

Fracturing and self-sealing in hollow cylinder specimens of Boom Clay and Opalinus Clay

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LMR
LABORATOIRE DE
MÉCANIQUE DES ROCHES

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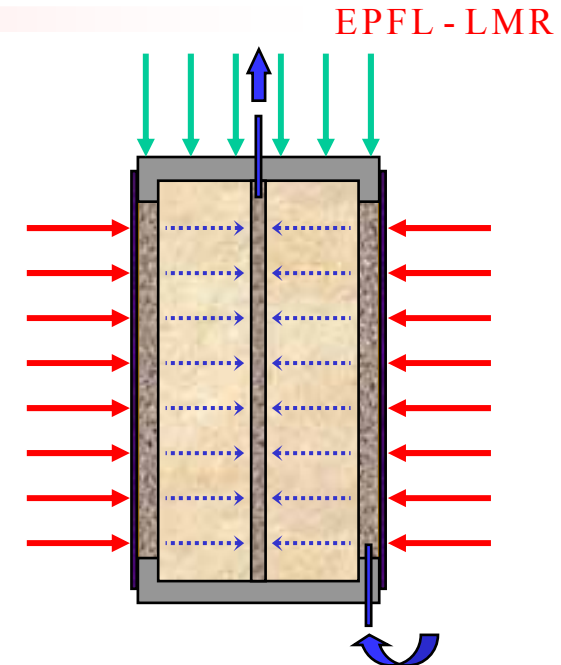
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1. Aim of the tests
2. Experimental device and procedure
 - Modified LEGEP cells
 - Testing procedure
3. Results on Boom Clay
4. Current results on Opalinus Clay
5. Conclusions

Aim of the EPFL tests on hollow cylindrical specimens

Check of the permeability changes related to localised crack proliferation (process A) and its potential self-sealing with time (process B)

- 1) Permeability measurement on the undisturbed sample.
- 2) Tensile fracturing of the sample without removing it from the cell.
- 3) Permeability measurement on the fractured sample just after fracturing.
- 4) Confining pressure kept constant and measurement of fluid flow some time after fracturing



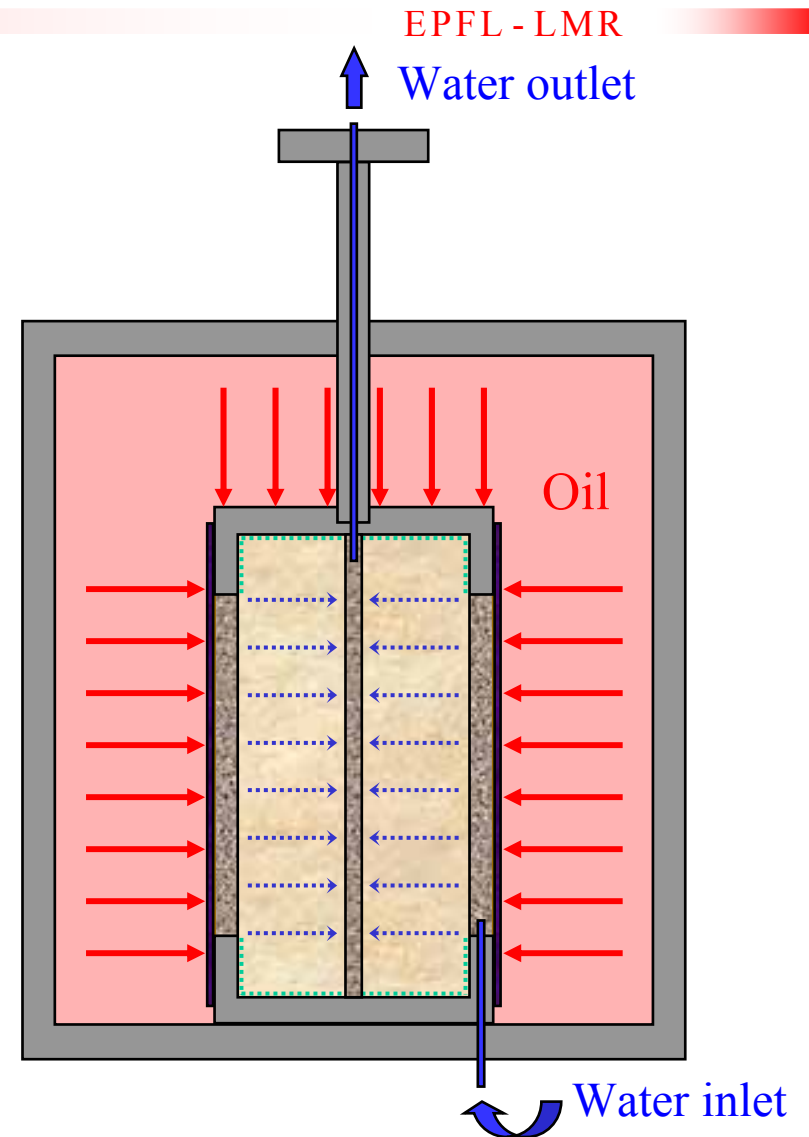
⇒ increase of permeability related to localised crack proliferation

⇒ check of the potential reduction in permeability and thus of the self-sealing capability of the clays

