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Slow-to-fast transition of giant creeping rockslides modulated by undrained loading in basal shear zones

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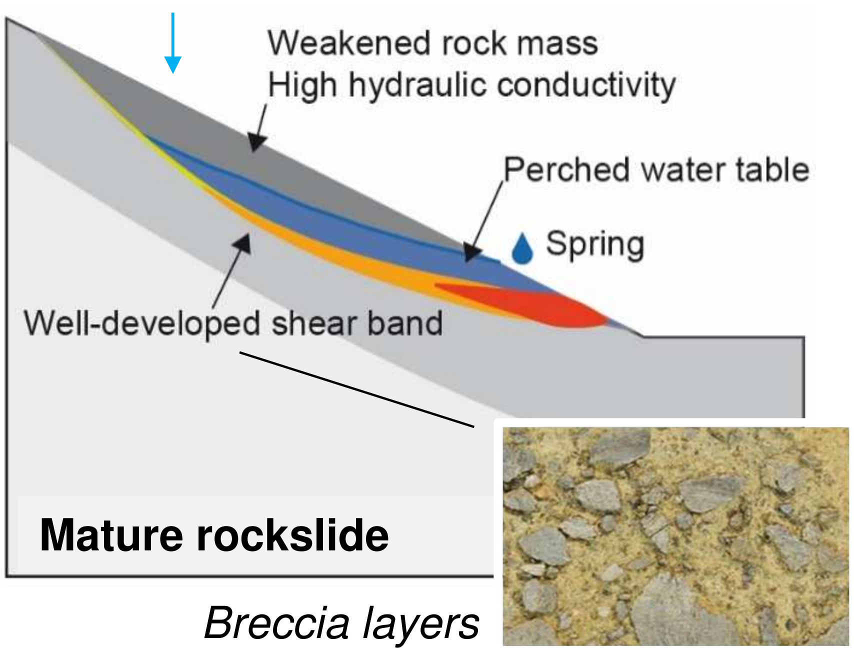
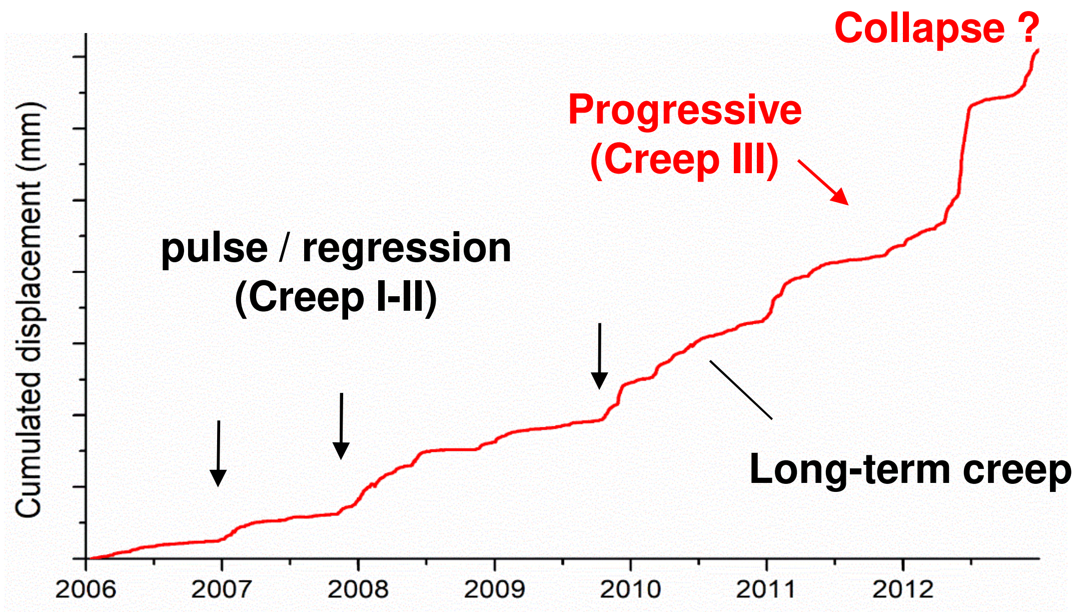
Motivation: time-dependent rockslide behavior





“mature” giant rockslides:

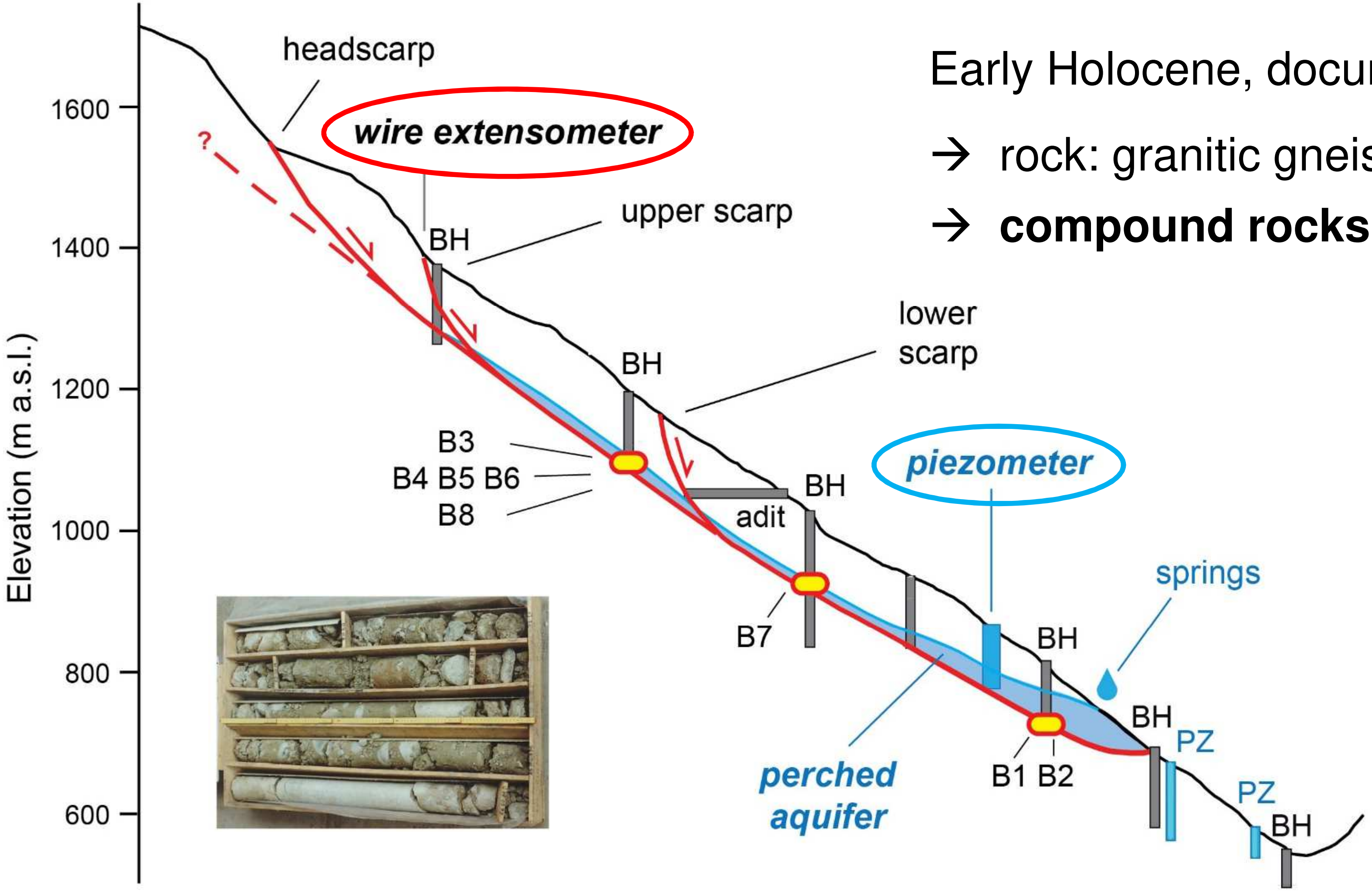
→ well-developed **cataclastic basal shear zones**

