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Research Letter

Can Precursory Moment Release Scale With Earthquake Magnitude? A View From the Laboratory

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On the scaling between precursory moment release and earthquake magnitude: Insights from the laboratory.

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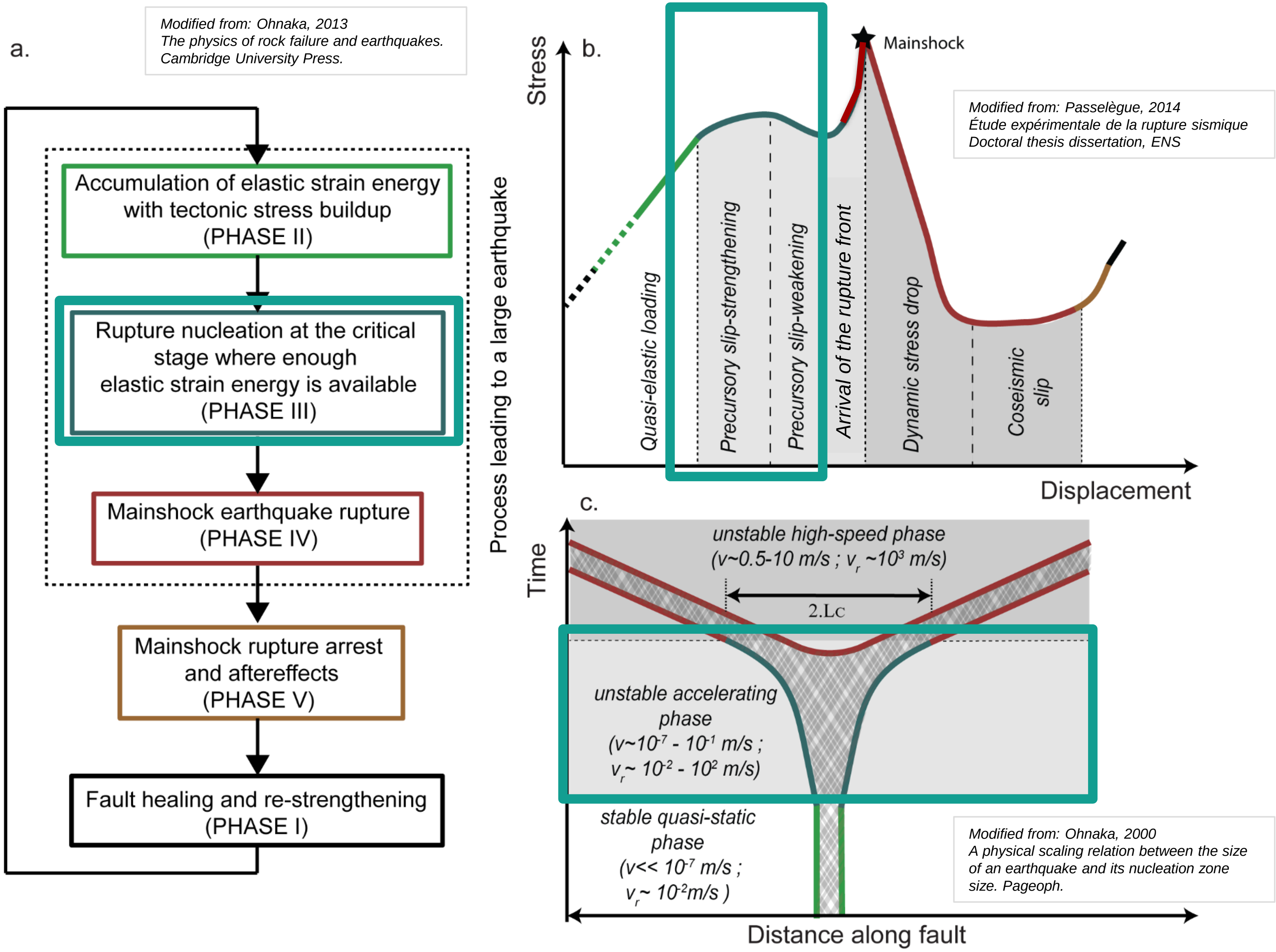
Earthquake Nucleation

The figure can be found in: Acosta, 2020
Experimental studies of Hydro-Mechanical couplings in Enhanced Geothermal Systems
Doctoral thesis dissertation, EPFL

- Experimental study of the influence of fluid pressures on earthquake nucleation.
- Relation between Nucleation and propagation phases?
- Information about an impending earthquake?



Study the effect of pressurized fluids on earthquake *nucleation*

Experimental Methods

- Triaxial stick-slip experiments on fault analogs.

