ULTimate CO_2

UNDERSTANDING THE LONG-TERM FATE OF GEOLOGICALLY STORED CO_2

Why do long-term processes matter?

An introduction based on the ULTIMATE-CO2 project

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BRGM

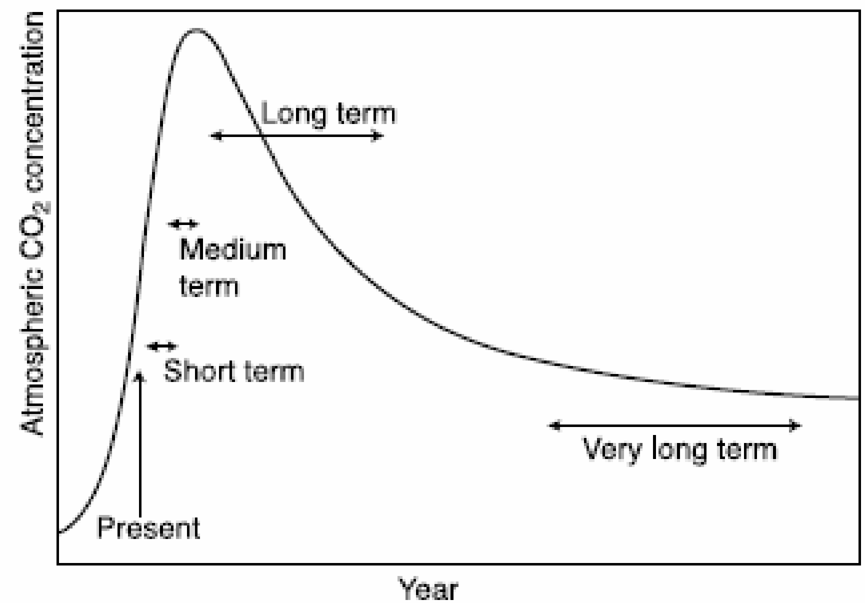
What is long term?

- Several milestones in the life of a CCS project can be defined as long term issues:
  - **Regulation aspects**
    - end of injection
    - end of monitoring
    - Site closure
  - **Physical aspects**
    - disappearance of free CO2
    - steady-state regime or stability (hydrological, chemical, mechanical, …) of the geological systems
  - 100, 1000, 10 000 years?

What is long term?

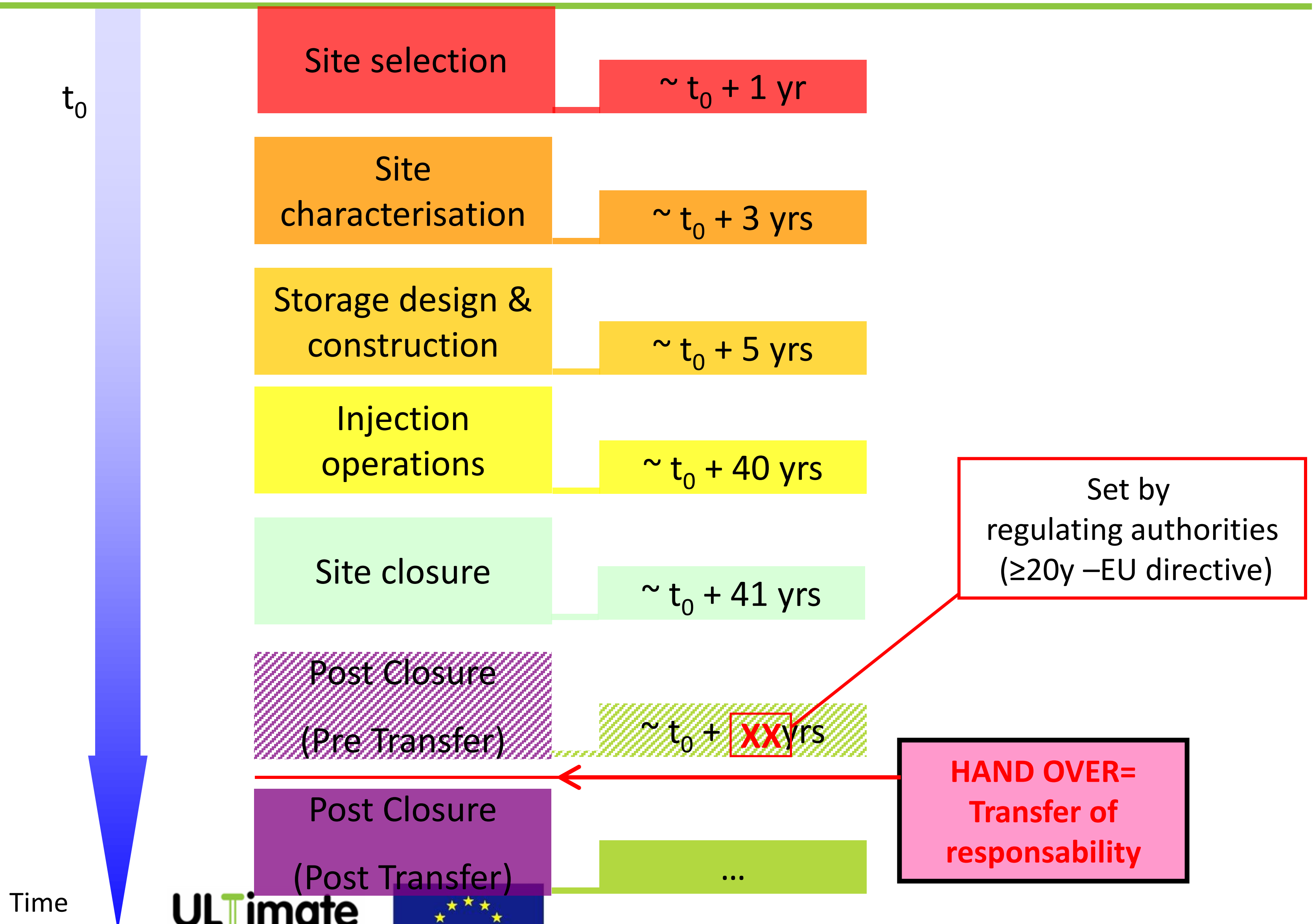
- Duration

CO$_2$ atmospheric content evolution (from IPCC, 2005)