→ **full spectrum of creep behaviors**

→ dominated by **friction** in granular materials and **hydro-mechanical coupling**

<u>Predictive models: often incomplete or lacking experimental support</u>

Spriana rockslide *(Val Malenco, Italian central Alps)*



Early Holocene, documented since 1878

→ rock: granitic gneiss

→ **compound rockslide**, **50 Mm³**

→ **basal shear zone**: max depth: **95 m**, inclination: **28-35°**

→ **cataclastic breccia** layers - **perched water table**

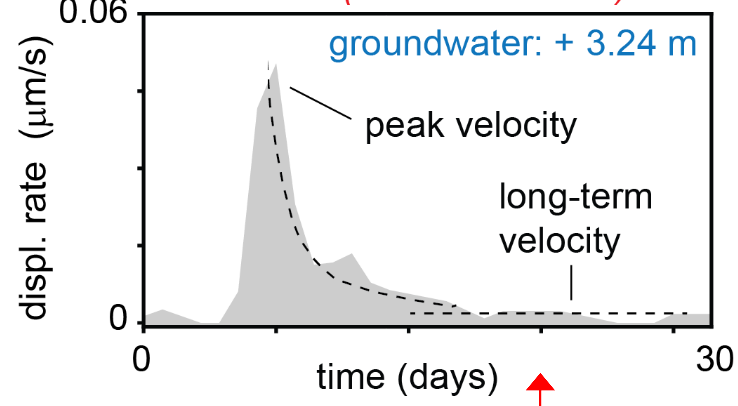
→ relatively small internal deformation

Spriana rockslide: in situ behavior

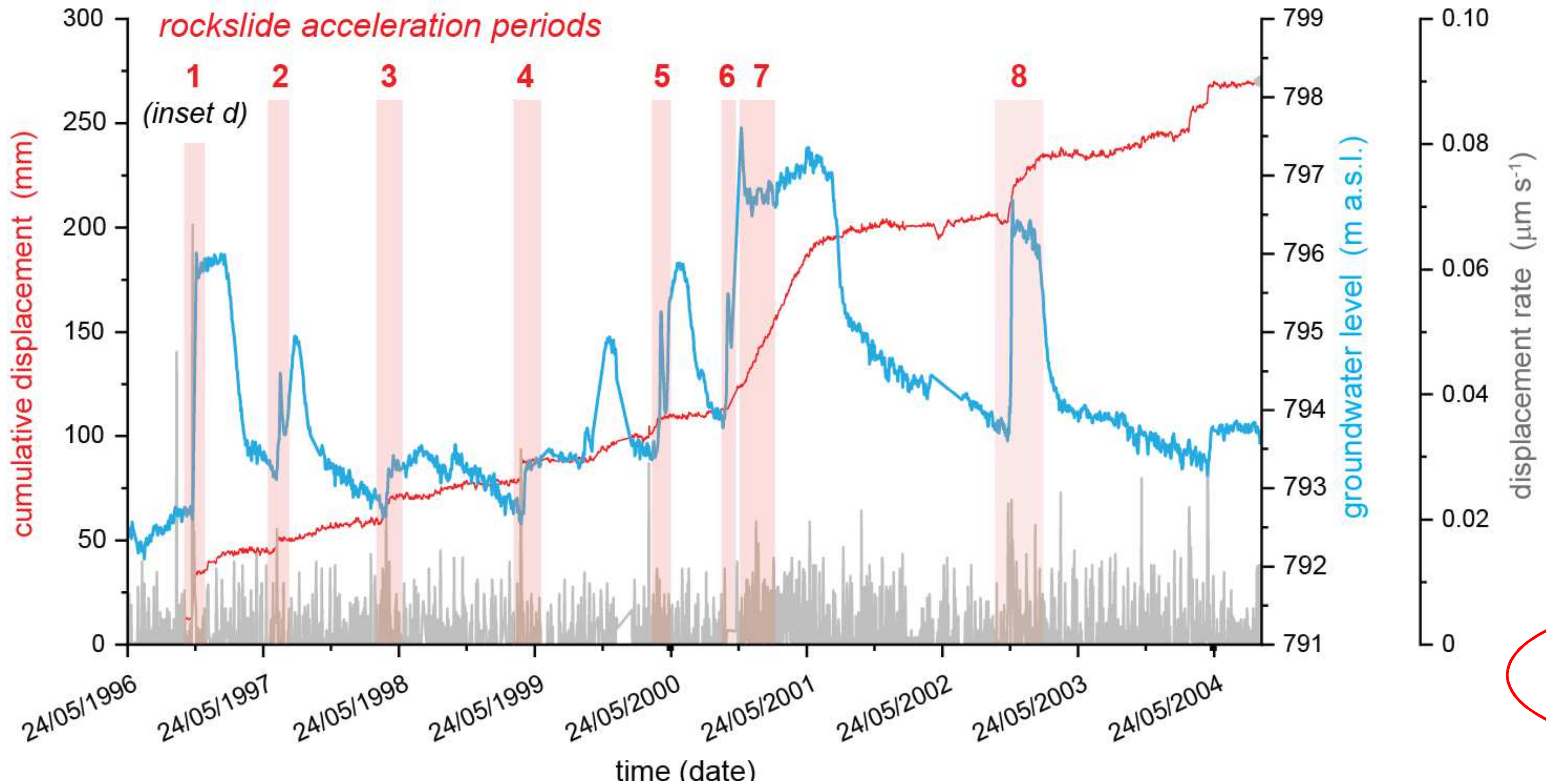
→ **long-term creep** (5-30 mm/yr) + **pulses**

→ trigger: rainfall, GW table rise > 2m

→ **acceleration pulses** + **deceleration**



8 acceleration periods



with sustained GW level

mechanisms?