  σ_3 = 45 - 95 MPa

  p_f = 0 – 60 MPa

- Samples:

  30 ° Saw cut

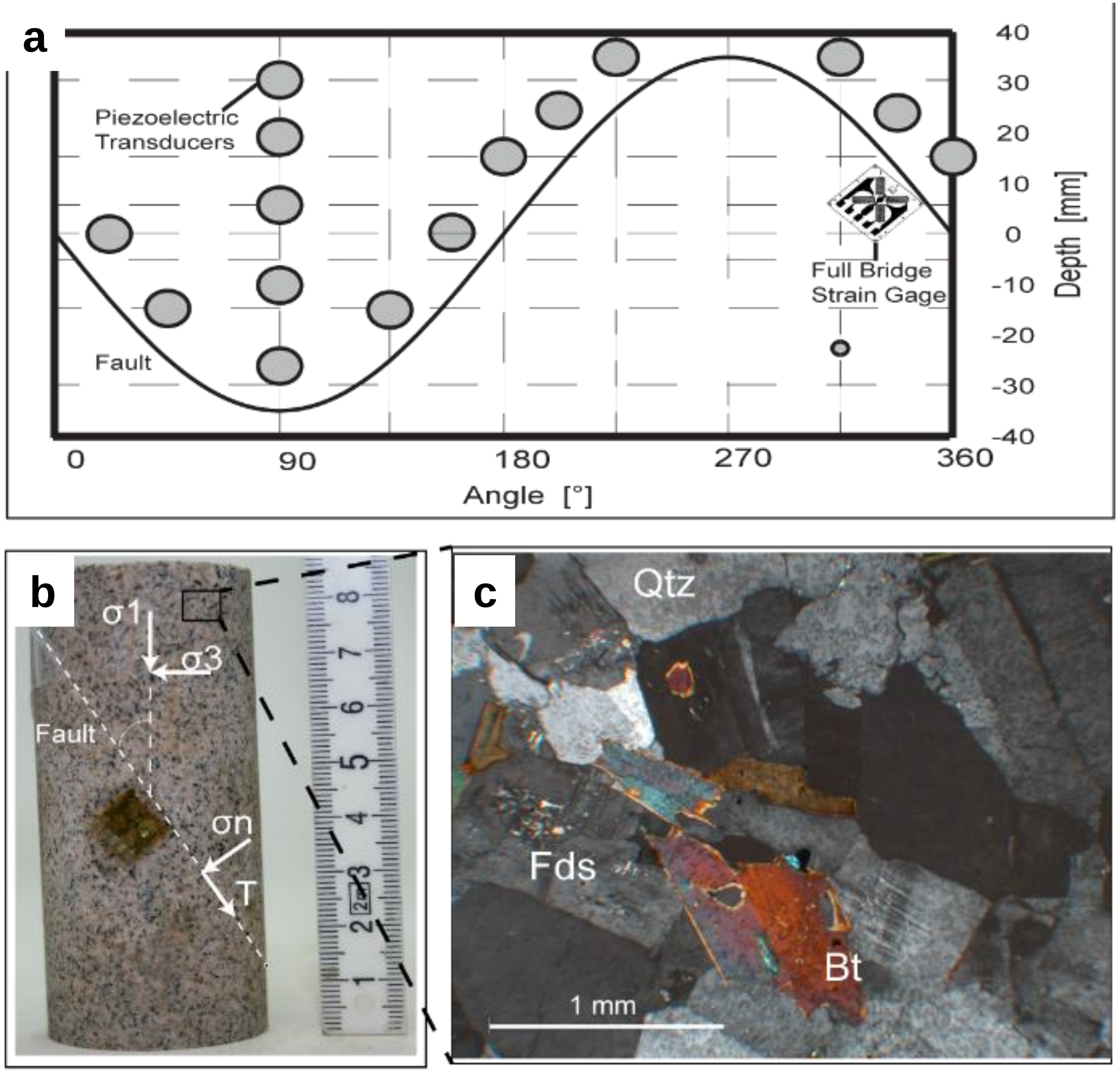
  Westerly Granite cylinders

  (ϕ=40 mm ; H=88 mm)

- Instruments:
  - External measurements: σ_1 ; σ_3 ; p_f ; ε_1
  - Internal sensors:

