Hydro-Mechanical Experiments in Fault Zones in Shales and Carbonated Rocks

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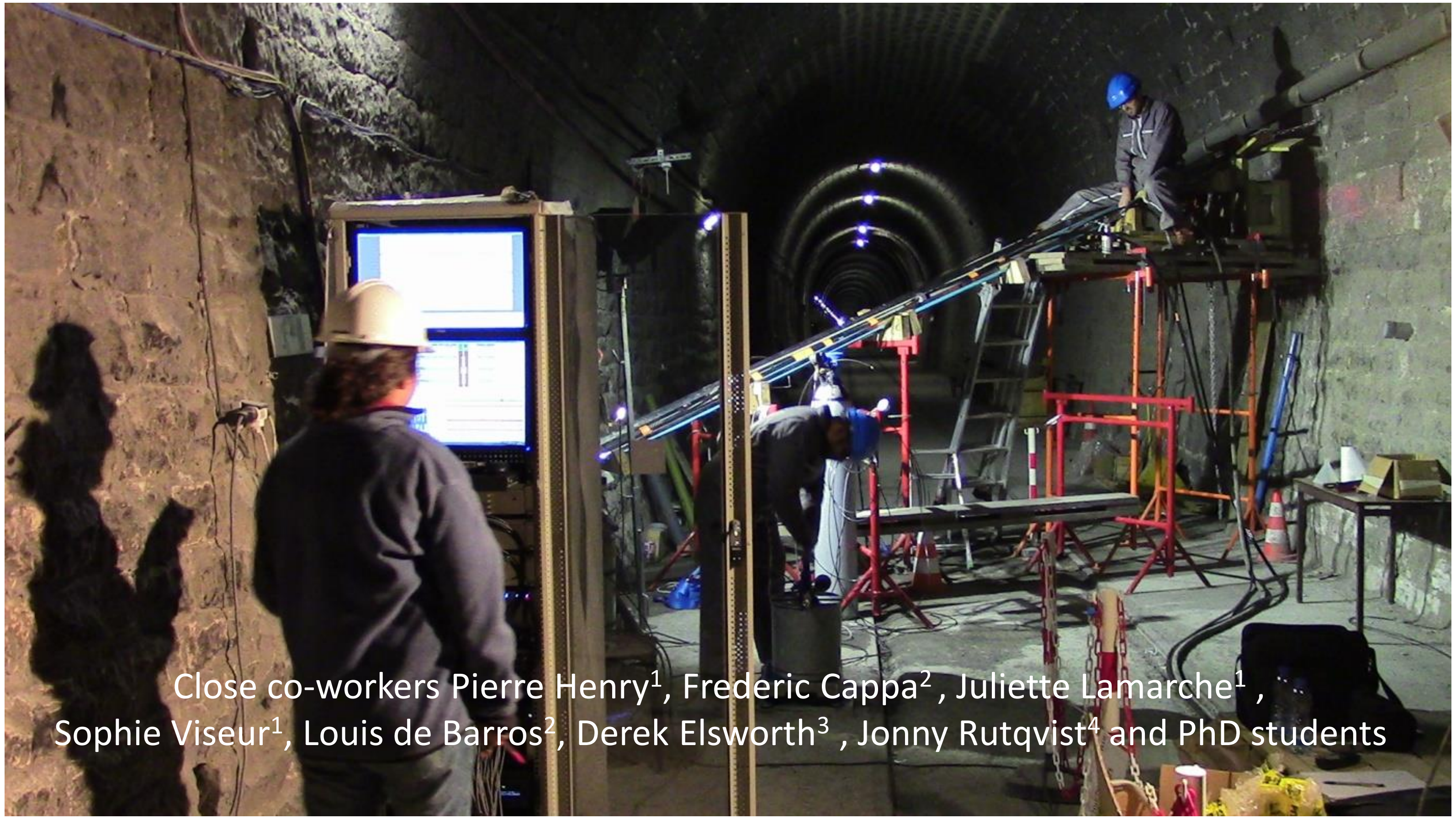

Photo
Tournemire IRSN URL

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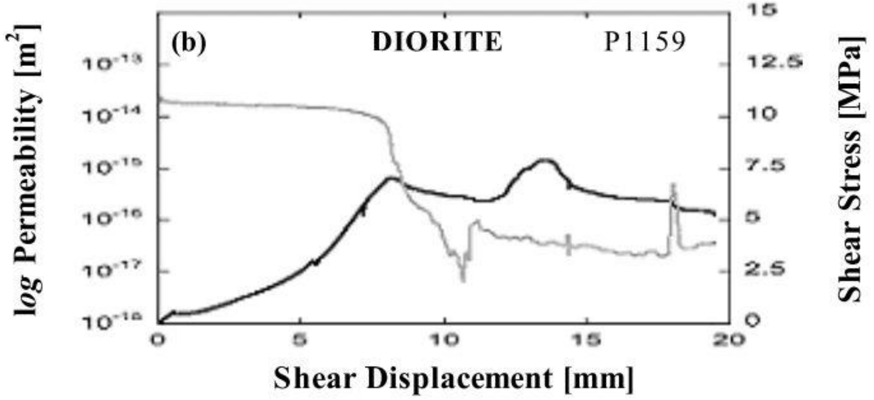
Hydromechanical processes and fault stability

Experimental studies are conducted either at the laboratory or at the reservoir scales

- *At the laboratory scale,*

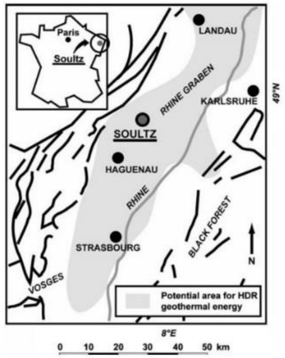
fracture permeability decreases with shear displacement…

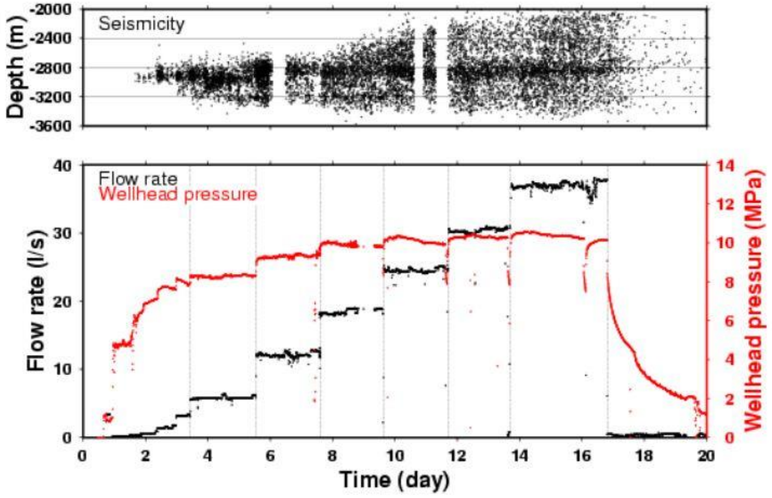
(*Faoro et al., 2009*)

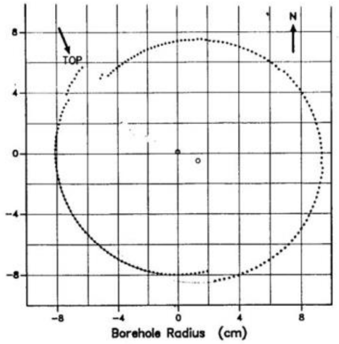


- *At the reservoir scale,*
    - Large cm scale displacements on pre-existing discontinuities
    - High permeability increase
    - A great amount of the displacement is aseismic

