INSU
Observer & comprendre

Energy budget of laboratory earthquakes

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Thanks to:
@ ENS: **Samson Marty, Jérôme Aubry**, Harsha Bhat, Damien Deldicque, Raul Madariaga
@ EPFL: **Mateo Acosta**, François Passelègue, Marie Violay
@ IPGP: Frédéric Girault, Javier Escartin

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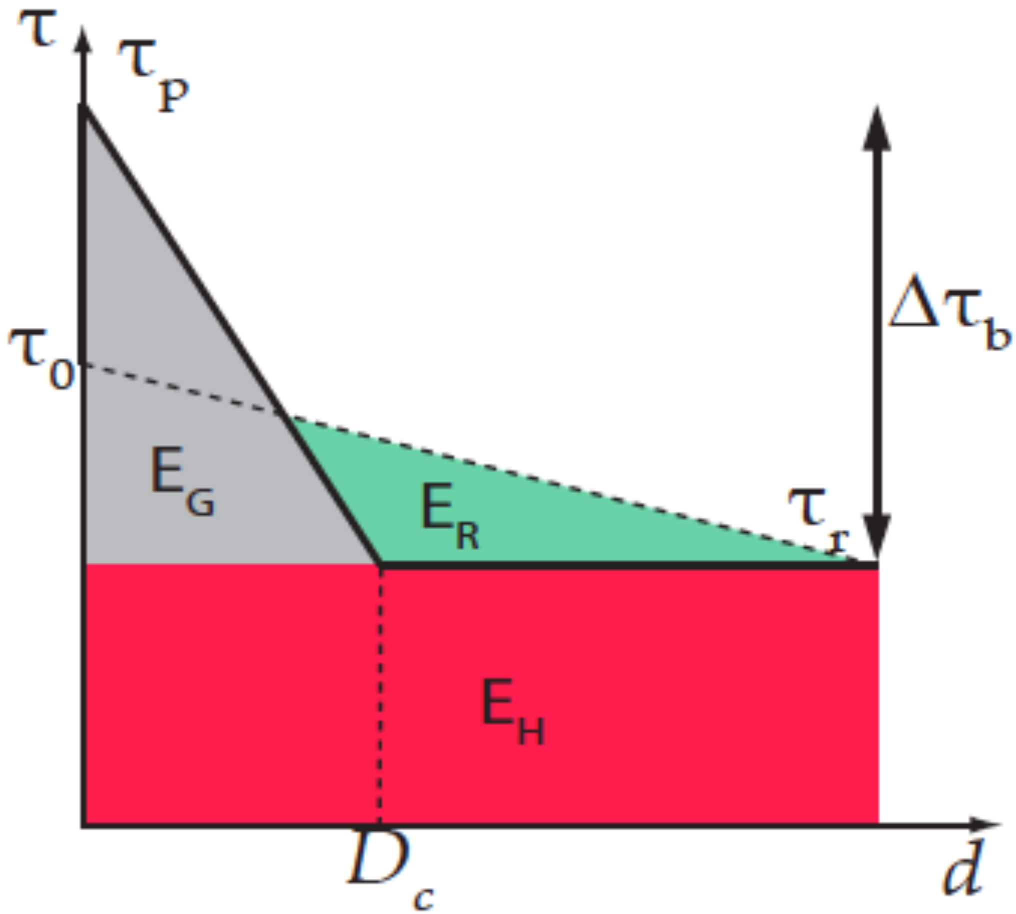
MOTIVATION



Energy partitioning during EQs

Outline

- EQs in the lab.
- Heat generation – How hot does it get?

  (Aubry et al. GRL 2018)
- With water, pressure matters

  (Acosta et al., Nat. Comm. 2018)
- HF radiation, where the waves come from?

  (Marty et al. GRL 2019)

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Stick-Slip as a Mechanism for Earthquakes

W. F. Brace; J. D. Byerlee

Science, New Series, Vol. 153, No. 3739. (Aug. 26, 1966), pp. 990-992.

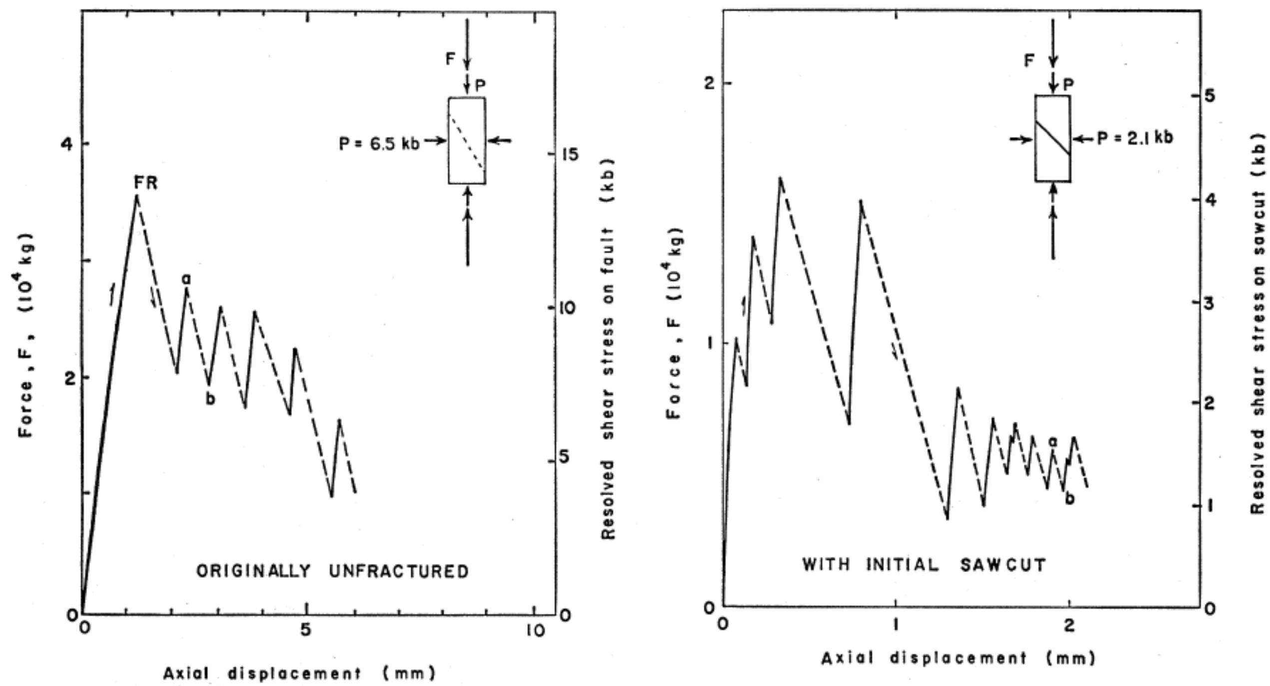


Fig. 1 (left). Force-displacement curve for the axial direction in a cylindrical sample of Westerly granite. Small diagram above the curve shows schematically how stress was applied to the sample. The sample fractured at point *FR* forming the fault which is shown as a dotted line in the small diagram. The exact shape of the curves during a stress drop (such as *ab*) is not known and is shown dotted. *P* is confining pressure. Fig. 2 (right). Same as Fig. 1 except that the sample contained a sawcut with finely ground surfaces as shown schematically (small figure) by a heavy line.

PREFACE: A SHORT GEOPHYSICAL HISTORY OF WESTERLY GRANITE

C. H. Scholz

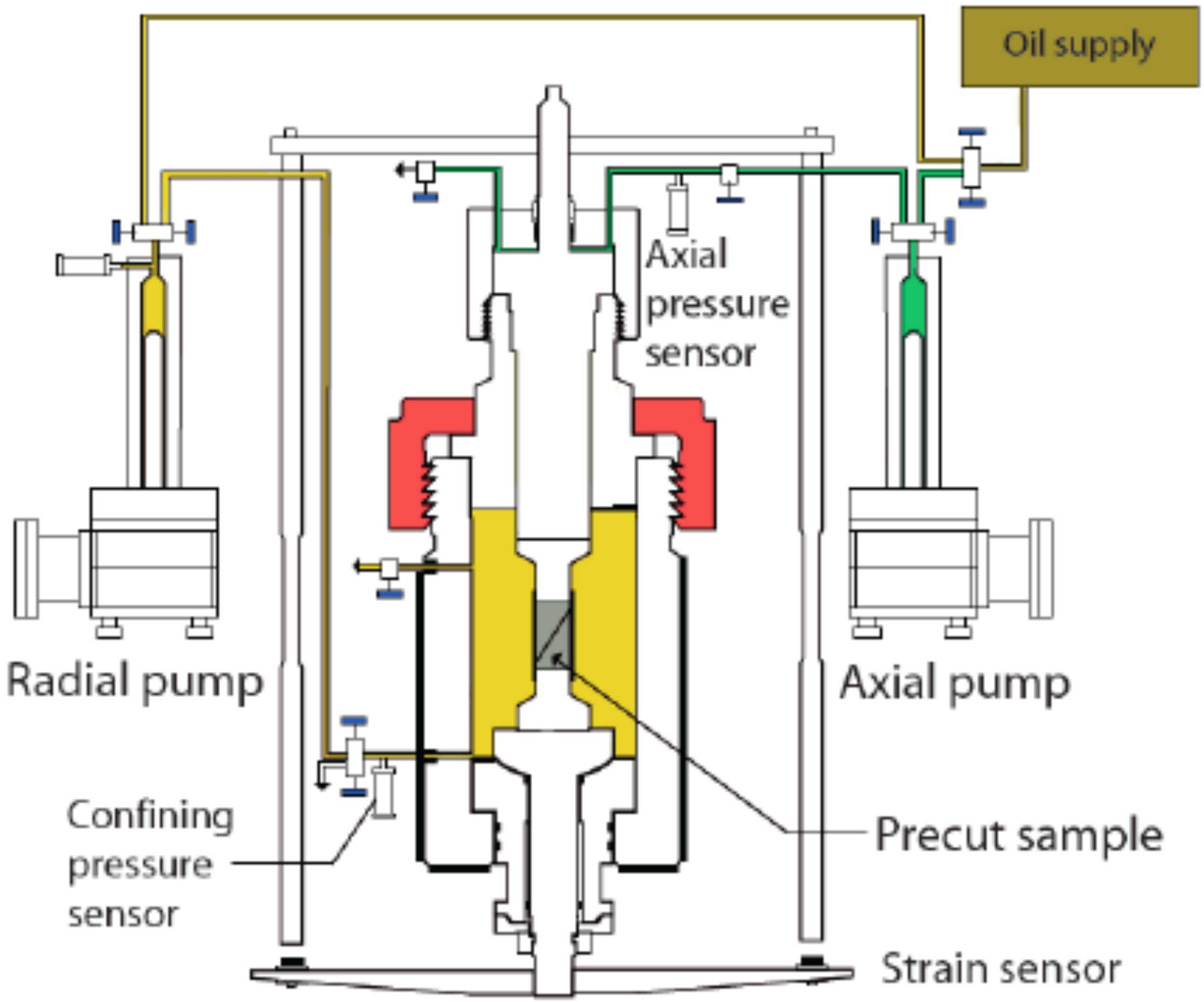
A number of rocks have achieved a kind of fame in geophysical circles because of their frequent

(...)