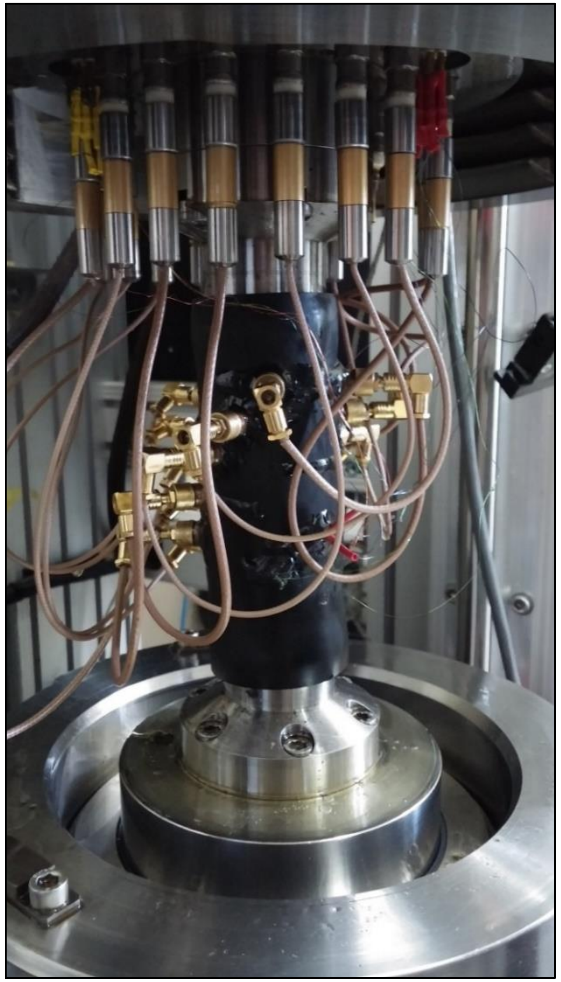
    Near fault strain gages

    Piezoelectric sensors

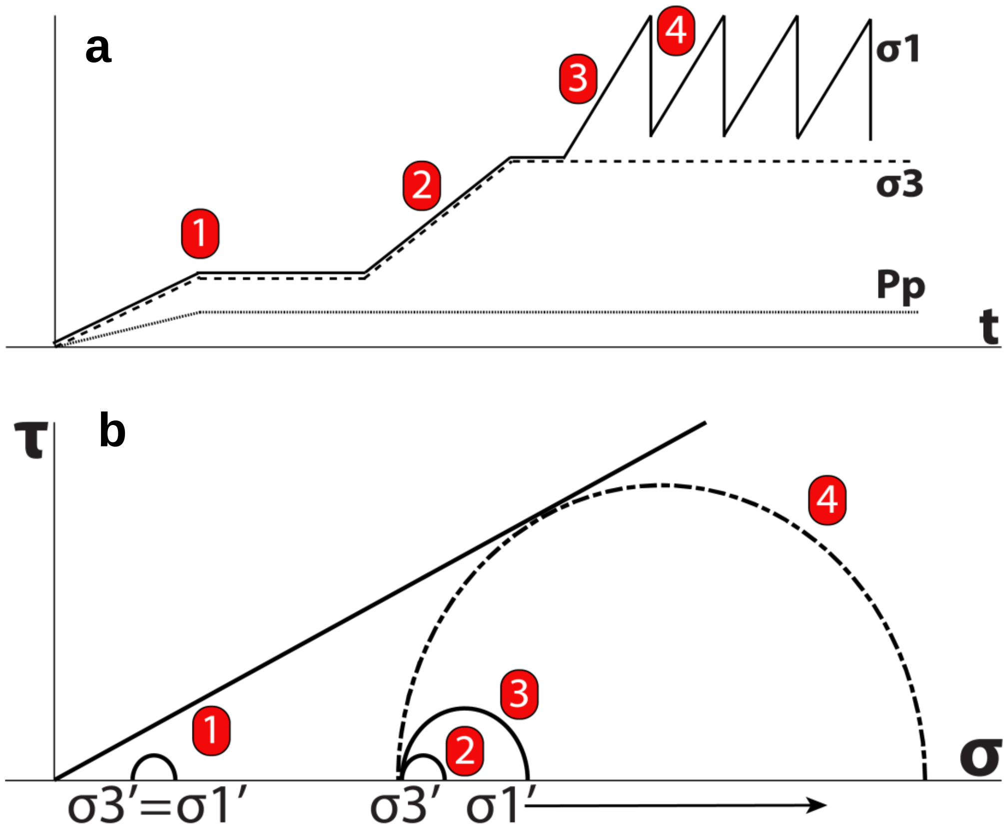


Laboratory earthquake analogs under realistic P_c and various P_f

Experimental Methods



1. Saturate samples at low σ_3 (while $\sigma_{1=}\sigma_3$).
2. Increase σ_1 & σ_3 until target σ_3 value.
3. Increase σ_1 (so σ_n & τ increase) at constant velocity.
4. Earthquakes spontaneously nucleate when strenght is reached.