Tested shear zone material

High-quality drillcores (depth: **85-90 m**)

→ grain size distribution
→ quantitative XRPD
→ X-ray CT (0.5 mm)
→ standard direct shear tests

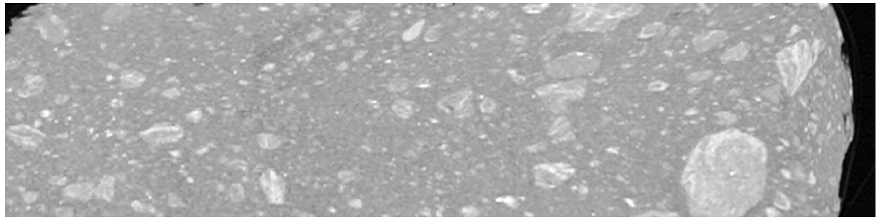
Breccia supported by silty-sandy matrix, sub-angular clasts up to 2.5 cm, no preferred orientations **(cataclastic texture)**

Lab experiments on fraction < 600 μm

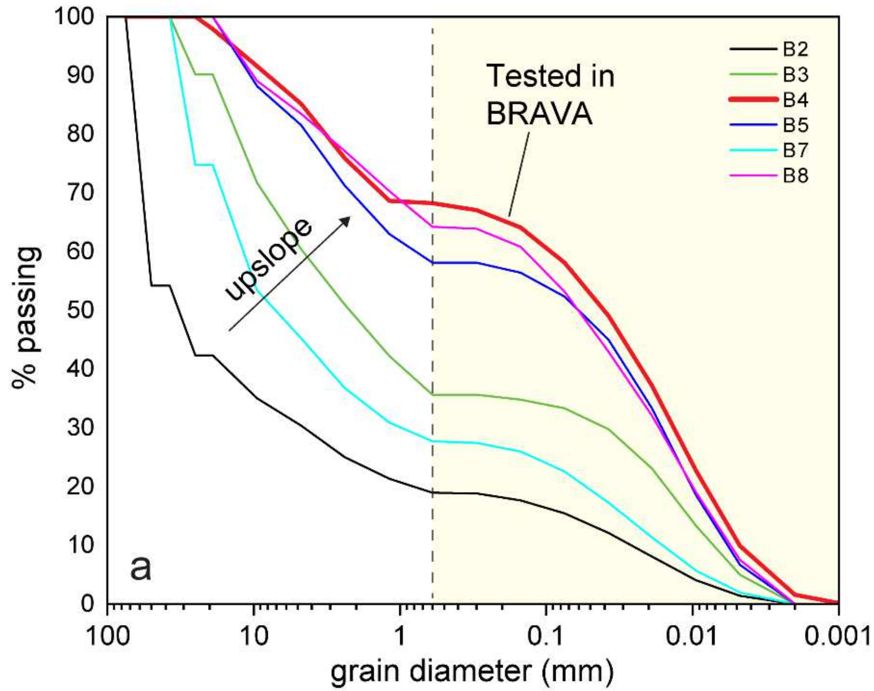
Mineral composition (% weight, XRPD)

quartz (Qz)	19-21
K-feldspar (Kfs)	34-38
white mica (Wm)	30-39
chlorite (Chl)	1-10
Amphibole (Amph)	3-5

Total phyllosilicate: **40%** - all size fractions



density: *1.92* *X-ray MIcroCT scan*

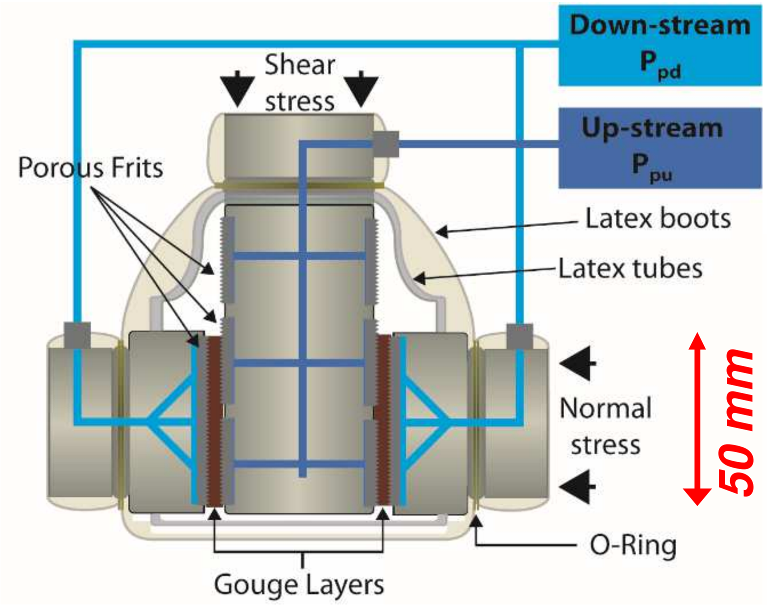


Experimental set up

→ **biaxial apparatus** within a **pressure vessel**
→ double **direct shear** configuration

Pore pressure / effective stress:

