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SUPPLY of ELECTRICITY

On the nature of induced seismicity: Control from initial state of stress

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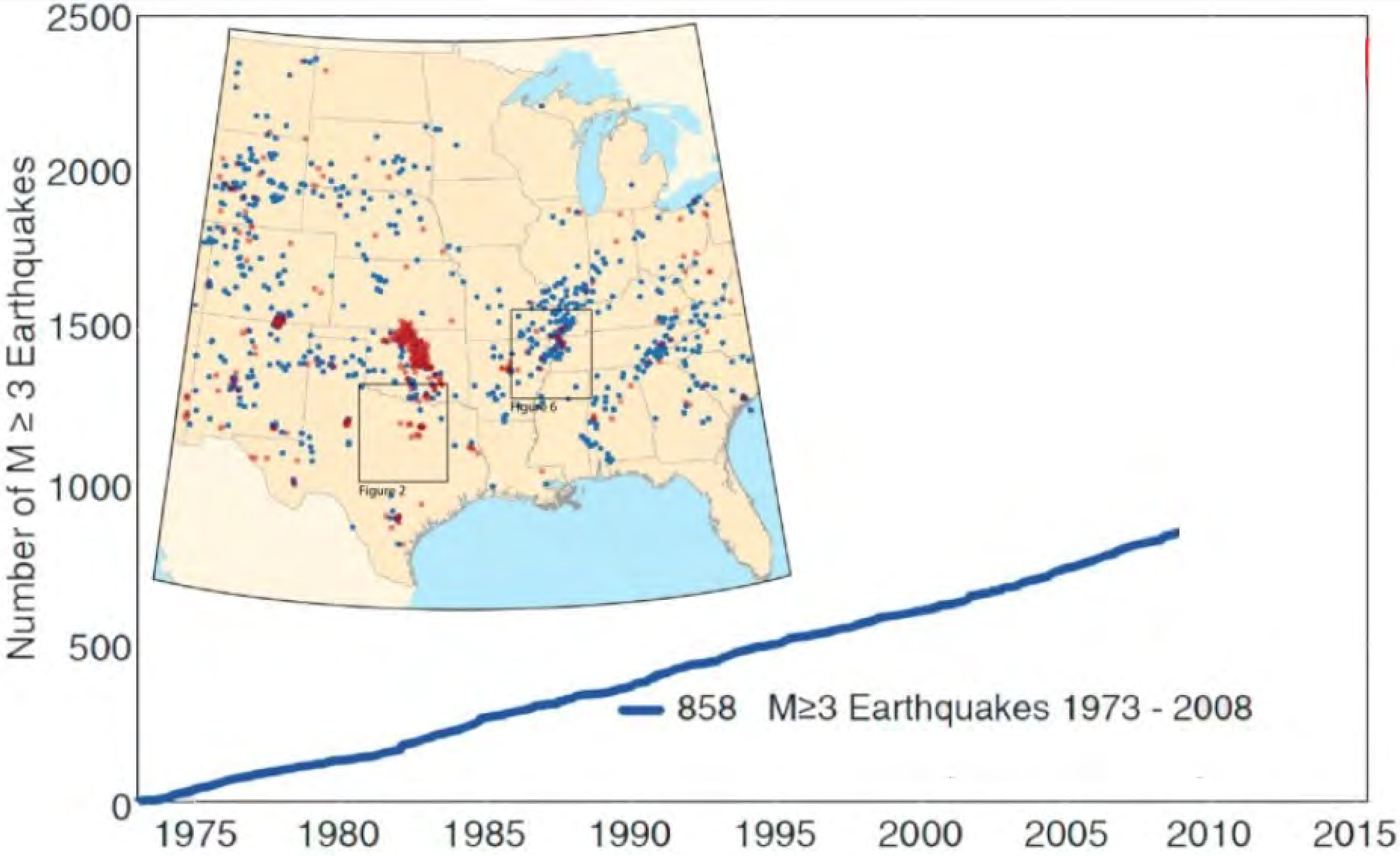
3. LSMS, École Polytechnique Fédérale de Lausanne, Switzerland

Acknowledgments: Alexandre Schubnel, Marie Violay, Nicolas Brantut, Tom Mitchell

Fluid induced seismicity



Modified from Ellsworth, 2013; Rubinstein and Mahani, SRL 2015, …

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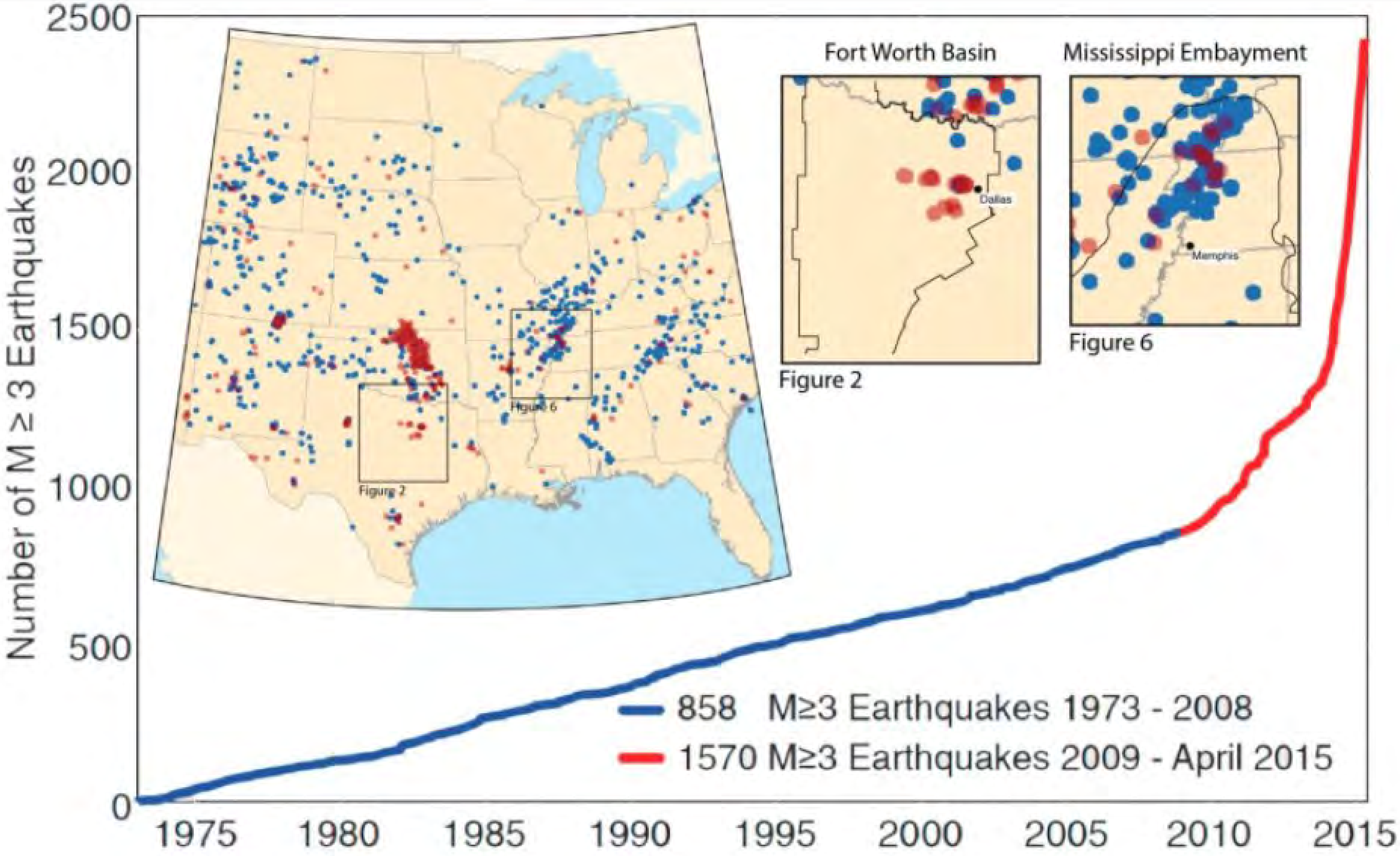

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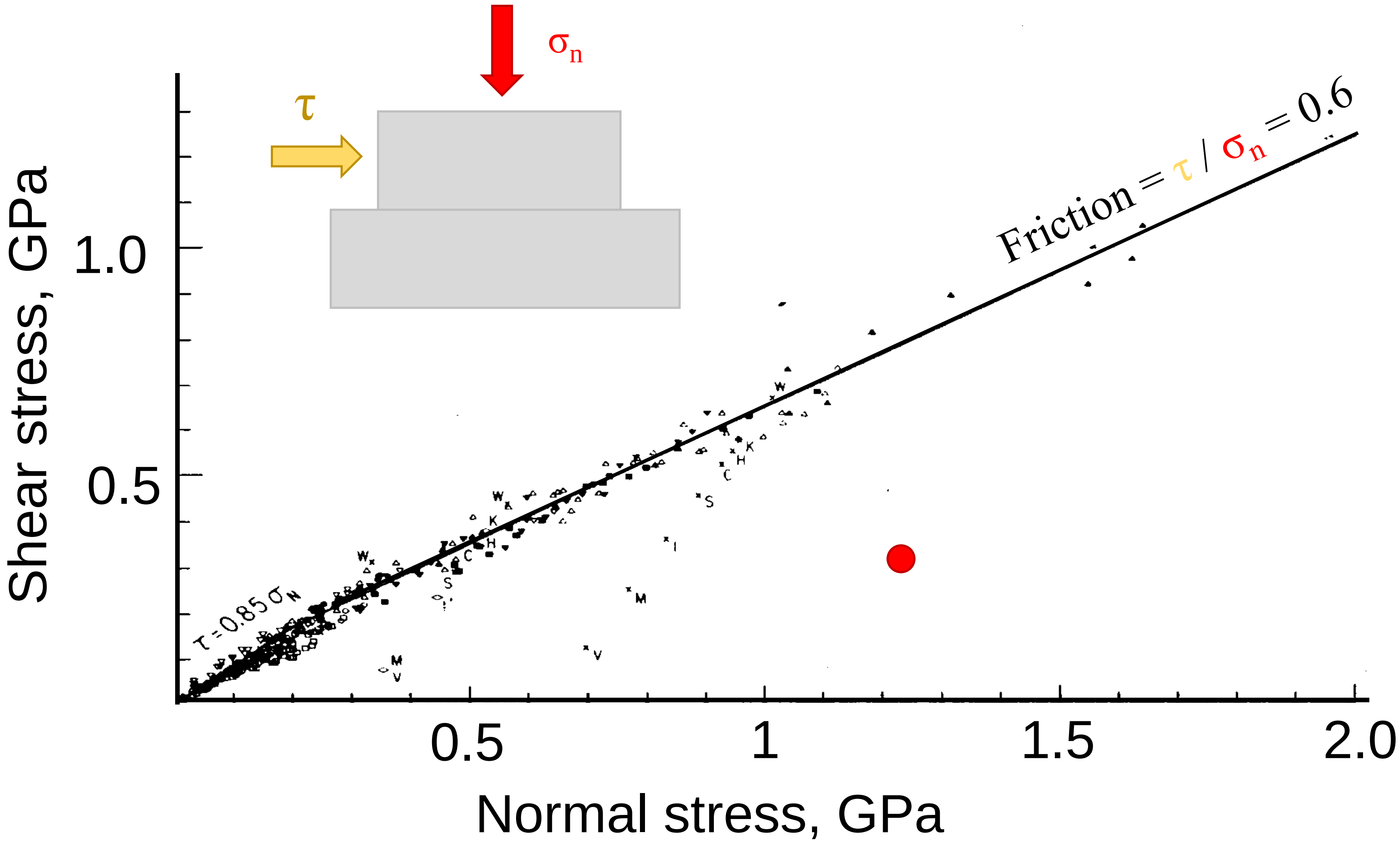
Static fault reactivation



[Byerlee, PAGEOPH,1978]

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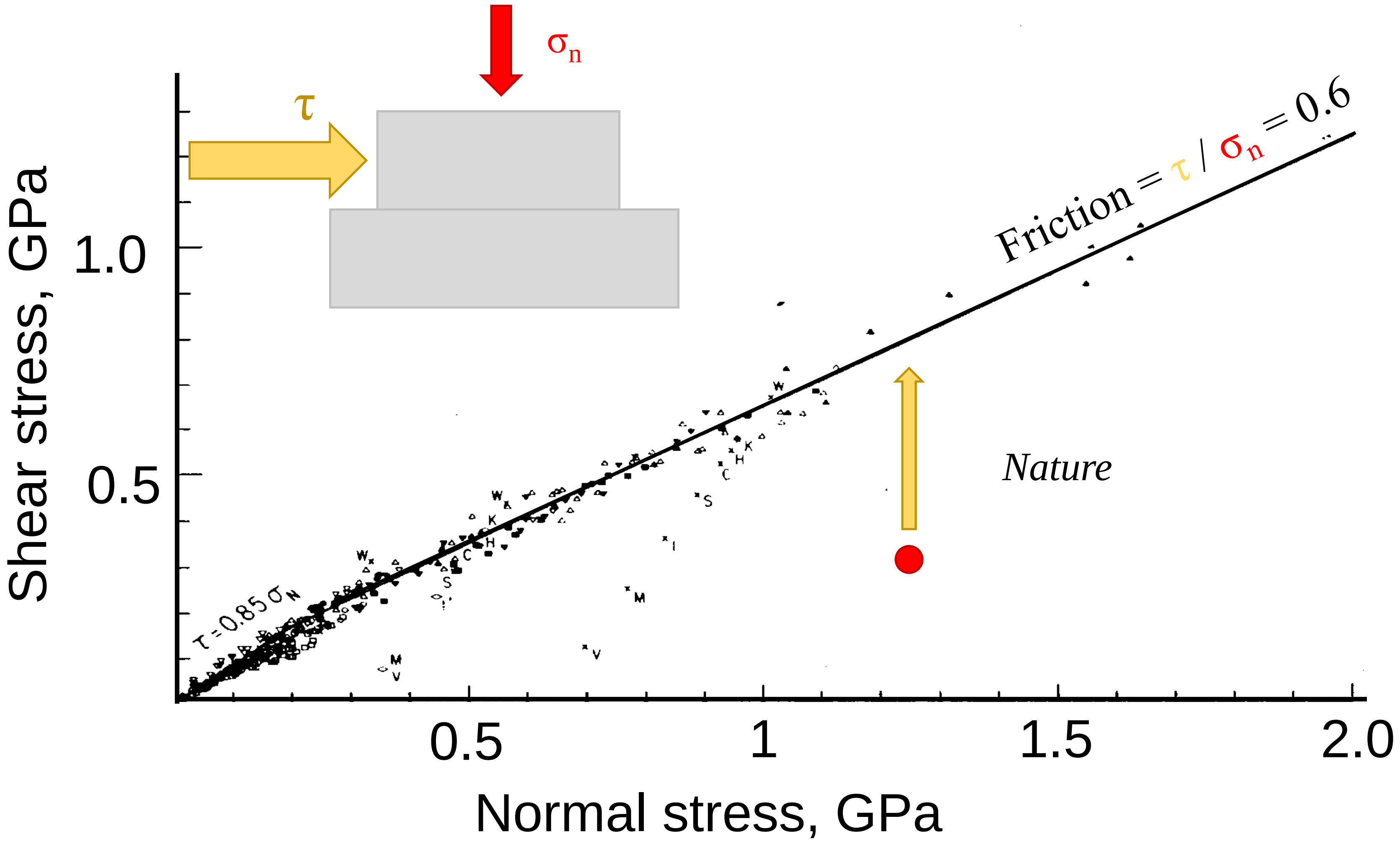