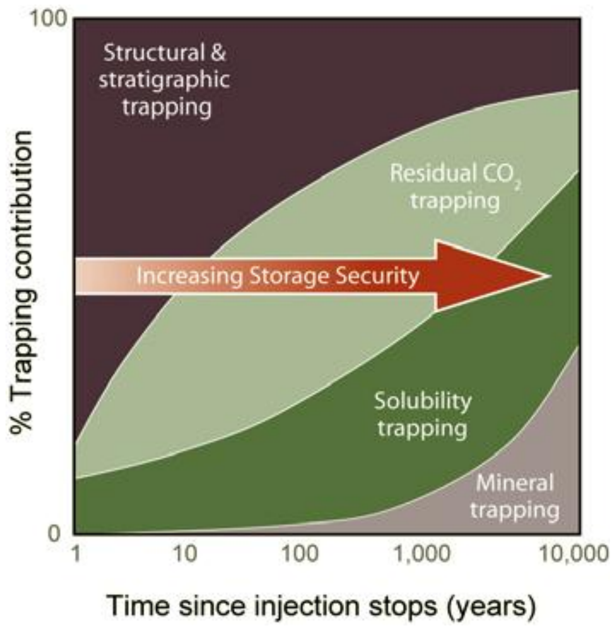
- **Global impact:** performance requirement to mitigate greenhouse gases emissions
  - At least 1000 years containment
  - Mean leakage rate < 0.1 % / year

What is long term?



‘Expected’ behaviour

SRDM Trapping
Structural
Residual
Dissolution
Mineral



from IPCC, 2005

Long term issues

SRDM Trapping
Structural
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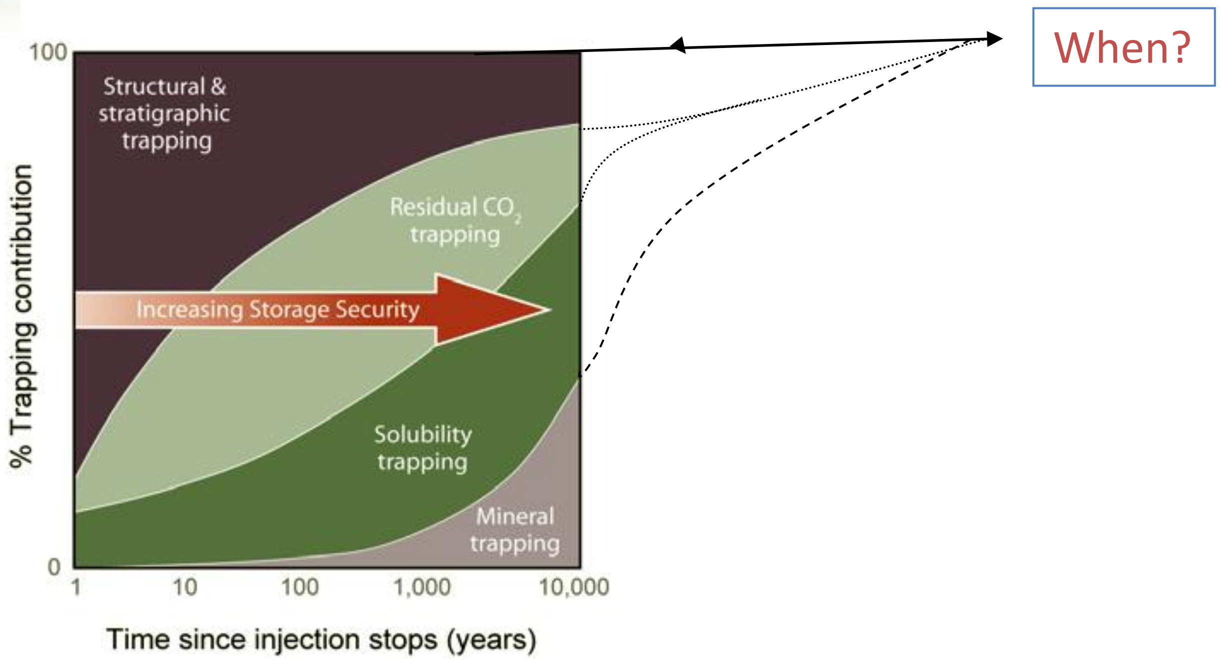
Mineral



from IPCC, 2005

Long term issues

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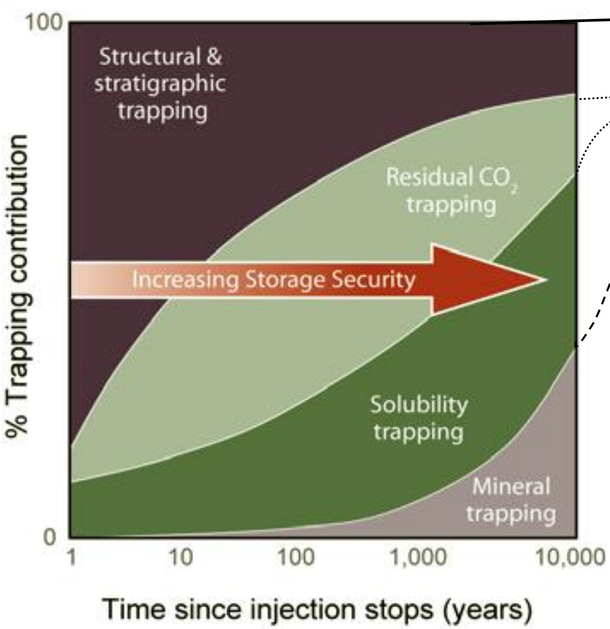

When?

What if leakage (fault, wells)?

from IPCC, 2005

Long term issues

SRDM Trapping
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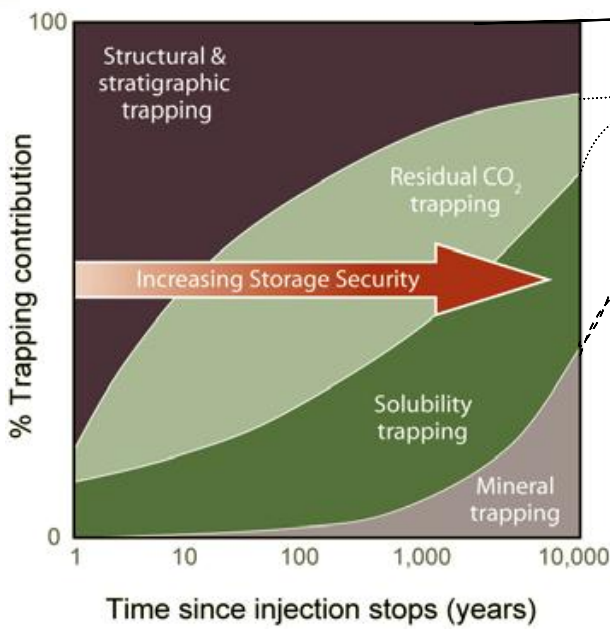

When?

