Seismic Velocity Changes Across the Transition from Slow- to Fast-Frictional Sliding in Earthquake-Like Laboratory Experiments

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Abstract:
Geological and geophysical evidence shows that active tectonic faults slip at different velocities ranging from aseismic creep to fast dynamic slip. Quasi-dynamic slip behaviors have been observed in a wide range of geologic settings, including subduction zone and faults within accretionary prisms, continental transforms, during fault reactivation induced by hydraulic fracturing, and in non tectonic environments such as landslides and beneath glaciers. Although seismic transients are overwhelming, the underlying mechanism(s) that limit slip velocity evolution is still enigmatic. Here, we describe laboratory shearing experiments designed to investigate stick-slip frictional sliding on experimental faults that undergo a full spectrum of slip behaviors. We dictate the stick-slip properties by controlling the stiffness of the testing machine and matching it with the fault frictional rheology.
We observe systematic variations of the physical properties of experimental faults across the transition from stable sliding to fast, earthquake-like stick-slip. We report continuous measurements of P-wave speed (Vp) and frictional strength during the complete seismic cycle of stick-slip. In the initial phase of the seismic cycle, both slow and fast earthquakes exhibit a common evolution characterized by increasing Vp and quasi-linear elastic loading. After that, slow earthquakes show marked pre-seismic creep linked to an evident precursory decrease in Vp that coincides with a deviation of the shear stress from the quasi-linear loading trend. This behavior, which we attribute to the small force imbalance between loading stiffness and fault rheology, promotes low slip velocity and small stress drop. In contrast, fast stick-slip events exhibit limited pre-seismic creep and nearly constant Vp preceding failure. This evolution, coupled with a large force imbalance, favors rapid slip and larger stress drop. Our observations point to a continuum in fault slip behavior with the evolution from slow to fast earthquake controlled by the fault frictional properties and the state of stress of both fault and loading medium. Our results also indicate that pre-seismic fault creep favors seismic velocity reduction, suggesting that real time monitoring of active faults may be a powerful tool to detect earthquake precursors.