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Acoustic probing of the internal state of gouge layer under realistic crustal normal stress

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1. Introduction

We showed that there is a close relationship between the amplitude of acoustic wave transmitted across an interface of bear surfaces and the frictional strength, which determine the relationship between applied shear stress and slip velocity on the interface as described in rate- and state- dependent friction law (JPGU 2006, S109). It can be explained by their common dependency on the contact state of the interface.

However it is known that natural faults generally contain gouge. In these faults, frictional strength and transmitted amplitude can be affected by not only the contact state but the mechanical structure of the gauge layer. So how transmitted amplitude depends on the state of such faults should be examined differently from the case of bare surfaces.

Yoshioka and Sakaguchi (2005) performed a stick-slip experiment on simulated gauge with observing the acoustic wave transmission under normal stress of a few kPa. They observed that the transmitted amplitude dramatically decreases with precursory slip and dilatancy. To examine if such a dramatic change in the amplitude can be observed under higher normal stress is so important in terms of the application to field that this is one of our purpose in this study.

In a friction experiment with simulated fault gauge, time-independent strengthening due to the gouge particle rearrangement are observed in addition to time-dependent strengthening as observed on bear surfaces. It is expected that we can infer how the state in gouge layer changes with such a strengthening by observing the gouge layer thickness and acoustic wave transmission.

2. Experiment

The experiments were performed in a double direct shear apparatus. Two gauge layers, which consist of quartz powder whose particle size is under 100 micron, were sandwiched by 3 granite blocks. Acoustic waves were transmitted and received by ultrasonic transducers attached on outer blocks. Gouge layer thickness was measured in order to obtain the information of internal structure change in the gouge layer. Although there is a spatial variation on the gauge layer thickness, we can estimate the thickness around the center of the outer block, through which the acoustic wave was transmitted, by measuring the distance between blocks at 3 points. We conducted slide-hold-slide test at a slip velocity of 1 micron/s under normal stress of 10 MPa with varying shear stress during hold and duration of hold.

3. Results

Time-independent strengthening, which depends only on shear stress during hold, was observed in addition to the time-dependent strengthening as reported by Nakatani (1998). The time-dependent strengthening can be observed as a peak of shear stress after hold only if the shear stress during hold is high. However transmitted amplitude increased linearly with the logarithm of hold time independently of the shear stress during hold and it also increased with reduction of shear stress. These increases of amplitude correspond to decrease of gouge layer thickness during hold. This result suggests that there are two different mechanism of state change whether time-dependent peak of shear stress can be observed or not and that the strength due to time-dependent strengthening can be reduced by a slight slip. The latter feature is supported by the data of amplitude and gouge thickness showing rapid decrease and increase respectively just after hold. This rapid decrease in amplitude after hold corresponds to dramatic decrease in amplitude due to precursory slip reported by Yoshioka and Sakaguchi(2005), although it was not so dramatic and 20% at most. After that, amplitude decreases and thickness increases gradually in the same way that shear stress decreases with slip at a constant rate. These results suggest that the strength of the gouge layer and acoustic wave transmission are both strongly dependent on the thickness or porosity of the gouge layer.