→ confining **Pc**
→ up / down **pore pressure** lines

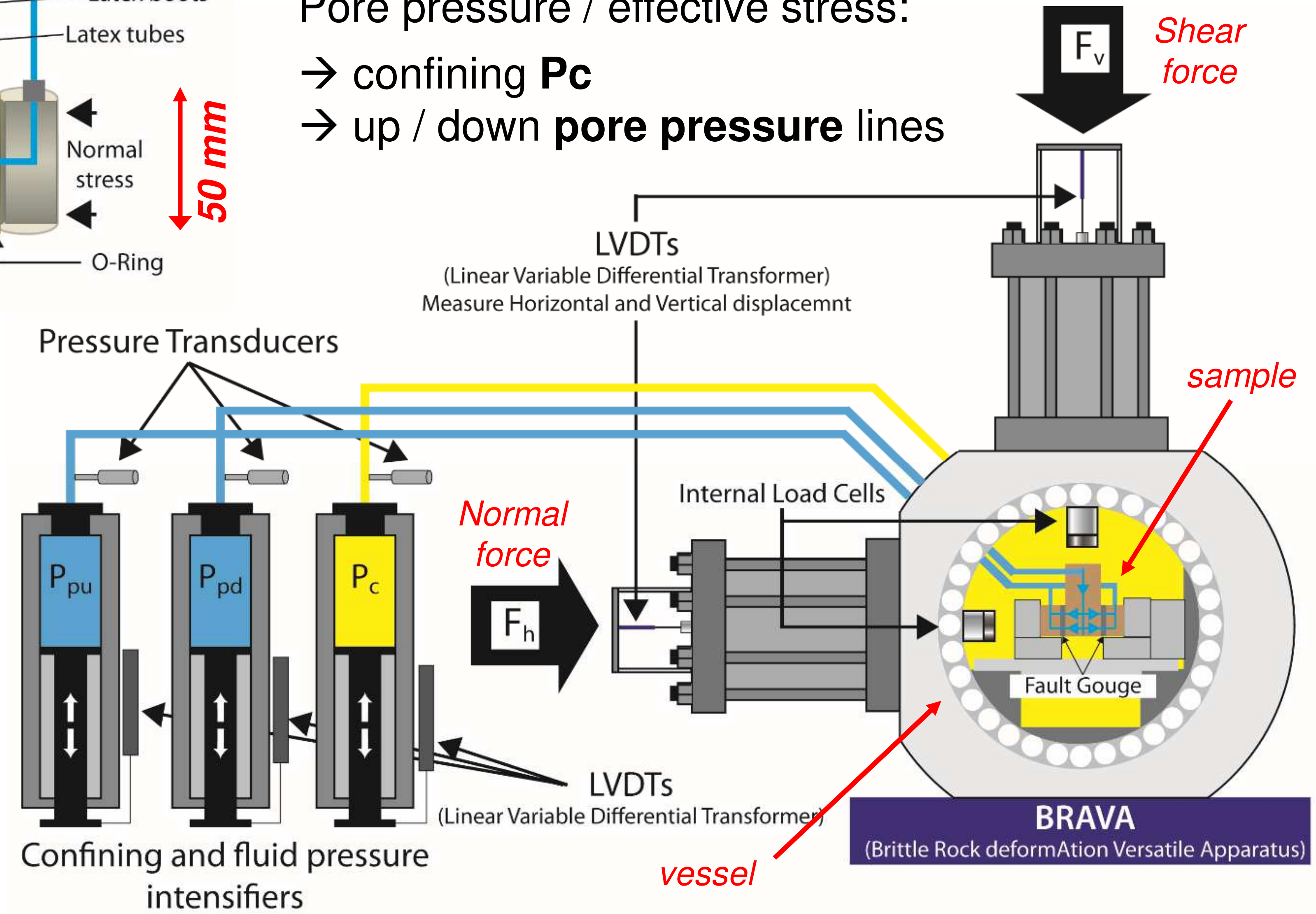


Sample assembly

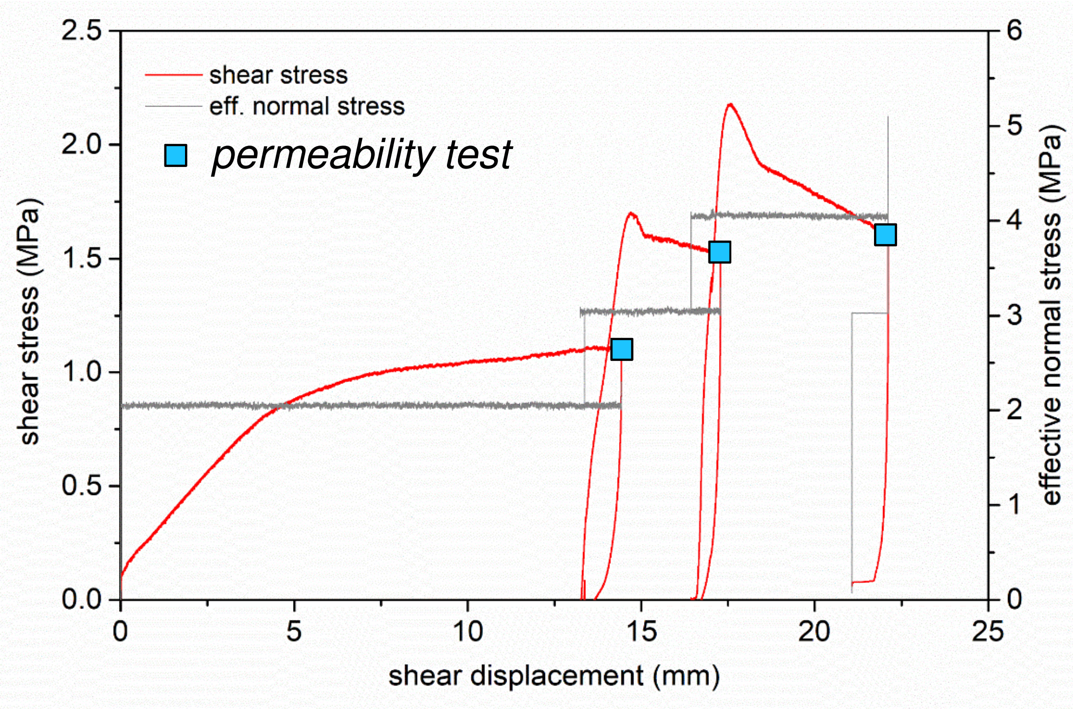
$$\sigma_n' = (\sigma_n + P_c) - P_f.$$

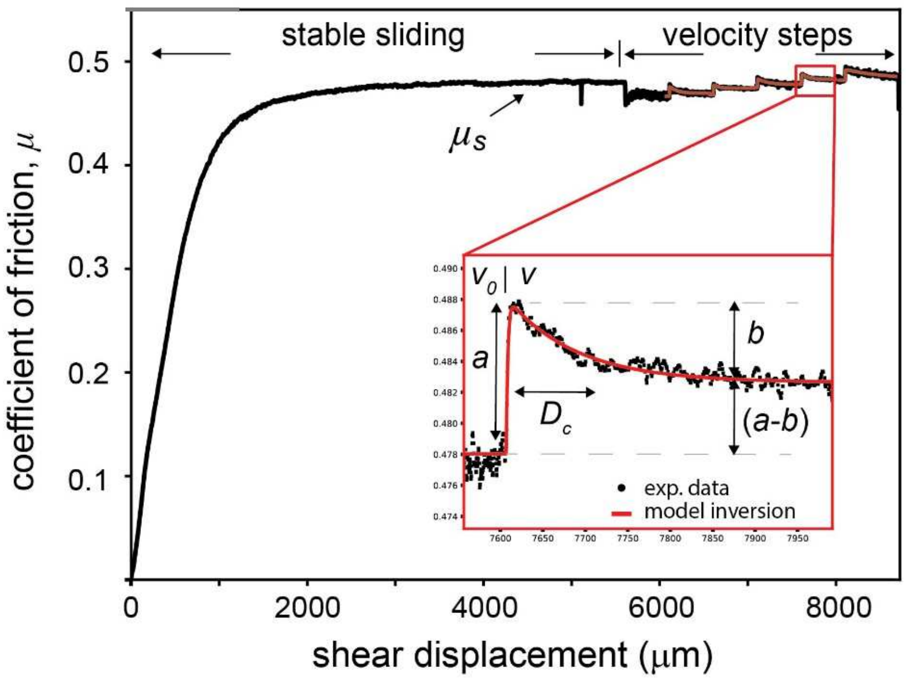
Latex jacket

Collettini et al. 2014
Scuderi & Collettini 2016



Laboratory experiments (1)





(A) **<u>stable-sliding shear experiments</u>**

→ effective **σ'$_n$**: **2,3,4 MPa**

→ displacement control (10 μm/s)