It is ironic that many who use the well-worn quip "geophysicists think that the crust is made of Westerly granite" are probably unaware that Westerly granite was once designated by the U.S. Geological Survey and the Carnegie Institution as 'G-1', the type rock of the continental crust [Fairbairn et al., 1951].

AGU Geophysical Monograph Series, EQ source mechanics, 1986

The soft (Earthquake) machine…



Scheme of the triaxial apparatus of the ENS

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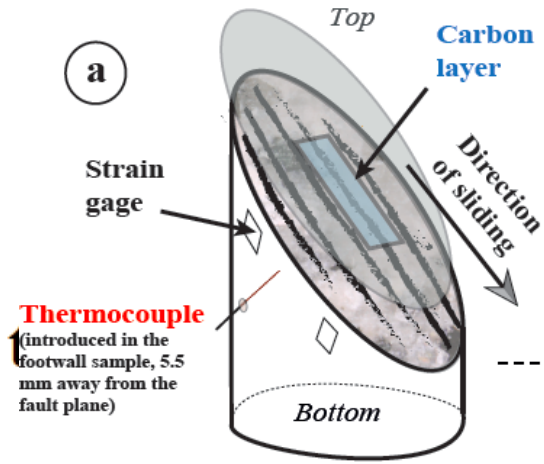
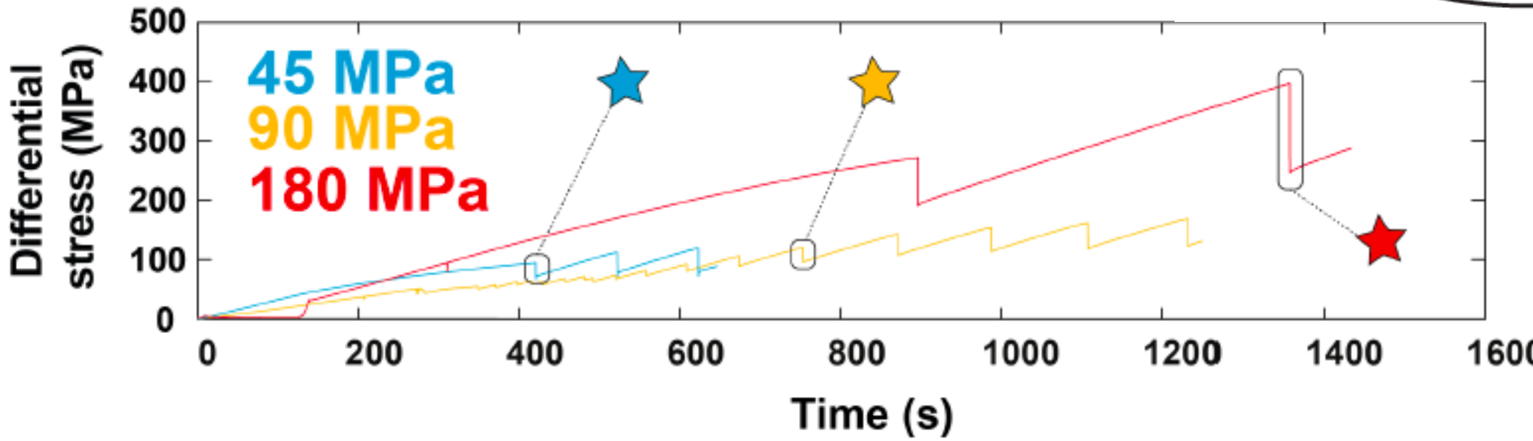
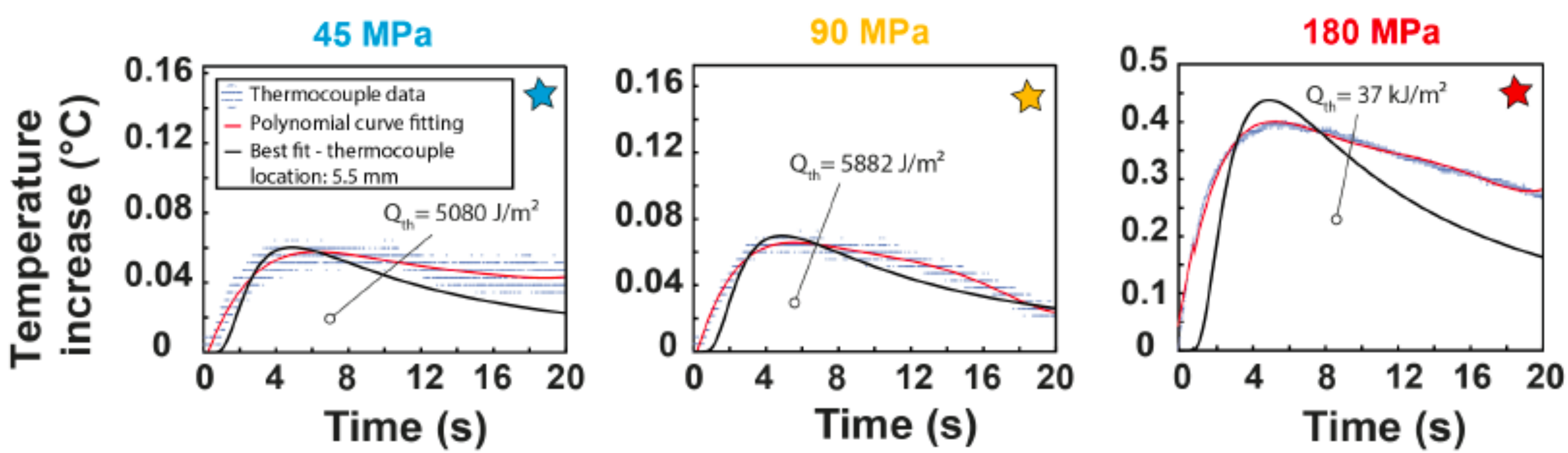
Measuring Heat

Frictional heat produced inferred from t

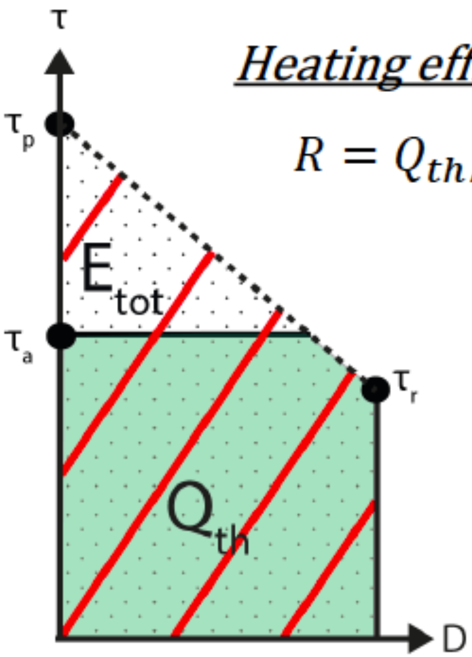






Aubry et al. GRL 2018

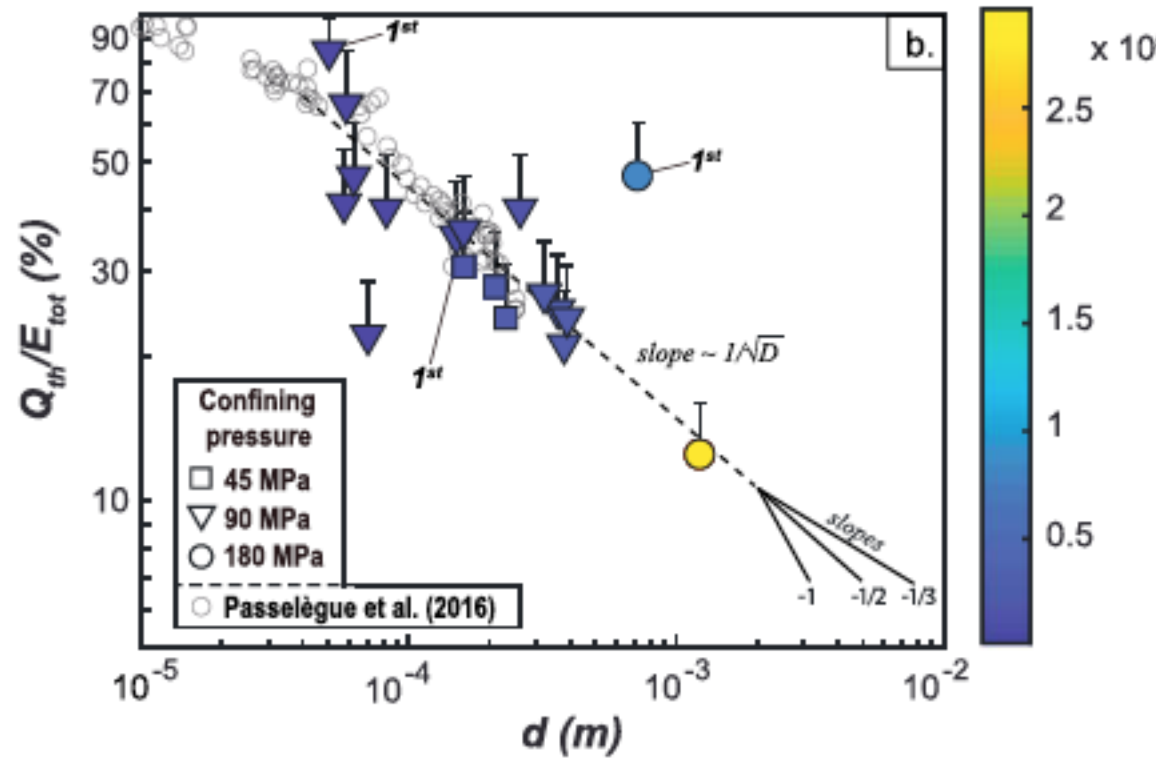
Heating efficiency



Heating efficiency:

