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Observations of slip behavior in plate-rate laboratory friction experiments

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Much of what we understand regarding fault slip behavior on plate-boundary faults is based on laboratory friction experiments conducted at a wide range of driving velocities, from slip rates of μm/s to over 1 m/s. Less data exists for shearing experiments driven at slow velocities approximating plate tectonic rates on the order of cm/yr (nm/s). Previous work using International Ocean Drilling Program samples from the Tohoku region at the Japan Trench, which experienced the 2011 M9 Tohoku earthquakes, showed that shearing at an imposed rate of 8.5 cm/yr produced small stick slips and slow slip events in the laboratory. The Tohoku fault zone material is mostly composed of the frictionally weak clay mineral smectite; however weak phyllosilicates are expected to exhibit velocity-strengthening friction favorable for stable creep rather than unstable or transient slip events. Therefore, the observations in the Tohoku material suggest that very slow forcing may be favorable for slip instability not necessarily predicted by experiments at higher velocity.
We report here on results of laboratory friction experiments using both natural and analogue fault gouge materials, conducted at cm/yr driving velocities. At these slow rates, we observe a wide range of slip behaviors. Consistent stick-slip with large stress drops is observed for several high-friction materials such as Westerly granite and Carrara marble. Behavior is more variable for weaker materials; stick-slip with smaller stress drops is observed for kaolinite, but no instabilities, either slow or fast, are observed in the illite-rich Rochester shale. For natural samples, chalk samples from offshore Costa Rica recovered during the Ocean Drilling Program exhibit stick-slip, consistent with the results for marble. Hemipelagic clay from the same region is weaker and exhibits slow events, similar to the Tohoku fault samples. Slow stick-slip is also observed in a sample of the Alpine Fault from New Zealand, sampled during the Deep Fault Drilling Project. Collectively, our results demonstrate that plate-rate shearing rates in the laboratory span the full range of frictional phenomena, but with a tendency toward more unstable slip behavior that better replicates seismicity on major faults in the natural system.