Source process of long-period seismic events at Taal volcano, Philippines: Vapor transportation and condensation in a shallow hydrothermal fissure

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We analyzed observations of a swarm of more than 40,000 long-period (LP) seismic events at Taal volcano, Philippines, in 2010–2011. Each event waveform has a peak frequency around 0.8 Hz and $Q = 6$. The waveforms were strongly correlated with no phase differences among events, consistent with a fixed source location and mechanism. We therefore stacked the waveforms to improve the signal-to-noise ratios in our analysis. The stacked waveform at a station on the rim of the main crater begins with a dilatational first motion. Our travel time analysis of the stacked waveforms pointed to a shallow (100–200 m) source beneath the northeastern flank of the active volcano island. A *P*-wave velocity of 2800 m s^{-1} minimized the travel time residual. Using these results, we performed waveform inversion, with and without corrections for site amplification factors, for four source geometries (vertical crack, horizontal crack, vertical pipe, and sphere). We obtained the minimum AIC value with a vertical crack and corrected waveforms. A grid search for the location, strike, and dip of a crack source using corrected waveforms yielded small residuals for cracks with dips of 30–60° near the location estimated by the travel time analysis. To explain the complex frequencies of the waveforms, we performed a simulation of the fluid-filled crack model of Chouet (1986, JGR). The observed *Q* was explained by the fundamental longitudinal mode resonance of a vapor-filled crack. Assuming that this mode represents oscillations of 0.8 Hz, the crack size was estimated to be 188 m. A satellite thermal infrared image taken during the swarm period suggested that the events were not directly linked to surface gas releases. The persistence and abundance of LP events during the swarm suggest that a considerable amount of vapor was continuously transported to the LP source. We considered a vapor transportation model in which vapor exsolved from magma and rose in a fissure connected to the LP source. This model suggested that 10^6 m^3 of magma was involved in the LP swarm and that the temperature of the vapor in the LP source crack was around 600 K, slightly higher than the boiling point of water at that depth. We modeled a triggering mechanism of the crack resonance based on sudden condensation of vapor at the tip in a cold aquifer. This model also explains the waveform and statistical characteristics of the events, including their fixed source location.