Laboratory-observed slow frictional slip instabilities in Tohoku plate boundary fault zone samples

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The plate boundary megathrust at the Japan Trench has exhibited remarkable slip behavior that has drastically changed our understanding of fault slip behavior. The 2011 Tohoku-Oki earthquake produced an extraordinarily large amount of coseismic slip (several 10’s of meters) up to the seafloor, on a portion of the megathrust previously thought to be aseismic. Additionally, this region is also known to generate slow earthquakes. One of these slow earthquakes occurred with the rupture area of the 2011 Tohoku earthquake; this event was observed one month before the 2011 earthquake and was likely ongoing during the earthquake. This shows that the Japan Trench megathrust does not exhibit strictly stable slip and thus failure can occur in a variety of styles. During Integrated Ocean Drilling Program Expedition 343, the Japan Trench Fast Drilling Project (JFAST), samples of the plate boundary fault zone in the Tohoku region were recovered ~7 km from the Japan Trench axis, within the region of largest coseismic slip during the 2011 Tohoku earthquake. We sheared these samples in laboratory friction experiments utilizing a slip velocity of 2.7 nm/s, equal to the convergence rate between the Pacific and North American plates (85 mm/yr). One key observation is that infrequent strength perturbations occurred which are interpreted to be laboratory-generated slow slip events (SSE). For intact samples, these events have stress drops of ~50-120 kPa that occurs over several hours. The stress drop matches the estimated stress drop of the SSE that occurred prior to the 2011 Tohoku earthquake. Peak slip velocities of the laboratory SSE reach 10-25 cm/yr, comparable to observations in natural subduction zone SSEs worldwide. Displacement records indicate a slip deficit accumulation prior to the laboratory SSEs which is recovered during the subsequent stress drop. The laboratory SSEs tended to occur more frequently in intact samples rather than powdered samples, suggesting that the intense scaly fabric is favorable for the SSEs. Velocity-stepping tests also reveal velocity-weakening frictional behavior, suggesting that the laboratory SSEs are slip instabilities or quasi-instabilities. This is supported the observation that in powdered samples, very large SSEs appear at 16 MPa effective normal stress whereas they are mostly absent at 7 MPa. This is consistent with critical stiffness theory, in which increased effective normal stress is associated with an increased likelihood of slip instability.

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