What if leakage (fault, wells)?

Stabilization?

from IPCC, 2005

Long term issues

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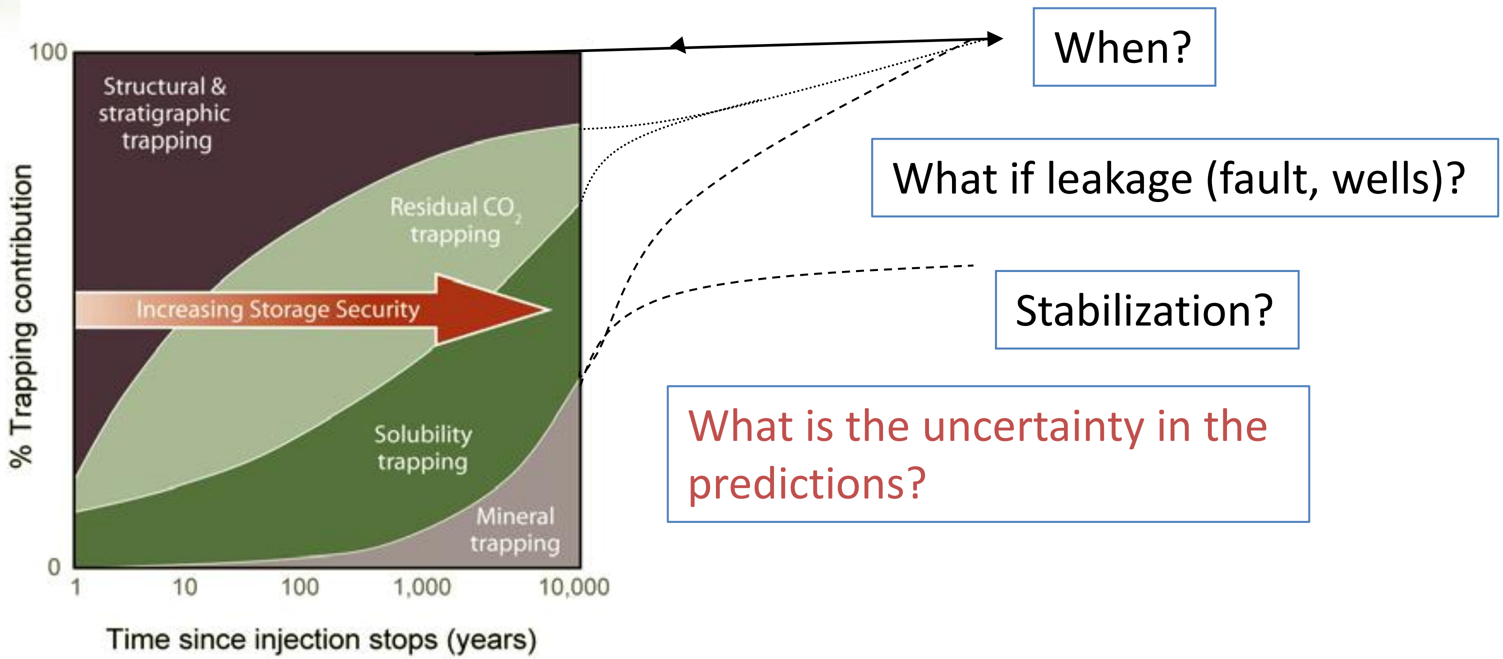
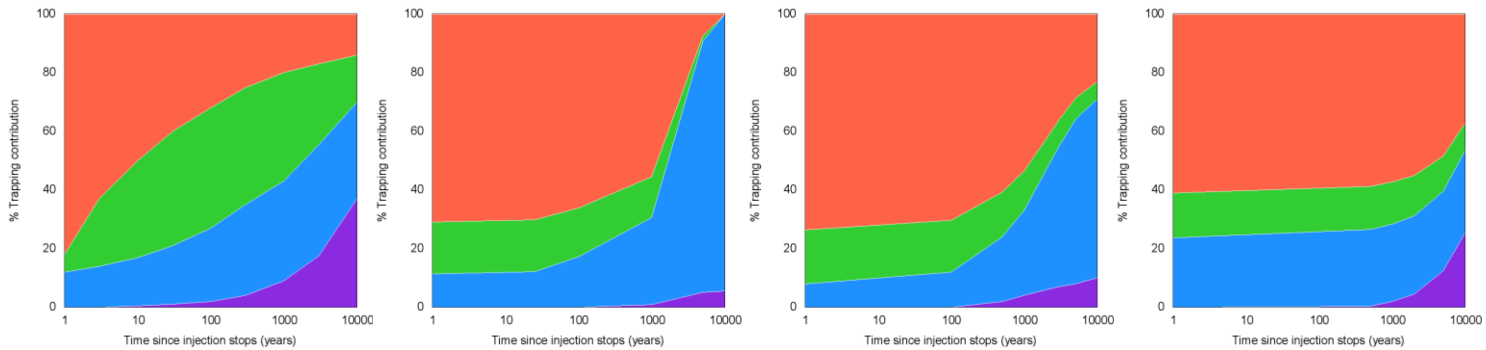


