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High-Velocity Frictional Properties of Westerly Granite and the Role of Thermal Cracking on Gouge Production

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With the advent of high-velocity shear apparatus, several experimental studies have been conducted in recent years improving our understanding of fault friction at seismic slip rates (0.1-10 m/s). Here, we present the results of a series of tests conducted on Westerly granite, at INGV Roma, on a Slow to HIgh Velocity Apparatus (SHIVA), coupled with a high frequency monitoring (4MHz sampling rate). Experiments were conducted under normal stress (σn) ranging from 5 to 20 MPa and at sliding velocities (V) comprised between 3 mm/s and 3 m/s. Additional experiments were conducted in the presence of pore fluid at equivalent effective normal stress.
In dry conditions, two friction drops are observed. The first drop is independent of the normal stress and occurs when V become higher than a critical value (Vc$\approx$0.15 m/s). The second friction drop occurs after a critical slip weakening distance which decreases as a power law with the power density (τV). The first, abrupt, drop is explained by flash heating and weakening mechanism while the second, smooth, drop is due to the formation and growth of molten patches on the fault surface. In wet conditions, only the second drop of friction is observed.
Average values of the fracture energy are independent of normal stress and sliding velocity at V > 0.01 m/s. However, measurements of elastic wave velocities travelling through the fault strongly suggest that higher damage is induced for 0.1 < V < 0.3 m/s for a same finite displacement. This observation is also supported by acoustic emission (AE) recordings. Indeed, most the AEs are recorded after the initiation of the second friction drop, that is, once the fault surface temperature is high. Some AEs are even recorded few seconds after the end of the experiments, suggesting they may be due to thermal cracking induced by heat diffusion. In addition, the presence of pore fluid pressure (water) delayed the apparition of AEs at equivalent effective pressure, supporting the link between AEs and the production and diffusion of heat.
Using the thermo-elastic crack model developed by Fredriech and Wong 1986, we demonstrate that damage can indeed be induced by heat diffusion. Our theoretical prediction explains well both the experimental results and the microstructures, which suggests that a part of heat is converted into fracture energy. Finally, we show that this new fracture energy term is non-negligible in the energy balance so that thermal cracking induced during seismic slip, in dry or wet conditions, could play a key role both in the evolution of the physical properties of the slip zone and the high frequency radiation. For instance, a strong increase in the permeability may be expected while large dilatancy strengthening effects could promote the transition between crack-like and pulse-like ruptures.