Integrated processing of muon radiography and gravity anomaly data toward realizing high-resolution 3D density structural analysis of volcanoes: case study of Showa-Shinzan lava dome, Usu, Japan.

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We have developed an integrated processing of gravity anomaly and muon radiography (muography) data for determining the 3D density structures of volcanoes with high spatial resolutions (100 - 200 m). We applied the method to a dacite lava dome (Showa-Shinzan) at eastern foot of Usu volcano, Hokkaido, Japan, and we determined the shape of the lava plug and its internal density variation.

Muography is a recently developed inspection method and is based on measuring the absorption of cosmic-ray muons inside matter. From the attenuation of muon flux, one can determine the amount of matter, which is given by density-length (density times length), present along a muon trajectory. Since gravity and muography are both sensitive to density, combining the two methods is expected to give density profile with higher spatial resolutions than conventional gravity inversion alone. Moreover, it enables 3D analysis.

Forward modeling is made by supposing the region of our interest which is subdivided into several voxels with unknown density parameters. Then, both gravity anomaly and density-length data can be written as linear combinations of the unknown parameters. The observation equation is solved by using Tarantola's [1987] probabilistic approach, in which an initial guess density and a correlation length are given as a priori information. The resolution test using a checker-board density model superimposed on the shape of Showa-Shinzan ensures that the horizontal and vertical resolutions are better than 200 m and 100 m, respectively.

Showa-Shinzan, a target volcano in our case study, was formed at eastern foot of Usu volcano in the 1943-45 Usu eruption. The eruption activity is characterized by the following three stages: (1) volcanic earthquakes occurred and the ground was uplifted significantly; (2) paroxysmal explosions happened at craters on the uplifted plateau; (3) dacite magma extruded from below the plateau to form the dome.

We applied our method to the gravity data at 30 stations on/around the dome and the muography data reported by Tanaka et al. [2007]. The results show that the western part, where the dome exists, has higher density (> 2000 kg/m^3) than the eastern part of the uplifted plateau (< 2000 kg/m^3). Inside the dome, we find significant density variation, characterized by two high density anomalies. One high density anomaly (2400 - 2800 kg/m^3) is located below the dome and is considered to be the lava stuck in the conduit. We conclude from this that the diameter of the conduit is about 200 m. The other dense anomaly (2400 - 3000 kg/m^3) is near the surface and is considered to be the solidified lava which was uplifted significantly at the last stage of the eruption.

Reference:

Tarantola, A. (1987), Inverse Problem Theory, Elsevier, New York.

Tanaka et al. (2007), Geophys. Res. Lett., 34(22):L22311-.