Effects of conduit pressurization during eruption transition on crustal deformation

*小園 誠史[1]、小屋口 剛博[2]
*Tomofumi Kozono[1], Takehiro Koyaguchi[2]

1. 東北大学大学院理学研究科地球物理学専攻、2. 東京大学地震研究所
1. Department of Geophysics, Graduate School of Science, Tohoku University, 2. Earthquake Research Institute, University of Tokyo

A temporal change of conduit flow during an eruption transition may cause a change in pressure inside a conduit, leading to an elastic deformation of surrounding rocks and geodetically observable surface displacements. In order to make it possible to detect the eruption transition from the geodetic observations, it is important to understand the relationship between the conduit processes and the crustal deformation patterns. In this study we investigated this relationship on the basis of the numerical modeling of the conduit flow and the crustal deformation. In the conduit flow model, the magma ascent through a cylindrical conduit accompanied with vesiculation, gas escape, crystallization is modeled as one-dimensional flow, and the conduit flow is coupled with the pressure change in a spherical magma chamber. In the crustal deformation model, the elastic modulus surrounding the conduit-chamber system is modeled by a finite element method with the two-dimensional axisymmetric domain.

In the analyses of the conduit flow model, we calculated the temporal change of the conduit flow during the transition from effusive to explosive eruptions accompanied with a drastic increase in magma discharge rate. During this transition, both the chamber pressure and the pressure inside the conduit first increase and then decrease, and the chamber pressure to reach maximum is followed by the pressure inside the conduit to reach maximum. The pressure distribution inside the conduit is characterized by a localized pressurization at a shallower level of the conduit. This pressurization originates from the balance between the gravitational load of magma controlled by magma density and the wall friction force controlled by magma viscosity. In general, because the magma density is determined by the competition between vesiculation and gas escape and the magma viscosity is affected by crystallization kinetics, the pressure distribution depends on parameters related to gas escape and crystallization during magma ascent such as gas permeability and crystal growth rate. When the pressure inside the conduit is in maximum, however, we found that the pressure distribution mainly depends on magma storage conditions at the magma chamber such as volatile content and phenocryst volume fraction because of inefficient gas escape and crystallization.

The crustal deformation models revealed that the above pressure changes at the magma chamber and inside the conduit are separately detectable by combining tilt measurements at distal area and strain measurements at proximal area: the chamber pressure change induces a deformation in a wide area, whereas the effect of the localized conduit pressurization is limited to the horizontal displacement at proximal area. When the magnitude of the pressurization inside the conduit is small, however, the effect of the conduit pressurization on the crustal deformation becomes much less than that of the chamber pressure change because of a distinct difference in the volume between the conduit and the magma chamber, leading to the case that the conduit pressurization is undetectable. We found that this case occurs under low volatile content at the magma chamber: when the degree of vesiculation decreases under the low volatile content, the pressure gradient becomes gentle because of the decrease in the magma density (i.e., the gravitational load), leading to decreasing the magnitude of the localized

pressurization. The lower volatile content induces a lower magma compressibility at the magma chamber, leading to an efficient change in the chamber pressure. This effect also promotes the dominance of the influence of the chamber pressure change on the crustal deformation. Our results indicate that it is important to obtain information on the magma storage conditions for assessing the detectability of the eruption transition from the geodetic observations.

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