Trial test on Boom Clay



- Hollow cylindrical specimens
- 80 mm external diameter
- 6 mm diameter central hole filled with sand (inner drain)
- Upper and lower parts of the sample glued to caps to allow extension
- Outer drain and neoprene membrane



Trial test on Boom Clay

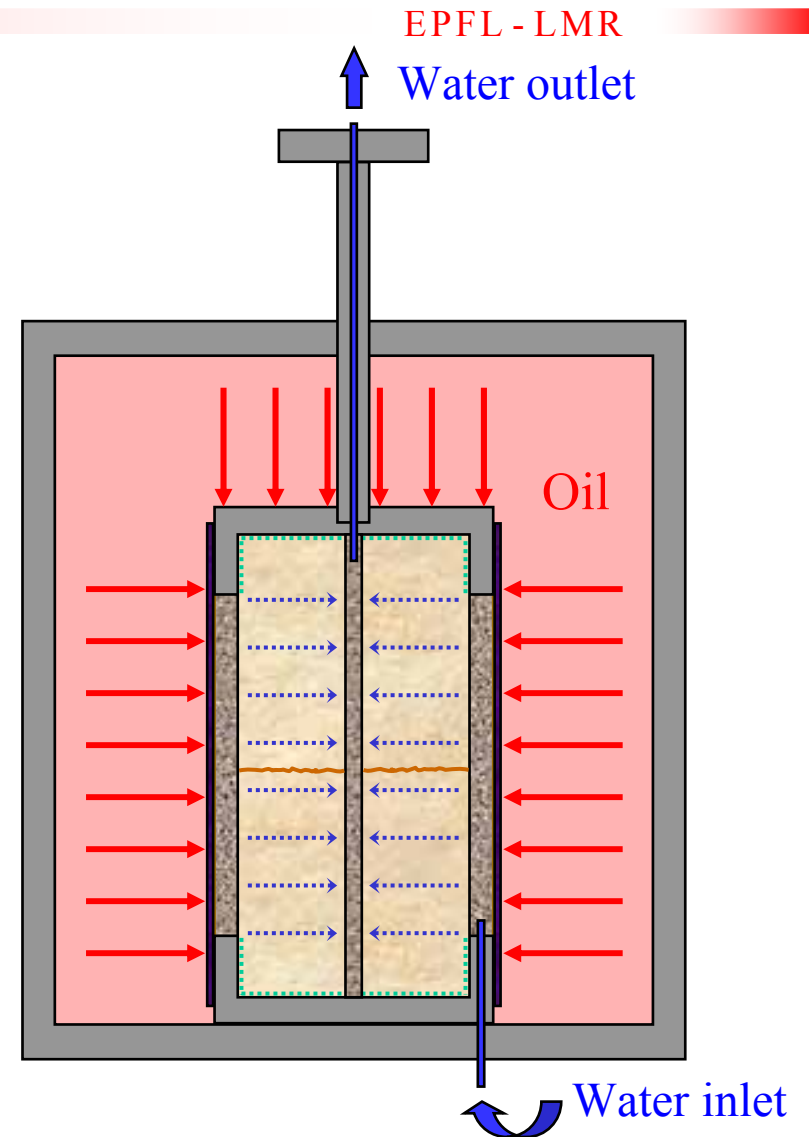
Encouraging results...

- ☺ horizontal fissure generated in the sample
- ☺ permeability measurements in agreement with in situ ones