$$R = Q_{th}/E_{tot}$$

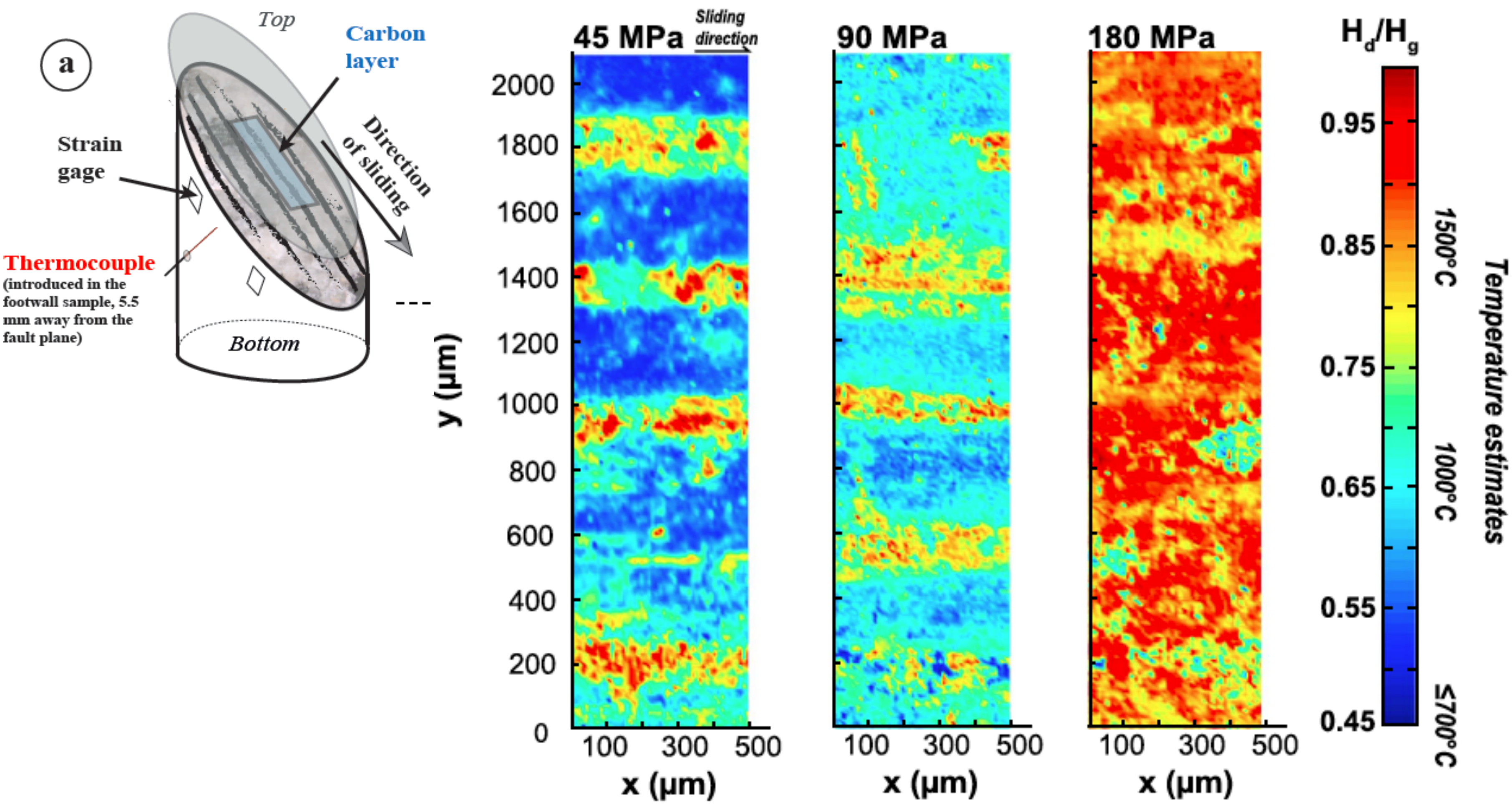
Aubry et al. GRL 2018



When looking at heat, rupture becomes more efficient with increasing sliding

Frictional heating is heterogeneous

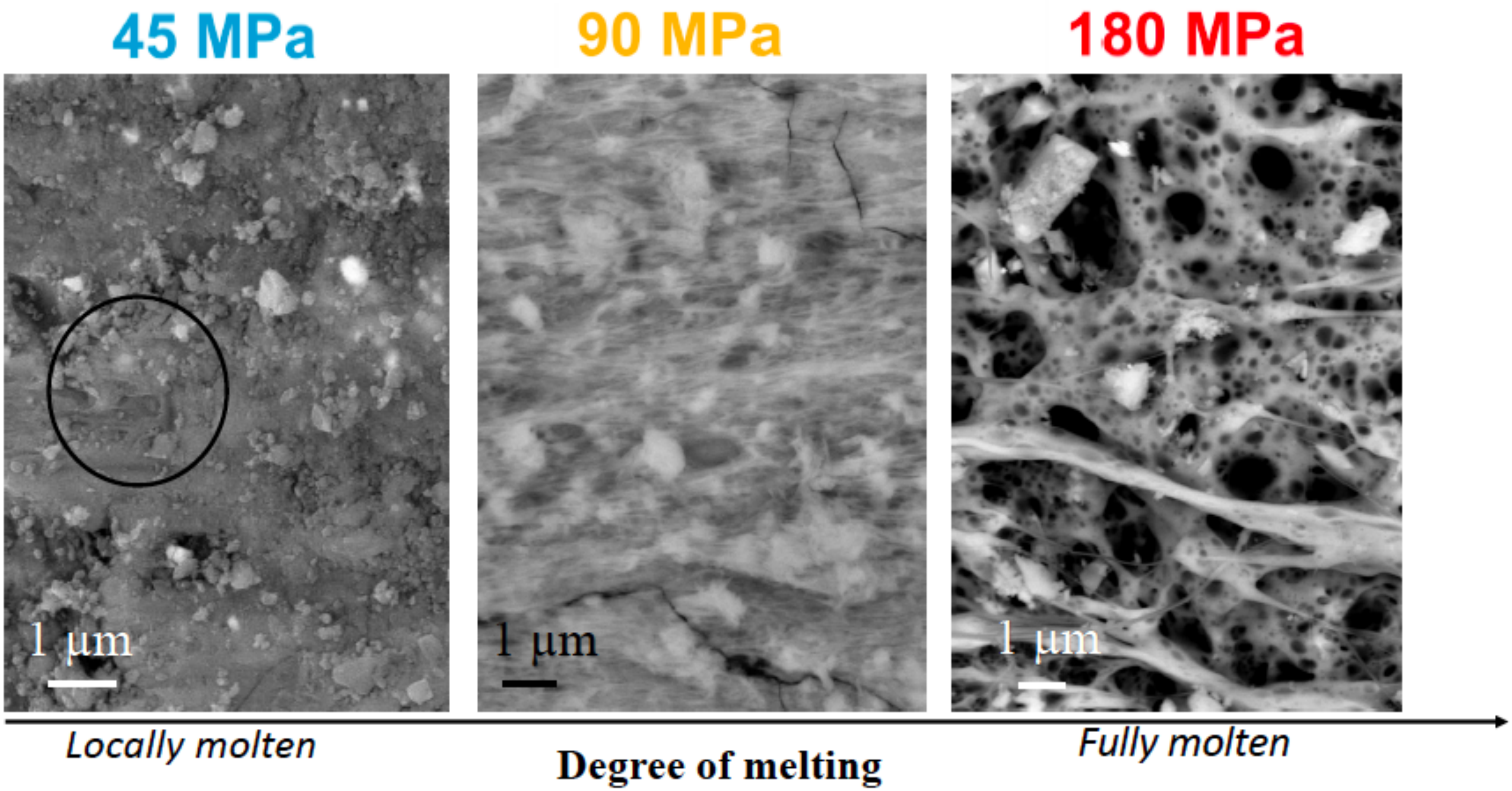
Temperature maps of the interface during frictional sliding



