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Effect of fluid viscosity on fault frictional behavior

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Fluids play an important role in fault zone and in earthquakes generation. Fluid pressure reduces the normal effective stress, lowering the frictional strength of the fault, potentially triggering earthquake ruptures. Fluid injection induced earthquakes, such as in geothermal reservoir, are direct evidence of the effect of fluid pressure on the fault strength. However, the frictional fault strength may also vary due to the chemical and physical characteristics of the fluid as discussed here.

Here we performed two series of experiments on precut samples of Westerly granite to investigate the role of fluid viscosity on fault frictional behavior. In the first series, we performed 20 rotary shear experiments with the machine SHIVA (INGV, Rome) on cylindrical (50 mm external diameter), at slip rate (V) ranging from 10 μm/s to 1 m/s effective normal stress (P) of 10 MPa and pore pressure varying from 0 (i.e., dry conditions) to 2 MPa. Three different fluid viscosities were tested using pure distilled water ($\eta = 1\ mPa$·s), 40%water/60%glycerol ($\eta = 10.5\ mPa$·s) and 15%water/85%glycerol ($\eta = 109\ mPa$·s) mixtures (all reported viscosities at 20 ˚C). In agreement with theoretical argumentations (Stribeck curve) we distinguished three lubrication regimes. At low product of slip-rate per fluid viscosity ($S = \eta$·V/P < 10^{-10} mm), steady state friction coefficient (μ_{ss}) was about 0.7 and independent of both fluid viscosity and velocity (velocity neutral, or boundary lubrication regime). At intermediate products of slip-rate per viscosity (10^{-10} < S < 10^{-7} mm), steady state friction coefficient was strongly influenced by both viscosity and slip rate, with μ_{ss} dropping from ∼0.7 to ∼0.2 (velocity weakening or mixed lubrication regime). In this regime, samples underwent stick slip motion. At high product of slip-rate per fluid viscosity (S >10^{-7} mm), μ_{ss} slightly increased with increasing slip rate (hydrodynamic lubrication regime).

In the second series of experiments, we reproduced the stick-slip motion of the mixed lubrication regime. To this end, we performed direct shear experiments at 1 MPa effective normal stress, using the same fluids and at 20˚C ambient temperature. During stick-slip, the magnitude of the static stress drops were controlled by both normal stress and viscosity. When fluid viscosity was ten time higher (e.g., 40%water/60%glycerol mixture vs. pure distilled water), stress drops were 1.5 higher.

This complex response of the experimental faults to loading conditions and fluid properties highlights the need for dedicated experiments aimed at uncovering the role of pore fluid physical characteristics on earthquake nucleation and propagation.