→ **Mohr-Coulomb** envelope

→ **hydraulic conductivity**

(B) **<u>velocity step experiments</u>**

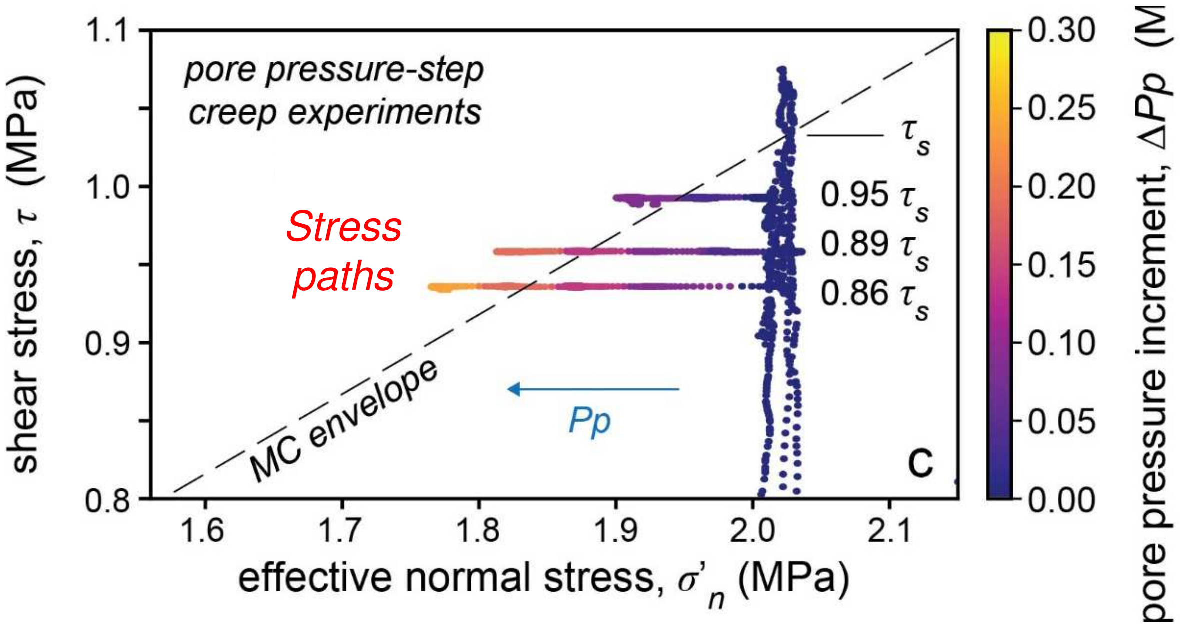
→ effective **σ'$_n$** : **2 MPa** (**situ**)

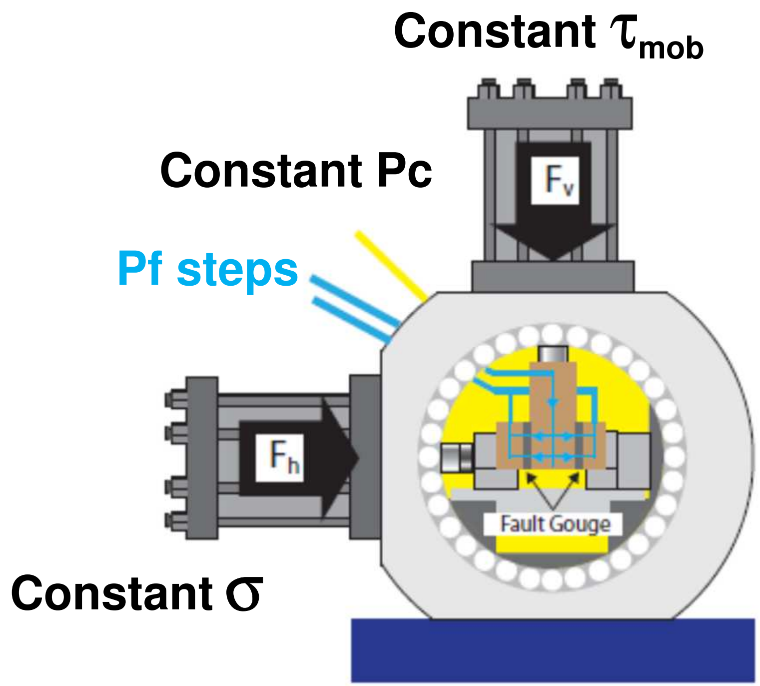
→ **dry** vs. **saturated** material

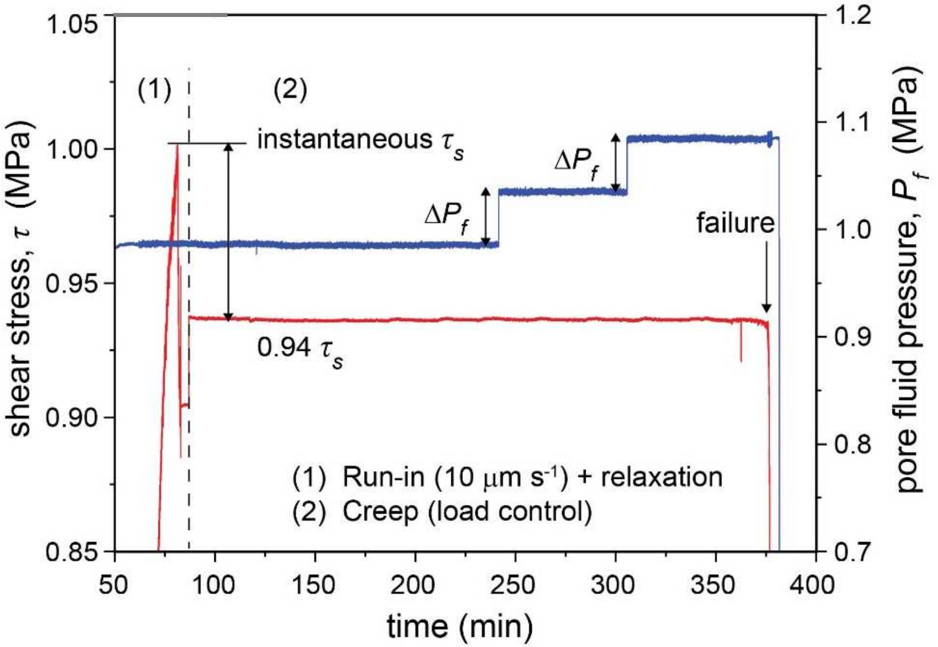
→ shear rate: **0.1-300 μm/s**

→ **rate-and-state** modeling

Laboratory experiments (2)







(C) Pore pressure-step creep exp.

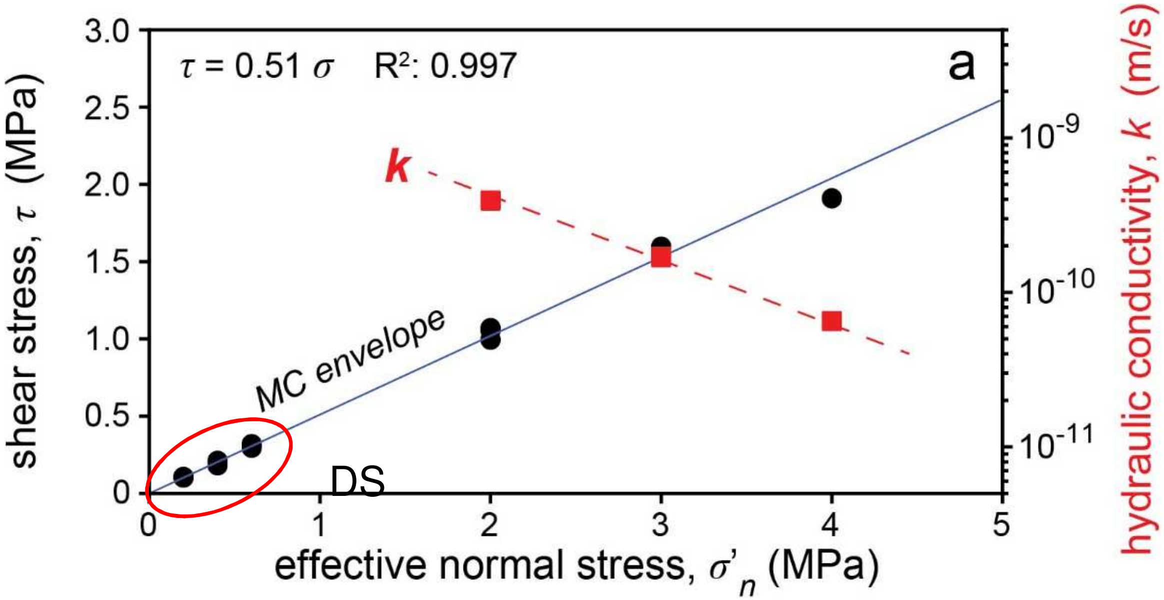
→ "run-in" (10 µm/s) to localize shear

→ **load control**: constant **shear stress τ**

→ **increase Pf** stepwise (eff. stress path), **simulate short-term GW recharge**

