

# Determination of the petrophysical characteristics of caprock samples for CO<sub>2</sub> storage in deep saline aquifers

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## General abstract :

Anthropogenic carbon dioxide emissions are one of the major contributors to the greenhouse effect. A promising solution to reduce these emissions is the CO<sub>2</sub> storage in deep saline aquifers. These are geologic formations containing unusable brine and they represent a very important storage volume. Due to the lack of interesting economic resources, these aquifers are badly known and, in order to guarantee the safety of the storage site, an important work of characterization has to be done. In particular, the transport parameters of caprocks, confining fluids in the aquifer, and their behaviour in contact with CO<sub>2</sub> are of primary importance.

## Objectives :

Assess the safety of a storage site by studying the migration of **supercritical** or **dissolved CO<sub>2</sub>** through **caprock** and its **evolution** with geochemical reactions

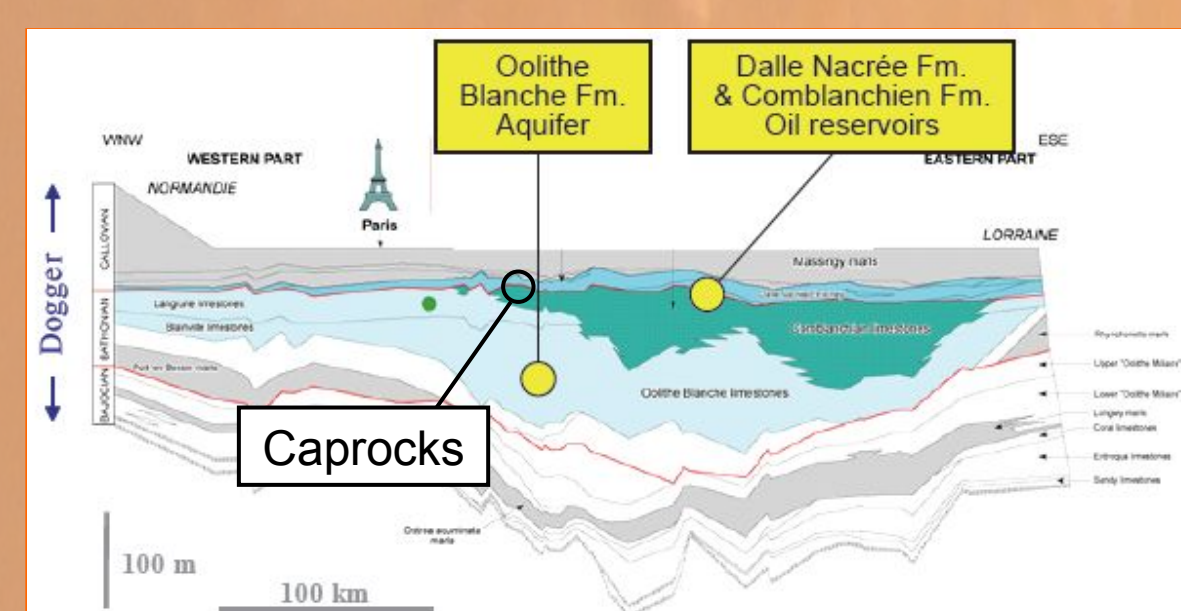
- Characterization of samples before and after their alteration in storage conditions
- First step : Analysis of samples before alteration with CO<sub>2</sub>

## Materials and Methods :

**Samples :** **Calcareous marls** from the Charmottes field in the Paris basin, **Comblanchien** and three types of "**dalle nacrée**" between 1910 and 2006 m deep :