...but

- ☹ significant convergence of the central hole of the hollow specimen

➔ Need to improve the sample preparation, the testing device and procedure

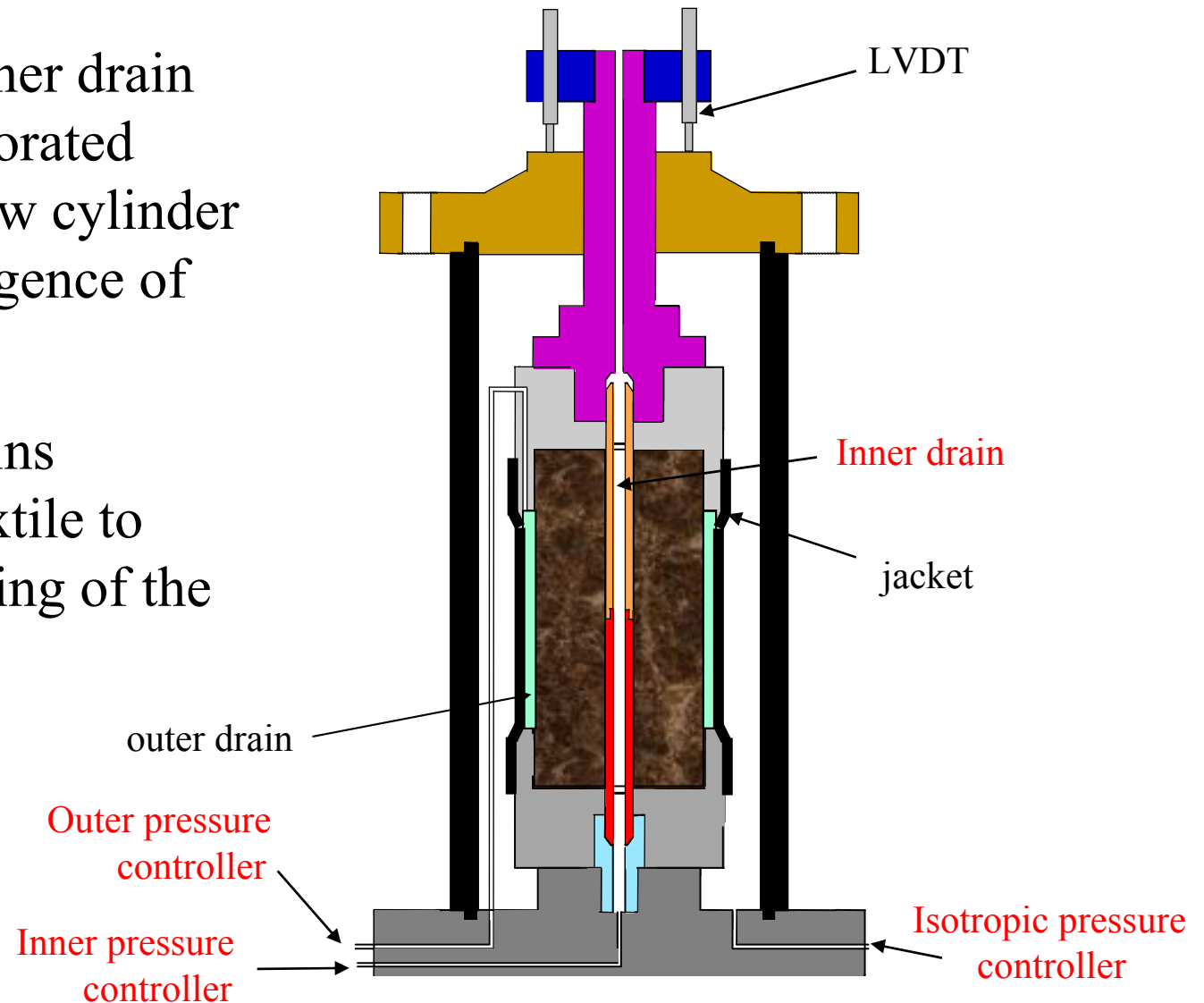


Sketch not at scale

Improvements to the LEGEP cell

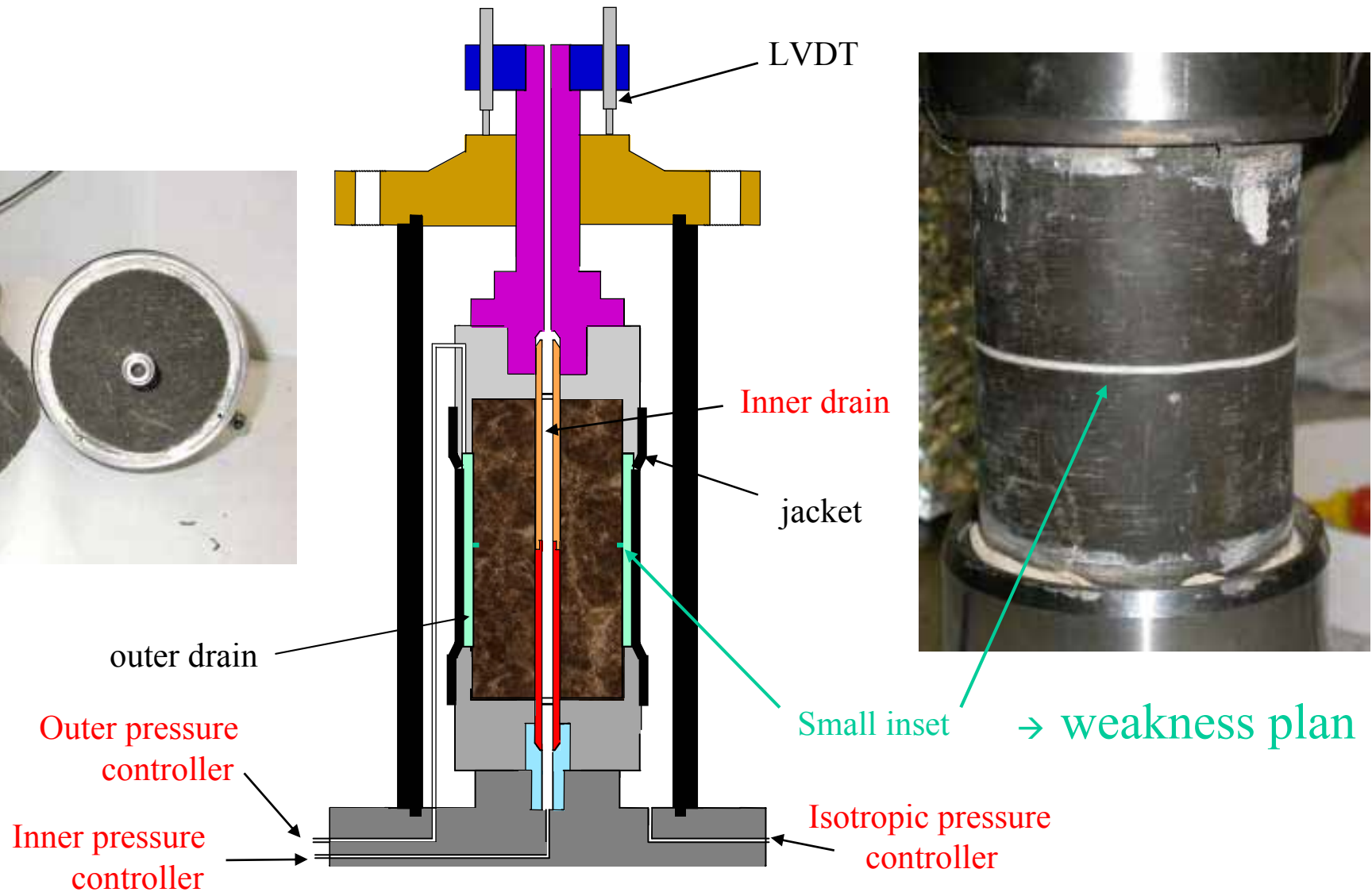
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- Outer part of the inner drain consisting of a perforated stainless steel hollow cylinder to avoid the convergence of the clay
- Inner and outer drains composed of geotextile to minimize the clogging of the hydraulic circuits



