The long-term fate of CO2 in the subsurface –
FP7 UltimateCO2 project

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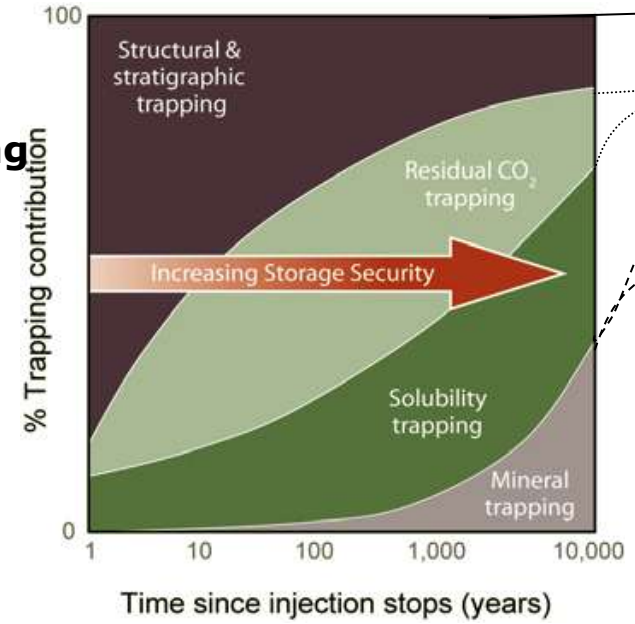
What is long term?

- Several milestones in the life of a CCS project can be defined as long term issues:
  - end of injection? end of monitoring? Site closure? (Regulation aspects)
  - disappearance of free CO2? stability of the systems? (Physical aspects)

SRDM Trapping
Structural
Residual
Dissolution
Mineral



When?

What if leakage (fault, wells)?

Stabilization?

What is the uncertainty in the predictions?

- ULTimateCO2 aimed at addressing some of these aspects in a non exhaustive manner

Objectives (1/2)

- Develop guidelines **for operators and regulators to enable a robust demonstration of the assessment of long-term storage site performance:**
  - by drawing on the lessons learned within the project,
  - by relevant research internationally
  - through dialogue with targeted stakeholders

- Help to raise confidence with key stakeholders:
  - Dissemination of scientific knowledge on the long-term efficiency and safety widely to a broad audience, (Operators of CO2 storage demonstration sites the investors, regulators, policy-makers, the research community and representatives of the general public NGOs and politicians)
  - To improve public perception

Objectives (2/2)

- Significantly advance our knowledge of specific processes that may affect the understanding of the long-term fate of geologically stored CO2
- Yield validated tools for predicting long-term storage site performance
- Laboratory, field and modelling studies of:
  - trapping mechanisms in the reservoir (structural, dissolution, residual and mineral [SDRM])
  - fluid-rock interactions and effects on mechanical integrity of the caprock
  - leakage associated with mechanical and chemical damage in the well vicinity
- Integration of the results
  - into assessing the overall long-term behaviour of storage sites at basin scale in terms of efficiency and security

Methodology

- "Realistic contexts and scales" through the collaboration with two demonstration sites
  - Off shore North Sea UK, Don Valley project, CO2 injection combined with EOR
  - On Shore outcropping former ULCOS, NER300 candidate in Lorraine in France
- Field data implementation:
  - realistic true-scale geological contexts to provide credible storage scenarios for assessing the long-term fate of CO2,
  - provision of data and samples of reservoir and caprocks for various experimental programmes and development of credible modelling test cases
- Natural & industrial analogue evidence:
  - A literature review, field survey and laboratory investigations was carried out to compile various analogue data.
  - Predictions more robust by addressing the **uncertainty** associated with numerical modelling at all stages

ULTimateCO2 consortium

Consortium

R&D Institute

NATURAL ENVIRONMENT RESEARCH COUNCIL

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IFP Energies nouvelles

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Ministère de l'Écologie, du Développement durable et de l'Énergie