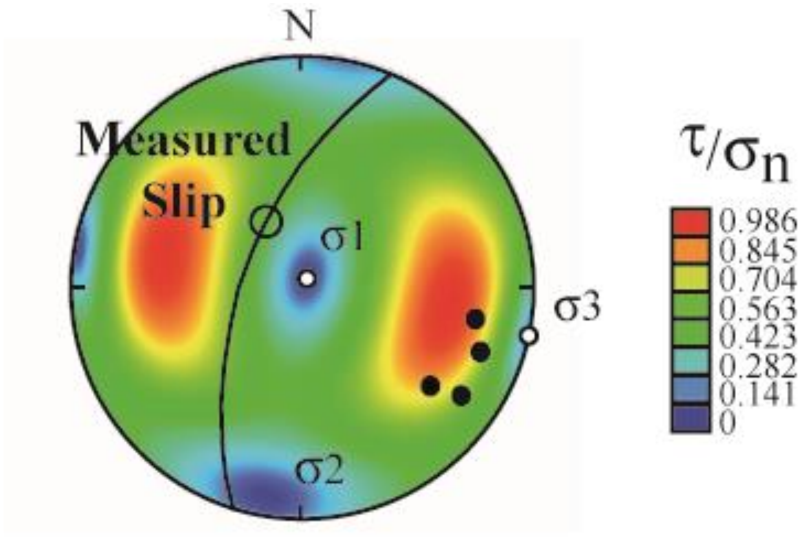
(Cornet, 2013)



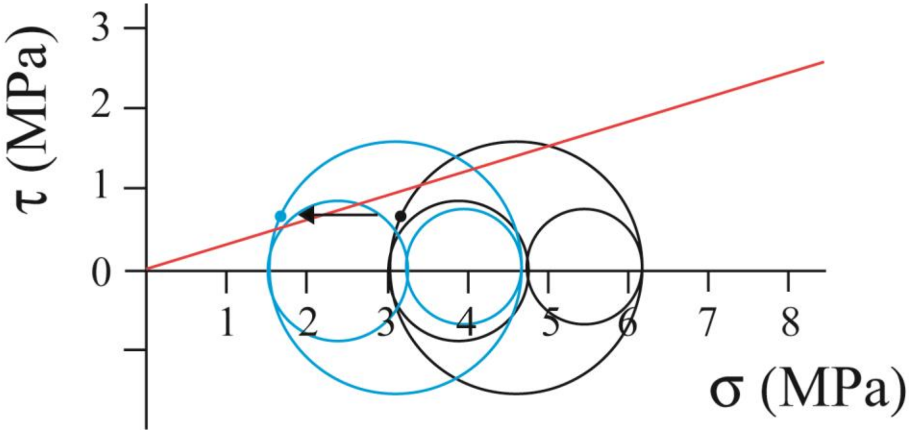


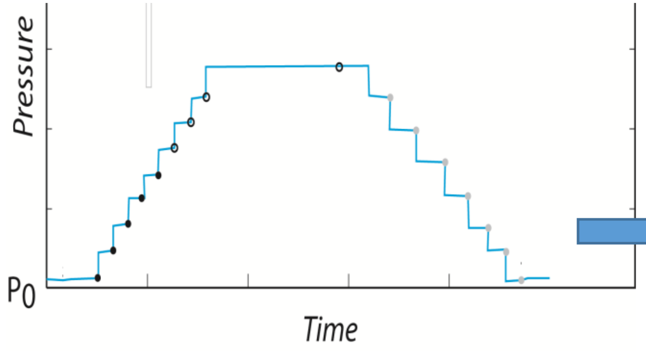


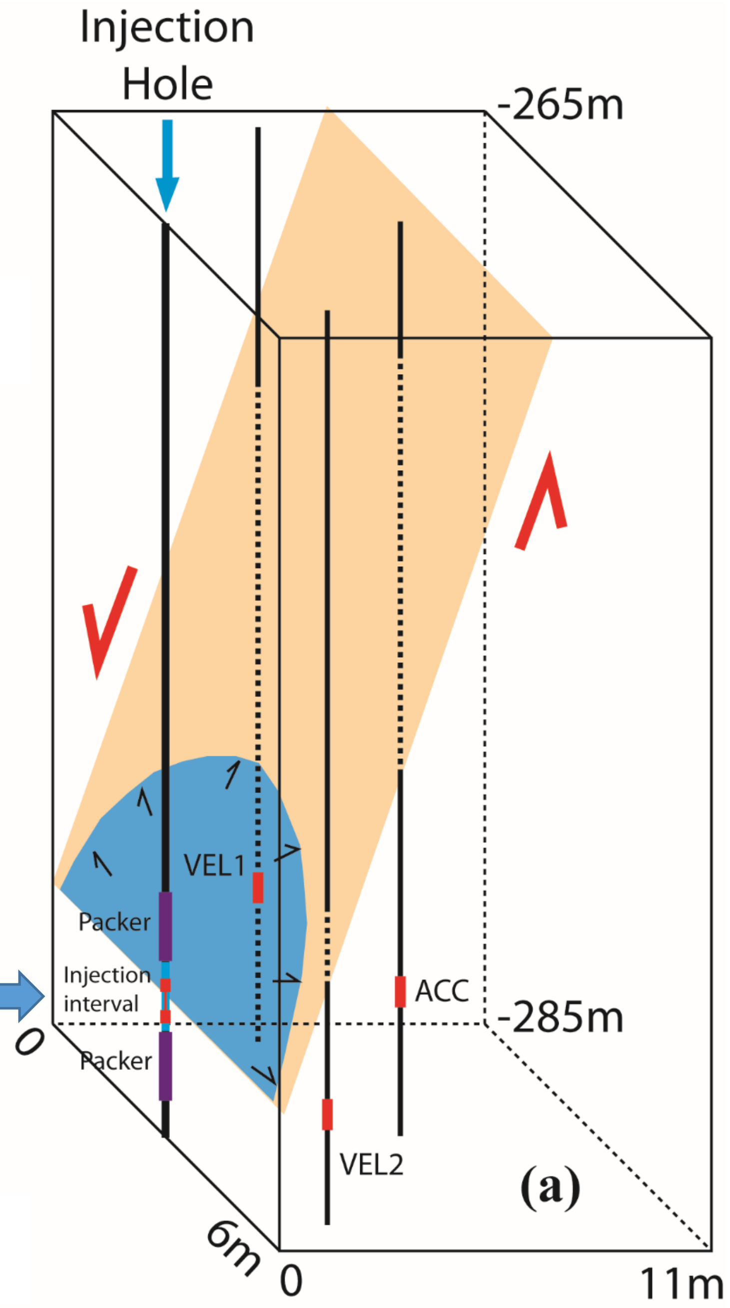
At the decameter scale, semi-controlled experiments in URLs



