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A new mechanism of oscillatory magma effusion and pressure changes during lava dome growth

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Periodic ground deformation around volcano is commonly observed during lava dome growth (e.g. those of the 1991-1995 eruption at Unzen Volcano and the1996-1997 eruption at Soufriere Hills volcano). Such ground deformation represents periodic changes in chamber pressure which is determined by the balance of supply and discharge of magma. So far two models have been proposed in order to explain oscillation in magma effusion and pressure. Ida (1996) proposed a model in which magma is supplied at a constant rate, accumulates in an elastic chamber, and flows out in a cylindrical vent that may widen or narrow due to viscous deformation of the surrounding country rock. Wylie et al. (1999) proposed another model in which viscosity change depending on the volatile content of the magma is taken into account. These models are basically expressed by two-dimensional ordinary differential equations that describe the time evolution of magma flux in conduit (Q) and pressure in magma chamber (P). In these equations, spatial distributions of physical parameters along the conduit are averaged, and they are not explicitly taken into consideration. For this reason, physical meanings of parameters used in these models are not always clear.

In order to take into account the spatial distributions of physical parameters along conduit, we developed a method in which a time evolution model and a one-dimensional steady conduit model are combined. Using a one-dimensional steady conduit model, we can obtain a steady solution of magma flux (Q) for a given chamber pressure (P) as well as spatial distribution of all the physical parameters along the conduit. From these results, we can estimate the relationship between P and Q that provides constant Q; the relationship is expressed by a curve in P-Q space (referred to as 'Q-nullcline'). Similarly, we can obtain another curve that provides constant P in P-Q space ('P-nullcline') from the balance of inflow and outflow in the magma chamber. The intersection of the two nullclines represents a stationary point of the dynamic system (i.e. a steady solution). The stability of the stationary point and the dynamic behavior around the stationary point (e.g. the occurrence of oscillation) can be systematically investigated in terms of the geometrical relationship between the two nullclines in P-Q space on the basis of two-dimensional dynamics theory.

In this study, we applied the above method to a one-dimensional steady conduit model by Woods and Koyaguchi (1994) where the effects of degassing through permeable conduit wall are taken into consideration. As a result, we found a new mechanism of oscillation that is caused by the decrease of bulk density of bubbly magma. As magma flux increases, the proportion of gas which escapes from the conduit wall decreases, and so the bulk density decreases, which increases magma flux. This means that the dynamical system conduit model has a positive feedback. At the same time, the system has a negative feedback; as magma flux increases, chamber pressure decreases, which decreases magma flux. The oscillation of magma flux in conduit and chamber pressure can be explained by the combination of these positive feedback and negative feedback.