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Role of Yield Stress in Magma Rheology

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Magmas are essentially multiphase material composed of solid crystals, gaseous bubbles and silicate liquids. They exhibit various types of drastic change in rheology with variation of mutual volumetric fractions of the components. The nature of this variable rheology is a key factor in controlling dynamics of flowing magma through a conduit. Particularly the existence of yield stress in flowing magma is expected to control the wall friction and formation of density waves. As the volumetric fraction of solid phase increases yield stress emerges above the critical fraction. Several previous studies have been conducted to clarify this critical value of magmatic fluid both in numerical simulations and laboratory experiments ([Lejeune and Pascal, 1995], [Saar and Manga 2001], [Ishibashi and Sato 2010]). The obtained values range from 13.3 to 40 vol%, which display wide variation and associated change in rheology has not been clarified well. In this presentation we report physical mechanism of emergence of yield stress in suspension as well as the associated change in the rheology based on laboratory experiments using analog material.

We utilized thermogel aqueous suspension as an analog material of multiphase magma. Thermogel, which is a commercial name for poly(N-isopropyl acrylamide) (PNIPAM) undergoes volumetric phase change at the temperature around 35C:below this temperature the gel phase absorbs water and swells while below this it expels water and its volume shrinks. Because of this the volumetric fraction of gel phase systematically changes with temperature and the concentration of gel powder. The viscosity measured at lower stress drastically decreases across this phase change with increasing temperature while the viscosity at higher stress does not exhibit large change across the transition. We have performed a series of rheological measurements focusing on the emergence of yield stress on this aqueous suspension. Since the definition of yield stress is not well defined in the suspension rheology we tested three types of measurement in determination of yield stress. Two methods utilized cone-plate geometry performing creep test (stress controlled) and variable shear rate test and one utilized narrow-gap concentric cylinder geometry with variable shear rate. Herschel-Bulckley model can be successfully applied to variable shear-rate tests to determine yield stress. Creep test and H-B model give almost identical yield stress, for instance 45 ± 5Pa at 2.5wt%. At the gel volume fraction of 50% yield stress emerges and it increases with the increase of the concentration of gel powder. This critical value roughly corresponds to the random loose packing fraction while the viscosity begins to increase at lower fraction.