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Worn fault surfaces and foreshocks: Modelling observed precursory seismicity in the laboratory with rate and state friction

Percy Eliel Gálvez Barrón (1,3), Paul Selvadurai (2), Ben Edwards (4), Thessa Tormann (5), Stefan Wiemer (2), and Steven Glaser (6)

(1) ETH Zurich, Institute for Geophysics, Seismology and Wave Physics, Switzerland, (3) King Abdullah University of Science and Technology, Thuwal, Saudi Arabia, (2) ETH Zurich, Institute for Geophysics, SED, Switzerland, (4) Department of Earth, Ocean and Ecological Sciences, University of Liverpool, Liverpool, United Kingdom, (5) Swiss Federal Institute of Technology Zurich, Zurich, Switzerland, (6) Civil and Environmental Engineering, University of California, Berkeley, California, USA

The study of large megathrust earthquakes have greatly benefited from the growing academy of geodetic instruments and methodologies. Large events appear to exhibit premonitory slow slip that persists over long time (years) and large lengths scales (kms). Studies have shown that these regions are prone to foreshocks, which, if better understood, could provide crucial information about the mainshock. Conditions that lead to foreshocks, or their location relative to the slow slip region, are currently impossible to predict with a degree of certainty. Moreover, once a foreshock rupture begins, little is known regarding possible traits in their seismic signatures that help us explain why they arrest and do not cascade-up into a 'mainshock'. Field observations of earthquakes, show that the ruptures begin to expand in a crack-like manner, accelerating outwards to a critical velocity, whereby they (may) transition to a pulse-like dynamic rupture. Whether a rupture transitions from a crack-like to pulse-like rupture mechanism is not well understood and may depend on numerous factors such as heterogeneous presence of barriers and asperities, which could help us explain foreshock behaviour.

We investigated a laboratory direct shear experiment where a frictional fault was formed by pressing two mature (worn) surfaces of poly(methyl methacrylate) together, then subjecting it to shear, until a 'stick-slip' failure occurred. Prior to failure, spontaneous ruptures were found to nucleate within a region of accelerated slip, but arrested locally, on the faulting surface. A concerted study employed standard seismological tools to measure source properties, such as, magnitude, source radius and static stress drop.

To reconcile these observations, we studied the postmortem surfaces and found that the worn fault displayed a clear bimodal Gaussian distribution of surface height. This is indicative of the existence of a preferentially smooth (polished) surface that was susceptible to rupture nucleation. This unique distribution was determined to be a proxy for a local description of the critical slip distance used in numerical calculation performed in a Quasi-DYNamic earthquake simulator (QDYN, Luo et al., 2017). Numerical calculations were validated by their ability to match the seismologically determined source properties. The validated model allowed us to study: (1) how the foreshocks initiated, (2) why they sometimes arrested, (3) their moment rate functions and (4) their spatial and temporal relationship to the hypocenter of other foreshocks and, more importantly, the impending mainshock.