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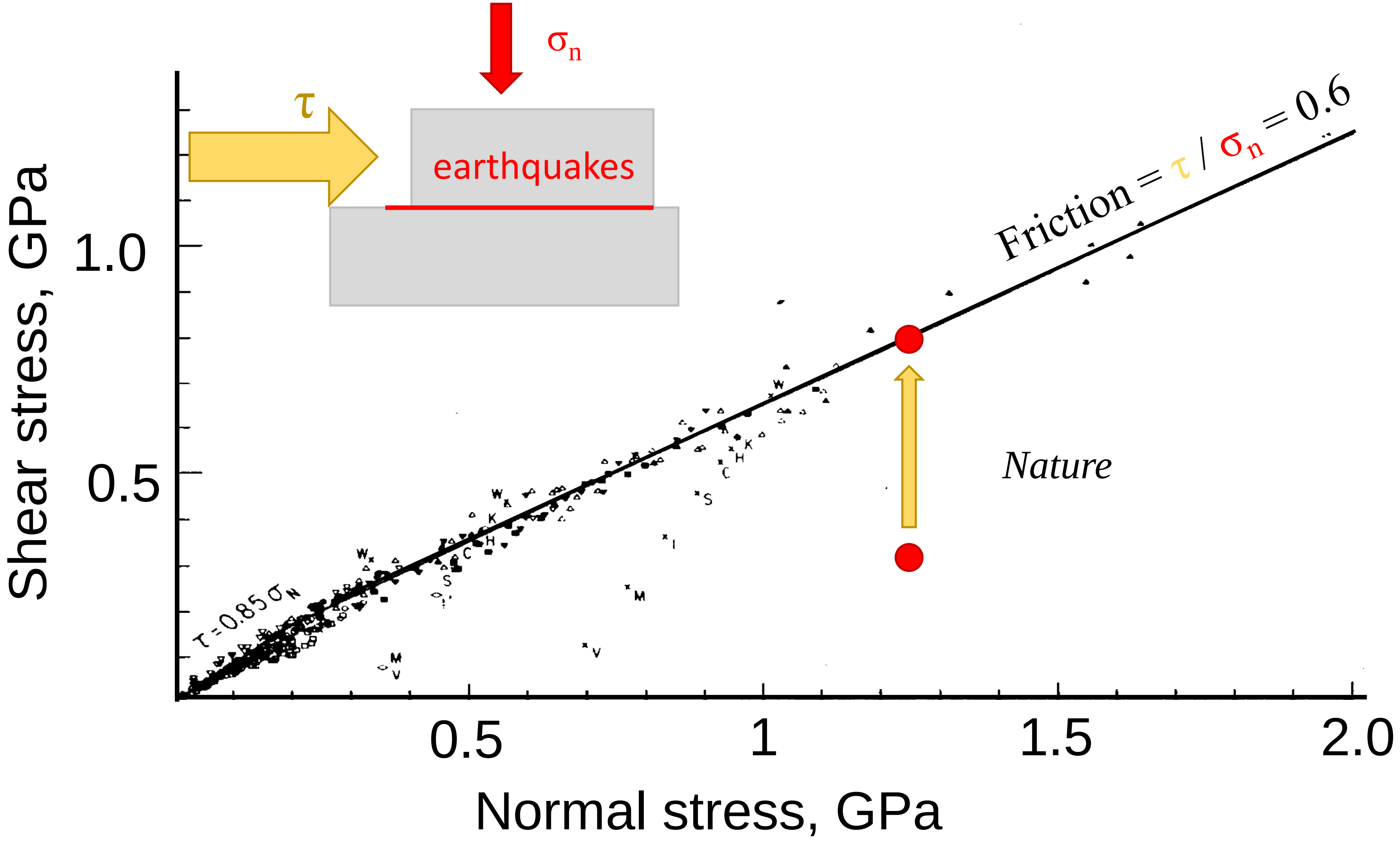

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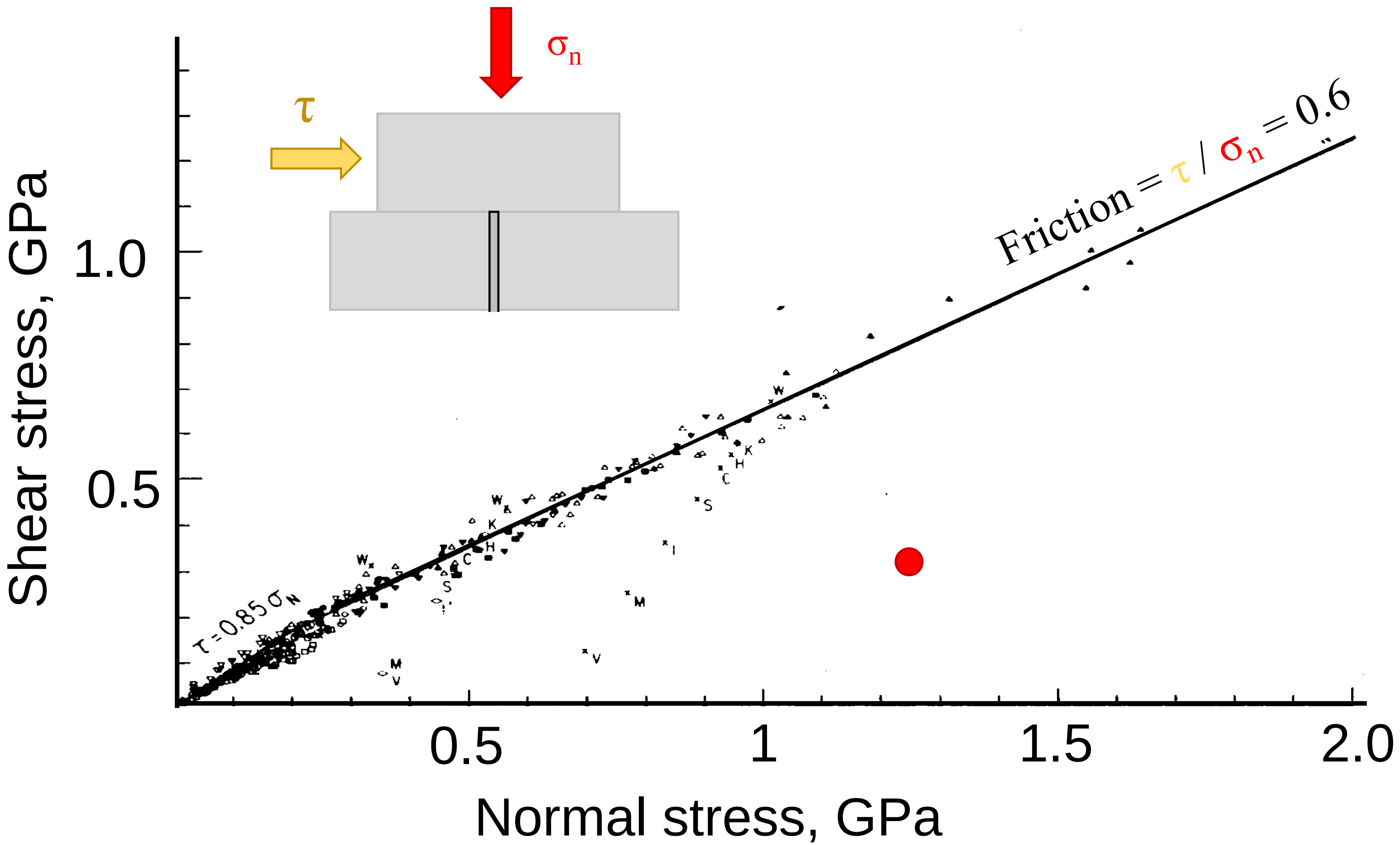

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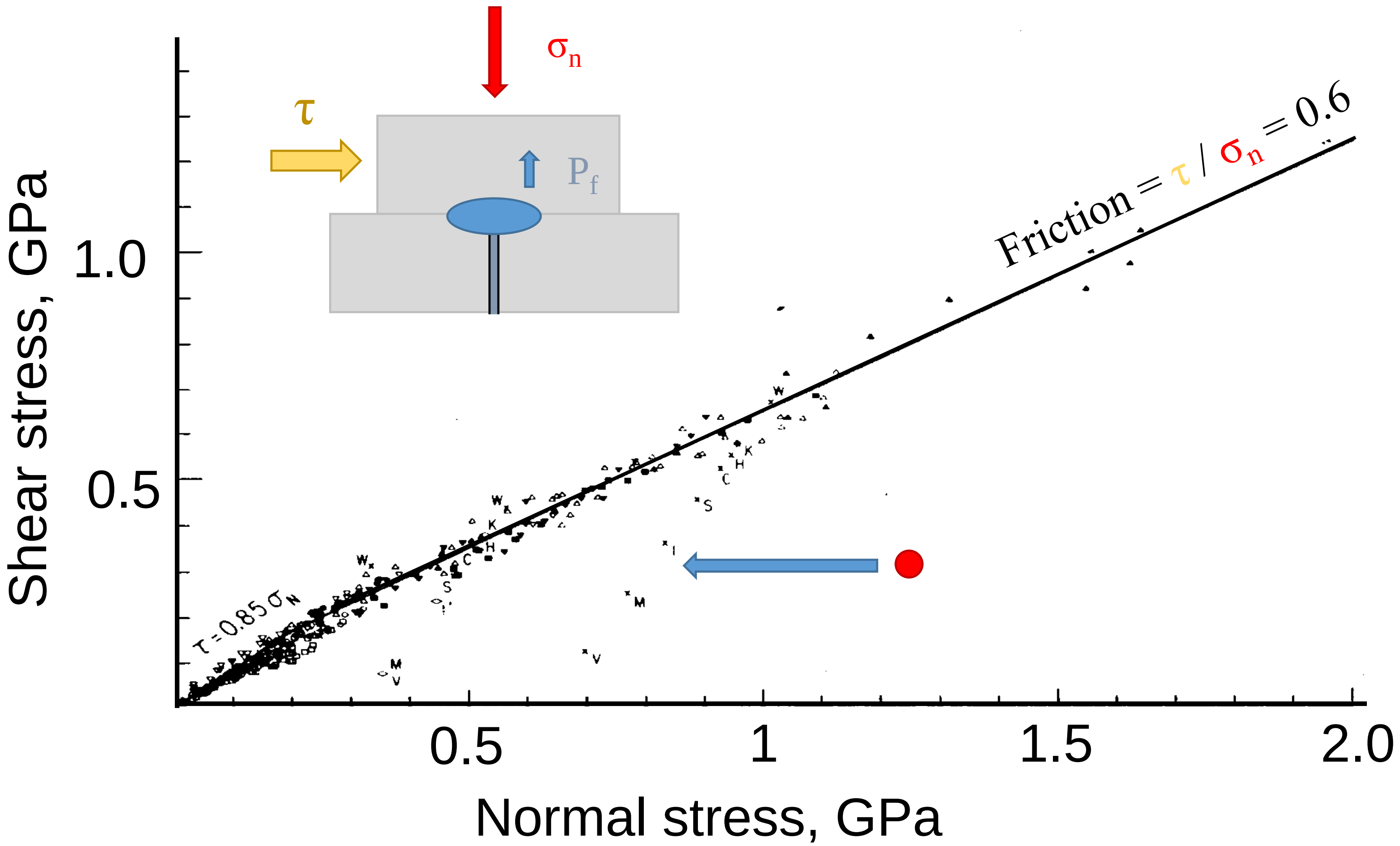

