Strength and Deformation Processes of SAFOD Gouge Deformed at Creep to Co-Seismic Rates

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The central segment of the San Andreas Fault (SAF) currently accommodates displacement by a combination of aseismic creep and recurring microseismicity. The mechanisms that cause creep and the potential for the creeping segment to host large earthquakes are unresolved questions in understanding the dynamics of the plate boundary over the long term. Fault rock recovered from approximately 2.7 km depth during the San Andreas Fault Observatory at Depth (SAFOD) program allows us to conduct rock deformation experiments to directly investigate the creep mechanisms and conditions of slip instability along the central segment of the SAF.

Triaxial and rotary shear deformation experiments were conducted on smectite-rich gouge collected from the Central Deforming Zone (CDZ) at SAFOD at rates that correspond to in-situ creep (~10^{-10} s^{-1}) and co-seismic slip (1 m/s). Frictional strength depends on rate, temperature, availability of pore water, and fabric development, all of which reflect operation of different microscopic mechanisms at high and low shear rates. Experiments reproducing the pressure, temperature and pore-water chemistry conditions at SAFOD show that, at in situ creep rates, dislocation glide in clay minerals is the rate controlling mechanism and is responsible for the low shear strength ($\mu = 0.11$), which limits the potential energy available for sustaining co-seismic frictional slip. Dynamic weakening at coseismic rates involves thermal fluid pressurization.

Our results and those of other researchers cumulatively show that the CDZ gouge is rate-strengthening at sub-seismic rates and transitions to apparent rate-weakening behavior as slip approaches co-seismic rates, and that the gouge is much weaker than quartzofeldspathic rocks at all deformation rates (Figure 1). The micromechanical processes identified from results of the deformation experiments are used to constrain and evaluate several different scaling relations between strength, critical displacement for frictional weakening, and normal stress for the CDZ gouge, and the implications of scaling relations for seismic slip along the creeping segment are discussed.

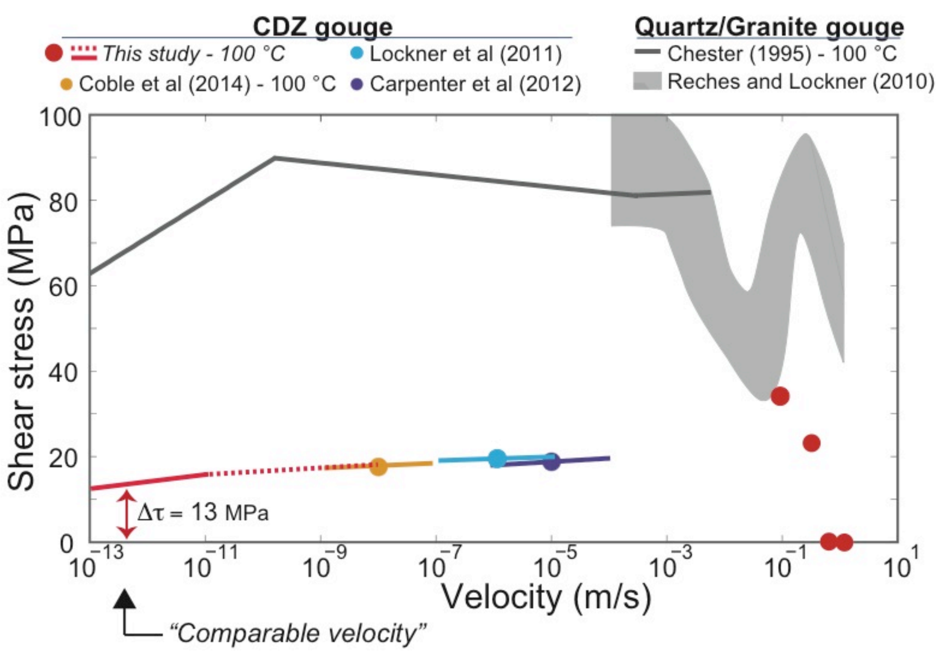

Figure 1. The shear strength of the CDZ gouge from this and previous studies; shear strength is $\tau = \mu\sigma_n$, where $\sigma_n = 120$ MPa is the normal stress at SAFOD (2.7 km depth) (Lockner et al., 2011). The strength of quartz-rich gouge is shown for comparison. 'Comparable velocity' is the laboratory velocity during the stress-relaxation experiments at which the shear strain-rate is equal to the inferred in-situ rate of 10^{-10} s^{-1}.