Frictional properties of Zuccale Fault rocks from room temperature to in-situ conditions:

Result from high strain rotary shear experiments

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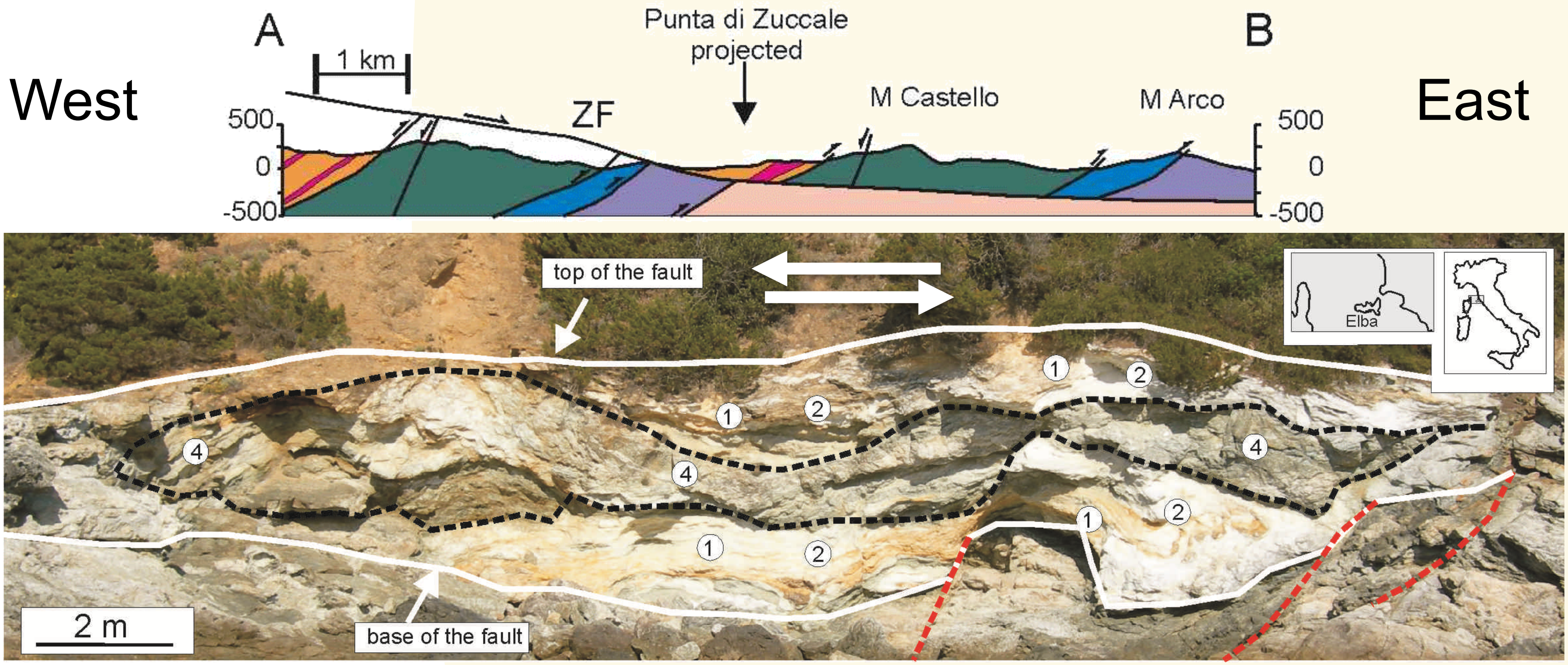
Background – The Zuccale Fault



Viti & Collettini, CMP, 2009
Collettini et al,EPSL, 2011

- Low angle normal fault, dip of ~15°
- Accomodated ~6-8 km displacement
- Exhumed from max. 8 km depth
- Complex geometry & deformation history
- Production of talc from dolomite in high strain domains

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Why the Zuccale Fault?

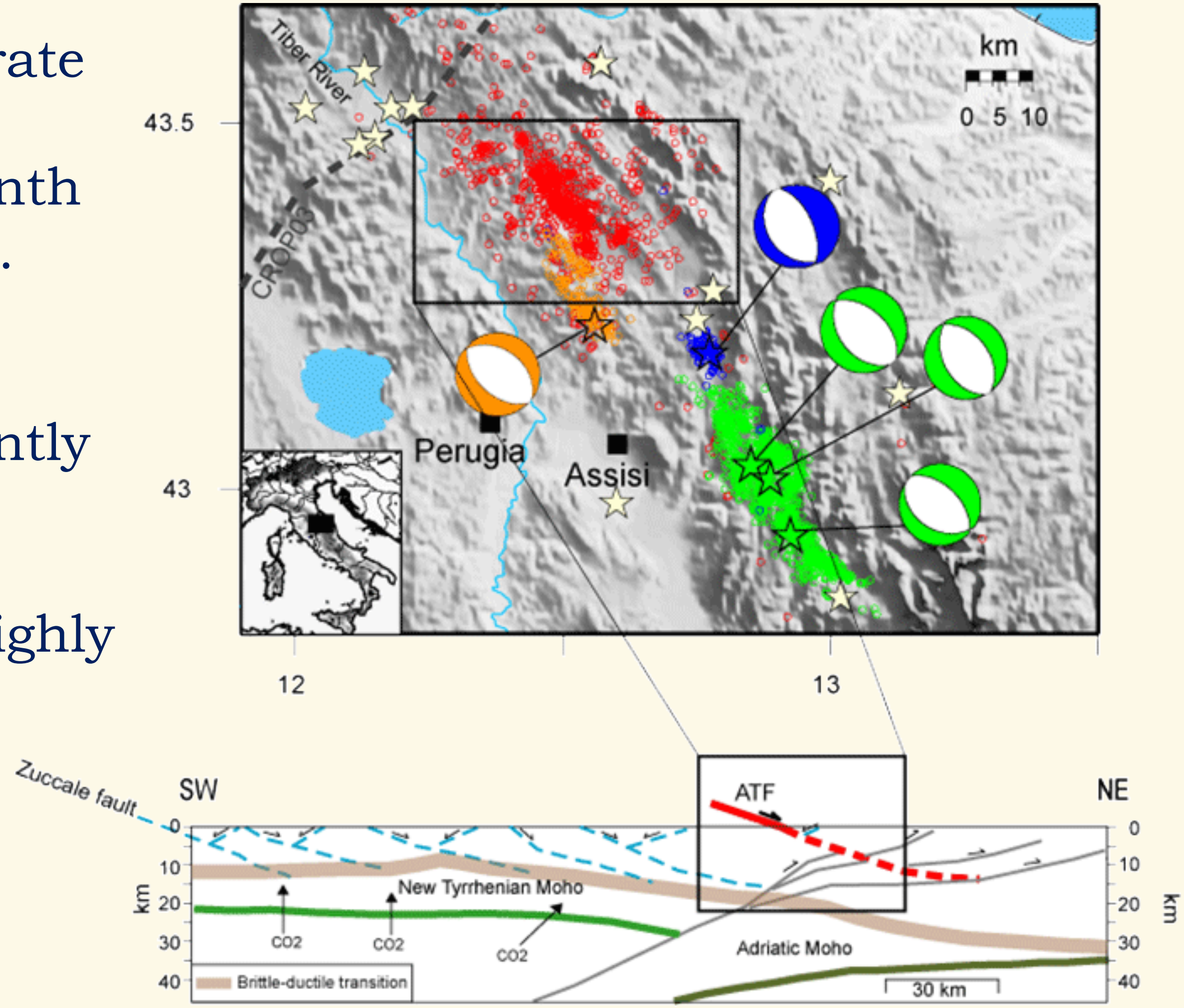
-Analogue for currently active Alto-Tiburina Fault

A) A constant seismicity rate 3.5 event/d, M_L<2.3, recorded during 8 month campaign (2000-2001).

B) Composite focal mechanisms with a gently E-dipping plane.

C) Multiple events with highly correlated waveforms.