Simulate tectonic loading under various P_f (instead of increasing P_f by fluid injections)

Precursory slip and seismicity

$P_{ceff}=P_c-P_f= 70$ MPa

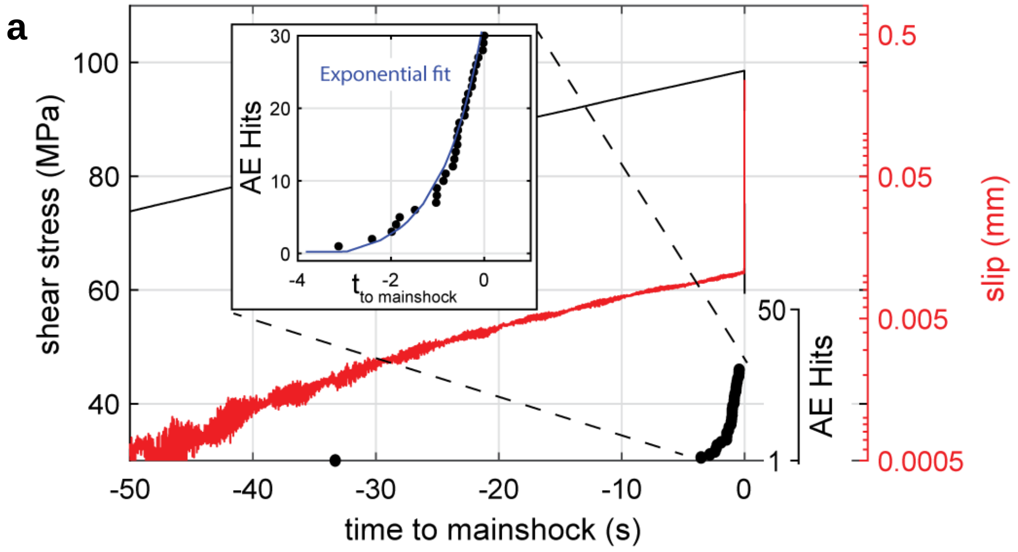
P_f held constant during experiment

Silent precursory phases were recorded under all P_f conditions

DRY

-Exponential evolution of slip

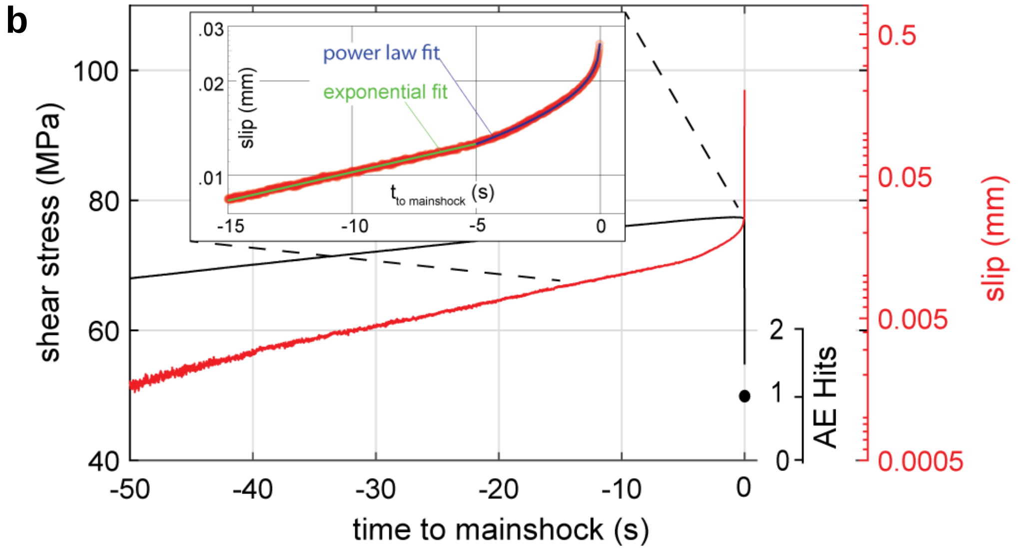
-Exponential evolution of AE



P_f = 1 MPa

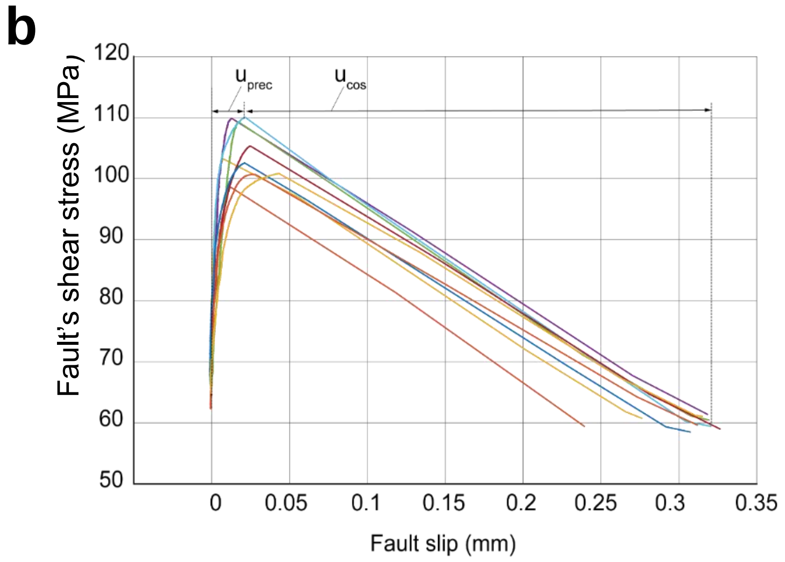
-Exponential and power law evolution of slip