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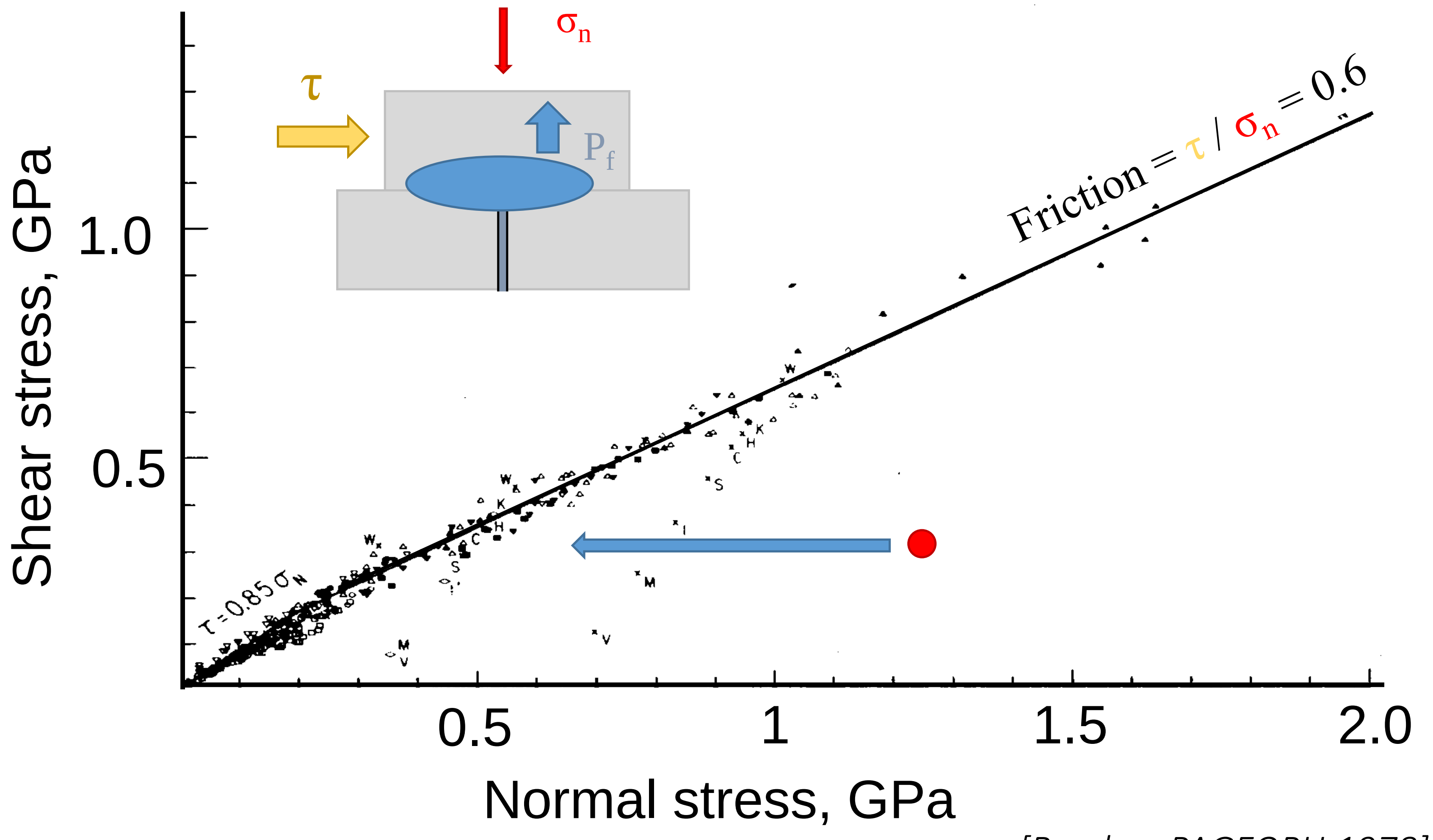

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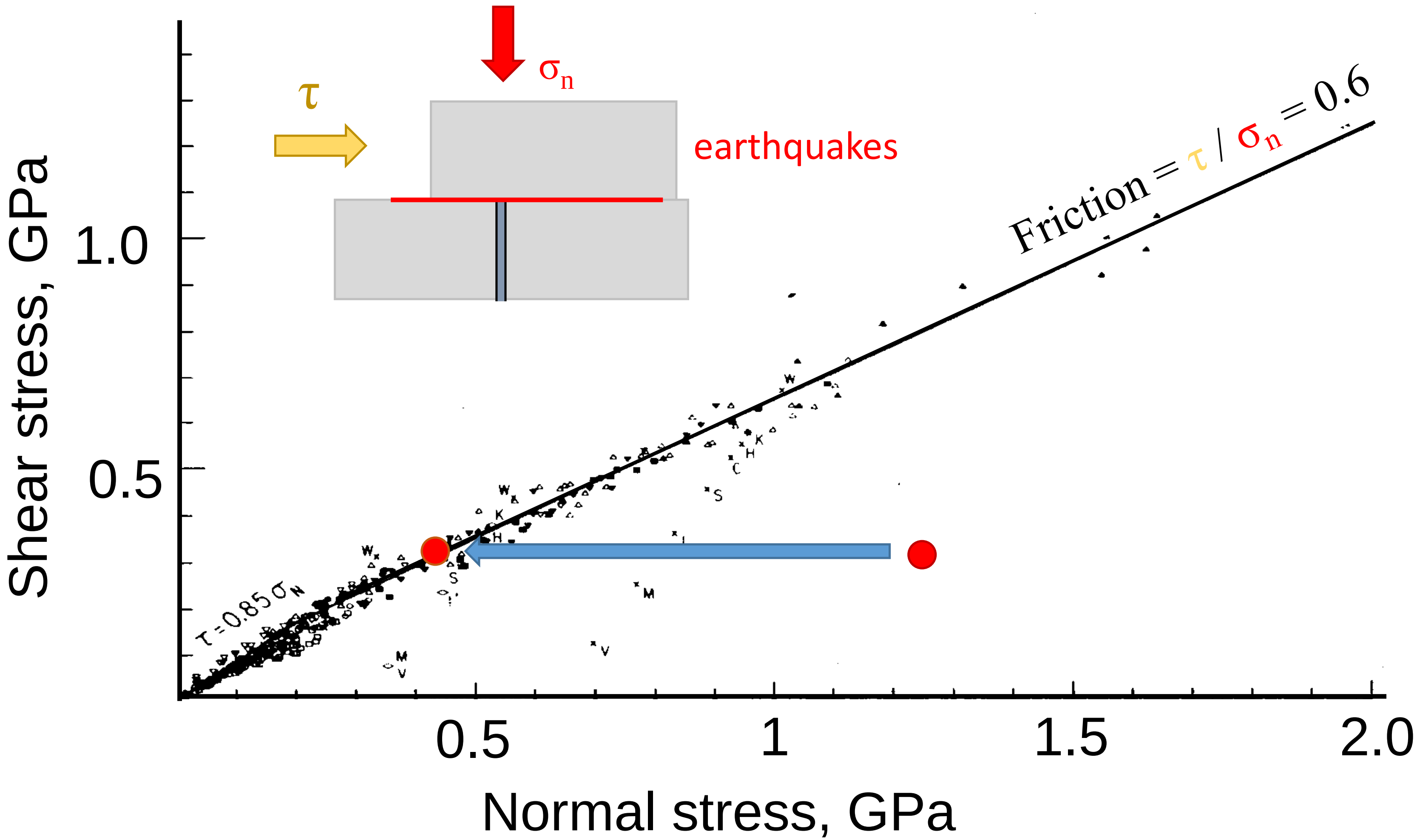

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Fluid-induced fault reactivation

Mohr-Coulomb approach is “0D”:

- Injection is local, reactivation is global.
- Stress distribution is key: non-local effects (e.g., Viesca & Rice,2012; Garagash & Germanovich, 2012).

Friction of interface is **not a constant material** (Ben-David et al., 2011)

- Stress distribution along the fault?
- Unknown of the fluid pressure leading to fault reactivation.

Stress/pore pressure distribution depends on:

- injection rate
- permeability/hydraulic diffusivity (and its P dependence !).

If fault reactivates:

- rupture velocity?
- Rupture length?

→ Potential damage

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Experimental set-up

Stress-relaxation experiments

- triaxial experiments on saw-cut Westerly Granite and low permeability Andesite.
- Very smooth (ground) surface.
- Stress relaxation conditions: lock
- Piston at given stress, then inject.
- Pc = 30; 60 & 95 MPa, Q = 90% of static friction
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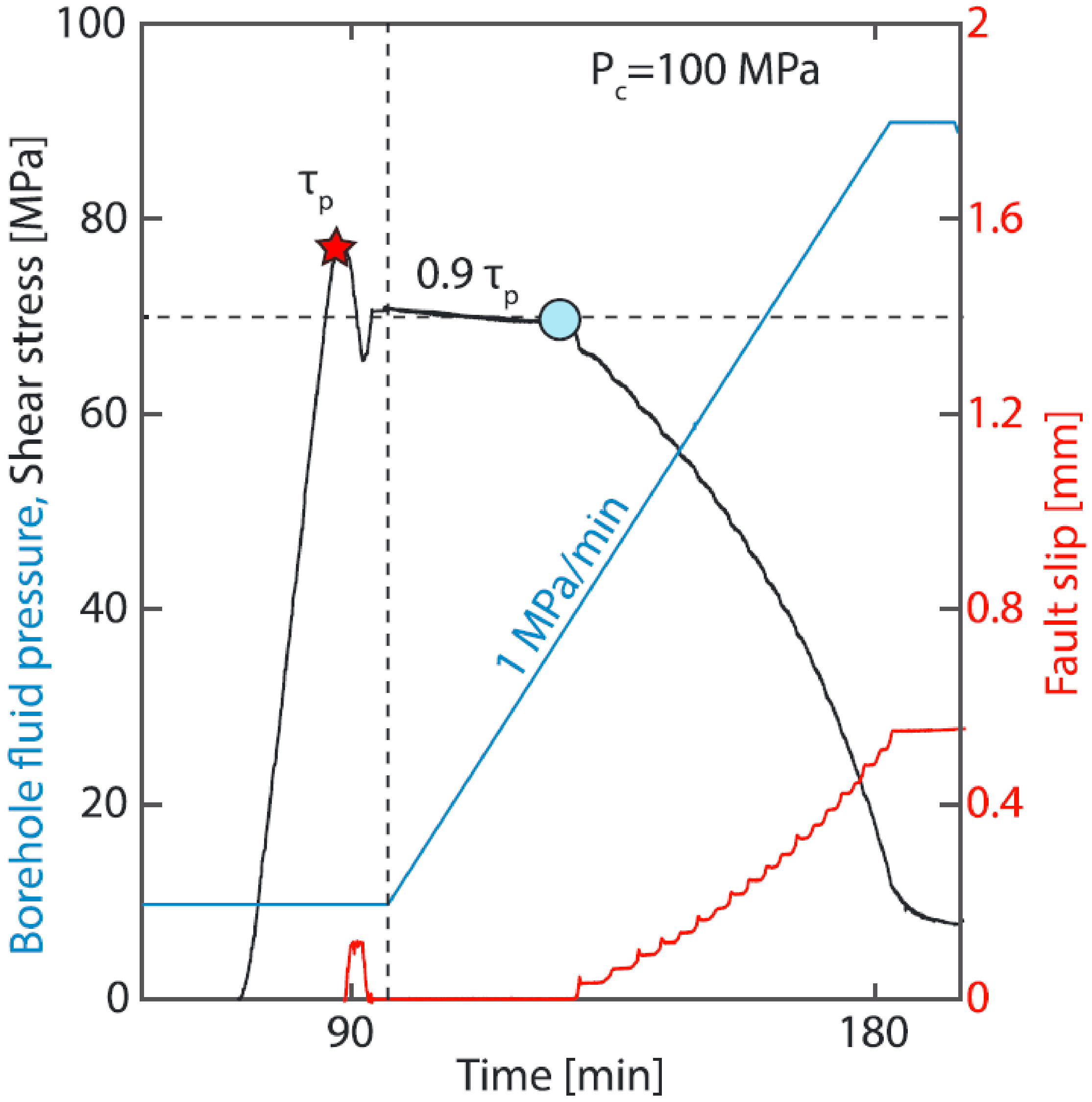

Experimental set-up

Injection experiments

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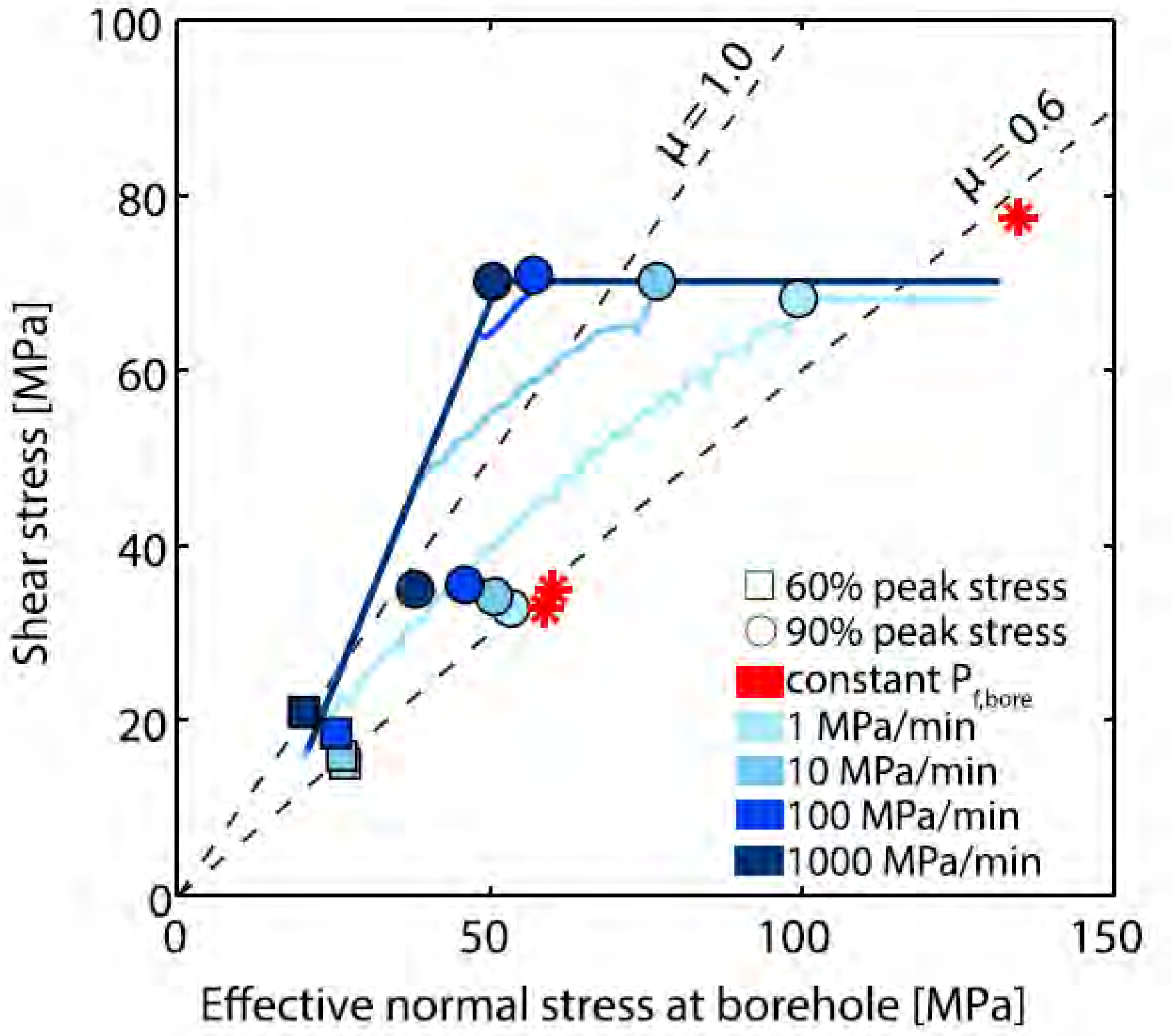
Injection experiments