Chiaraluce et al. JGR, 2007



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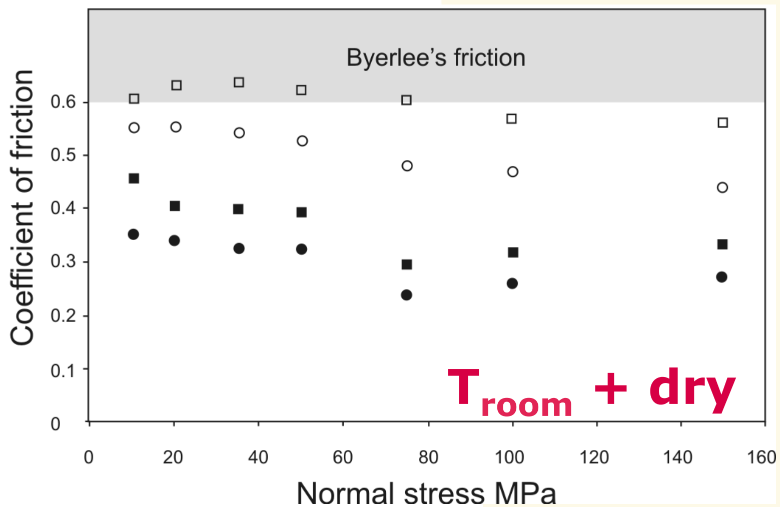
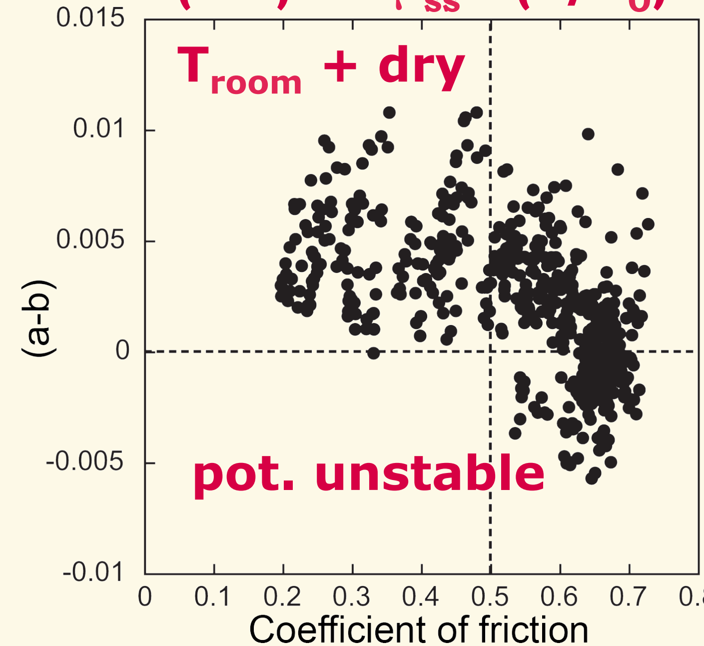
Problem & current aims

- Fault at high angle to σ_1 (vertical) => fault is weak !
- Weakness result of the presence of a phyllosilicate foliation
- But also (micro)seismicity !
-

$$(a\text{-}b) = \Delta\mu_{ss}\ln(v/v_0)$$



Collettini et al, Nature, 2009

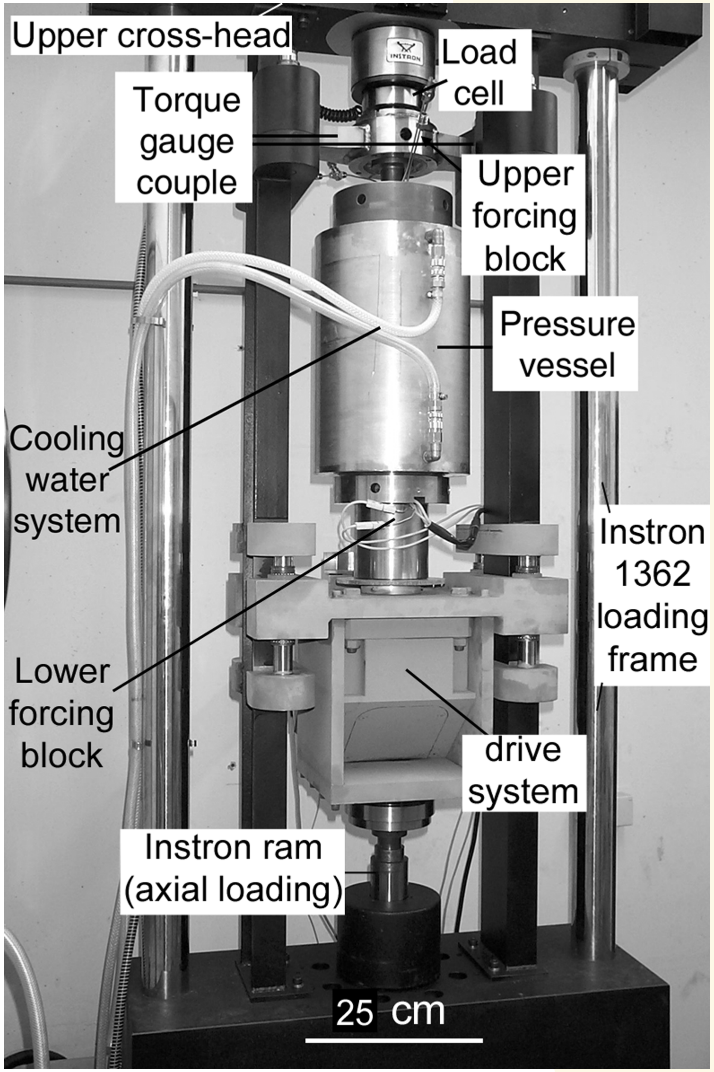


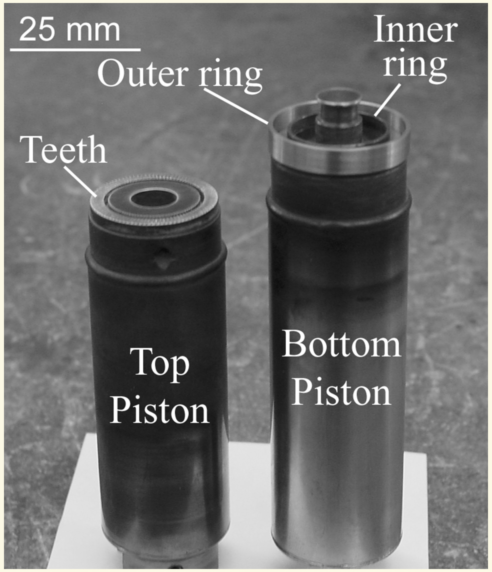
Ikari et al, Geology, 2011

Previous work at T_{room} & dry => hydrothermal conditons:
-Weakening due to talc formation ?
-Effect of temperature on slip stability ?
-Effect of fluid pressure/normal stress on slip stability ?

Experimental apparatus

Hydrothermal rotary shear apparatus at HPT Laboratory





- -Ring-shaped samples 22/28 diameter
- -Internally heated pressure vessel
- -T_{max}=700 °C
- - σ_{nmax}=~300 MPa, P_{fmax}=300 MPa
- -Pressure-compensated piston
- -Displacement rates 3 nm-300 μm/s
- -Infinite displacement

Sample material & procedure

- Simulated analogue of 80/20 wt % dolomite/quartz
- 4 powdered samples from the foliated fault core
- 1 powdered sample from a non-foliated portion (ZF05)
- Phyllosilicate content variable from ~6 wt% up to 58 wt%

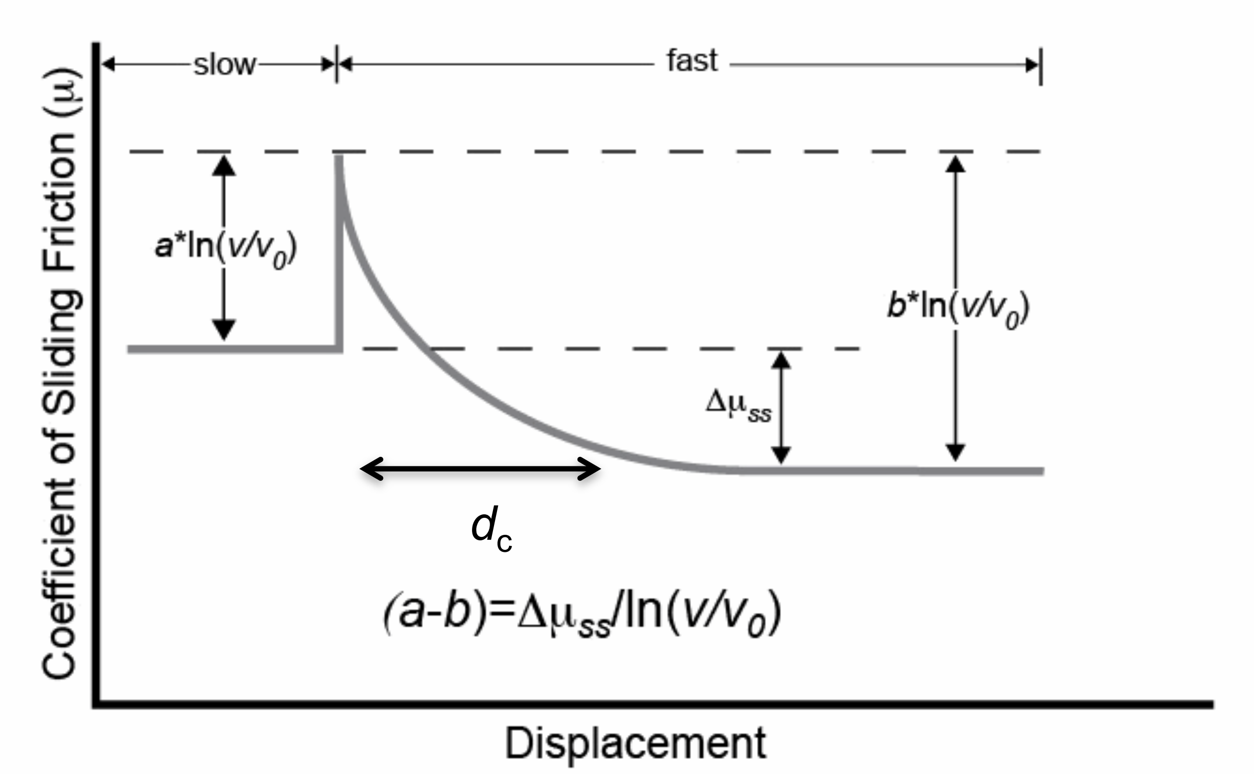
Sample	Calcite	Tremolite	Talc	Clays	Dolomite
ZF01	42	0	56	2	0
ZF02	23	42	22	13	0
ZF03	78	0	16	5	0
ZF04	43	46	0	6	0
ZF05	29	0	7	0	64