→ monitor **slip behaviour (creep)**

Hydraulic and frictional properties



hydraulic conductivity

→ **4*10^{-10} m/s** (*in situ* conditions)

→ consistent with literature data *(Strauhal et al., 2016)*

→ **low k, perched aquifer**

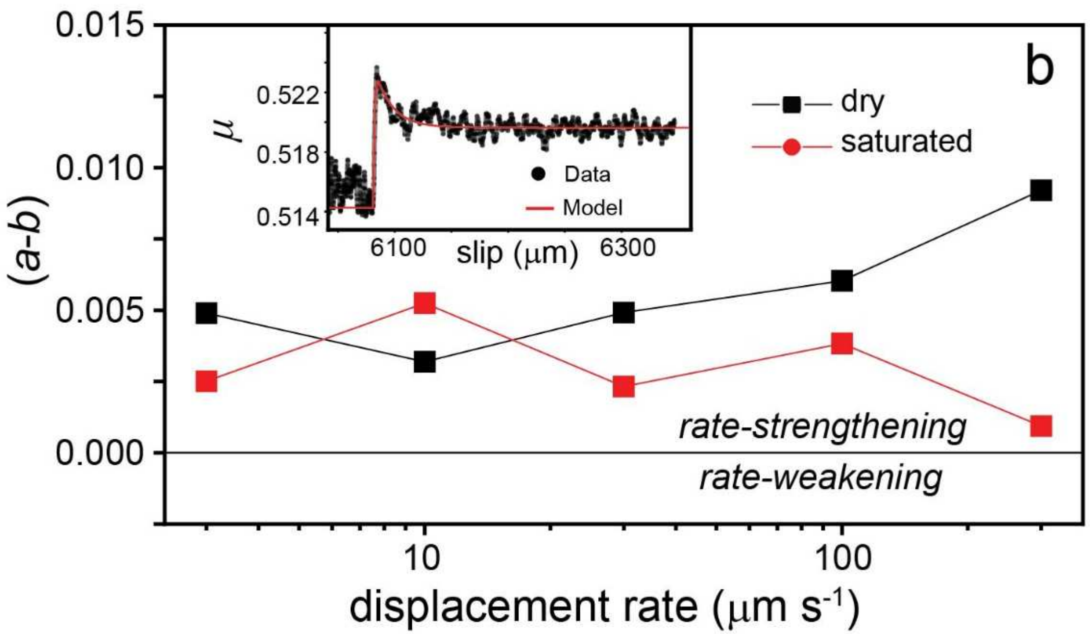
Frictional properties

→ steady-state μ=**0.51** (Φ' ~ 27°)

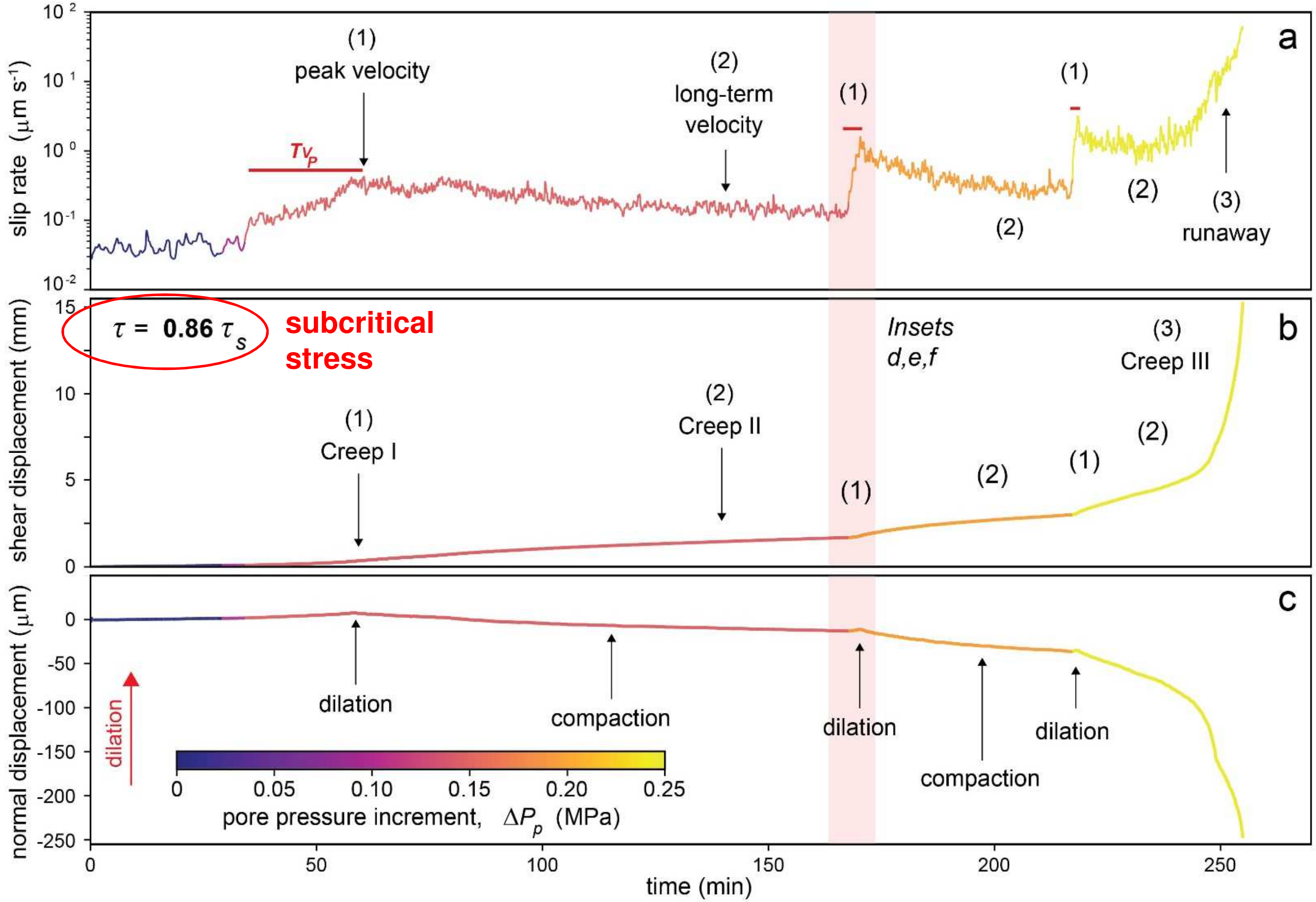
→ consistent with **back-analyses** *(Belloni & Gandolfo, 1997)*

