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Frictional slip instability in plate-rate laboratory experiments: Observations and mechanisms

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Earthquake slip that breaches the Earth's surface represent tremendous hazard, not only from the earthquake itself but also from associated landslides and/or tsunami. Evaluating the possibility of near-surface earthquake slip requires knowledge of how frictionally stable shallow fault materials are. In general, laboratory friction experiments have shown that weak phyllosilicates, which are commonly found in the shallow portions of major faults, tend to be stable and creep. Frictional instability which is favorable for earthquake slip tends to be observed in stronger materials. However, this framework is based primarily on experimental studies performed at intermediate driving velocities of roughly a μm/s to mm/s range. This is much faster than plate convergence rates of several cm/yr, or on the order of nm/s, which represent the natural driving condition on major faults. In this study, we investigate the frictional behavior of natural fault zone materials recovered by scientific drilling projects targeting subduction zones (Japan Trench, Nankai Trough, Costa Rica, Barbados, Cascadia), continental strike-slip faults (San Andreas Fault, Alpine Fault), and a detachment normal fault (Woodlark basin). Our results demonstrate that under naturally slow driving rates, velocity-weakening friction is frequently observed for weak fault materials (friction coefficient < 0.5). This indicates a tendency for unstable slip which was not recognized at intermediate slip velocities employed in typical laboratory experiments.

Further evidence of frictional instability is experimentally-observed slow slip events (SSE) at cm/yr driving rates. The SSE we observe exhibit stress drops in the range of 20-870 kPa and peak slip velocities in the range of 8-84 cm/yr. We observe that SSE with larger stress drops consistently tend to reach higher peak slip velocities, which is consistent with SSE being slow frictional instabilities. Larger effective normal stress also correlates with larger stress drops and higher peak slip velocities. The appearance of frictional instability at very slow driving rates suggests that it arises from a process that occurs over timescales much longer than the duration of typical laboratory experiments. Previous experimental and theoretical work has suggested that time-dependent frictional strengthening (or "frictional healing") correlates with frictional instability. Limited data from healing experiments at very long hold times (corresponding with the very slow driving velocities we utilize) indicate advanced healing at longer timescales, which may explain why frictional instability in weak materials requires much slower driving rates.