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Institut des Sciences de la Terre

Pressurized fluid flow within the mechanical stability domain of fault zones in shale

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Fluid and Fault project

- **Objective of the project:** to constrain a relationship relating permeability, pressure, stress and strain in fault zones in shale.

- Does the permeability only depend on fluid pressure and the minimum in-situ stress?

- Do we need to take into account “limited” shear-reactivation of natural discontinuities to explain fluid migration?

- Are the hydraulic response and the plastic behavior of discontinuities always associated?

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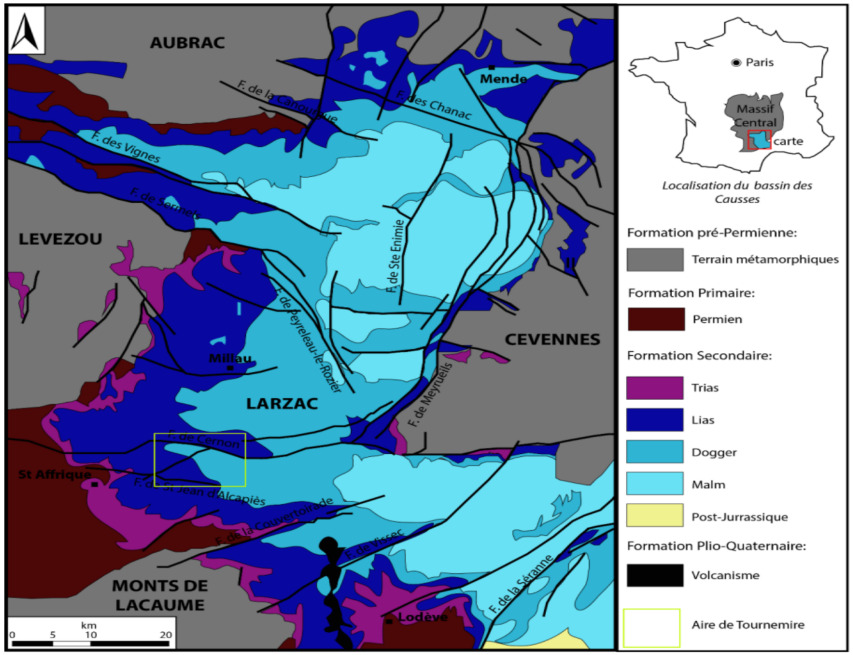
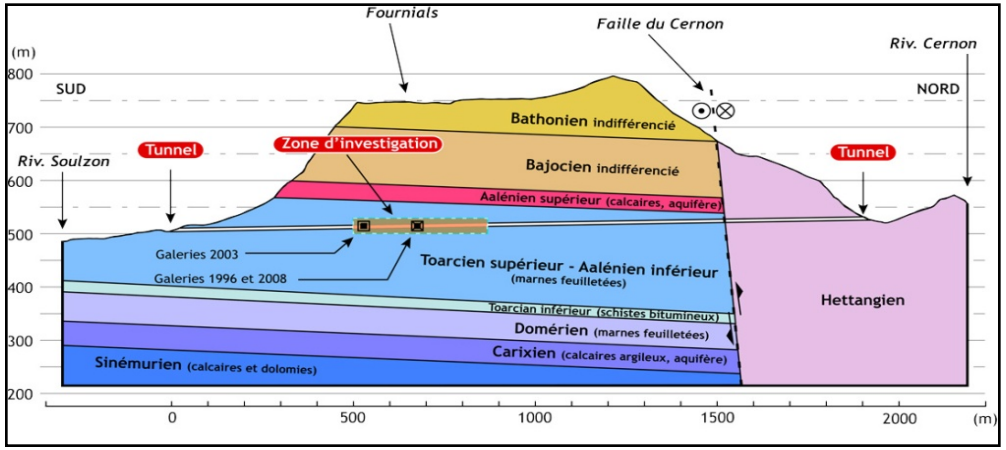
Tournemire test site (IRSN)





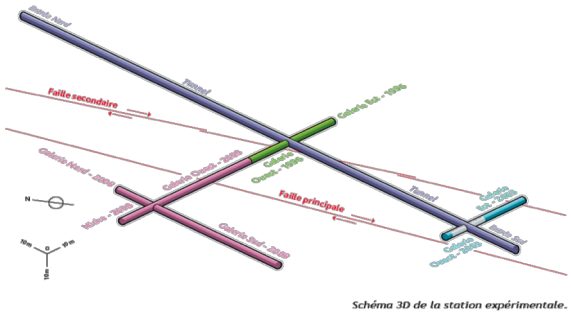
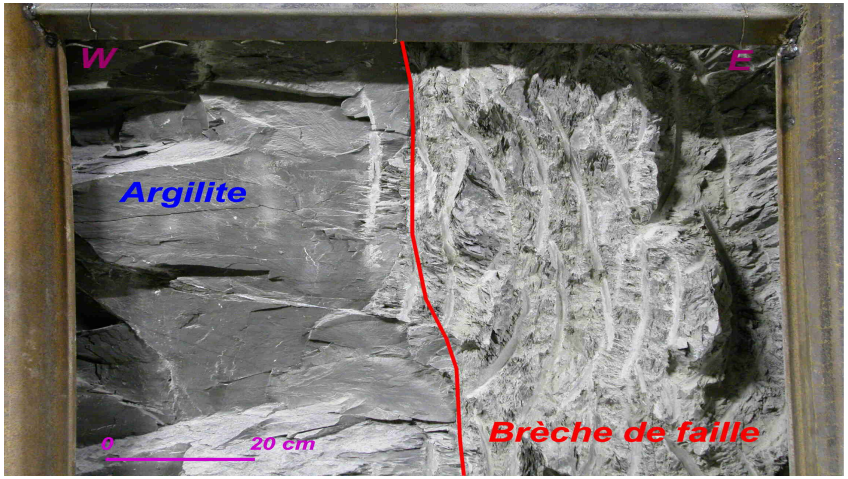


Schéma 3D de la station expérimentale.

Shales with 50% of clay content Illite and Chlorite



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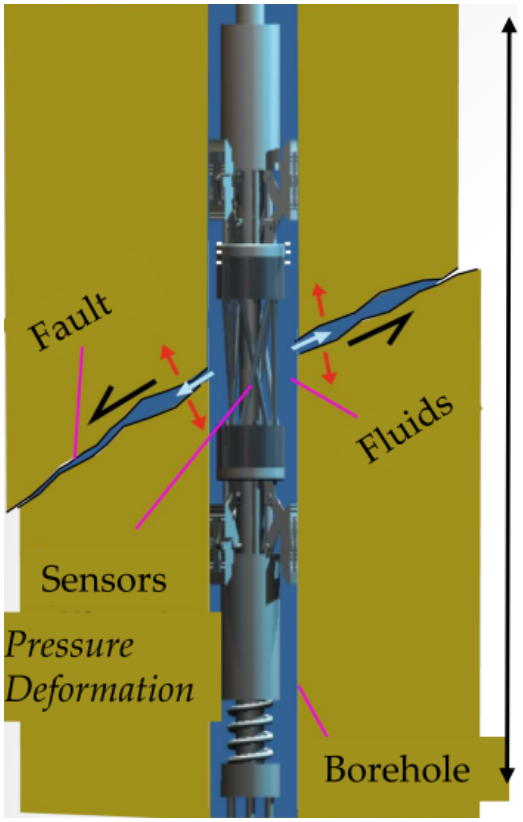
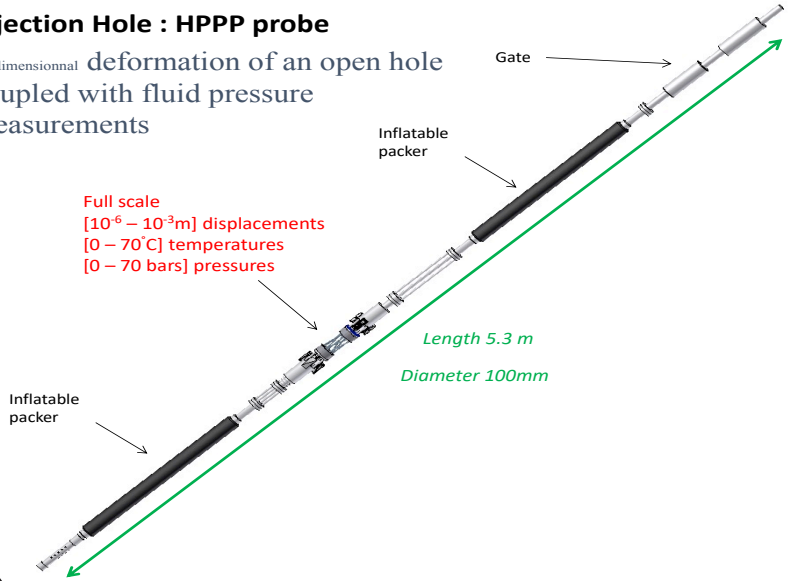
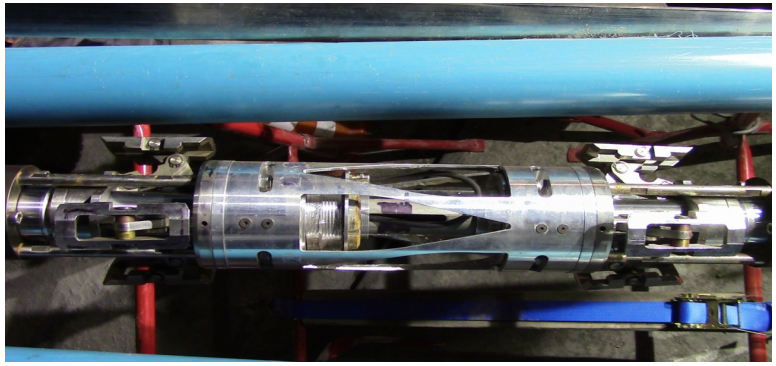
Injection: fluid pressure and strain



