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Parameterization of conduit flow model based on the inverse analysis of data from ground deformation and magma extrusion

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During volcanic eruptions, slight changes in geological conditions often result in various types of eruptions such as effusive and explosive eruptions. In order to understand such complexities of conduit flow dynamics, several conduit flow models have been proposed (e.g., Melnik and Sparks, 2005). In the conduit flow models, temporal evolution of pressure and velocity in the conduit are calculated from model parameters such as volume of magma chamber and magma properties. In order to forecast the transitions of eruptions, these model parameters need to be estimated from the inverse analysis of time-series data of observation. Anderson and Segall (2013) formulated a posterior probability density function of model parameters given ground deformation and magma extrusion data based on Bayes' theorem, and yielded probabilistic estimates for the model parameters using a Markov Chain Monte Carlo (MCMC) algorithm. However, because their inverse analysis includes many model parameters, it is difficult to understand the influence of each observation on the parameter estimation. The present study aims to systematically investigate the influence of ground deformation and magma extrusion data on parameter estimation, and ultimately, to estimate model parameters of a more sophisticated conduit flow model that takes into account the effects of gas escape and crystal growth during magma ascent (e.g., Kozono and Koyaguchi, 2012).

In this study, a model consists of the magma plumbing system where pressure of a spherical magma chamber in elastic rocks is determined by the balance between magma influx and outflux. We also assume that conduit flow is determined by the balance between pressure gradient and viscous force (i.e., Poiseuille flow). In this system, model parameters include chamber volume, conduit length, effective elastic modulus of magma in the chamber and the chamber itself, conduit radius, magma density and viscosity. On the other hand, observables include the time-series data of the volume change due to inflation/deflation of the chamber (ΔV_G) and the amount of extruded magma (ΔV_E).

Assuming that magma density and viscosity are constant in the conduit, extrusion rate Q and magma chamber pressure P approach the steady solution (Q_s,P_s) with a time constant τ. A parameter τ is determined by chamber volume, effective elastic modulus, magma viscosity, conduit radius and conduit length. In the case where τ can be estimated from the time-series data of ΔV_G and ΔV_E, the estimated value of τ provides the information related to the conductivity of the conduit flow and the system size, whereas the difference between ΔV_G and ΔV_E provides the information related to magma compressibility and the shape of the chamber.

We have also preliminarily investigated the influence of gas escape and crystal growth on the parameter estimation assuming various function forms for magma density and magma viscosity. In this preliminary study, we compare the probability density distribution of model parameter estimated numerically using a MCMC algorithm with the analytical results in order to understand how the parameter estimation using MCMC algorithm is applicable to the problems of complex conduit flows with gas escape and crystal growth.

Keywords: volcanic eruption, conduit flow, lava dome, ground deformation, inverse analysis