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The role of gouge and temperature on flash heating and its hysteresis

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Geophysical observations such as the low heat anomaly suggest that mature faults weaken significantly during earthquakes. These observations are supported by high-velocity friction experiments on natural samples that show dramatic weakening at typical seismic slip rates. One proposed weakening mechanism is the breakdown of frictional contacts at a critical weakening temperature, a process known as flash heating. For bare surface sliding *Rice* [2006] showed that heat generation at frictional contacts triggers flash heating above a critical weakening velocity V_w of ~ 0.1 m/s. However, all faults generate a gouge layer at least a few millimeters wide, and the efficiency of flash heating in gouge is still unknown.

Building on *Rempel* [2006] and *Beeler et al.* [2008], we model flash heating in gouge by assuming that the total slip rate applied across the deforming zone is shared between multiple frictional contacts. Solving for the contact temperature we show that flash heating occurs when the strain rate in the deforming gouge exceeds a critical weakening strain rate controlled by the gouge properties, corresponding to the local slip rate at a single contact reaching the critical weakening slip rate for bare surface sliding. Our results show that the presence of a thin gouge layer dramatically reduces the efficiency of flash heating, with the slip rates required to trigger flash heating at least an order of magnitude greater than those predicted for bare surface sliding in *Rice* [2006].

Having developed a model for flash heating during distributed shear, we next model the weakening of a uniformly sheared gouge layer. We show that if flash heating is triggered then the evolution of the bulk fault temperature leads to a near total strength drop in just a few milliseconds, and use this insight to predict a slip weakening distance that is inversely proportional to the normal stress. This dependence on normal stress is in good agreement with data from high-velocity friction experiments, and of great importance when extrapolating experimental results to seismogenic depths. In addition, we couple flash heating with a model for thermal pressurization, allowing us to determine the dominant weakening mechanism for a range of fault conditions. Our results show that flash heating is likely unimportant at shallow depths where thermal pressurization dominates, but becomes as important as thermal pressurization further down in the seismogenic zone.

Finally, we link our model with the recent experimental results presented in *Proctor et al.* [2014]. We show that the evolution of sliding surface temperature may explain some of the hysteresis commonly seen in bare surface sliding experiments that trigger flash heating, with higher friction observed during acceleration than deceleration. Our model gives excellent agreement with the experimental data from *Proctor et al.* [2014] for both acceleration and deceleration over a wide range of slip rates. Building on this we discuss the role of flash heating near the trailing edge of a rupture where temperatures are high and slip is decelerating.