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The Spectrum of Fault Slip Rates, From Creep to Stick Slip in Laboratory Friction Experiments

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A wide range of slip rates have been documented in both strike-slip and subduction zone faults around the world, yet mechanisms for understanding slow and transient-slip are incomplete. Elevated pore-fluid conditions and dilatancy, coupled with rate and state friction, are possible mechanisms, however there is a paucity of data that can be used to evaluate these mechanisms under the conditions of tectonic faulting. We report on laboratory friction experiments on a variety of materials that show a range of slip behaviors between creep and stick-slip.

To explore transient fault slip we conduct both standard laboratory stick-slip experiments with constant driving velocity and creep-style experiments with constant shear stress. Experiments were conducted in the double-direct shear configuration, using rigid forcing blocks and two shear zones sandwiched between the blocks. The normal contact area is constant (10 cm x 10 cm) during shear and the initial layer thickness is 1 cm in our suite of experiments. Our experiments include detailed measurements of seismic wave speeds and elastic properties of the layers during failure. We focus on four materials with a range of frictional behaviors. Glacial till is strongly velocity strengthening, quartz powder and fine-grained sand are transitional from velocity strengthening to weakening, with stick-slip, and glass beads stick slip in all cases. Stick-slip experiments are conducted at a constant driving velocity of 20 μm/s on glass beads. Aseismic and slow slip are achieved in creep experiments, by holding shear stress constant near the frictional strength, and allowing for spontaneous acceleration associated with tertiary creep. We observe both the acceleration of slip rate during the onset of quasi-dynamic stick-slip and, in most cases, the transition back to primary and secondary creep.

We have measured properties of failure events that range from stick-slip to quasi-static and, for the same materials, the velocity dependence of friction (a-b) during stable sliding. We find a systematic relationship between failure event parameters and the rate/state friction parameter a-b. Slip event durations range from 100's of seconds for quasi-dynamic slip in glacial till to 100's of μs for glass beads. Stick slip events range from sharp, audible bangs to sub-audible groans. We quantified acoustic emissions using an accelerometer with a frequency range from 0.5 Hz to 16.5 kHz. We observe a signals that last a few μs for stick-slip and $\sim$1s in slow slip with the amplitude $\sim$50x larger in stick slip. We find that slow slip in the laboratory can be produced in several materials, independent of velocity strengthening/weakening and both in the presence and absence of fluids.