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Frictional properties of DFDP-1 Alpine Fault rocks under hydrothermal conditions and high shear strain

André R. Niemeijer (1), Carolyn Boulton (2), Virginia Toy (3), John Townend (4), and Rupert Sutherland (5)

(1) Utrecht University, Faculty of Geosciences, HPT Laboratory, Netherlands (a.r.niemeijer@uu.nl), (2) University of Liverpool, Earth, Ocean and Ecological Sciences, Liverpool, U.K., (3) University of Otago, Department of Geology, Dunedin, New Zealand, (4) Victoria University of Wellington, School of Geography, Environment and Earth Sciences, Wellington, New Zealand, (5) GNS Science, Lower Hutt, New Zealand

The Alpine Fault, New Zealand, is a major plate-bounding fault that accommodates 65-75% of the total relative motion between the Australian and Pacific plates. Paleoseismic evidence of large-displacement surface-rupturing events, as well as an absence of measurable contemporary surface deformation, indicates that the fault slips mostly in quasi-periodic large-magnitude earthquakes ($< M_w$ 8.0). To understand the mechanics of earthquakes, it is important to study the evolution of frictional properties of the fault rocks under conditions representative of the potential hypocentral depth. Here, we present data obtained on drill core samples of rocks that surround the principal slip zone(s) (PSZ) of the Alpine Fault and the PSZ itself. The drill core samples were obtained during phase 1 of the Deep Fault Drilling Project (DFDP-1) in 2011 at relatively shallow depths (down to $\sim$150 m). Simulated fault gouges were sheared under elevated pressure and temperature conditions in a hydrothermal ring shear apparatus. We performed experiments at temperatures of 25, 150, 300, 450 ˚C, and 600 ^{o}C. Using the shallow geothermal gradient of 63 ˚C/km determined in DFDP-1, our highest temperature corresponds to a depth of $\sim$7 km (Sutherland et al. 2012); it would correspond to 10 km depth using a more moderate geotherm of 45 ^{o}C/km (Toy et al. 2010). All samples show a transition from velocity-strengthening behavior, i.e. a positive value of (a-b), to velocity-weakening behavior, i.e. a negative value of (a-b) at a temperature of 150 ˚C. The transition depends on the absolute value of sliding velocity, with velocity-weakening dominating at lower sliding velocities. At 600 ^{o}C, velocity-strengthening dominates at low sliding velocity, whereas the high-velocity steps are all velocity-weakening. Moreover, shear stress depends linearly on effective normal stress at 600 ^{o}C, indicating that shearing is essentially frictional and that no transition to ductile (normal stress independent) flow has occurred. Thus, depending on the background (nucleation) strain rate, our data indicate that the Alpine Fault should be able to generate earthquakes at all temperatures above room temperature. However, at the highest temperature investigated (600 ^{o}C), the transition to velocity-weakening is postponed to slip rates above 10 mm/s (strain rate $\sim 10^{-2}$ s^{-1}). This observation, combined with the absence of strength recovery after long holds, suggests that seismic slip may propagate into regions of the fault unlikely to nucleate earthquakes. We propose that in our porous gouges, thermally activated processes operate simultaneously with granular flow, postponing ductile flow to higher temperatures or lower strain rates.

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