Geophysical Research Abstracts
Vol. 21, EGU2019-2702, 2019
EGU General Assembly 2019
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The physical processes driving transition from lava dome to explosive eruptions

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The physical processes of transition from lava dome to explosive eruptions are investigated using a model of magma plumbing system, where a magma erupts through a conduit from a magma chamber located in elastic crustal rocks. A new magma is supplied from below to the chamber at a constant rate and the chamber pressure is determined by the balance between the supply and eruption rates. The dynamics of conduit flow is calculated using a one-dimensional conduit flow model, in which the effects of lateral and vertical gas-escape are considered (Kozono and Koyaguchi, 2012).

In this model, the evolution of the system during an eruption is described by a trajectory in the parameter space of chamber pressure (P) and mass eruption rate (Q). When the volume of conduit is sufficiently smaller than the chamber volume, the trajectory is constrained by the relationship between P and Q for the steady conduit flow (the steady P-Q curve). The steady P-Q curve typically has a sigmoidal shape; $dP/dQ>0$ in the low-Q and high-Q regimes, whereas $dP/dQ<0$ in the intermediate regime. The low-Q and high-Q regimes represent two extreme cases: the efficient gas-escape (EGE) and no gas-escape (NGE) cases. The P-Q curve of the intermediate regime connects the curves for the EGE and NGE cases, and its negative dP/dQ is caused by a positive-feedback mechanism of gas-escape; as Q increases, magma porosity increases due to less efficient gas escape, which leads to further increase in Q because of reduction of gravitational load.

Our results show that the eruption sequence is typically divided into 4 stages. In Stage 1, P and Q increase along the steady P-Q curve of EGE case. In Stage 2, Q rapidly increases from the P-Q curve of EGE case to that of NGE case, whereas P is kept approximately constant. In Stage 3, P and Q decrease along the steady P-Q curve of NGE case. When P reaches its minimum of the steady P-Q curve, Q rapidly decreases and the eruption stops (Stage 4). A transition from lava-dome to explosive eruptions occurs during the rapid increase of Q in Stage 2. During Stage 2, the porosity of the conduit flow remarkably increases as the conduit is filled by gas-rich magma. When the porosity reaches a critical value at the top of the conduit, the magma fragmentation occurs there. The fragmentation surface travels downwards in a short time scale. Finally, the profile of conduit flow approaches that of a steady explosive eruption in Stage 3. It is suggested that the transition from lava dome to explosive eruptions is driven by a combination of two physical processes with different time scales: replacement of gas-rich magma inside the conduit and rapid decompression associated with magma fragmentation.

Acknowledgement. A part of numerical simulations used in this study were carried out by Y. Inagaki and K. Koyama.