Dynamic Rupture Processes during Stick-slip Experiments in Westerly Granite

François X. Passelègue
Laboratoire de Géologie, Ecole Normale Supérieure, Paris

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Since the proposal by Brace and Byerlee [1966] that the mechanism of stick-slip is similar to earthquakes, many experimental studies have been conducted in order to improve the understanding of rupture mechanics. Here, we report the results of macroscopic stick-slip events in saw-cut Westerly granite samples deformed under controlled upper crustal stress conditions in the laboratory. Experiments were conducted under triaxial laoding ($\sigma_1>\sigma_2=\sigma_3$) at confining pressures ranging from 10 to 100 MPa. The angle between the fault plane and the maximum stress (σ_1) was imposed to be equal to 30°. Usually a dual gain system, a high frequency monitoring array, recorded the microseismicity during stick-slip sequences and the particle accelerations during macroscopic instabilities. While strain, stress and axial shortening were measured until 100 Hz sampling rate, we also recorded for the first time the dynamic stress changes during macroscopic rupture using dynamic strain gages located close to the fault plane (10 MHz sampling rate).

We show that increasing the normal stress acting on the fault plane (i) increases the intensity of foreshock activity prior to the main rupture, (ii) increases the friction along the fault plane, (iii) increases the seismic slip, and (iv) induces the transition from sub-Rayleigh to supershear ruptures [Passelègue et al., 2013]. In addition, after demonstrating that our stick-slip instabilities exhibit a purely slip weakening behavior, we estimated the rupture processes parameters including the size of the breakdown zone (R), the slip-weakening distance (D_c), the energy rate (F) and the fracture energy (G). We compare our results with linear elastic fracture mechanics and previous experimental studies.

In all experiments, we observed an exponential increase in the amount of precursory slip prior to the mainshock. While most of the precursory slip is aseismic under low normal stress conditions, the experimental fault evolves like an asperity model at higher normal stress, where most of the precursory slip is seismic, in agreement with our acoustic records. This evolution in the precursory behavior is explained by (i) the increase in the value of G required to fail the entire fault which continuously increases with the normal stress and (ii) the increasing normal stress reducing the critical size of the nucleation, allowing small asperities (like minerals) to become seismic. Under high normal stress, both slip evolution and foreshock activity follow an exponential law, in agreement with previous experimental work and field observations.

Finally, the dynamic stress drop is almost complete at high normal stresses with dynamic friction drop ranging from 0.5 to 0.7. These results are consistent with steady-state friction coefficients inferred from high velocity friction tests and with the onset of melting, which was confirmed by our post mortem microstructural analysis (XRD, SEM, TEM). These results show that weakening mechanisms are activated after only 80 μm of slip, suggesting that, at least at the scale of asperities, the resulting dynamic stress drop could be much larger than current seismological estimates. In addition, we demonstrate that the radiation efficiency decreases with the dynamic friction coefficient (i.e. the amount of slip), suggesting that rupture processes become more dispersive under high normal stress conditions.