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Initiation of slow slip events: Insights from plate-rate shearing experiments and rate-and-state friction

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Slow slip events (SSEs) are recognized as an important form of fault slip, due to their potential to interact with ordinary earthquakes and to provide information on fault slip behavior. Some key questions regarding SSEs include how they initiate, what the underlying mechanisms of their initiation are, and whether they should be considered to be frictional instabilities. Ultra slow, plate-rate friction experiments conducted at cm/yr driving rates and low pressures and temperatures can generate spontaneously occurring laboratory SSEs. Using a dataset of laboratory SSEs observed in 11 natural samples from major fault zones, measurements of the slip velocity history and stress drop can be compared with rate-and-state-dependent friction (RSF) parameters measured during velocity step tests to investigate the nature of SSEs.
Most of the samples which produce laboratory SSEs exhibit velocity-weakening friction, allowing critical stiffness analysis by comparing the RSF parameters with the known apparatus stiffness. An alternative method for measuring critical stiffness is employed, which involves directly measuring the unloading stiffness of the sample during SSE stress drops. Despite frequent velocity-weakening friction and measureable SSE stress drops, most of the samples do not satisfy the condition for frictional instability. Rather, the data show that the SSEs are better characterized as stably accelerating slip events, although this condition is also rarely satisfied.
A general feature of the laboratory SSEs is that the slip velocity reduces below the driving velocity prior to the stress drop, signaling partial locking, before accelerating to a peak velocity that is several times the driving velocity. The complete dataset shows a clear inverse relationship between pre-SSE and peak slip velocity. Considering these and other observations, these laboratory SSEs may be explained by a conceptual model within the framework of RSF laws, where a Dieterich-type healing mechanism is invoked to explain the partial locking. The partial locking causes a slip deceleration defining a healing-dominated departure from steady state. Subsequent failure of the partially-locked fault drives the system to a slip-dominated departure from steady-state, defined by stably accelerating slip and SSE stress drop. This highlights the potential importance of frictional healing over long timescales for SSEs and fault slip behavior in general.