Aubry et al. GRL 2018

Transition from asperity to bulk surface melting

Microstructural evidences of melting



Aubry et al. GRL 2018

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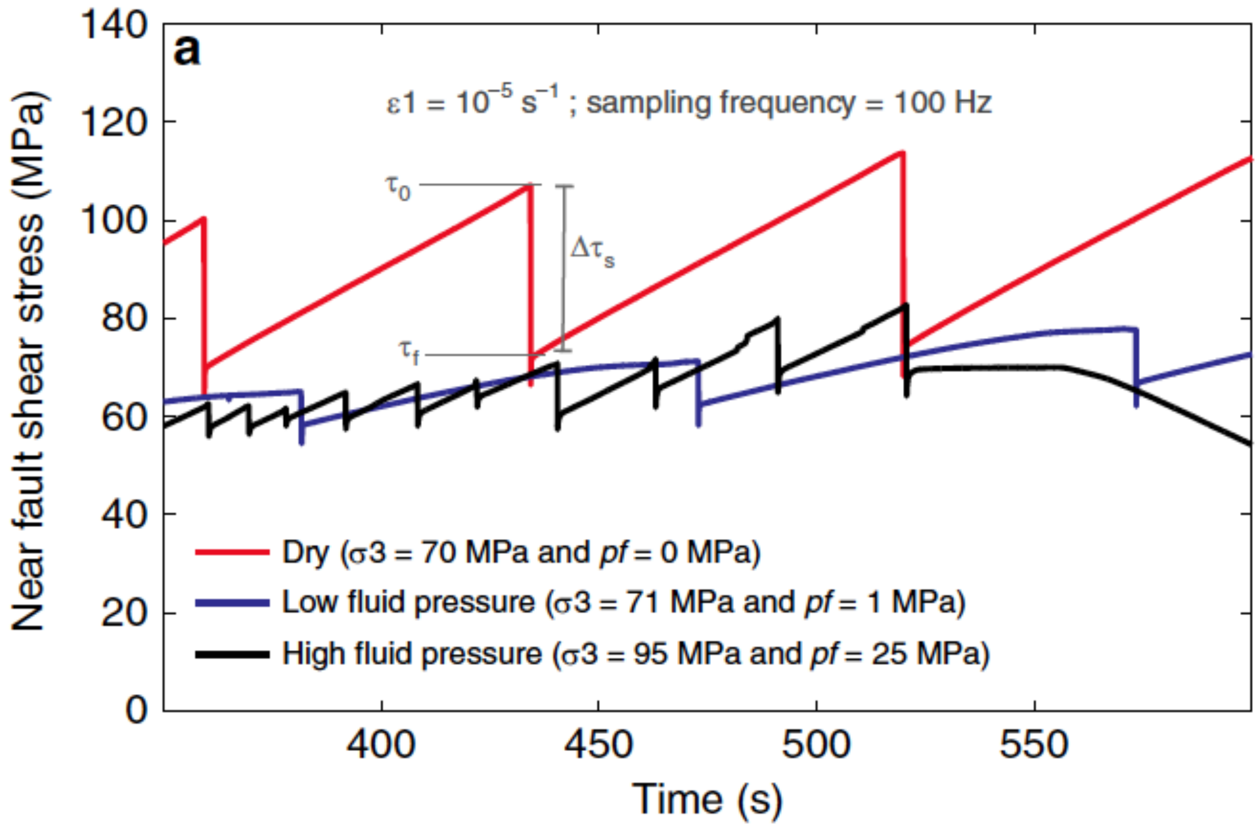
Stick-slips and stress drops

the fluid version



Acosta et al. Ncomms, 2018

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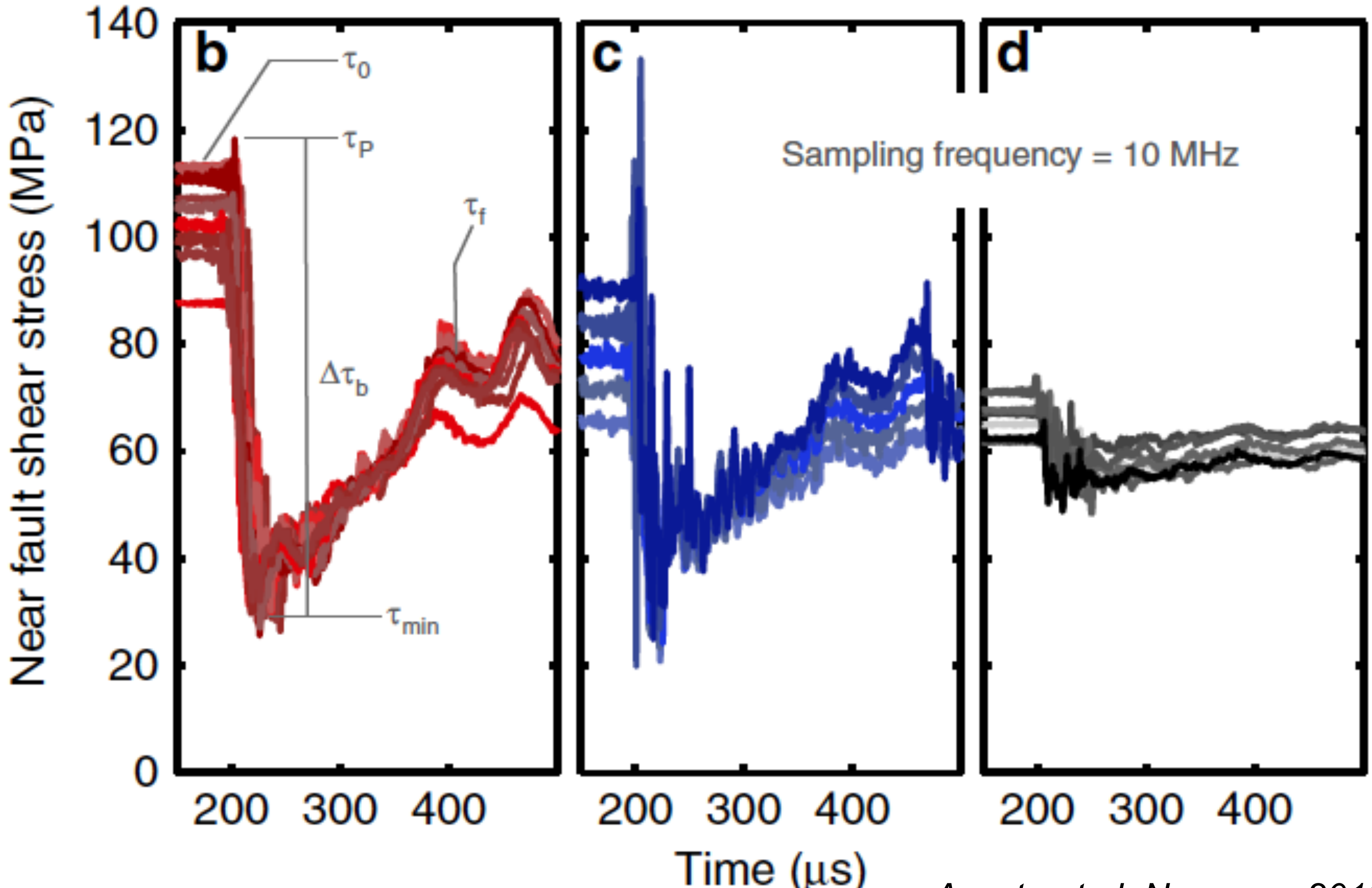

