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Frictional properties of megathrust fault gouges under true in-situ subduction zone conditions

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The seismogenic zone of most subduction megathrusts spans a temperature range of ∼150-350°C, while Slow Slip Events (SSEs) are reported to occur at temperatures up to ∼500°C. Fault rocks at the corresponding depths are expected to consist of mixtures of phyllosilicates with quartz. At temperatures of ∼100-200°C, the dominant phyllosilicate phase is illite, which is replaced at ∼200-300°C by increasingly well-crystallized muscovite. However, relatively few data are available of the frictional behaviour of gouges of this composition at in-situ megathrust conditions. We determined the frictional characteristics of mixtures of ∼65% illite or muscovite plus ∼35% quartz at temperatures of ∼100-600°C, effective normal stresses of ∼50-500 MPa and pore fluid pressures up to ∼250 MPa, using sliding velocities of 1-100 μm/s. The illite-rich gouge showed three slip stability regimes, characterized by velocity weakening behaviour ([a-b]<0) at temperatures between 250°C and 400°C and velocity strengthening ([a-b]>0) at both lower and higher temperatures. In addition, the rate and state dependent friction parameters (a, b and Dc) as well as the friction coefficient μ and slip/strain hardening rate, all showed distinct changes around ∼300-350°C. Experiments on muscovite-rich gouges show similar behaviour, with the transitions in velocity dependence shifted up in temperature by ∼100°C. Taken together, the results for illite and muscovite suggest that velocity weakening under subduction zone conditions starts at ∼200°C at sliding velocities of ∼1 μm/s and may persist to temperatures of ∼500°C and hence to depths beyond the down-dip limit of the seismogenic zone. This offers a possible explanation for the nucleation of SSEs observed at these depths. Our data also suggest a shift in the onset of velocity weakening behaviour to temperatures of ∼150°C at sliding velocities approaching those relevant for earthquake nucleation, which corresponds well with the updip seismogenic limit in many subduction zones. In addition, preliminary results suggest that a similar shift in the onset of velocity weakening to lower temperatures occurs with increasing effective normal stress. Contrasting to previous expectations based on room temperatures experiments on illite, this points to the possibility of velocity weakening slip in illite gouges at temperatures as low as ∼100°C. Such behaviour may help explain events such as the Tohoku earthquake (NE Japan), which nucleated at a depth of ∼25 km in a region characterized by temperatures of ∼130-160°C.