Use of a **small inset** to initiate the fissure in the central part of the clayey sample

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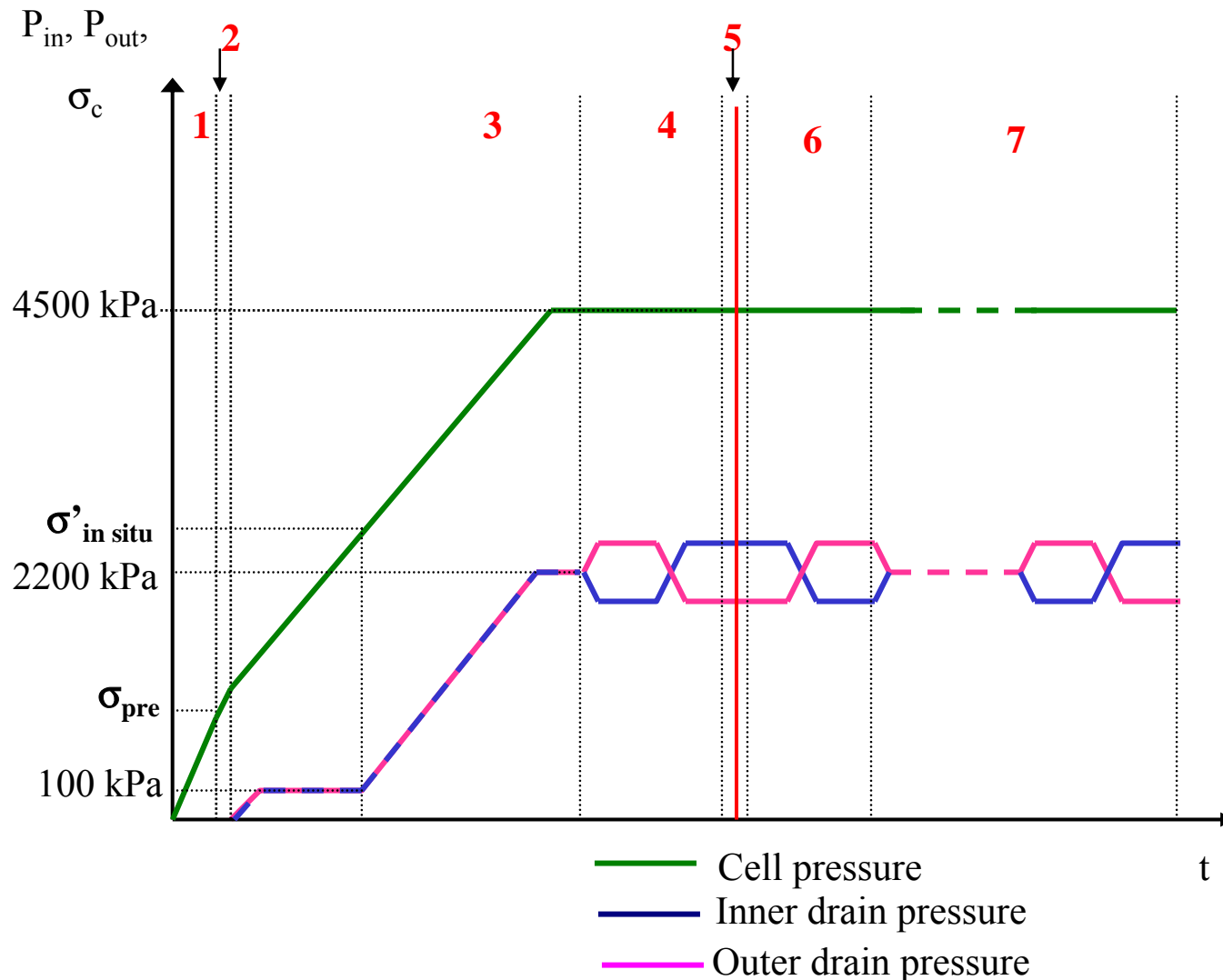
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Experimental procedure

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- 1: preloading**
- 2: hydraulic circuits saturation**
- 3: consolidation stage ($v=500\text{ kPa/day}$)**
- 4: permeability measurement on the virgin sample**
- 5: fracturing**
- 6: permeability measurement on the fractured sample**
- 7: self-sealing analysis**