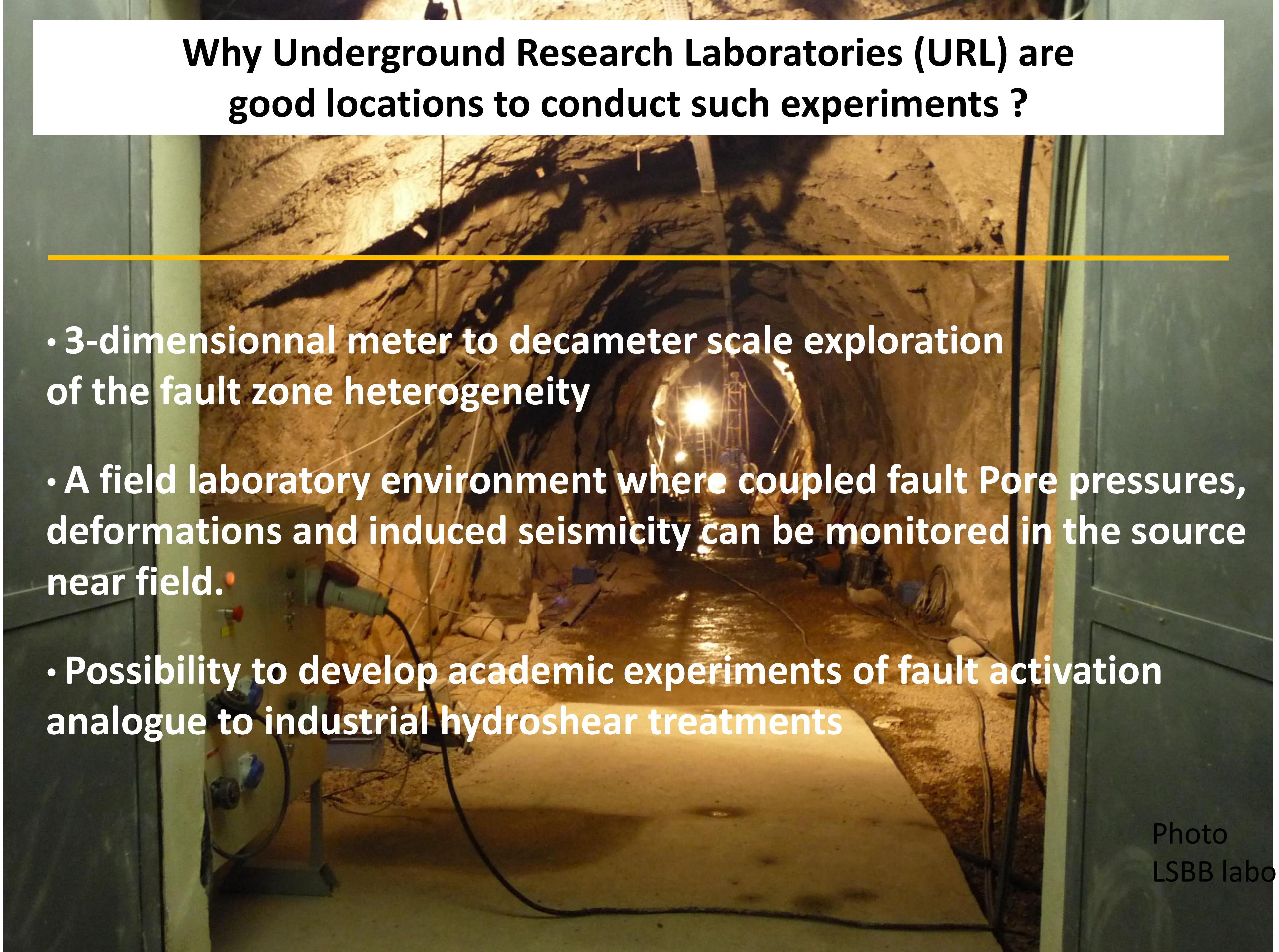
- A critically stressed fault geology
- A controled step-by-step pressure Injection in the fault plane
- A real-time high frequency monitoring of fault opening, slip, leakage, pressure and seismicity







Why Underground Research Laboratories (URL) are good locations to conduct such experiments ?



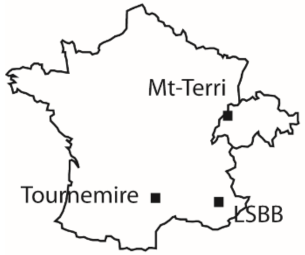
- 3-dimensionnal meter to decameter scale exploration of the fault zone heterogeneity

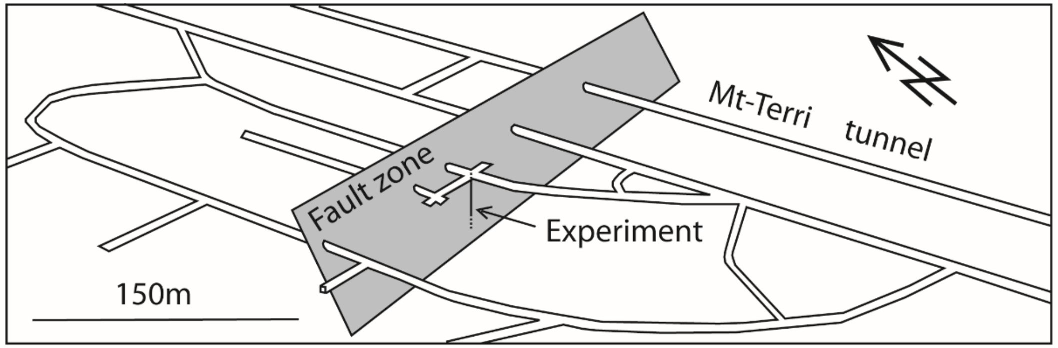
- A field laboratory environment where coupled fault Pore pressures, deformations and induced seismicity can be monitored in the source near field.

- Possibility to develop academic experiments of fault activation analogue to industrial hydroshear treatments

Photo
LSBB laboratory

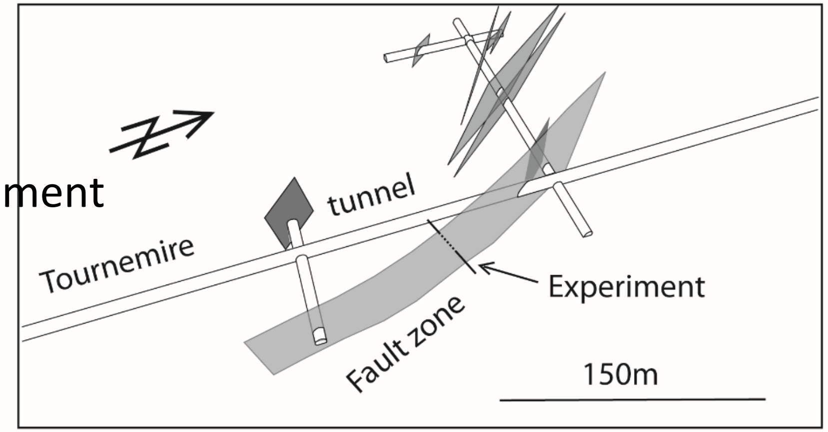
Past and Current projects in URLs …

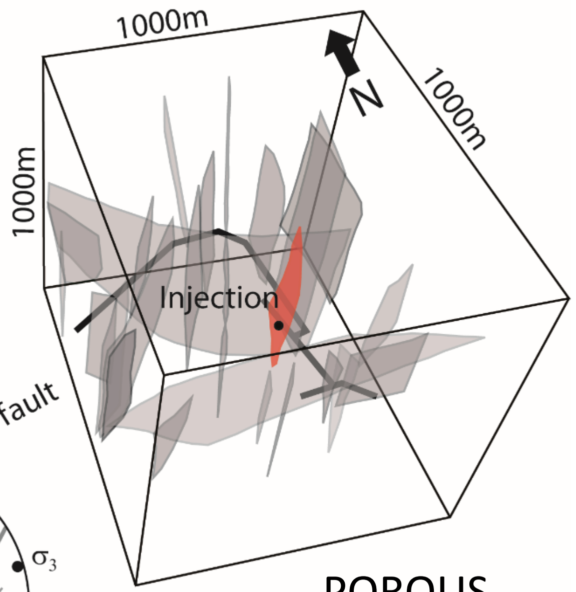


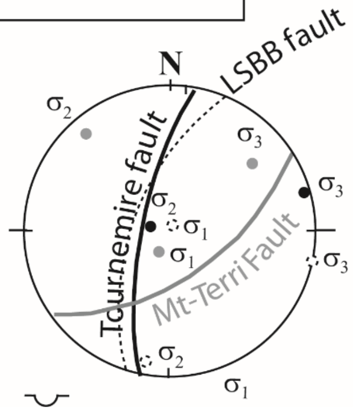


SHALES
FS experiment (2015)

SHALES
Fluids and Faults experiment
(2014)



