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Earthquake nucleation scaling from laboratory to Earth

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Migrating foreshock sequences along major plate boundaries and geodetic transient anomalies have been interpreted as indicators of aseismic creep for days to months prior to the initiation of earthquakes. In other cases no significant precursory activity is detected, even at well-instrumented sites, suggesting an abrupt rupture initiation. Both the nucleation size (e.g. Rice and Ruina's h^*_{RR} or Andrew's L_c) or its duration can be highly variable. Here we analyse the scaling of nucleation and the controls on stick-slip instability based on a review of recent laboratory experimental results. (1) Rupture propagation experiments on smooth model faults show a two-phase nucleation process with variable size and duration depending on loading rate, normal stress and frictional parameters. These results can be reproduced by numerical models incorporating rate-and-state friction laws, and can be up-scaled to simulate the nucleation process of crustal earthquakes. We used frictional properties from samples of the San Andreas Fault Observatory at Depth (SAFOD) to model the nucleation phase for magnitude$\sim$2 repeating earthquakes at a 2.8-km depth. We predict that the nucleation could be detectable a few hours before the earthquake by strain measurements in the existing borehole. (2) An alternative set of experiments on rough model faults, instead, shows that initiation of rupture is primarily controlled by the size and the amount of heterogeneity induced by the fault topography and its interplay with the normal stress. In this case the onset of stick-slip is not predicted by the stability analysis within the rate-and-state framework, but rather by energy considerations more akin to Griffith's criterion in the presence of flaws. Although these two sets of experimental observations and their modelling are difficult to reconcile, they may be representative end members of earthquake faults with different degrees of heterogeneity.