Comblanchien 1910 m



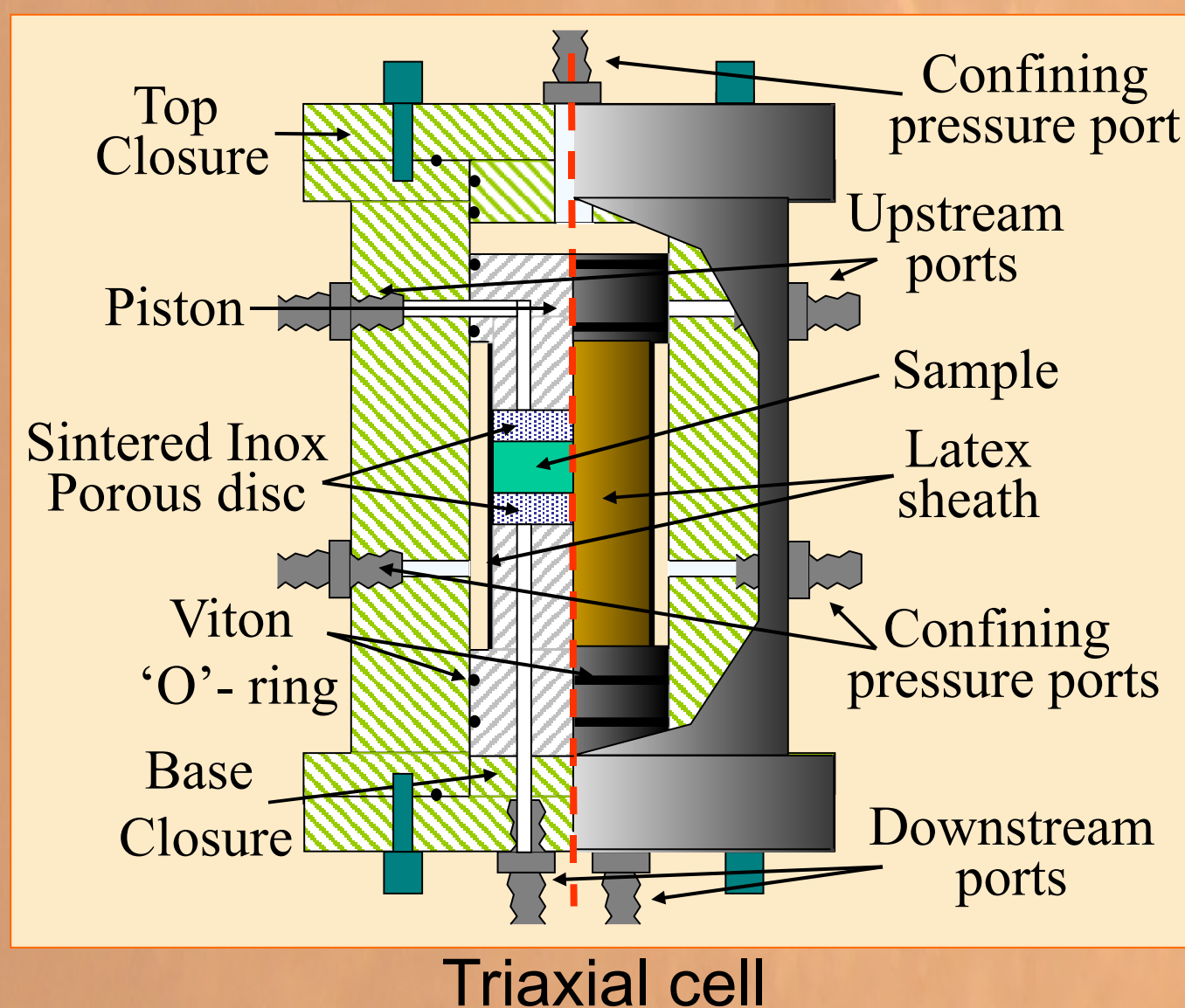
The Paris basin

Main minerals	Calcite	Ankerite	Pyrite	Gypsum	Quartz
Comblanchien 1910 m	95%	traces	-	-	traces
Dalle nacrée 1958 m	40%	30%	5%	traces	20%
Dalle nacrée 1961 m	40%	30%	5%	traces	20%
Dalle nacrée 2006 m	90%	traces	5%	5%	traces