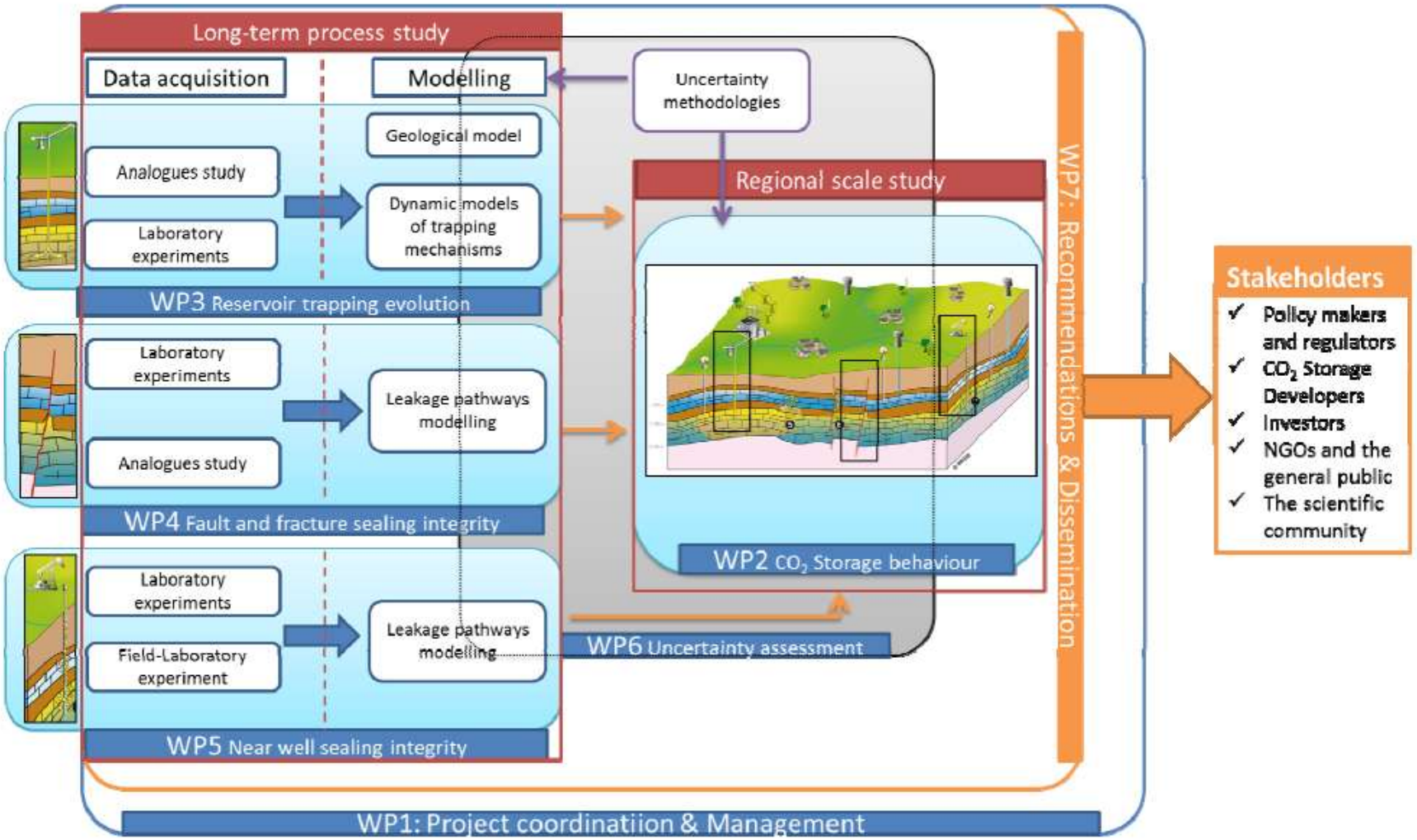
Department of Energy & Climate Change

Private Consultant

T. Torp (retired STATOIL)

ULTimate CO2

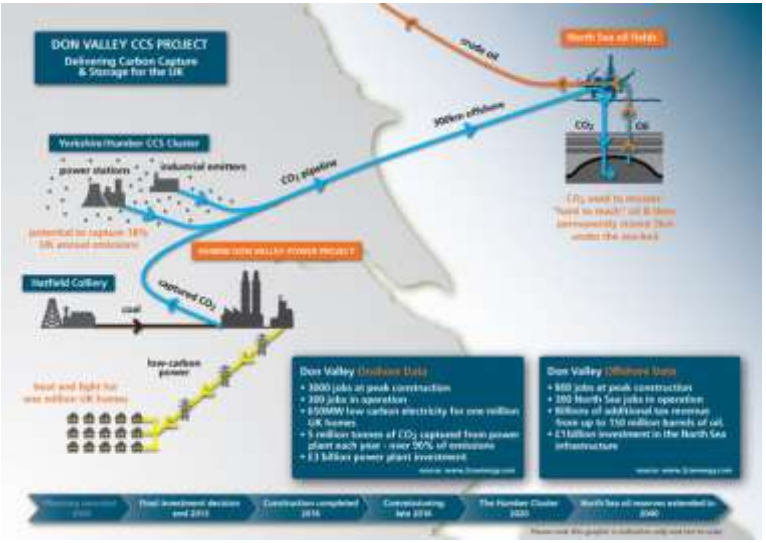
ULTimateCO2 Work Program



Long Term Reservoir trapping evolution

- Elaboration of static geological models based on two demonstration sites:

