FRICCTIONAL PROCESSES OF SMECTITE-RICH GOUGES AT HIGH SLIP RATES

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Abstract
The determination of frictional processes of smectite-rich gouges at high slip rates (~1 m/s) is important to understand the unusually large coseismic slip in the shallower part of tsunamogenic megathrusts (e.g. 2011 Tohoku earthquake) and the mechanics of catastrophic landslides (e.g. 1963 Vajont landslide). At present, only rotary shear apparatuses can reproduce simultaneously the slip and slip rates of these natural events. I will present here new frictional data obtained with two rotary shear machines. Experiments were performed on natural gouges from the Vajont slide, and on selected monomineralic smectite gouges and smectite-quartz mixtures. Deformed and undeformed powders will be investigated with x-ray powder diffraction (Rietveld method), scanning and transmission microscopes. The final and most challenging goals of my thesis are the understanding of the frictional processes triggered in smectite-rich gouges at high slip rates and the formulation of an empirical law to describe them.

Full Report
Introduction
Smectite is a mineral often occurring in many critical geologic environments: i) fault zones of plate-boundary subduction faults (e.g. megathrust faults), depending on the local sediment input (e.g. in Nankai trough, Barbados accretionary prism and Japan Trench), ii) shallow active fault zones (e.g. the San Andreas Fault and the Chelchongpu Fault in Taiwan), and iii) landslide décollement, (e.g. the 1963 Vajont landslide, Italy and the Kamenose landslide, Japan).

Its presence in fault zones was supposed to control the occurrence of aseismic and seismic fault patches, the propagation of seismic ruptures and great tsunami generation, and in the case Vajont slide, the final acceleration from 1.5 cm/day up to 20 m/s.

The properties of smectite are controlled by its mineral structure. Smectites are T-O-T sheet silicates with layer charge between -0.2 and -0.6 (low- to high-charge). They can be considered as an incomplete, complex solid solution between dioctahedral and trioctahedral species and, in each group, between species with octahedral and tetrahedral layer charge. The low layer charge (-0.2 to -0.6) allows the ingress of hydrated cations (K+, Ca++, Na+, Mg++) that are necessary to neutralize the bulk negative charge, thus leading to the expandability of the interlayer. The cations can be exchanged with those from the pore fluid and their hydration energy control: i) the amount of swelling, ii) the flocculation-delamination in aqueous environment, iii) frictional strength in presence of water.

Among the great abundance of frictional studies about smectite gouges few works made accurate links between frictional strength and the chemical properties of the smectite (Moore and Lockner, 2007) and on the role of interlayer cation on both friction and permeability (Behnse and Faulkner, 2013). Some experimental works were also focused on the influence of smectite on the frictional behaviour of mixtures of smectite with quartz and illite (Tembe et al., 2010), and smectite and quartz with variable water content (Ikari et al., 2007). However, most of these experiments were performed at slow speed rates (< 0.1 mm/s). Other frictional studies at high speed velocities were carried on natural samples, which are complicated mixtures of prevailing smectites plus other minerals (e.g. calcite, quartz and other clays; Mizoguchi et al., 2009; Ferri et al., 2011; Ujiie et al., 2013; French et al., 2014; Sawai et al., 2014; Smith et al., 2014).

Despite this, smectite frictional properties were never studied systematically at high (> 10 mm/s) slip velocities. Smectite role in controlling the frictional-high-speed properties of clay-rich gouges was suggested from the similarity of the mechanical data of Vajont smectite-rich (Ferri et al., 2011) and JFAST megathrust samples (Ujiie et al., 2013, Smith et al., subm.), both with up to 60 wt% of smectite.
This similarity suggested us a path for further research, also because the physical processes (dehydration? grain boundary sliding?) controlling friction at these experimental conditions are almost unknown.

Methods

In this thesis I am using two rotary shear apparatuses to obtain new experimental datasets. Starting materials are pure mono-mineral dioctahedral smectite-rich gouges (montmorillonite =Mnt, beidellite=Bei). After I will determine the frictional properties of these smectite pure end-members, I plan to extend our dataset to mixtures of a smectite (Mnt or Bei) with a non-clay mineral, such as quartz or calcite. The mechanical results on pure and mixed smectitic gouges will be used to discuss mechanical data of natural gouges, sampled at Vajont slide slipping zones. Other potential developments may consider different cation-exchanged Mnt or Bei, and extending at high-speed velocities the results of Behnsen and Faulkner (2013).

I plan to measure friction at intermediate to high velocities (from 100 µm/s up to 6.5 m/s) using the rotary shear machines installed in Padova (ROSA, Rempe et al., 2014; Ma et al., subm.) and Rome (SHIVA, Di Toro 2010; Niemeijer et al., 2011). The normal stresses will be consistent with the natural one: i) 1-5 MPa, representative of landslide conditions and ii) 1-9 MPa for shallow megathrusts, being 7 MPa the effective normal stress calculated for J-FAST sampling site (Fulton et al., 2013). I will test vacuum-dry, room humidity and wet (partially saturated) conditions (I will consider the limitations of equilibrating pore pressure in rotary shear experimental assembly).

