Two positive-feedback mechanisms controlling the bifurcation of gas-escape processes during volcanic eruptions

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The dynamics of conduit flow is affected by density change of magma due to gas-escape and viscosity change due to crystallization. The processes of gas-escape and crystallization, therefore, lead to diverse features of volcanic eruptions such as a transition from a lava-dome forming eruption to an explosive eruption. The diverse features of eruption sequence are investigated using a model of magma plumbing system composed of a conduit and a magma chamber in elastic rocks, in which the effects of lateral and vertical gas-escape, as well as that of crystallization, are taken into consideration (Kozono and Koyaguchi, 2012). Here, using this model, we estimate the effects of gas-escape on the diverse features of eruption sequences.

Generally, the dynamics of conduit flow is controlled by the relationship between chamber pressure (P) and mass flow rate (Q) for steady conduit flow (the P-Q relationship). The diverse features of eruption sequence can be explained by the variation in the P-Q relationship. The variation in the P-Q relationship can be systematically described using the two reference relationships of extreme cases: the efficient gas escape (EGE) case and the no gas escape (NGE) case. The P-Q relationship for general cases is located between the EGE and NGE cases. In the P-Q relationship for general cases, there are two mechanisms that cause a transition from the EGE case to the NGE case and bring forward its change (the two positive-feedbacks).

The first positive feedback occurs during the waxing stage of an eruption. As the magma flow rate, Q, increases in the waxing stage, magma porosity increases with increasing Q because of less efficient gas escape, which leads to further increasing in Q because of reduction of gravitational load. This feedback mechanism causes complex dynamics; Q changes abruptly and/or cyclically even if magma supply at depth gradually increases. This abrupt increase in Q may account for the transition from a stable lava-dome eruption to an explosive eruption.

The second positive feedback occurs during the waning stage of an eruption. During the waning stage, as the chamber pressure, P, decreases, the pressure inside the conduit also becomes lower than the lithostatic pressure. The decrease in pressure inside the conduit reduces the efficiency of the lateral gas escape. This reduction of lateral gas escape increases magma porosity, which, in turn, leads to a decrease of the gravitational load and a further decrease in P. This feedback mechanism is particularly important in the sense that it controls the magnitude of decrease in chamber pressure during eruption (i.e., pressure drop), and hence, the scenario towards the end of an eruption.

Results of an extensive parametric study indicate that whether the second feedback mechanism plays a role or not is sensitive to a slight change in the permeability of the country rocks. For the condition where this feedback does not work, an eruption ends when the initial overpressure of magma chamber is relaxed. When this feedback plays a role, on the other hand, even after the initial overpressure of magma chamber is chamber is relaxed, an eruption continues until the chamber pressure becomes as low as the static pressure of gas-rich magma.

Keywords: magma plumbing system model, gas-escape process, eruption sequence, bifurcation