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Very-long-period signals observed immediately before a Vulcanian eruption accompanying pyroclastic flows at Tungurahua, Ecuador

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Tungurahua, located near the center of the Ecuadorian Andes, is a large andesitic stratovolcano that has been erupting since 1999. In July-August 2006, Tungurahua reached the highest eruption activity, in which Vulcanian eruptions accompanying collapse-type pyroclastic flows repetitively occurred. The heightened eruption activity was observed by a permanent broadband seismic and infrasonic network deployed on the volcano. During the activity, three stations (BCUS, BMAS, BRUN) were in operation. A series of very-long-period (VLP) signals appeared about 20 minutes prior to the biggest Vulcanian eruption that occurred on August 17, 05:50 (UTC). This eruption and associated pyroclastic flows devastated the western flank of the volcano. The individual VLP signals are characterized by impulsive signatures with the characteristic period of 20-50 s. Since data from BCUS were contaminated by local noise originated from sustained eruptive activity before the biggest eruption, we used data from two stations (BMAS and BRUN) to estimate the source mechanism of the VLP signals.

We performed waveform inversion in the frequency domain using an extended approach of Nakano and Kumagai [GRL, 32, L12302, 2005]. Lateral dimensions of 4.8 x 4.8 km centered at the summit and a vertical extent of 3.9 km were used as the domain for a grid search to find the best-fit solution. We assumed isotropic and horizontal and vertical crack point sources at each node point, where we performed a grid search in the azimuthal angle for a vertical crack. Green's functions were calculated by a finite-difference method with the topography of the volcano assuming a homogeneous medium with a compressional wave velocity of 3500 m/s, a shear wave velocity of 2000 m/s, and density of 2500 kg/m^3. The computation of Green's functions was performed in the domain with lateral dimensions of 2000 x 2000 km and a vertical extent of 30 km to avoid the contamination of reflected waves generated at the domain boundaries. A uniform grid of 300 m was used in the calculation of Green's function and grid search in space. We used the observed displacement seismograms bandpassed between 20 and 50 s in our inversion.

The inversion result indicates that an isotropic source at a depth of 3 km under the summit crater is the best-fit solution, although a vertical crack at a similar location also provides a small residual close to that of the best-fit solution. In any case, the inversion points to a volumetric source at a depth of 3 km under the crater. We interpret that the VLP signals were generated by a volumetric expansion caused by bubble growth in newly supplied magma at this depth. The magma containing bubbles further ascended along the conduit and resulted in the Vulcanian eruption accompanying pyroclastic flows. If we assume a closed conduit during the VLP event and accordingly lithostatic pressure at the VLP source, the magma beneath Tungurahua should initially contain the mass fraction of water at least 2.6-3.5 wt % for bubble formation to occur at the estimated VLP source depth. Here, we used Henry's constant of 9x10^-12 - 16x10^-11 Pa^-1 for an andesitic magma. The estimated water content is consistent with a petrologic estimation using Tungurahua's volcanic products.