Laboratory Observations of Slow Earthquakes - Insights on the mechanics of slow stick-slip

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Abstract:
Recent observations have shown that fault failure modes span a wide range of slip durations and rates, from normal earthquakes, to low-frequency earthquakes and transient slow slip events, to aseismic creep. Whereas regular earthquakes are known as catastrophic failure events with rupture velocity and fault slip speed governed by friction and elastic wave speed, the processes that give rise to the broad observed spectrum of fault slip behaviors are not well understood. Limited laboratory observations and numerical studies have provided some clues about the origin of these phenomena, but key questions remain about the mechanics of slow slip and the in situ fault zone properties and conditions that dictate fault slip rates and propagation speeds of tremor and slow earthquakes. Here we present laboratory observations for shearing experiments that exhibit slip behaviors spanning the full spectrum from stable sliding to slow slip to rapid stick slip. We dictate these slip behaviors by controlling the stiffness of the loading system (k) relative to the rheologic critical stiffness of the fault (kc), which is in turn defined by the fault's frictional properties (rate dependence and critical slip distance) and the effective normal stress. Theory predicts a threshold in stability defined by the case where k= kc; slip will be unstable when k< kc, and stable when k> kc. We show that for our experimental faults, the critical stiffness ratio (k/kc) is the overarching controlling factor that links the physics of both slow and regular earthquakes. Our observations show a linear scaling of event peak slip velocity and event slip duration with the critical stiffness ratio, such that events exhibit systematically slower peak slip velocity and have longer durations as the stability threshold is approached. Other hypotheses for slow slip include mechanisms that suppress rapid slip through poro-elastic effects or complex frictional rate dependence, including dilatancy hardening and so-called "designer friction laws". We note that these hypotheses are in fact largely derivative of our results, in the sense that they all influence effective stress and/or the critical rheologic stiffness of the fault. We believe that this simple framework can help explain the broad range of geologic environments in which slow earthquakes are observed.