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Rheology of the Deep Crust: Reconciling Lab Data with Field Observations

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The extrapolation of laboratory measurements to natural conditions provides quantitative viscosity estimates of lower crust and upper mantle. Extrapolation of experimental data in space and time involves assumptions concerning material composition and prevailing thermodynamic conditions. Dominant mineral phases in lower crust and upper mantle are feldspar, pyroxene and olivine and robust constitutive equations now exist for feldspar and olivine rocks.

We performed triaxial creep and large-strain torsion experiments on synthetic feldspar rocks in a gas deformation apparatus at temperatures of 950-1200 ˚C, and confining pressures of 100-450 MPa. In axial compression experiments at stresses of 10-400 MPa resulting strain rates were between $\approx 6\cdot10^{-7}$ – $3\cdot10^{-3}$ s^{-1}. Torsion tests were performed at constant twist rates resulting in shear stresses of 3-90 MPa and shear strain rates between $\approx 2\cdot10^{-5}$ – $2\cdot10^{-4}$ s^{-1}. Dense samples with a grain size of about 3 μm were prepared by hot-isostatic pressing of anorthite glass powder. Hydrous samples contain about 0.33 $\pm$ 0.14 wt% H_2O and dry specimens 0.0005-0.02 wt% H_2O, mainly as molecular water located at grain boundaries. The estimated residual glass content of wet samples is $<$ 2 vol%. Samples deformed in grain boundary diffusion-controlled creep but dislocation creep dominated at stresses $>$ 150 MPa. We estimate an activation volume of V = 24 $\pm$ 21 cm^3mol^{-1} and 38 $\pm$ 21 $cm^3mol^{-1}$for anhydrous samples and hydrous samples, respectively, deforming in diffusion creep. Creep rate of hydrous anorthite aggregates depends on water fugacity raised to a power of r = 1.0 $\pm$ 0.3, suggesting hydrolysis of oxygen bonds. Large-strain torsion experiments on hydrous anorthite aggregates were performed to investigate the evolution of microstructure and mechanical behaviour with strain. The striking observation of these experiments was that samples developed significant cavitation with increasing

strain ultimately leading to catastrophic failure at elevated pressures and maximum shear strains of about 3-4. Up to failure stress sensitivity remains about n=1 indicating linear viscous behaviour.

In extrapolating the data to conditions of the continental crust we use a strain rate of 10^{-12} s^{-1} and 20 μm grain size for diffusion-controlled creep, which are typical values for localized deformation in high-temperature shear zones. For rocks deforming in dislocation creep, data is extrapolated to strain rates of 10^{-14} s^{-1}. At hydrous conditions feldspar rocks are predicted to be significantly weaker than pyroxenites and olivine rocks in agreement with field observations. Low viscosity estimates of 10^{18}-10^{19} Pa·s from modeling postseismic stress relaxation of the continental lower crust can only be reconciled with laboratory experiments assuming dislocation creep at high temperatures $>$ 900 ˚C or, at lower temperatures, diffusion creep of fine-grained rocks possibly localized in abundant high strain shear zones. The experimentally observed cavitation and ductile failure suggests that local instabilities may be generated in high-temperature ultramylonites.