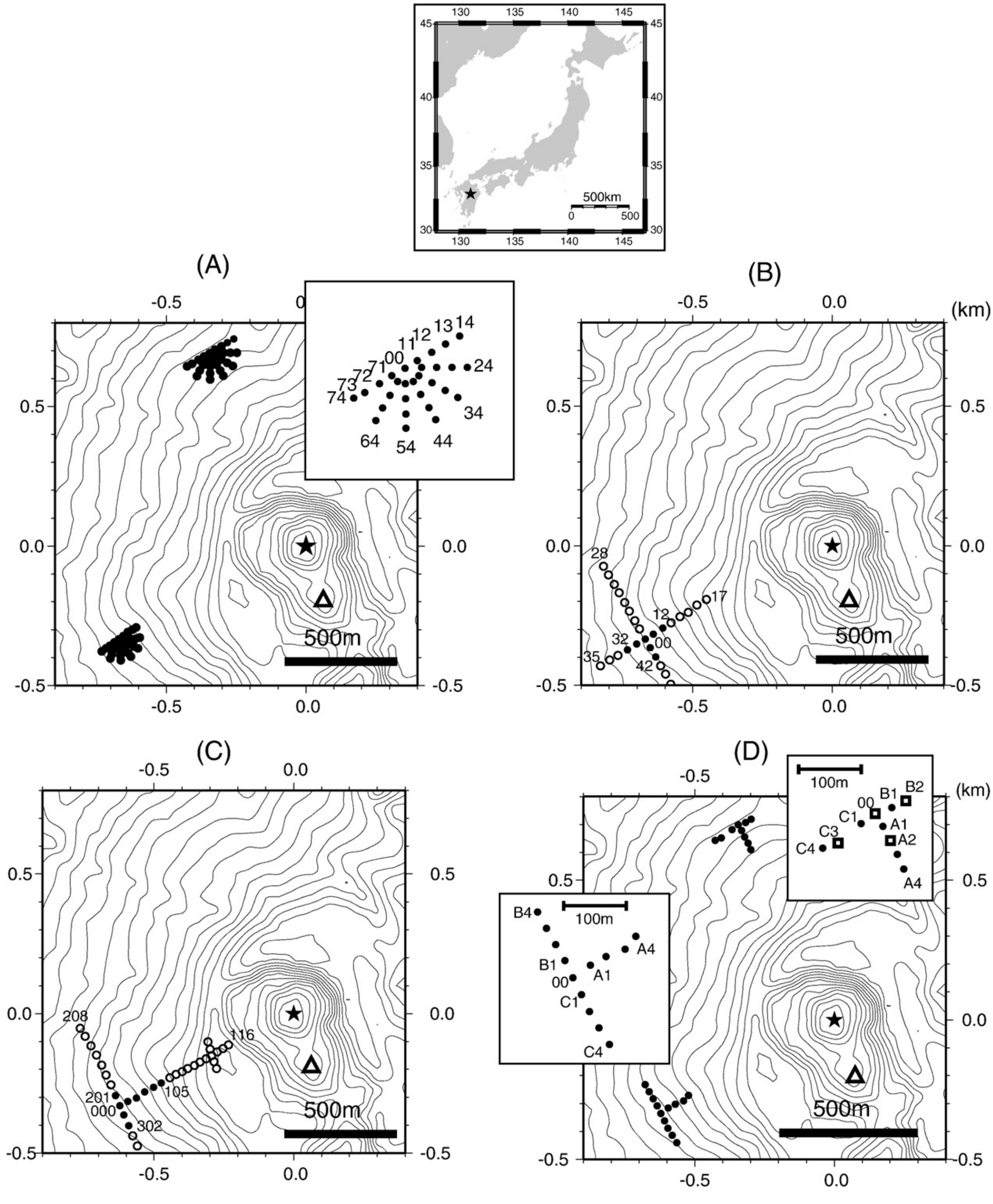

Fig. 1. Top: The location of Aso Volcano (star in the map). Bottom (A) to (D): Topography maps of the Nakadake (also called the active crater). One tick of the axes corresponds to 100 m. Topography contour interval is 10 m. Star marks the center of the active crater. Triangle shows the location of an older crater which has been inactive since major eruptions in the mid 1930's. (A): Solid dots show the locations of the sensors of the two arrays deployed approximately west (the W99 array) and north (the N99 array) of the active crater during the 1999 observation. Enlarged figure of the arrays is also shown to indicate the sensor numbers. (B) and (C): The locations of the arrays for the 2001 (W01) and the 2002 (W02) observations. Solid and open dots show the locations of sensors which are used and unused for the analyses of this paper, respectively. Selected sensors are labeled. (D): The locations of the arrays deployed during the 2003 observation (W03 and N03). Enlarged figures of the arrays are also shown. For the north arrays, dots and open squares are the sensors used for the N03 array in the first stage, and open squares are the sensors used for the N03 array in the second stage.