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The frictional properties of faults at shallow depths: implications for rupture propagation.

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Most synoptic models of faults assume the presence of a shallow stable, velocity-strengthening aseismic region due to the presence of incohesive gouges, poorly lithified continental sediments (continental faults) and phyllosilicate-rich rocks (accretionary prisms at subduction zones). The near-surface portions of faults are therefore viewed as effective energy sinks with the potential to arrest/slow down the propagation of earthquakes, preventing them from reaching the surface. However, recent events, such as the 2009 Mw 6.3 L'Aquila and 2011 Mw 9.0 Tohoku-Oki earthquakes, have demonstrated that moderate/large co-seismic ruptures can propagate to the surface causing vast damage and destructive tsunamis.

In order to better understand rupture propagation at shallow depths, we investigated the frictional properties of a range of bedrock lithologies, typical of the oceanic (gabbros) and continental crusts (granite, limestone), together with phyllosilicate-bearing lithologies typical of subduction zones and continental sedimentary deposits. Laboratory experiments have been performed in a low to high velocity rotary shear apparatus, on granular materials with grainsize up to 200 μm, under dry, water- and brine-saturated conditions, at slip rates ranging from 10 μm/s up to 1 m/s, with normal loads up to 18 MPa and displacements up to 1 m.

Velocity step experiments performed at sub-seismic slip rates (10-100 μm/s) on dry, water- and brine-saturated granite and calcite rocks show that velocity strengthening behaviour evolves to velocity-neutral/-weakening behaviour due to slip localization attained after critical displacements of a few tens to hundreds of mm. The critical displacement value is inversely proportional to the applied normal load. Dry, water- and brine-saturated gabbros show velocity-weakening behaviour and slip localization regardless of the displacement attained and applied normal load. Dry, water- and brine-saturated phyllosilicate-rich gouges show velocity-strengthening behaviour for any applied displacements and normal loads. Dry continental sediments show initial velocity-strengthening behaviour evolving to velocity-neutral/-weakening behaviour for increasing displacement. At low normal loads (1 MPa), water-saturated continental sediments show velocity-strengthening behaviour, regardless of the displacement attained, and an evolution to velocity-weakening behaviour with increasing displacement at higher normal loads (18 MPa). Conversely, brine-saturated continental deposits always show velocity-strengthening behaviour, regardless of the displacement attained and applied normal load. Cyclic slide-hold-slide experiments show that, after sliding at sub-seismic slip rates, static friction increases with time according to a logarithmic relationship (fault healing) for almost all tested materials under dry, water- and brine-saturated conditions. The only exceptions are organic-rich oil-mature black shales, which show a decrease in static fault friction with time (negative fault healing). The positive and negative healing rates tend to increase under water- and brine-saturated conditions, respectively.

Our experimental results suggest that the frictional stability and healing rates of shallow fault patches will be controlled by factors such as depth/thickness (normal load), mineralogical composition, organic matter content, presence/composition of fluids, displacement and slip history (slip localization). Our findings may explain many of the discrepancies observed between the behavior of real earthquakes and that predicted by fault zone models, which rely on the simplistic assumption of a uniform, stable sliding frictional behavior at shallow depths.