- No AE: silent precursory phase

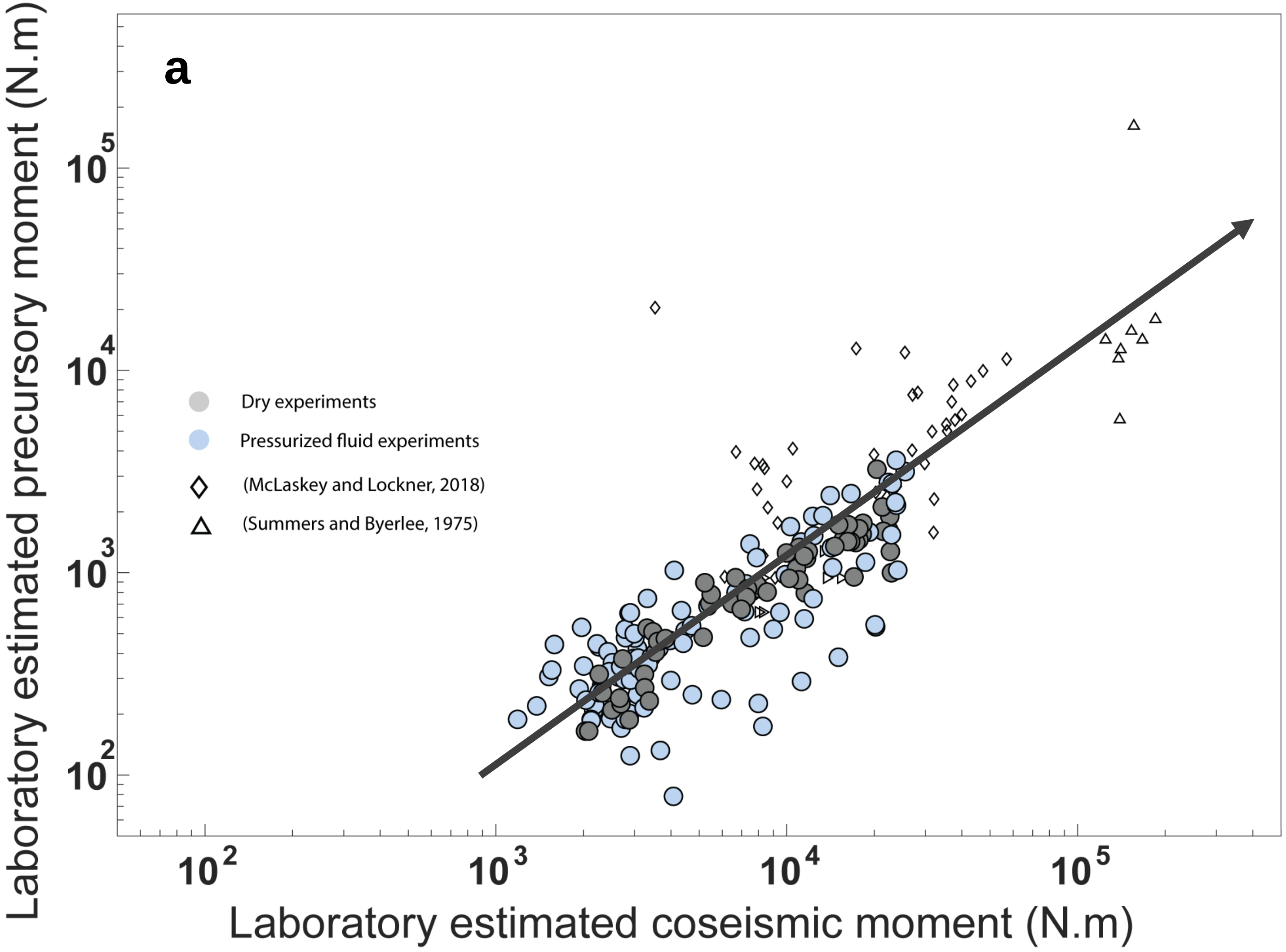


Precursory slip and seismicity drastically change with 1 MPa of P_f

Precursory and co-seismic moment: Laboratory



$$M_{\mathrm{p}} = \mu.A.u_{\mathrm{prec}} \qquad M_0 = \mu.A.u_{\mathrm{cos}}$$



A trend exists between total precursory and co-seismic moments (panel **a**)

