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Volcanic Process of the 2011 Shinmoedake Eruption inferred from Strain Data

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Measurements of crustal deformation with high precisions are essential in understanding and forecasting volcanic processes. The most precise observation of crustal deformation is achieved by means of extensometers in vaults. When observation in a vault is conducted at a suitable location to monitor volcanoes, they will provide extremely small changes in strain of the order of 10^{-9}-10^{-10}, which are undetectable by GPS.

Disaster Prevention Research Institute, Kyoto University, has been conducting highly accurate observations of crustal strain at Isa (Yoshimatsu) Observatory (ISA). The ISA site is approximately 18 km away from the summit crater of Shinmoe-dake, which produced major eruptions in January 2011. Extensometers at ISA are composed of 30 m lengths of super-invar rods installed in tunnels in three independent horizontal directions in order to determine a horizontal strain tensor. Considering sensor resolutions and electric noise-level, accuracies of data during the activity of Shinmoe-dake were evaluated to $2x10^{-10}$ in two directions, and $2x10^{-9}$ in one direction.

The strain data at ISA are examined in order to understand magmatic processes involved in the activity of Shinmoe-dake. We picked up remarkable changes in strain data by visual inspections, and estimate locations and sizes of sources of deformation by assuming a point source in a half-space (i.e. Mogi model). When the Mogi model is assumed, direction to a source from the observation point can be estimated even if data are available only at one site. Moreover, the size and depth of the source can be estimated if we assume certain values of horizontal distance between the site and the source. Given the horizontal distance between ISA and Shinmoe-dake is sufficiently larger than the size of magma chambers, we can expect point source approximation is sufficient enough to trace movements of pressure sources.

Most prominent changes in strain are recorded at the time of three subplinian eruptions on 26 and 27 January, and during a magma accumulation process from 28 through 31 January. We estimated locations and sizes of sources by using only strain data at ISA and compared them with results of GPS data inversions in order to evaluate the accuracy of estimations given by strain data at ISA. In the estimation, we assume horizontal distance between ISA and the source is fixed to 15 km. Estimated depths of volume changes corresponding to three subplinian eruptions and following magma accumulation are 7.2, 7.0, 7.6 and 8.3 km, respectively, which are consistent to those inverted from GPS data. Estimated changes in volume corresponding to these events are 1.25, 1.59, 0.94 and $5.25x10^{+6}m^3$, respectively, which are smaller than those estimated by other means. These results suggest that we can estimate directions to the source from ISA only by using strain data at ISA, although the quantitative estimation may be somewhat erroneous.

In addition to large changes simultaneous to eruptions, small changes several hours prior to each suplinian eruption are also found in strain data at ISA. The magnitudes of the pre-eruption strain changes are of the order of $1x10^{-9}$, which are about 1% of the magnitudes of co-eruption changes in strain. Temporal changes in these pre-eruption changes suggest that a gradual expansion and following quick contraction occurred beneath Shinmoe-dake. Accurate estimation of locations and sizes of these deformations is difficult because changes in strain are close to detectable limits. Nevertheless, calculations considering reading errors indicate that the deformation source is on the same direction to the magma chamber from the ISA, and its depth is shallower than the magma chamber. This result proposes a hypothesis that some portion of magma in a chamber moves upward in a final stage of the eruption processes, and it is ejected from the surface of the ground.

Keywords: extensometer, geodetic observation in vaults, Shinmoe-dake, volcanic process, crustal deformation prior to eruptions