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Analysis of infrasonic and seismic events related to the 1998 Vulcanian eruption at Sakurajima

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ABSTRACT

We present results from a detailed analysis of seismic and infrasonic data recorded over a four day period prior to the Vulcanian eruptive event at Sakurajima volcano on May 19, 1998. Nearly one hundred seismic and infrasonic events were recorded on at least one of the nine seismic–infrasonic stations located within 3 km of the crater. Four unique seismic event types are recognized based on the spectral features of seismograms, including weak seismic tremor characterized by a 5–6 Hz peak mode that later shifted to 4–5 Hz. Long-period events are characterized by a short-duration, wide spectral band signal with an emergent, high-frequency onset followed by a wave coda lasting 15–20 s and a fundamental mode of 4.2–4.4 Hz. Values of Q for long-period events range between 10 and 22 suggesting that a gas-rich fluid was involved. Explosive events are the third seismic type, characterized by a narrow spectral band signal with an impulsive high-frequency onset followed by a 20–30 second wave coda and a peak mode of 4.0–4.4 Hz. Volcano-tectonic earthquakes are the fourth seismic type. Prior to May 19, 1998, only the tremor and explosion seismic events are found to have an infrasonic component. Like seismic tremor, infrasonic tremor is typically observed as a weak background signal. Explosive infrasonic events were recorded 10–15 s after the explosive seismic events and with audible explosions prior to May 19. On May 19, high-frequency impulsive infrasonic events occurred sporadically and as swarms within hours of the eruption. These infrasonic events are observed to be coincident with swarms of long-period seismic events. Video coverage during the seismic–infrasonic experiment recorded intermittent releases of gases and ash during times when seismic and acoustic events were recorded. The sequence of seismic and infrasonic events is interpreted as representing a gas-rich fluid moving through a series of cracks and conduits beneath the active summit crater.

1. Introduction

Infrasonic transients have been observed to accompany explosive eruptions at Sakurajima volcano since activity began at the summit crater of Minamidake in 1955 (Ishihara, 1990). These events, referred to as air shocks, are characterized by an impulsive, compressive first motion, and typically accompany seismic explosion earthquakes. Air shocks are visible when they pass through clouds at the summit causing the clouds to change in appearance (Ishihara, 1985). Since these events accompany explosive eruptions, it has been suggested that the air shocks share the same source process as the explosive seismic event (Ishihara, 1985).

Explosion infrasonic and seismic events have been recorded at other volcanoes such as Stromboli volcano in Italy (Braun and Ripepe, 1993; Ripepe, 1996; Vergniolle et al., 1996; Ripepe et al., 2001a,b), Arenal volcano in Costa Rica (Garces et al., 1998; Hagerty et al., 2000), Erebus volcano in Antarctica (Rowe et al., 2000), Pavlof and Shishaldin volcanoes in Alaska (Garces et al., 2000; Johnson et al., 2003), Karymsky volcano of Kamchatka (Vergniolle et al., 1996), Etna volcano in Italy (Ripepe and Marchetti, 2002b; Gresta et al., 2004), Sangay and Tungarahua volcanoes in Ecuador (Johnson et al., 2003) and Kilauea volcano in Hawaii (Garces et al., 2003). Explosion infrasonic events recorded at Erebus, and some at Stromboli, Sangay and Karymsky volcanoes are characterized by impulsive, compressive onsets followed by a 2–5 second wave coda (Vergniolle et al., 1996, Ripepe and Marchetti, 2002a; Johnson et al., 2003). Coupled with observations of vent activity, these types of short duration, impulsive infrasonic events result from bubble bursts or the release of gas slugs into the atmosphere in an active crater (Vergniolle et al., 1996; Johnson et al., 2003). In addition to discrete impulsive infrasonic events, more continuous events with durations that last 10 s of seconds are common occurrences prior to and during volcanic activity at Hawaii, Arenal, Karymsky, Seremu and Merapi volcanoes and have been interpreted as resulting from gas flow at or near the surface through a channel or conduit (Hagerty et al., 2000; Garces et al., 2003).

Infrasonic signals are more representative of the source process than the related seismic signals that are altered by diffraction and

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scattering in the volcanic edifice (Garces et al., 1999; Ripepe and Marchetti, 2002a; Johnson et al., 2003). Geometric spreading and atmospheric attenuation are the primary factors that attenuate energy from an infrasonic signal. This makes infrasonic signals the more accurate means by which the source process than seismic signals may be interpreted (Johnson et al., 2003). Furthermore, infrasonic observations at Sakurajima volcano have been found to be more effective than video coverage when there is no visible surface activity or when weather obscures visibility into the active crater where gas and ash emissions may be occurring (Takayuki et al., 2000).

In this paper, results are presented from a detailed spectral analysis of seismo-acoustic signals recorded in 1998 at Sakurajima volcano (Garces et al., 1999). By analyzing the spectral content of the waveforms from over twenty seismic and infrasonic events, several unique types of events are identified. These events are interpreted as representing fluid movement in cracks and conduits beneath the active summit crater.

