Geophysical Research Abstracts
Vol. 18, EGU2016-18293, 2016
EGU General Assembly 2016
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Experimental Studies of Dynamic Fault Weakening Due to Thermal Pressurization of Pore Fluids

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High-velocity friction experiments and geophysical observations suggest that mature faults weaken dramatically during seismic slip. However, while many coseismic weakening mechanisms have been proposed, it is still unclear which mechanisms are most important or how the efficiency of weakening varies within the seismogenic zone. Thermal pressurization is one possible coseismic weakening mechanism driven by the thermal expansion of native pore fluids, which leads to elevated pore pressures and significant coseismic weakening. While thermal pressurization has been studied theoretically for many decades, and invoked in recent earthquake simulations, its activation in laboratory experiments has remained elusive. Several high-speed friction studies have yielded indirect evidence for thermal pressurization, yet none has directly linked with existing theoretical models or the relevant physical parameters, such as permeability, slip, and slip rate, that control the weakening rate. To fill this gap, we are conducting thermal pressurization experiments on fluid-saturated, low-permeability rocks (Frederick diabase) at slip rates up to ∼5 mm/s, at constant confining pressures in the range 21–149 MPa and initial imposed pore pressures in the range 10–25 MPa. The impractically low permeability of the as-is diabase, ∼10-23 m2, is increased prior to the test by thermal cracking, yielding measured permeabilities in the range 1.3*10-18 to 6.1*10-19 m2. These values of permeability are high enough to allow sample saturation over one to several days, but low enough to confine the elevated pore pressures generated by frictional heating during rapid sliding. Our experiments reveal a rapid decay of shear stress following a step-change in velocity from 10 μm/s to 4.8 mm/s. In one test, the decrease in shear stress of ∼25% over the first 28 mm of slip at 4.8 mm/s agrees closely with the theoretical solution for slip on a plane (Rice [2006]), with an inferred slip-weakening distance of ∼500 mm, which is in the range predicted by inserting laboratory-determined rock and fluid properties into the formula for L* from Rice [2006]. In another test, steps from 10 μm/s to three different velocities (1.2 mm/s, 2.4 mm/s, and 4.8 mm/s) all fit the Rice solution with values of L* that varied systematically with velocity as predicted by the theory. Deviations from the theoretical prediction occur at displacements larger than 28 mm, since the experimental sample is not a semi-infinite half space, as assumed in the models, and heat is lost to the high-conductivity steel of the sample assembly. To our knowledge, this is the best experimental validation of thermal pressurization to date.