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A microphysical interpretation of the rate-and-state friction direct effect: implications for the seismic cycle

Martijn van den Ende, André Niemeijer, and Christopher Spiers
Utrecht University, Earth Sciences, Utrecht, Netherlands (m.p.a.vandenende@uu.nl)

For many years, empirical rate-and-state friction laws have been successfully applied to describe the transient frictional behaviour of fault zones, as observed in laboratory experiments and in nature. However, the rate-and-state friction parameters and equations are still poorly understood in terms of the underlying processes that operate at a micro-scale. In addition, there exist large discrepancies between lab-derived values and estimated values for natural fault zones. Because of these discrepancies, extrapolation of the frictional behaviour from sample-scale to the spatial and temporal scales of natural faults is non-trivial. Most notably, there is only a small theoretical basis for the near-instantaneous increase in friction after a sudden increase in sliding velocity (known as the direct effect). Marone et al. (1990) observed a positive relationship between the direct effect and dilatation in quartz gouges. However, the magnitude of the dilatation was significantly higher than expected based on the change in friction, which they explained by non-coaxial dilatation. In more recent years, Beeler et al. (2007) used a normalisation scheme to show that in the case of phyllosilicates, the magnitude of the direct effect is comparable to the stress required for dislocation glide. However, dislocation glide does not explain a-values for "hard" minerals such as quartz and calcite, especially when fluid-rock interactions are rapid.

To address these issues, room temperature velocity stepping experiments have been conducted on granular calcite, and granular rock salt as an analogue for quartz under hydrothermal conditions. These experiments clearly demonstrate that the magnitude of the direct effect is much larger in gouges where pressure solution rates are high and deformation is distributed. A large contribution of dilatation to the magnitude of the direct effect becomes apparent in these gouges. In contrast, calcite gouges in which pressure solution is slow, show a small direct effect, which can not be accounted for by dilatation alone. Localisation of deformation decreases the magnitude of the direct effect, which is in agreement with observations by Marone et al. (1990). We are in the process of developing a microphysical model to explain the observed behaviour and to allow for extrapolation to natural conditions. Our microphysically based and experimentally verified model will help gain a better understanding of the seismic cycle.

References:

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