

Observation of the Structure of Adsorbed Water on a Mica Surface to Understand the Mechanism of Creeping Faults

Creeping faults are characterized by continuous slip without large earthquakes. One of the famous creeping faults is the central zone of the San Andreas Fault. Although the mechanism of creeping faults is not yet clear, the most plausible hypothesis is lubrication due to layered-structure minerals and adsorbed water on the mineral surfaces. We have tried to understand the mechanism of low friction due to adsorbed water. Since the mechanism should be closely related to the structure of the water/mineral interfaces, we have conducted X-ray surface scattering measurements for the mica/saltwater interface and revealed the presence of adsorbed hydrated sodium ions on the mica surface. The water molecules around the sodium ions would act like ball-bearings and result in low friction between mica surfaces.

Rock fracture and fault slip are triggered by the movement of tectonic plates and cause earthquakes. However, there is a “creeping fault” type of slipping which occurs continuously without large earthquakes. One possible explanation for the continuous slip is the low frictional strength of the faults due to the presence of layered clay minerals and adsorbed water molecules on these mineral surfaces [1-3]. We have experimentally demonstrated that saltwater can be a good lubricant between muscovite (mica) surfaces even when compressed to a thickness of 1 nm [4]. Mica is ubiquitous in igneous rocks and the structure is similar to clay minerals. The thickness of 1 nm corresponds roughly to a layer of three water molecules. However, the mechanism of this lubrication is not well understood, so we have tried to understand the electronic states of the mica/NaCl solution interface because the structure should be closely related to the mechanism of water lubrication [5].

The electron density of the interface between mica and saltwater was measured by the X-ray crystal truncation rod (CTR) scattering technique. Although this technique can reveal the electron density profiles of solid/liquid interfaces with sub-nanometer resolution, on its own it cannot directly provide information about the elements. Therefore, the distribution of chemical elements at the interface was discussed by comparing the results of X-ray CTR scattering with those of molecular dynamics (MD) simulations. The X-ray CTR scattering experiments were conducted at the BL-4C. The interatomic potential model used in the MD simulations was originally developed. These experiments and simulations revealed the structure of the muscovite/NaCl solution interface, the main features of which are as follows. (1) Oscillation of the electron density profile in the saltwater was observed within 1.2 nm of the mica surface (Fig. 1).

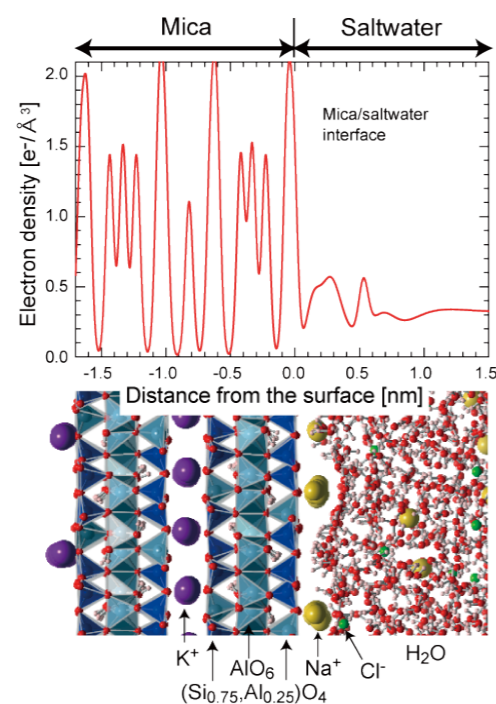


Figure 1
The electron density profile (top) and a plausible snapshot (bottom) of the mica/saltwater interface.

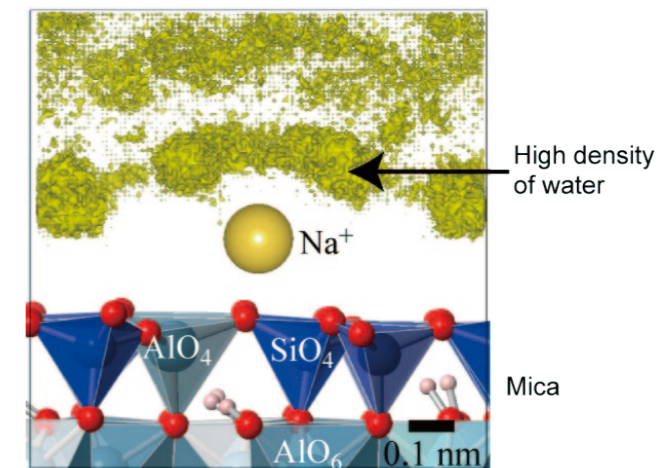


Figure 2
The iso-density surface of water on a mica surface. The yellow surface shows the positions where the density of water is six times higher than that in the bulk.

- (2) Hydrated sodium ions adsorbed on the negatively charged mica surface were present as the inner sphere complexes (Fig. 2).
- (3) The radii of the first hydration shell of the adsorbed sodium ions were approximately 0.5 nm.

These results provide a plausible mechanism for the high lubrication between mica surfaces due to the presence of saltwater. When saltwater is compressed to a thickness of 1 nm between opposite-facing mica surfaces, the first hydration shells of the sodium ions adsorbed onto the mica surface contact each other between both sides of the mica surfaces. The water in the first hydration shell has strong attractive interaction with the Na^+ and therefore the water should remain, even under the compressed condition, between the mica surfaces. These water molecules would act like ball-bearings between mica surfaces and result in low friction between the surfaces.

A systematic understanding of the effects of adsorbed water on the lubrication between minerals present at faults is important to establish the fundamental physics of faults. The mechanism proposed here to ex-

plain the low friction between mica surfaces due to the adsorbed water molecules provides a new perspective for the development of studies in this field.

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