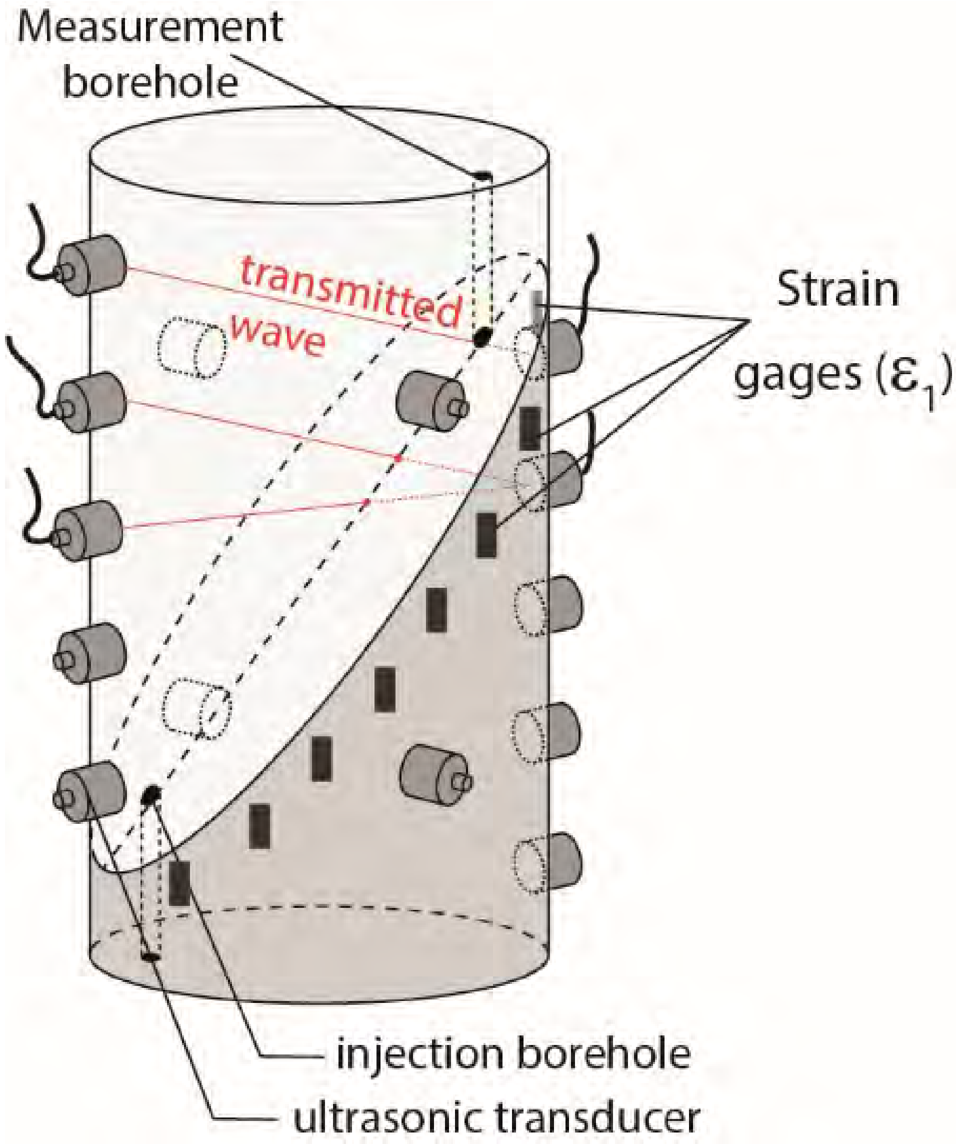
Influence of injection rate and stress

[Passelègue et al, GRL,2018]



Large injection rate, or low fault permeability: high pore pressure excess for reactivation

Fluid pressure distribution along the fault



Fluid-induced reactivation

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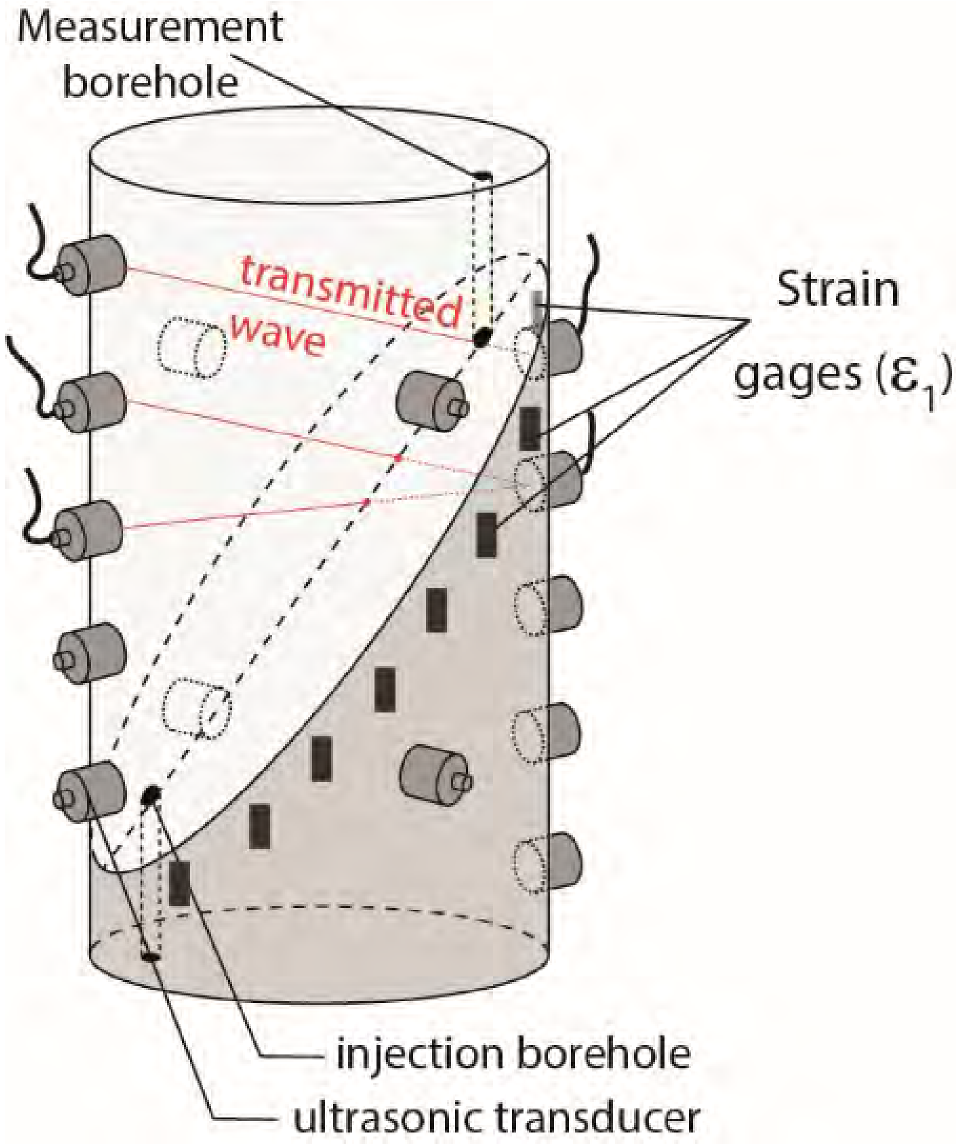
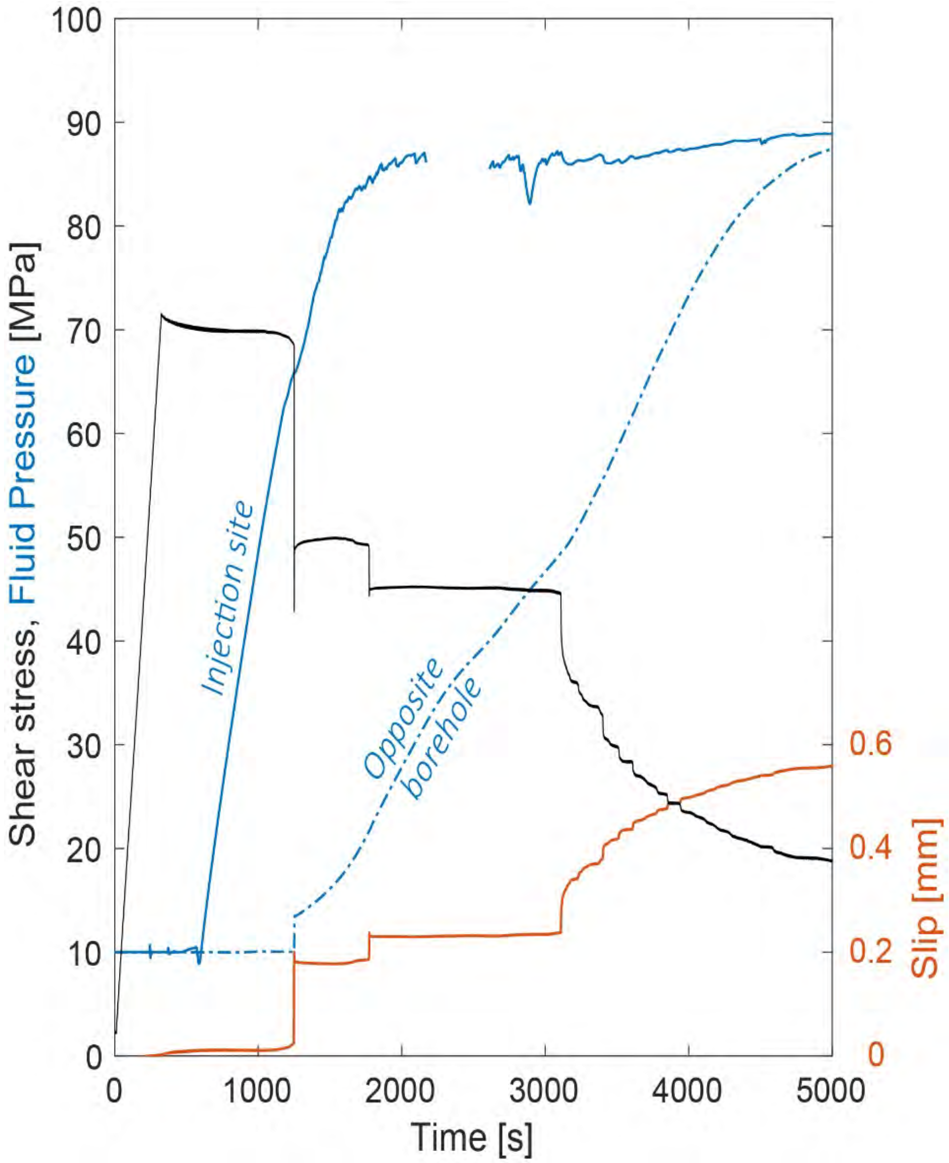
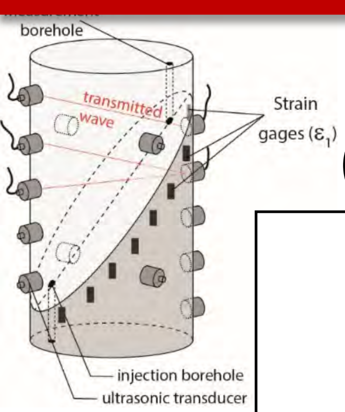




