低周波地震から探るマグマ・熱水システム

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Long-period events as probes of magmatic and hydrothermal systems

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Long-period (LP) seismicity, including the LP event and tremor, has been widely observed in relation to magmatic and hydrothermal activities beneath volcanoes. The LP event, whose waveform consists of a superposition of simple decaying harmonic oscillations except for a brief time interval at the event onset, can be viewed as oscillations of a fluid-filled resonator triggered by a time-localized excitation, while tremor may be viewed as oscillations in response to a sustained excitation.

The LP waveform is particularly important to quantify the source, because the complex frequencies, namely the frequencies and quality (Q) factors, of the decaying harmonic oscillations in the tail of the waveform may be used to determine the characteristic properties of the resonator system. The onset of the LP waveform provides information about the excitation applied at the source. In this paper, I review our recent efforts to quantitatively interpret the LP waveform for a better understanding of magmatic and hydrothermal systems beneath volcanoes.

It is recognized that the complex frequencies of LP events show spatial as well as temporal variations, in which the Q factors can have values ranging from tens to several hundred [*Kumagai and Chouet*, 1999; *Nakano et al.*, 1998]. *Kumagai and Chouet* [2000, 2001] presented a comprehensive description of the acoustic properties of a crack containing various types of fluids whose compositions are compatible with those expected for magmatic and hydrothermal fluids. Their results show that the Q factor predicted from the crack model ranges from almost unity to several hundred, which consistently explains the wide variety of Q factors observed in LP events. They underscore the importance of dusty and misty gases to explain long-lasting oscillations with Q significantly larger than 100.

Kumagai et al. [2001a] apply the estimated acoustic properties of a crack to the interpretation of the temporal variations in the complex frequencies of LP events observed at Kusatsu-Shirane Volcano. They showed that the observed temporal variations during the period from August 1992 through January 1993 are consistently explained by the dynamic response of a crack containing hydrothermal fluids to a magmatic heat pulse, in which

a growth of a crack first occurs, then the fluid in the crack gradually dries, and finally the crack collapses. This study suggests the usefulness of the complex frequencies of LP events to diagnose the state of fluids beneath volcanoes.

Kumagai et al. [2001b] perform the waveform inversion of the harmonic oscillations in the LP waveform based on the method developed by *Ohminato et al.* [1998] and *Nakano et al.* [2001]. They show from synthetic tests using synthesized seismograms radiated by the fluid-filled crack that the harmonic oscillations provide useful information about the source location, geometry, and force systems. They perform the waveform inversion of an LP event observed at Kusatsu-Shirane Volcano. The results point to a subhorizontal crack located at a depth of about 200 m below the summit crater lake.

The quantitative analyses of LP events thus constitute critically important steps toward a better understanding of the state of fluids and physical processes at the source of LP events. The real-time observation and routine analyses of LP waveforms may offer great potential to image and monitor magmatic and hydrothermal systems beneath volcanoes.

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