Undeformed and deformed powders will be systematically analyzed using X-ray powder diffraction by Rietveld method. We focus on the determination of the amorphous phase percentages (Smith et al., subm.) to check if it correlates with the frictional work or frictional work rate. Microstructural studies with SEM and TEM microscopy will be performed to investigate the possible chemical and physical processes activated at high slip velocities responsible of the large measured weakening (see Figs. 1-2b).

Preliminary results

In this first year, I first fixed several problems (e.g., gouge leaks, data reproducibility, noise) about using clay-rich gouges with rotary shears. New friction measurements were produced on these materials:

- Ca-Mnt and Quartz 1:1 mixture
- Vajont gouge: mixed-layer Illite-smectite
- Vajont gouge: up to 50% Sme + Qtz + Cal
- Interlab SAFOD powders: Sme + Qtz, Talc, ground Westerly granite.
- Ca-Mnt purchased from Clay Mineral Society (STX-1B)

I performed 23 preliminary tests with ROSA on the SAFOD interlab mixtures (Qtz, as F110 Ottawa foundry sands and Ca-Mnt, as CABSORB SM1502A in 1:1 weight ratio), both at room humidity and wet (13 wt% de-ionized water) conditions to understand the main experimental problems related to both the material and the ROSA machine.

I performed a series of experiments on natural gouges from the Vajont area, sampled in March 2014 in different clayish interbeds close to the main sliding surface. Experiments were performed at different velocities and room humidity or wet (18 wt% de-ionized water) conditions. Both SHIVA and ROSA rotary machines (12 and 10 experiments) were used to reproduce the experimental results of Ferri et al. (2011) and to make a comparison among the two machines. The main difference was in the specimen holder, which, in the case of SHIVA was tested and calibrated (Aretusini et al., 2014).

We run 13 experiments on Vajont gouge (courtesy of Fabio Ferri) to reproduce the Ferri et al. (2011) trend (Fig. 1a) with ROSA, at imposed slip rates from 0.001 to 1 m/s, mostly in room humidity conditions and at 1 and 2 MPa normal stress.

I run 10 experiments to check the accuracy of our experimental measures obtained with ROSA, and how these measurements compare with experimental data obtained on identical materials with bi-axial, tri-axial and rotary machines of the SAFOD interlab. For this goal we sheared, talc gouges, ground Westerly Granite and 1:1 mixture of Qtz and Mnt. We confirmed both the precision and accuracy at room-humidity conditions since the results were consistent with those obtained from other friction machines installed in other labs worldwide.

I started a series of experiments (by now, 14 in total) at different sliding velocities in Ca-Mnt (STX-1B, 95 wt% Ca-Mnt of Gonzalo’s County) to begin the systematic testing and XRD measures of the mixtures.

We acquired a good reproducibility of the experimental data at almost all speed rates, given the acquired control on several experimental phases and details (Fig. 2a). Preliminary results show a similar trend as the one previously determined in smectite-rich materials (compare Fig. 1 with Fig. 2b).

Figure 2. a) Apparent friction vs. slip for five experiments at reference velocities of 0.0003, 0.001 and 0.01 m/s showing reproducibility. b) Apparent friction at 0.5 m of displacement vs. log of reference velocity, STX-1B at room humidity. Red circles indicate the corresponding values in a) and b).

References


SUMMARY OF ACTIVITY IN THIS YEAR

Courses:
ROSS J. ANGEL: “Scientific Communication”, Dipartimento di Geoscienze, Università degli Studi di Padova
MONICA BORG: “Consolidating skills in English: A Multimedial Approach”, Dipartimento di Geoscienze, Università degli Studi di Padova
LYDIA GULICK: “Corso avanzato di Inglese Scientifico”, Dipartimento di Geoscienze, Università degli Studi di Padova
LANG WU and LUIGI SALMASO: “Statistics for Engineers 2014”, Dipartimento di Ingegneria Industriale, Università degli Studi di Padova

Communications:

Posters:
ARETUSINI, S., SPAGNUOLO, E., CARPENTER, B., COLLETTINI, C., DI TORO, G., 2014. Experimental investigation of the frictional properties of smectite/illite/chlorite rich gouges over a large


Publications:

FONDRIEST, M., ARETUSINI, S., DI TORO, G., SMITH SAF, (submitted). Structure of an exhumed seismogenic fault zone in dolostones: the Foiana Fault Zone (Southern Alps, Italy). In: Tectonophysics

Teaching activities:

Other: