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Frictional processes in smectite-rich gouges sheared at slow to high slip rates

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The slipping zones of shallow sections of megathrusts and of large landslides are often smectite-rich (e.g., montmorillonite type). Consequently, similar "frictional" processes operating at high slip rates ($>$ 1 m/s) might be responsible of the large slips estimated in megathrust (50 m for the 2011 Tohoku Mw 9.1 earthquake) and measured in large landslides (500 m for the 1963 Vajont slide, Italy). At present, only rotary shear apparatuses can reproduce simultaneously the large slips and slip rates of these events. Noteworthy, the frictional processes proposed so far (thermal and thermochemical pressurization, etc.) remain rather obscure.

Here we present preliminary results obtained with the ROtary Shear Apparatus (ROSA) installed at Padua University. Thirty-one experiments were performed at ambient conditions on pure end-members of (1) smectite-rich standard powders (STx-1b: $\sim$68 wt% Ca-montmorillonite, $\sim$30 wt% opal-CT and $\sim$2 wt% quartz), (2) quartz powders (qtz) and (3) on 80:20 = Stx-1b:qtz mixtures. The gouges were sandwiched between two (1) hollow (25/15 mm external/internal diameter) or (2) solid (25 mm in diameter) stainless-steel made cylinders and confined by inner and outer Teflon rings (only outer for solid cylinders). Gouges were sheared at a normal stress of 5 MPa, slip rates V from 300 μm/s to 1.5 m/s and total slip of 3 m. The deformed gouges were investigated with quantitative (Rietveld method with internal standard) X-ray powder diffraction (XRPD) and Scanning Electron Microscopy (SEM).

In the smectite-rich standard endmember, (1) for 300 μm/s $\leq V \leq$ 0.1 m/s, initial friction coefficient (μ_i) was 0.6±0.05 whereas the steady-state friction coefficient (μ_{ss}) was velocity and slip strengthening (μ_{ss} 0.85±0.05), (2) for 0.1 m/s $< V <$ 0.3 m/s, velocity and slip neutral ($\mu_i = \mu_{ss}$ = 0.62±0.08) and (3) for $V >$ 0.8 m/s, velocity and slip weakening (μ_i = 0.7±0.1 and μ_{ss} = 0.25±0.05). In the 80:20 Stx-1b:qtz mixtures, (1) for 300 μm/s $\leq V \leq$ 0.1 m/s, μ_i ranged was 0.7±0.05 and increased with slip to μ_{ss} = 0.77±0.02 (slip-strengthening behavior), (2) for V = 0.1 m/s velocity and slip neutral ($\mu_i = \mu_{ss}$ = 0.77±0.02) and (3) for $V \geq$ 0.3 m/s the friction coefficient was velocity and slip weakening with μ_{ss} = 0.32±0.02 for V = 1.5 m/s.

The Rietveld analysis of the smectite-rich standard endmember showed (1) the insensitivity of the amount of the amorphous fraction with frictional work and (2) the shift and broadening of both the (001) and (110) peaks of Ca-montmorillonite with increasing frictional work (i.e., product of shear stress with slip, here from 5.2 Jm^{-2} to 11.8 Jm^{-2}). Instead, mineralogical and lattice changes were unrelated to the frictional work rate (i.e., product of shear stress with slip rate). Strain localization in the gouge layer was observed for $V \geq$ 0.3 m/s (SEM investigations); for $V <$ 0.3 m/s, strain was distributed and the gouge layer pervasively foliated. We conclude that the degree of amorphization of the sheared gouges was not responsible of the measured frictional weakening; instead, weakening was concomitant to strain localization.