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Rheology of Volatile-rich Crystal Mush

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Magma batholiths are commonly highly crystalline (> 50 vol%; crystal mush, Bachmann and Bergantz, 2008a) and possible modes of mobilization and emplacement have been intensively discussed in the last decades. Recently, it has been proposed that a stiff mushy batholith must be reheated to mobilize; this produces a reduction in crystallinity that leads to an increase of the magma buoyancy (Burgisser and Bergantz, 2011). Another way of batholith mobilization in the crust can be caused by addition of volatiles (mainly H_2O and CO_2) released by ascending hydrous mafic magmas coming from the mantle (Bachmann and Bergantz, 2008b). The enrichment in volatiles induces a drastic decrease in the bulk viscosity of the granitic body and, thus, an evident change in the rheological properties of the batholith. The rheology of such very crystal-rich highly viscous systems is still a matter of debate. To provide some additional experimental constraints relevant to this discussion, we deformed hydrous (2.52 wt% H_2O) haplogranitic magmas containing variable amounts of quartz crystals (from 55 to 65 vol%), and fixed volume of gas-pressurized CO_2-bubbles (9-10 vol%), in simple shear using a HT-HP Paterson-type rock deformation apparatus. Strain rates ranging between 1•10-5 s-1 and 4•10-3 s-1 were applied at temperatures between 823 and 1023 K and constant confining pressure of 200-250 MPa (8-9 km depth). The results suggest that three-phase suspensions are characterized by strain rate-dependent rheology (non-Newtonian behavior). Two non-Newtonian regimes were observed: shear thinning (decrease of viscosity with increasing strain rate) and shear thickening (increase of viscosity with increasing strain rate). The first effect dominantly occurs because of crystal size reduction and shear localization, enhanced by the presence of gas bubbles in the weak shear bands. However, when the solid crystal framework induces an internal flow blockage due to crystal interlock, the second effect becomes dominant. Comparing our results with previous ones for the rheology of crystal-bearing systems (Caricchi et al., 2007), the presence of limited amount of gas bubbles (12 vol% maximum) favors an evident decrease in viscosity; e.g., at about 70 vol% crystals a decrease of about 4 orders of magnitude in relative viscosity is caused by adding only 9 vol% bubbles. These experiments suggest that magma rheology is strongly controlled by the simultaneous presence of bubbles and crystals in the melt phase and their interactions during deformation. The localization in strain favors granite mobilization in the crust and the occurrence of large-scale eruptions; in contrast, the crystal interlocking halts the batholith in the crust and determines its viscous death.

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