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Four frictional regimes as a function of slip rate in halite and halite-muscovite gouge deformed from low to high velocities

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The evolution of friction as a function of slip velocity is an important factor in understanding earthquake nucleation and propagation. The velocity dependence of the coefficient of friction may not be constant but vary with slip rate. When such variations in the sign (velocity weakening vs. strengthening) and/or magnitude of the velocity dependence of friction are included in numerical modelling of rupture, it is observed that more complex and more realistic rupture patterns are produced compared to using a single constant velocity dependence. It is thus important to study the coefficient of friction over the entire range of velocities relevant to earthquake nucleation and propagation, which may be done in the laboratory. Most laboratory experiments are either conducted at low velocities (10-8 – 10-4 ms-1) or high velocities (0.01 – 1 ms-1). Few experiments however bridge the gap between these two regimes. Also, reproducing in situ conditions is difficult during high velocity experiments since normal stress is often limited, pore pressure is hard to control and often room temperature is used. In this research we aim to study the evolution of friction of a single material from low to high slip rates, which deforms via processes representative to upper crustal deformation of quartzite fault rock (with phyllosilicates) at conditions accessible at low and high velocities. Analogue halite and halite-muscovite gouges were deformed over a 7 orders of magnitude slip range (0.1 μms-1 – 1 ms-1) using a low-to-high velocity rotary shear apparatus at Hiroshima University. The applied normal stress was 5 MPa, the experiments took place at room temperature and gouges were room-dry. Microstructural analysis was conducted to study the deformation mechanisms. Four frictional regimes as a function of slip rate could be recognized from the mechanical data, and each regime was associated with a distinct microstructure, reflecting a transition from mainly brittle-dominated to more plastic and temperature activated deformation mechanisms. At 0.1 and 1 μms-1, pure halite gouge was strong and slip hardening, and deformation took place mainly via cataclasis. The mixed gouge was significantly weaker, and showed stick-slip at 1 μms-1. The second regime (1 μms-1 – 1 mms-1) was characterized by rapid slip weakening and stick-slip behaviour, and the microstructure indicated deformation took place mainly on a localized boundary shear. Samples became weaker with increasing velocity. From 0.01 to 0.1 ms-1, both gouge materials became stronger with velocity. The microstructure suggested a combination of agglomeration of material through plastic processes and brittle fracturing of this material to be controlling deformation. At slip rates from 0.1 to 1 ms-1 both gouges weakened rapidly to very low coefficient of friction. The microstructure indicated localized deformation on a boundary shear, possibly through melting, with plastic deformation in the region flanking the boundary shear. The observed strength profile (strong, hardening – weakening – strengthening – weakening) may have large implications for earthquake rupture simulations.