Injection Hole : HPPP probe

3 dimensionnal deformation of an open hole coupled with fluid pressure measurements





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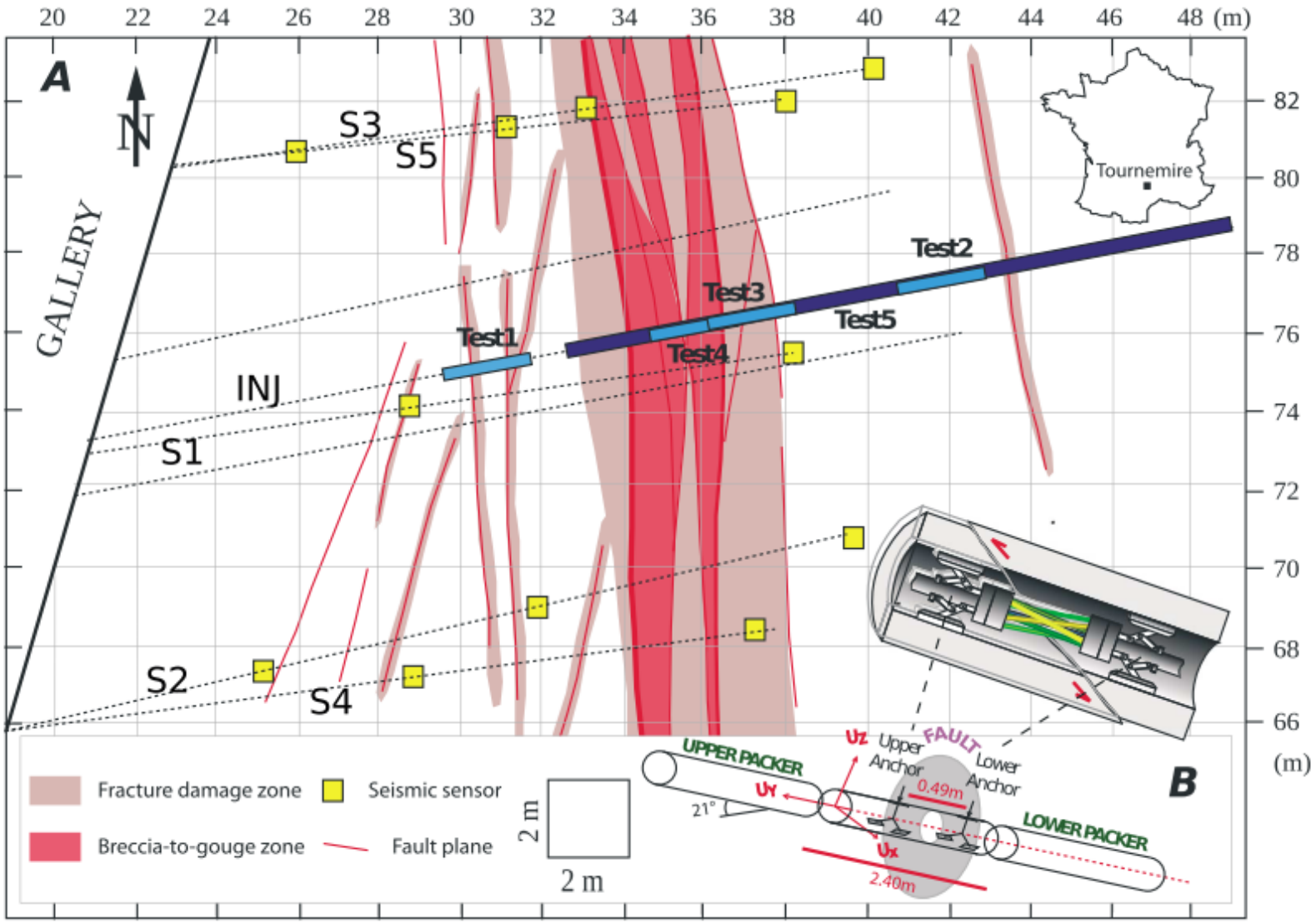
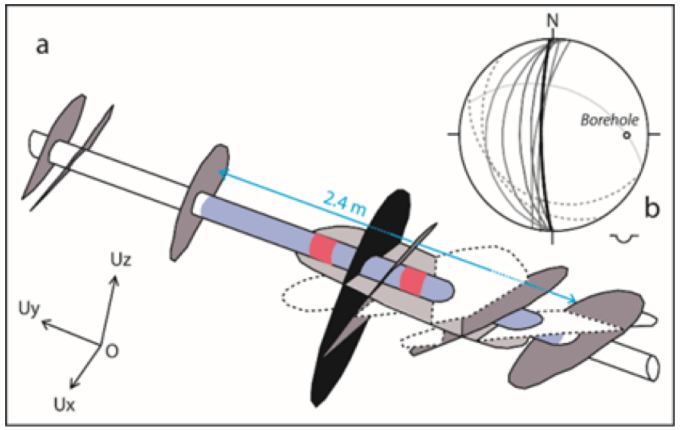
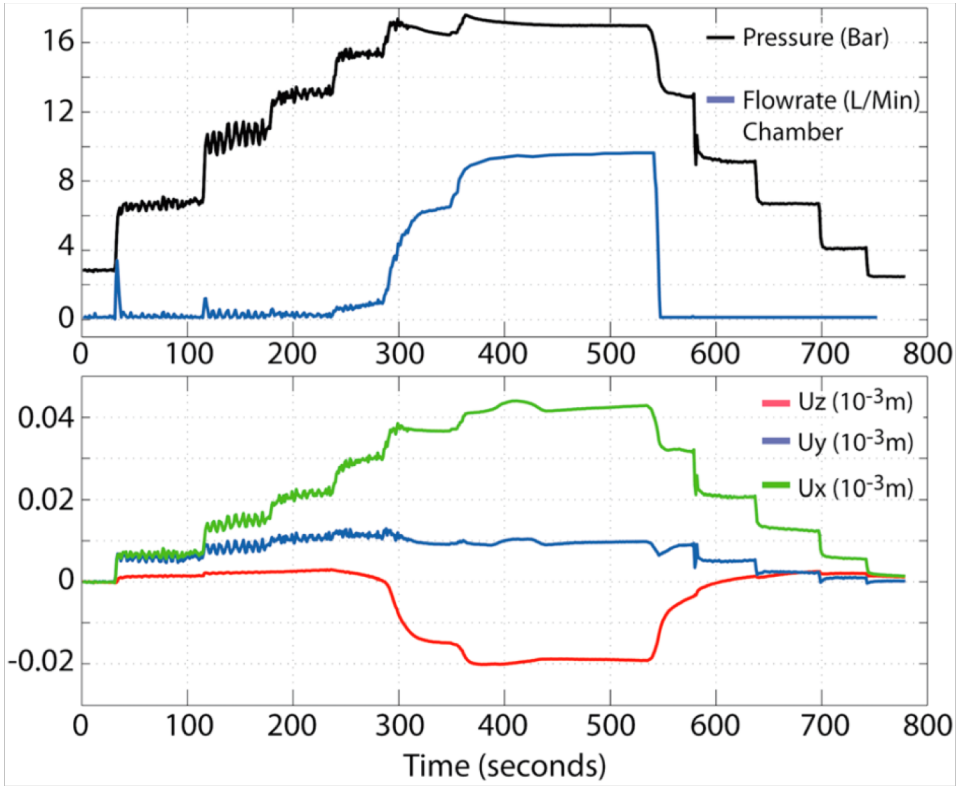
Map view of the experiments



West damaged zone: TEST-1

N0 – 80°W
N20 – 20-to-40°W
N110-to-140 – 60-to-30°N or S





HTPF method (Cornet, 2000):

- $\sigma_1 \approx 4$ MPa, horizontal and oriented N162° ±15° E,
- $\sigma_2 \approx 3.8$ MPa, sub-vertical (plunge=83-82° and azimuth=N072°) and
- $\sigma_3 \approx 2.1$ MPa, plunge=7-8° and azimuth N072° .