Permeability measurement

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- when steady state is reached

$$Q_{\text{inner drain}} = Q_{\text{outer drain}}$$

- $$K = \frac{Q \cdot \gamma_w}{2 \cdot \pi \cdot h \cdot \Delta P} \cdot \ln \frac{r_1}{r_2}$$

with:

K [$\text{m} \cdot \text{s}^{-1}$]: hydraulic conductivity

Q [$\text{m}^3 \cdot \text{s}^{-1}$]: entering or leaving flow

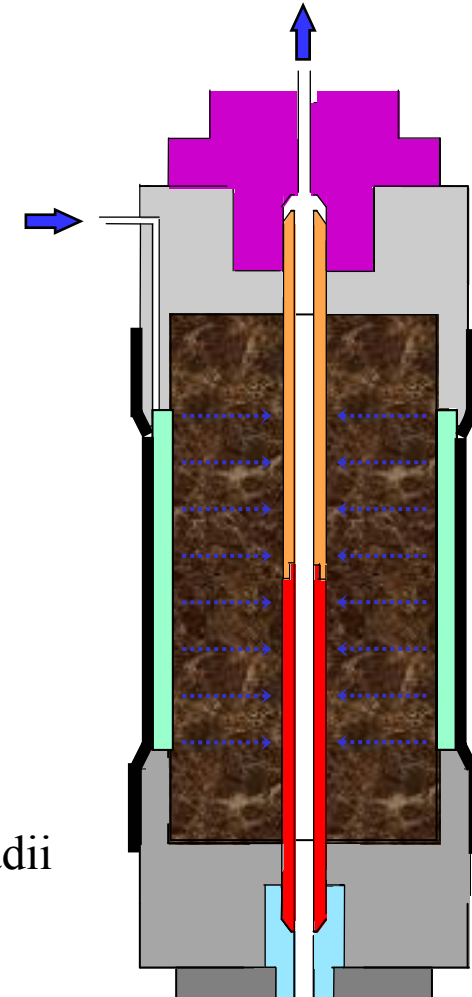
γ_w [$\text{kg} \cdot \text{m}^{-2} \cdot \text{s}^{-2}$]: unit weight of the fluid

h [m]: height of drainage

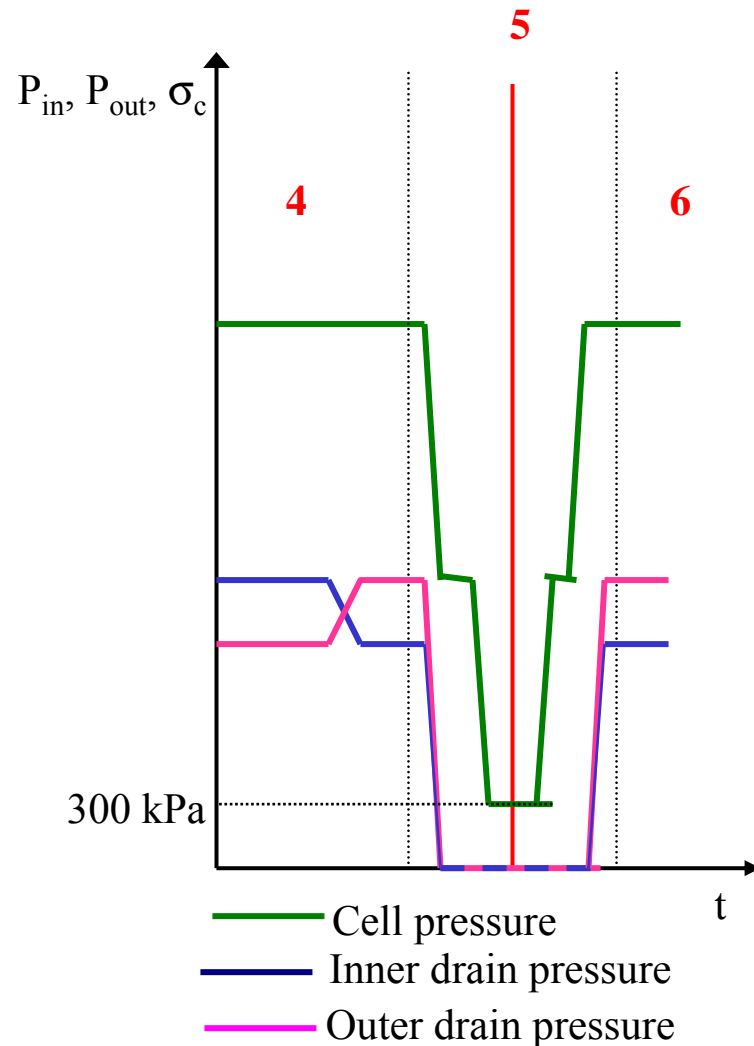
ΔP [Pa]: pressure difference between internal and external radii