Fluid-induced reactivation

Inversion of fluid pressure profile

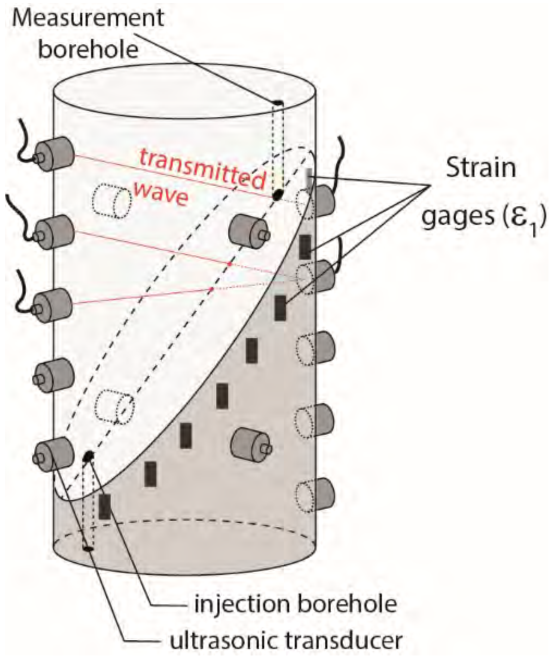


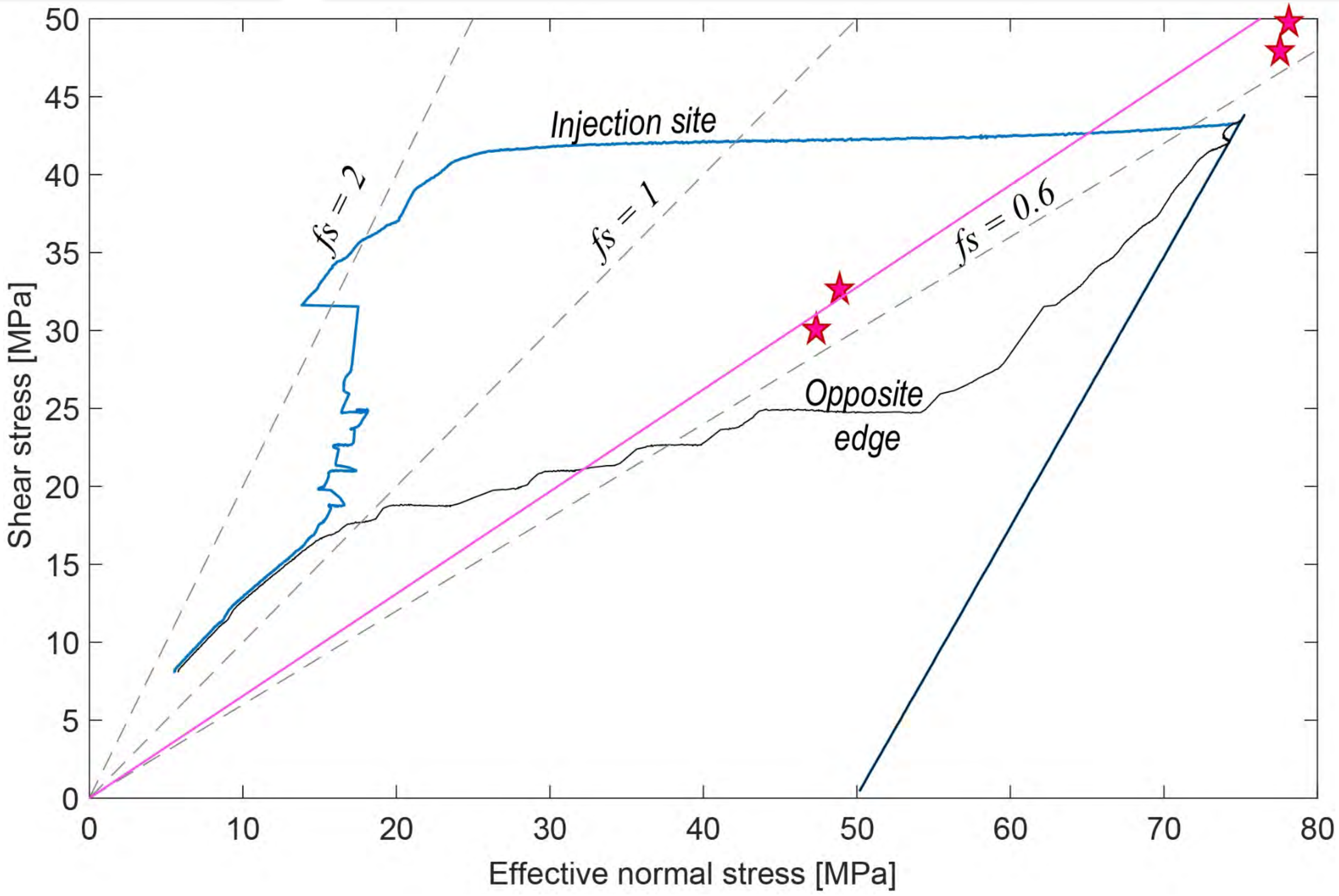
2D diffusion model:
(See poster M. Almakari)

- Input: fluid pressure in injection site
- Inversion of the fluid pressure in the borehole
- Ouput: Evolution of the hydraulic diffusivity, Pf distribution

Hydraulic diffusivity enhanced by slip events, and effective stress drop!

Influence of fluid pressure heterogeneities





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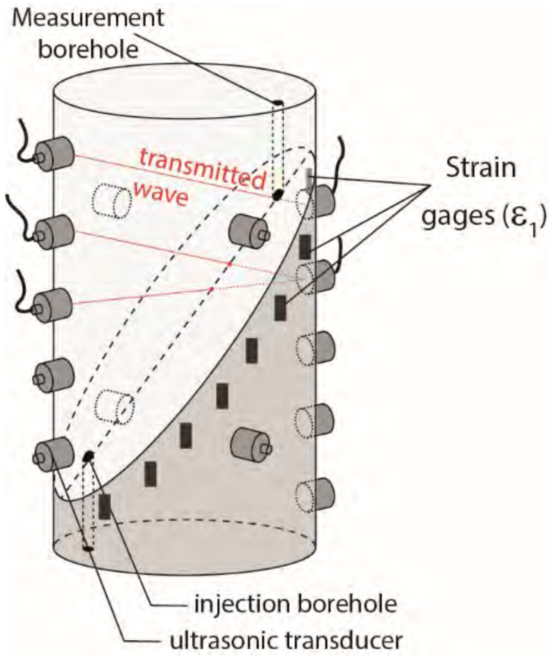
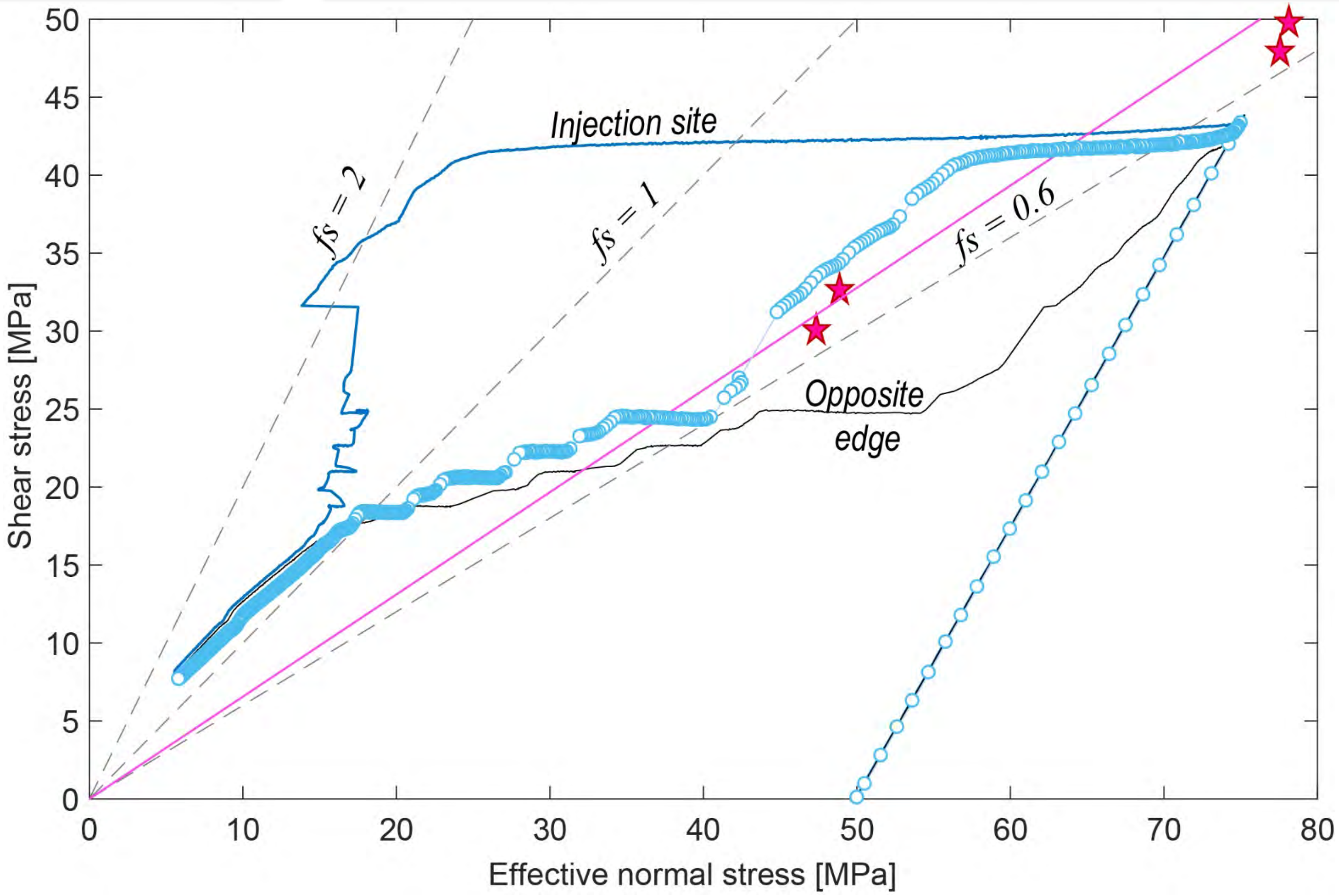


$\overline{P_f}$(from profile inverted)

$\overline{\tau_0}$(from strain gages array)



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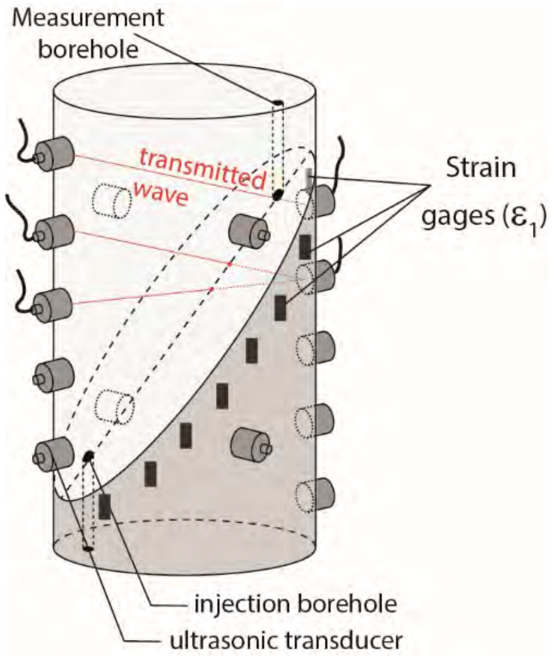

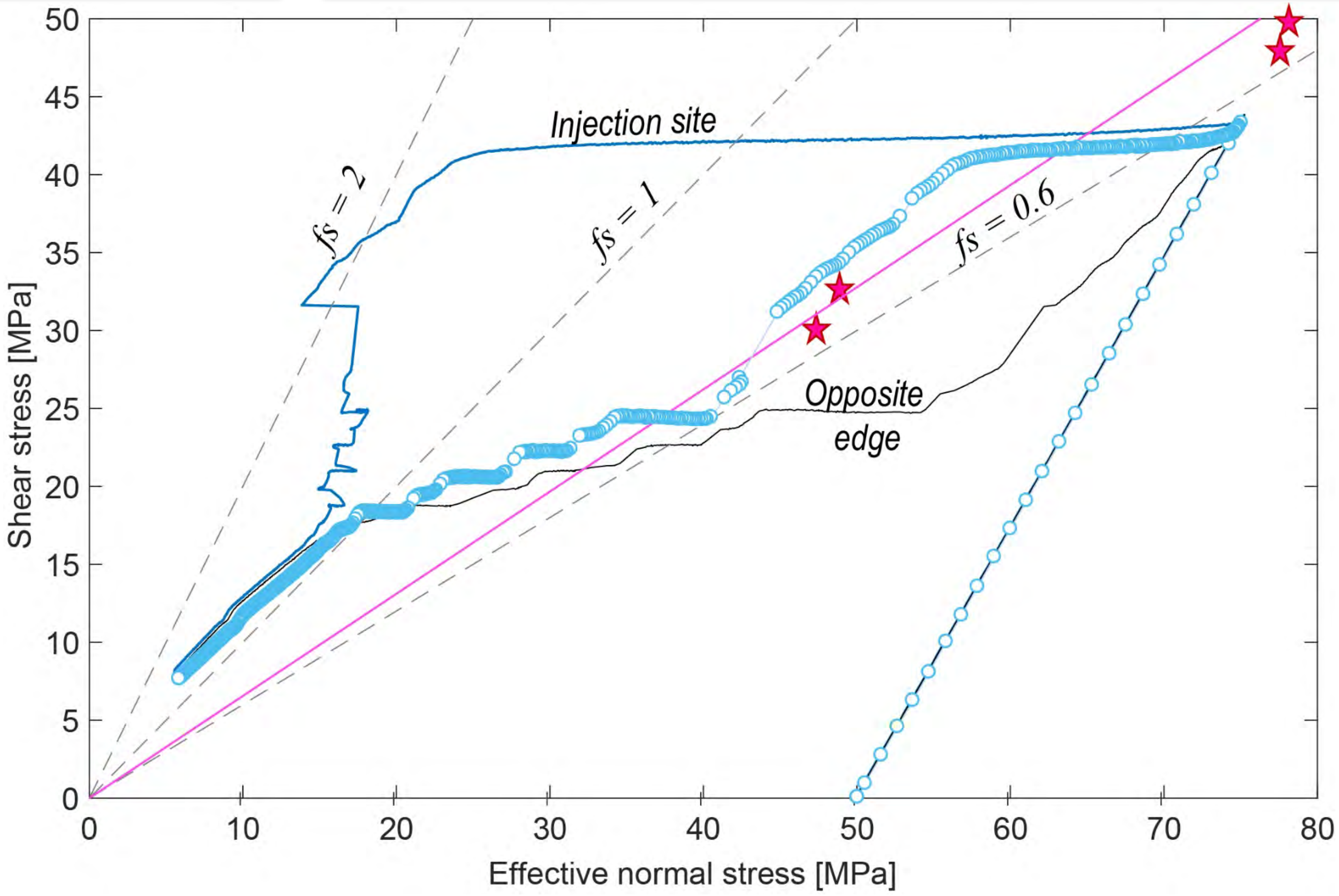

$\overline{P_f}$(from profile inverted)