Acosta et al. Ncomms, 2018

Stick-slips and stress drops

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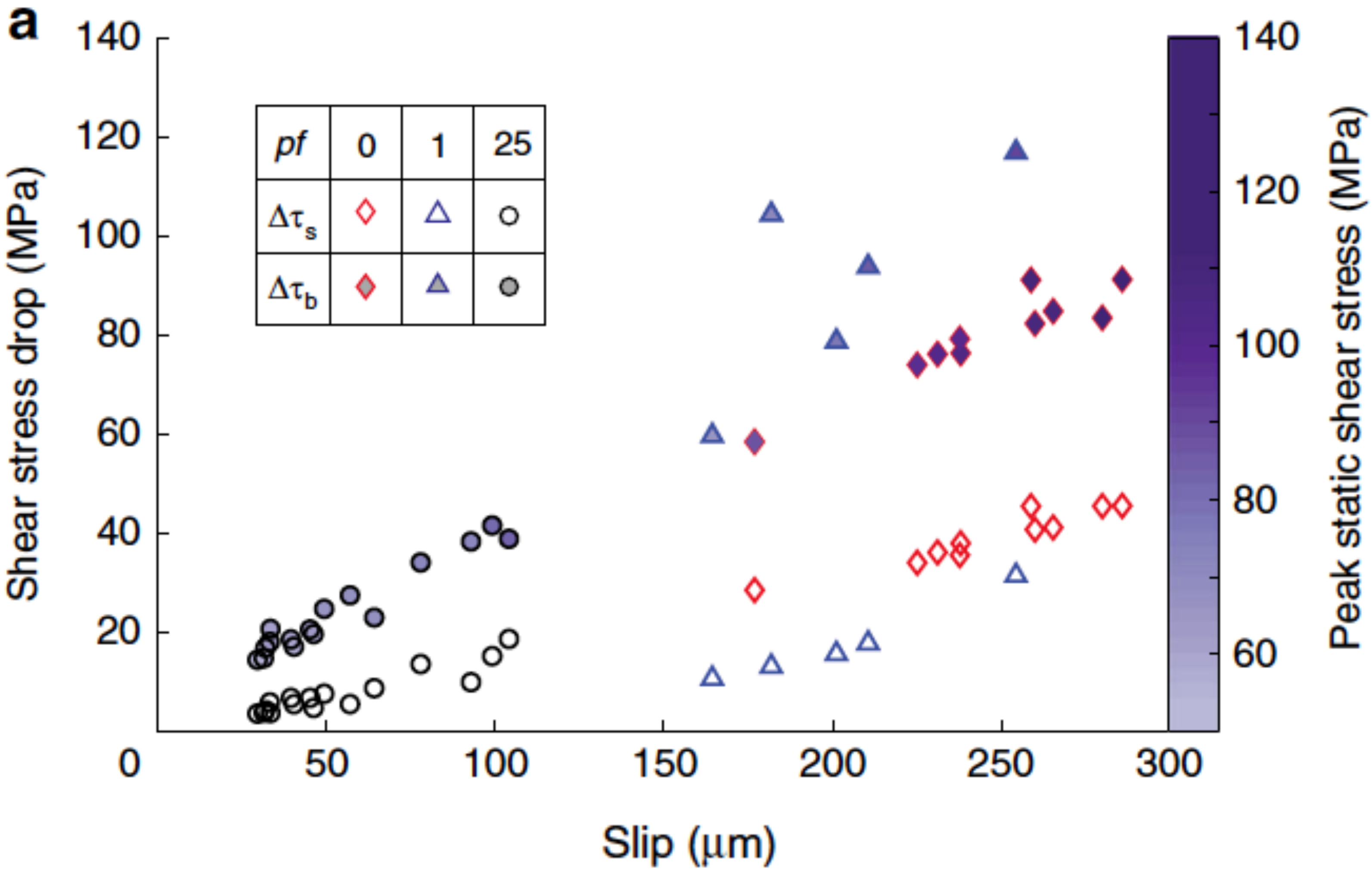
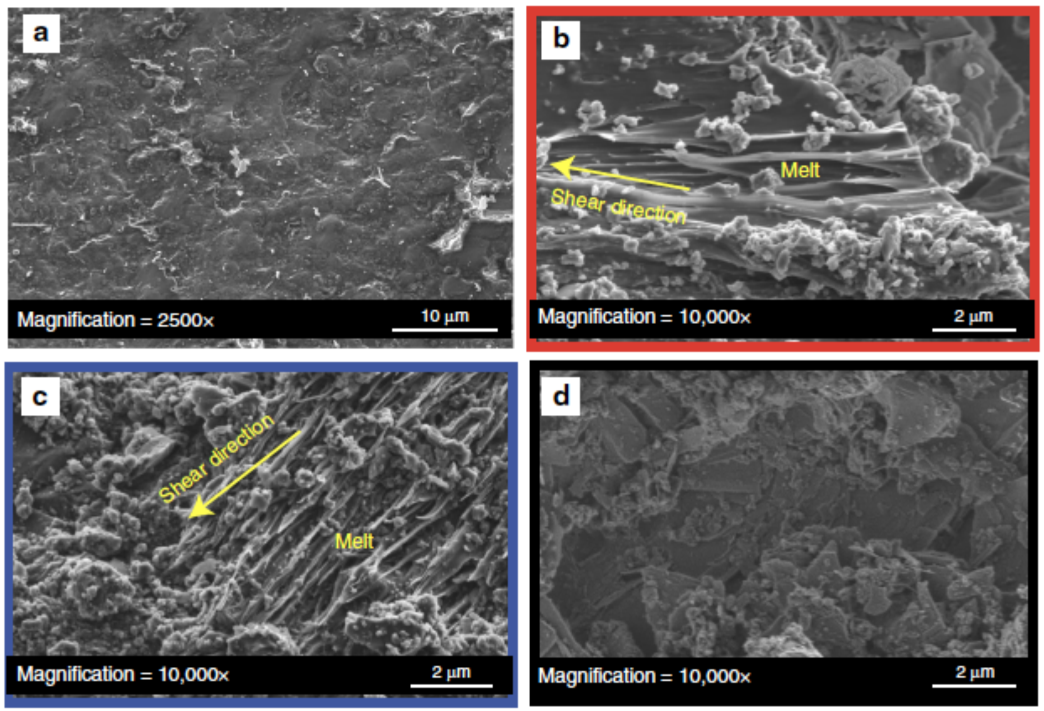
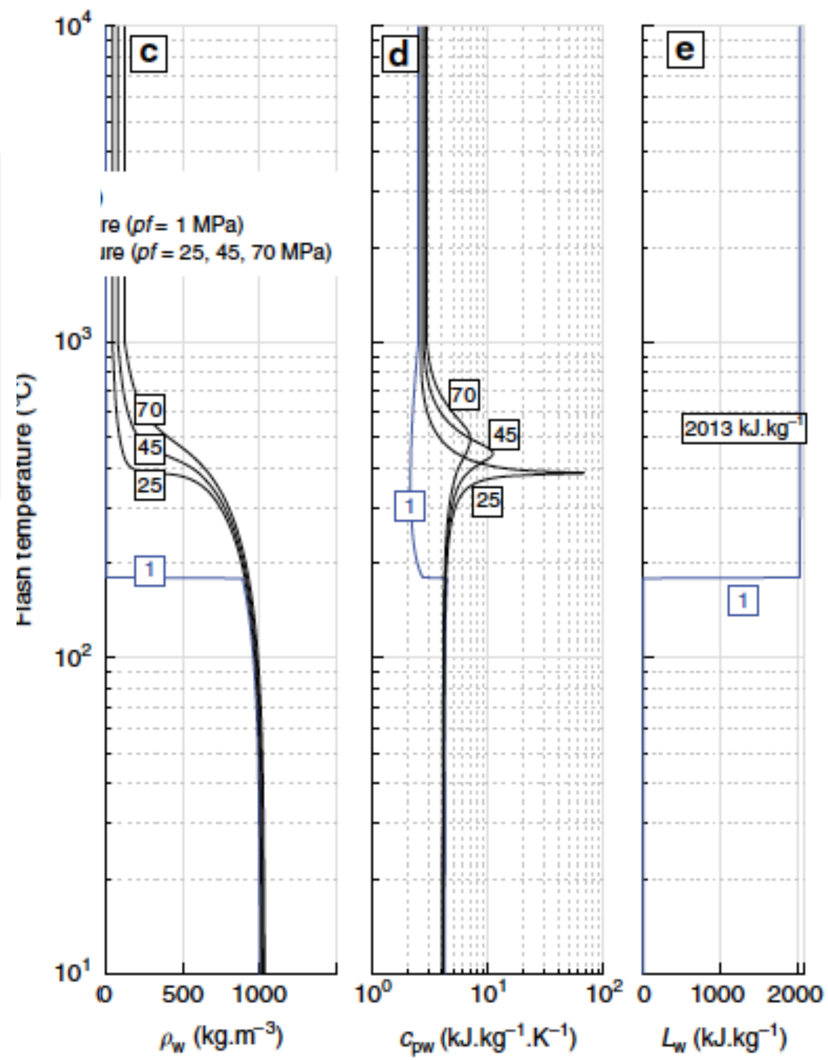


Acosta et al. Ncomms, 2018

Stick-slips and stress drops
the fluid version





Acosta et al. Ncomms, 2018

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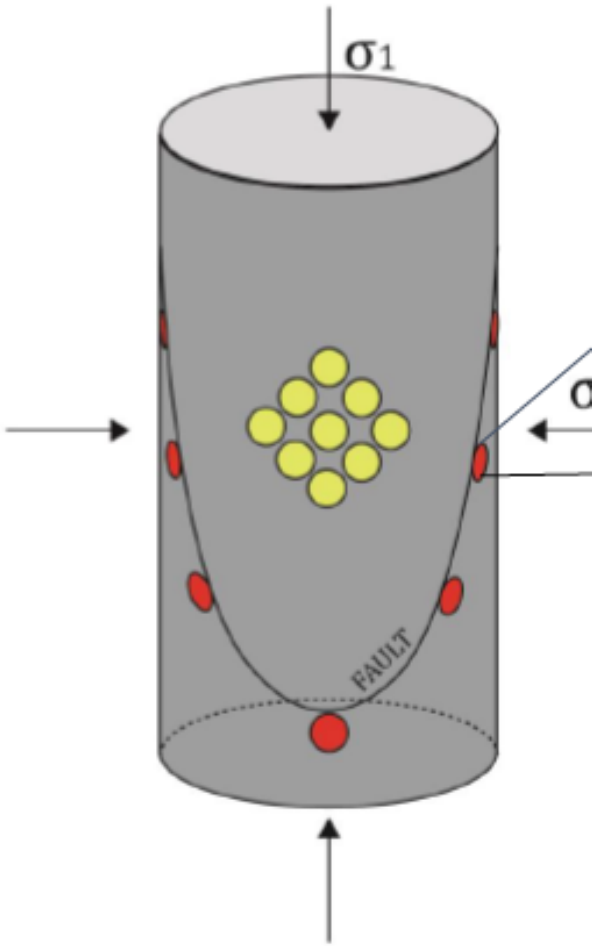
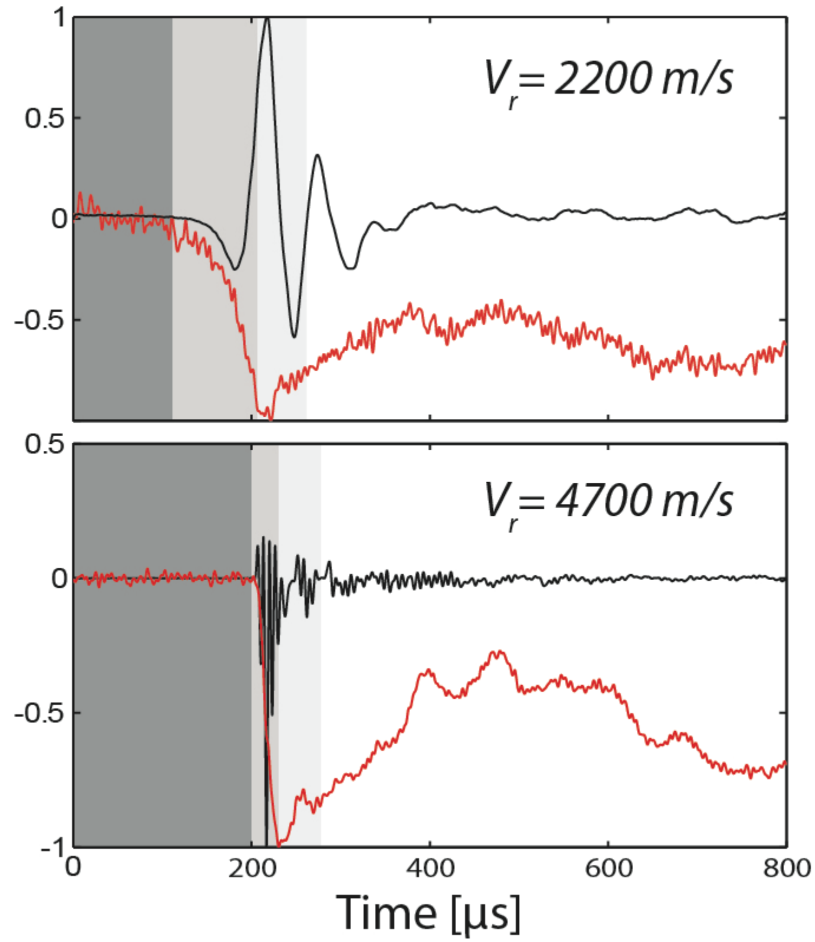
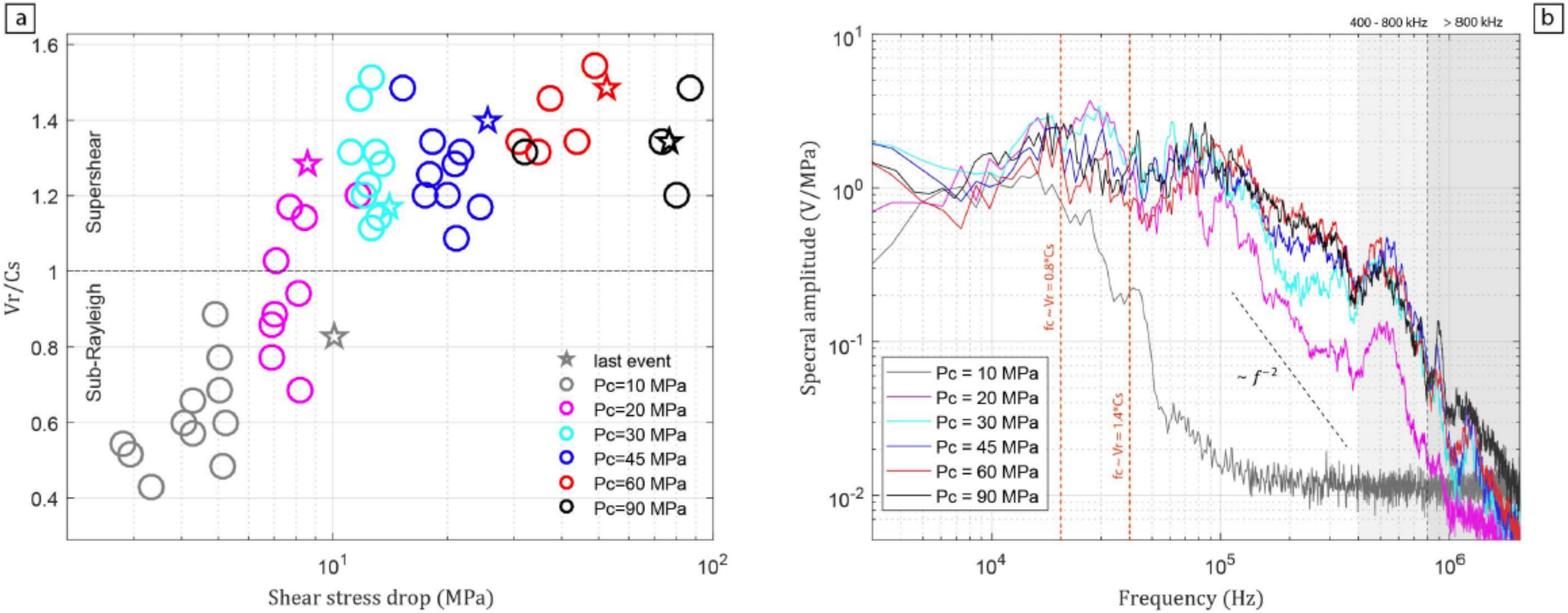
Rupture velocity and HF radiation