r_2 [m]: external radius

r_1 [m]: internal radius



Fracturing



4: permeability measurement on the virgin sample

5: fracturing

6: permeability measurement on the fractured sample

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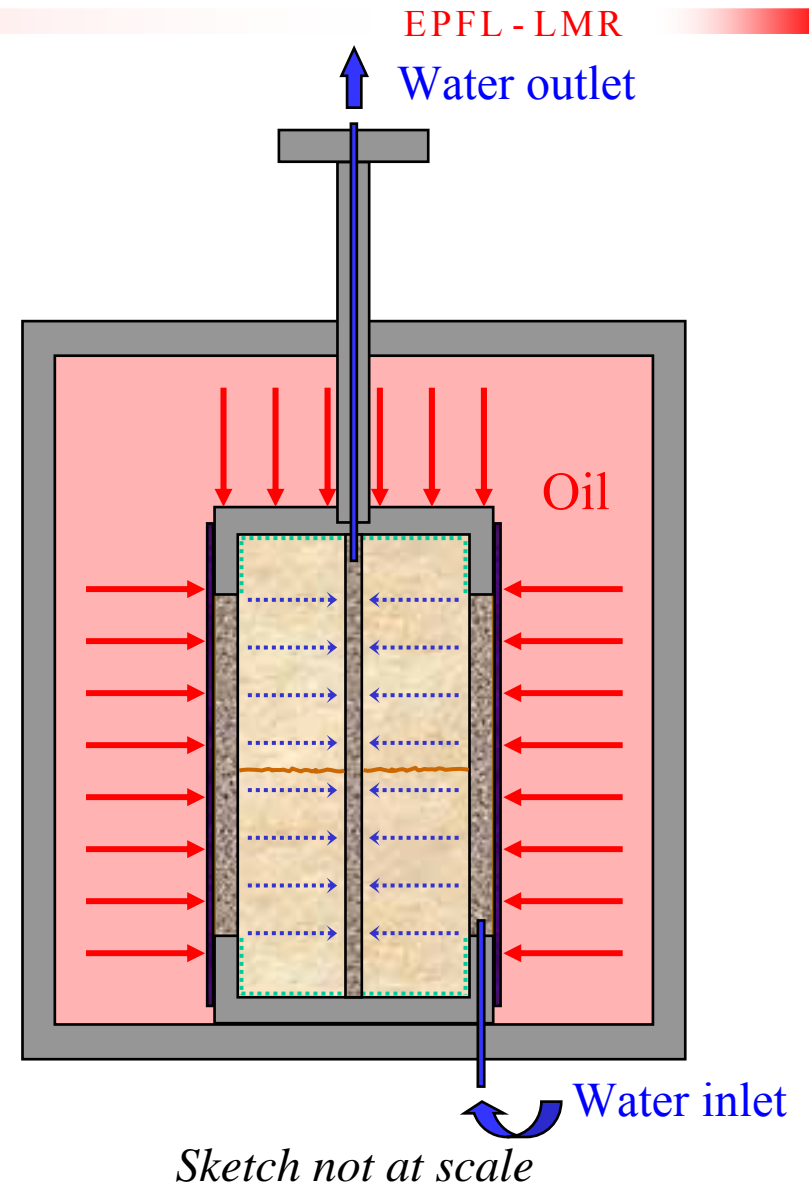
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Results of the trial test on Boom Clay

☺ fissure generated in a horizontal plane, i.e. parallel to the bedding planes

!! Testing conditions not similar to the in situ ones : $\sigma_3 = 5 \text{ MPa}$, $u = 0.5 \text{ MPa} \rightarrow \sigma'_3 = 4.5 \text{ MPa}$

	$k [\cdot 10^{-13} \text{ m/s}]$
virgin sample	8
fracturing	
10 μ	80
40 μ	180
80 μ	16'000
closure of the fissure	
fractured sample	16



Development of shear bands in test 1

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**Shear bands observed on
sample 1**

☹ No tensile fracture occurred in the sample even under an extension axial deformation of 10%

...but

☺ no change of permeability observed related to the development of shear bands.

➔ No change in permeability related to diffuse crack proliferation

(in accordance with L3S observations)

Tensile fracture achieved in next tests

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Tensile fracture observed on sample 2
(cored parallel to the bedding planes)

☺ fissure orientated horizontally,
perpendicularly to the symmetry
axis and the bedding planes.

After the removal of the sample from the cell

☺ fissure hardly discernable,
☺ small traction required to reopen it

➔ **Some self-healing effect**
(unfortunately not quantifiable)

Summary of the experimental results on Boom clay

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Before fracturing

Test	1	2	3	4	5
K_{conv} (m/s)	3.9 E-12	3.4 E-12	3.3 E-12	4.1 E-12	-
K_{div} (m/s)	3.7 E-12	3.2 E-12	3.3 E-12	3.3 E-12	2.3 E-12

After fracturing

K_{conv} (m/s)	-	2.9 E-12	-	4.1 E-12	-
K_{div} (m/s)	-	2.6 E-12	3.4 E-12	4.1 E-12	2.3 E-12

The permeability a few days after fracturing is hardly different from that measured on the virgin sample



