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Dynamic earthquake sequence simulations with fault constitutive law accounting for brittle-plastic transition and pressure solution-precipitation creep

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Fault mechanical behavior is presumably dictated by a pressure-sensitive friction law in the brittle regime where cataclastic deformation dominates, and by a pressure-insensitive flow law in the plastic regime where milonytes are generated. A fault constitutive law in the transitional regime is of great importance in considering earthquake cycles as evidenced by field observations of repeating brittle and ductile deformations [e.g., Sibson 1980].

Shimamoto and Noda [2014] proposed an empirical method of connecting the friction law and the flow law without introducing a new parameter, and demonstrated 2-D dynamic earthquake sequence simulations for a strike-slip fault [e.g., Lapusta et al., 2000] with the friction-to-flow law. A logarithmic rate- and state-dependent friction law (aging law) and a rate- and state-dependent flow law (power law) [Noda and Shimamoto, 2010] with a quartzite steady-state flow law (power exponent $n = 4$) [Hirth et al., 2001] were adopted for the friction law and the flow law, respectively. Our numerical models are realization of conceptual fault models [e.g., Scholz, 1988]. “Christmas tree” stress profiles appear as a result of evolution of the system, and fluctuate with time. During the interseismic periods, creep fronts penetrated into the locked depth, slow slip events were generated, and then nucleation of dynamic rupture took place either in the shallower or deeper creeping region. The dynamic ruptures spanned the locked depth, reaching the ground surface and extending downwards even deeper than the depth of maximum pre-stress where the deformation mode was in the transitional regime preseismically where S-C mylonitic texture was expected [Shimamoto, 1989]. The coseismic deformation was in the frictional regime because the pure flow law predicts tremendously high flow stress at high strain rate and “the weaker wins”. Our simulations reproduced repeating overprint of brittle and ductile deformations.

We attempt here to include pressure solution (or solution-precipitation) processes to the friction-to-flow law. There would be two ways to include the processes, (1) to replace the flow law by pressure-solution flow law [Rutter, 1983, J. Geol. Soc.] and (2) to replace the friction law by friction law including pressure-solution processes [Bos and Spiers, 2002, JGR; Niemeijer and Spiers, 2007, JGR]. For (1), a model for pressure solution-precipitation creep of quartz [Rutter and Mainprice, 1979] ($n = 1$) is adopted. In this case, similar “Christmas tree” stress profiles appeared. It should be noted that the smaller n results in the larger sensitivity of the flow stress to the width of the ductile shear zone, and the more delicate tuning was needed to produce a numerical model with a realistic seismogenic depth range. Further constraints of the shear zone width as well as other parameters such as the grain boundary diffusivity and grain size as a function of depth are required to develop a more realistic fault model.