Deep high-temperature hydrothermal systems in active volcanoes estimated by numerical simulations based on resistivity structure

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SUMMARY

Numerical simulation of hydrothermal flow is useful for quantitatively understanding the highly complex hydrothermal processes within active volcanoes. However, comprehensive schemes for constructing realistic permeability structures, crucial for the simulation, have not been thoroughly explored. As a first step towards establishing such schemes, this study focuses on resistivity, a physical quantity closely related to permeability. We attempted numerical modeling of volcanic hydrothermal systems using resistivity structures estimated from magnetotelluric (MT) surveys. The target of this study is Kusatsu-Shirane Volcano (KSV), Japan, an active volcano known for its well-developed hydrothermal system.

We first created a 3-D permeability structure by semi-quantitatively converting the resistivity structure of KSV from Matsunaga et al. (2022) based on their interpretations. Then, using the TOUGH3 code (Jung et al., 2017), we simulated the flow of saline fluid to reproduce a quasi-steady state that matches the original resistivity structure and hot spring discharge pattern (this model is called “reference case”). Additionally, we performed a sensitivity analysis for different permeability structures, modified from the reference case, to identify the key structural factors that control the hydrothermal circulation within the volcanic edifice. The most influential structure identified was the silica sealing layer assumed to surround the conduit through which high-temperature magmatic fluids are supplied. Without this layer, the simulation could not reproduce the original resistivity structure and distribution of hot spring discharge.

Next, to investigate hydrothermal flow in the high-temperature region (>400ºC) inside the silica sealing zone, which TOUGH3 cannot calculate, we conducted another simulation using the HYDROTHERM code (Hayba and Ingebritsen, 1994, 1997; Kipp et al., 2008). The results of simulations indicated that the permeability and degree of closure of the sealing layer determine the pressure structure within the region it encloses. Thus, those factors are responsible for forming the significant sub-vertical conductors found beneath KSV.

In recent years, significant subvertical low-resistivity regions, similar to those found in KSV, have been observed in several volcanoes and are thought to be closely related to volcanic activity. Our proposed modeling scheme would provide a deeper insight into the internal structure of such low-resistivity regions.

Keywords: hydrothermal system, numerical simulation, magnetotellurics, resistivity structure