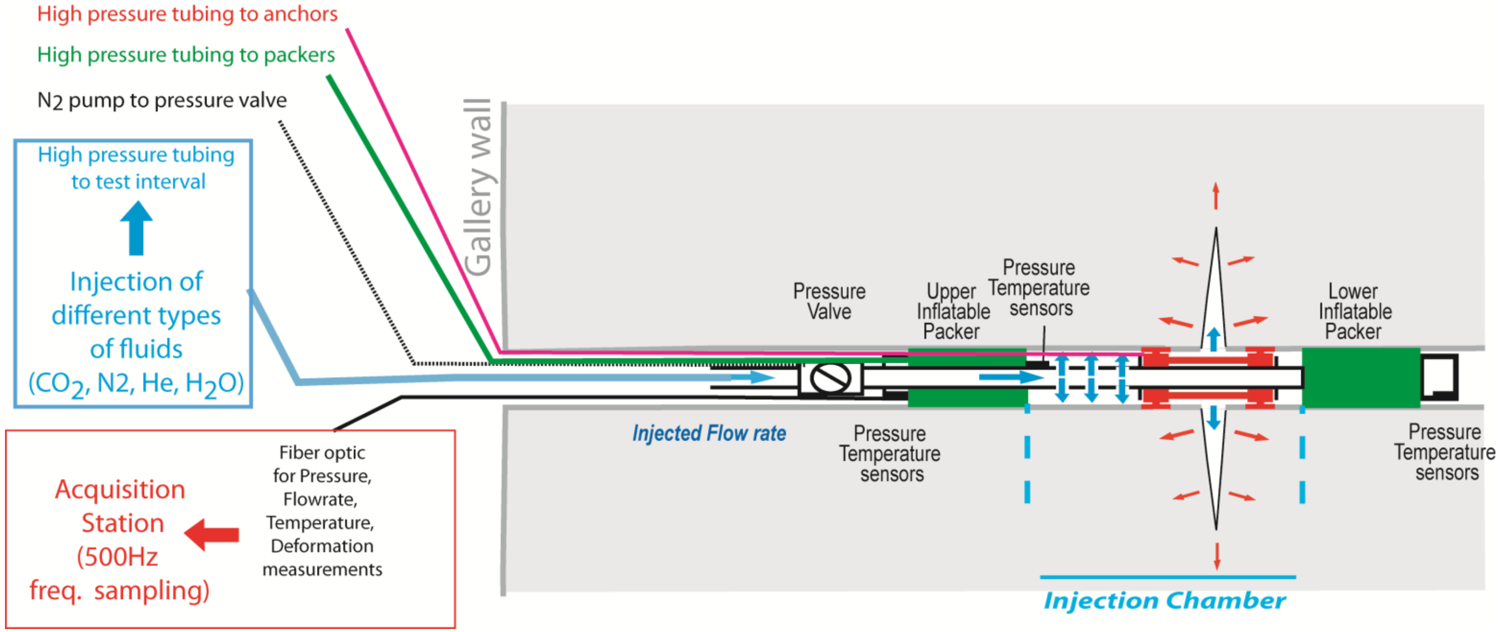




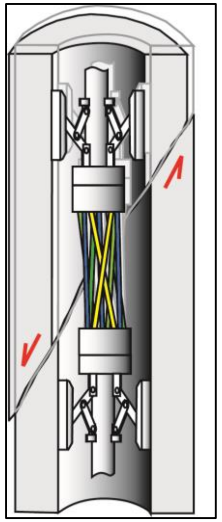
POROUS
CARBONATES
HPPP experiment (2011)
Hydroseis-HPMSCa experiments (2015)

Development of a HM testing Protocol

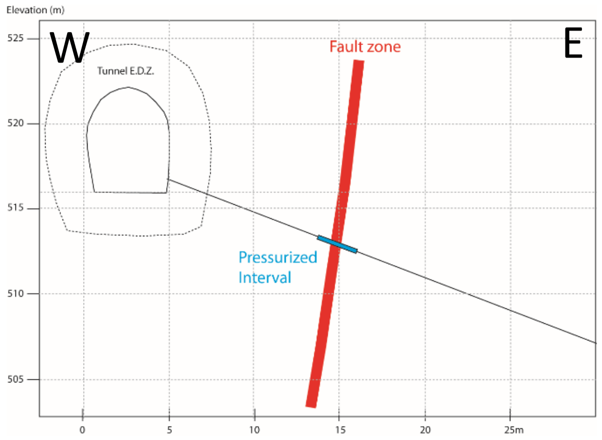
- Straddle packer device
- A strain sensor is set in the injection interval
- Sensor monitors the 6 components of the activated fault movements using fiber optics
- Fault movement is induced by fluid pressurization within the straddle packer interval



Full scale of the displacement sensor
- displacements of a few mm
- rotations of a few degrees



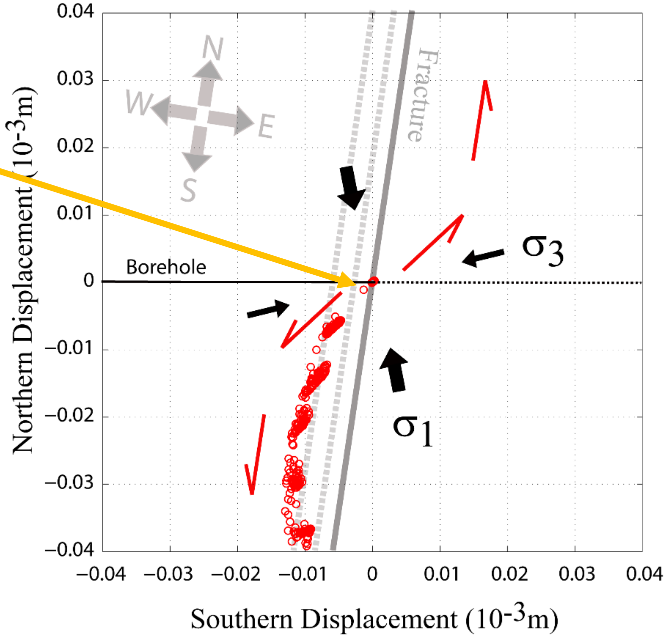
Capturing 10^{-6} to 10^{-3}m fault movements with a SIMFIP Probe (ex. of Tournemire experiments)



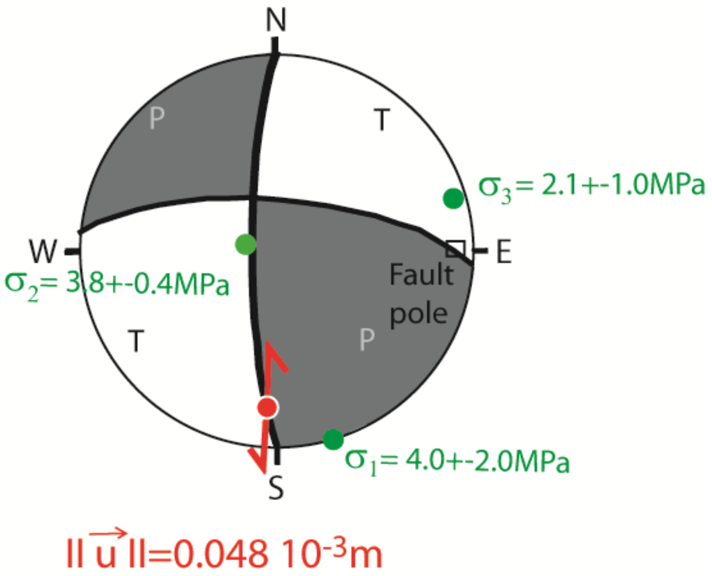
- **Possibility**

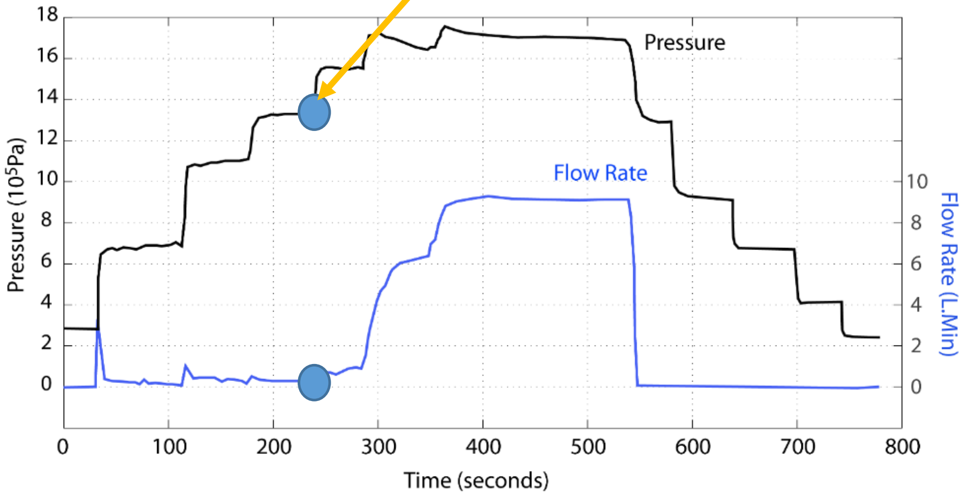
to estimate the stresses in the fault zone
to estimate fault permeability vs stress

