Seismic and transient slip characteristics of frictional-viscous shear zones in subduction environments

Whitney Behr and Taras Gerya
Department of Earth Sciences, ETH Zürich, Geological Institute, Earth Sciences, Zurich, Switzerland (wbehr@ethz.ch)

The deep roots of subduction megathrusts exhibit aseismic slow slip events, commonly accompanied by tremor and low-frequency earthquakes. Observations from exhumed rocks suggest that the deep subduction interface is a shear zone in which frictional lenses are embedded in a weaker, distributed viscous matrix deformed under high fluid pressures and low stresses. Here we use numerical models to explore the transient slip characteristics of finite-width frictional-viscous shear zones. Our model formulation utilizes an invariant form of rate- and state-dependent friction (RSF) and simulates earthquakes along spontaneously evolving faults embedded in a 2D continuum. The setup includes two elastic plates bounding a viscoelastoplastic shear zone (subduction interface) with inclusions (clasts) of varying sizes, aspect ratios, distributions and viscosity contrasts with respect to the surrounding matrix. The entire shear zone exhibits the same velocity-weakening RSF parameters, but the low viscosity matrix in the shear zone has the capacity to switch between RSF and linear viscous creep as a function of its local viscosity and stress state. Results show that for a range of matrix viscosities near a threshold viscosity (representative of the frictional-viscous transition), viscous damping and stress heterogeneity in these shear zones both 1) sets the ‘speed limit’ for earthquake ruptures that nucleate in clasts such that they propagate at velocities similar to observed slow slip events; and 2) simultaneously permits the transmission of slow slip from clast to clast, allowing slow ruptures to propagate substantial distances over the model domain. For reasonable input parameters, modeled events have moment-duration statistics, stress drops, and rupture propagation rates that match natural slow slip events. Events resembling very low-frequency earthquakes appear to be favored at high clast densities and low matrix viscosities, whereas longer duration, higher-magnitude slow slip events are favored at intermediate clast densities and near-threshold viscosities. These model results have potential to reconcile geophysical constraints on slow slip phenomena with the exhumed geological record of the slow slip environment.