Style and process of magma intrusion based on combined ground deformation data in and around Sakurajima volcano, southern Kyushu, Japan

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Abstract

Some source models are applied to the ground deformations in different stages of volcanic activity of Sakurajima to make clear style and process of magma intrusion.

One is slow ground inflation with highly eruptive activity at the Showa crater. A model of stacked spherical sources was applied to continuous combined geodetic data from a global navigation satellite system (GNSS), tilt and strain. The data were recorded during ground inflation throughout an eruptive episode that began in October 2011 and ended in March 2012. Using a genetic algorithm, the locations and volumes of three sources were obtained. A pressure source analysis of ground inflation during the period from October 2011 to March 2012 revealed inflation sources to be located at a depth of 9.6 km below sea level beneath the Aira caldera (A-source) and 3.3 km below sea level beneath Kita-dake (K-source), and a shallow deflation source is located at a depth of 0.7 km below sea level beneath Minami-dake (M-source). The A-source corresponds to the main magma reservoir at a depth of 10 km below sea level beneath the Aira caldera inferred by previous geophysical studies. The K-source is a sub-reservoir of Sakurajima volcano, where magma intrudes from the main magma reservoir beneath the Aira caldera during the first stage of eruptive activity. The M-source is a shallow deflation source beneath Minami-dake estimated using tilt and strain data during explosions at the Showa crater. Magma injection into the A-source started in mid-November 2011, instantly triggering the migration of increased volumes of magma from the A-source to the K-source. Approximately one month later, in mid-December 2011, an increased volume of magma started migrating from the K-source to the M-source and finally erupted at the surface. The accumulation rate for the A-source is comparable to the magma supply rate for the past 100 years (0.8 to 1.6 × 10^7 m^3). The three-pressure-source model was applied to inflation events before the 2011 event in order to reconstruct the magma migration process. Applying the obtained three-pressure-source model to earlier activity phases, injected magma from the A-source was found to remained at the K-source and a small amount of magma began to move from the K-source to the M-source before the start of eruptive activity at the Showa crater in June 2006; furthermore, a large amount of magma was found to have moved toward the crater during this violent volcanic activity. The magma injection rate

into the A-source was also found to have sometimes reached the level of the average injection rate of the past 100 years during the ground inflation events.

The other is much rapider and larger ground deformation on August 15, 2015, when eruptive activity was decreasing from July 2015. The pattern of horizontal displacement during the period from August 14 to 16, 2015 shows a WNW-ESE extension, which suggests opening of a tensile fault. Using a genetic algorithm, position, dip, strike length, width and opening of the rectangular tensile crack were obtained based on the composite data of GNSS, tilt and strain. A nearly vertical dike with a strike of NNE-SSW is obtained at a depth of 1.0 km below sea level beneath the Showa crater. The length and width are 2.3 km and 0.6 km, respectively. The opening 1.97 m yields its volume increase $+2.7 \times 10^6$ m^3.

Associated with the inflation on August 15, 2015, 887 volcano-tectonic (VT) earthquakes occurred beside the dike, differently from the 2011 event while only 93 VT earthquakes occurred for the 6 months. Half of the total amount of deformation of the August 15 event was concentrated from 10:27 to 11:54. It is estimated that the intrusion rate of magma was 1×10^6 m^3/h during the period. This rate is 2200 times larger than magma intrusion rate (460 m^3/h) into the K-source during the 2011 event. The quite rapid intrusion rate caused extremely high-rate accumulation of strain in surrounding rocks, and this forced significant increase in seismicity. The 2011 event is considered to be a process of magma accumulation and migration among the pre-existing spherical reservoirs, similarly to the previous activities in 2009–2010 and during the pre-active period of Minami-dake. Conversely, the August 2015 intrusion is dike-creating event at a different place from the pre-existing reservoir beneath the Showa crater, and magma stopped at a shallow depth of 1.0 km. The direction of the opening of the dike coincides with the T-axes of deeper VT earthquakes at the SSW flank and is influenced by tectonic stress around the Sakurajima volcano.