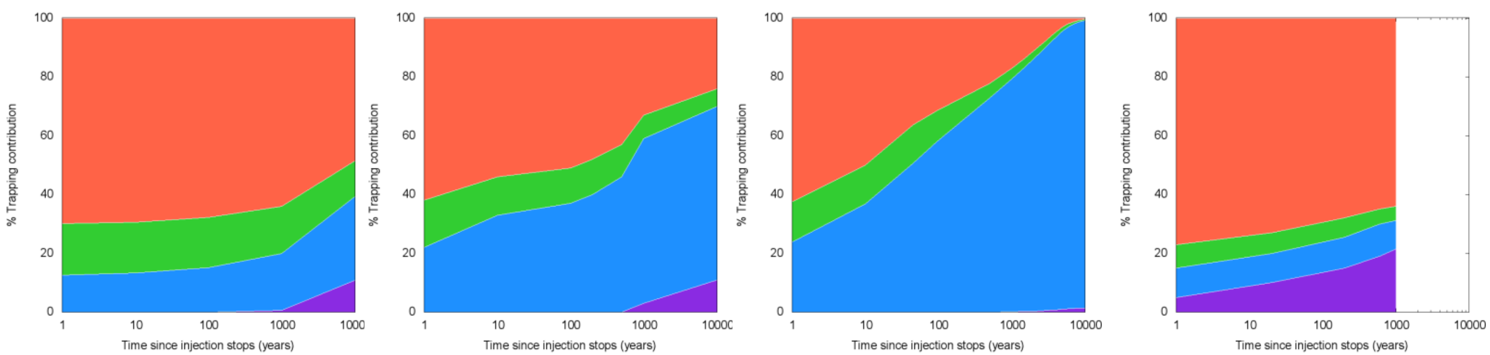
from IPCC, 2005

Trapping diagram diversity



Conceptual diagram from Benson & Cook (2005) and 3 trapping diagrams for different published studies with different site relations and different input for start parameters. (Benson, Audigane, Ranganathan, Xu)

Red: Structural/stratigraphic trapping – potentially unsafe; Green: CO_2 residually trapped in pore space – rather safe; Blue: CO_2 dissolved in brine – fairly safe; Purple: CO_2 trapped as mineral phase – stable.



Zhang-20-2009, Sato-2010, Kempka-2013(Ketzin), Estublier-2013(Sleipner-100)

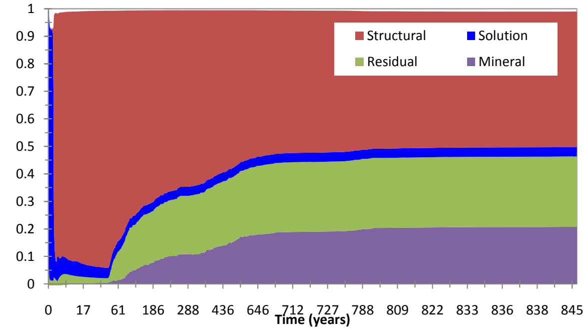
P. Frykman (GEUS)

Tools for assessing LT

- **Numerical modeling** is identifed as the main tool to provide a 'vision' of predictions for long time scales
  - efficient for estimating capturing some specific processes

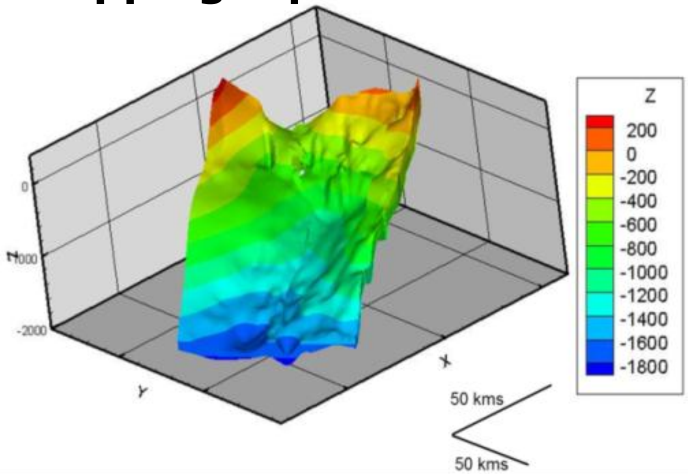
BUT

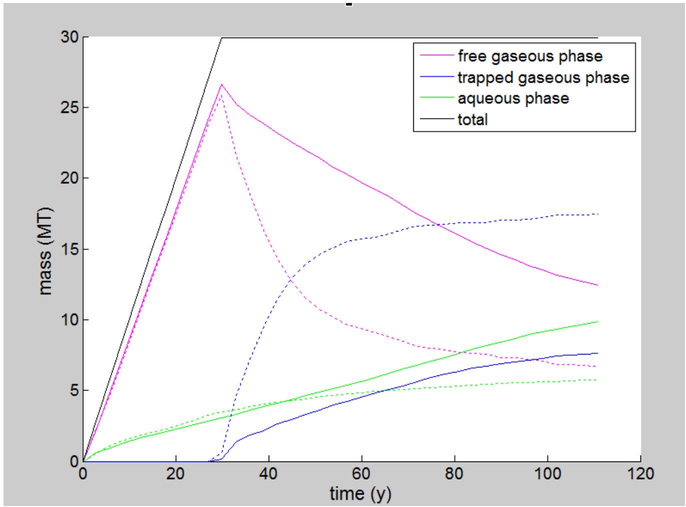
  - requires data for calibration which are not always available
  - tends to simplify the reality
  - Limitations for coupling processes