Passelègue et al., Science 2013

Rupture velocity and HF radiation

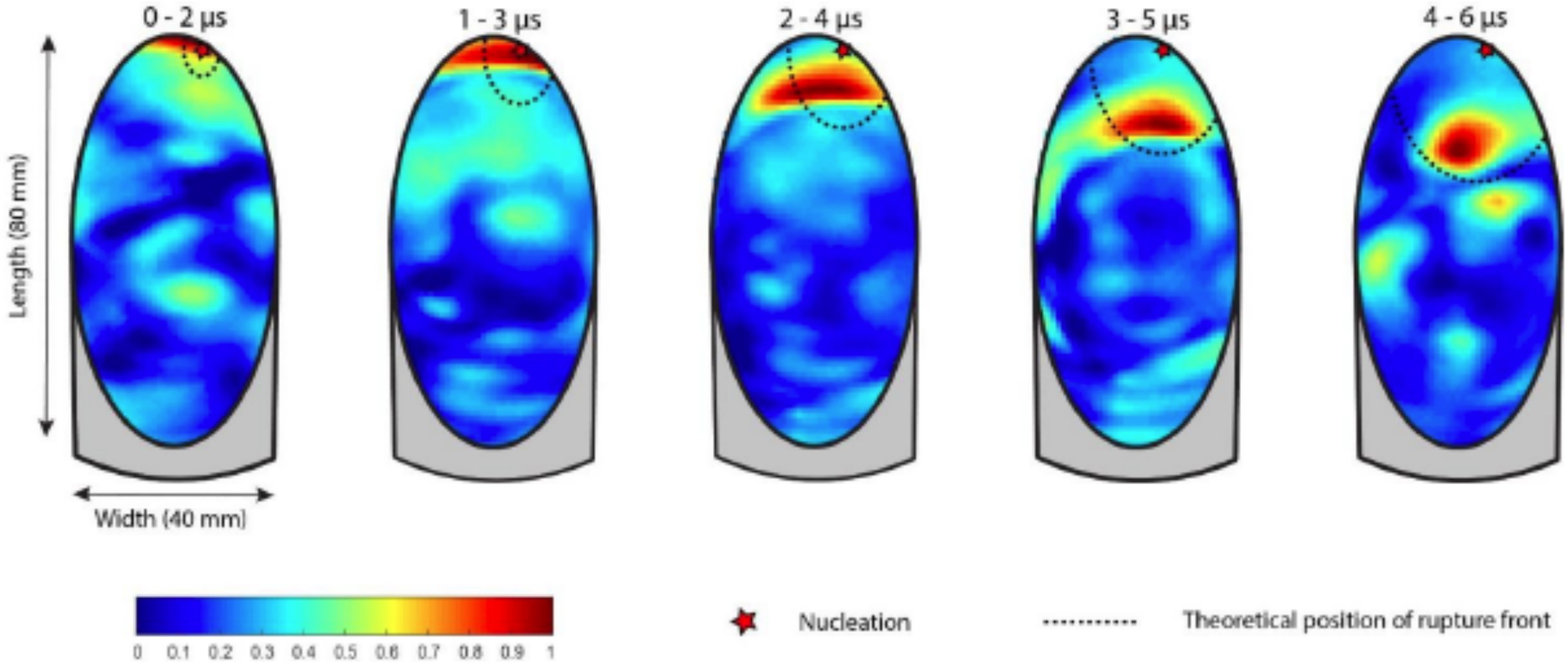


- HF radiation are enhanced with both Pc and Vr.
- Supershear ruptures are highly enhanced in HF radiation compared to sub-Rayleigh ruptures : Mach-wave signature

Marty et al., GRL 2019

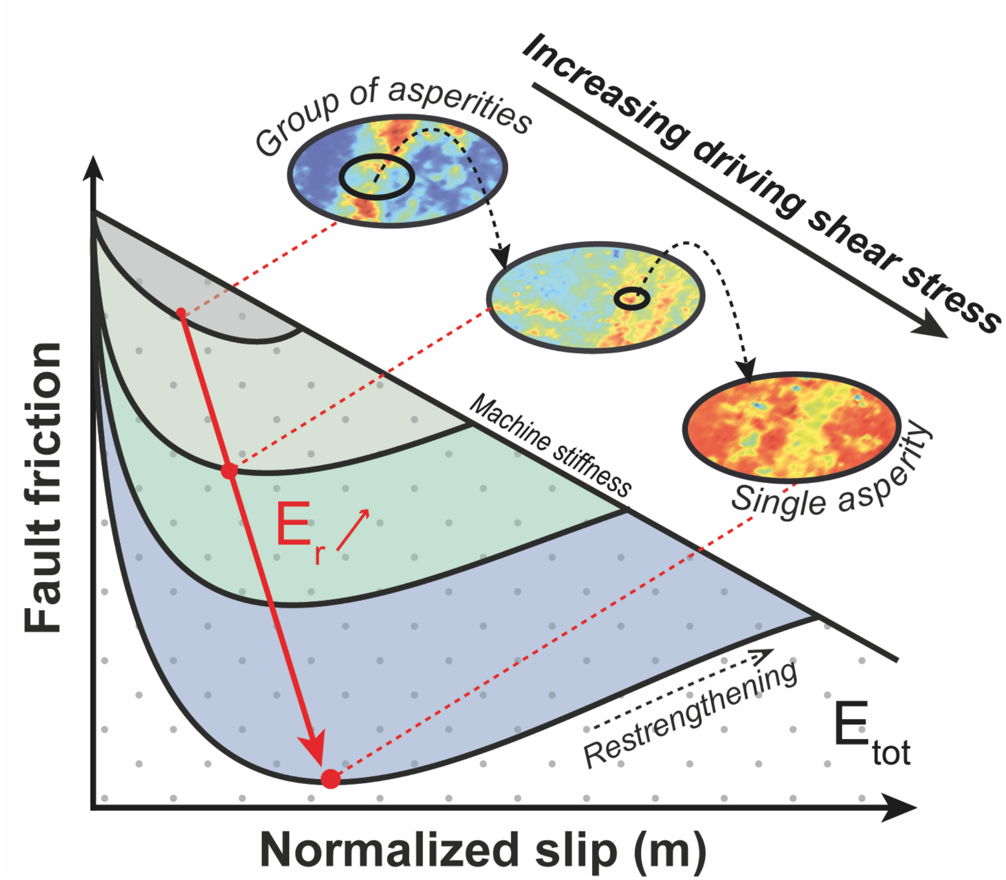
HF radiation

Back projection of the HF content locates at rupture front



Marty et al., GRL 2019

Energy budget summary



Mw [-4 , -3] earthquakes, AT THE LABORATORY SCALE
IN THE RIGHT σ-P-T CONDITIONS

Transition from multiple asperities (low seismic efficiency, low rupture speed, small stress drop & low HF radiation) to a single asperity (high seismic efficiency, high stress drop, high rupture speed, & high HF radiation).