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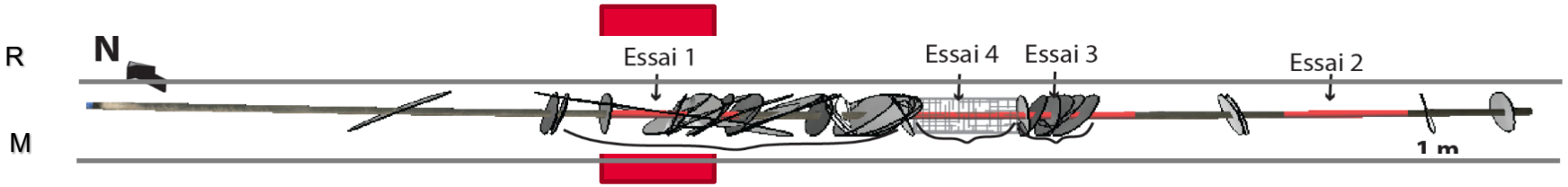
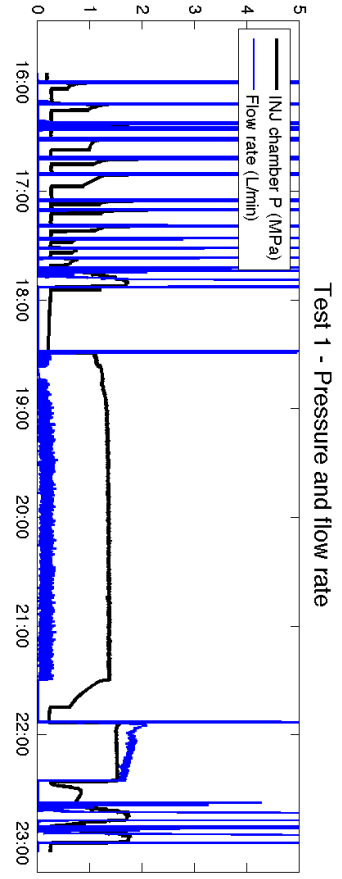
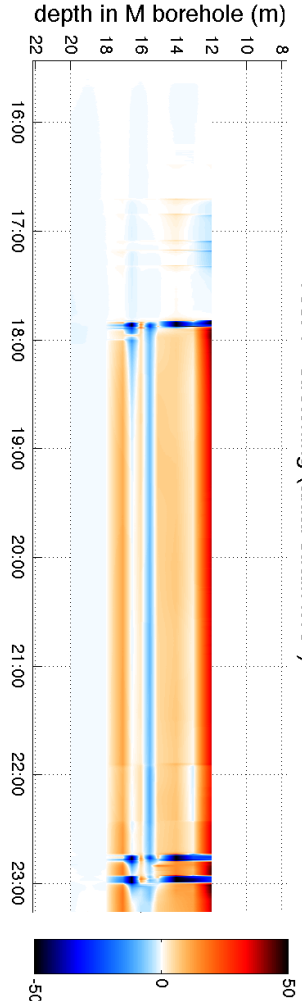
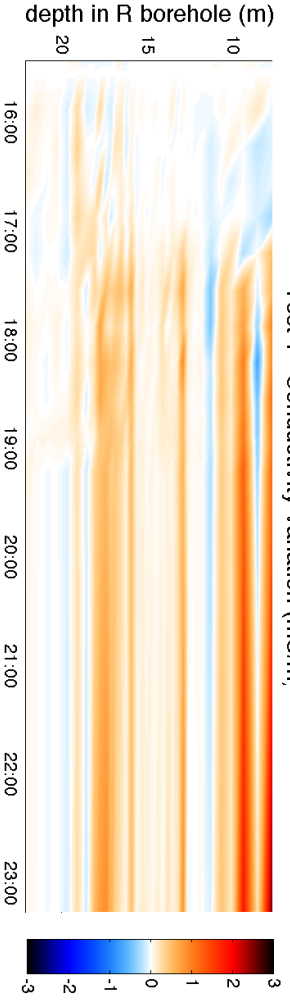
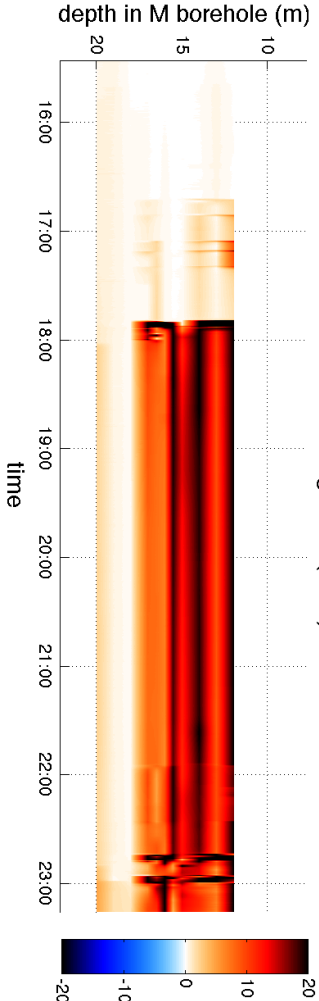
West damaged zone: TEST-1



