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Magma mixing/mingling and viscous fingering: Analog model experiment and geometry of interfaces

Nodoka Takada[1*], Eiichi Sato[1], Kazuhito Yamasaki[1]

[1]Department of Earth and Planetary Sciences,Faculty of Science,Kobe University

Magma mixing/mingling is common in the dynamics of volcanic eruptions and igneous activities, and its processes have been investigated by several experimental and theoretical studies (Eichelberger, 1980; Koyaguchi, 1985; Wada,1995). Especially, the morphology of interfaces between the magma have different viscosity shows the various complex patterns due to the difference in physical and chemical condition under the mixing/mingling process (De Rosa et. al., 2002; Perugini et. al., 2005; Sato and Sato, 2009). Since the quantity that we can observe easily now is the geometrical patterns of the interfaces, it is important to express this physical phenomenon in terms of the geometrical quantities of the interfaces. In this work, we call it as the geometry of interfaces.

The geometry of interfaces enables us to extract the useful information of the mixing/mingling process from the morphological analysis of the interfaces of rocks in nature (Perugini and Poli, 2005; Sato and Yamasaki, 2012). However,few attempts have been made to consider how the dynamic quantities such as the growth rate of the interfaces affect the geometry of the interfaces in the mixing/mingling process. The purpose of this work is to clarify this point based on the analog model experiment and the differential geometry.

In this work, to simulate the replenishment of felsic magma chambers/pockets by continuous inputs of mafic magmas, we perform the analog model experiment in which we inject air into glycerin using the Hele-Shaw cell. In this case, the mixing/mingling process can be described by the DLA model (e.g., Nittmann et al., 1985), and the interfaces show the viscous fingering pattern due to the instability of the interfaces that also occur in the natural cases (e.g., Perugini and Poli, 2005). The following results were obtained.

(1) We estimate the three fractal dimensions: the interfaces Di, the area of the higher viscosity fluids Dh and that of the lower viscosity fluids Dl. We find that the sum of Dh and Di is the conserved quantity, and the Di is proportional to Dl. This implies that the fractal dimension of the interfaces (easily observed quantities) enables us to estimate the fractal dimension of the area of the felsic or mafic magma (hardly observed quantities).

(2) We find that the radius of curvature of the viscous fingerling depends on the growth rate of the interfaces. This is agreed with the solutions of the development equation of the curvature in the differential geometry (e.g., Nakamura and Wadati, 1993). This implies that we can estimate the growth rate of the interfaces by the radius of curvature of the mafic magmas.

Keywords: magma mixing, viscous fingering, fractal dimension, Hele-Shaw cell, curvature, DLA