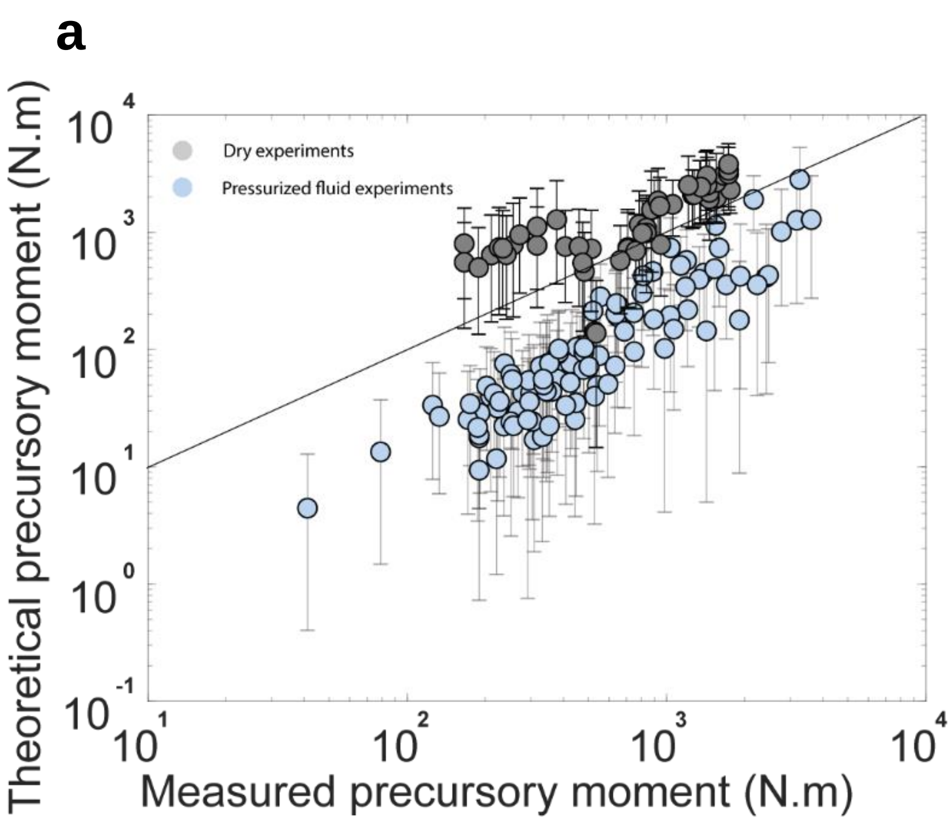
Precursory and co-seismic moment: Theory

Nucleation ends in Slip-weakening

Ida, 1972; Campillo & Ionescu, 1997

$$\underbrace{M_p^{Lc} = \mu . u_{prec} . L_c^2 \qquad L_c = \beta . \frac{\mu \, G'}{\Delta\sigma_d^2}}_{}$$

$$M_p = \mu^3 u_{prec} \left(\frac{\beta G'}{\Delta\sigma_d^2}\right)^2$$



Nucleation theory predicts (fairly) well the experiments

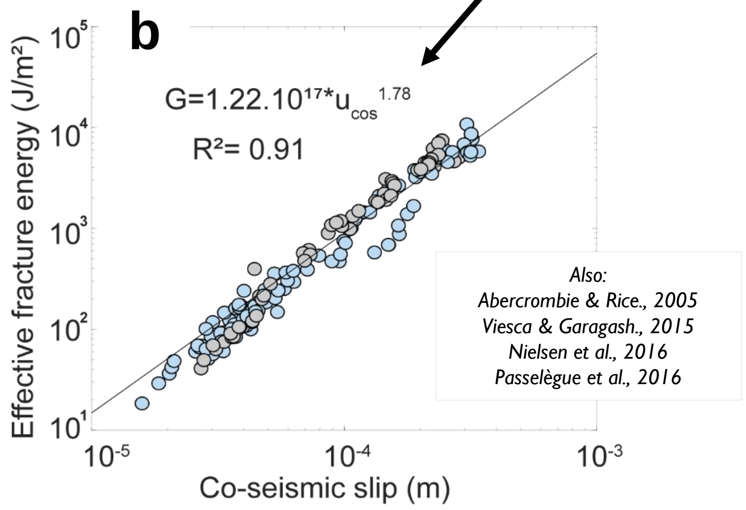
Precursory and co-seismic moment: Theory

$$\left.\begin{array}{l} M_0 = \mu . u_{\cos} . L^2 \\ \Delta\sigma_s = C.\mu.\frac{u_{cos}}{L} \end{array}\right\} \quad u_{cos} = \frac{\Delta\sigma_s^{\frac{2}{3}} M_0^{\frac{1}{3}}}{\mu\, C^{\frac{2}{3}}}$$