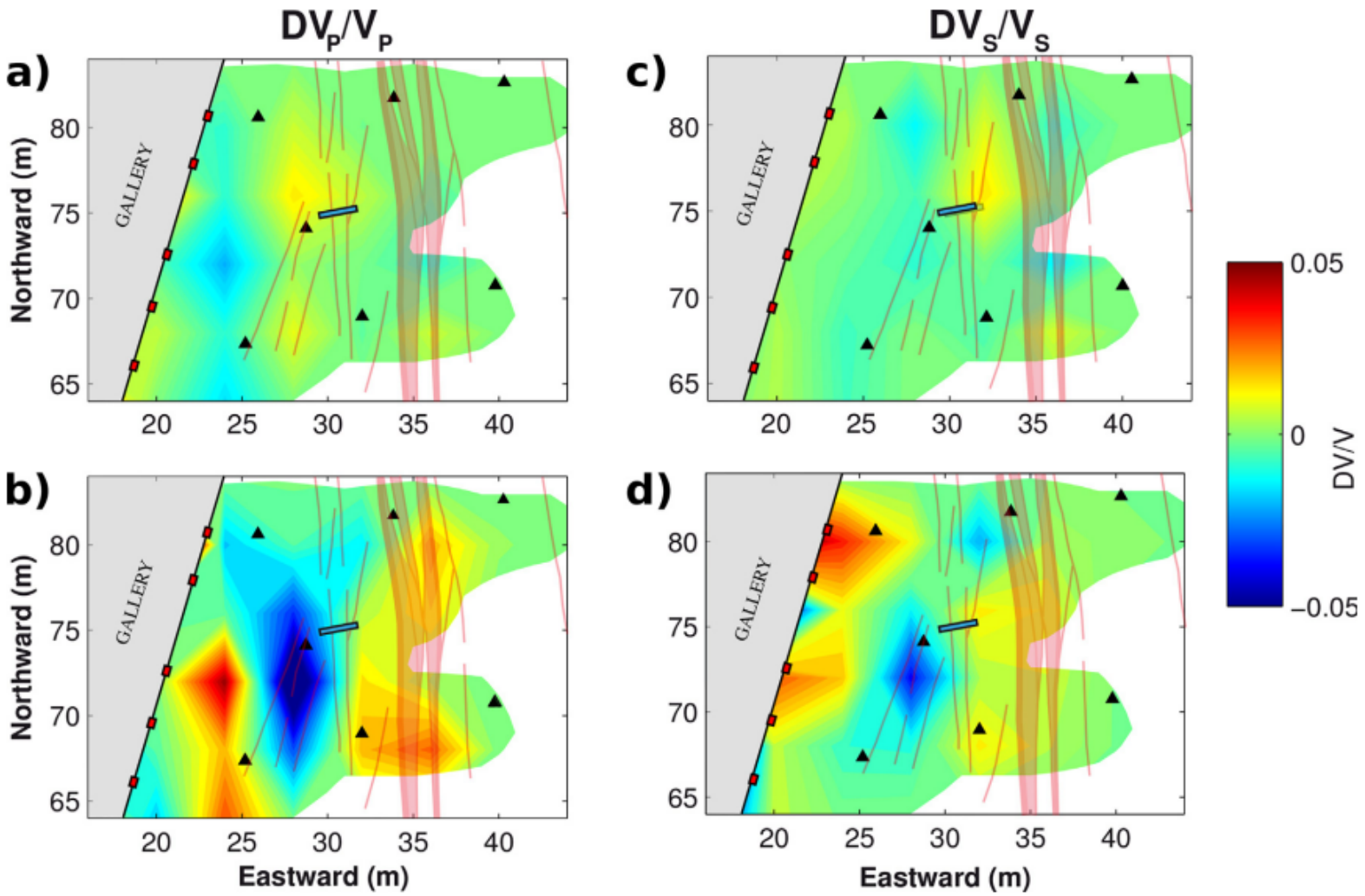






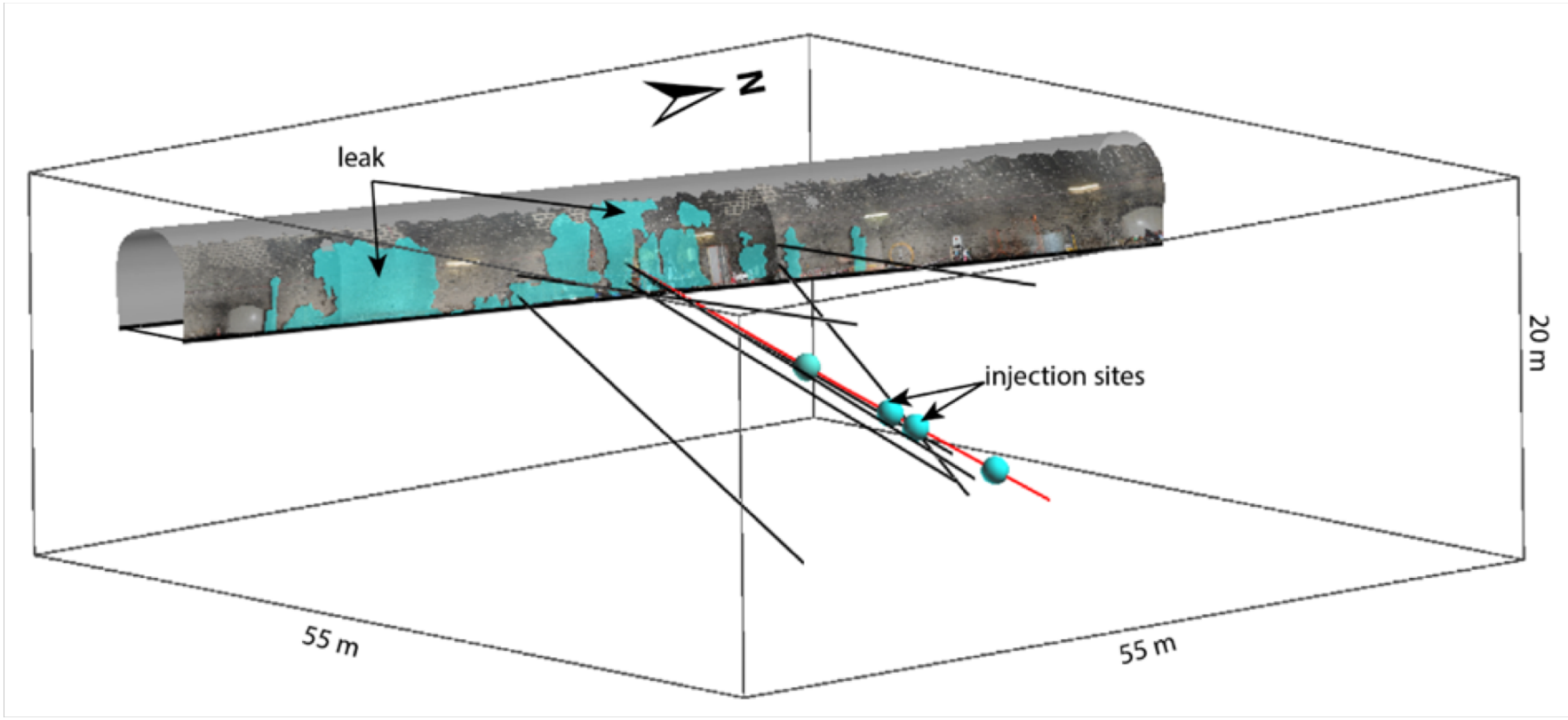


Map view of the P- (left panels, a and b) and S-wave (right panel, c and d) velocity variations observed during test 1



De Barros et al., 2018

Fluid dynamics – flow across fault



Localization of leaks in the tunnel (test series **TEST1** and **TEST5**).

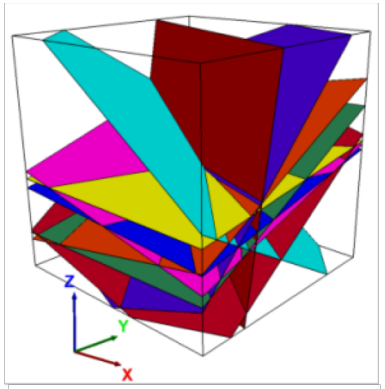
No leak when injecting in the western compartment (**TEST2**) or the core zone (**TEST3-6**)
The fault acts as a barrier for flow

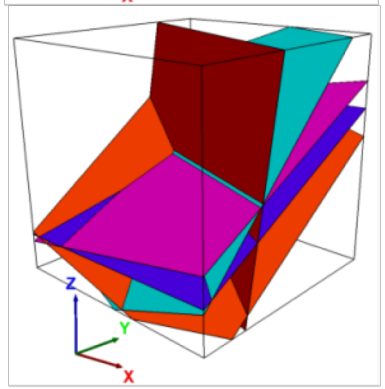
Test-1: Discrete Element Model using 3DEC

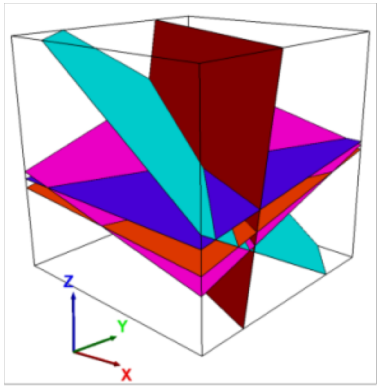
All discontinuities model

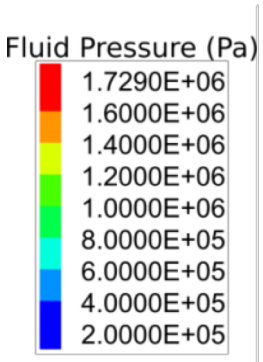
Main secondary fault+
sub-vertical fractures

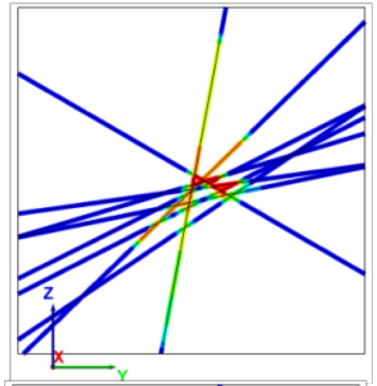
Main secondary fault+
sub-horizontal fractures

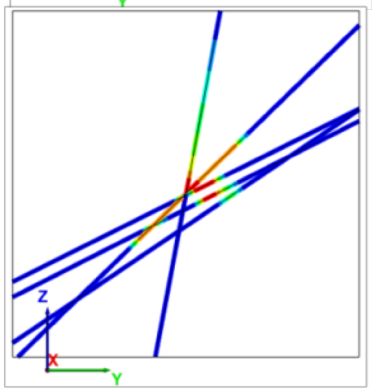


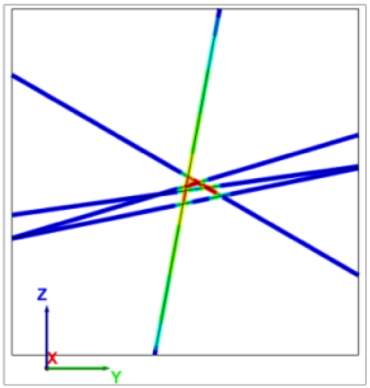






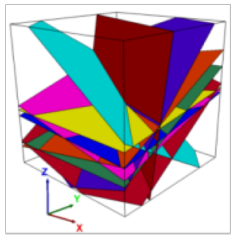


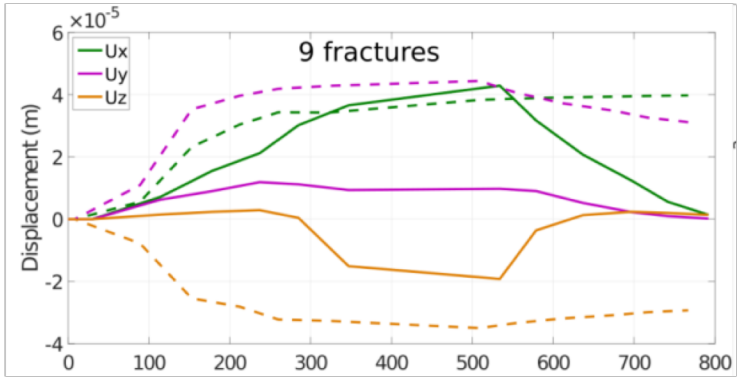


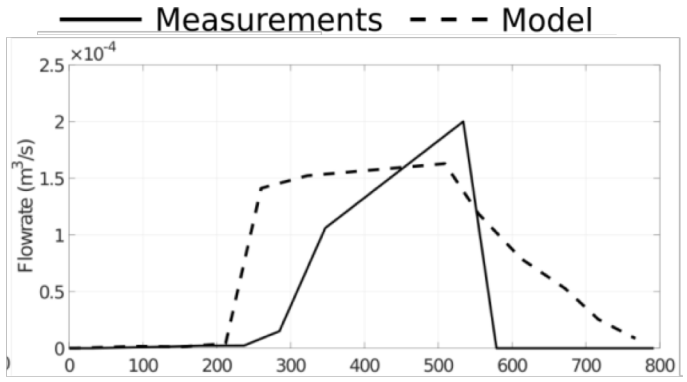


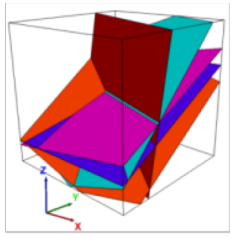
10 m

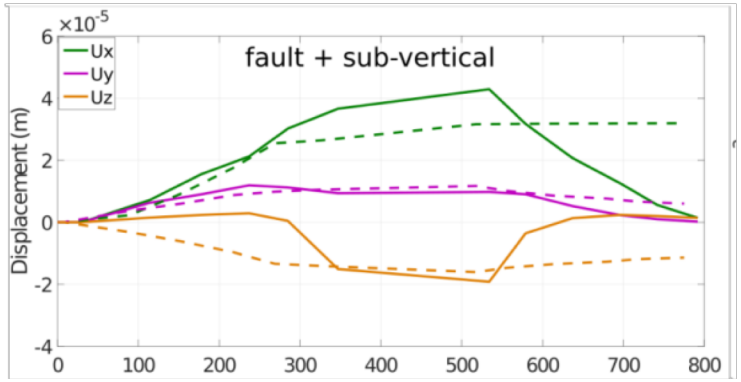
Numerical results: irreversible displacements!