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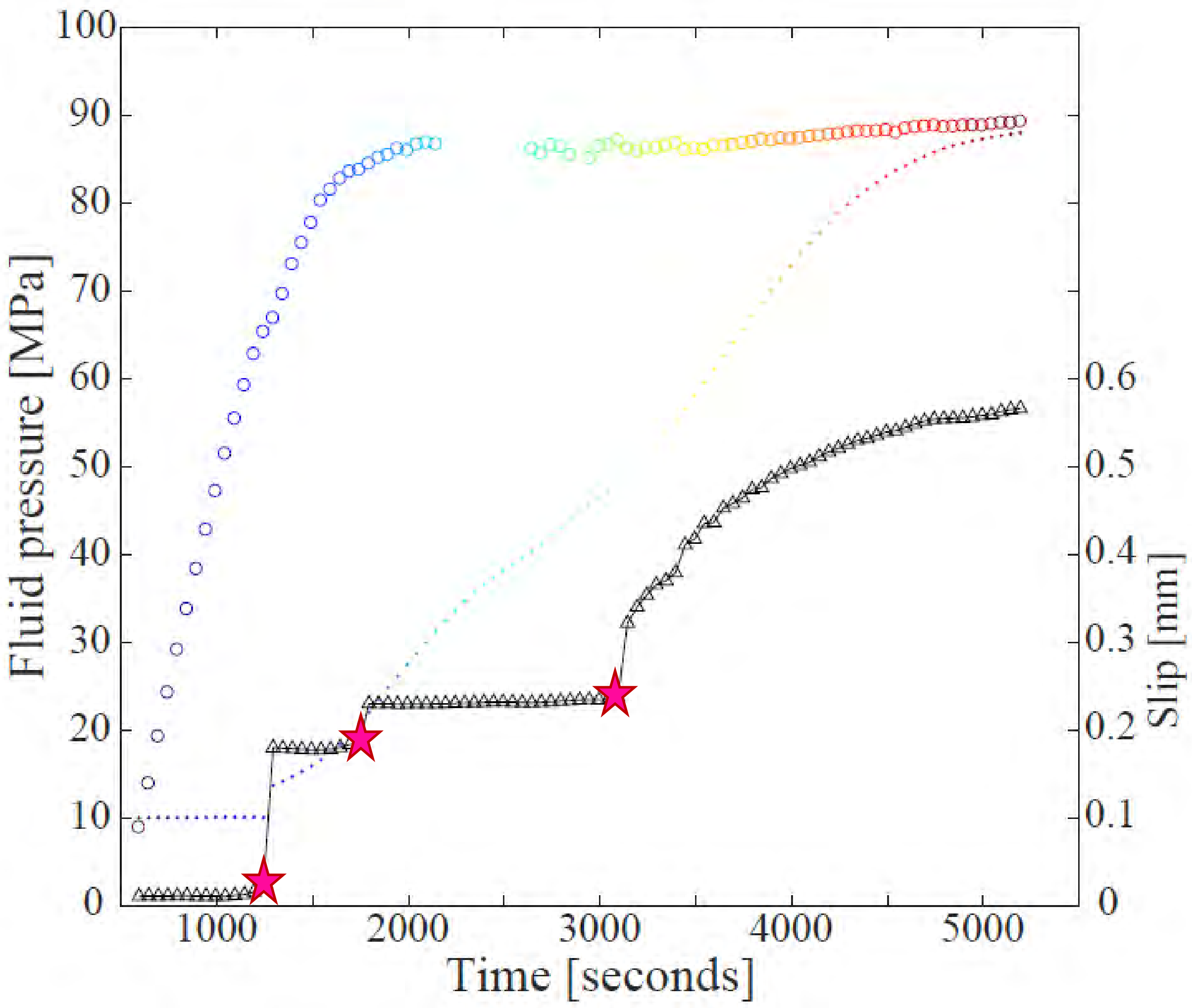
Fault reactivates close to expectations. What about the nature of seismicity?

Nature of seismicity

Influence of pressure heterogeneities



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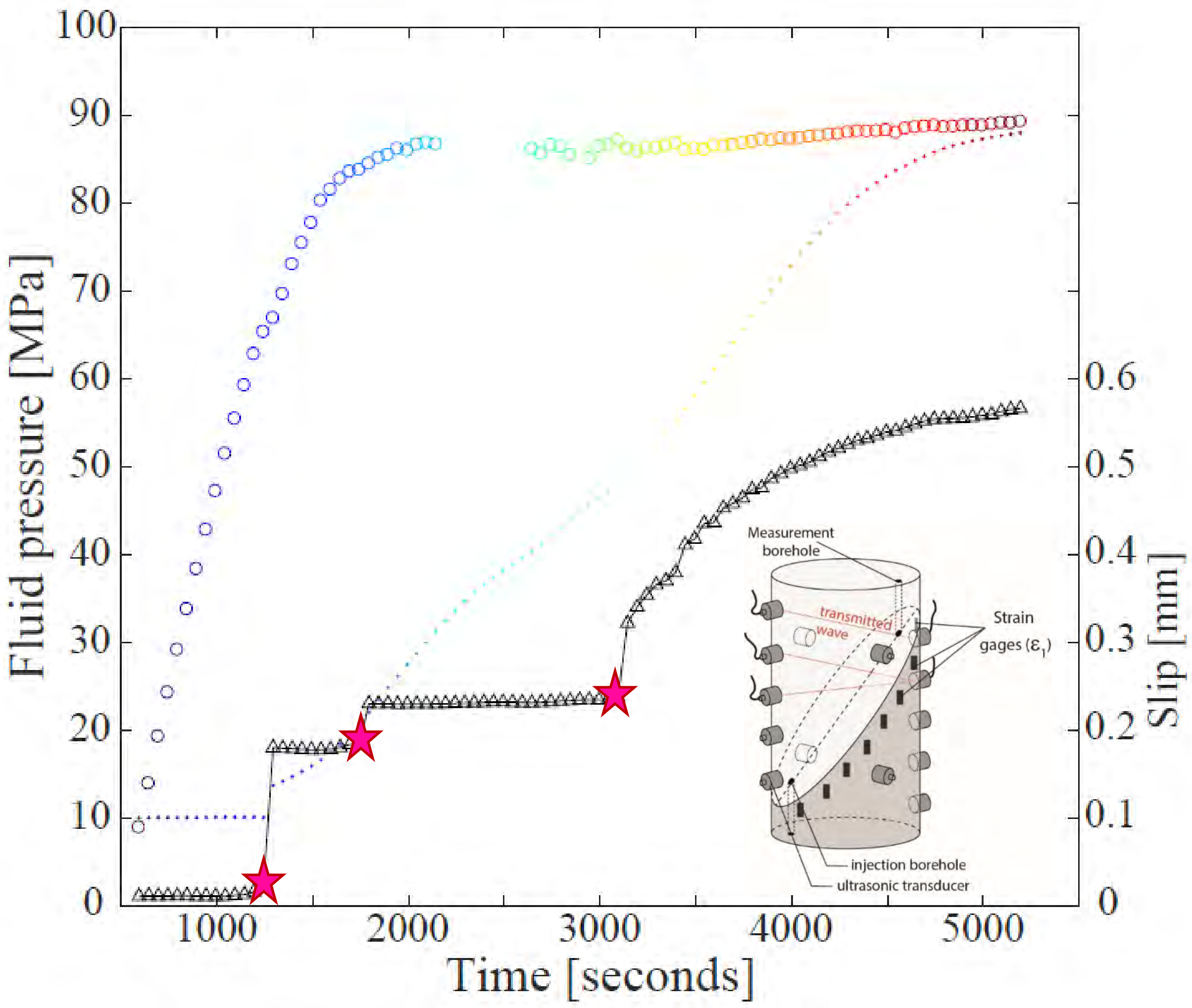

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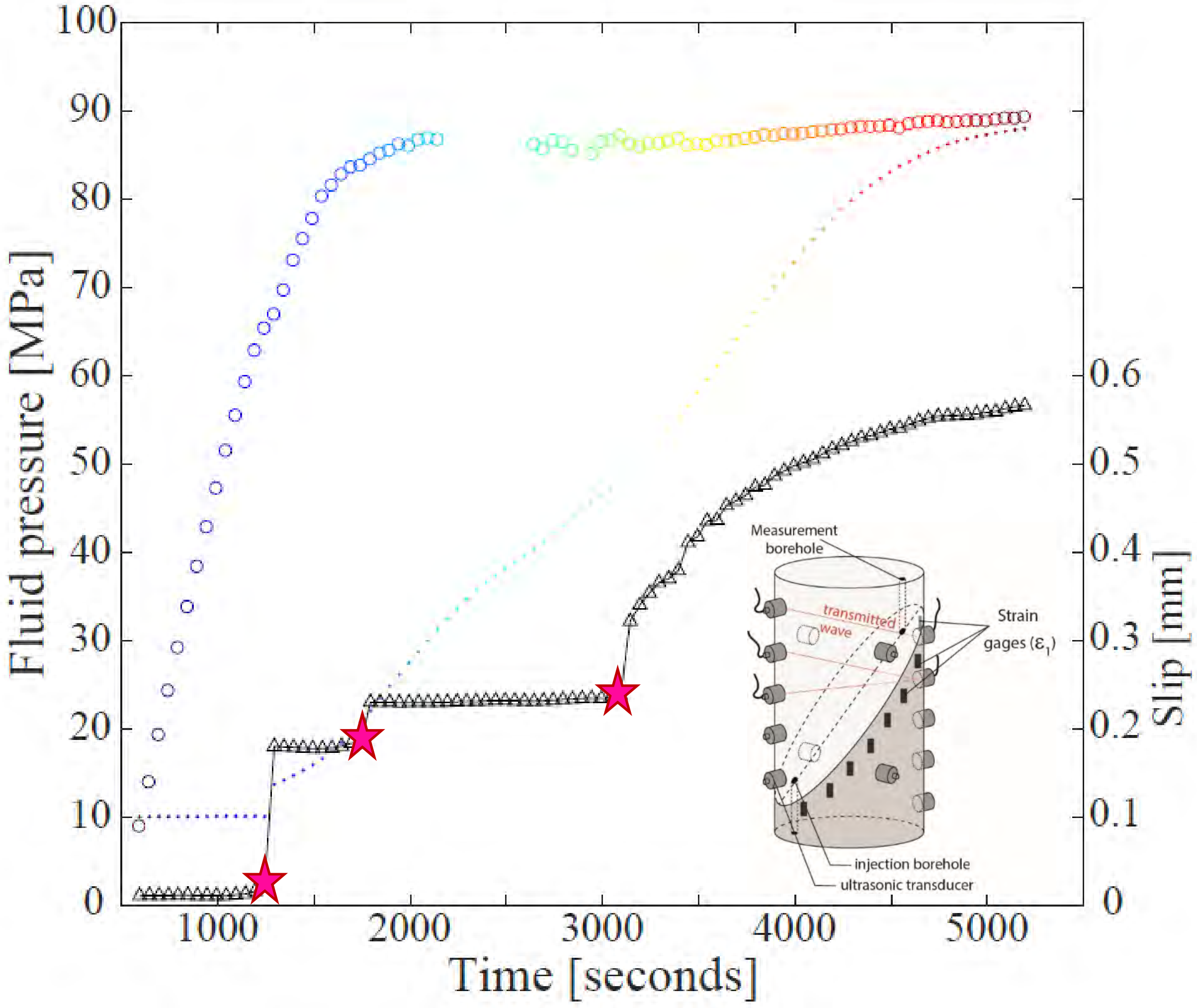

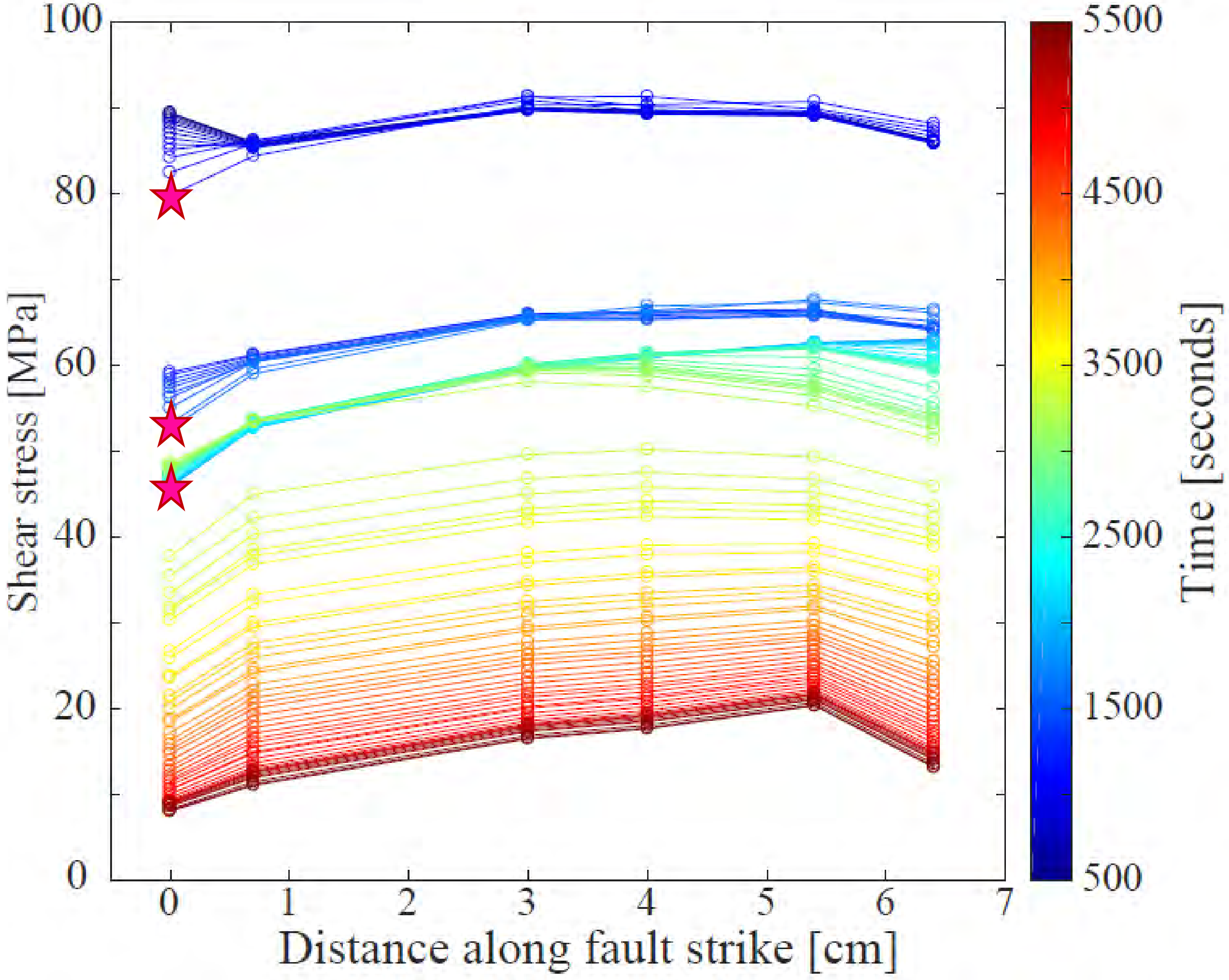

Fast ruptures observed for high initial stress and/or strong fluid pressure heterogeneity?