→ **rate-strenghtening / neutral**

→ **prone to slow creep**



Shear zone response to short-term Pp change



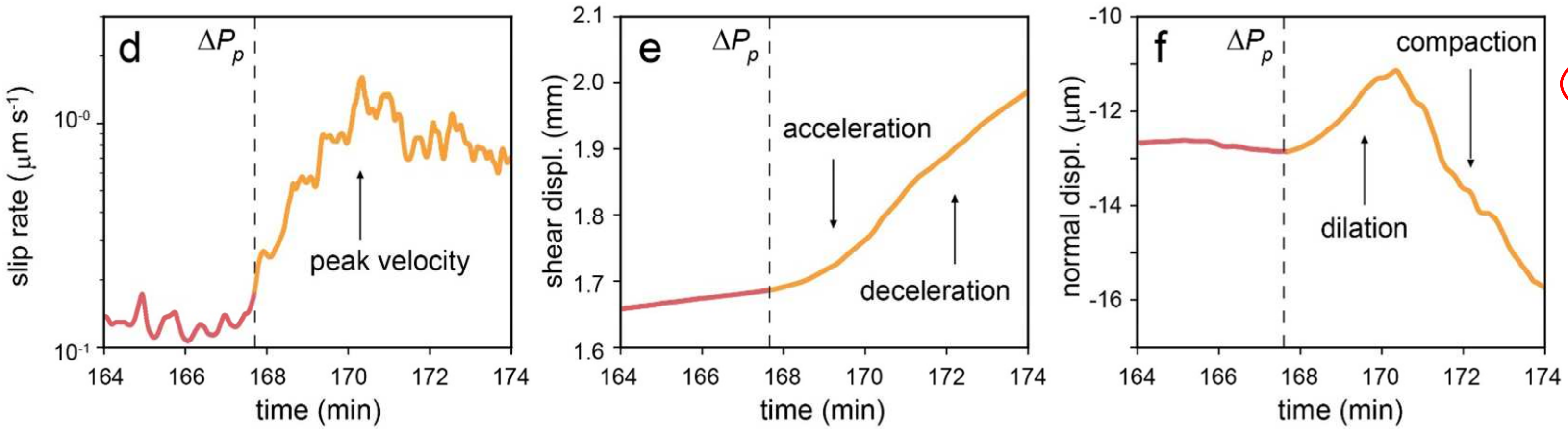
(1) **acceleration** pulse + **self-deceleration** (**dilation**) → **Creep I**

(2) **long-term steady slip rate** (**compaction**) → **Creep II**

(3) **critical Pf threshold**: transition to accelerated creep → **Creep III**

full spectrum of creep styles

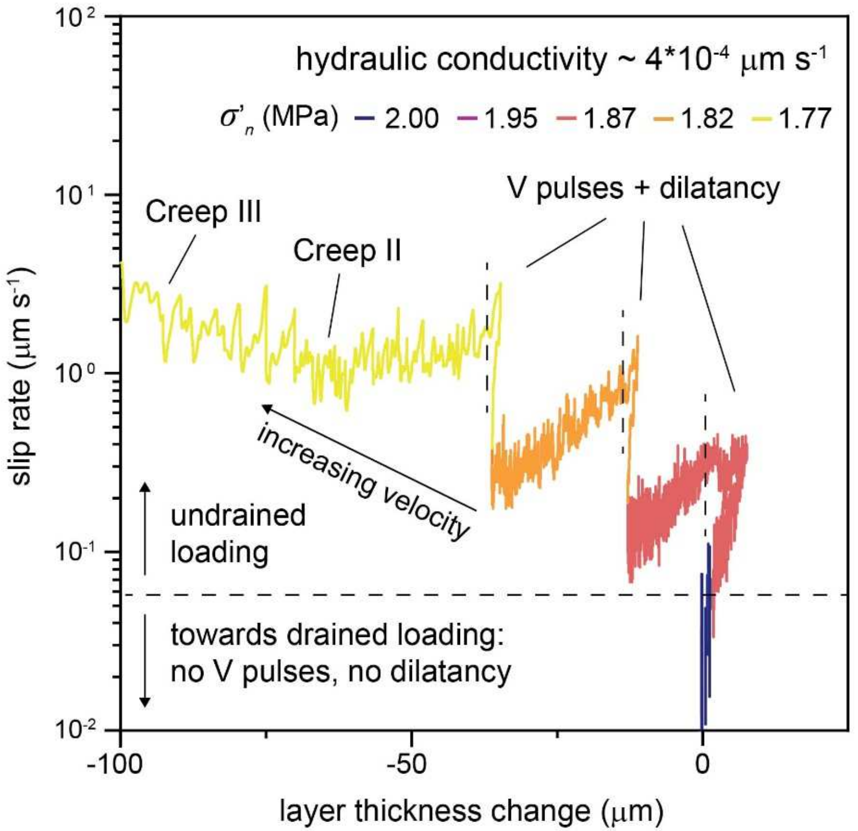
Hydro-mechanical behaviour



short-term ΔPp

↓

undrained fluid to solid HMC



1) **< effective stress**, **weakening**, acceleration

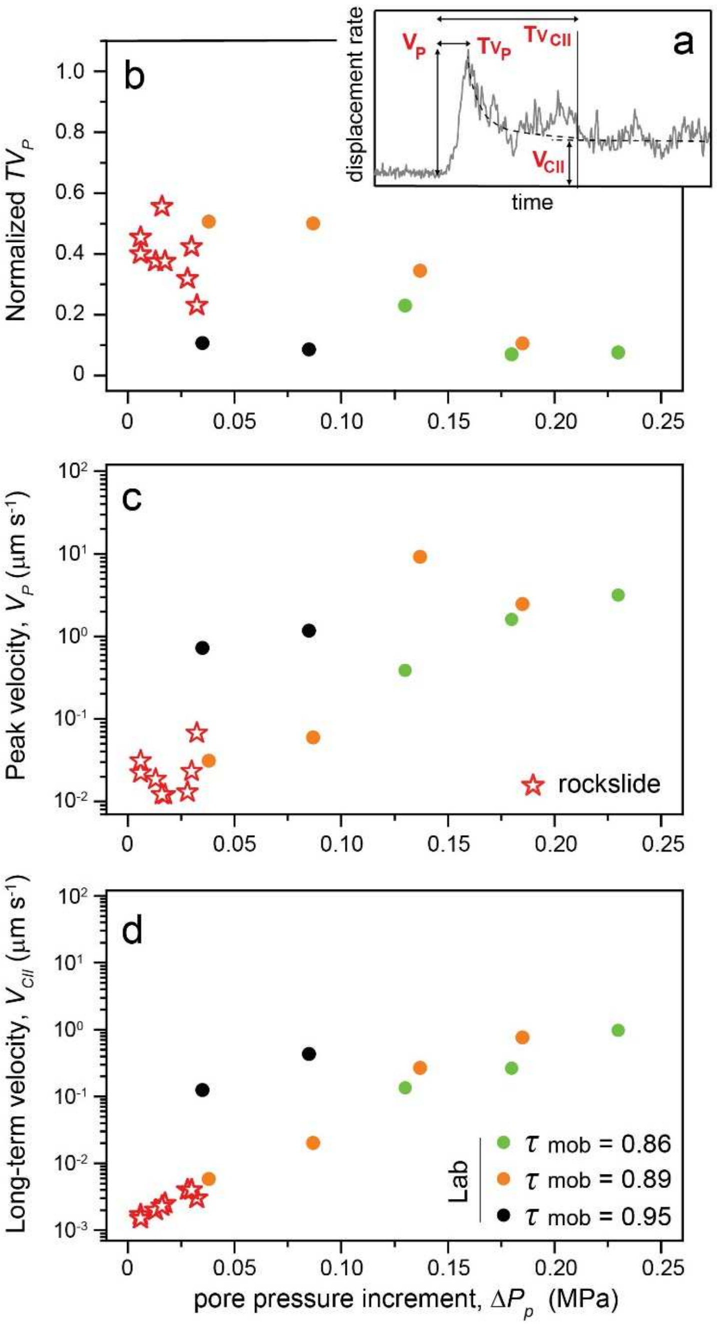
2) **dilatancy**, **strengthening**, deceleration: **Creep I** *(Iverson 2005; Segall et al 2010)*