Off shore North Sea UK, Don Valley project, CO2 Injection combined with EOR

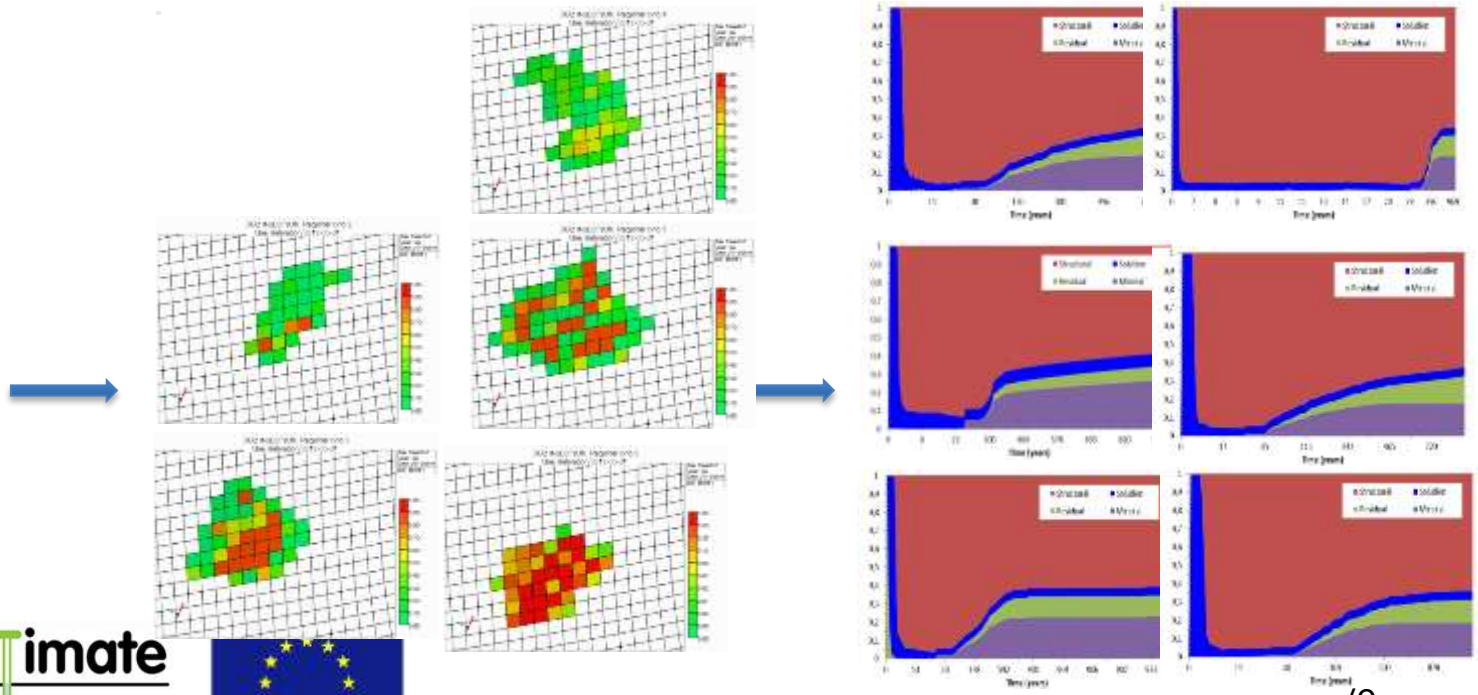


On Shore outcropping former ULCOS, NER300 candidate in Lorraine in France

- **BUT**: difficulties encountered with Don Valley operators to collaborate, ULCOS project closed

