3D inversion of onshore controlled source electromagnetic data in the Kusatsu-Shirane Volcano

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SUMMARY

A controlled source electromagnetic (CSEM) method uses artificial sources to explore subsurface resistivity structures. We obtained CSEM data in the Kusatsu-Shirane Volcano, Japan where phreatic eruptions have occurred in the past. Eight receivers deployed 4–6 km away from a transmitter recorded CSEM signals from 0.5 km north-south and 1.0 km east-west dipole transmitter. Due to stacking of the long observation time of one week, most of the processed CSEM data showed low standard errors of <2%. We applied three-dimensional inversion to the CSEM data. The inversion is based on the data-space Occam algorithm and its forward modelling part uses the finite difference method. The inversion yielded a resistivity model that sufficiently explained the observed data. The resistivity structure specified a low resistivity anomaly (C1) and a conductor (C2) and a resistor (R1) below C1. We interpret that C1 is a clay cap layer, C2 is a liquid-phase hydrothermal reservoir, and R1 is a two-phase vapor-liquid hydrothermal reservoir. These structures are associated with occurrences of phreatic eruptions and monitoring these structures in the future is effective for understanding phreatic eruptions.

Keywords: Volcanic hazards and risks, Controlled source electromagnetics (CSEM), Magnetotellurics, Inversion

INTRODUCTION

A controlled source electromagnetic (CSEM) method employs artificial sources to investigate the subsurface resistivity structures. CSEM method is robust for noise effects because the injected current can be adjusted against the noise. Furthermore, by customizing the transmitting waveforms and positions of the transmitter and receiver, the CSEM survey can increase the detectability of a target structure.

The Kusatsu-Shirane Volcano is known for occurrences of phreatic eruptions. The phreatic eruptions are associated with the clay cap layer and hydrothermal reservoir below the clay cap layer. Understanding the distributions of these structures is necessary for revealing the mechanism of phreatic eruption occurrences. We aim to investigate the distribution of these structures related to the occurrences of phreatic eruptions.

Noise level is relatively high in this study area. Thus, we consider a CSEM method for investigating the Kusatsu-Shirane Volcano. The CSEM survey used a transmitter with 0.5 km north-south and 1.0 km east-west dipoles and eight receivers.

INVERSION RESULT AND DISCUSSION

Our CSEM survey uses an Electromagnetic-Accurately Controlled, Routinely Operated Signal System (EM-ACROSS). The EM-ACROSS is useful for obtaining low-error CSEM response in a noisy environment. The basic feature of EM-ACROSS is that it can repetitively transmit the precisely controlled signals. The precisely controlled signals are useful for stacking of long-term observation data. The stacking of long long-term data may yield CSEM responses with low errors.

EM-ACROSS transmitted the current from 0.5 km north-south and 1.0 km east-west dipole and eight receivers deployed 4–6 km away from a transmitter (Figure 1). The receivers recorded the transmitter signals for a week. Due to stacking of the long observation time of one week, most of the processed CSEM data showed low standard errors of <2%.

We use 3D CSEM inversion code developed by Ishizu et al., (2022). This inversion code is based on the data-space Occam algorithm. The data-space algorithm is useful for reducing computational costs when the data number is much less than the number of model parameters. The forward modeling algorithm of the inversion code applies the finite difference method with a primary-secondary field approach. The primary-secondary can prevent the numerical singularity at the source positions. The primary field is analytically computed using the 1D primary model. The linear system for the finite difference method is solved using a sparse direct solver of PARDISO.

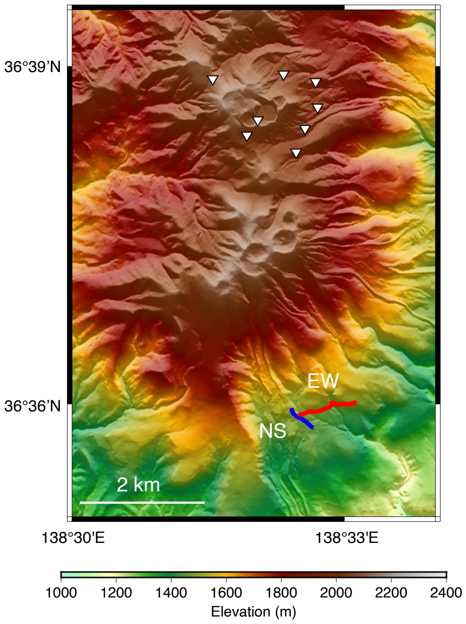

Figure 1: Map of the survey area. The locations of the transmitter and receivers are overlaid on the map.

We inverted the observed CSEM data consisting of five-component electromagnetic data (Ex, Ey, Hx, Hy, and Hz) with a frequency range of 0.1–50 Hz. The initial model for the inversion was 10 Ωm half-space. We used 80 × 70 × 81 cells in x, y, and z directions for model discretization. The RMS misfit for the initial model was 19. The inversion obtained a resistivity model after 27 iterations with an RMS misfit of 1.5. The model responses sufficiently fit the observed data.

The resulting resistivity model specified important structures for the Kusatsu-Shirane Volcano: a clay cap layer (C1) and a hydrothermal reservoir (C2 and R1) below the clay layer (Figure 2). The resistivity values vary in the hydrothermal reservoir. We interpret the high resistivity zone (R1) is a two-phase vapor-liquid hydrothermal reservoir and the low resistivity zone (C2) is a liquid-phase hydrothermal reservoir. These structures are associated with occurrences of phreatic eruptions.

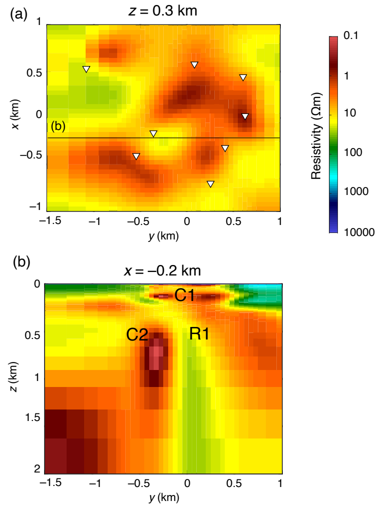

Figure 2: Inversion result. (a) Horizontal 2D section and (b) Vertical 2D section of the resistivity model. White triangles show receivers.

CONCLUSIONS

We conducted a CSEM survey using two sources and eight receivers in the Kusatsu-Shirane Volcano. EM-ACROSS was used for the CSEM survey. Due to the long observation time of one week, the CSEM survey obtained the CSEM data with low errors. The five-component data with the frequency range of 0.1–50 Hz were analyzed using the 3D inversion code. The resulting resistivity model specified important structures for the Kusatsu-Shirane Volcano: a bell-shaped clay layer and a hydrothermal reservoir below the clay layer. The resistivity values vary in the hydrothermal reservoir. We interpret the high resistivity zone is a two-phase vapor-liquid hydrothermal reservoir and the low resistivity zone is a liquid-phase hydrothermal reservoir. These structures are associated with occurrences of phreatic eruptions and monitoring these structures in the future is effective for understanding phreatic eruptions.

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