~ 1 mm starting thickness

- Run-in at 10 μm/s, followed by velocity-steps from 0.3 – 100 μm/s
- Velocity-dependence of friction expressed as $(a-b) = \Delta\mu_{ss}\ln(v/v_0)$,

$(a-b) < 0 \Rightarrow$ potentially unstable (seismic) slip

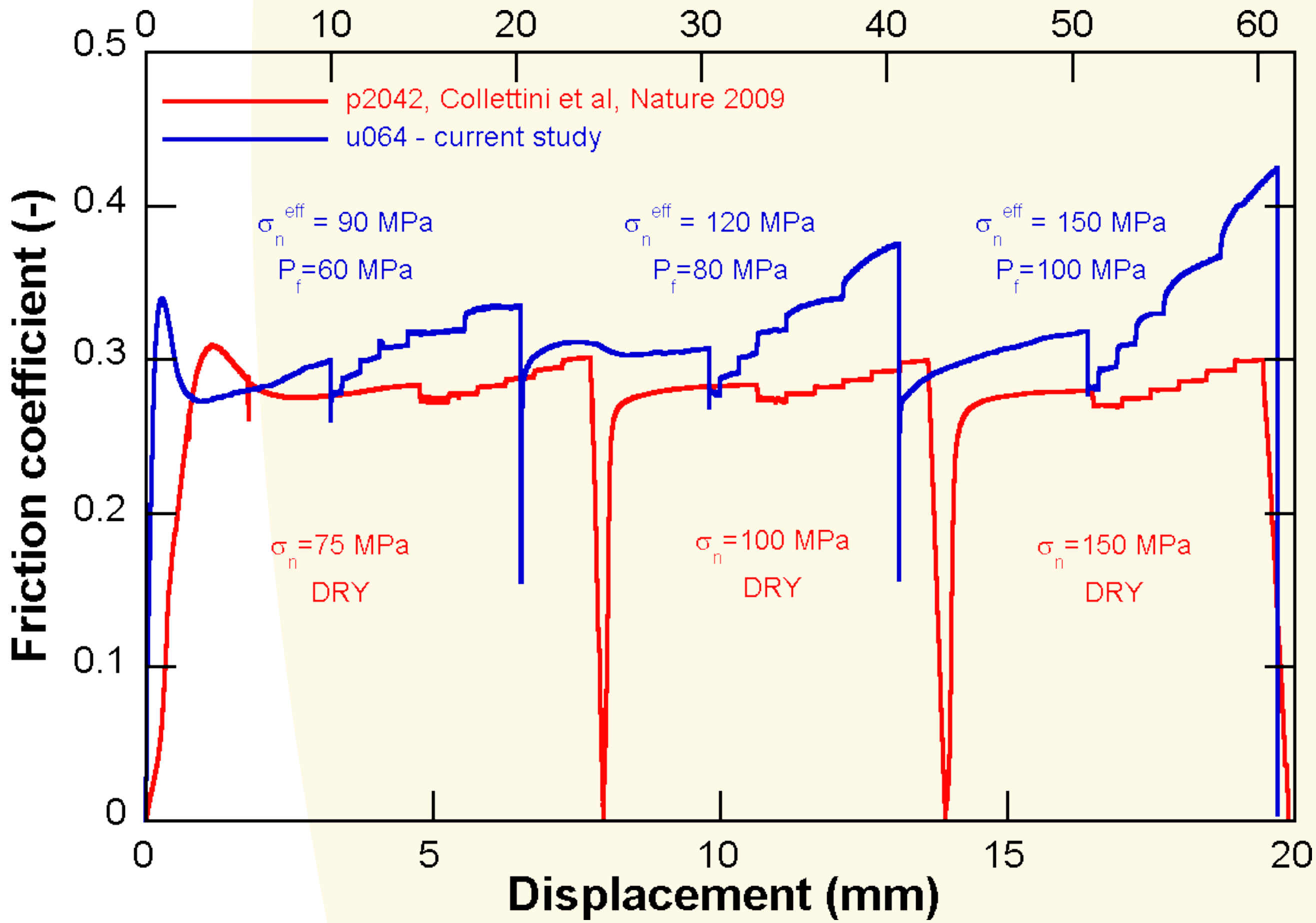
Rate and state friction



$$\mu = \mu_0 + a \cdot \ln\left(\frac{V}{V_0}\right) + b \cdot \ln\left(\frac{V_0 \cdot \theta}{d_c}\right)$$

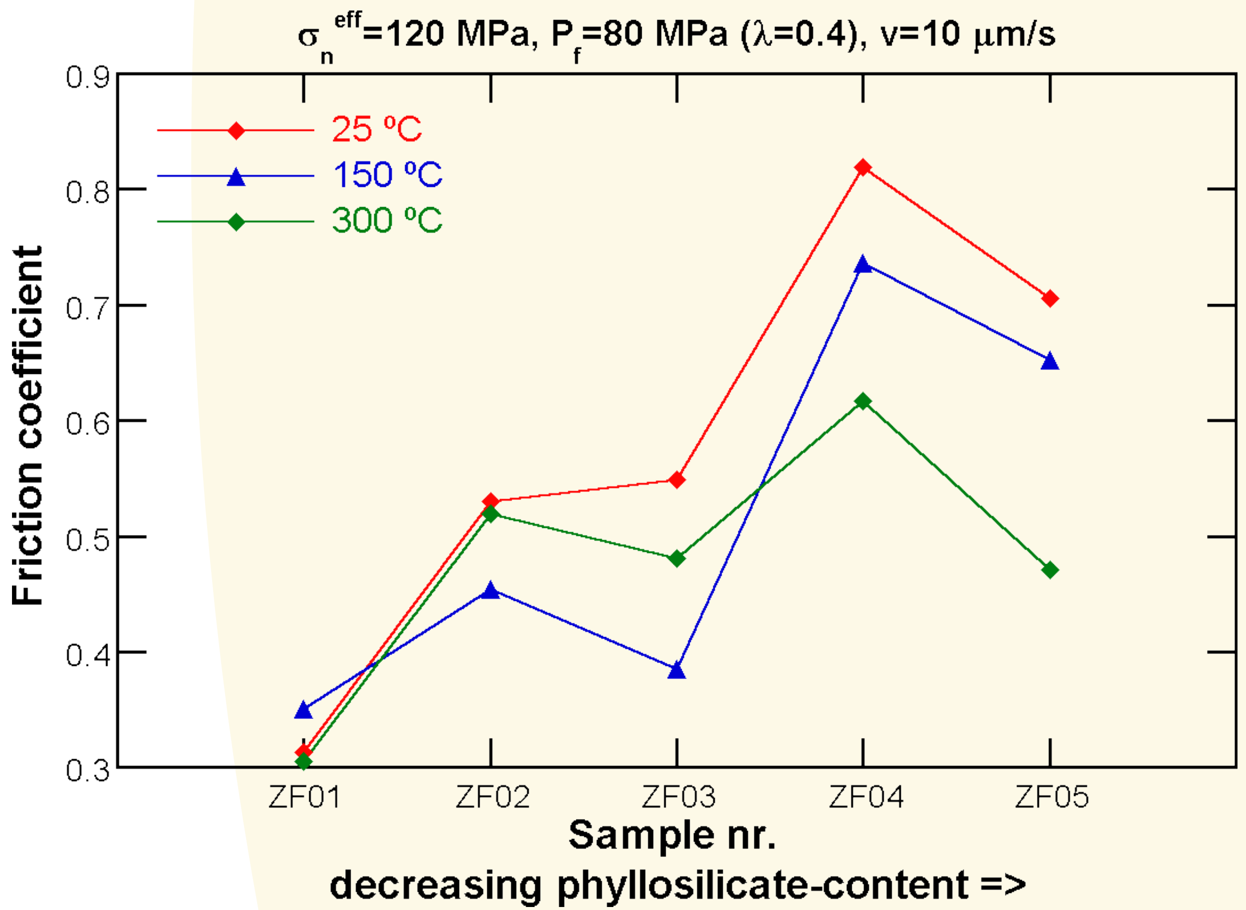
Coupled with Dieterich evolution equation

