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Effective rheology of partially molten rocks: Numerical and experimental data

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We analyze the mechanical and rheological behavior of a two-phase system consisting of rigid grains and an interconnecting viscous fluid. For this purpose we use 2D direct numerical finite element simulations on the spatial scale of individual grains. We derived expressions for the effective viscosity for both Newtonian and non-Newtonian rheologies. Simulations using instantaneous deformation demonstrate that the effective rheology of the assemblage is non-Newtonian only if the fluid has a non-Newtonian rheology. At low fluid fractions the strain rates within the fluid are locally up to three orders of magnitude higher than the overall applied background strain rate. This may explain experimentally observed Newtonian to non-Newtonian rheological transitions.

Laboratory experimental studies indicate that melt-grain systems behave non-linearly for moderate to high strain rates. However, the relative importance of shear heating, non-linear rheology, elasticity, plasticity and finite strain of the assemblage remains to be examined and may influence the effective rheology in a counter-intuitive manner. We have developed a 0D visco-elastic inversion model, which allows us to extract the effective rheological parameters from both numerical and laboratory experiments. We test the model against a series of 2D finite strain grain-scale numerical simulations. The rheology of each phase is controlled independently. Rheologies can be either linear or non-linear visco-elastic and the viscosity can be either temperature and composition dependent or independent. The simulations also account for shear heating. The 0D model reproduces well the rheological parameters (viscosity, temperature, elastic shear modulus) for the synthetic models. From this success we conclude that the model can be used to extract rheological information from laboratory data.

Simulations with realistic grain shapes and linear visco-elastic rheology show no evidence that grain rearrangement causes a change to non-linear aggregate rheology. Thermal effects for strain rates <10-3 s-1 are too small to induce significant shear heating. However, realistic grain shapes do cause higher local stresses compared to regular grain shapes, e.g. spherical grains. Higher stresses enhance plastic failure, which aids in turn to locally reduce the viscosity. Such a process may additionally induce non-linear behaviour of the melt-grain system. The new findings can be applied to laboratory experiments on the effective rheology of partially molten rocks and have implications for volcanic eruptions and batholith emplacement.