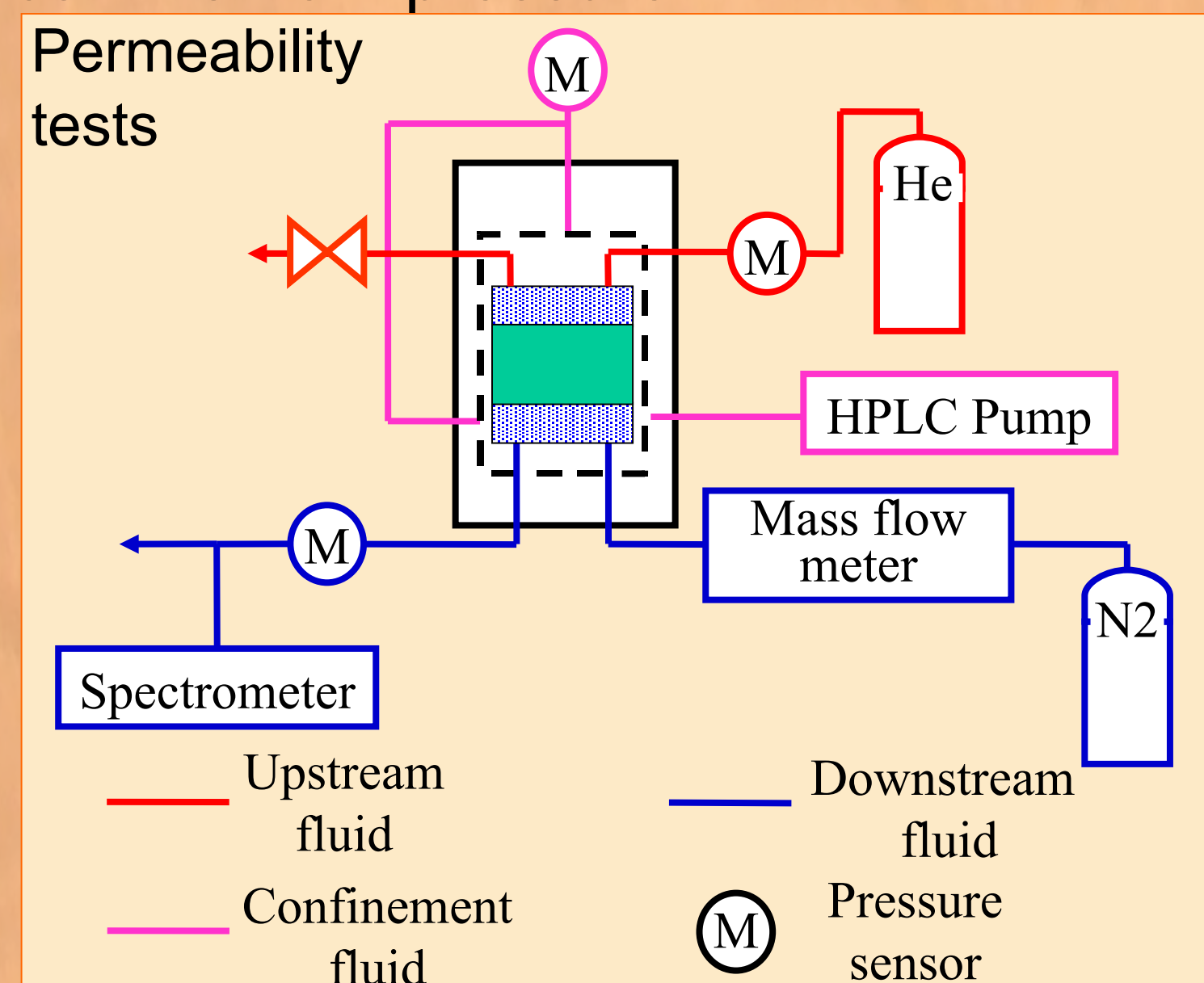
Samples composition

## Transport parameters experiments :

- Mercury porosimetry :** - measurements of rocks **porosity** using a non-wetting fluid
  - similar to the intrusion of a gas into a saturated sample
  - leads to the **capillary pressure vs. saturation curve**
  - allows a rough estimation of **entry pressure**
- Permeability measurements :** - using **helium** in a dry sample
  - triaxial cells allowing a **200 bar** confinement pressure



