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Dramatic reduction of fault strength at the onset of dehydration of antigorite serpentinite

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The dehydration reaction of serpentine to olivine and free fluid phase has a significant effect on the strength and stability of serpentine-bearing faults, and is therefore key for interpreting the generation of earthquakes along subduction zones. In order to investigate the effect of the dehydration reaction on fault stability, using two torsion apparatuses friction experiments were performed on an antigorite serpentinite from Taiwan with a pre-cut fault surface perpendicular to the cylindrical axis of the specimen. Here, we present our preliminary experimental results.

The first series of experiments was done in a Paterson high PT gas apparatus in ETH Zurich at a confining pressure of 200 MPa, axial stresses of 0 and 100 MPa and constant slip rates of 1.0-1.5x10^-4 mm/s to 2.5 mm in displacement. A small hole along the specimen axis penetrated the fault and thus acted as a fluid conduit for any fluid released during the reaction. We also deformed specimens without a hole to compare the mechanical behavior of drained and partially drained specimens. To evaluate the effect of the reaction on fault stability, the temperature was increased from 500 to 720C at a ramping rate of ~2 C/min after the fault slip achieved a steady state. Experimental results indicate that (1) stable slip occurred at conditions within the stability field of serpentine, (2) visible stick-slip behavior started at the onset of the reaction at ~620C, (3) the magnitude of the stress drop increased with temperature (degree of the reaction) and axial stress, (4) dramatic reduction of stress (with a friction drop from 0.75 to 0.3) occurred in the specimen without a hole at ~680C, and (5) tiny stick-slips were observed even after the reaction was completed. These data imply that the dehydration instability occurs at the onset of the reaction even under drained conditions (i.e. specimen with a hole), probably due to local high pore pressures on the fault surface and to unstable slip behavior of the reactants.

The second series of experiments was performed using a high-velocity rotary-shearing apparatus in Kyoto University to evaluate the frictional behavior during dehydration induced by frictional heating at seismic slip rates. We deformed the same antigorite at slip rates of 2 cm/s to 1.2 m/s and normal stresses of 1.3-20 MPa at room pressure and temperature conditions. At low slip rates (2-20 cm/s) and normal stresses (1.3-2.6 MPa) where the fault surface temperature remains below the temperature needed to dehydrate antigorite (~620C), steady-state frictional coefficients varied from 0.35 to 0.5. In contrast, at a slip rate of 1.2 m/s and a normal stress of 15-20 MPa where the dehydration reaction favorably took place on the fault surface, friction initially increased to 0.33 at the beginning of the run and immediately dropped to ~0.12 with a weakening distance of ~40 cm. During the sliding, large amounts of serpentinite gouge (probably partially dehydrated) were ejected from the fault zone. Observed slip weakening and low fault strength must be due to continuous vaporization of fluid released during the reaction.

The results imply that even at conditions where serpentinite is stable, once earthquake slip propagates into a serpentinite body, frictional heating induces the dehydration reaction on the fault surface, which may promote slip weakening behavior and fault instability.