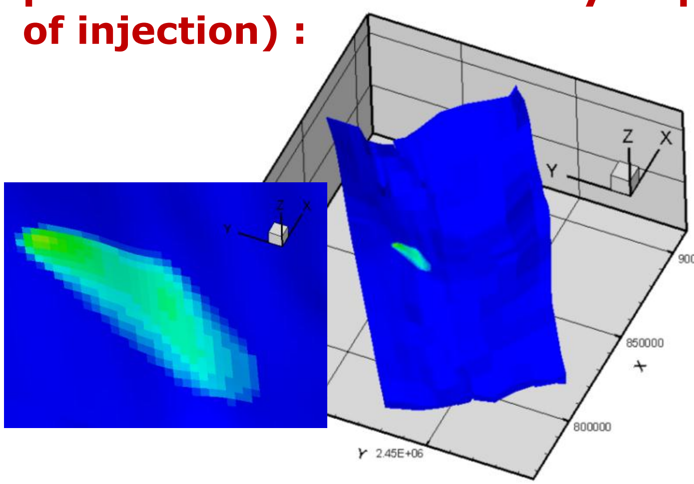
An example of Model uncertainty

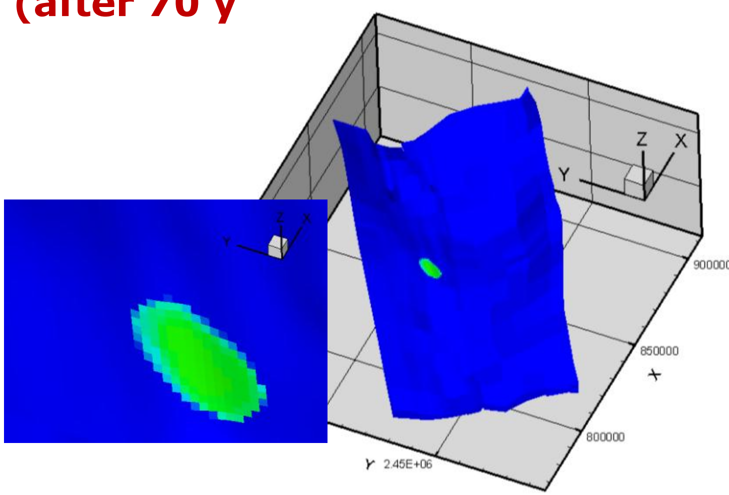
Slopping aquifer in Paris basin





Impact of two relative permeability laws on the prediction of CO2 residually trapped (after 70 y of injection) :





ULTimate CO2

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Impact of Model uncertainty

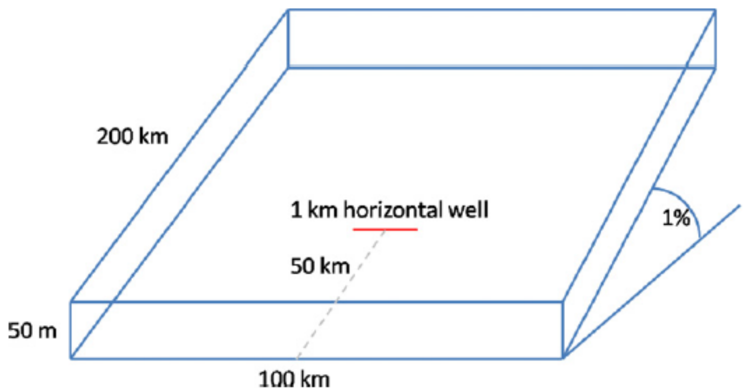

Fig. 1. Domain for benchmark problem.

20 y of injection and long term evolution (see Dahle et al., 2008)

Sources of model uncertainty:

- Specific physical processes modeled;
- Numerical modeling;
- Upscaling approach;
- Interpretation of the problem and metrics

Table 1
Participants of the benchmark study. Colors reflect the colors used to identify the different participants in the subsequent figures.

Participant	Simulator	Approach	Max. # cells	Indicator
U. Stuttgart	DuMu^X	3D, IMPEC	45,760	Stu-X-Y
SINTEF ICT	Inhouse	3D, IMPES+O.S.	1,200,000	Sintef
U. North Carolina	Inhouse	Vert. upsc. + IMPES	40,000	UNC-X
GFZ-Potsdam	E-100	3D, FIM	1,000,000	Pot-X
Heriot-Watt U.	E-100, GEM	3D, AIM	190,000	HWU
Stanford U.	GPRS	3D, FIM	300,000	Stanford

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Impact of Model uncertainty

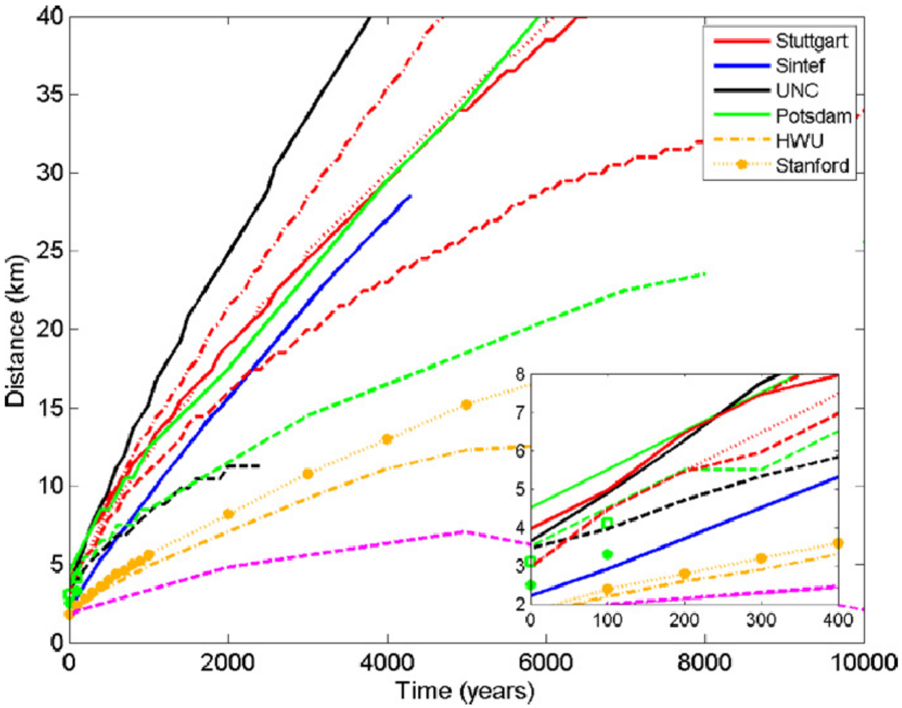

Fig. 3. Updip extent of the center of mass of mobile CO_2 measured from the injection point, as a function of time since injection stop. Colors represent different participating groups, while different lines styles represent different runs within the same group. Solid lines refer to common base case. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

- **All types of uncertainty have an influence**
- **Approaches of each team = valid, but lead to divergent solutions**

Note:

- Large impacts emphasized by the simplicity of the problem
- In more realistic problem, uncertainties on properties might dominate