Fractures undergo a very fast sealing under an hydrostatic state of stress

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Experimental difficulties

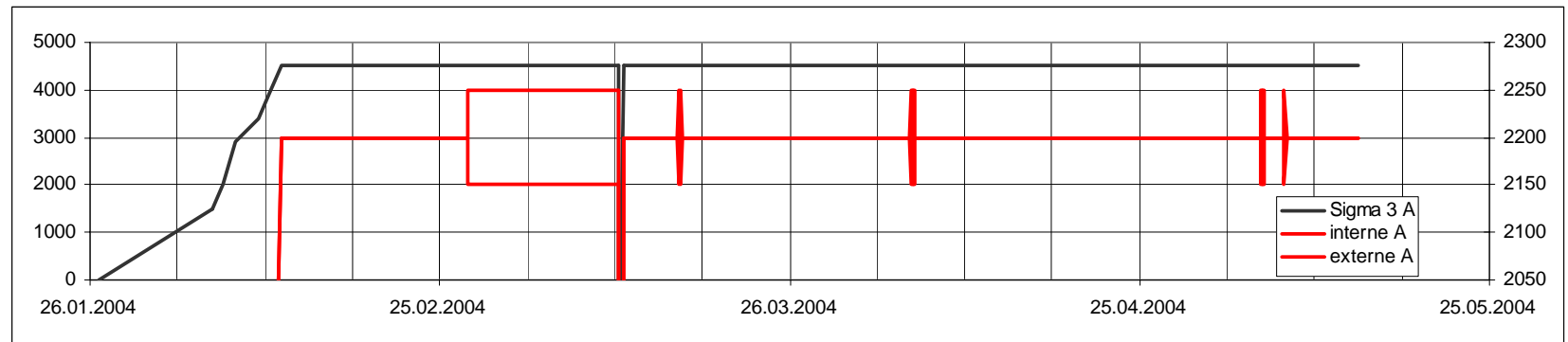
- Very low permeability of the virgin samples
 - Extremely long tests
 - Perfectly steady states are probably not reached (but tests are carried on for pragmatic reasons...)

- Difficult to keep a constant pressure gradient in the fissured samples
 - Clear connection between the inner and outer drains through the induced fissure

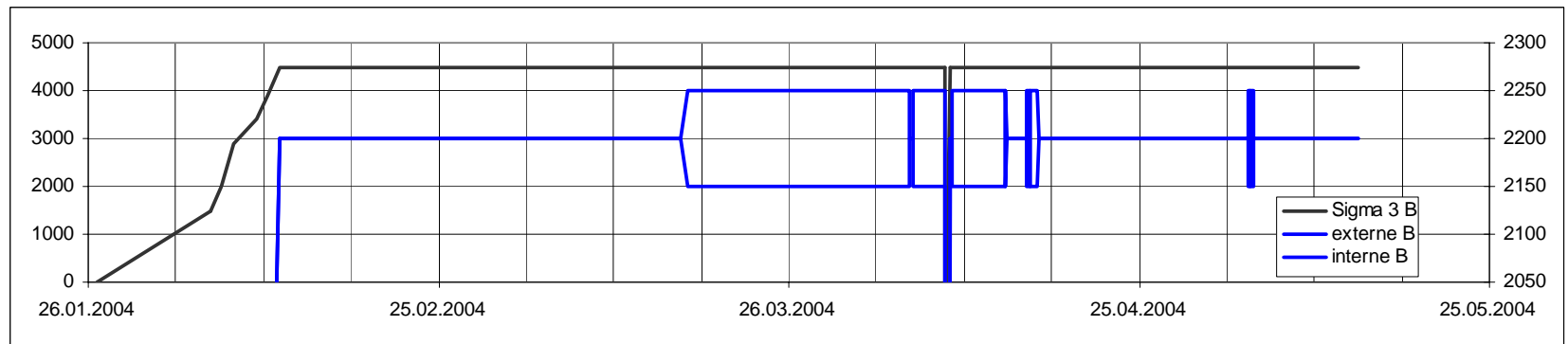
Parallel testing of three samples

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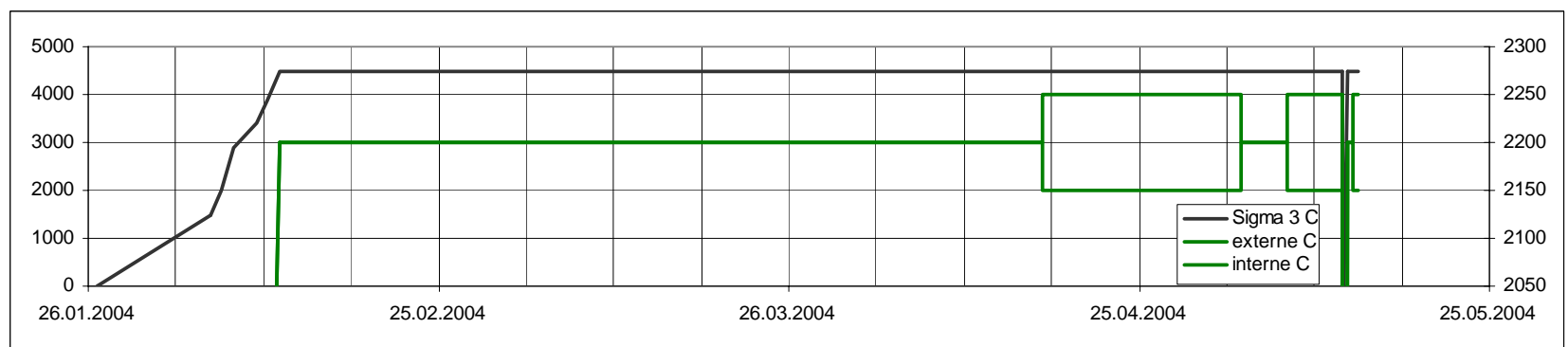
Sample 1



