Rate and state dependent friction of single-crystal muscovite from room to elevated temperature

*Hiroshi Sakuma[1], Diane E Moore[2], David A Lockner[2]

1. National Institute for Materials Science, 2. U.S. Geological Survey

Deformation in the crust often localizes along faults. The rate and state friction (RSF) law (Dieterich 1979; Ruina 1983) achieved great success in characterizing the friction of simulated faults and gouges as a function of slip velocity and holding time. However, the RSF law is semi-empirical and it is difficult to extrapolate the law to various pressure, temperature, and material conditions without experimental data. To develop a non-empirical friction law, the physics behind the RSF law must be revealed.

The critical parameter in the RSF theory for the response of the change in slip rate is the so-called direct-effect parameter "a". The direct effect has been interpreted as a thermally activated process at asperity contacts (Stesky 1978; Heslot et al. 1994). The process was simply considered to explain the response to rate changes based on an empirical Arrhenius equation. Therefore, multiple mechanisms may be included in the response (Nakatani 2001), and the mechanism may depend on the material being tested. For example, dislocation glide in serpentinite (Reinen et al. 1992) and subcritical crack growth in granite (Lockner 1998) may contribute to the direct effect.

To reveal a critical property of material on the direct effect, velocity-stepping shear tests should be conducted on pure materials on a well-defined shear plane. Here we conducted triaxial shear experiments on single-crystal muscovite sheets. Test conditions were: 25 to 200ºC, effective normal stress of 100 MPa, slip rates of 0.01 to 3 μm/sec, and vacuum-dry condition. The "a" value obtained by velocity-stepping tests clearly decreased with increasing temperature. This temperature dependence is inconsistent with thermally activated theory (Heslot et al. 1994; Sleep 1997). These findings imply that the direct-effect mechanism for mica does not originate from a thermally activated process.
Preliminary modeling using non-equilibrium molecular dynamics simulations were conducted for muscovite from room to 400ºC. While a simulated slip rate >=1 m/s (required by computational costs) was much higher than experimental rates, the simulated "a" value decreased with increasing temperature as observed in the experiments. These results suggest that macroscopic properties may be interpreted from the atomic-scale friction.

Keywords: Direct effect, Thermally activated process, Phyllosilicate, Temperature effect, Rate and state dependent friction law