Fault induced movement is a strike-slip
48 micrometer slip



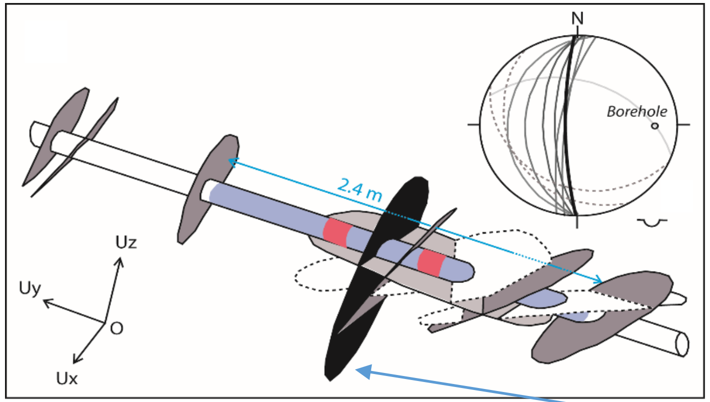
At 1.6MPa there is a high Flowrate increase



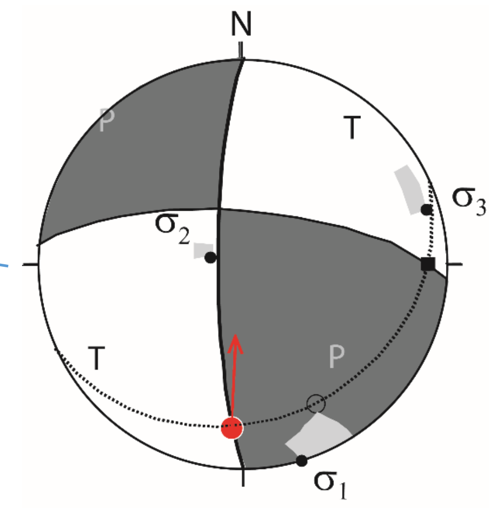


Test key results in Tournemire: A small slip produces a high permeability increase

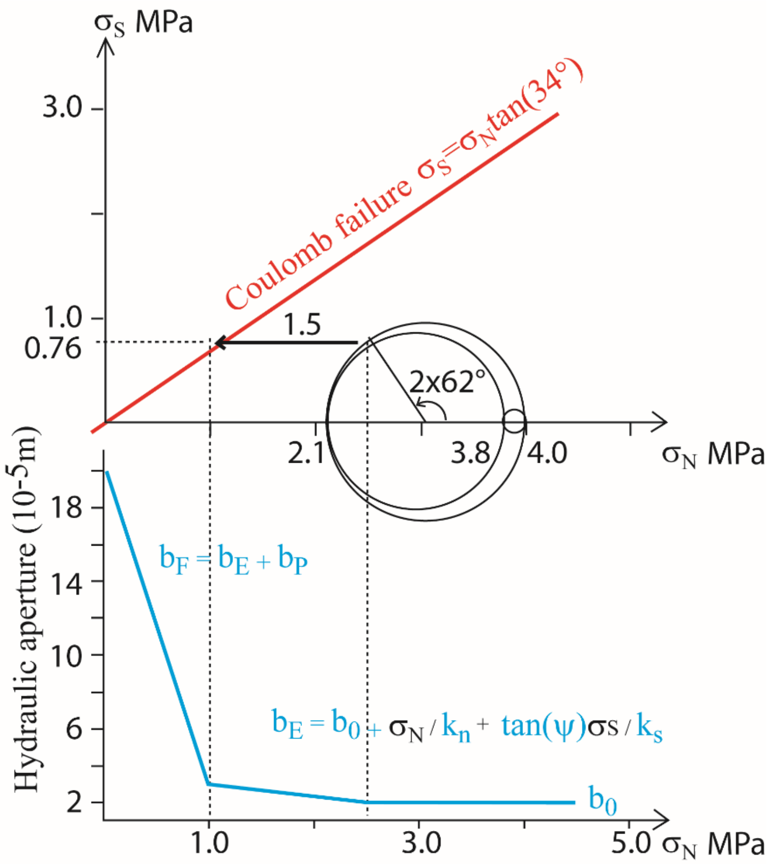
Identification of the activated fault
in the naturaly fractured tested interval



Strike slip regime
Shear slip magnitude = 48 10^{-6}m



High permeability increase
with shear



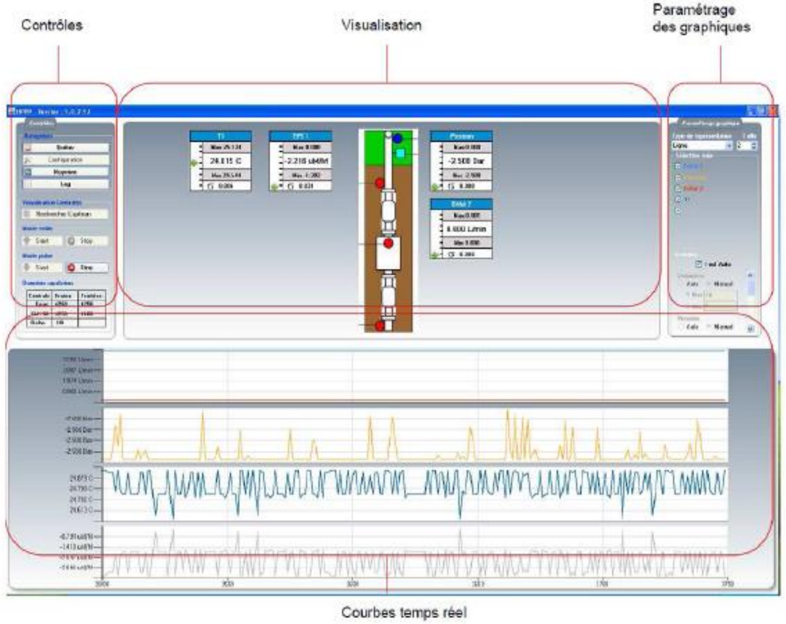
For more information about the test

Rock Mech Rock Eng
DOI 10.1007/s00603-013-0517-1

ISRM SUGGESTED METHOD

ISRM Suggested Method for Step-Rate Injection Method for Fracture In-Situ Properties (SIMFIP): Using a 3-Components Borehole Deformation Sensor

Yves Guglielmi · Frederic Cappa · Hervé Lançon · Jean Bernard Janowczyk · Jonny Rutqvist · C. F. Tsang · J. S. Y. Wang