Results: comparison with previous experiments, talc-rich sample ZF01



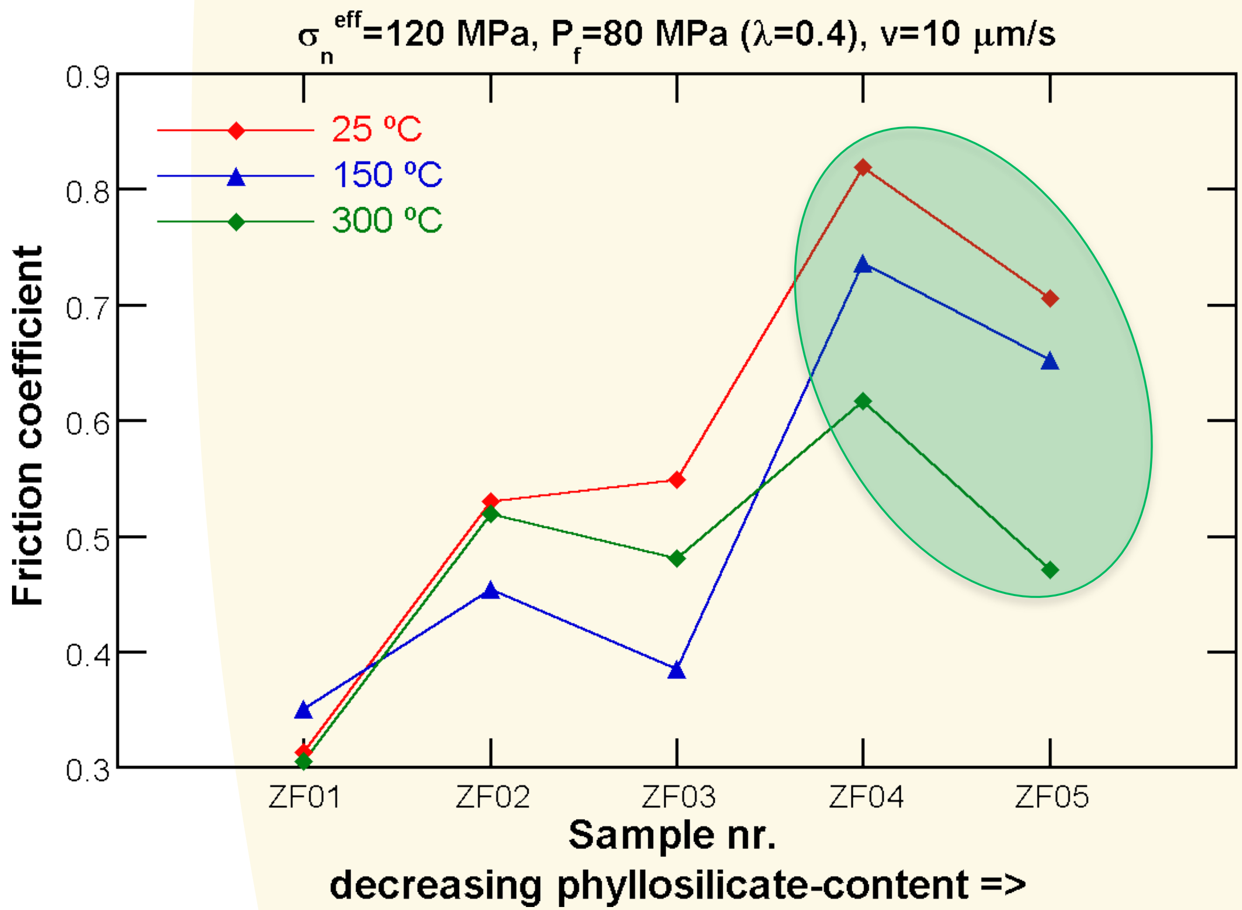
• Presence of fluids at pressure has only small effect on μ
• Velocity-strengthening enhanced

Results – effect of T



- General decrease in friction with increasing phyllosilicate-content
- Some weakening with temperature

Results – effect of T



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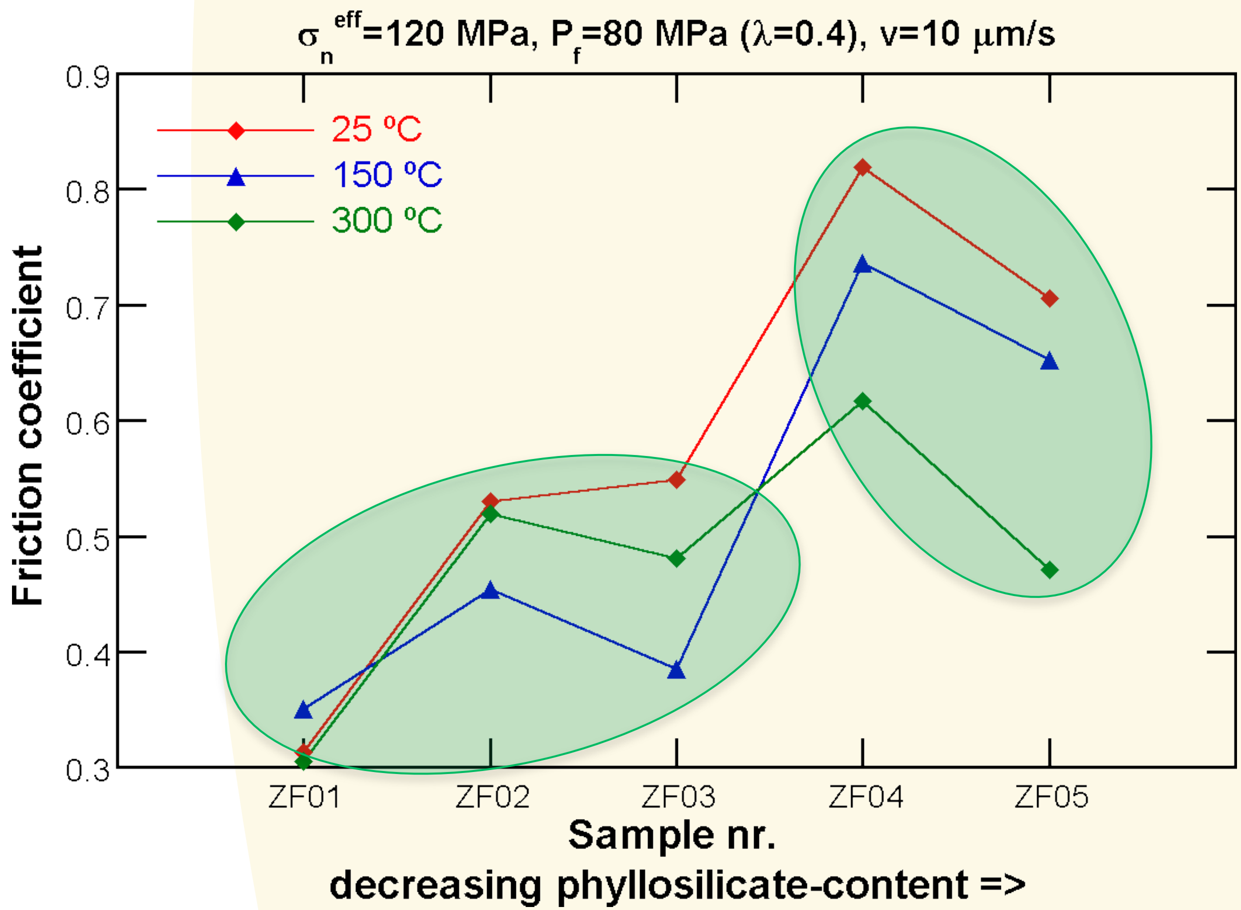
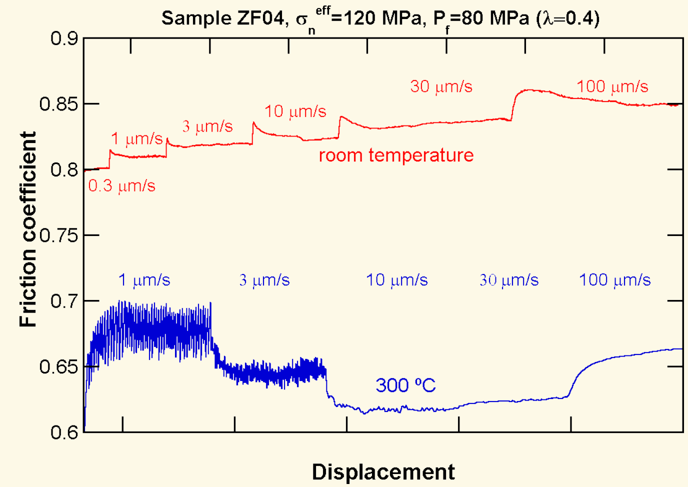
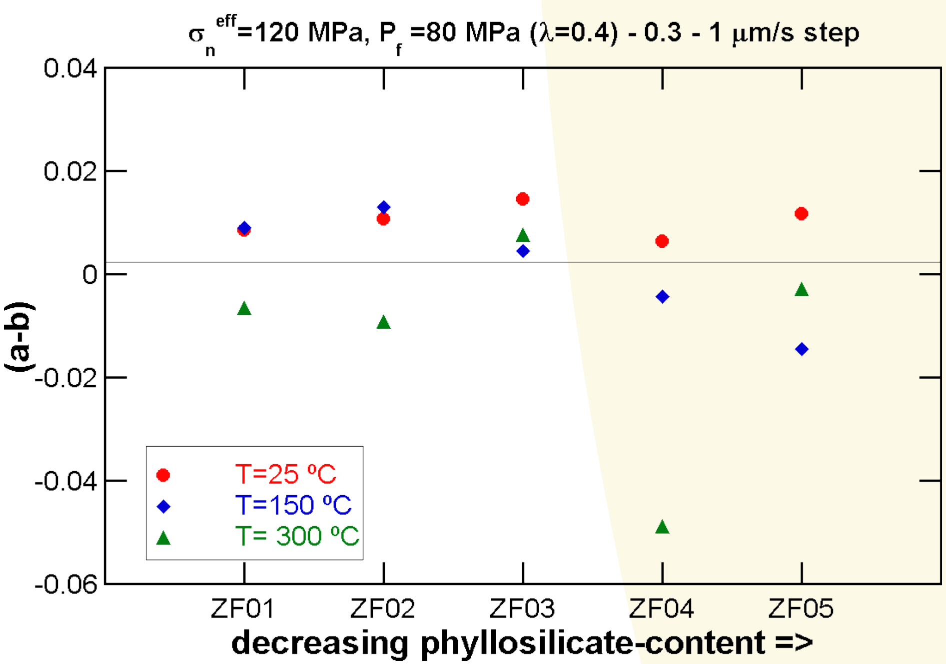


