Verification of unstable sliding behavior during dehydration of clay minerals as elevated temperature

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Along plate boundary subduction thrusts, the transformation of smectite to illite within fault gouge at temperatures around 100 - 200 °C is one of the key mineralogical changes thought to control the updip limit of seismicity (Hyndman et al., 1997). Ikari et al. (2007) suggest that decreasing water content may contribute to transition from velocity-strengthening to velocity-weakening behavior. Although they analyzed the velocity dependence of clay materials over a wide range of normal stresses and estimated the effect of hydration state on friction properties, their friction experiments were performed with controlling its water content. In the fact that hydration state of clay minerals is possible to vary from moment to moment in nature, systematic studies to investigate the effect of dehydration and hydrate state on frictional properties with progression of a removal of water is rare. In this study, we focus on the effect of dehydration of water on the frictional properties of clay minerals, and compare the results during dehydration process undergoing.

For the friction experiments, starting materials we used are Ca-montmorillonite (CaMMT). The powder materials of clays were placed on the simulated fault surface and two side blocks were placed together to produce a double-direct shear configuration. Normal stress was applied via a hydraulic ram on the side block with 60 MPa, and then, shear stress was applied by advancing the central block downward at a constant velocity. The sample assembly was heated by an external furnace up to 400 °C that is monitored by thermocouples located in the central part of sample assembly. We started to elevate the temperature around the specimen at a constant heating rate of 1, 3, and 10 °C/min, reaching after steady-state friction at 5 mm deformed. Then, we observed friction behavior of CaMMT during dehydration as elevated temperature. Because of the limitation of total displacement to 20 mm in our assembly, we used different slip rate 0.6, 1.2, and 3.0 μm/s at a heating rate 1, 3, and 10 °C/min, respectively.

CaMMT gouge showed unique friction behavior development as elevated temperature at a heating rate of 10 °C/min, which is divided into three stages; friction coefficient decreased at relative low temperature (1), friction coefficient increased at middle temperature (2), and stick-slip behavior occurred at high temperature (3). Stick-slip behavior as elevated temperature implies to have a potential of velocity weakening behavior. However, observed stick-slip behavior occur at a temperature of 324 °C, which is extremely higher from a temperature range of occurring dehydration for CaMMT (100 - 200 °C). We also performed subsequent experiments that heat gouge layer more slowly, using other heating rate; 1 and 3 °C/min. CaMMT gouge at a heating rate 1 °C/min showed similar friction behavior development to that of development at 10 °C/min, divided into three stages as described above. However, the temperature that stick-slip behavior occur shifted to lower temperature, 193 °C. If temperature controlled frictional behavior, the temperature of staring to occur stick-slip behavior is independent of heating rate, and there could be the threshold of temperature starting to exhibit unstable sliding. The observed systematical shift suggest that these frictional behavior is not controlled by temperature, but progression of dehydration. Each friction stages are related to dehydration process, at a first stage friction coefficient decreased because of generation of pore pressure during dehydration. At a second stage, friction coefficient

increased because of a removal of interstitial water, and at a third stage stick-slip behavior occurred when stiffness of gouge layer satisfies a given relationship (Rabinowicz, 1956). Dehydration of clay minerals is intimately connected to friction behavior, and it may have a possibility to trigger seismic friction.

Keywords: effect of dehydration, friction property, clay minerals, elevated temperature, stick-slip

