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Muographic imaging of Usu volcano with a multilayer detector

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Usu volcano is one of the most active volcanoes in Japan and has erupted for four times in the recent 100 years (1910, 1943, 1977-1978 and 2000). In the 1977-1978 eruption, 18 craterlets and a U-shaped fault were formed in the summit crater. The eruption also caused the deformation in the summit crater area with a diameter of 1.8 km and formed an upheaval called Usu-Shinzan.

Preceding studies suggested that the cooling magma intrusion with a height of 600 m and a width of 300 m was located below the Usu-Shinzan by magnetotelluric soundings (e.g. Ogawa et al., 1998, Matsushima et al., 2001). And Yokoyama and Seino (2000) built a tilt model to interpret the formation of Usu-Shinzan. In this model, a block with a width of 800 m tilted approximately 11^o on a pivot at a depth of 800 m. So, in the present work, we conducted the muographic imaging (radiography with cosmic-ray muon) of Usu volcano to confirm the existence of magma intrusion beneath Usu-Shinzan.

But there is the issue of background (BG) noise of muographic imaging for a large volcano ($>$1 km thick). Since the integrated intensity of traversing cosmic-ray muons steeply decays as a function of the thickness of the target, the signal-to-noise (S/N) ratio also decreases seriously as the size of target becomes larger, and thus the density distribution cannot be accurately measured at a large volcano. The background (BG) noise that reduces the S/N ratio mainly consists of the fake tracks that are generated by the accidental coincidence of the electromagnetic (EM) shower particles. The values of BG noise were 10^{-6} cm^{-2} sr^{-1} s^{-1} (Lesparre et al., 2012) and 10^{-7} cm^{-2} sr^{-1} s^{-1} (Carloganu et al., 2013). BG noise of 10^{-7} cm^{-2} sr^{-1} s^{-1} corresponds to integrated cosmic-ray muon intensity after traversing 1 km of 2.65-g cm^{-3} rock.

In order to solve this problem, we developed a novel muon detection system that consists of multiple layers of position sensitive detectors (PSDs) in conjunction with a trajectory analysis method to effectively reduce the BG noise. In this method, the EM shower-originated fake tracks are rejected by requesting a linear trajectory for a muon event (linear cut method) since EM shower particles randomly hit each PSD layer and make a non-linear trajectory in the detection system. This detection system was applied to Usu volcano, Hokkaido, Japan to image its internal density structure (the spatial distribution of the density). In this measurement, we utilized a muon detection system that consisted of 7 layers of PSDs. One PSD consisted of x- and y- arrays of plastic scintillator strips with an active area of 1.21 m^2 and a segmented area of 10x10 cm^2. The angular resolution was +/- 3^o. The measurement duration was 1977 hours (82 days).

In this measurement, we compared the integrated cosmic-ray muon intensity traversing 2500 m of 1.5-g cm^{-3} rock with observed data at an elevation angle of 55.6 mrad. Assuming that the residual between the calculated intensity and data is BG noise, we obtained the BG noises of 5.4×10^{-5} cm^{-2} sr^{-1} s^{-1} with two PSDs and 1.9×10^{-6} cm^{-2} sr^{-1} s^{-1} with seven PSDs. The multilayered muon detector was effective to reduce the BG noise. However, BG noise remains and they may be attributed to another source of BG noise such as upward-going particles(Jourde et al., 2013). This measurement yielded the following results: (A) by analyzing the region that has a thickness of more than 1000 m, we confirmed that our detection system is sensitive to a density variation of 10% in 1300-m rock; and (B) there are high- and low-density anomalies beneath between Oo-Usu and Usu-Shinzan peaks, which is consistent with the magma intrusion and the resultant fault generation suggested by Yokoyama and Seino (2000), Ogawa et al. (1998) and Matsushima et al. (2001).

For the future prospect, we will try to use the shield in order to distinguish the upward-going particles from muons arriving from a volcano side.

Keywords: muography, muon, radiography