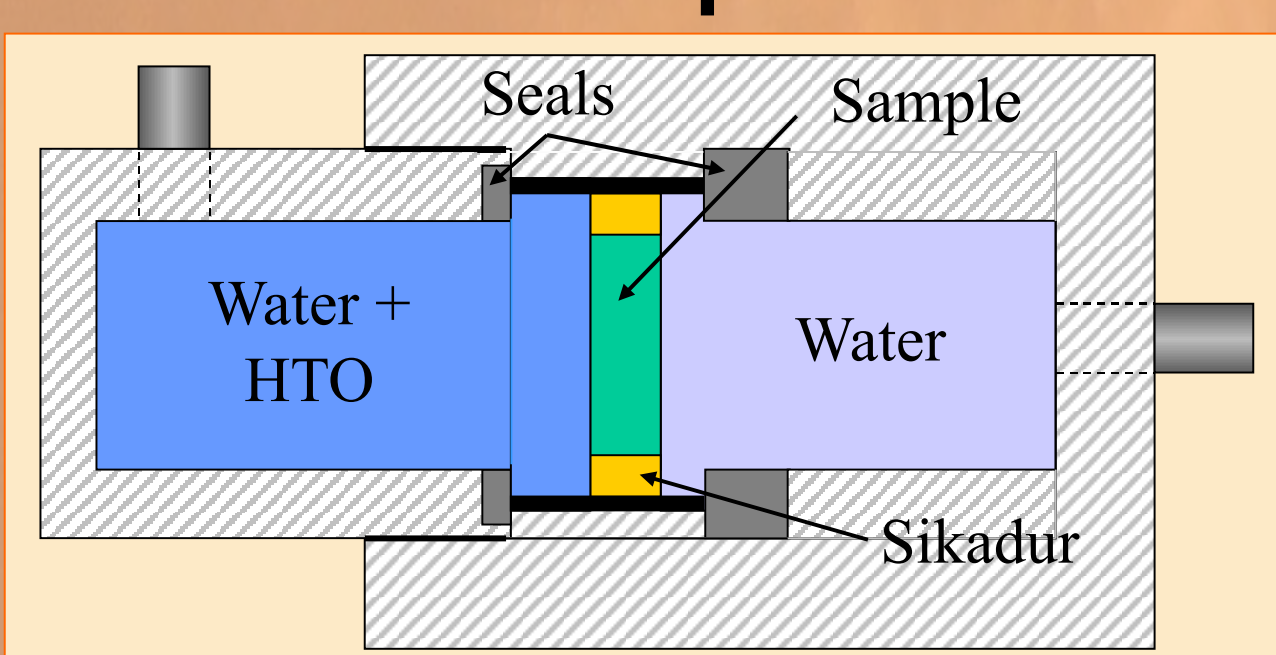
Triaxial cell



Permeability tests

## Diffusion experiments :

- determination of water **self-diffusion**
- method of **through-diffusion** with
- same behaviour as **dissolved carbon dioxide**



Diffusion cell

## Glossary :

**Supercritical state :** Physical state reached above the critical point under which a fluid has properties intermediate between a liquid and a gas  
**Permeation :** Migration of a fluid through a porous medium in response to a pressure gradient  
**Entry pressure :** Pressure above which a non-wetting fluid displaces a wetting fluid in a porous medium  
**Triaxial cell :** Equipment allowing the application of a stress on a sample in order to reproduce the lithostatic pressure in laboratory  
**Through-diffusion method :** Diffusion coefficient measurement by maintaining a concentration gradient on each side of a sample