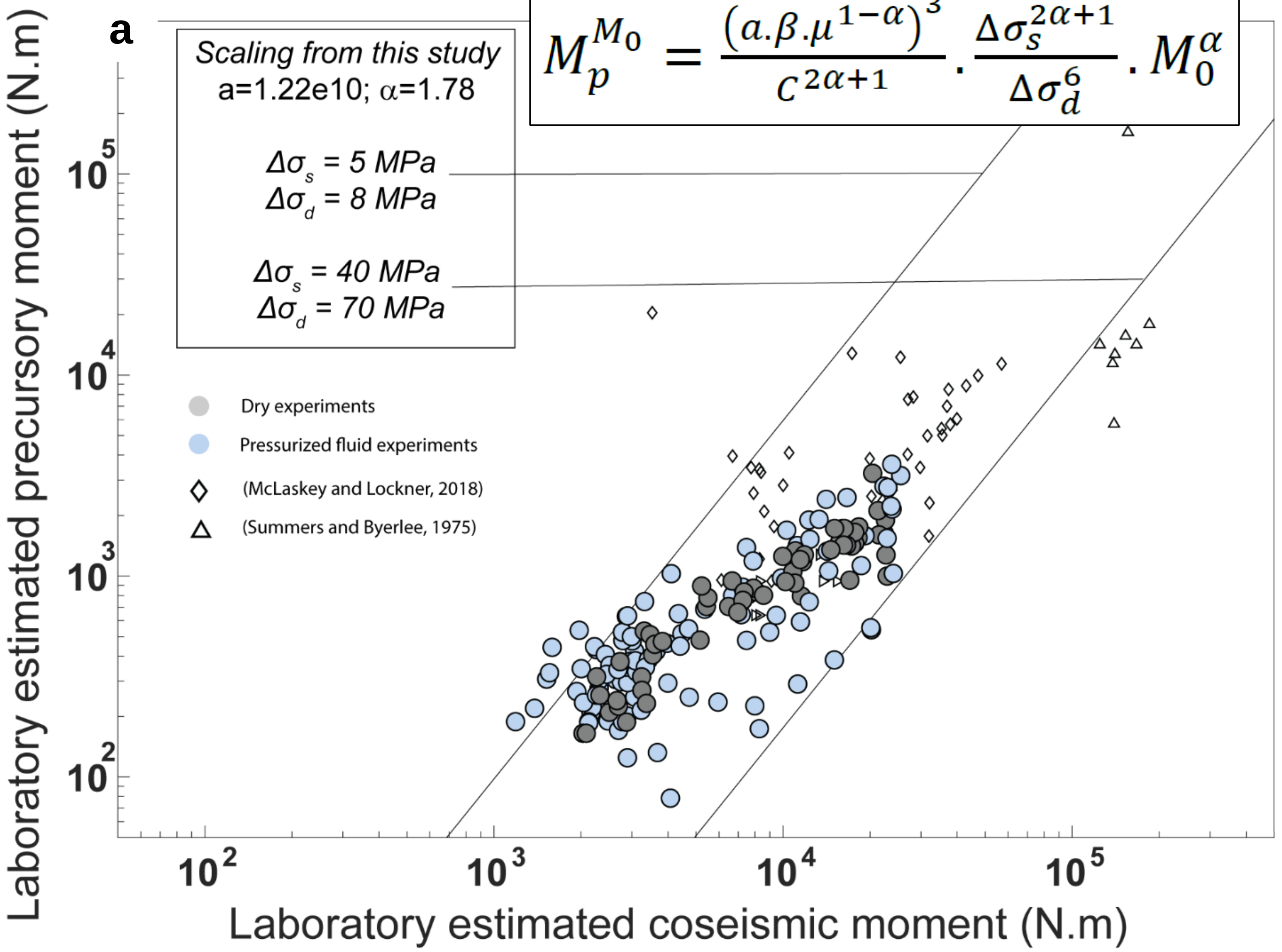
Kanamori and Brodsky, 2004

$$M_p^{G'} = \frac{(\beta\mu G')^3}{C} \cdot \frac{\Delta\sigma_s}{\Delta\sigma_d^6}$$

$$\boxed{G' = a\, u_{cos}^{\alpha}}$$



$$M_p^{M_0} = \frac{(a.\beta.\mu^{1-\alpha})^3}{C^{2\alpha+1}} \cdot \frac{\Delta\sigma_s^{2\alpha+1}}{\Delta\sigma_d^6} \cdot M_0^{\alpha}$$

