Volcanic eruption and ground rotational motion

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The dynamics of explosive eruptions, such as Plinian, sub-Plinian, Vulcanian, and Strombolian ones, is one of the most fascinating subjects in volcano physics. The explosive eruptions and magma effusions usually cause ground deformation due to stress and/or volume change in a volcanic conduit. Recent development of seismometers and data transmission technology enable us to deploy broad-band seismometer and tiltmeter near active volcanic vents and craters. These instruments have detected increasing numbers of seismic events involving tilt motions, which are rotational motion around horizontal axes. In this paper, we present several examples of tilt motions recorded near active vents and craters, and mention an importance of rotational motion observation in volcano physics.

The first example is a very-long-period pulses (VLP) activity at Asama volcano, Japan. After VLP occurred, large amount of volcanic gas was emitted sometimes from the vent in the summit crater. In 2008 and 2009, we deployed up to 14 broad-band seismometers near the summit crater of Asama volcano, and observed seismic events consisted of one-sided velocity pulse with duration of 5 to 30 seconds (VLP). To reveal the source mechanism of VLP, we conducted moment-tensor inversion analyses for these events employing the Green's functions of not only translational motions but also of tilt motions. The moment tensor solution suggests that VLP is excited by synchronized volumetric changes of a tensile crack and a cylinder which consist of initial rapid inflation phases and subsequent gradual deflation phases [Maeda and Takeo, 2011]. This source process is consistent with the surface observation of gas emission, indicating that VLP is excited by a sudden gas emission. At Asama volcano, the last Vulcanian eruptions had started on September 1th 2004, lasting until December 2004. Before June 2004, VLP activity was synchronized with the seismicity of volcanic earthquake, but it had gradually decreased toward the eruption in spite of increment of the seismicity. At this turning point, unique long-period earthquakes and nonlinear volcanic tremor, which suggested a blockage of the conduit, occurred in cluster, resulting the decline of VLP activity due to shielding of gas emission and the increment of seismicity due to stress accumulation in and around the conduit. VLP activity and its source process are closely related with a volcanic eruption as in the example above. The tilt motions were key data for the source process analysis of VLP. If we observed the rotational motions isolated from the translational motions, we could get more information about the source process, because rotational strains at the sources directly generate rotational motions in seismic waves [Takeo and Ito, 1997].

The second example is ground deformations in a magma-effusive stage and sub-Plinian and Vulcanian eruptions at Kirishima and Nishinoshima volcanos, Japan. During the early period of volcanic activity at the Shinmoe-dake, Kirishima volcano in 2011, various kinds of activities, such as sub-Plinian eruptions, a magma effusion, and Vulcanian eruptions, occurred sequentially. The sub-Plinian and the Vulcanian eruptions were preceded by inflations at shallow depths near the summit. Almost all Vulcanian eruptions were preceded by trapezoidal inflations, whose durations systematically lengthened as time progressed. The inflation-deflation cycles were recorded during the magma-effusive stage, with a typical period of one hour, synchronized with volcanic tremors or long-period events. We also observed an inflation-deflation cycle with periods of 1 hour to 1.5 hours, which synchronized with long-period events, during a magma-effusive stage of 2017 eruption in Nishinoshima volcano, Izu-Bonin islands arc. These inflation-deflation cycles at both volcanos were accompanied by volcanic tremors and/or long-period events. Some volcanic tremors associating with the inflation-deflation cycle at Shinmoe-dake volcano represented characteristics of harmonic tremor [Natsume et. al, 2019]. Takeo (2019) proposed a probable mathematical model of harmonic tremor, which reproduce phase portraits of the observed harmonic tremor successfully. This model suggests that a local inhomogeneous movement of conduit wall is essential factor in the excitation of harmonic tremor, and this inhomogeneous motion in the source excites larger rotational motion compared to a homogeneous motion. It is an important subject to make clear a dynamics of magma ascending process how the inflation-deflation motion correlates with the tremor and the long-period event. These inflation-deflation cycles were retrieved from broad-band seismometers deployed near the summit crater at Shinmoe-dake and near the pyroclastic cone at Nishinoshima. Therefore, we needed to filter out frequency components higher than about 0.02 Hz from these seismograms to avoid contamination due to translational acceleration. However, rotational motions of higher frequency range than 0.02 Hz will be a key data to progress the subject, because the typical frequency of tremors and long-period events are ranging from 0.5 Hz to 2 Hz and these durations are almost less than 1 minute. If we observed rotational motions of harmonic tremors isolated from the translational motions, we could get more information about the source process of harmonic tremor. Understanding of volcanic tremor provide us knowledge in the physical condition of conduit, helping us to make clear the magma ascending process and eruption mechanism. In conclusion, an observation of pure rotational motion in wide frequency range is very important subject to reveal physical processes in a volcanic conduit before and during eruption.