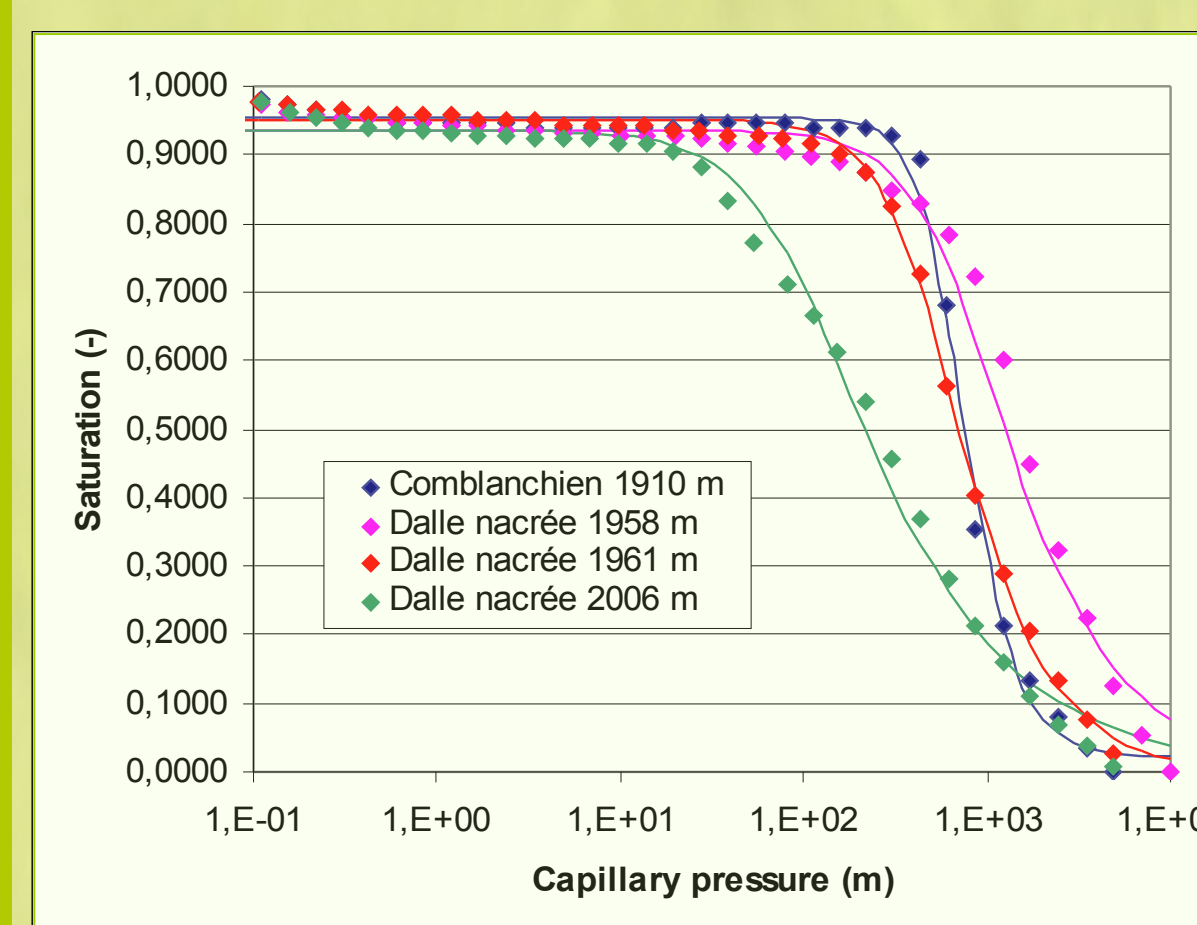
## Technical abstract :

When injected in the aquifer, carbon dioxide is either in supercritical state, due to the high temperature and pressure conditions in the reservoir, or dissolved in the aquifer brine. Several leakage mechanisms through the caprock may take place. The high pressure of the bubble might lead to the percolation of supercritical CO<sub>2</sub> and the permeation of dissolved carbon dioxide. Molecular diffusion may also cause the migration of dissolved CO<sub>2</sub>. These phenomena are controlled by different parameters such as entry capillary pressure, permeability or diffusion coefficient. They are measured in laboratory before and after the alteration of samples by CO<sub>2</sub> with experiments reproducing storage conditions. Their evolution give valuable data on the reactions taking place and on leakage possibilities.

## Results :

**Mercury porosimetry :** - Measurements of **porosity** :

	Comblanchien 1910 m	Dalle nacrée 1958 m	Dalle nacrée 1961 m	Dalle nacrée 2006 m
Porosity ε (%)	2,9	6,1	3,8	5,9