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Tools for assessing LT

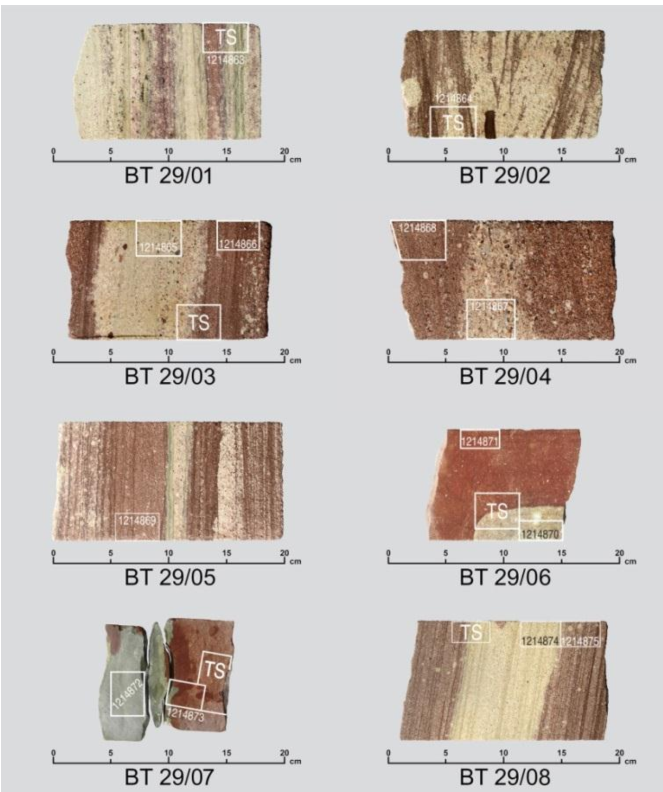
- **Natural analogues** are often used as a representation of formations in contact with CO2 after millions of years
  - They offer the possibility to observe CO2 interactions with rock after long time scales

BUT

  - The history of the system (burial, uplift, circulation of water, etc.) is difficult to invert: what and when the CO2 has played a role compared to the role of diagenesis processes?
  - The injection scenario for natural analogues differ drastically from CCS, as often the source of CO2 is slowly intruding the system for millions of years ➔ extrapolation?

Natural Analogues Germany

- **Effects of ascending CO_2** (and trace gases) **in the near-field of a fault system**



- Study of **geochemical bulk composition, mineralogy and microstructure** of 32 red and green colored sandstone to siltstone
- Drill site at Bad Teinach (B29/91)
- Comparison of bleached and unbleached zones
  - What types of bleaching occur?
  - What elements are accumulated or depleted in bleached and unbleached rock samples respectively?
  - How can this be related to an exposure to CO_2-rich fluids?

Tools for assessing LT

- **Laboratory experiments** are also a mean to evaluate changes induced by either chemical or mechanical degradation of geological objects (caprock, reservoir rock, faults) or wells

- **Pre-degradation** of samples to mimic the ‘aging’ can allow for evaluation of long term behavior

- **But** experiments are usually conducted over short period of times (weeks to years) which limit the interpretation to long time scales➔ **extrapolation?**

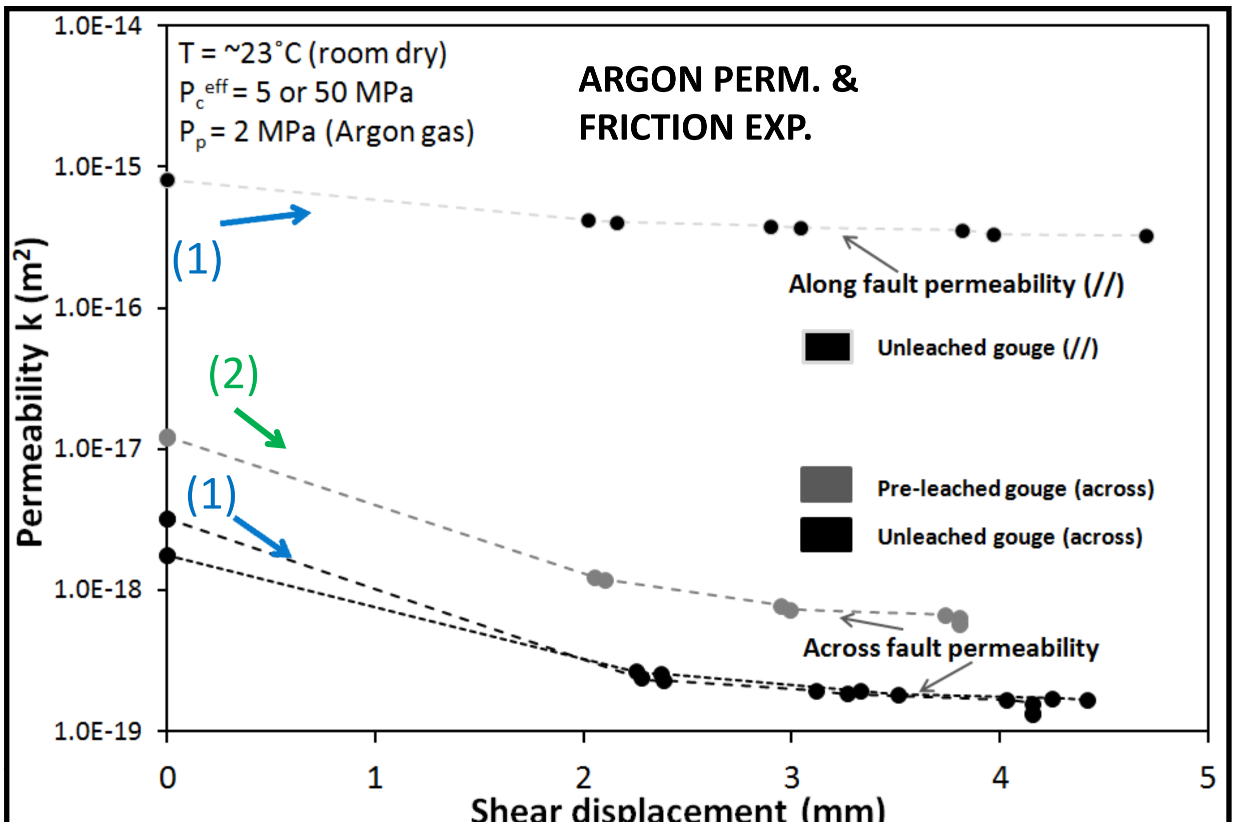
Fault gouge's flow behaviour

Results: Permeability during frictional shear

Universiteit Utrecht

- **Opalinus Clay fault gouge**
  - (1) Unleached gouge
  - (2) Pre-leached gouge