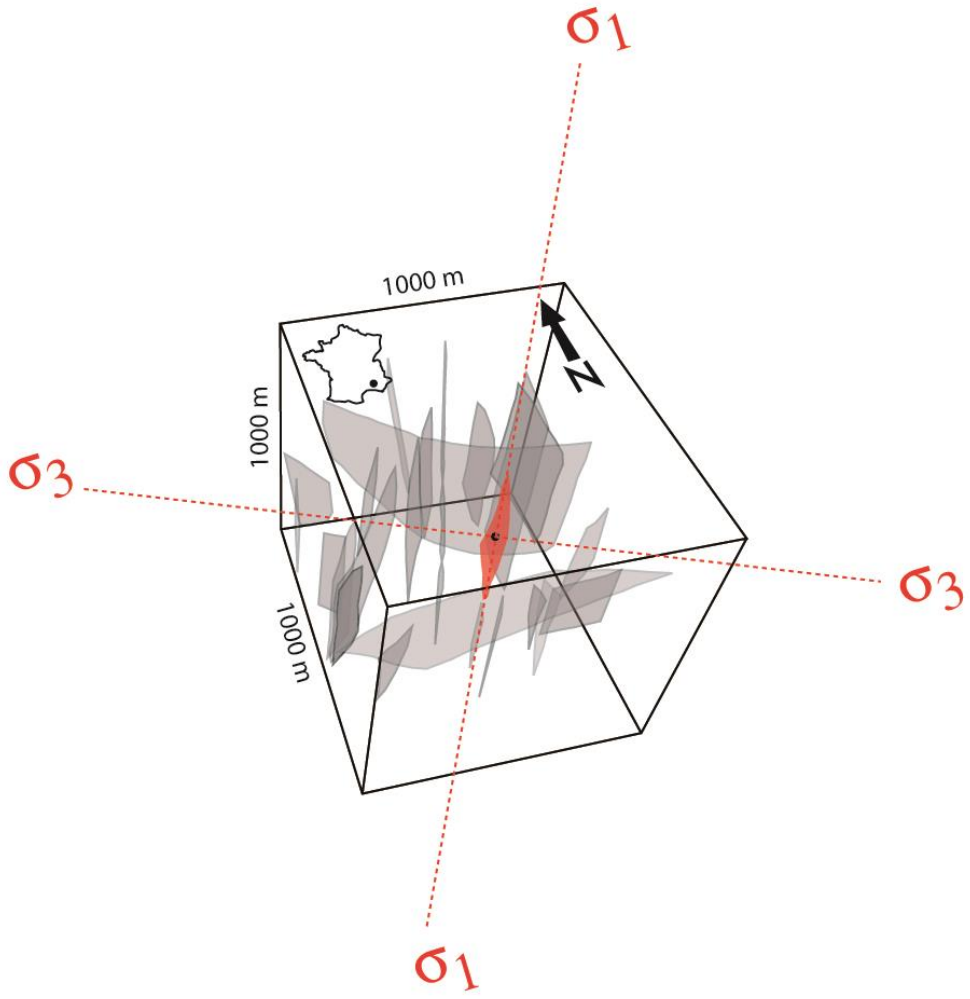


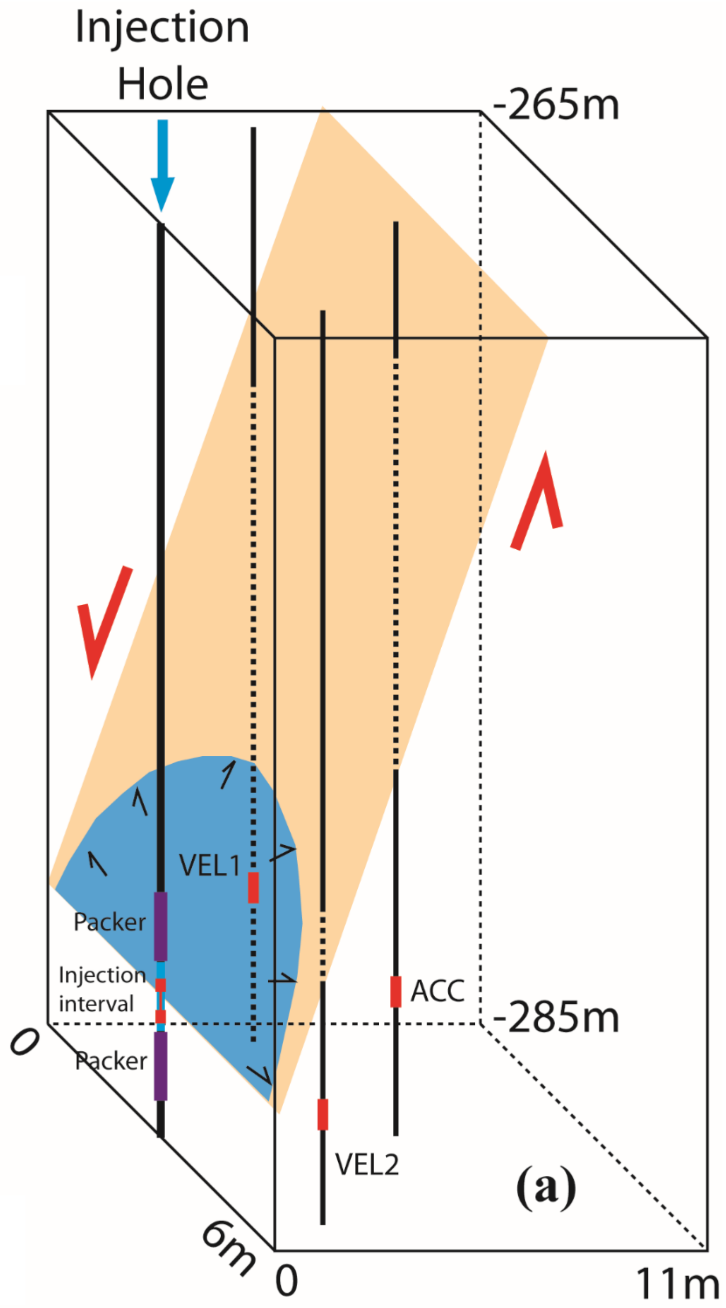
Comparison with another experiment…

Coupling Fault HM response to seismicity

Ex. LSBB experiments

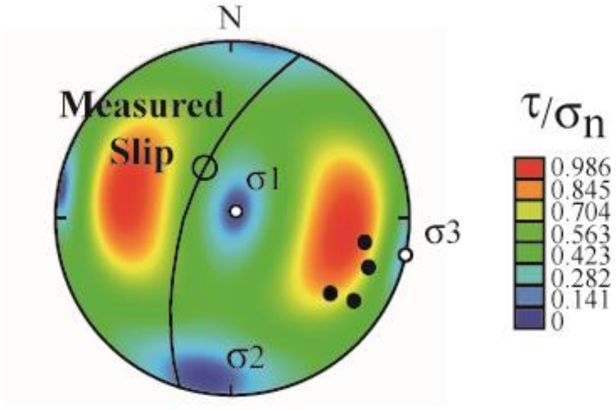
Activation of a fault in carbonates

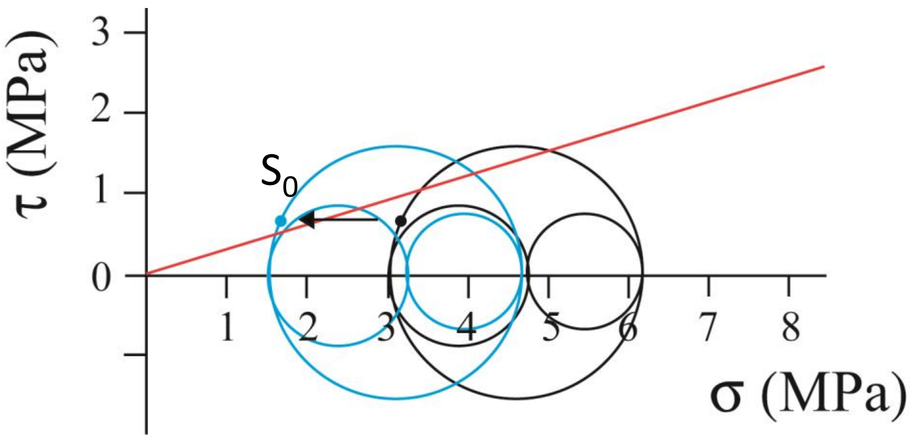


