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Shallow hydrothermal activity at Taal volcano, Philippines, inferred from long-period seismic events

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Taal volcano is located 60 km south of metropolitan Manila. Most of the Taal eruptions have taken place after quiescent periods of less than 30 years, but more than 30 years have passed since the last eruption in 1977. This implies a high risk of near-future eruption at Taal. We have monitored the volcano after installation of a multi parameter observation network including five broad-band seismometers (Fig. 1a) in fall 2010 through a JST-JICA project.

Long-period (LP) seismic events with a dominant period of 0.8 Hz (Fig. 1b) have been observed by the network. They are most distinct in vertical component at station VTDK. Using this component, we have detected 46,687 events having amplitudes and waveform correlations larger than $2x10^{-6}$ m/s and 0.8, respectively. Most of them occurred between December 2010 and January 2011. Waveform correlations among the events are quite high, often exceed 0.95. Amplitudes of the events are smaller than $5x10^{-6}$ m/s and obey two exponential distributions partitioned at $3x10^{-6}$ m/s. The event intervals obey a superposition of Weibull and log Weibull distributions. Dominant frequency represents a bi-modal distribution with peaks of 0.8 and 0.72 Hz, and proportion of the events having the lower dominant frequency was relatively high during periods when the LP activity was high. We can see no distinct relationship among the event amplitude, interval, and dominant frequency.

We applied the waveform inversion method of Nakano and Kumagai (2005) for the LP events that occurred after 6 March 2011 when vertical component data at VTMC were available. We used stacked waveforms at stations VTDK and VTMC. Only events having large waveform correlations at the both stations were used. To calculate the Green functions, we used a homogeneous medium with a P-wave velocity V_p = 3000 m/s. Following Maeda and Kumagai (2011), we took into account crater and caldera lakes as well as topography. Fig. 1c indicates the inversion result. The minimum residuals for tensile crack and pipe sources are 61.2 and 61.9 %, respectively. The residual difference is too small to infer which mechanism is better. We also conducted inversion using V_p = 2000 m/s. The source locations obtained using the two structures were similar but the crack orientations were quite different to each other (Fig. 1c). These results indicate that the source location was relatively well determined whereas the mechanism was poorly determined.

The estimated source location is close to surface dikes intruded in 1990s and current steaming vents. The obtained source depth of 300-500 m is similar to the depths for LP events at other volcanoes, which were interpreted in terms of hydrothermal activity (e.g. Nakano et al., 2003; Ohminato, 2006). The vertical waveforms at VTDK indicate Q=6, which can be explained by a fundamental mode oscillation of a crack filled with vapor using the crack model of Kumagai and Chouet (2000). Assuming that this mode corresponds to the observed oscillation frequency of 0.8 Hz, we obtain the crack length L = 150 m, which is a reasonable crack size for the LP source. Anomalies including intense seismicity, inflation, water temperature increase, and increase in steaming activity were observed from June to August 2010 and from April to July 2011 at Taal. The LP activity was intensified between these two active periods. A possible interpretation is that a magma intrusion related to either of these active periods may have supplied heat to a shallow hydrothermal system at Taal, generating the LP events. No LP event has been observed after September 2011, which is consistent with a low level of volcanic activity during this period.

References

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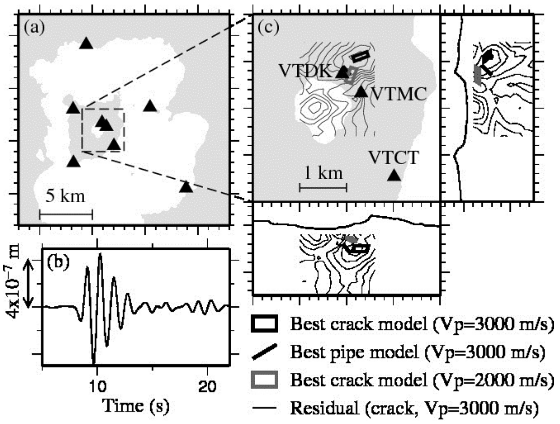

Fig. 1