Temporal variations and size distribution of seismic moments inferred from waveform inversion of long-period events

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Long-period (LP) events are considered as the acoustic vibrations of fluid-filled cracks in shallow magmatic and hydrothermal systems and analyzing LP events contributes to better understanding eruption processes. Taguchi et al. (JGR, 2018) developed a method to estimate the crack size (V) and fluid properties from the complex frequencies (peak frequencies f and quality factors Q) of LP events and applied it to LP events at Kusatsu-Shirane volcano. Nakano and Kumagai (GRL, 2005) performed full-waveform inversion to estimate crack source (source location, mechanism, and seismic moment) for one LP event at Kusatsu-Shirane volcano. However, systematic source estimates for LP events at Kusatsu-Shirane volcano have not been conducted. In this study, we systematically estimated seismic moments (M_0) defined as $M_0 = \mu \Delta V$ (where μ and ΔV are rigidity and volume change of crack resonator, respectively) by using the following inversion method. We use observed mean amplitudes band-passed around the lowest f of a resonance spectral peak at individual seismic stations within 3-s time windows from the arrival times of maximum amplitudes. The observed amplitudes corrected for site amplification factors are fitted to band-passed synthetic amplitudes calculated with the discrete wave number method by assuming the source mechanism as a crack. We first applied this method to the LP event which was analyzed by Nakano and Kumagai (2005), which showed that our estimated sub-horizonal crack source was similar to that obtained by the previous study. We found the difficulty to estimate the crack source mechanism especially for high-frequency LP events. Since LP events in our studied period are considered to be excited from the same source in view of their arrival times, we assumed the sub-horizonal crack source mechanism to estimate M_0 values for other LP events. We analyzed more than 200 LP events observed during the seismically active periods in 1989–1993. Our M_0 estimates tend to increase gradually in August–September 1992 and decrease in October 1992–January 1993. Similar trends can be seen in October–November 1989 and July–October 1991. Our estimated seismic moment size distribution does not follow the Gutenberg and Richter law, but has a peak around $M_0 = 7\times10^9$ Nm. The relationship between M_0 and f indicates that M_0 for a certain f varies from small to large values and the maximum M_0 for each f decreases with increasing f. Moreover, the relationship between M_0 and Q around $f = 1$ Hz shows a negative correlation, indicating that the LP events with larger Q values exhibit smaller ΔV values. Assuming that M_0 or ΔV is proportional to V, the seismic moment size distribution suggests that there is a characteristic crack size and its growth and collapse repetitively occurred in our studied period. This is consistent with the indication by Taguchi et al. (2018) based on the temporal changes in the complex frequencies of LP events in 1992–1993. The relationship between M_0 and f suggests that the maximum V becomes smaller as f increases. Moreover, the negative correlation between M_0 and Q indicates that V becomes smaller as Q increases in the constant f value, which depends on the crack length (L) and the sound speed of fluid within the crack (a). To achieve the constant resonance frequency for a cack with smaller V and hence smaller L, a must be smaller. Thus, the negative correlation suggests that Q increases with decreasing a. This is consistent with the indication that Q is dependent on α/a (where α is elastic medium P wave) from the crack model (Kumagai and Chouet, JGR, 2000). Our study demonstrates that systematic estimates of M_0 provide useful information to understand LP source processes and to monitor LP activity.

Keywords: volcano seismicity, long-period (LP) events, waveform inversion

