Geophysical Research Abstracts
Vol. 17, EGU2015-10065, 2015
EGU General Assembly 2015

Laboratory observations of shear zone development and rheological behavior of crustal rocks

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Quantitative viscosity estimates of the lower crust and upper mantle may be based on modeling postseismic surface deformation, analysis of natural shear zones and extrapolation of laboratory measurements to natural conditions. Extrapolation of experimental data is largely in space and time and involves assumptions concerning material composition and prevailing thermodynamic conditions. Dominant mineral phases in the lower crust and upper mantle are feldspar, pyroxene and olivine for which robust constitutive equations now exist although mechanical data on phase mixtures are still scarce. In general, numerous field studies suggest that extrapolated laboratory data of rocks deformed at hydrous conditions are in good agreement with independent field evidence for crustal stresses and viscosities.

The deformation of rocks in the Earth's middle and lower crust is often localized in ductile shear zones. To better understand the initiation and propagation of high-temperature shear zones induced by the presence of structural and material heterogeneities, we performed deformation experiments on feldspar aggregates and recently on Carrara marble samples covering diffusion and dislocation creep regimes. The samples were mostly deformed in torsion at a bulk shear strain rate of $\approx$ 10-4 – 10-5 s-1 to bulk shear strains γ between 0.02 and 4 using a Paterson-type gas deformation apparatus. The experiments demonstrate that the presence of material heterogeneities is crucial to initiate localized creep and potential ductile failure at local stress concentrations irrespective of rheological regime. We find that recrystallization-induced grain size reduction may only locally promote grain boundary diffusion creep. Significant weakening of the bulk material is only observed if localization is associated with significant structural changes within the developing shear zones.