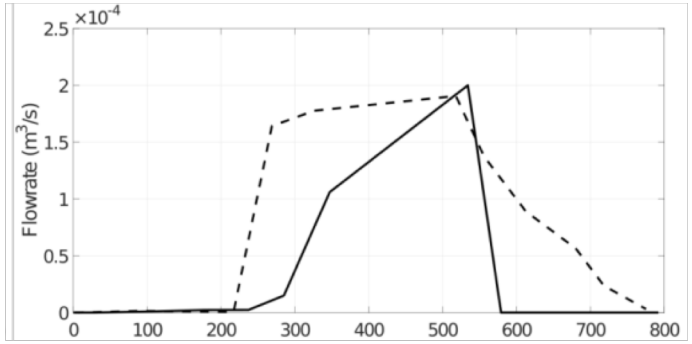


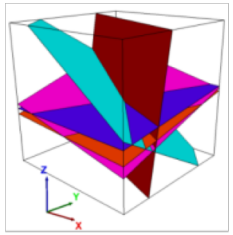


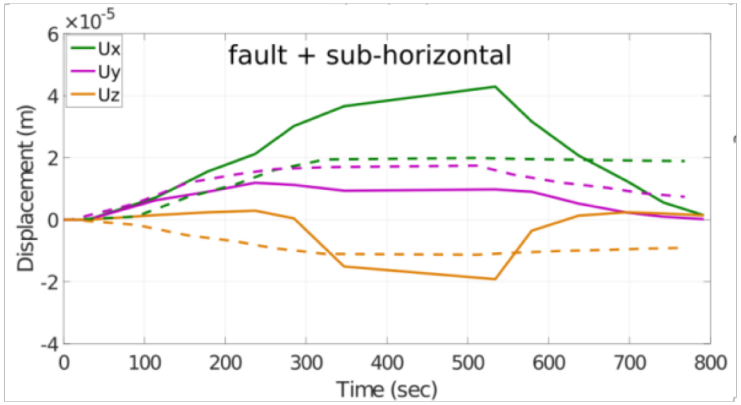


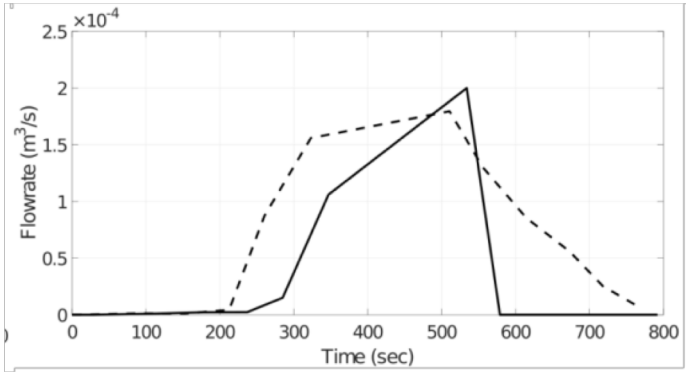












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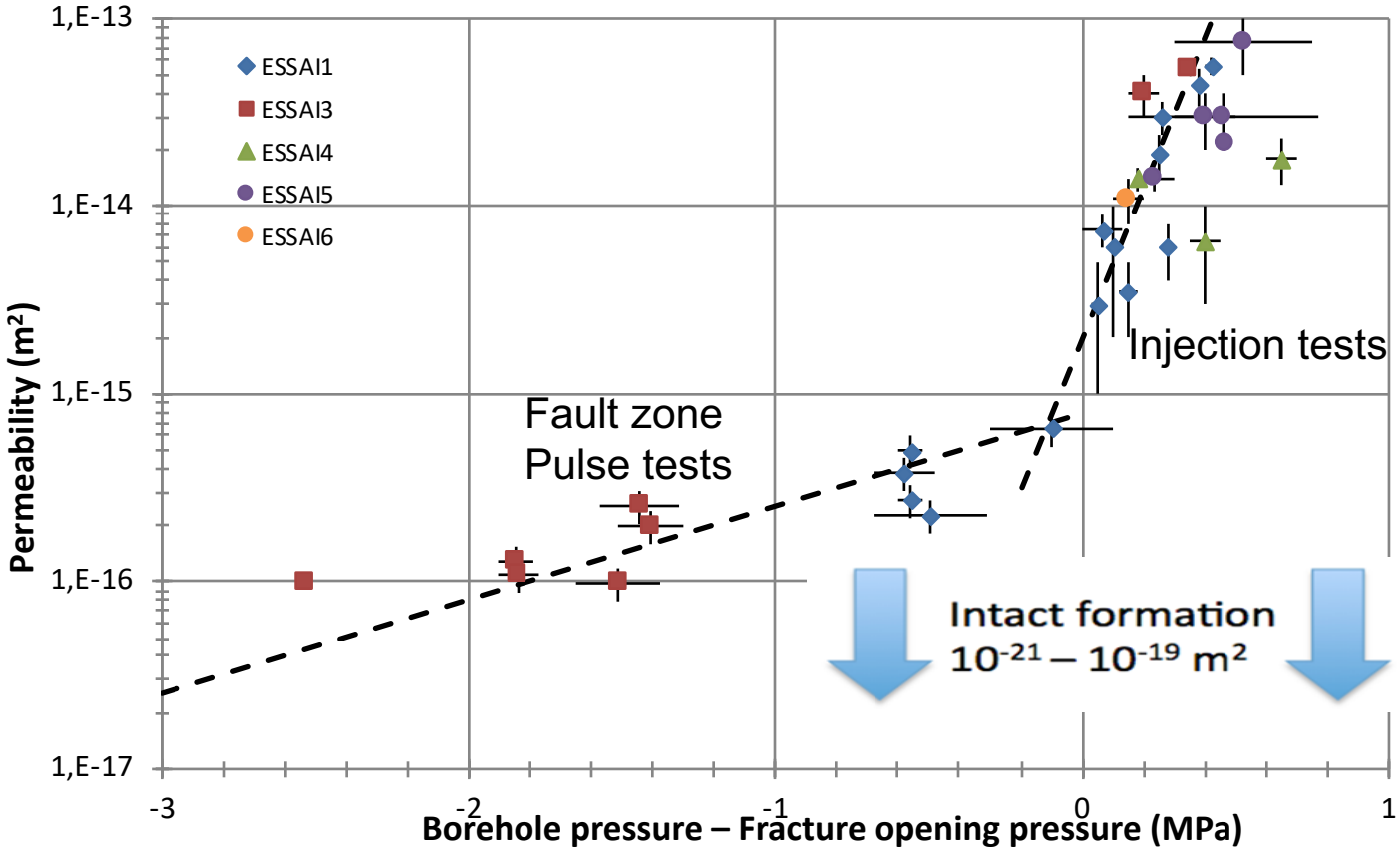
Permeability evolution

FOP (Formation Opening Pressure): more than 0.1 L/min



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Permeability evolution

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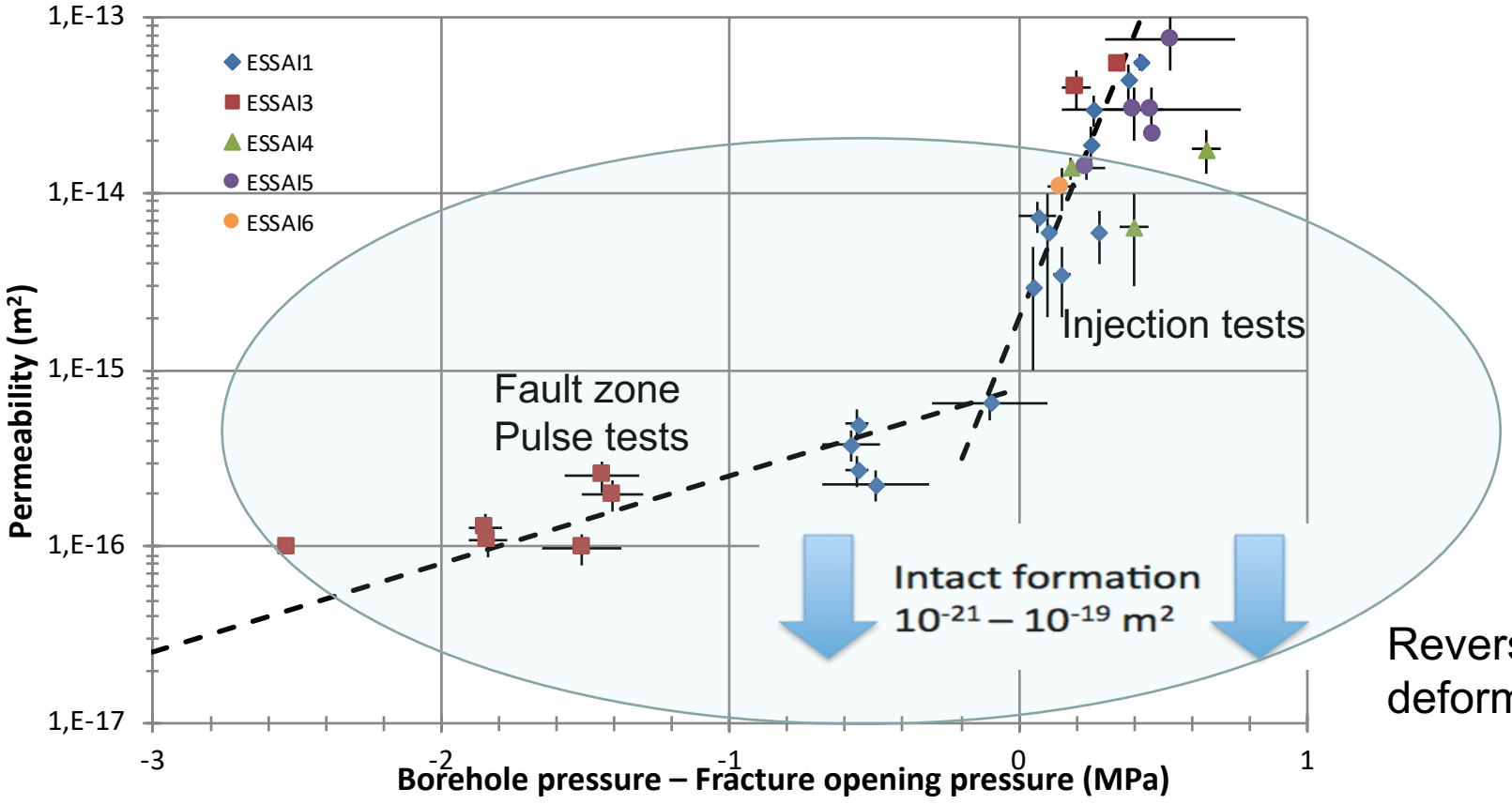


Reversible deformation!

