Constraining the size and state of magma reservoirs through a quantitative approach combining MT, lab measurements and petrological modelling

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SUMMARY

Magnetotelluric measurements are a powerful tool to image the subsurface under active volcanic regions. 3-D models, computed from magnetotelluric data, nowadays provide detailed multi-scale images of the electrical conductivity distribution. Since electrical conductivity is predominantly controlled by the presence of melt and fluid phases, conductivity models proved to be highly suitable for mapping the distribution of melt and for constraining melt fractions. Melt fractions can be estimated by combining laboratory models for melt electrical conductivity and mixing laws to derive the bulk electrical conductivity of multiphase systems. Melt electrical conductivity depends on the composition of the melt, the amount of dissolved water as well as temperature and pressure conditions. However, estimates of melt fractions are often based on arbitrary combinations of these parameters, and they do not consider the dependance of melt interconnectedness on melt fraction.
Here we present an interdisciplinary approach to interpret electric conductivity models from three volcanoes in the Main Ethiopian Rift. We use rhyolite-MELTS to model magma crystallization and storage conditions constrained by petrological analyses of on-site erupted products. To derive the electrical conductivity of melt during fractional crystallization we derive an expanded melt electrical conductivity model by interpolating between existing models for rhyolite, dacite and andesite melt. Thereby we obtain a generalized model that describes the electrical conductivity of melt in dependence on the SiO_2 and H_2O content, pressure and temperature. These parameters are given by rhyolite-MELTS. Decreasing melt connectedness with diminishing melt fraction is considered by varying the cementation exponent, *m,* in the generalized Archie's law whilst taking into account conservation of connectedness. Furthermore, we describe the magma reservoirs as three-phase systems consisting of crystals, melt and magmatic volatiles.
The results show that this approach enables us to constrain the current state of magma reservoirs in terms of melt fraction, temperature, and free volatile abundance. The latter is of eminent importance when discriminating between the two major mechanisms that drive volcanic unrest: magma on the move or increased degassing of a crystallizing magmatic system, so-called second boiling.
With this study we demonstrate the great capability of the presented interdisciplinary solution approach that combines geophysical observations, petrological probes, and laboratory models to capture the current state of volcanoes.
The outcome is of major importance when it comes to realistic volcanic hazard assessment and geothermal energy applications that require a detailed understanding of magmatic heat sources that sustain geothermal reservoirs.

Keywords: 3D inversion, volcano imaging, volcano deformation, interdisciplinary geophysical and petrological modelling