Permeability decreases with shear displacement



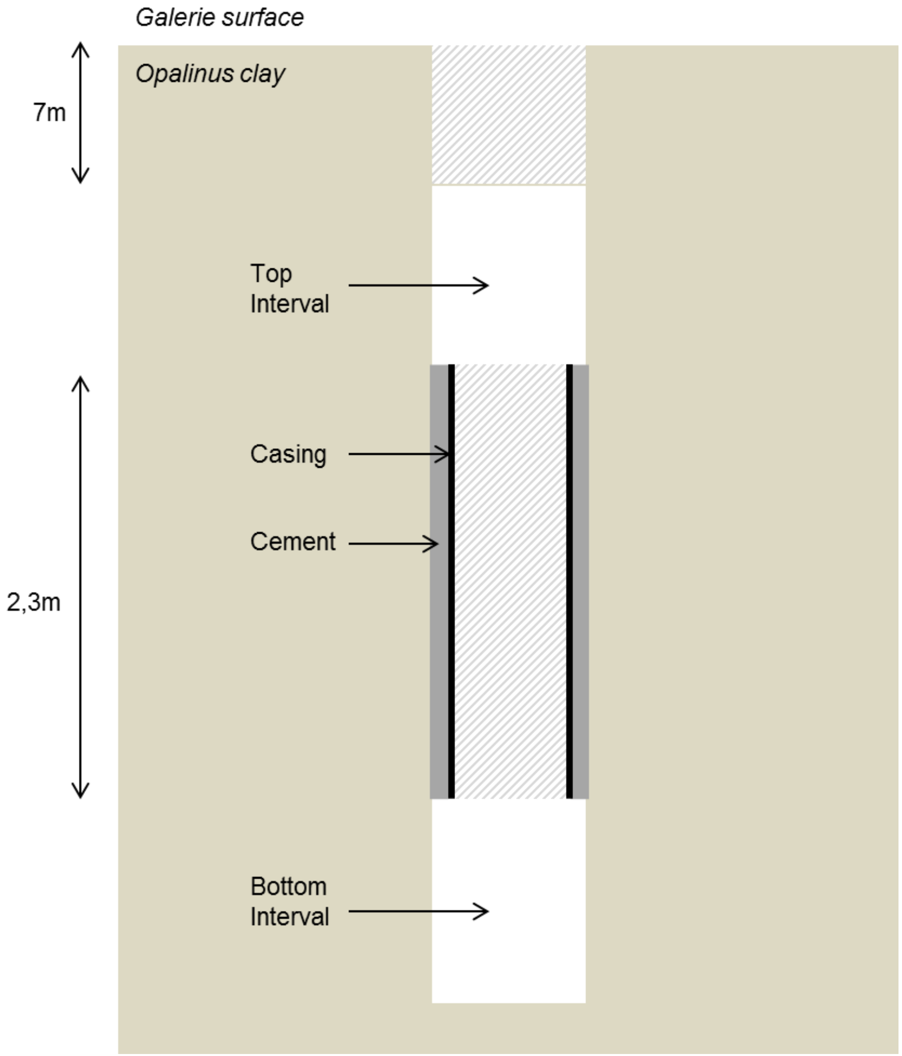
Wellbore sealing integrity: Mont-Terri experiment

- **Intermediate scale between:**
  - **Laboratory** studies (cement hydraulic properties, cement carbonation rates analysis, casing corrosion,…)
  - **Field** studies (vertical interference tests, study on CO_2 producer samples)

- Objective: **Evaluate the integral behavior of a well over time, before and after influence of CO_2**

Manceau, Tremosa, Audigane (BRGM)

Wellbore sealing integrity: Mont-Terri experiment



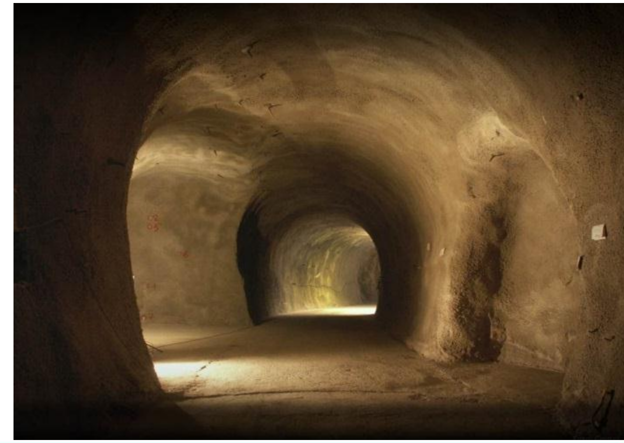
Not to scale

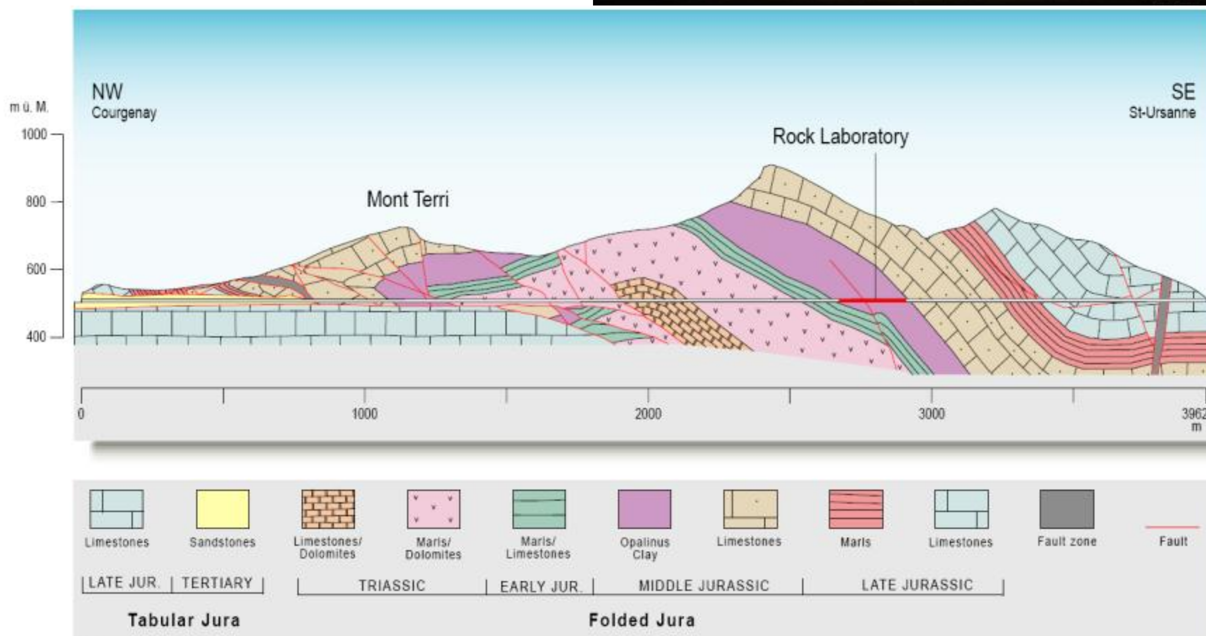
- Main Objectives
  - Build well elements
  - Measure of the flow outside the casing -> *sealing changes*
  - Sample fluid across time -> *fluid changes*
  - Take samples of the different elements (overcoring) -> *mineralog. changes*