2. Background

Preliminary observations were made during a 10-day seismo-acoustic experiment at Sakurajima volcano, Japan in May 1998 (Garces et al., 1999). A nine-station temporary network was set up on May 10 at a 2–3 km radius from the vent. Of the several hundred events recorded during the ten-day period, we initially reported on two events that were recorded over the entire network (Garces et al., 1999). One of the seismic and infrasonic events recorded on May 17 was characterized by impulsive waveforms observed to be coincident with an audible explosion from the summit. The other event recorded on May 18 was characterized by more emergent seismic and infrasonic waveforms and coincided with intermittent ash ejections above the crater (Garces et al., 1999). The seismic and infrasonic events were interpreted as representing shallow processes driving the explosive volcanic eruptions (Garces et al., 1999).

The source processes of explosive infrasonic and seismic events recorded at Sakurajima volcano since eruptive activity began in 1955 (Ishihara, 1990) with continued intermitted eruptions, have been interpreted as being related to the accumulation of gas at the top of a magma chamber located 2–4 km beneath the active crater (Ishihara, 1985, 1990). Based on the distribution of volcanic earthquake foci recorded since 1955 (Ishihara, 1985, 1990), a near surface conduit with a 200 m radius extends down to the shallow reservoir (Fig. 1). A shallow magma chamber has been identified in a zone between 3 and 6 km beneath the active crater where seismic wave attenuation occurs (Ishihara, 1985; see Fig. 1). A conceptual model of the source process for the explosive events was developed by Ishihara (1985, 1990) in which an air shock is thought to represent the explosive release of a gas pocket from the conduit (Ishihara, 1985, 1990). The gas pocket is created by the exsolution of volatiles in the upper part of the shallow chamber which then abruptly moves up through the conduit producing the explosion earthquake and may lead to failure of a lava dome that frequently occupies the conduit (Ishihara, 1985, 1990). Ishihara's (1985, 1990) conceptual model for the source processes inferred from seismic events recorded since 1955 is applied to the interpretations of the 1998 infrasonic and seismic data presented in this paper because there has been no major eruptive event that has significantly altered the structure of the volcano.

3. Data

3.1. 1998 seismic–acoustic experiment

Fig. 2 shows the location of each of the nine temporary stations of the seismic–infrasonic experiment with respect to the active crater at Sakurajima volcano in May of 1998 (Garces et al., 1999). Each station was equipped with an infrasonic sensor and a three-component Mark L-22 2 Hz seismometer recording in trigger mode with a sampling rate of 100 Hz. The type of infrasonic sensors used in the experiment included two Bruel and Kjaer, low-frequency microphones, one ACO low-frequency microphone, and six Setra model 270 microbarometers. The instrument response curve of the pressure sensors is flat between 0.1 and 20 Hz, the reader is directed to Garces et al. (1999) for details on the installation and instrumentation. During the first five days of the experiment, technical difficulties and high winds resulted in extremely noisy recordings across the network. From May 16 the network of seismic and infrasonic stations was recording without any technical problems or adverse weather conditions.

During the deployment and recording periods of the experiment minor eruptive activity occurred in the summit crater of Sakurajima volcano. On May 10, a small explosion occurred, releasing steam and ash that was followed by additional releases of steam and ash over the next four days. On May 15 a strong sulfur odor was observed that accompanied another minor ash release. On May 16 a brown ash cloud was observed above the summit. On May 17 a strong audible explosion originated from the crater that was accompanied by an ejection of ash that was more reddish in color then previous days. On May 18 jetting sounds were heard and a minor ash column was observed at the summit. Activity at the summit crater reached a climax on May 19 when a Vulcanian eruptive event sent ash and gases at least 2 km above the summit.

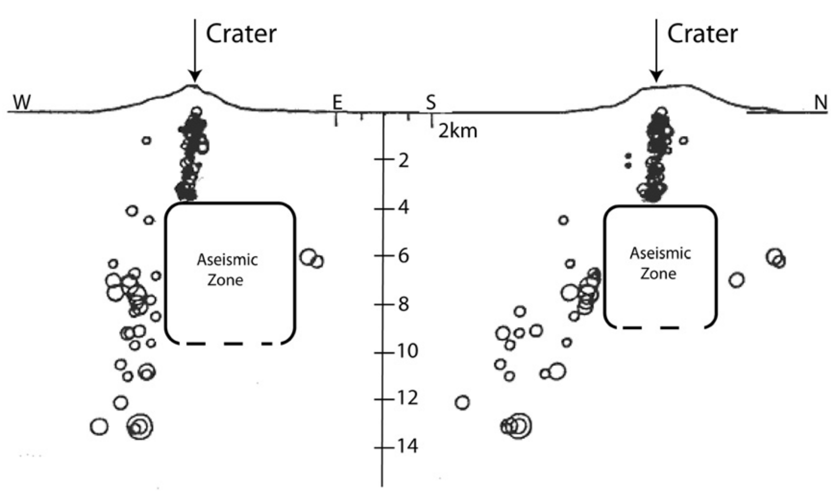

Fig. 1. Schematic drawing of inferred structural features beneath Sakurajima volcano based on the location of volcano-tectonic earthquake hypocenters denoted by circles in both W–E and S–N profiles recorded between 1975 and 1986. Circle size represents increasing earthquake magnitude. Horizontal distance not to scale. Box defines the aseismic zone interpreted as the location of a magma body (Ishihara, 1990). Figure adapted from Fig. 14 of Ishihara (1990) and does not include error bars shown in the original figure.