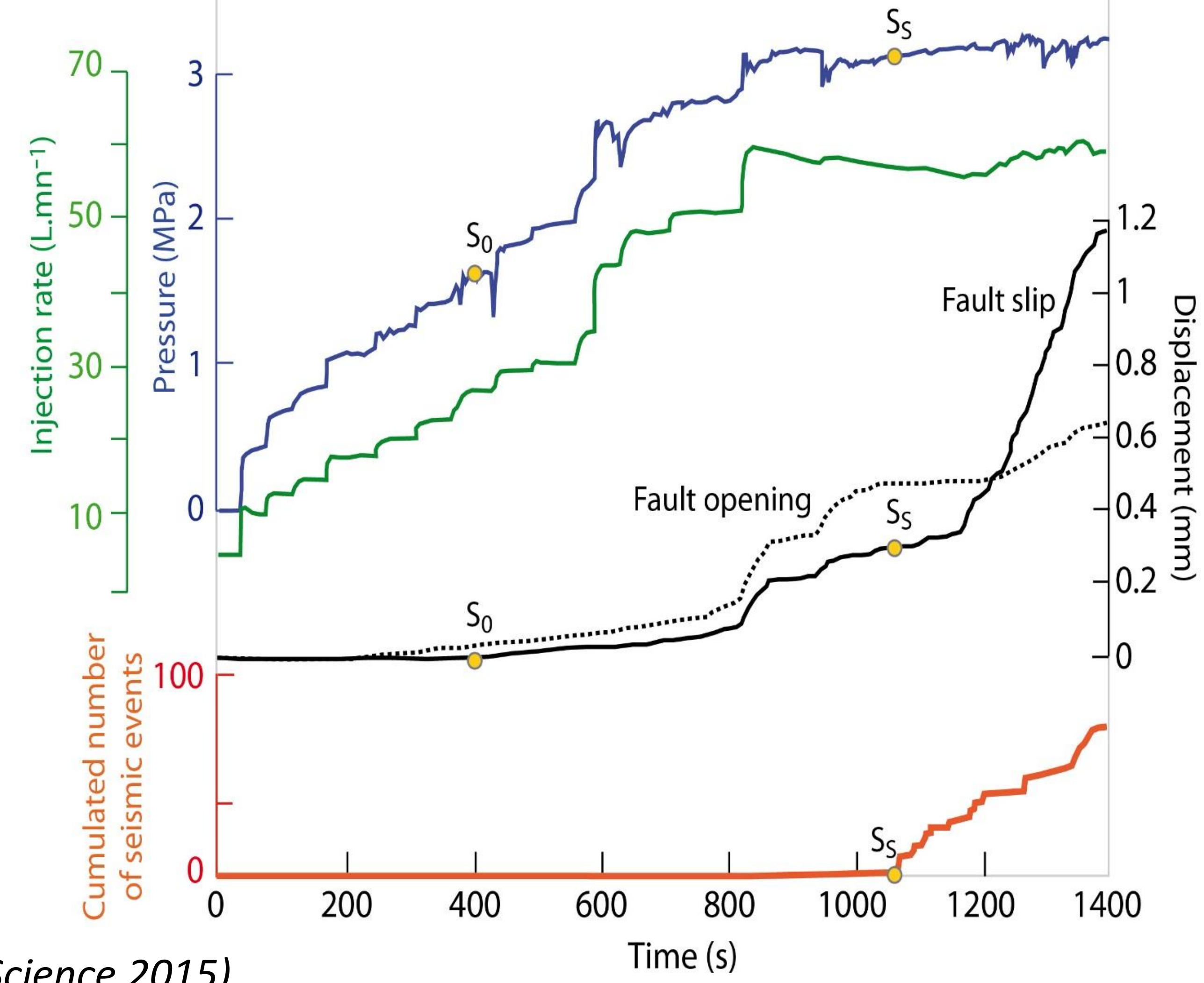


Activation of the fault slip first is aseismic

Seismicity occurs second …

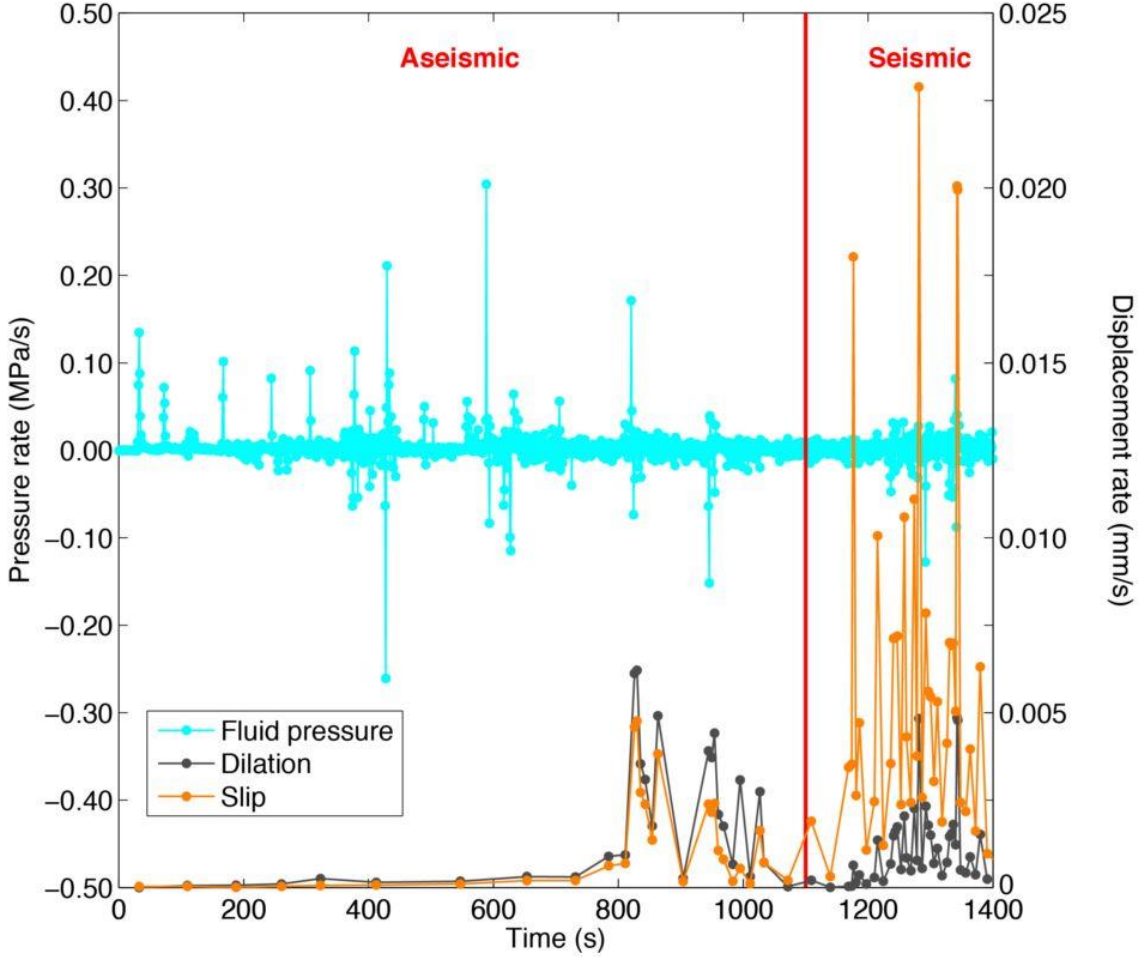






(Guglielmi et al., Science 2015)

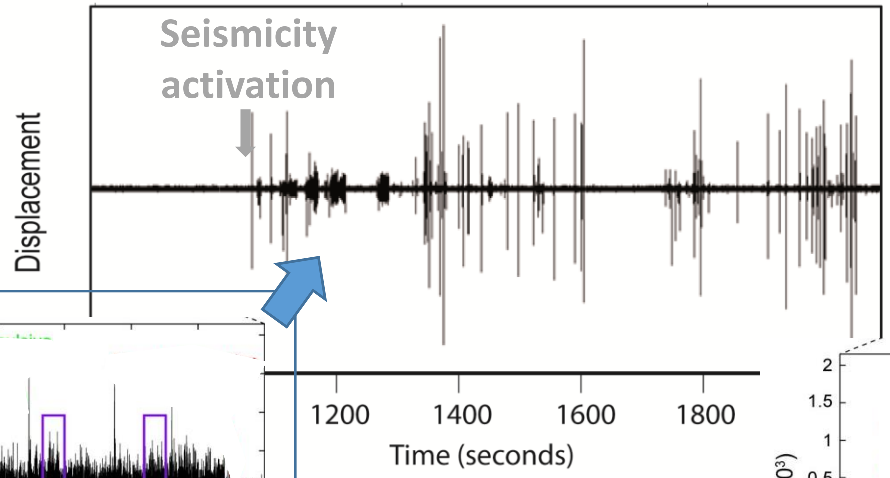
Seismicity occurs when there is a fault slip rate increase and a dilation rate decrease

