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Controls on Fault Zone Stability and the Mechanics of Slow Earthquakes

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Recent observations have shown that many plate boundary faults host modes of fault failure that release energy more slowly than regular earthquakes. Such events, including slow-slip events, slow and low-frequency earthquakes, and episodic tremor and slip, present some of the most challenging questions encountered by earthquake seismology and rock mechanics. Here we present laboratory data from a suite of carefully controlled shearing experiments designed to probe the transition between stable and unstable slip. Our results show that the boundary that demarcates the stability field of frictional sliding is more complex than previously thought, with a dependence on the rate of shearing, the effective stiffness of the system (K), and the rheologically defined frictional stiffness of the fault (K_c).

We constructed experimental faults in the double-direct shear configuration using Min-U-Sil, an angular SiO_2 powder with a mean grain size of 10μm. Each powder layer is 3mm thick prior to the application of normal load. The sample is sheared in a biaxial shearing apparatus at a constant velocity for ~50mm of shear displacement (shear strains of ~15). The stability of the system is controlled by changing the normal stress, which changes the rheologically defined critical stiffness, or by changing the forcing blocks, which modifies the loading system's stiffness. We accomplish the latter by replacing the steel central forcing block with an acrylic one to reduce the system stiffness. We have also shown that using blocks of acrylic in series with the steel blocks can produce similar destiffening effects.

Frictional theory predicts a threshold in stability defined by the case where $K = K_c$; slip will be unstable when $K < K_c$, and stable when $K > K_c$. We show that for our experimental faults, the critical stiffness ratio (K/K_c) is the overarching controlling factor that links the physics of both slow and regular earthquakes: repeating slow stick-slip events arise spontaneously when K/K_c =~1, and event duration, slip velocity, and stress drop all vary systematically as this threshold is approached. We also show that the velocity of shearing affects the stability of the system. Higher driving velocities lead to a greater tendency for stable behavior, whereas slower driving velocities are more likely to host quasi-dynamic or dynamic slip events.