Manceau, Tremosa, Audigane (BRGM)

Wellbore sealing integrity: Mont-Terri experiment

Use of Underground Rock laboratory, Mont Terri in Switzerland
Opalinus clay considered representative of a caprock





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Wellbore sealing integrity: Mont-Terri experiment

Different steps:

- Design – May-July 2012
- Production – July-Oct. 2012
- Installation – Oct.-Nov. 2012
- Saturation of the system with porewater – Nov.-Feb. 2013
- Characterization initial state – March 2013
- Temperature cycles and characterization – April-December 2013
- **Injection dissolved CO_2 – February 2014**
- Characterization – 2014
- Overcoring – End 2014 (delayed according to the initial schedule)

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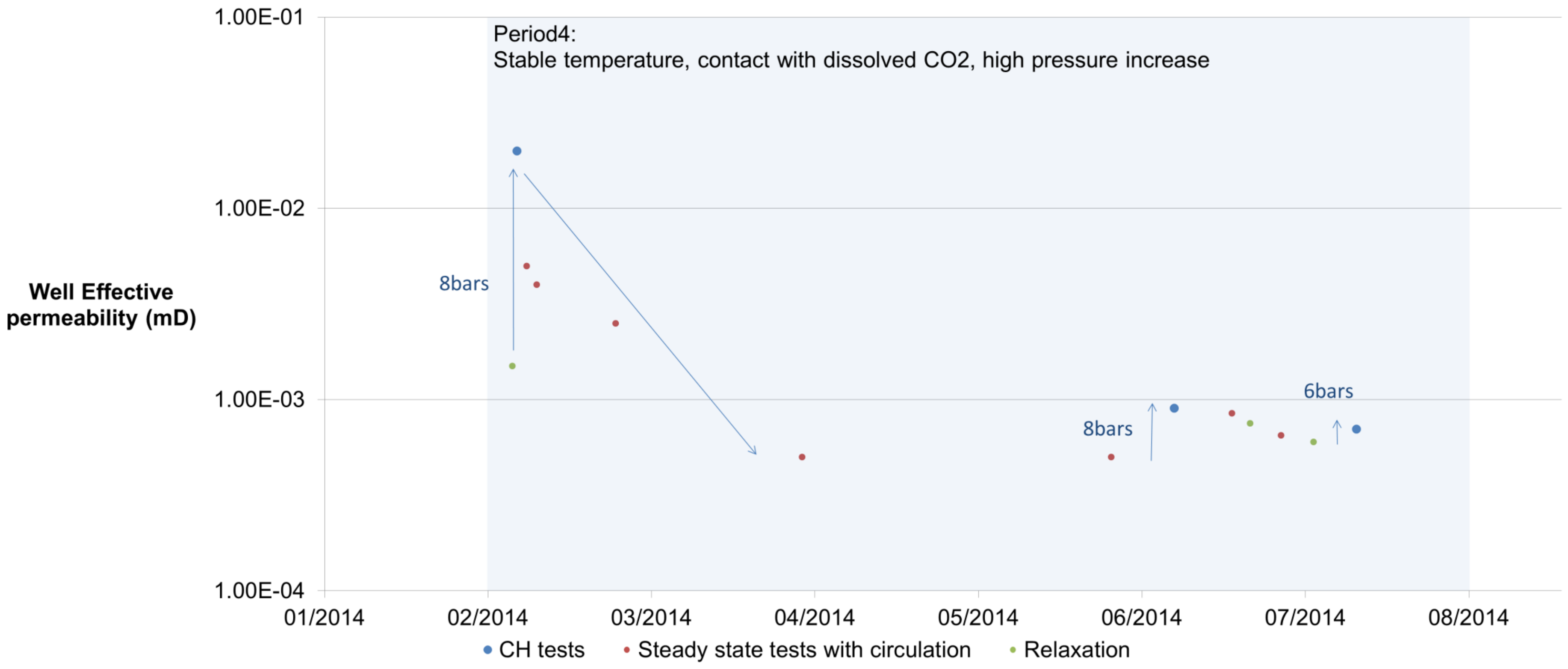
Mont-Terri experiment: Role of CO2(aq) ?



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Public perception

- **Public perception on long term issue is usually negative…**

- Can we ensure that the **reactive** CO2 will not modify the **chemistry** of underground formations?
- Can we ensure no **cracks** or **seismicity**?
- **Where** will the CO2 go?
- Can we ensure no **leakage**?
- Can we really **predict** the behavior of CO2 storage in underground over decades? centuries? Millenium?

Key points

- Need to **improve scientific knowledge** on LT effects induced with CO2 storage
- Need to **increase confidence** (or reduce uncertainty) that CO2 can be completely and permanently contained
  - Help gain social acceptance of CCS
  - Help answer questions, backed up by scientific facts on the safety and efficiency of LT CO2 geological storage
- Need to **improve robustness and clarity of CO2 storage regulations**
  - provide criteria to stakeholders (regulators, operators) for establishing the conditions under which CO2 can be permanently contained

Tools

- **Numerical** simulations
- Study of **natural analogues**
- **Lab-** experiments
- Innovative **meso-scale** (between lab- and field-scale) experiments

Open questions

- How to **reduce (or constrain) the uncertainty** in the long term predictions?
- Role of **monitoring**? **Data availability** on long term?
- What is the **representiveness** (rate of degradation, scale) of lab, field, meso-scale experiments? How to **extrapolate** these observations?