Conclusions

- **During sliding, heat generation is limited to asperities**. **Flash melting on asperities (sliding velocities >m/s)** drives the discrepancy between static and dynamic stress drop and generate **high velocity ruptures**.

- **Flash melting is inhibited at large pore fluid pressure** (thermodynamics of water matters).

- **Faster (Supershear) ruptures are accompanied by HF radiation,** which originates at (or close to) rupture front (dynamic off-fault damage triggering and/or breakdown zone).

Thanks for your invitation!

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@ EPFL: **François Passelègue**

@ IPGP: Frédéric Girault, Javier Escartin

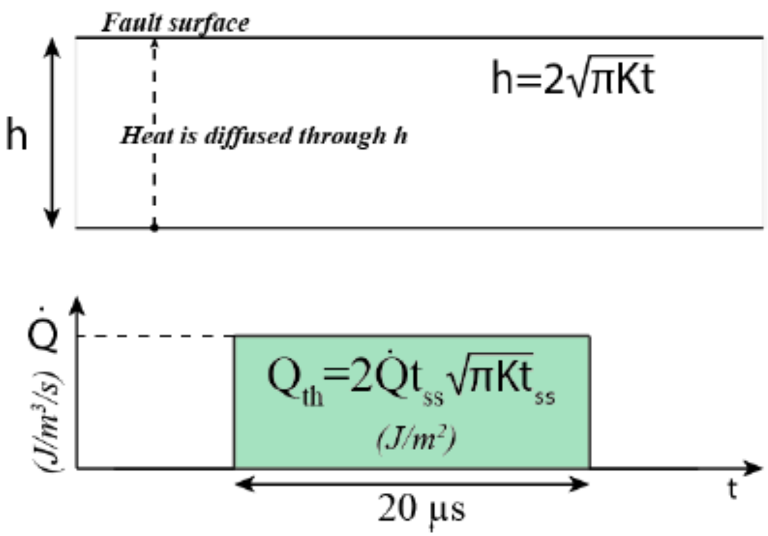
@ Durham U.: Stefan Nielsen

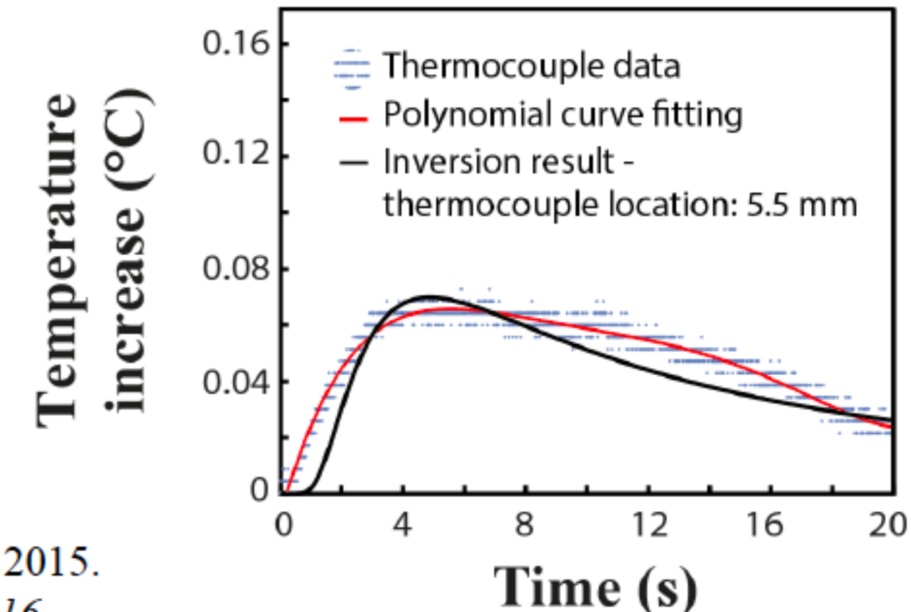
Measuring Heat

Heat diffusion model - Thermocouple data inversion

- Constant heat rate during stick slip duration $t_{ss} = 20\ \mu s$
- Heat produced on the fault and diffused within the sample

$$\rho C_p h \frac{dT_{th}}{dt} = \dot{Q} + K \frac{d^2 Tth}{dy^2}$$





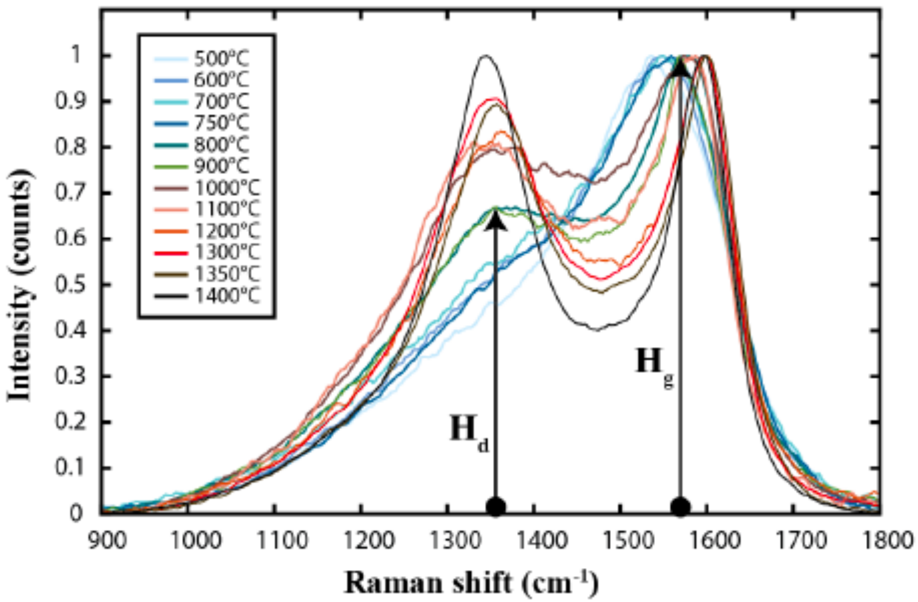
Thermal diffusivity K = $1.2e^{-6}$ m²/s ; *Lockner et al.*, 2015.
Stick slip duration t_{ss} = 20 µs ; *Passelègue et al., 2016.*

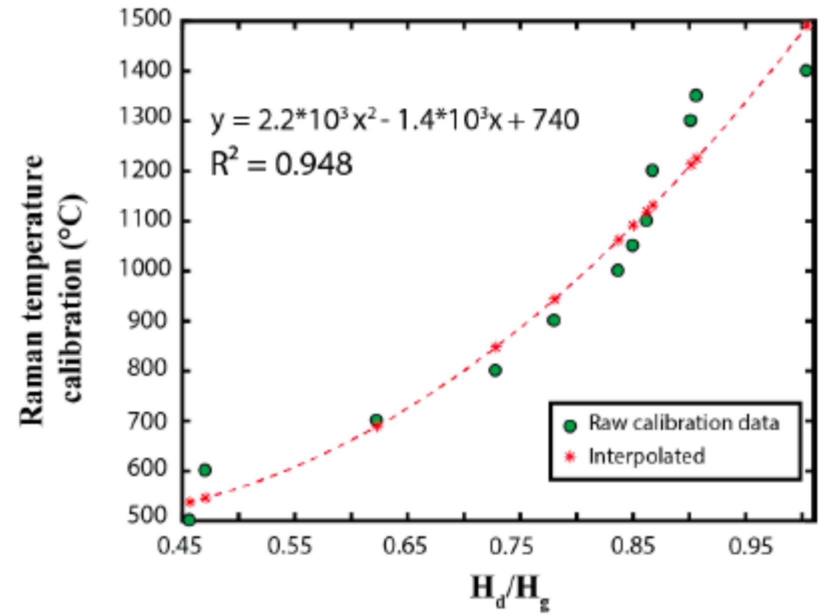
Aubry et al. GRL 2018

Heat dissipation…

Mapping the interface by the help of amorphous carbon

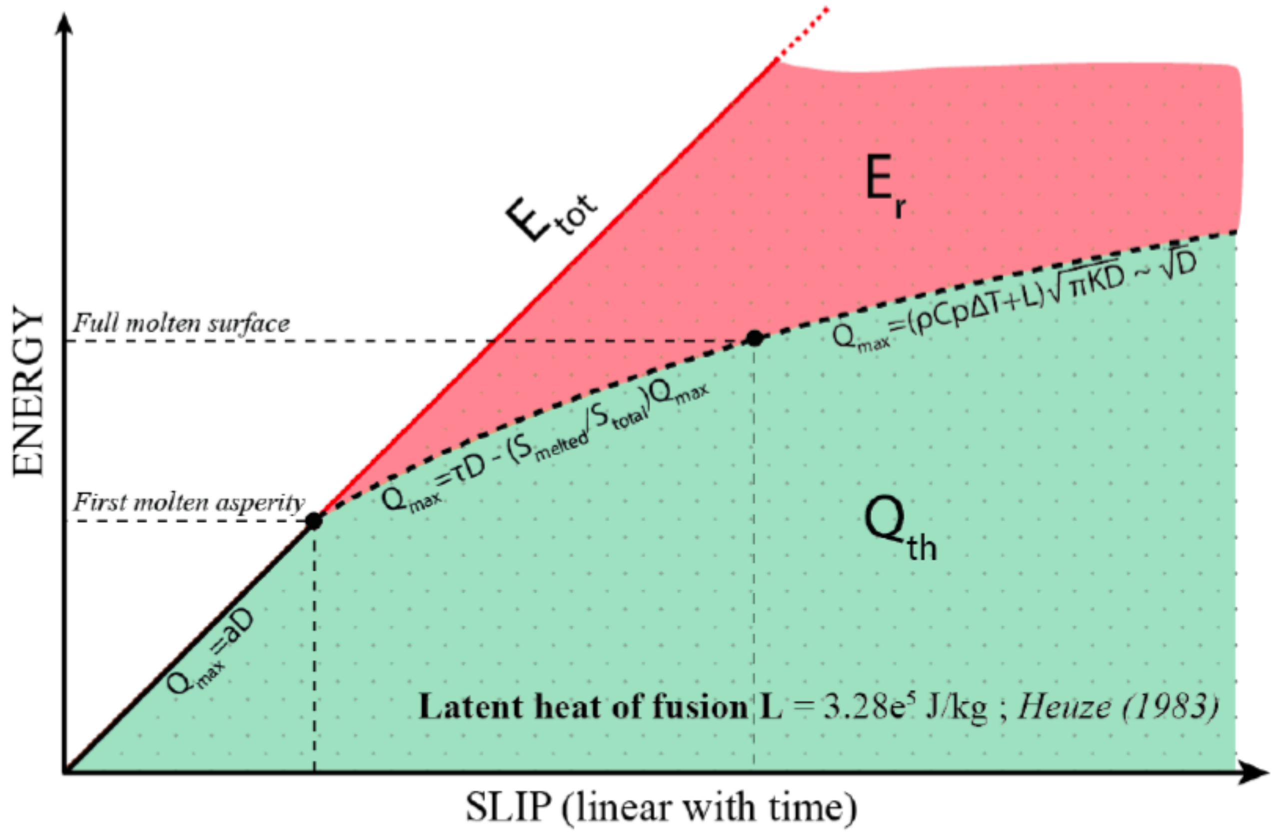
Calibration made with **specific coated samples** (other than these for experiments) heated in an oven during 10 s.





