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重力観測と宇宙線ミューオンラジオグラフィーの組み合わせによる火山内部密度構造の３次元イメージング
3D imaging of the internal density structures of volcanoes by a combination of gravity and muon radiograpy

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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). In this report, we describe the method and the case study at Showa-Shinzan Lava Dome at eastern foot of Usu volcano, Hokkaido, Japan. We focus on the resolution test using a checkerboard model to show that muography data is helpful in gravity data interpretation.

Muography is a recently developed inspection method and is based on measuring the absorption of cosmic-ray muons inside matter. From attenuation of muon flux, one can determine the amount of matter, which is given by density-length (density times length), present along muon trajectories. 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.

To verify the performance of our method, we performed a resolution test using a checker-board density model superimposed on the shape of Showa-Shinzan. We compared the models reproduced from the following data sets: (a) gravity anomaly data only; (b) gravity anomaly data and muography data. The result of the case (b) is better than that of the case (a), which ensures that muography data constrains the solution well and is helpful in gravity interpretation. In the case (b), 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. 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 ($>$ 2.0 g/cc) than the eastern part of the uplifted plateau ($<$ 2.0 g/cc). Inside the dome, we find significant density variation, characterized by two high density anomalies. One high density anomaly (2.4 - 2.8 g/cc) 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 (2.4 - 3.0 g/cc) is near the surface and is considered to be the solidified lava which was uplifted significantly at the last stage of the eruption.

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