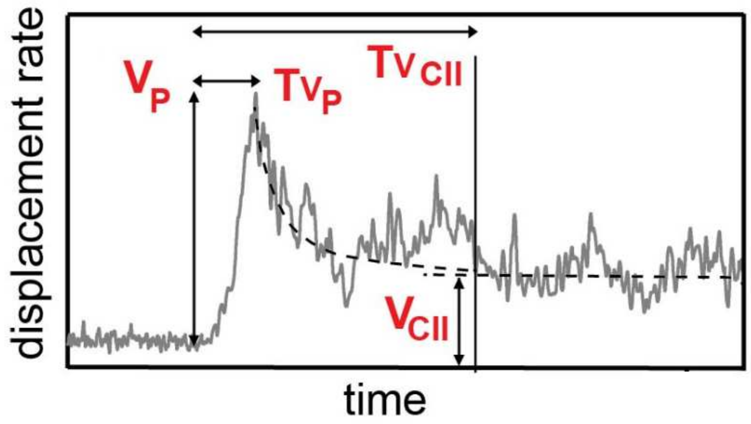
3) **fabric rearrangement**, **compaction**: long-term sustained slip rate: **Creep II**

Increasing ΔPp: faster response, less effective dilatant strengthening

Critical ΔPp: runaway instability, **Creep III**

Laboratory vs in situ behavior





V_P: peak velocity

Tv_P: time to V_P

V_{CII}: long-term V

Similar creep styles in the lab and *in situ*

→ shear zone reacts sooner (Tv_P) and faster (V_P) with increasing ΔPp - noisy *in situ* values

→ strong correlation between long-term creep velocity (V_{CII}) and ΔPp (lab and *in situ*)

Quantitative consistency despite scale and complexity!

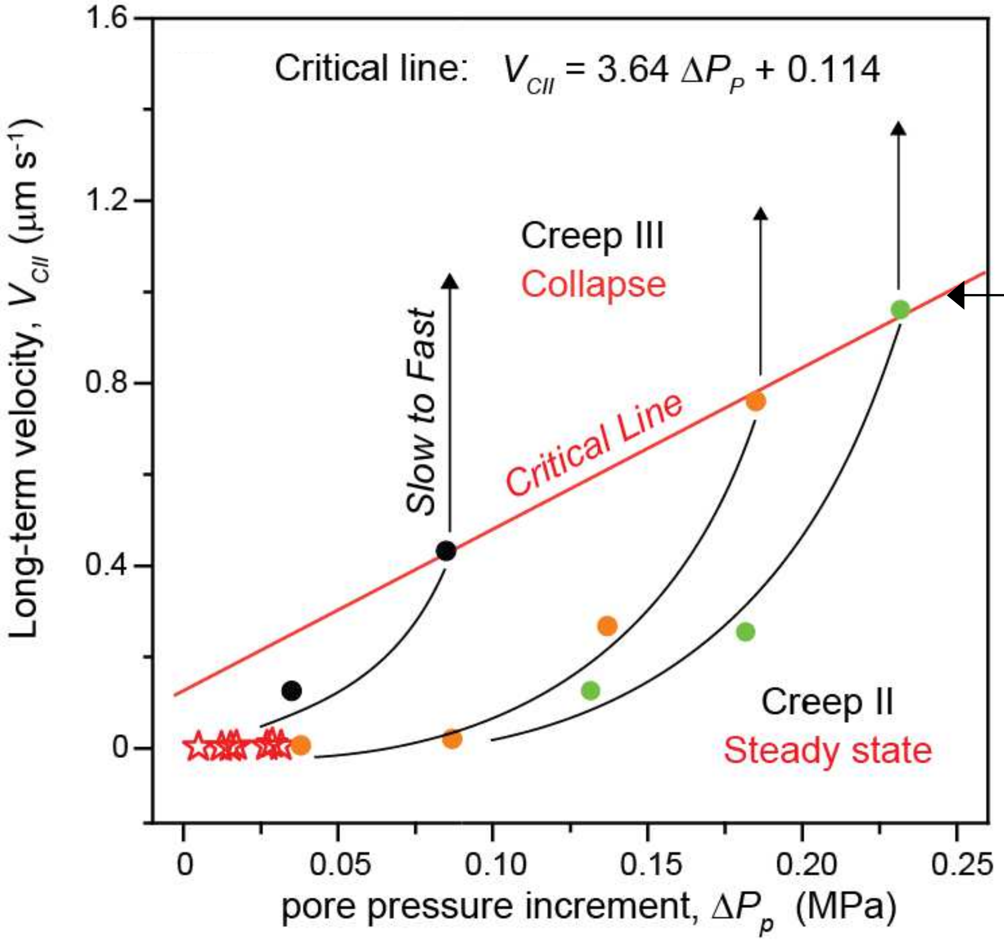
~ *90% of instantaneous τ_s mobilized at Spriana*

Towards slow-to-fast prediction

→ statistically-robust **log-linear correlation** between $\mathbf{V_{CII}}$ and **ΔPp**

→ separate short-term and long-term processes hampering / favoring collapse

→ $\mathbf{V_{CII}}$ **critical values** for slow-to-fast transition well fitted by a **linear envelope**



Critical line

→ threshold values of $\mathbf{V_{CII}}$ for specific **ΔPp**

→ critical **ΔPp** for specific τ_{mob}

Scale-independent experimental constraints to rockslide prediction

Conclusions

Our experiments:

→ capture the **full spectrum of creep** observed in **giant mature rockslides** in crystalline rocks

→ reproduce ***in situ* response** to short-term pore pressure perturbations

→ shed light on **hydro-mechanical interactions** underlying different **creep styles** and the slow-to-fast transition

→ allow separating the **effects of interplaying processes** modulating rockslide movements, often hampering the efficacy of empirical forecasting tools

→ provide **physics-based, scale-independent constraints** to improve prediction

Reference

Agliardi F., Scuderi M.M., Fusi N., Collettini C. Slow-to-fast transition of giant creeping rockslides modulated by undrained loading in basal shear zones. *Nature Communications* **11**, 1352 (2020).