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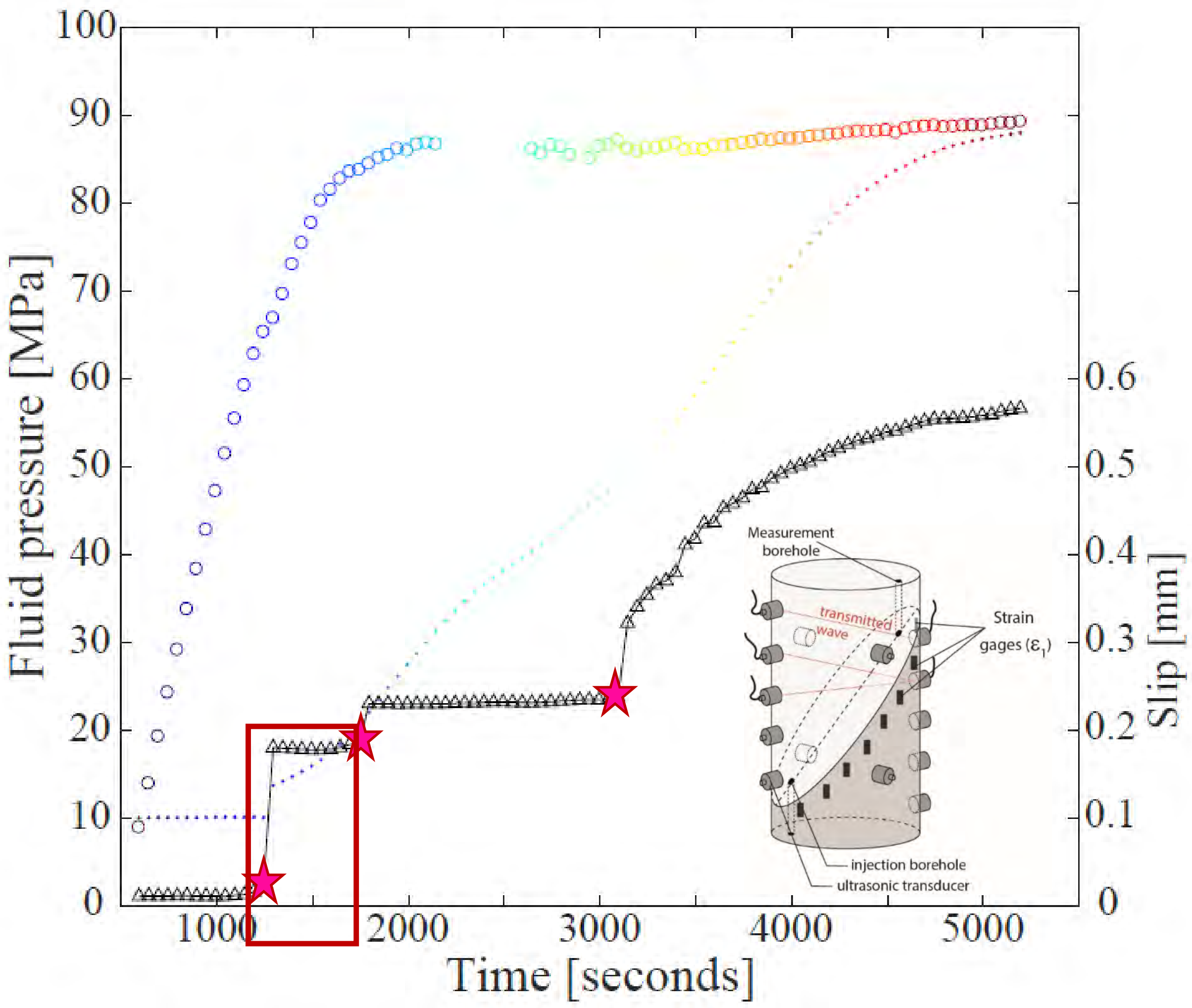

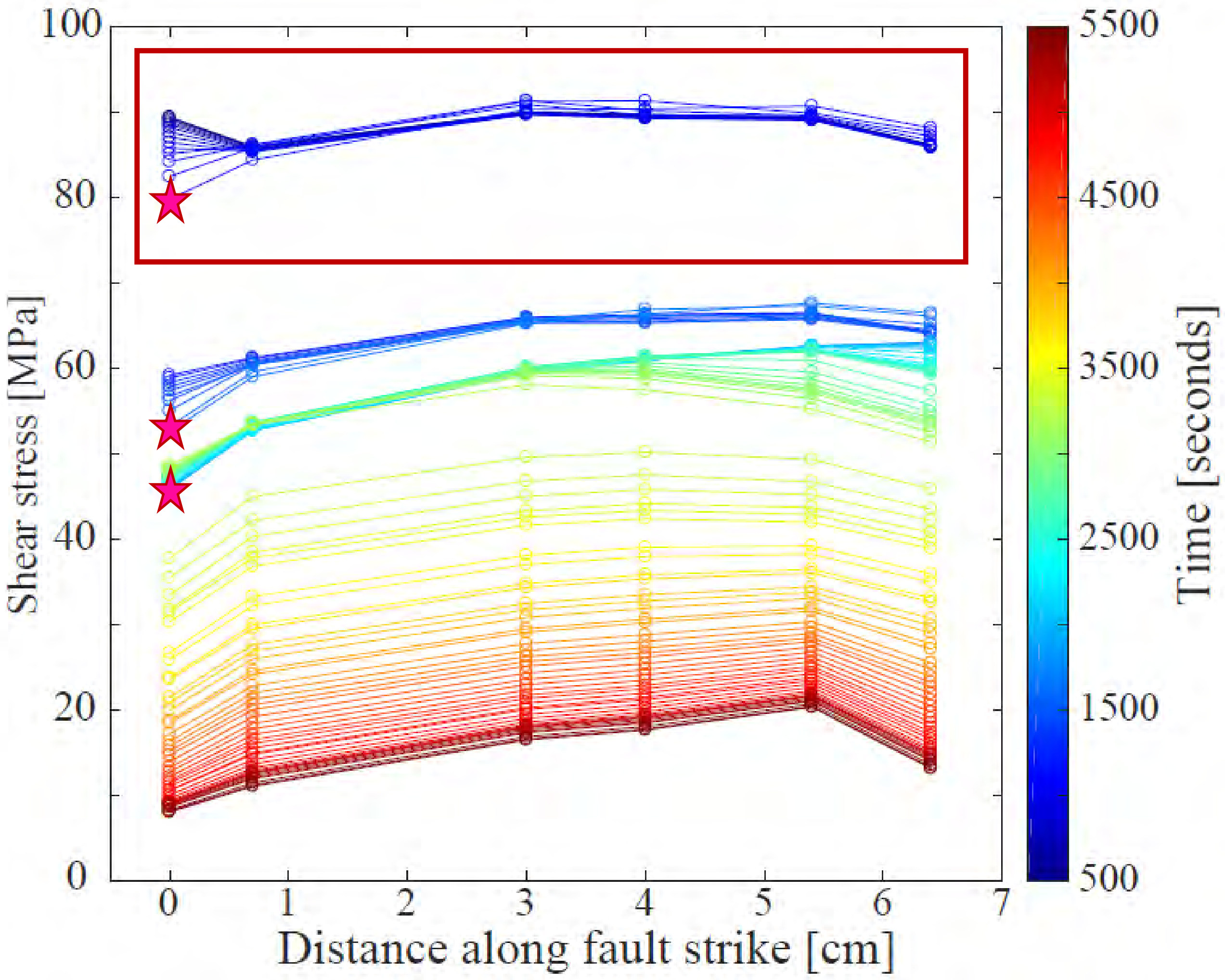

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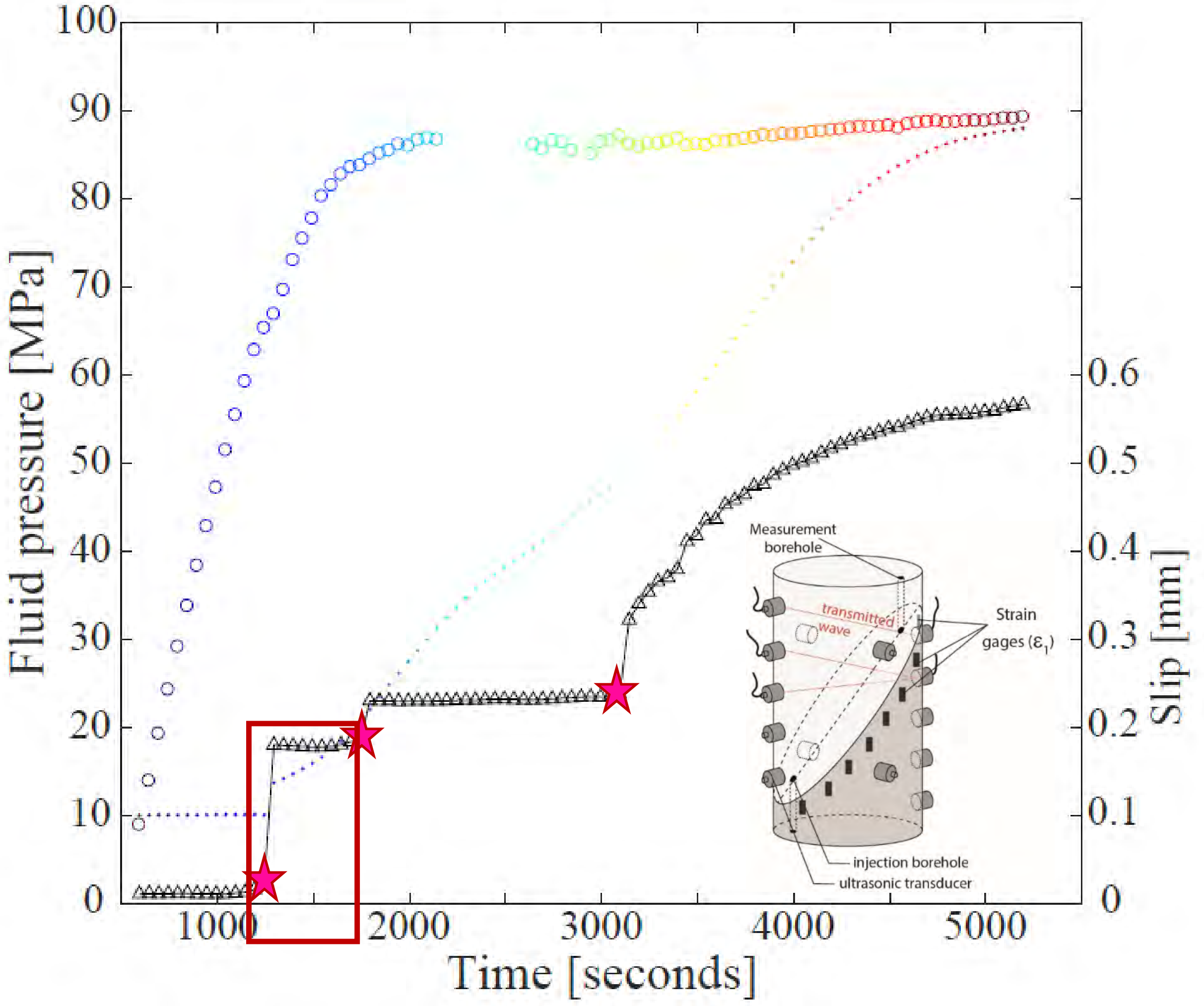
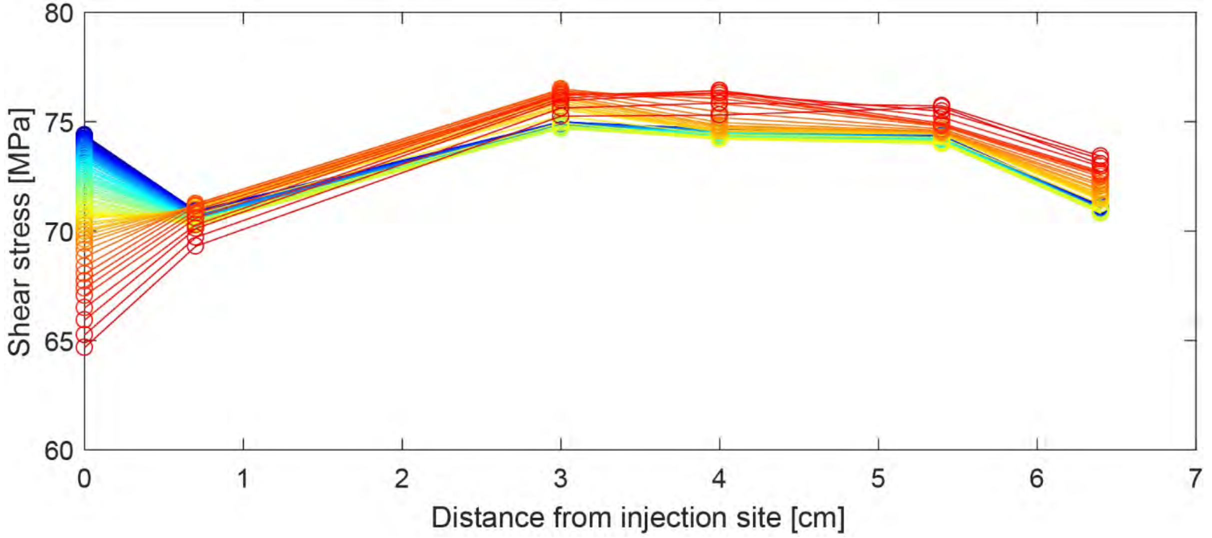