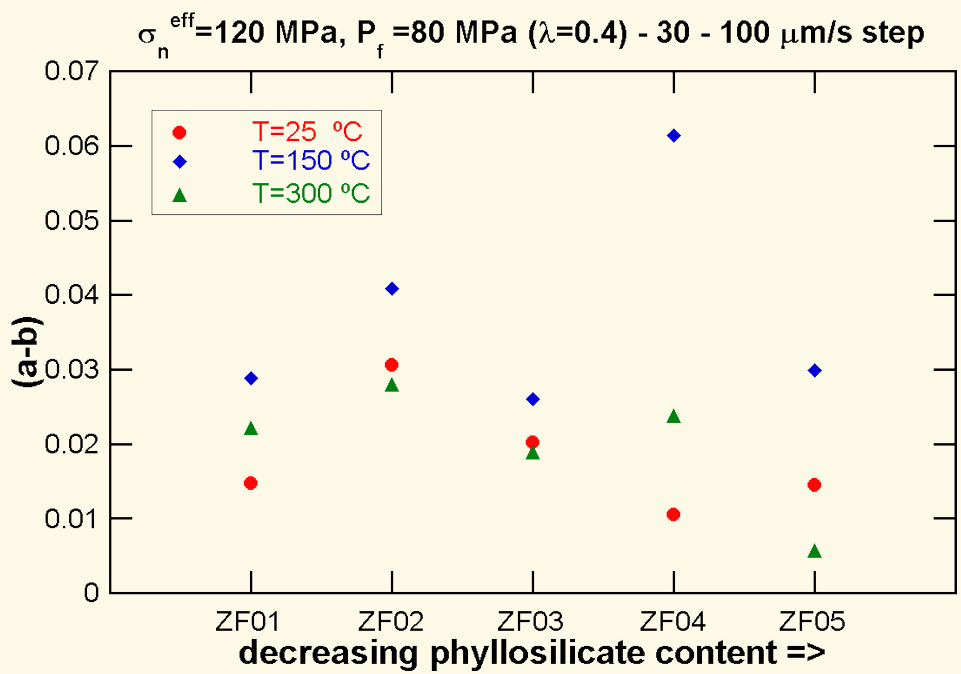
- General decrease in friction with increasing phyllosilicate-content
- Some weakening with temperature

Results – effect of T

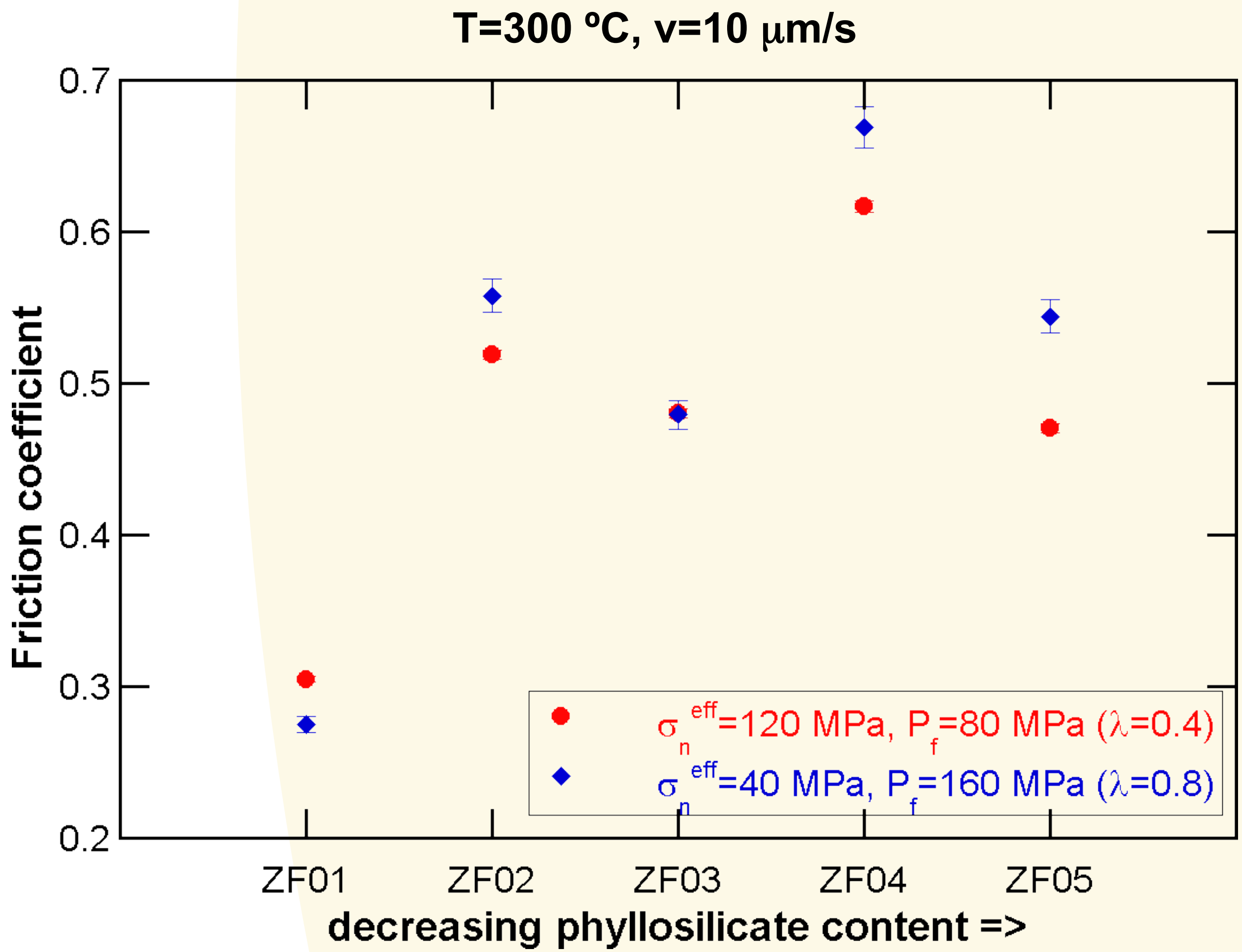
- (a-b) more positive for samples with more phyllosilicates
- Negative (a-b) at T=150 °C & 300°C and low v
- In some cases unstable slip observed
- (a-b) increases with increasing velocity







