Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SSS30-28 Room:Main Hall Time:April 29 15:15-15:30

Effect of temperature on frictional behavior of smectite and illite: Implication for the up-dip limit for seismogenic zon

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Introduction: Along plate boundary subduction thrusts, the transformation of smectite to illite within fault gouge at temperatures of ˜150C is one of the key mineralogical changes thought to control the updip limit of seismicity. Saffer and Marone (2003) reported illite shale exhibited only velocity-strengthening behavior, opposite to the widely expected, potentially unstable velocity-weakening behavior of illite. They concluded transformation of smectite to illite is not responsible for the seismic-aseismic transition in the updip limit of subduction zones. However, their experiments were limited at room temperature although the updip limit of seismogenic zone is thermally controlled that occurs at temperature around 150oC. Therefore, in this study, we determined the effect of temperature of frictional properties of smectite and illite and discuss whether the smectite-illite transition accounts for the updip limit of seismogenic zone along subduction thrust.

Experimental methods: Frictional experiments were performed using a biaxial frictional testing machine at Hiroshima University. 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 15, 40, 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 200oC that is monitored by thermocouples located close to the central block. Mechanical data were recorded continuously with a sampling rate of 10 Hz and the frictional coefficient was calculated from the shear force divided by the normal force assuming zero cohesion.

In the frictional experiments, we determined the velocity dependence of sliding friction, which is a key parameter for stable or unstable sliding (e.g., Dieterich, 1979). After steady-state sliding, the loading velocity of 3 μm/s was abruptly changed to 30 μm/s in each frictional experiments to determine the velocity dependence of these clay minerals. We calculated the velocity dependence of sliding friction as follow:

$$(a-b)=d\mu(d \ln V)$$

where a,b is the frictional parameter and V is sliding velocity. The velocity dependence is important to show seismic slip, in which negative values of (a-b) reflect velocity-weakening behavior, whereas positive values of (a-b) reflect velocity-strengthening behavior and thence stable (aseismic) sliding.

Results and Discussion: In comparison of steady-state fictional strength of clay minerals, the value of frictional strength of smectite is nearly half as large as that of illite. The effect of temperature on the frictional strength is rather weak, and the steady state friction is slightly increased at high temperatures. Our results suggest that the shear stress required to initiate sliding is much lower for smectite than illite, and smectite could not accumulate much strain energy.

The velocity dependence at room temperature shows always positive at normal stress higher than 40 MPa, which is similar to the results of Saffer and Marone (2003). However, at temperature of 200C, illite shows negative values of (a-b), suggesting that illite exhibits unstable velocity-weakening behavior. This results explains smectite is potentially aseismic for stable sliding at the subduction thrust, whereas illite becomes seismic due to a negative velocity dependence and unstable sliding at high temperatures. These experimental results indicate that the smectite-illite transition potentially account for the updip limit of seismogenic zone along subduction thrust, which is opposite to the previous results at room temperature.

Keywords: updip limit, smectite-illite transformation, effect of temperature, velocity dependence