Dynamic events: Large/long nucleation **C_R> Vr > 180 m/s**



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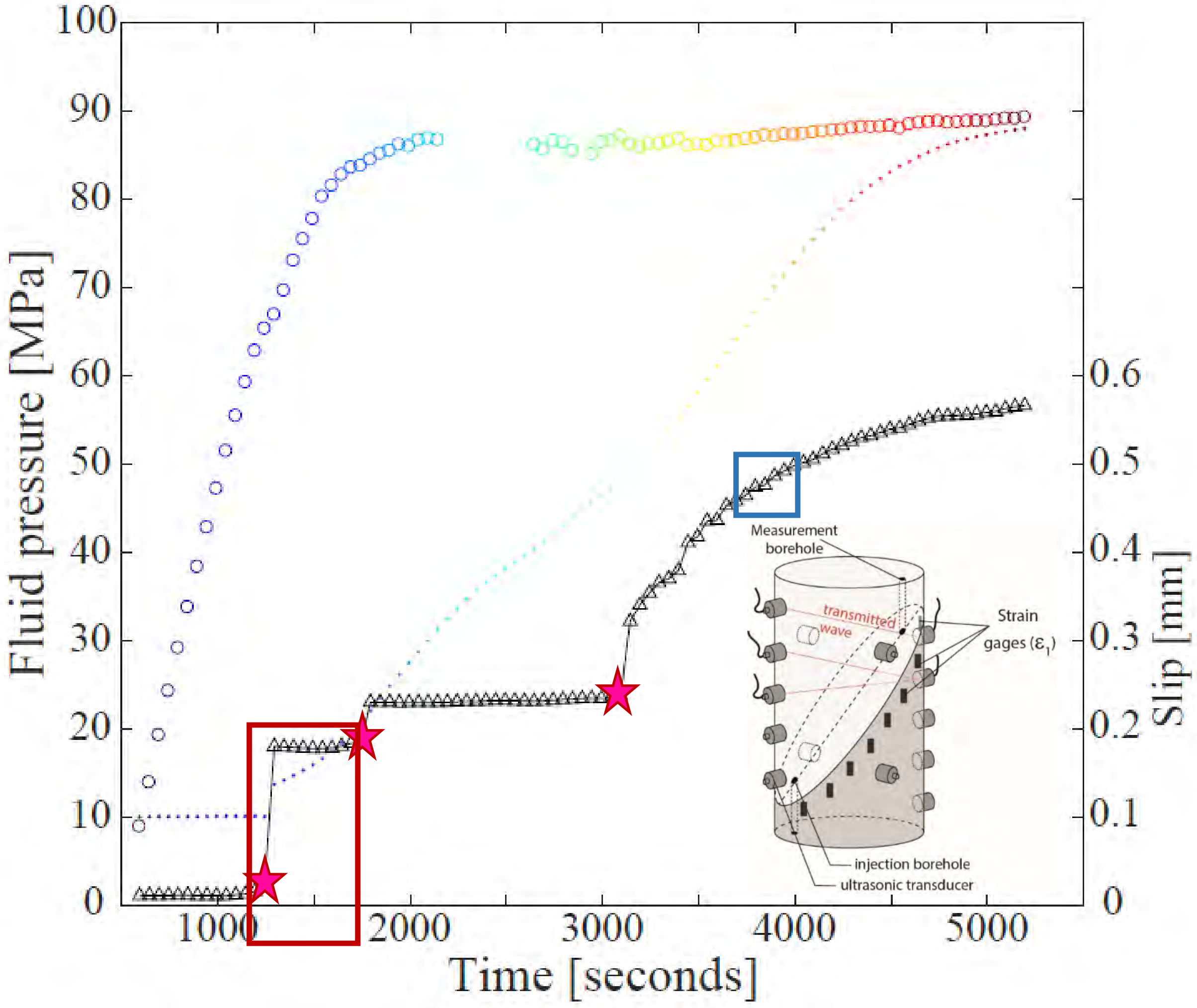

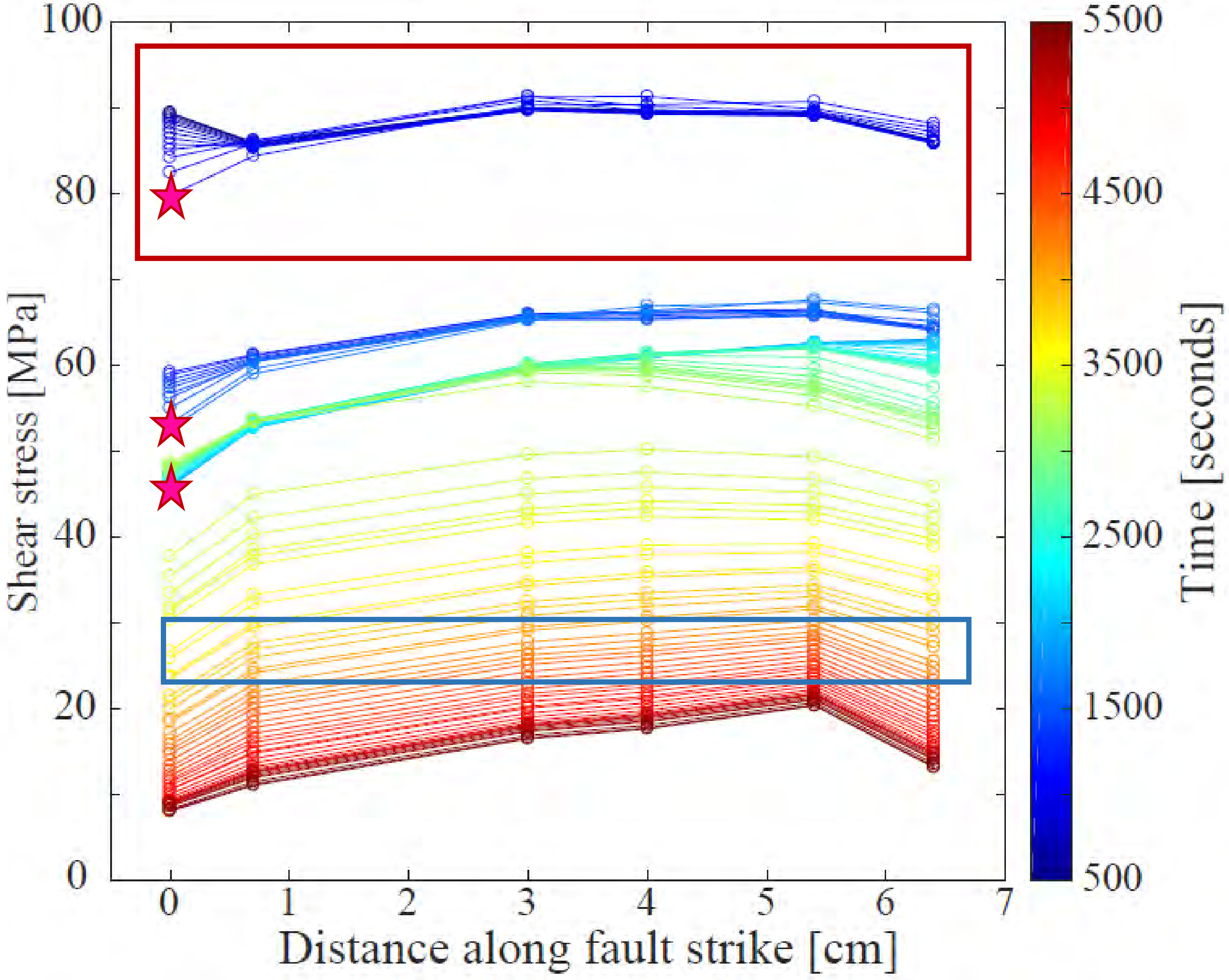

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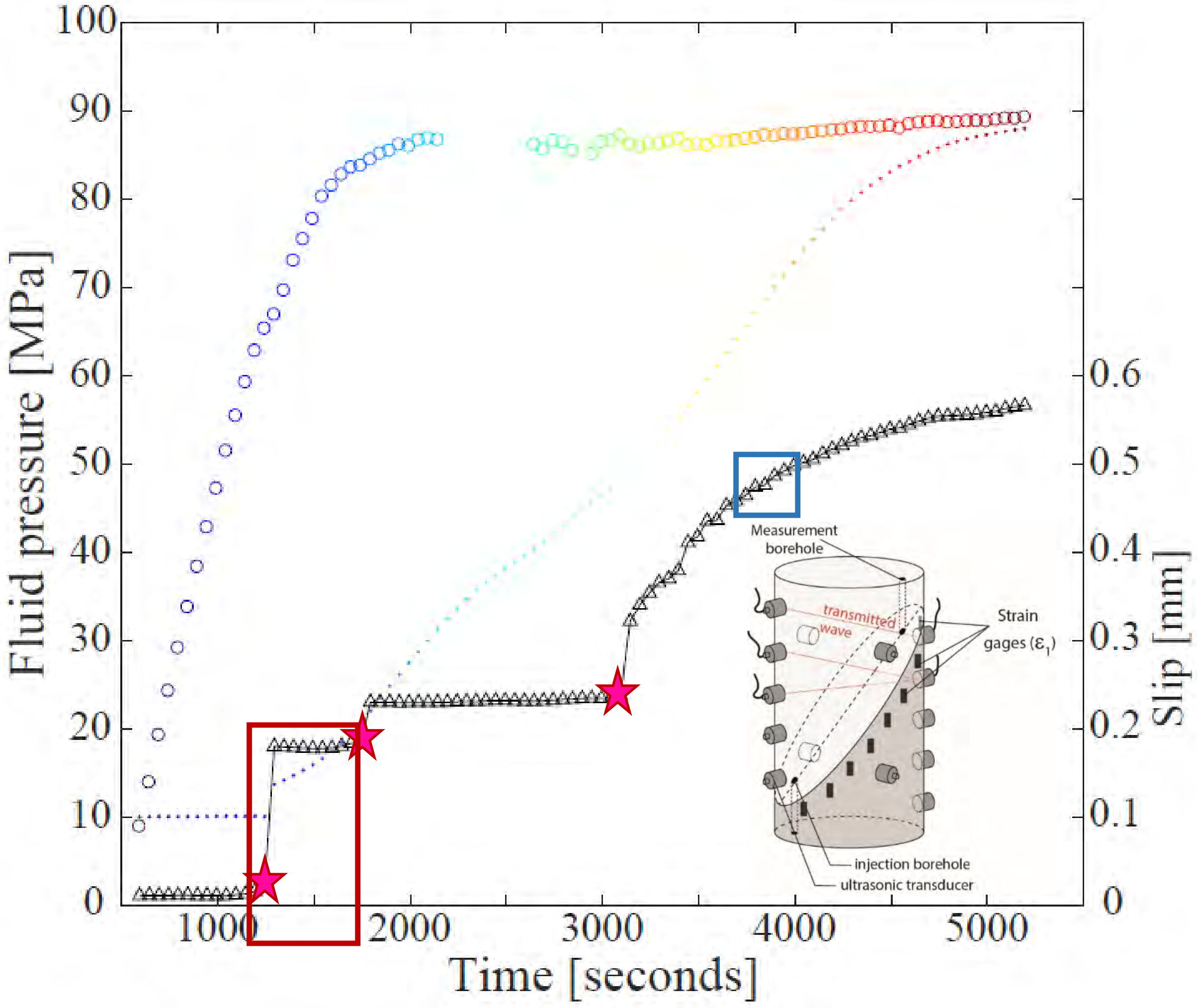
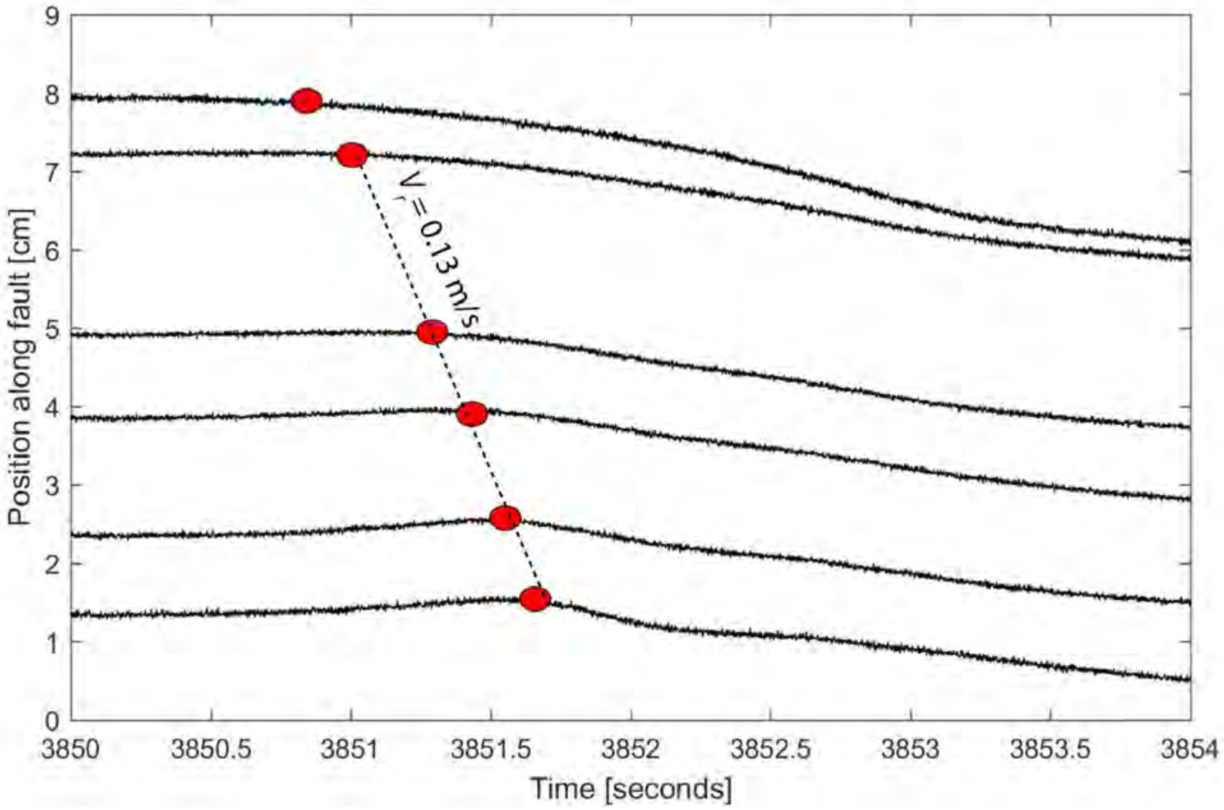


Dynamic events:	Large/long nucleation	C_R> Vr > 180 m/s
Slow slip events:	Small nucleation	Vr≈ $0.13\ m/s$



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Control from initial state of stress (τ_0 and P_f)

Work in progress:

Nucleation is complicated ⟺ Propagation is not? (LEFM)

Freund 1990; Svetlisky et al., 2018

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Explains our experimental results!

↘ τ_0 ↗ P_f ⟷ ↘ V_r

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Problem: Value of stress in nature?

Take home message

- Injection-induced slip: non-local problem.
- High injection rates or low permeability fault! local overpressures.
- Pore fluid diffusion far behind slip and/or rupture front.
- Local fluid overpressure drives stress transfer and entire fault reactivation!

- Rupture speed depends of the stress acting along the fault!
- What about rupture length? Also predictable from LEFM!
- Nucleation processes are complicated in experiments: Finite fault size problem!

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