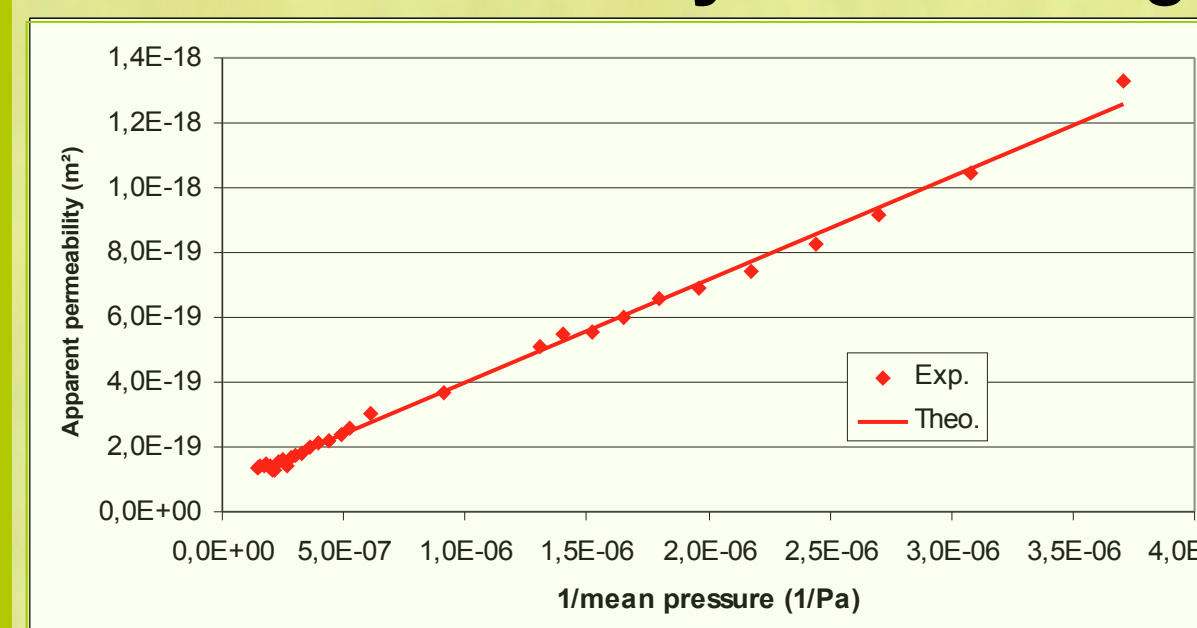


- Capillary pressure/saturation curve for ained with the **Laplace law** :  
 - Theoretical curve calculated with the **model** :

- Estimation of **entry pressure** for CO<sub>2</sub>/brine couple

	Comblanchien 1910 m	Dalle nacrée 1958 m	Dalle nacrée 1961 m	Dalle nacrée 2006 m
Entry pressure P <sub>e</sub> (Bar)	11,4	11,4	5,8	0,7

**Permeability tests :** - **apparent permeability** measured with **Darcy's Law** for gas :



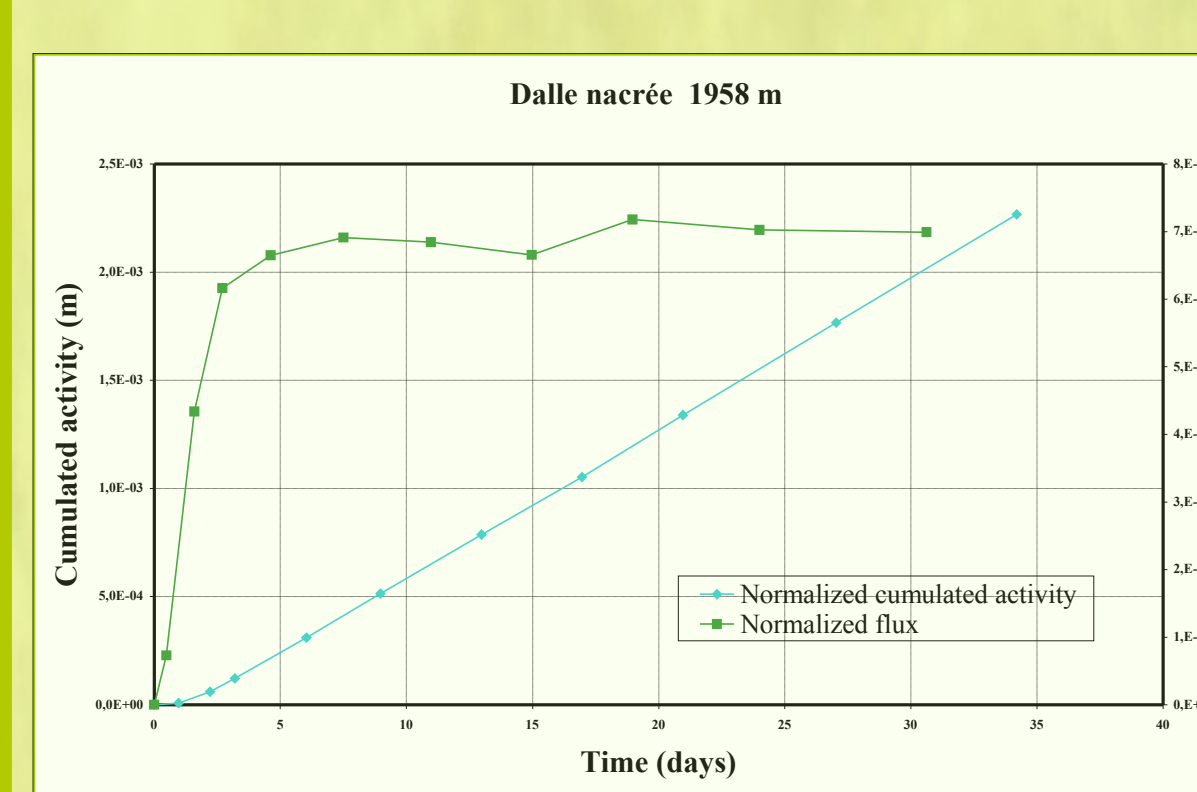
- **intrinsic permeability** calculated with the **Kozeny-Carman's method** :

