Frictional behaviour of simulated muscovite fault gouge at shear strains up to 120 and temperatures of 20-600 ºC

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1. Introduction & problem

Phyllosilicates, such as muscovite, are common constituents of large-scale crustal fault zones and are widely expected to be relatively weak around the brittle-ductile transition, leading to low fault strength. However, quantitative data on the frictional strength of muscovite are limited, especially at large shear strains and under hydrothermal conditions.

The present study aims to investigate the frictional strength of phyllosilicates under hydrothermal conditions by determining the effects of temperature T, shear strain γ, sliding velocity V and effective normal stress σ_{eff}.

2. Action

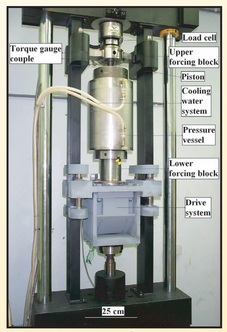

Figure 1: Experimental set up.

Rotary shear experiments:

- Normal stress-stepping experiments
- Velocity-stepping experiments
- Experiments at constant V and σ_{eff}

Materials:

Sample: Muscovite gouge
average grainsize d=13 µm
~10% quartz impurities

Pore fluid: Deionised water

Conditions:

- Fluid pressure P_f: 100 MPa
- Temperature T: 20-600ºC
- Effective normal stress σ_{eff}: 20-100 MPa
- Sliding velocity V: 0.03-3.8 µm/s
- Shear strain γ: up to 120
- Shear strain rates: ~10^{-3}-10^{-5} s^{-1}

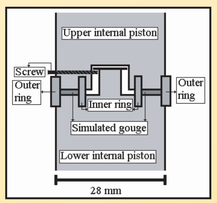

Figure 2: Schematic diagram of the experimental set up.

3. Mechanical behaviour

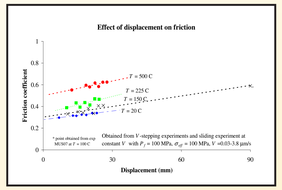

Figure 3: Friction coefficient μ versus displacement. Temperature as indicated.

- Friction coefficient μ increases with displacement (γ) at all T.

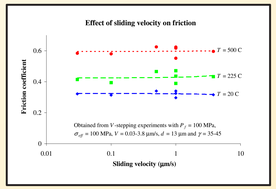

Figure 4: Friction coefficient versus log sliding velocity. Temperature as indicated.

- μ independent of V at all T.

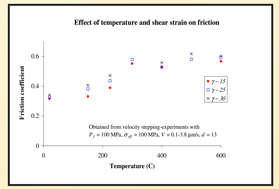

Figure 5: Friction coefficient versus temperature. Shear strain as indicated.

- μ increases with T, notably from 200-300 °C.
- μ remains constant in the range 300-600 °C.

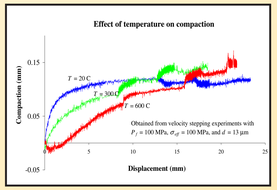

Figure 6: Compaction versus displacement. Temperature as indicated.

- Compaction increases with γ.
- At γ < 15 compaction decreases with T.
- Dilatation at low γ at T > 300°C.

4. Microstructures and deformation mechanisms

Low T ↓

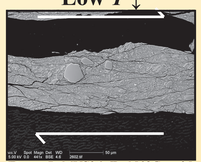

Figure 7: MUS26, T=150°C, γ~35, σ_{eff} = 100 MPa, V=0.03-3.8 µm/s.

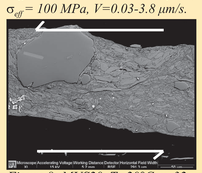

Figure 8: MUS20, T=20°C, γ~32, σ_{eff} = 100 MPa, V=0.03-3.8 µm/s.

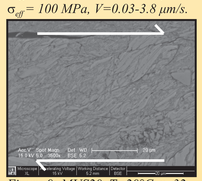

Figure 9: MUS20, T=20°C, γ~32, σ_{eff} = 100 MPa, V=0.03-3.8 µm/s.

Low T (20-225 °C)

- Strong grainsize reduction to form a well foliated matrix (< 2 µm).
- Widespread quartz and muscovite porphyroclasts (~10 µm).
- Structure cross cut by shear bands in Riedel and Y-shear orientations.

High T (300-600 °C)

- Increasingly characterised by dense, elongate lenses (30 x 10 µm), separated by an anastomosing network of ultra-fine (< 1 µm) cataclastic zones.
- Lenses consist of fine, folded and kinked grains (5-10 µm).

Deformation mechanisms	
Low T →	**High T**
1. Cataclastic flow 2. Particle alignment/slip giving a foliation	1. Cataclastic flow 2. Plastic deformation/ kinking 3. Healing by diffusive mass transfer processes

High T ↓

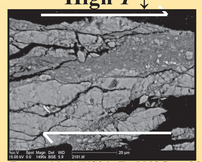

Figure 10: MUS21, T=500°C, γ~85, σ_{eff} = 100 MPa, V=1.0 µm/s.

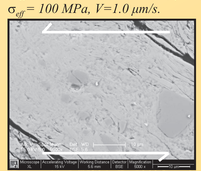

Figure 11: MUS21, T=500°C, γ~85, σ_{eff} = 100 MPa, V=1.0 µm/s.

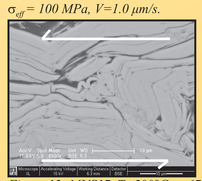

Figure 12: MUS17, T=500°C, γ~67, σ_{eff} = 100 MPa, V=0.1 µm/s.

5. Discussion & conclusions

- The friction coefficient of muscovite increases from ~ 0.33 to ~ 0.44 in the temperature range 20-225 °C, reaching 0.57 at T = 300-600 °C.
- The low T friction coefficient is in agreement with values prevously reported in the literature[1-4]. However, the high T value is higher than previously reported[5], possibly due to the strain hardening effects seen in our high strain experiments.
- No rate-depedent behaviour (e.g. dislocation/diffusion creep) was observed even at the highest temperature studied. Such effects have been previously reported[5] at T = 700 °C, and at strain rates below 10^{-5} s^{-1}.

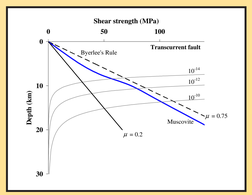

Figure 13: Crustal strength profile comparing Byerlee's Rule with the frictional strength profile for muscovite, drawn using data presented in Figure 5. We assumed a geothermal gradient of 25 °C/km, an average crustal density of 2.75 kg/m³, and a Byerlee friction coefficient of 0.75. The frictional strength profile corresponding to μ = 0.2 is added to represent the strength expected for the San Andreas fault zone on the basis of heat flow measurements[6]. The plastic flow strength of quartz is added following Luan and Paterson, (1992)[7], since this is lower than the flow strength of muscovite under low-crustal conditions.

- In the frictional regime, muscovite fault gouge is, even after strain hardening, weaker than most rocks that obey Byerlee's Rule (μ = 0.60-0.85), but only slightly (*Figure 13*).
- The frictional strength of muscovite gouge is not low enough to explain the weakness inferred for faults, such as the San Andreas fault zone, from geological and geophysical evidence[6].
- Next step: Determine the behaviour of quartz / muscovite mixtures under hydrothermal conditions.

References:

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