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Experimental investigation of thermal pressurization of fault gouge and its characteristic microstructures

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Thermal pressurization (i.e., fluid pressurization and reduction of effective normal stress due to frictional heating) is thought to be one of the important dynamic weakening mechanisms of fluid-infiltrated faults during earthquakes. Although there have been numerous theoretical studies on thermal pressurization, their experimental investigation and the characterization of microstructures associated with thermal pressurization have been insufficient. We performed high-velocity friction experiments on a clay-rich fault gouge at a slip rate of 1.3 m/s and normal stresses ranging from 0.6 to 2.0 MPa under wet conditions. The clay-rich fault gouge was taken from the megasplay fault zone in the Nankai accretionary prism off Kumano, where earthquake ruptures may propagate repeatedly during great subduction earthquakes such as the 1944 Tonankai earthquake. In order to monitor the change in temperature during the experiments, a thermocouple was installed on the stationary side at 9.5 mm from the boundary between the fault gouge and impermeable granite. All experiments show slip weakening and increase in temperature of the fault gouge due to frictional heating. The steady-state friction is less than 0.2 and is established almost immediately (i.e., the slip-weakening distance is very small). There is no marked change in axial shortening during the experiments, suggesting that the compaction of the fault gouge is inhibited by the generation of fluid pressure. The steady-state shear strength is almost independent of the normal stress. These experimental results indicate that thermal pressurization is responsible for the very rapid weakening of the wet fault gouge; the thermal pressurization causes the gouge to behave as a viscous fluid. After the experiments, the microstructures of the fault gouge are characterized by the presence of internal boundaries that separate the zone of preferred orientation of clay particles from the zones of random orientation of clay particles. These internal boundaries may separate the shearing region from the nonshearing rigid regions (i.e., the gouge zone is partially sheared). At the marginal part of the specimen of the fault gouge, the large grains are concentrated in the upper part of the gouge layer. Such grain-size sorting could arise from the dispersive pressure associated with granular collision in granular-fluid shear flow. The spatial distribution of the grain size sorting possibly reflects that the dispersive pressure is proportional to the square of the shear rate (Bagnold law). The results of our experiments imply that earthquake ruptures propagate smoothly through wet clay-rich fault gouges with very small fracture energy. The characteristic microstructures observed in the experimental gouge zone are potentially useful for the recognition of past viscous behavior of fault gouges by thermal pressurization. In particular, the grain-size sorting of large grains in a fault gouge could provide new textural evidence for the occurrence of high slip rate.