- **The more advanced the process of carbonization and the higher the ratio H_d/H_g.**
- **We are aware of kinetic problem (10 s heating) compared to the duration of stick-slip (20 µs).**

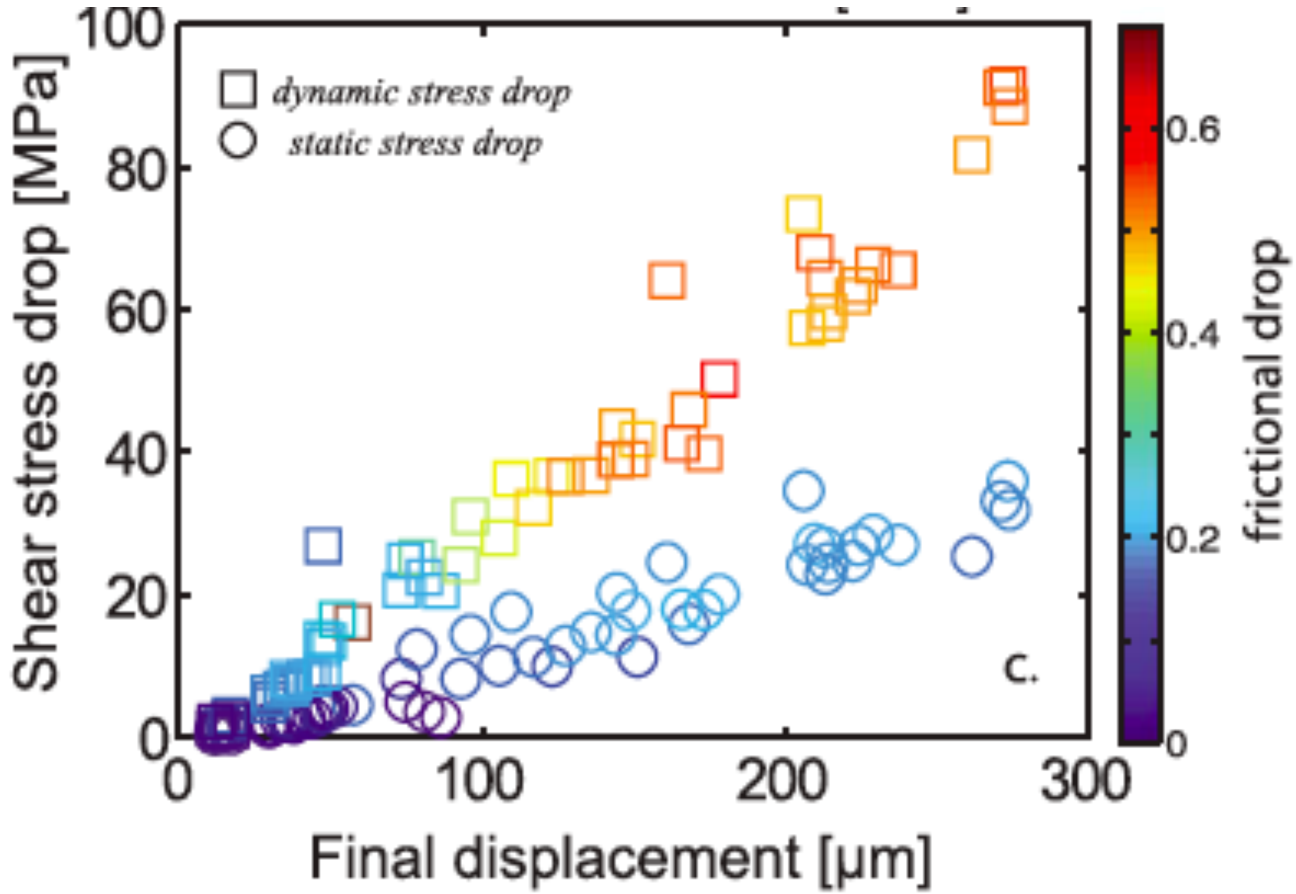
Heating efficiency



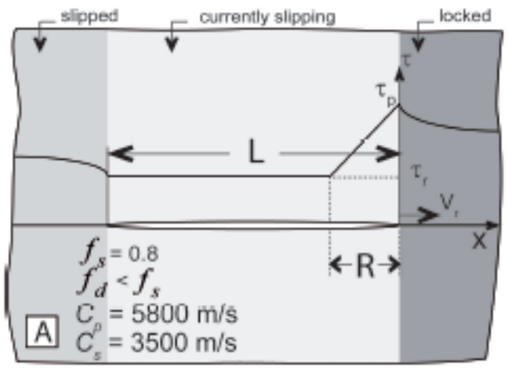
Rupture becomes more efficient with increasing sliding
because heat is bounded
by melting (or phase change) temperature and heat diffusion

Static vs. dynamic stress drops

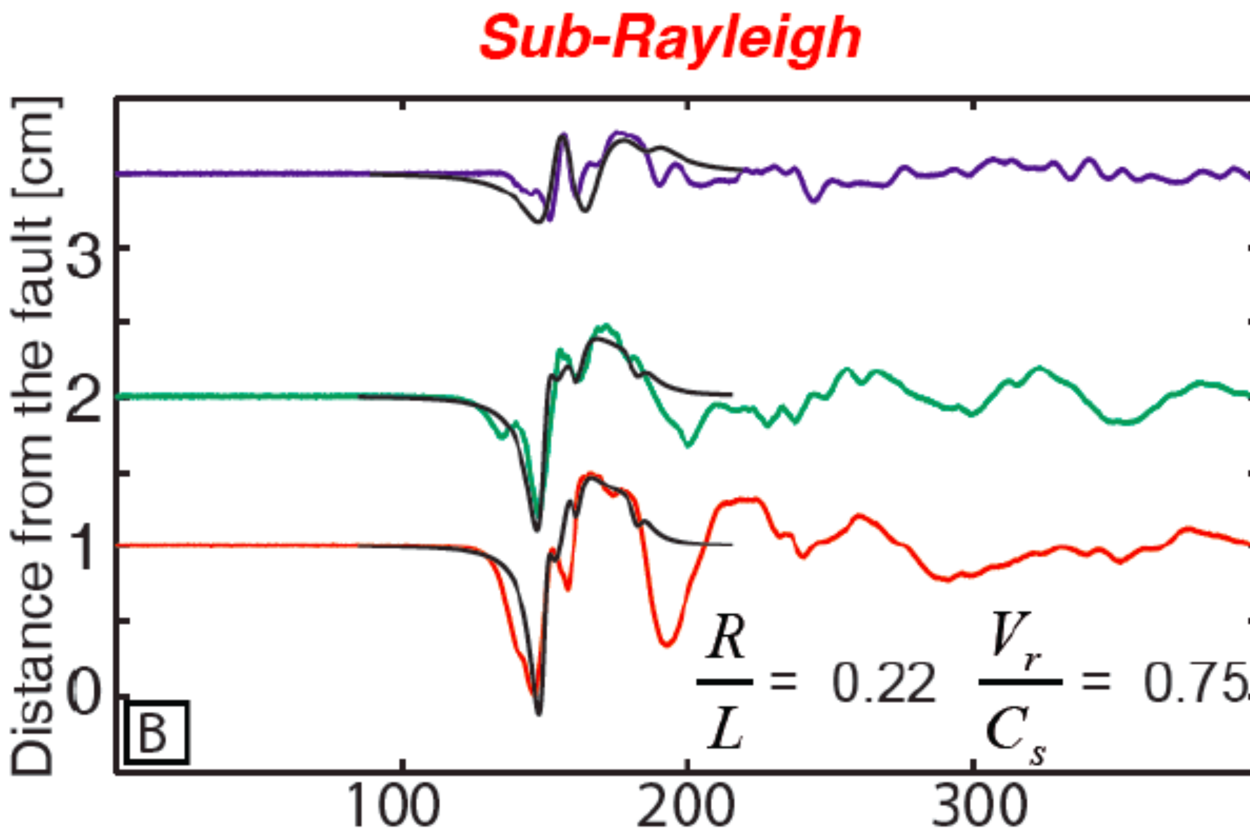
Passelègue et al. JGR 2016



Comparison with synthetics



2D steady state
slip pulse model
(Dunham and Archuleta, 2005)



Passelegue et al, 2013