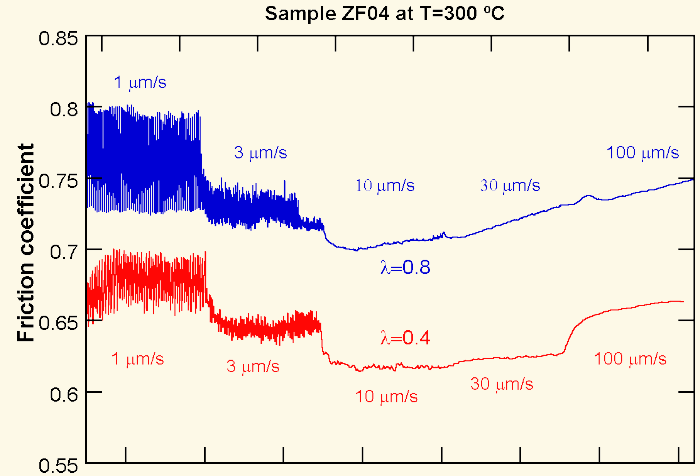
Results – effect of P_f & σ_n^{eff}

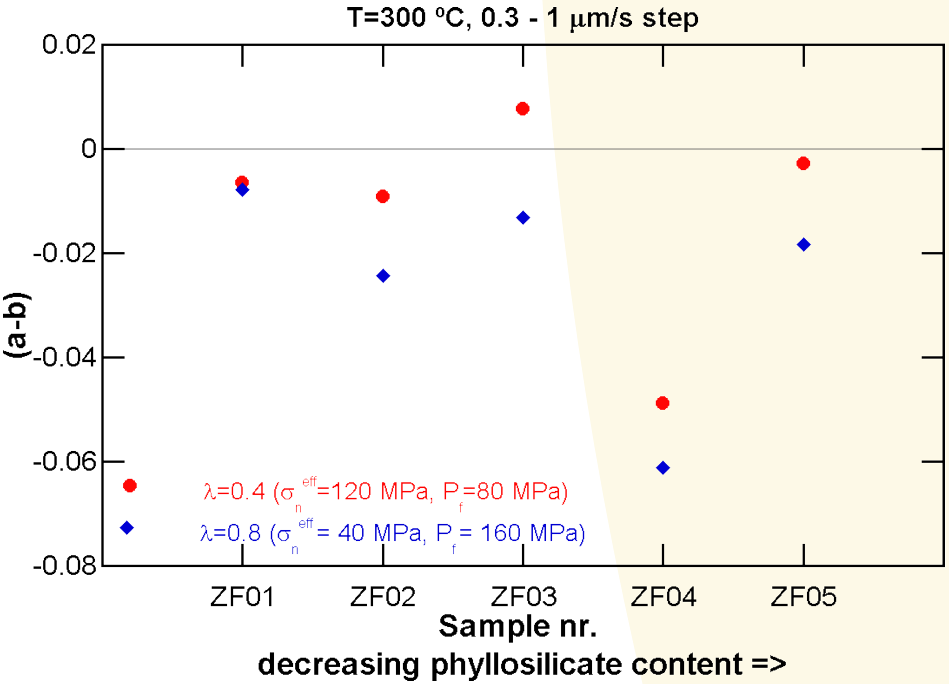


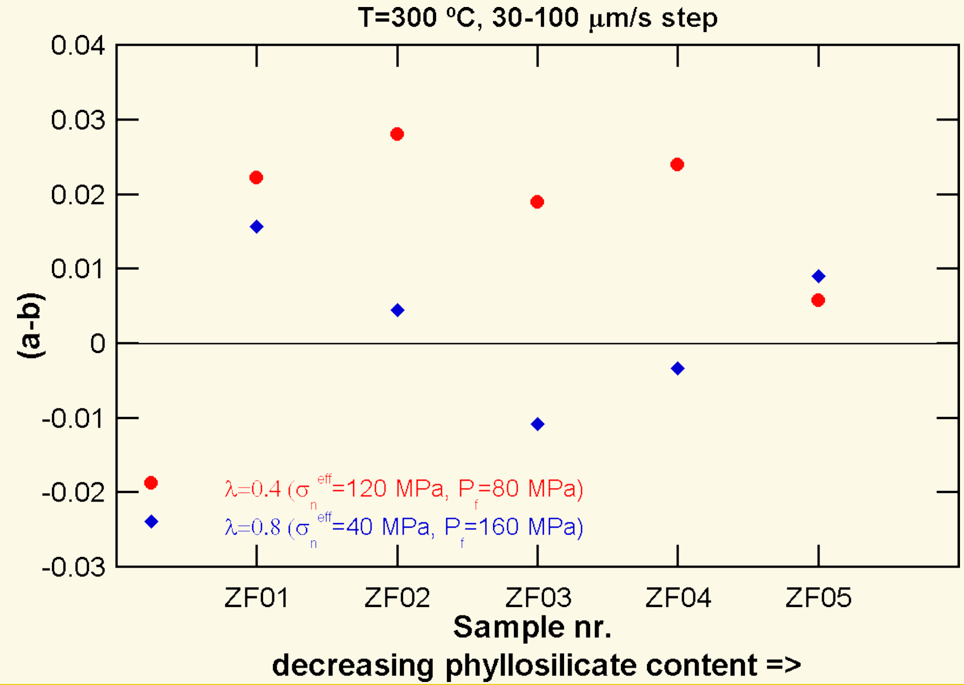
- Only small effect on friction coefficient in all samples

Results – effect of P_f & σ_n^{eff}

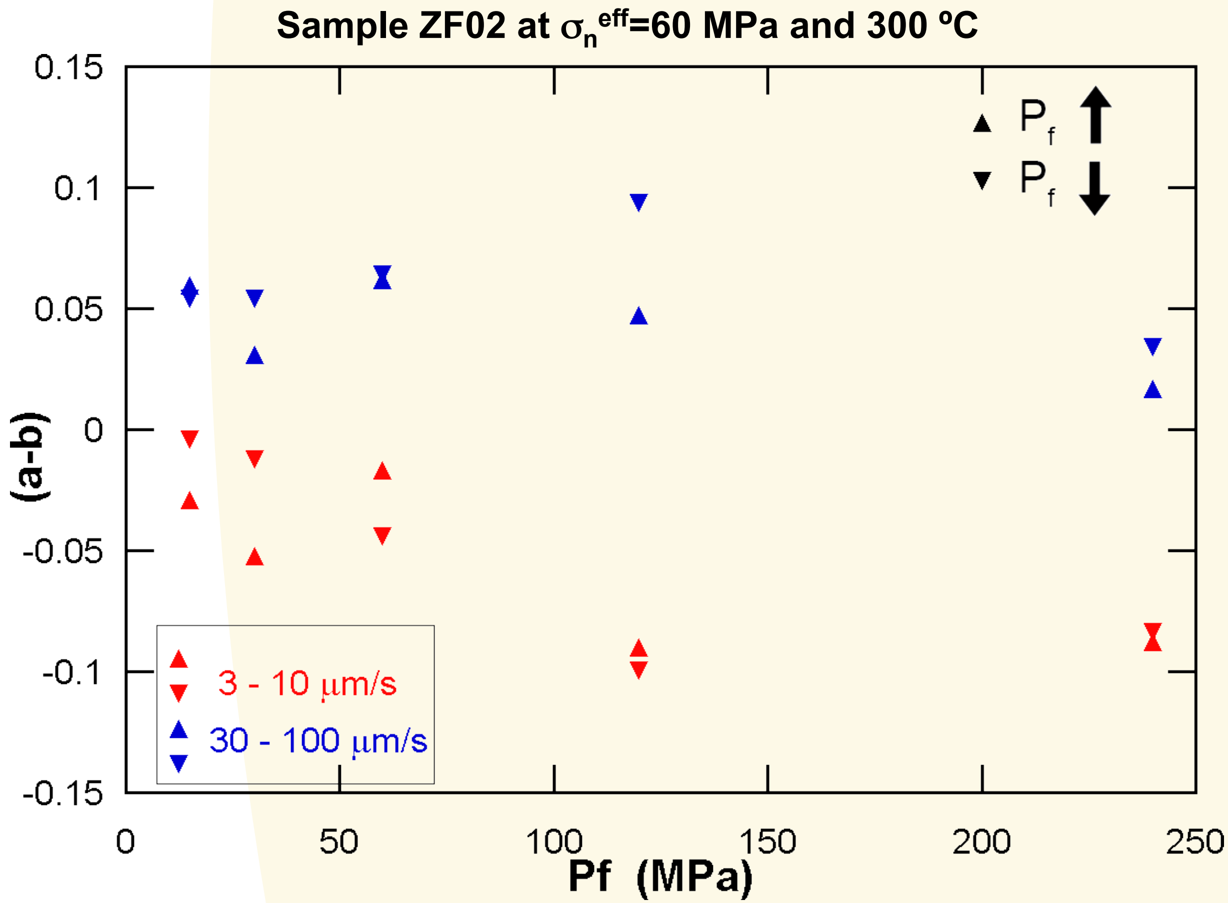
- Larger stick-slip events at high P_f & low σ_n^{eff}
- (a-b) decreases with higher P_f & lower σ_n^{eff}
- No effect on velocity-dependence of (a-b)