Surface roughness of fractures?

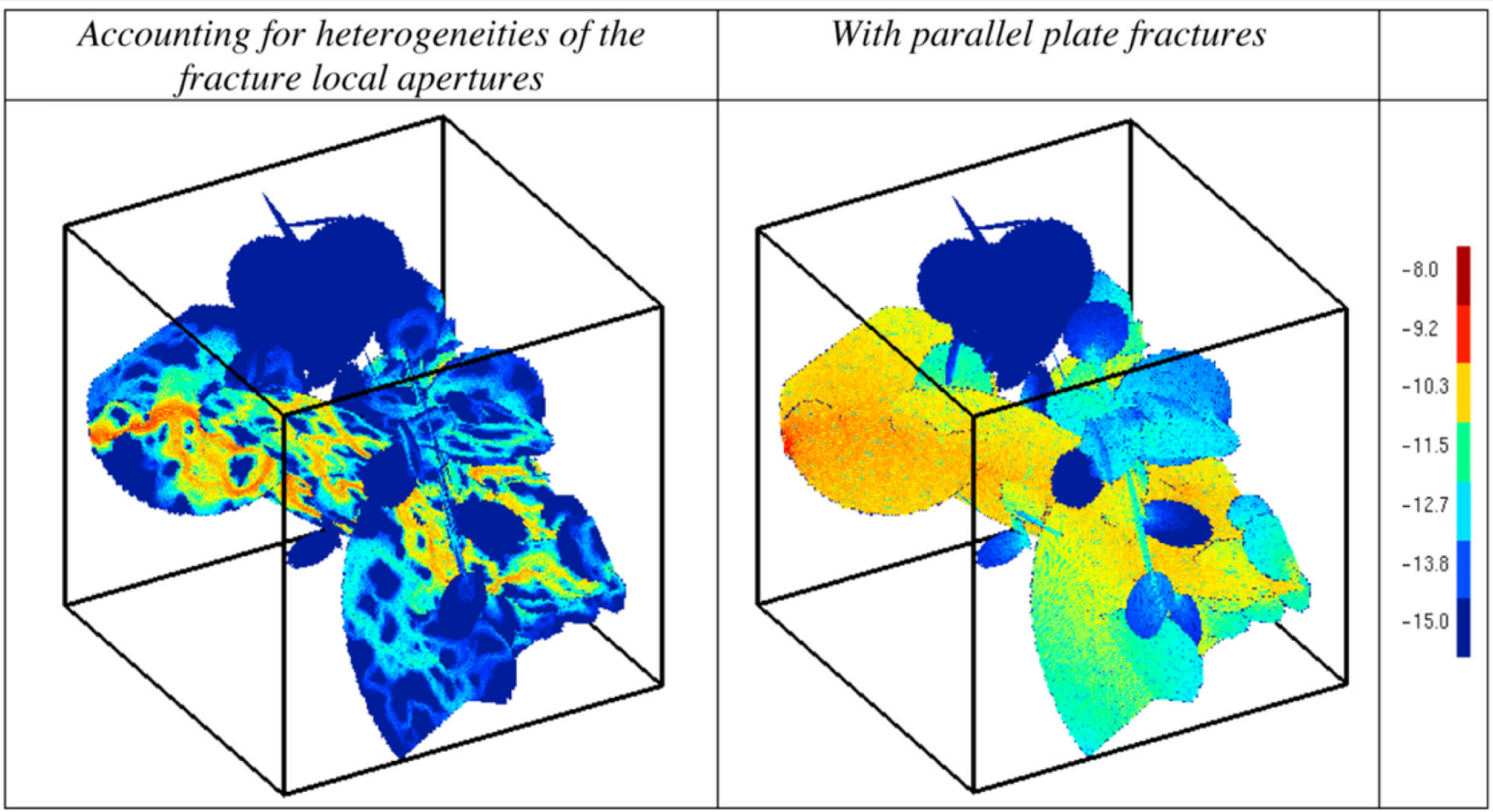
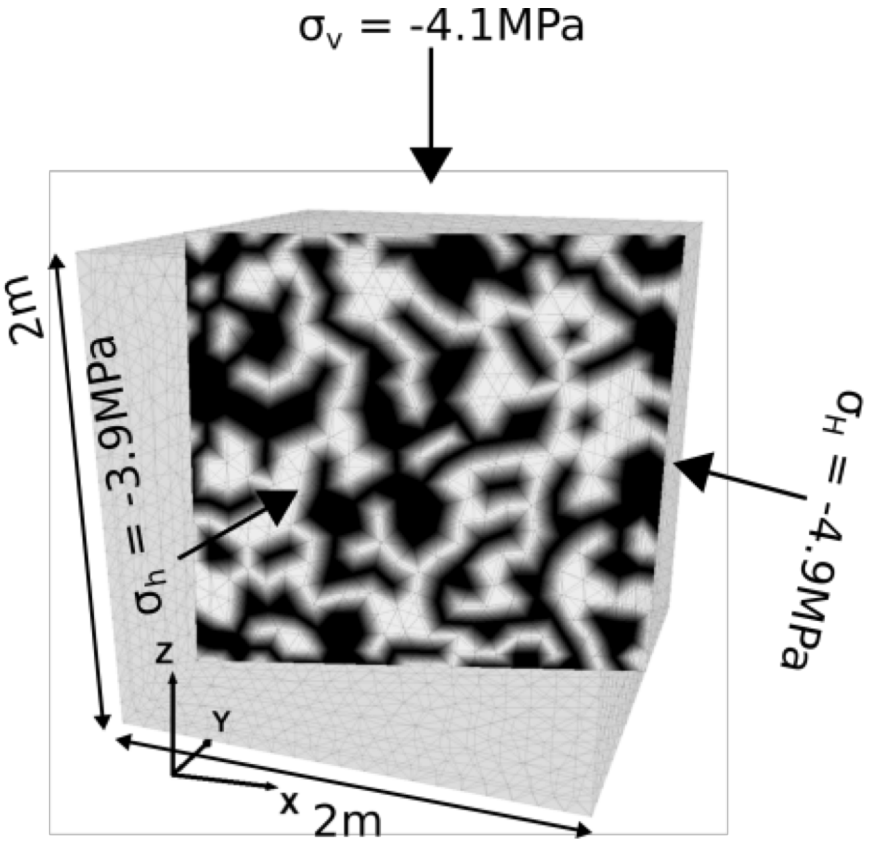
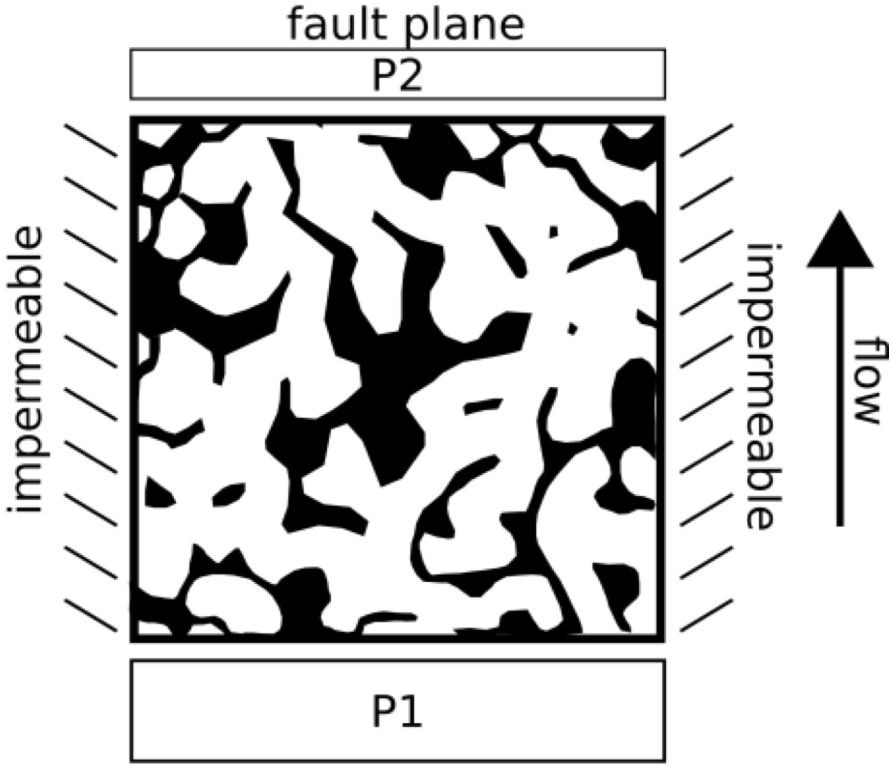


Figure 3. Flow field within the sparse DIST network shown in Figure 1 (top middle), (left) when heterogeneities of the fracture local apertures are taken into account ($c_{frac} = 1$) and (right) when fractures are modeled as parallel plates. Scale on the right displays the logarithm of the mean flow value within a mesh cell.