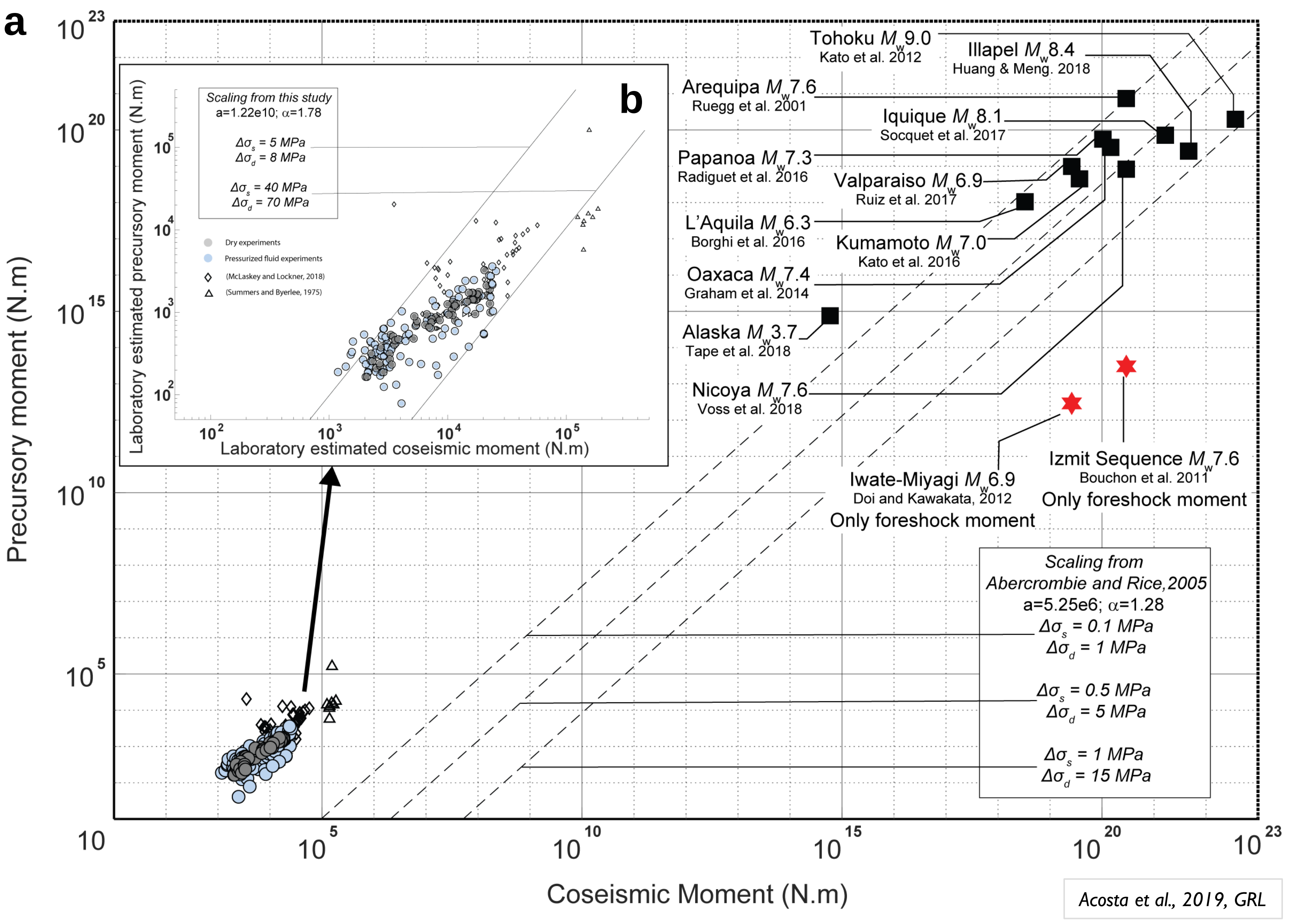


Nucleation theory predicts (fairly) well the experiments and predicts a trend between M_p and M_0^{α}

Precursory and co-seismic moment: Natural earthquakes

Different methods for estimation of precursory moment release:

- GPS
- InSAR
- Foreshocks
- Repeating Earthquakes
- Waveform analysis and modelling
- Borehole tiltmeters
- Combination of the abovec



Several observations of natural earthquakes seem to be compatible with the scaling

Conclusions

- P_f controls the temporal evolution of foreshocks and precursory slip
- In the lab, precursory moment scales with co-seismic moment release independent of P_f, set-up, stress state, and fault history
- In Natural earthquakes M_p seems to scale with M_0
- It could be valid for anthropogenic seismicity too (blue points)