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Shape, propagation style and velocity of a buoyancy-driven crack : a parameter study

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Introduction: Magma is considered to ascend in the form of a diapir by deforming the host rock in the asthenosphere whereas it ascends as a dyke by brittle fracturing in the lithosphere (Rubin, 1995). How does the magma ascend in the transitional regime? We have been studying the ascent mechanism in the transitional regime by model experiments using a viscoelastic agar and widely varying its stiffness (Sumita and Ota, 2011). Here we report the results of experiments which focus on the effect of fluid viscosity on the magma migration in a viscoelastic medium.

Experimental method: We conducted (1) rheology measurement of an agar and (2) fluid injection experiments. We inject magma (CsCl solution to which a thickener is added) using a syringe from the top of a cylindrical acrylic tank (height of 250 and 500 mm). The fluid has a volume of 1ml, a density difference with the agar of 0.580 and 0.770 g/ml, and is injected at a constant rate of 1 ml/s. We vary the agar concentration(C) in the range of C = 0.06-0.5 wt% and the fluid viscosity(η) in the range of η = 10^-3 - 1300 Pas. As we increase the agar concentration in this range, the yield stress and the rigidity of the agar increases by 3 and 2 orders of magnitude, respectively. From creep test conducted under a constant shear stress, we find that the agar can be approximated by a Voigt model to which a spring is connected in series for C › 0.1wt%, and a Burgers model for C ‹ 0.1wt%. The experiments are recorded using video cameras from two sides and from the bottom of the tank.

Result: From the crack shape, propagation style and velocity, we classified the experiments into the following 3 regimes. Regime Ⅰ: The crack has a 2D(blade-like) shape, a straight trajectory and stops propagating in a short distance. We fit the distance(z) vs time(t) data to a power-law($z \propto t$^n) relation, and find that the power law exponent is n$\sim$1/5. The migration velocity depends on viscosity as $\sim$ 1/n. Regime Ⅱ: The crack shape transforms from 2D to 3D(i.e. , having a bulged head) and its trajectory is curved or meanders. The power-law exponent varies as n=1/3-1. We find that as the fluid viscosity increases, the amplitude of the meandering becomes smaller and transforms to a straight path. The same transformation was observed when the fluid density becomes smaller (Sumita and Ota, 2011). The migration velocity is intermediate from those of regimes Ⅰ and Ⅲ. Regime Ⅲ: The crack shape is 3D, the trajectory is straight and the propagation distance is long. The power-law exponent is n$\sim$1. The dependence of migration velocity on viscosity is small.

Discussion: The condition for the regime Ⅰ-Ⅱ transition can be approximately described using the dimensionless buoyancy B=$\triangle\rho$gV^1/3/G($\triangle\rho$: density difference, g: gravity, V: crack volume)as B$\sim$1. However in detail, we find that the B value becomes larger for a high viscosity fluid. This is because when the propagation velocity is small, a larger fraction of the fluid is left along the crack tail such that the crack head volume become smaller, which results in a smaller effective B value . The migration velocity was found to be comparable to or smaller than the channel flow velocity(n=1/3:Taisne et al. (2011)) in regime Ⅰ and comparable to the Stokes settling velocity(n=1) and shear wave velocity in regime Ⅲ. This suggests that the propagation velocity is also rate-limited by rupture velocity. We indeed confirmed that the propagation becomes faster when there is a preexisting crack. We find that the meandering of regime Ⅱ no longer occurs under a large viscosity. This suggests that in addition to B$\sim$1, there is a critical velocity, or a critical Reynolds number required for meandering to occur.

References :

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