De Dreuzy et al., 2012

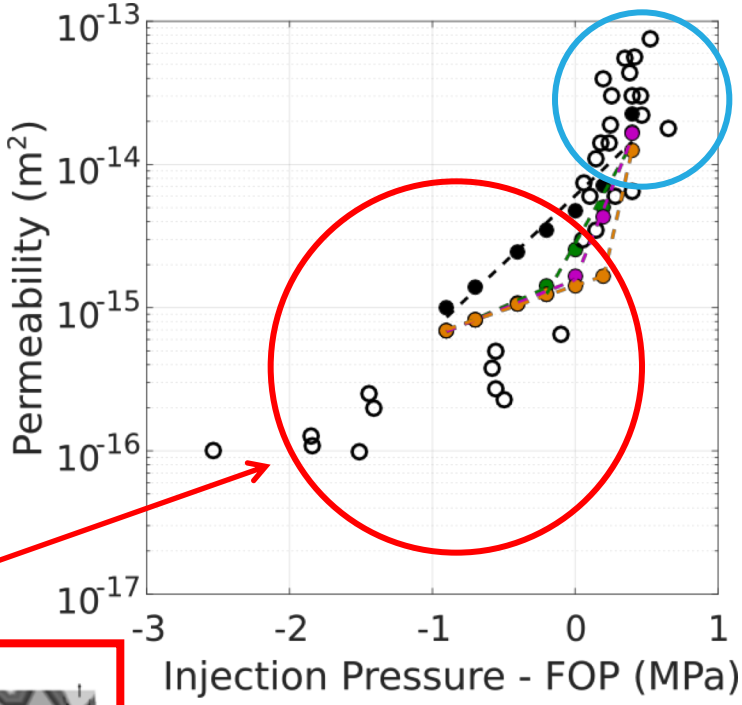
Numerical modeling with surface roughness

