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Effects of gas escape and crystallization on a transition from lava-dome to explosive eruption

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During lava dome eruptions, the degree of gas escape and that of crystallization strongly affect the dynamics of conduit flow. Generally, the dynamics of conduit flow is determined by the relationship between chamber pressure p_{ch} and mass flow rate q for steady conduit flow ("the p_{ch}-q relationship"). When the slope of the p_{ch}-q relationship (dp_{ch}/dq) has a positive value ("positive differential resistance"), the steady flow is stable. When dp_{ch}/dq has a negative value ("negative differential resistance"), on the other hand, complex dynamics such as abrupt change and/or cyclic change of magma discharge rate can result. In this study, on the basis of an one-dimensional conduit flow model, we investigated how the coupled effects of gas escape and crystallization control the features of the p_{ch}-q relationship and transitional process of conduit flow induced by the negative differential resistance.

For conduit flow involving gas escape and crystallization, two positive-feedback mechanisms that result in the negative differential resistance are identified. First, effective magma viscosity decreases with increasing q because of delay of crystallization, leading to the reduction of viscous wall friction (feedback 1). Second, magma porosity increases with increasing q because of less efficient gas escape, leading to the reduction of gravitational load of magma (feedback 2). These two feedback mechanisms induce a sigmoid p_{ch}-q relationship for some realistic conditions; the positive differential resistance in the low-q and high-q regimes, and the negative differential resistance in the intermediate regime. Stable solutions of conduit flow in the low-q and high-q regimes are characterized by low- and high-porosities at vent, corresponding to a stable lava-dome eruption and an explosive eruption, respectively. The analyses of time-dependent conduit flows indicate that, because of the sigmoid p_{ch}-q relationship, magma discharge rate abruptly increases from the low-q to high-q regimes as magma supply at depth gradually increases from the low-q regime to the intermediate regime. We consider that this abrupt increase in magma discharge rate accounts for the transition from a lava-dome eruption to an explosive eruption.

We found that the governing mechanism for the transition from a lava-dome eruption to an explosive eruption changes depending on phenocryst content of magma. For high phenocryst content (volume fraction $>$0.5), the feedback 1 is the main mechanism that forms the negative differential resistance. In this case, the transition from lava-dome to explosive eruption occurs when the magma supply rate at depth exceeds a fixed critical value. On the other hand, for low phenocryst content (volume fraction $<$0.5), the feedback 2 plays a key role so that the transition is controlled by the permeability of the surrounding rocks; the critical magma supply rate remarkably decreases with decreasing permeability. The transition due to the feedback 2 is associated with a change in chemical composition of volcanic gas, a drastic increase in magma porosity from nearly 0 to greater than 0.8, and overpressure at a shallower level, which can be detected from geochemical and geophysical observations.

Keywords: lava dome eruption, conduit flow, numerical model, transition of eruption, gas escape, crystallization