Geophysical Research Abstracts
Vol. 17, EGU2015-7140, 2015
EGU General Assembly 2015

The role of fluids on the brittle-ductile transition in the crust

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To characterize stress and deformation style at the base of the seismogenic zone we investigate how the mechanical properties of fluid-rock systems respond to variations in temperature and strain rate. The role of fluids on the processes responsible for the brittle-ductile transition in quartz-rich rocks has not been explored at experimental conditions where the kinetic competition between microcracking and viscous flow is similar to that expected in the Earth. Our initial analysis of this competition suggests that the effective pressure law for sliding friction should not work as effectively near the brittle-ductile transition (BDT) as it does at shallow conditions. Our motivation comes from three observations. First, extrapolation of quartzite flow laws indicates the brittle-ductile transition (BDT) occurs at $\sim$300 °C at geologic strain rates for conditions where fault strength is controlled by a coefficient of friction of $\sim$0.6 with a hydrostatic pore-fluid pressure gradient. Second, we suggest that the preservation of relatively high stress microstructures indicates that the effective stress law must sometimes evolve rapidly near the BDT. There is abundant evidence for the presence of fluids during viscous deformation of mylonites (e.g., recrystallization and redistribution of micas, dissolution and reprecipitation of quartz). The relatively high viscous stresses inferred from these microstructures are incompatible with the standard effective stress relationship. A similar “paradox” is evident at experimental conditions where viscous creep is studied in the laboratory. In this case, the presence of fluid (which should produce low effective stress) does not promote localized brittle failure, even though these experiments are conducted under undrained conditions. Third, experiments on partially molten rocks illustrate viscous creep behavior during both drained compaction and undrained triaxial deformation tests, even though the melt pressure approaches or equals the confining pressure (from which one would predict stresses much lower than observed by applying the conventional effective pressure law). We developed a simple physically-motivated contact-scale model that qualitatively explains these observations. Our model provides new insights for understanding stress, deformation and seismicity near the brittle-plastic transition and in the broad transition zone that occurs on the deep segments of some plate boundary faults. The model also provides a context to investigate how the effective stress law evolves with variations in lithology (through its effects on asperity rheology), tectonic environment, strain rate and the evolution of pore-fluid pressure.