

## Conditions for transition from lava dome to explosive eruption

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Conduit flow dynamics involving magma vesiculation, gas escape, and crystallization during a lava dome eruption lead to complex processes such as a transition to an explosive eruption. Because the transition from the lava dome to the explosive eruption is accompanied with a drastic increase in eruption intensity, it is important for volcanic hazard mitigation to determine conditions for this transition to occur. In this study, on the basis of a 1-dimensional conduit flow model, we investigated how the conditions for the transition from the lava dome to the explosive eruption depend on magmatic and geological parameters.

In order to systematically investigate the dependence of the transition conditions on the magmatic and geological parameters, we used 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, the steady flow is unstable. The negative differential resistance is generated by two positive-feedback mechanisms. First, effective magma viscosity decreases with increasing  $q$  because of delay of crystallization, leading to reduced viscous wall friction (feedback 1). Second, magma porosity increases with increasing  $q$  because of less efficient gas escape, leading to reduced gravitational load (feedback 2). These two feedback mechanisms induce a sigmoidal  $p_{ch}$ - $q$  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. The analyses of time-dependent conduit flow model indicate that, because of the sigmoidal  $p_{ch}$ - $q$  relationship, as magma supply at depth gradually increases from the low- $q$  regime to the intermediate regime, magma discharge rate abruptly increases from the low- $q$  to high- $q$  regimes. This abrupt increase in magma discharge rate accounts for the transition from a stable lava-dome eruption to an explosive eruption. We, therefore, define the value of  $q$  at the boundary between the low- $q$  and the intermediate regimes as the critical magma supply rate for the transition ( $q_{cr}$ ).

Our results show that  $q_{cr}$  is mainly controlled by the feedback 2 for a wide range of magmatic and geological conditions, whereas it is controlled by the feedback 1 only when phenocryst content is very high. When  $q_{cr}$  is controlled by the feedback 2, the value of  $q_{cr}$  depends on parameters related to gas escape such as the permeability for vertical gas escape and that for lateral gas escape. We found that for a plausible range of vertical permeability which is constrained from permeability measurements of volcanic rocks,  $q_{cr}$  remarkably decreases with decreasing lateral permeability, and it becomes substantially lower than typical magma discharge rates for observed lava-dome eruptions in the limiting case of zero-lateral permeability (i.e. no lateral gas escape). This indicates that the presence of lateral gas escape is a necessary condition for a stable lava-dome eruption to occur. In addition, we found that  $q_{cr}$  strongly depends on conduit radius owing to the effects of the change in the conduit radius on the degree of gas escape. As the conduit radius decreases, the ascent of the liquid is suppressed because of the increase in wall friction force, which promotes vertical gas escape. The decrease in the conduit radius also induces an increase in the ratio of the perimeter to the cross-sectional area of the conduit and a decrease in the length scale of pressure gradient that drives lateral permeable gas flow, which promotes lateral gas escape. These promotions of gas escape lead to an increase in  $q_{cr}$ . The above results suggest that the variation of conduit radius is a key factor for the transition from a lava-dome to an explosive eruption.

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