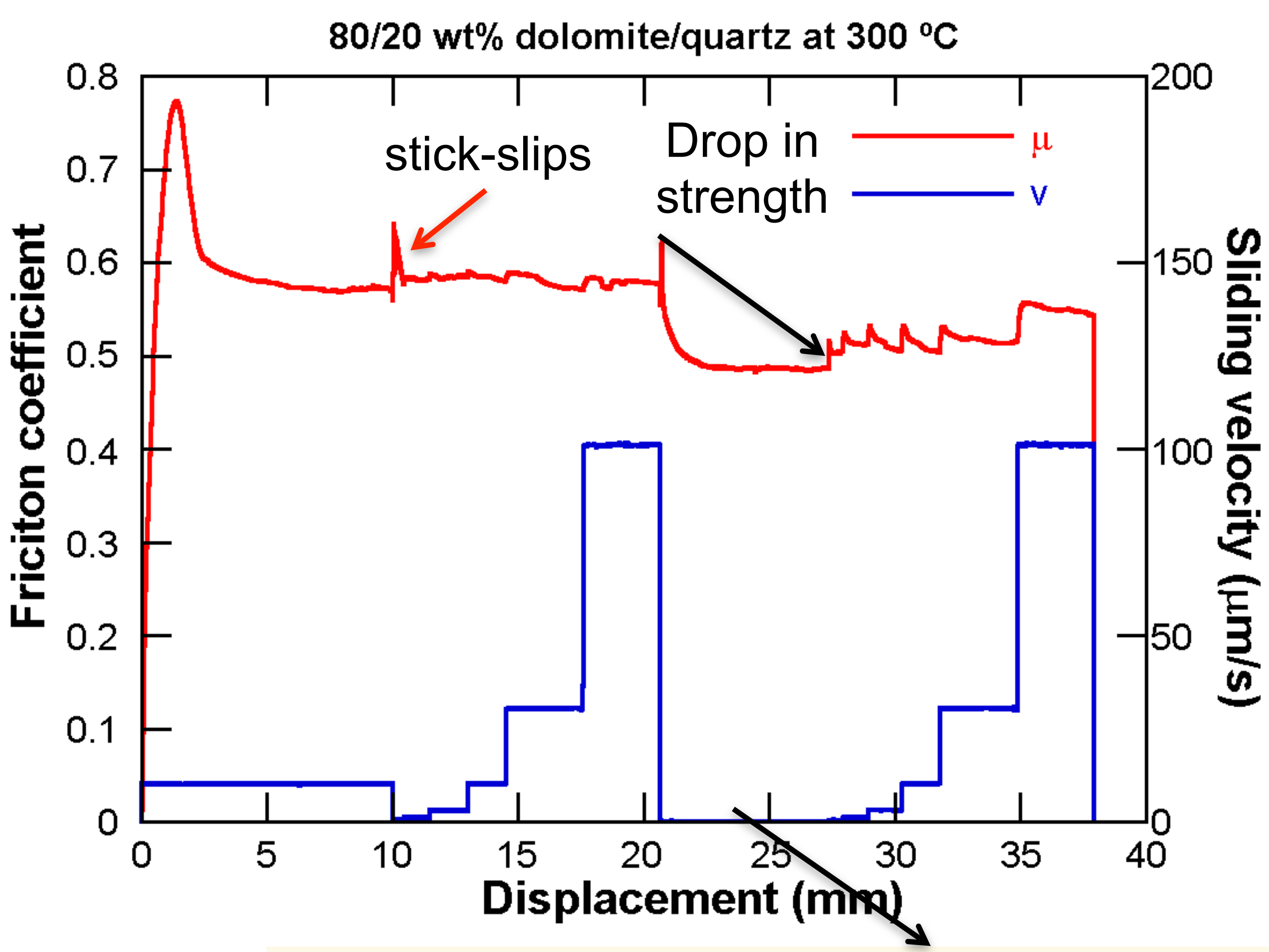


Fluid pressure or effective stress?



- Effect depends on velocity
- Smaller (a-b) when $P_f \geq 120$ MPa
- Strain has little effect

Weakening due to talc production
Starting material: 80/20 wt% dolomite/quartz
σ_n=120 MPa, P_f=80 MPa



slow shearing for 76 hours

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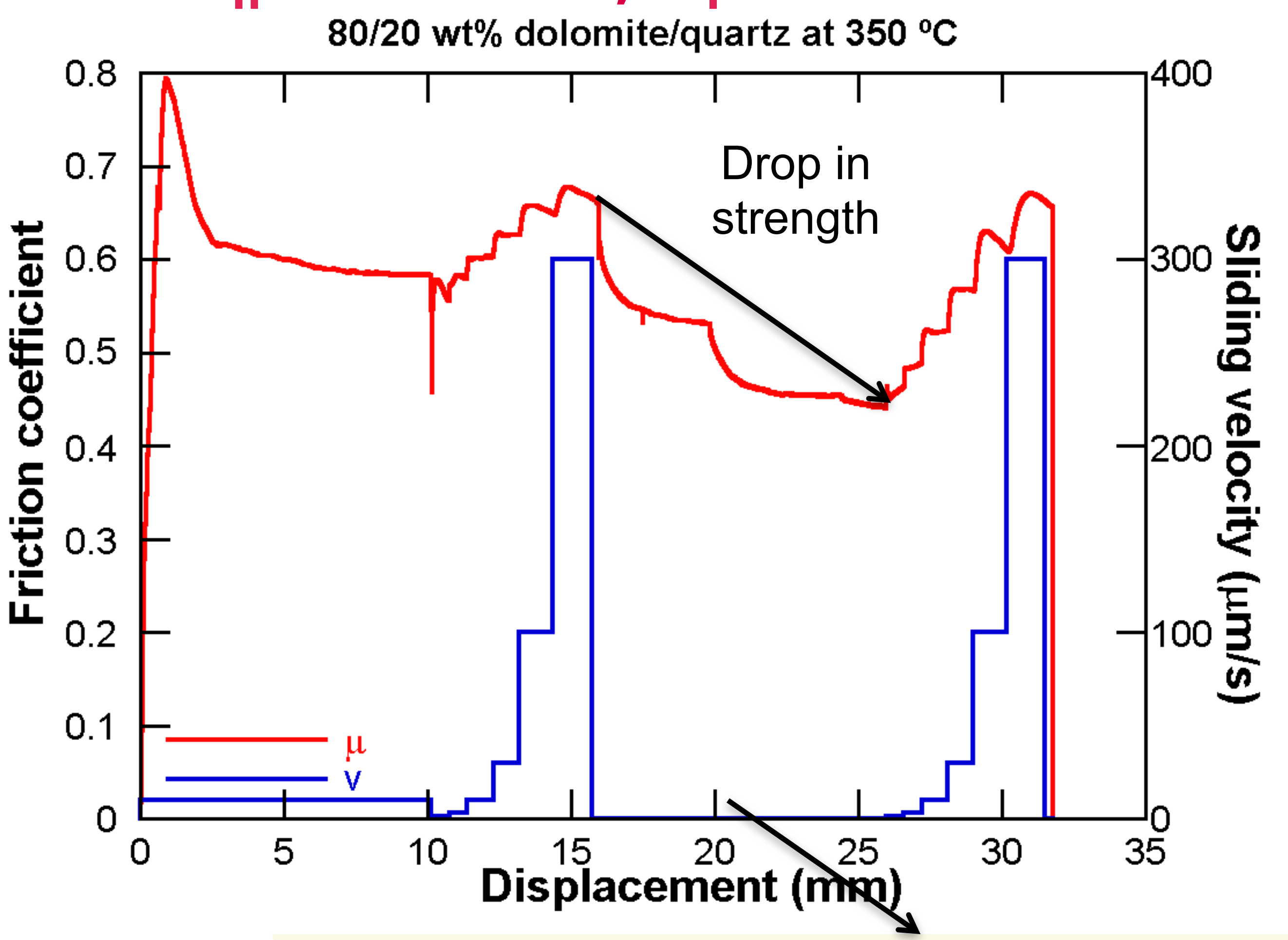

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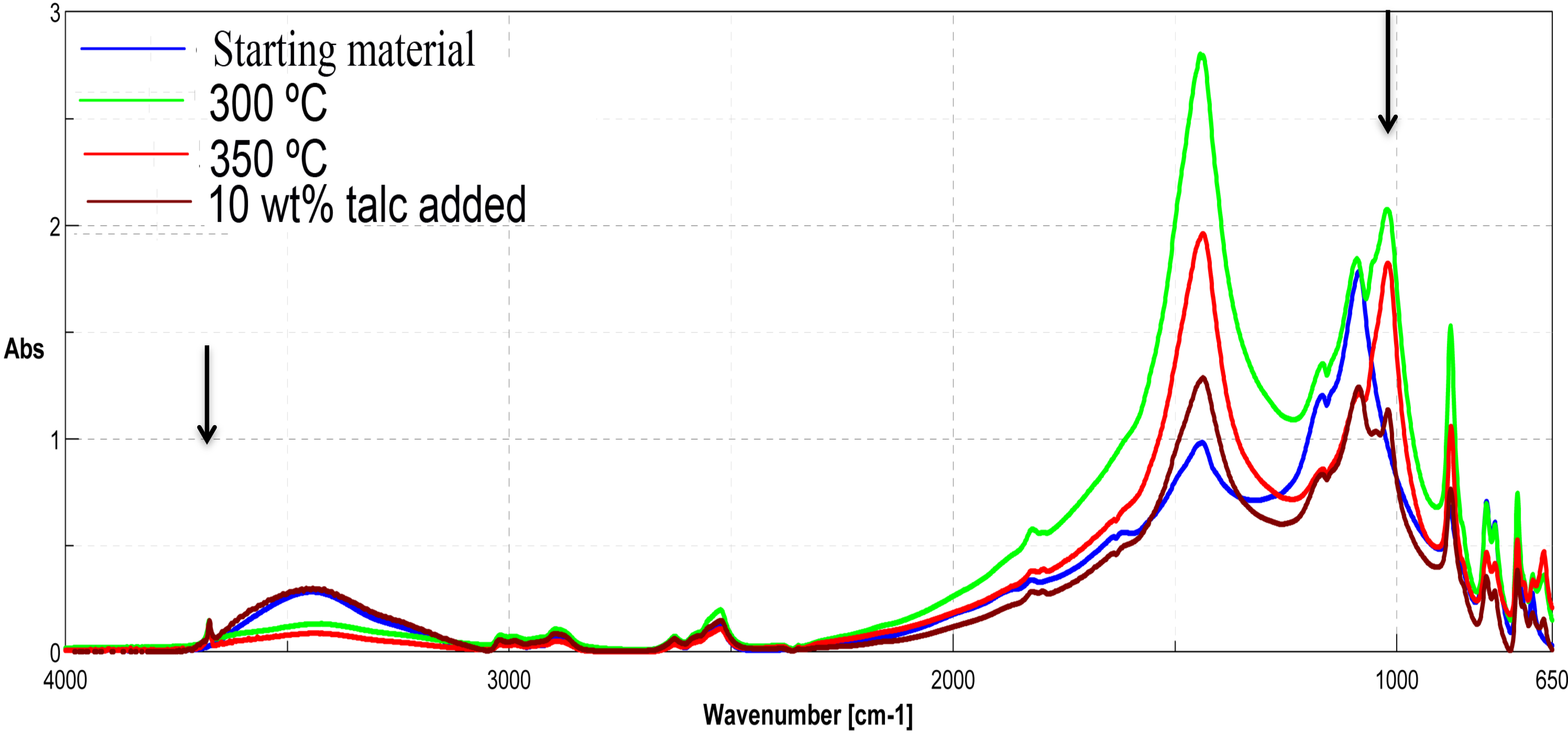