- When (possible) **several samples** of the **same studied** :

	Comblanchien 1910 m	Dalle nacrée 1958 m	Dalle nacrée 1961 m	Dalle nacrée 2006 m
Intrinsic Permeability k <sub>o</sub> (m <sup>2</sup> )	7,9.10 <sup>-20</sup>	2,0.10 <sup>-19</sup>	4,7.10 <sup>-19</sup>	9,2.10 <sup>-19</sup>
Klinkenberg Parameter b (Pa)	4,0.10 <sup>6</sup>	1,9.10 <sup>6</sup>	1,2.10 <sup>6</sup>	1,2.10 <sup>6</sup>

**Diffusion experiments :** Asymptote solution of Fick's second law for long term :

$$A(t) = SC_0 e^{-\epsilon/6} (D_e t e^2 - \epsilon/6)$$



	Comblanchien 1910 m	Dalle nacrée 1958 m	Dalle nacrée 1961 m	Dalle nacrée 2006 m
Effective Diffusion Coefficient D <sub>e</sub> (m <sup>2</sup> /s)	1,1.10 <sup>-11</sup>	4,7.10 <sup>-12</sup>	8,1.10 <sup>-12</sup>	1,1.10 <sup>-11</sup>
D <sub>e</sub> (m <sup>2</sup> /s)	5,7.10 <sup>-12</sup>	1,1.10 <sup>-11</sup>	2,7.10 <sup>-11</sup>	

## Conclusions :

- Determination of some caprocks **transport parameters** before their **alteration** with CO<sub>2</sub>
- Measurements showed **low** porosity, permeability and diffusion coefficient
- Overall high confining properties**
- Future work will consist in **rock ageing** under **storage conditions** and observation of the **evolution** of **previously studied parameters**
- These caprocks, due to **high proportion of carbonates**, should be **greatly reactive to CO<sub>2</sub>**

## References :

- A. Hildenbrand and B.M. Krooss, "CO<sub>2</sub> migration processes in argillaceous rocks: pressure-driven volume flow and diffusion", Journal of Geochemical Exploration, Volumes 78-79, Proceedings of Geofluids IV, Pages 169-172, May 2003
- M.Th. Van Genuchten, "A closed-form equation for predicting the hydraulic conductivity of unsaturated soils", Soil Science Society of America Journal, Volume 44, Pages 892-898, 1980
- L.J. Klinkenberg, "The permeability of porous media to liquids and gases", Drilling and Production Practice, American Petroleum Institute, Pages 200-213, 1941
- P. Egermann, J.-M. Lombard and P. Bretonnier, "A fast and accurate method to measure threshold capillary pressures in caprocks under representative conditions", Paper SCA A46, International Symposium of the Society of Core Analysis, Trondheim, September 2006