Implications of possible laboratory-observed tremor in samples from the Tohoku plate boundary megathrust

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Following the 2011 M_w = 9 Tohoku-Oki earthquake which generated an extraordinarily large amount of coseismic slip (several 10’s of meters) at the seafloor and an enormous tsunami, several studies have shown that the Japan Trench can exhibit a wide range of fault slip behaviors at shallow depths. This includes slow slip events, tremor, and afterslip of large earthquakes, which are important for understanding the mechanics of shallow megathrusts as they relate to the occurrence of both megathrust earthquakes (Tohoku) and tsunami earthquakes such as the 1896 Meiji Sanriku earthquake farther north. To address the slip behavior of the shallow Tohoku megathrust, several laboratory shearing experiments have been performed on samples of the plate boundary fault zone recovered from within the region of largest coseismic slip during the 2011 Tohoku-Oki earthquake. The samples come from a borehole located ~7 km from the Japan Trench axis, drilled during Integrated Ocean Drilling Program Expedition 343, the Japan Trench Fast Drilling Project (JFAST).

We present the results of laboratory experiments using a single-direct shear device, at room temperature, effective normal stresses of 7-19 MPa and driving velocities from 2.7 nm/s (the Japan Trench plate convergence rate of 8.5 cm/yr) to 10 μm/s (86 cm/day). As reported in previous studies, these experiments produced slow slip events (SSE) with stress drops of ~3-15% of the shear strength and peak slip velocities of ~10-50 cm/yr, which both slightly increase with increasing effective normal stress (or simulated depth). New analyses show that these experiments also produce small stick-slip events that are distinct from the SSEs, and do not occur at the same time as the SSEs. These events are highly regular and repetitive, have smaller stress drops of ~0.5-2% and faster slip velocities on the scale of μm/s. Therefore, we interpret these events to be analogous to repeating very low frequency earthquakes that produce a tremor signal.

We observe that the SSEs and tremor events occur under different conditions. Whereas the SSEs are only observed during steady-state shearing at the plate rate of 2.7 nm/s, the small stick slips, or tremors at a range of velocities from 2.7 nm/s to 10 μm/s. However, when driven at the plate rate the tremor events only appear during a transient loading phase immediately following a drop in velocity following the faster “run-in” at 10 μm/s, and do not appear during steady-state sliding at the plate rate. At higher driving velocities of 0.1-10 μm/s, the tremor events appear consistently during steady-state shearing but not during any periods of transient shear stress changes. These differences suggest that the SSEs and tremor events have a different mechanism of origin, and that the Tohoku fault zone material is capable of producing different slip events under the same ambient conditions, but different forcing conditions. We speculate that the SSEs originate from the frictional properties of the material at plate-rate driving conditions, and that elevates slip rates during the SSEs may drive tremor. Also, the appearance of tremor without accompanying slow slip may provide information on the loading state of the fault. Ongoing work includes using the measurements of the laboratory tremors to constrain the characteristics of the fault slip events which cause the tremor observed in ocean bottom seismometer networks near the Japan Trench.

Keywords: Tohoku-Oki Earthquake, Slow Slip, Tremor, Friction Experiments, Subduction Zone