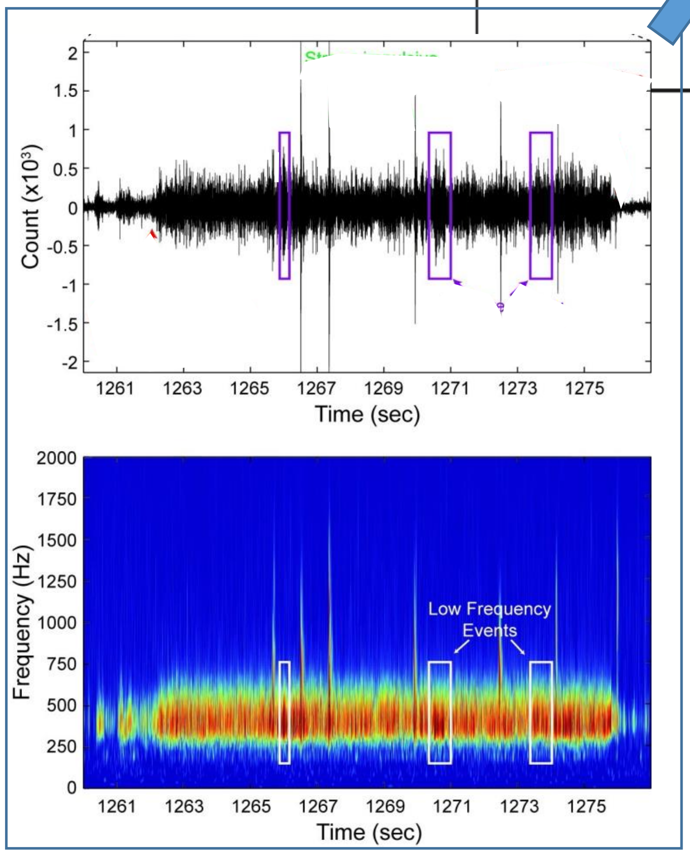


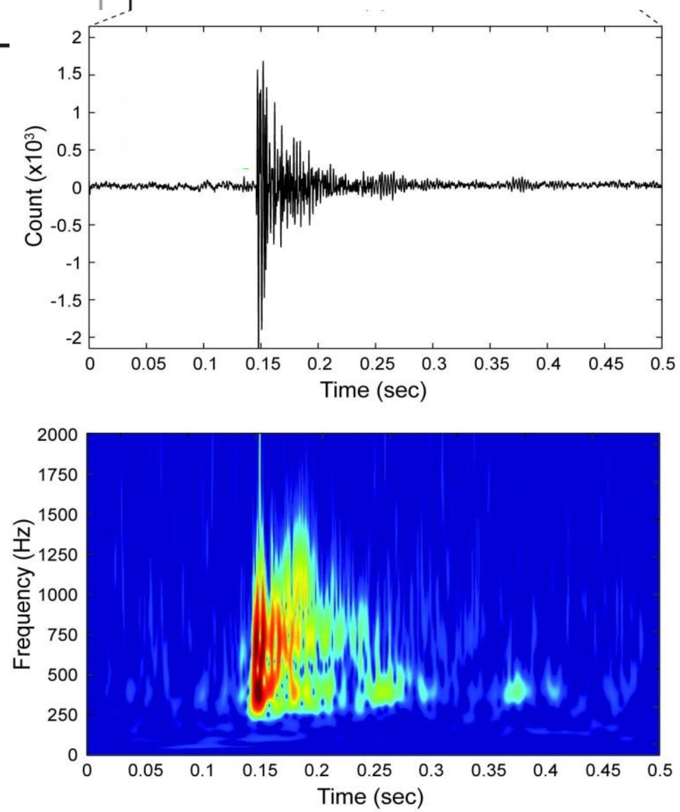
Seismicity = a complex Evolution from Tremor Like Signals to Impulsive Like Signals

Impulsive events [200 – 1500 Hz] Tremors [250 – 700 Hz]

(Derode et al., GRL – 2015)





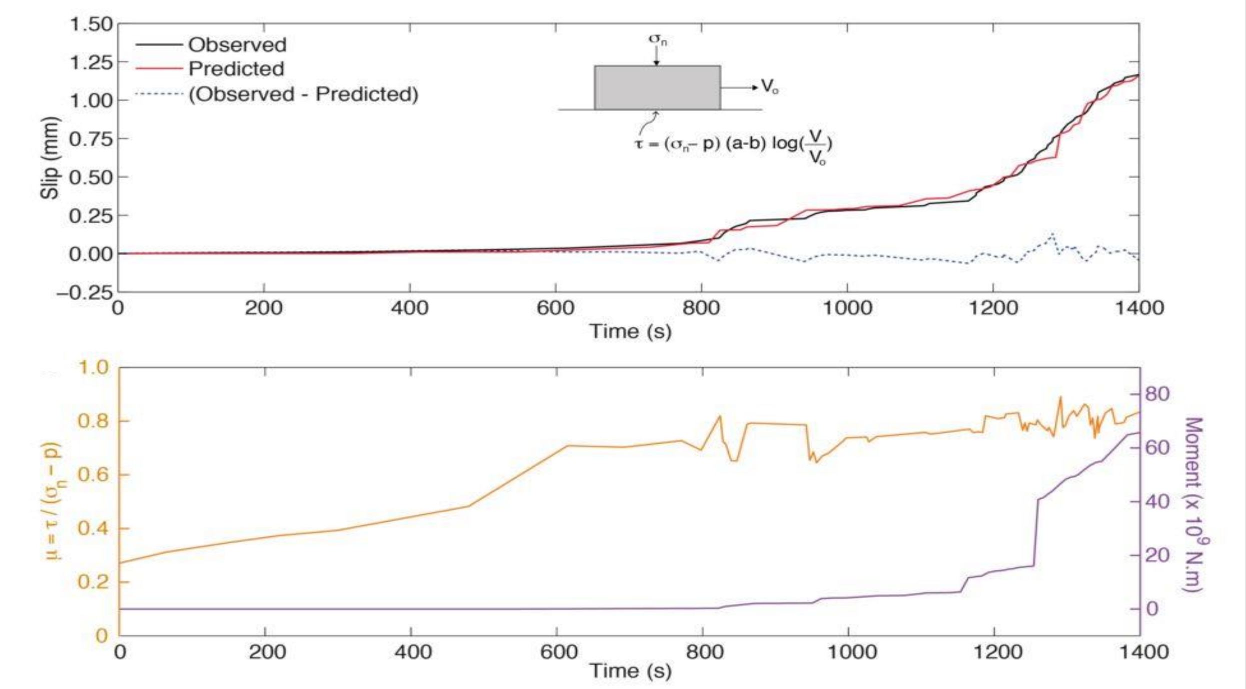


Test key results in LSBB:

Transition from aseismic to seismic fault movements that are time and rate dependent was isolated in situ!

Best fit for a work strengthening of the fault

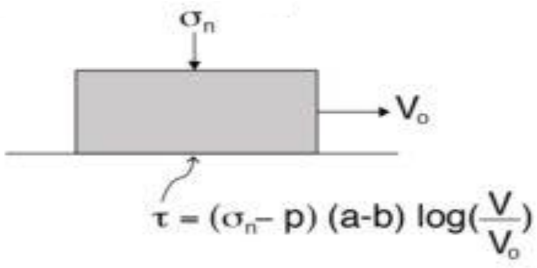
$a\text{-}b = 0.0447$ and $v_o = 1.3424 \times 10^{-8}$ mm/s.



$M_o = 65 \times 10^9$ N.m corresponds to a moment magnitude of about $M_w = 1.17$

A rate and state law analogue to laboratory ones reasonably explains the data

(fault being schematically figured as a single crack of length L)



Conclusion : Activated faults hydromechanical processes
deduced from semi-controled field experiments conducted in Underground Research Laboratories

- **a high (exponential, multilinear?) permeability increase related to fault slip activation**
  - *relevance of such results at higher strains and stresses ?*

- **the role of friction**
  - *validity of the rate and state friction models at the semi-controlled experiments scale (decameter)!*

- **a large fraction of the moment which is aseismic**
  - Seismicity only explaining a part of the moment in LSBB carbonate fault
    - *Exponential permeability increase which allows large pressurized water amounts to invade the fault may be a key process !*
    - *Is there a link between the stable slip and the tremor like activity ?*