Laboratory insights into the wide range of slip behavior on the Tohoku plate boundary megathrust

*Matt Ikari[1], Yoshihiro Ito[2,4], Kohtaro Ujiie[3,4], Achim Kopf[1]

1. MARUM, University of Bremen, 2. Kyoto University, 3. University of Tsukuba, 4. JAMSTEC

The plate boundary megathrust at the Japan Trench is now well known for the 2011 M_w = 9Tohoku-Oki earthquake, which generated an extraordinarily large amount of coseismic slip (several 10's of meters) at the seafloor and an enormous tsunami. This region has also experienced slow slip events which occurred within the eventual rupture area of the 2011 Tohoku earthquake. This shows that the Japan Trench can exhibit a wide range of fault slip behaviors, and understanding of role of slow earthquakes as they relate to the occurrence of both megathrust earthquakes and tsunami earthquakes is necessary to mitigate these disasters in the near future.

We use laboratory shearing experiments to characterize the frictional behavior of the Japan Trench megathrust. Samples of the plate boundary fault zone in the Tohoku region were recovered during Integrated Ocean Drilling Program Expedition 343, the Japan Trench Fast Drilling Project (JFAST). The JFAST borehole is located ~7 km from the Japan Trench axis, within the region of largest coseismic slip during the 2011 Tohoku earthquake. We use powdered gouge samples of the plate boundary fault zone in experiments conducted in a single-direct shear apparatus. We explore a range of shearing conditions which include effective normal stresses up to 19 MPa, and slip velocities as low as 2.7 nm/s, equal to the plate convergence rate at the Japan Trench (8.5 cm/yr). By employing both constant velocity and velocity-stepping tests, we evaluate both the velocity- and slip-dependence of friction.

Experiments at the plate convergence rate generate discrete strength perturbations which are interpreted to be laboratory-generated slow slip events (SSE). At in-situ stresses (7 MPa) these events have stress drops of ~3-7 % (50-120 kPa) that occur over several hours, and peak slip velocities that reach 10-25 cm/yr. Increasing normal stresses to 19 MPa produces SSE with stress drops of ~12% and peak slip rates of ~50 cm/yr. Velocity-stepping tests reveal frequent instances of velocity-weakening frictional behavior, suggesting that the Tohoku gouge has the ability to nucleate slip instabilities or quasi-instabilities at very shallow depth (~800 mbsf) and very close to the trench, and that the tendency for slip instability should increase downdip.

Because the shallow Tohoku gouge is prone to generating slow slip events, we speculate that how the fault reacts when perturbed may depend on the style of deformation that may be occurring at that particular time. To explore these effects, we analyze the slip dependence of friction induced by changes in slip velocity, using slip velocities relevant to specific slip behaviors in the Tohoku area. We report that for the Tohoku fault zone samples, increasing sliding velocity to above 1 μm/s can induce a change from steady-state friction or slip hardening friction to slip-weakening frictional behavior. In the Japan Trench region, two instances of slow fault slip were observed to be ongoing at the downdip edge of the mainshock coseismic slip zone. One of these is an SSE with a slip velocity of 0.1 μm/s, and one is afterslip of the largest Tohoku earthquake foreshock with a slip velocity of ~2 μm/s. Our measurements show that increasing slip velocity from SSE rates to 140 μm/s (the maximum velocity in our experiments) does not induce slip-weakening friction; however steps from faster rates consistent with afterslip to 140 μm/s do induce slip weakening. This suggests that the portion of the fault undergoing afterslip was likely experiencing active weakening, which may have facilitated the large coseismic slip during the mainshock of the Tohoku-Oki earthquake.

Keywords: Subduction zone, Fault, Friction, Slow Slip, Earthquake