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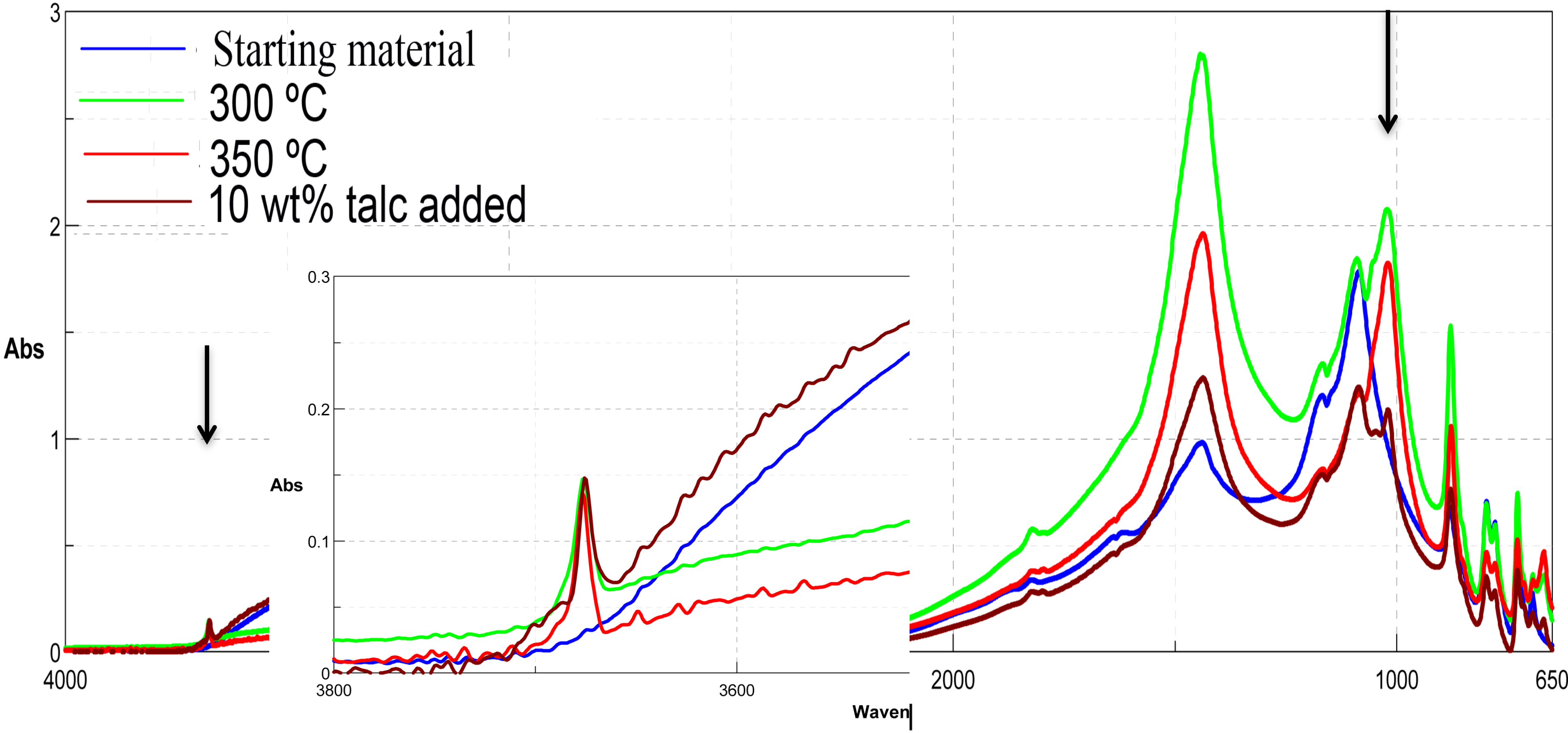

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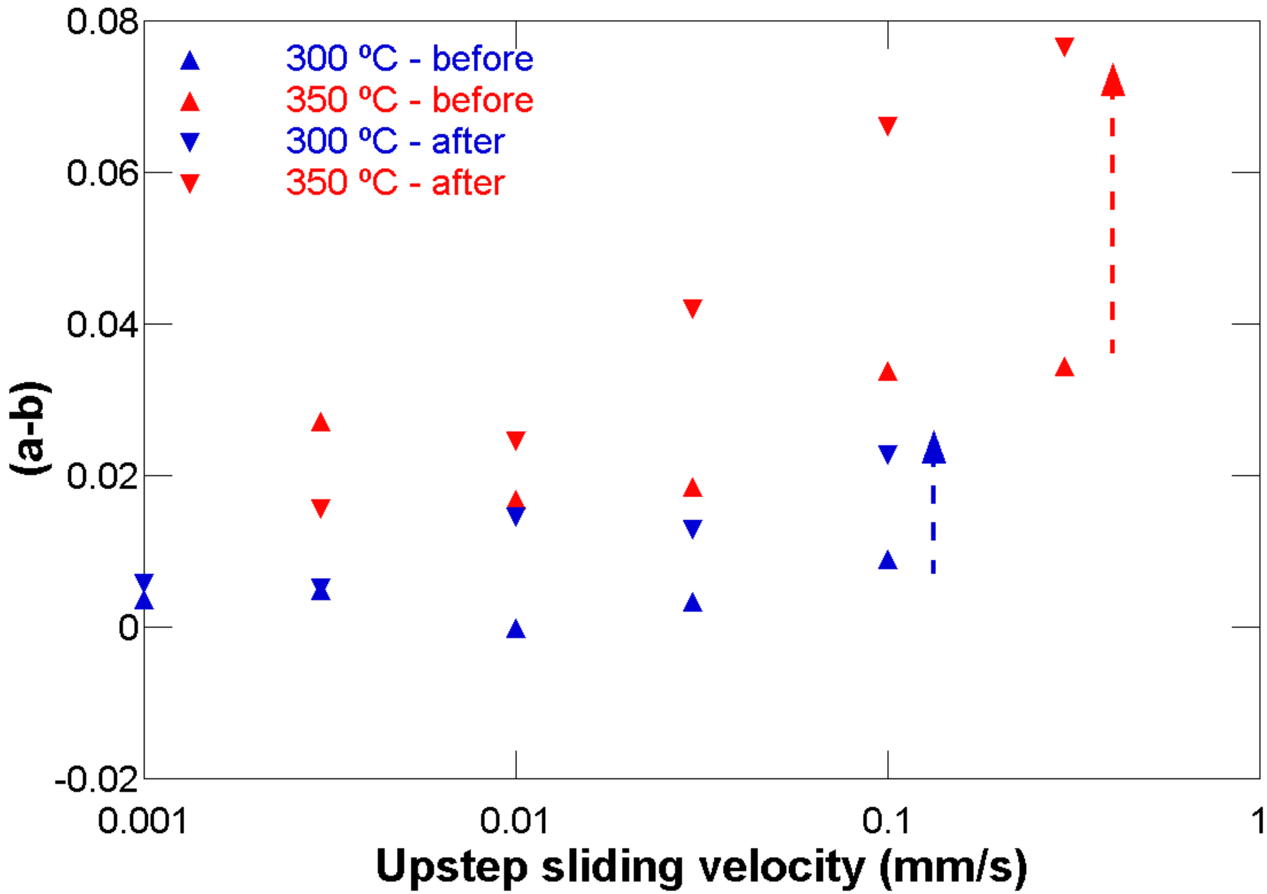

Significant change in (a-b) !

Summary

1. Large variation in strength of fault units as a function of the amount of reaction products (notably talc).

2. The velocity dependence of friction of Zuccale fault rocks under hydrothermal conditions depends strongly on the velocity.

3. Strong portions of the fault show the potential for unstable, seismic slip at elevated temperature and low sliding velocity.

4. Negative velocity-dependence of friction is more pronounced at elevated fluid pressures and low effective normal stresses.

5. Change in (a-b) due to mineral reactions at low velocity

6. Velocity dependence of friction controlled by a time-dependent,thermally activated, fluid-assisted process ?
   Similar velocity-dependent behaviour observed in calcite gouges at 100-150 ºC (Verberne et al., BSSA, 2011)
   Stability controlled by carbonate-content ?

Thank you !