Geophysical Research Abstracts
Vol. 14, EGU2012-10949, 2012
EGU General Assembly 2012

Micromechanics of brittle creep and implications for the strength of the upper crust

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In the upper crust, the chemical influence of pore water or other aqueous solutions promotes time dependent brittle deformation through sub-critical crack growth. Sub-critical crack growth allows rocks to deform and fail at stresses far below their short-term failure strength, and even at constant applied stress ("brittle creep"). Here we present a new micromechanical model describing time dependent brittle creep of water-saturated rocks under triaxial stress conditions. Macroscopic brittle creep is modelled on the basis of microcrack extension under compressive stresses due to sub-critical crack growth. The incremental strains due to the growth of cracks in compression are derived from the sliding wing crack model of Ashby and Sammis (1990). Crack length evolution is computed from Charles' power law description of stress corrosion crack growth. The macroscopic strains and strain rates computed from the model are non-linear and compare well with experimental results obtained on granite, low porosity sandstone and basalt samples. Primary creep (decelerating strain rate) corresponds to decelerating crack growth, due to an initial decrease in stress intensity factor with increasing crack length in compression. Tertiary creep (accelerating strain rate as failure is approached) corresponds to an increase in crack growth rate due to crack interactions. Secondary creep, with apparently constant strain rate, arises as merely an inflexion between these two end-member phases. The strain rate at the inflexion point can be estimated analytically as a function of model parameters, effective confining pressure and temperature conditions, which provides an approximate creep law for the process. The creep law is used to infer the long term differential stress as a function of depth in the upper crust for tectonic loading rates: sub-critical cracking induces an offset of the rock strength, which is equivalent to a decrease in cohesion. For porous rocks, the competition between sub-critical crack growth and pressure solution has also been investigated, and brittle creep appears to be the dominant mechanism only at high ($> 10^{-10}$ s^{-1}) strain rates and shallow (< 1 km) depth in the crust.