Sample 2

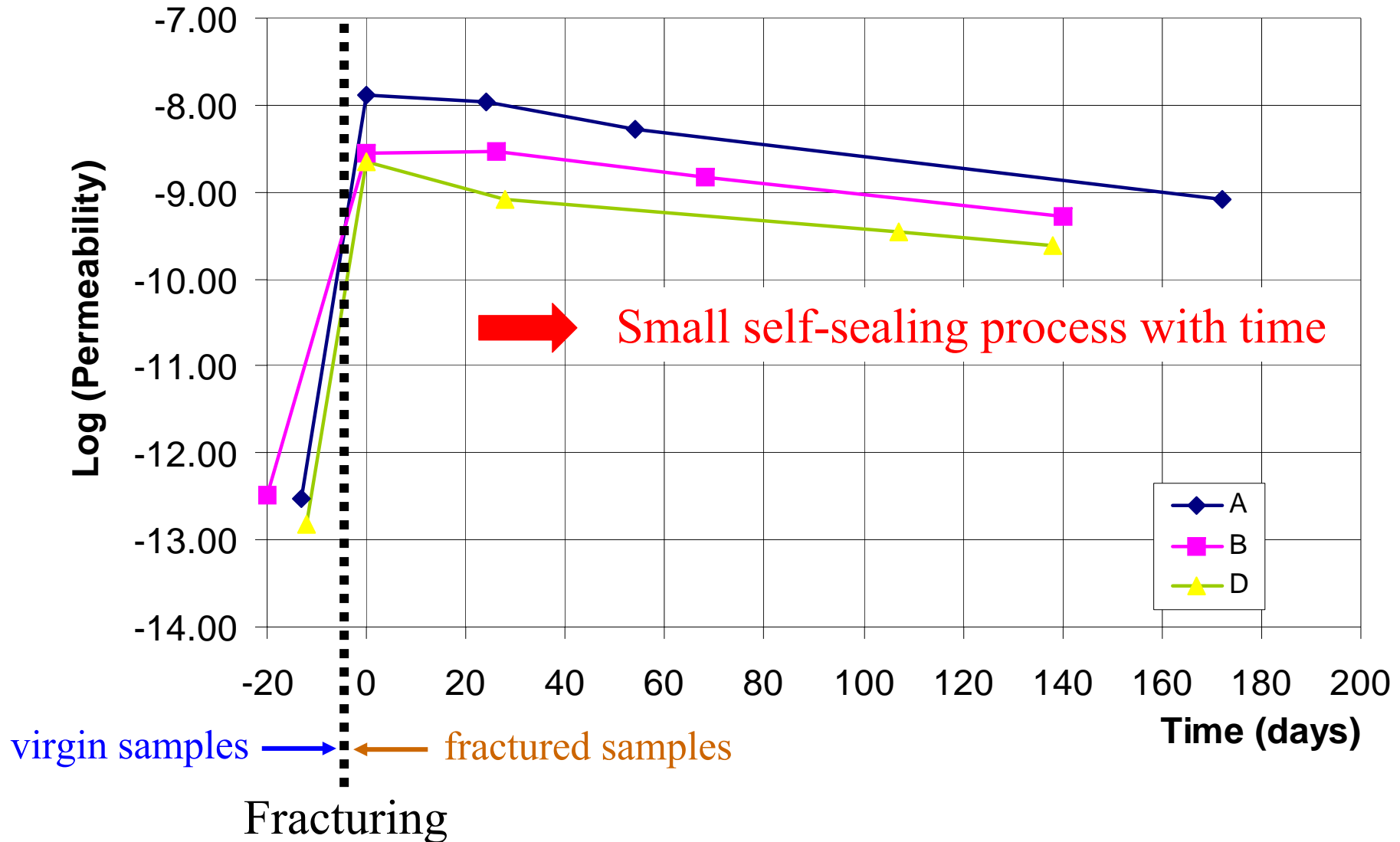


Sample 3



Change in permeability in the Opalinus Clay samples

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Current conclusions for Opalinus Clay

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- Permeability of the Opalinus Clay **virgin** samples :
 $3 \cdot 10^{-13}$ m/s
 - Permeability of the Opalinus Clay **fissured** samples :
4 to 5 orders of magnitude larger
 $1 \cdot 10^{-8}$ to $2 \cdot 10^{-9}$ m/s
 - **Small self-sealing with time**
in agreement with the in situ experiment n°1 carried out at Mont Terri, even if the process seems to be slower in laboratory tests
- ! Valid for localised cracks induced by traction**
Conclusions could be different for diffused cracks (e.g. shear bands)

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Boom Clay

- No change in permeability related to diffuse crack proliferation
- Very fast sealing of localised cracks in specimens kept under an hydrostatic state of stress
- Some self-healing effect noticed

Opalinus Clay

- Significant increase of permeability for localised cracks
- Small self-sealing process with time for localised cracks in specimens kept under an hydrostatic state of stress
- Self-healing effect not checked for the moment