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On the scale dependence in the dynamics of rupture

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Potential energy stored during the inter-seismic period by tectonic loading around faults can be released through earthquakes as radiated energy, heat and rupture energy. The latter is of first importance, since it controls both the nucleation and the propagation of the seismic rupture. On one side, the rupture energy estimated for natural earthquakes (also called Breakdown work) ranges between 1 J/m^2 and tens of MJ/m^2 for the largest events, and shows a clear slip dependence. On the other side, recent experimental studies highlighted that at the scale of the laboratory, rupture energy is a material property (energy required to break the fault interface), limited by an upper bound value corresponding to the rupture energy of the intact material (1 to 10 kJ/m^2), independently of the size of the event, i.e. of the seismic slip.

To reconcile these contradictory observations, we performed stick-slip experiments, as an analog for earthquakes, in a bi-axial shear configuration. We analyzed the fault weakening during frictional rupture by accessing to the on-fault (1 mm away) stress-slip curve through strain-gauge array. We first estimated rupture energy by comparing the experimental strain with the theoretical predictions from both Linear Elastic Fracture Mechanics (LEFM) and the Cohesive Zone Model (CZM). Secondly, we compared these values to the breakdown work obtained from the integration of the stress-slip curve. Our results showed that, at the scale of our experiments, fault weakening is divided into two stages; the first one, corresponding to an energy of few J/m^2, coherent with the estimated rupture energy (by LEFM and CZM), and a long-tailed weakening corresponding to a larger energy not observable at the rupture tip.

Using a theoretical analysis and numerical simulations, we demonstrated that only the first weakening stage controls the nucleation and the dynamics of the rupture tip. The breakdown work induced by the long-tailed weakening can enhance slip during rupture propagation and can allow the rupture to overcome stress heterogeneity along the fault. Additionally, we showed that at a large scale of observation the dynamics of the rupture tip can become controlled by the breakdown work induced by the long-tailed weakening, leading to a larger stress singularity at the rupture tip which becomes less sensitive to stress perturbations. We suggest that while the onset of frictional motions is related to fracture, natural earthquakes propagation is driven by frictional weakening with increasing slip, explaining the large values of estimated breakdown work for

natural earthquakes, as well as the scale dependence in the dynamics of rupture.