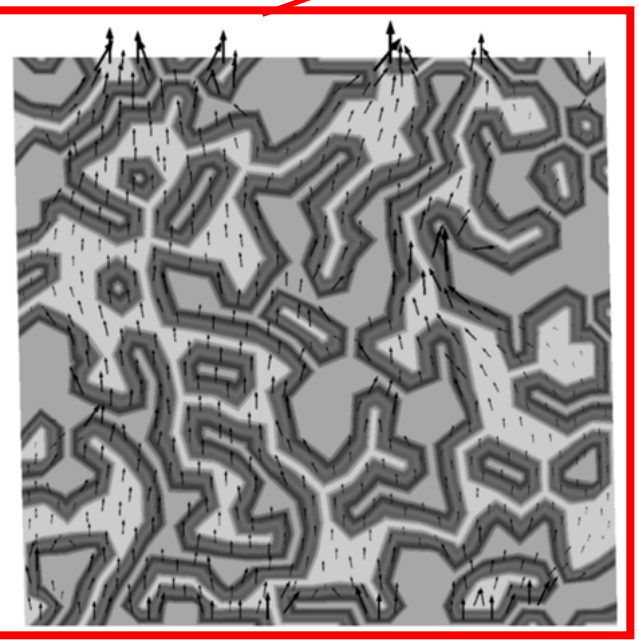


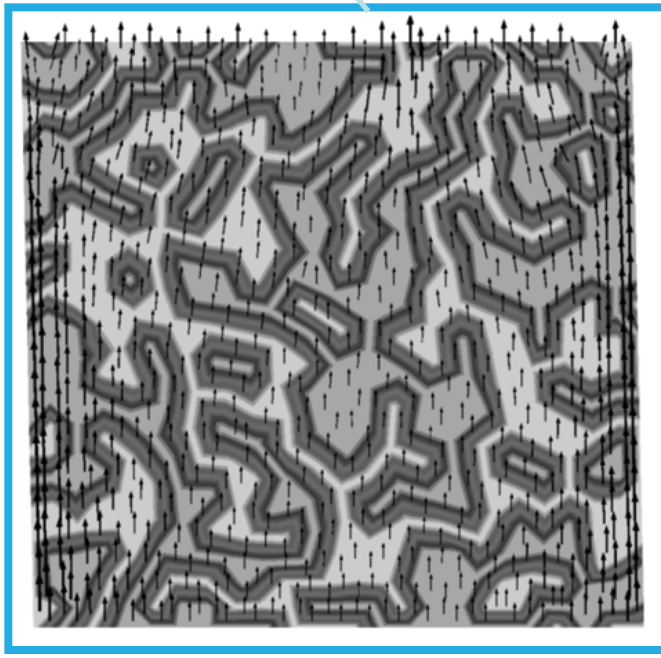


$$k_{in} = k_{out} = \frac{Q\mu}{A}\frac{dx}{dP}$$

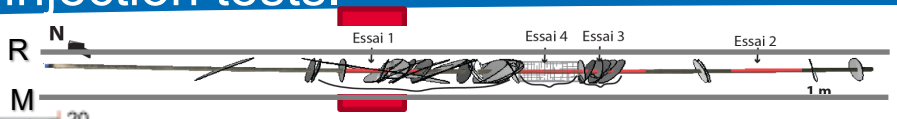
From fluid channeling to the mechanical

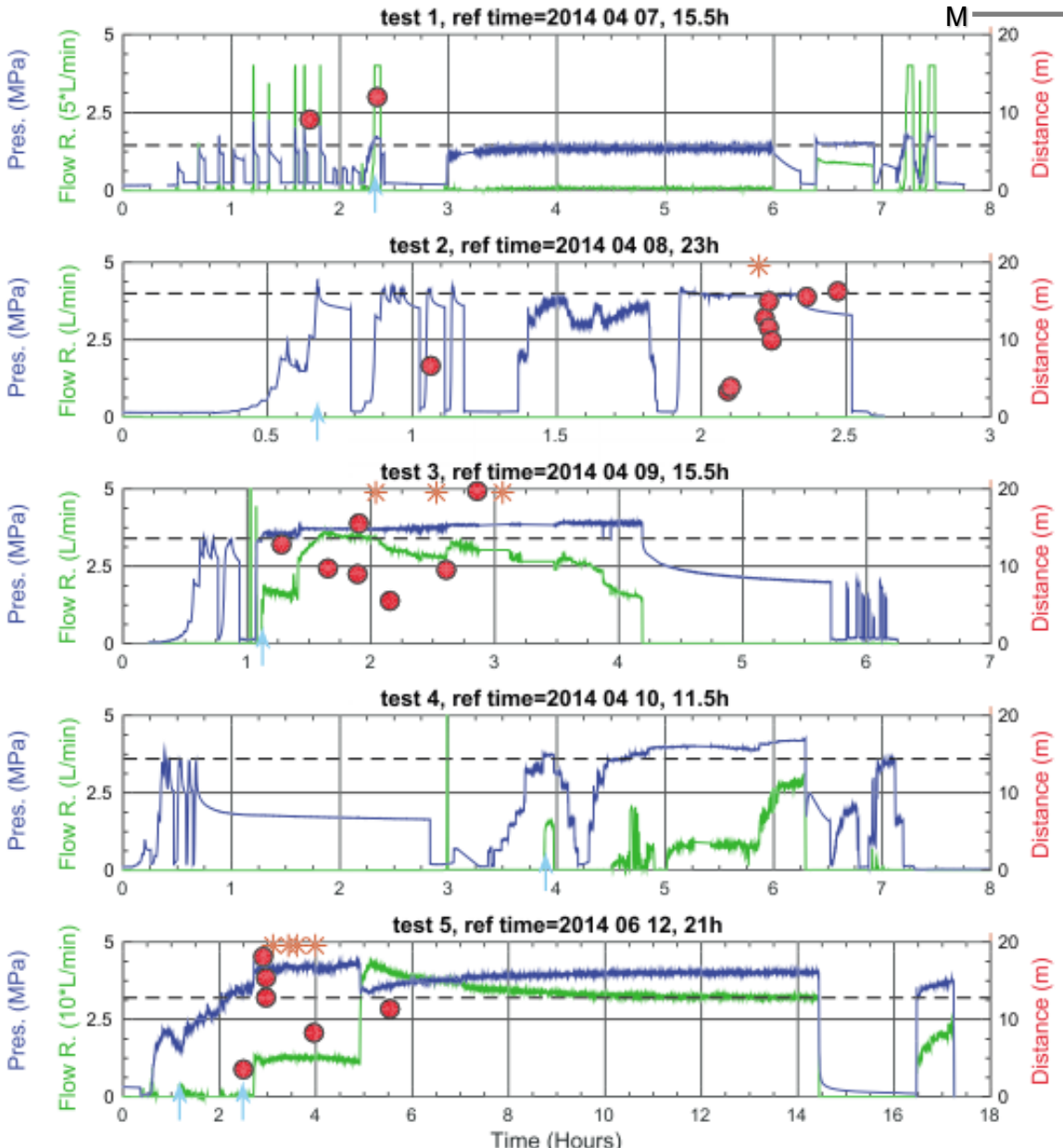






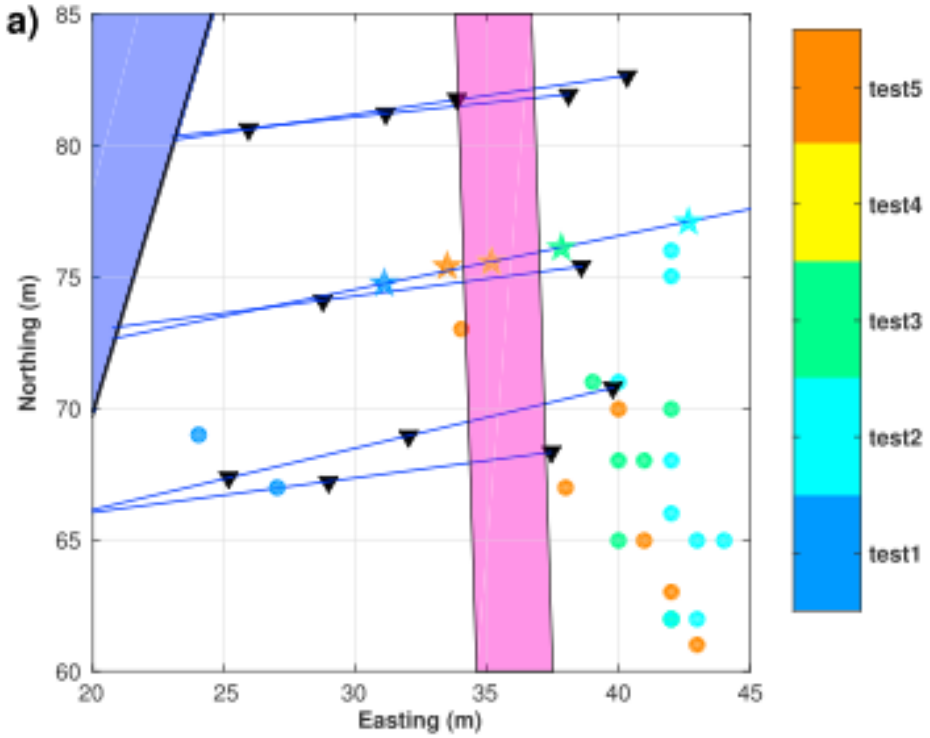
Injection pressure (blue lines), flow rate (green lines), and event hypocenter distance (red dots) versus time for the five injection tests.

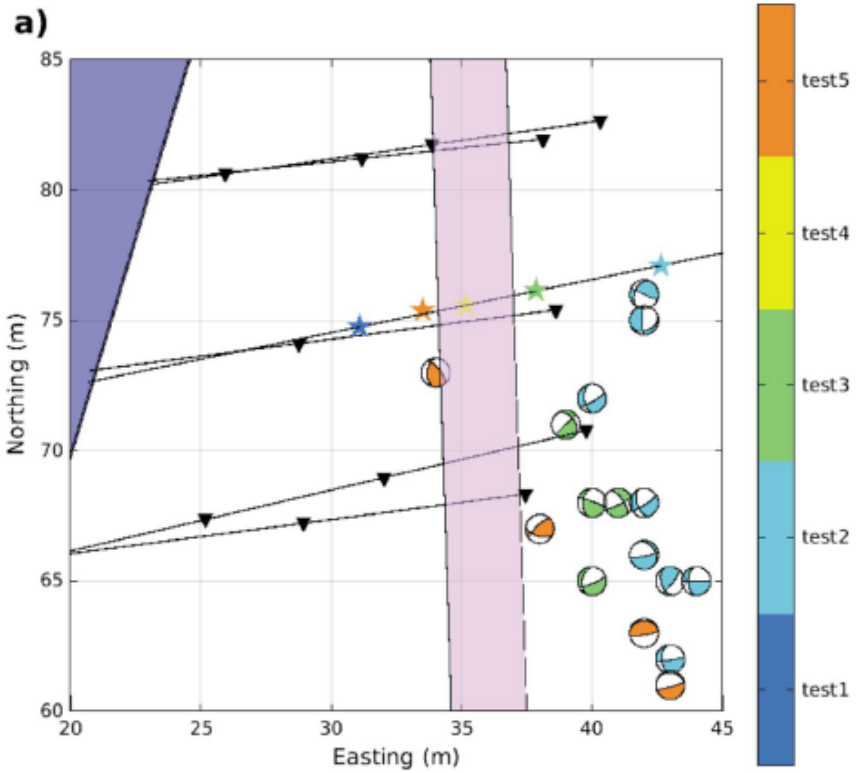


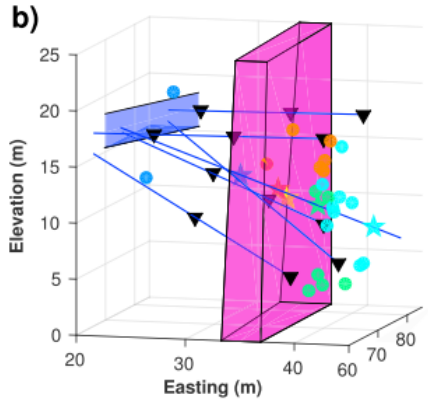


De Barros et al., 2016

Microseismic events







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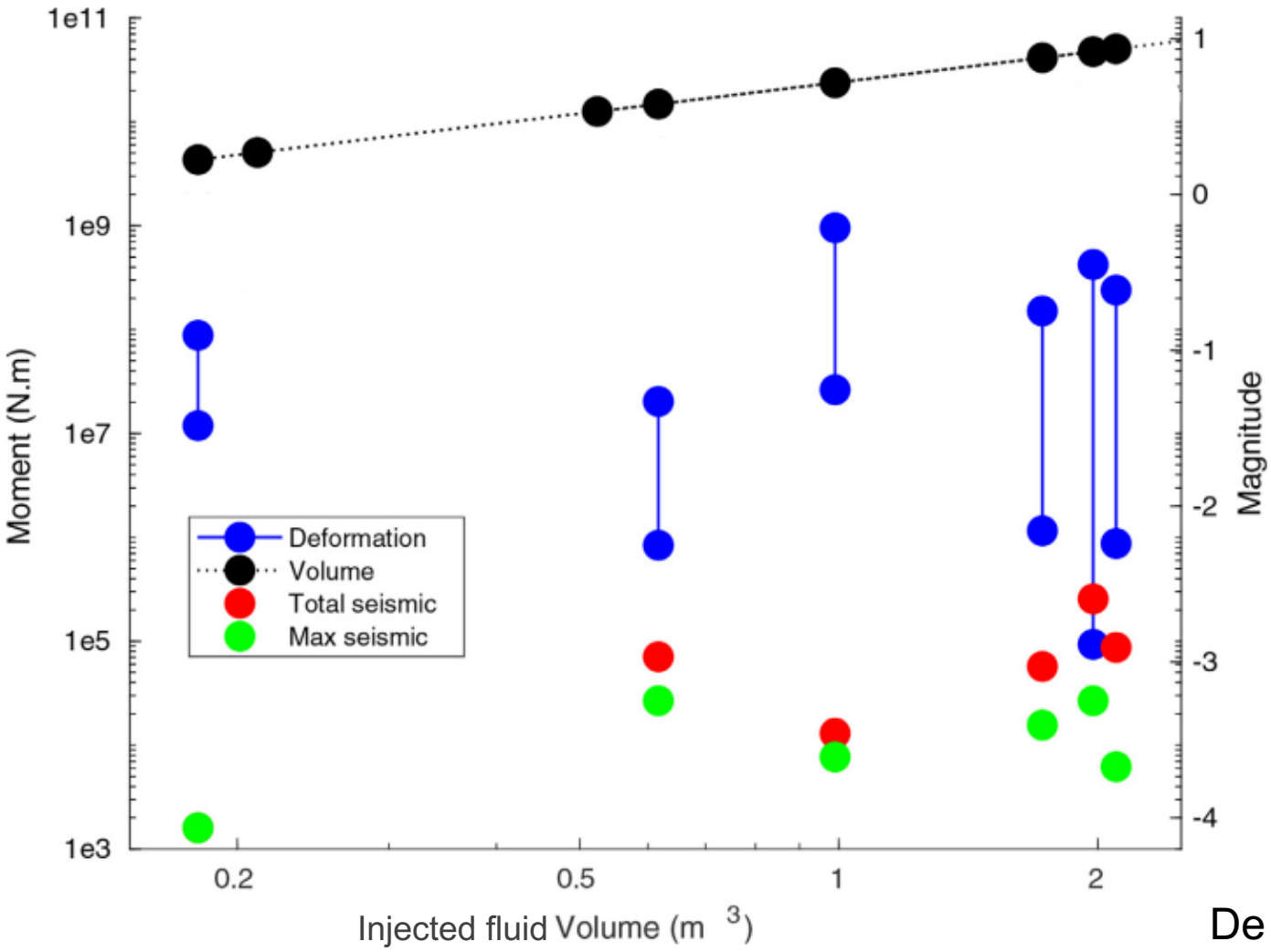
Cumulated and maximum seismic moment (red and green symbols), deformation moment and predicted volume moment (blue and black symbols)



$M_0^{max} = \mu V.$

McGarr (2014) prediction

$M_0^{def} = \mu S D.$

Error bars related to S (rupture surface) and D (displacement) uncertities

De Barros et al., 2018

Dual processes for fluid-induced seismicity, as inferred from the in-situ experiments