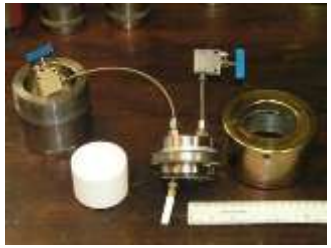
Long term reservoir trapping evolution

- Classical reservoir multiphase flow simulation with a focus on dissolution, residual trapping + coupling with chemical change of the reservoir fluid composition
- **Gas phase evolution**
- **Impact of heterogeneity on convection flow**
- **Balance versus time of the SDRM trapping magnitude**
- **Long term residual trapping in slopping aquifer**

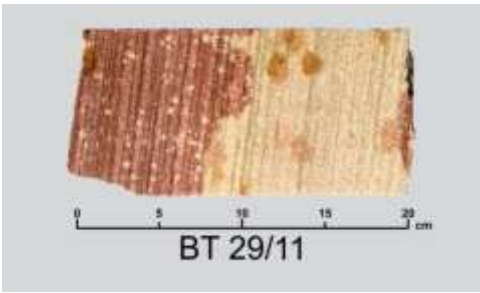


Long term reservoir trapping evolution

- Evaluation of long term chemical processes occurrences in storage formation
  - Empirical assessment of impurity (H2S, SO2, NO2) impacts & Fe mobility

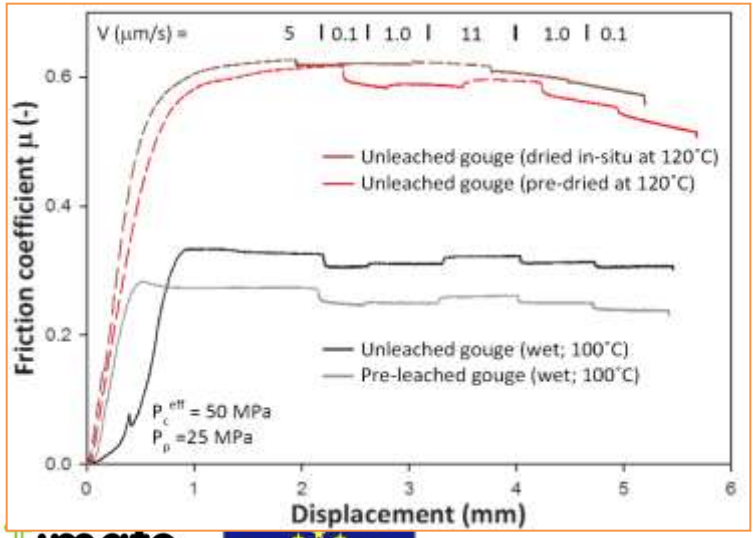


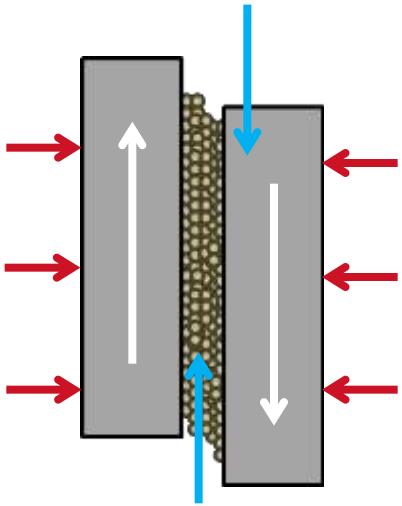
- Evidence for long term trapping evolution in storage formation reservoir
  - Kingfisher field (UK)
    - CO2 gradient
  - Bad Teiner (Germ.)
    - Outcrop Fr demo
  - Werkendam (Holland)
    - CH4/CO2 nat analog.



Long term fault sealing integrity

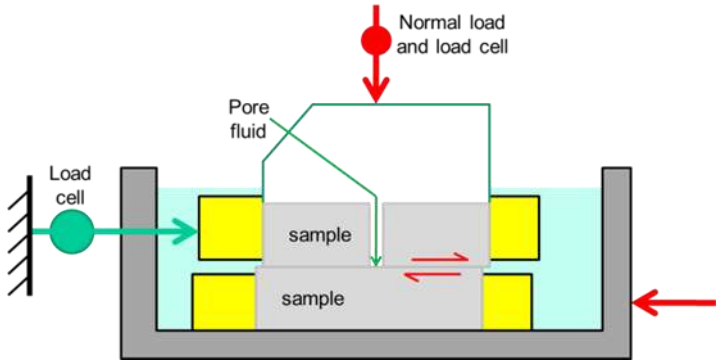
- Faulted caprock: effects of fluid-rock interaction
  - Great interest in the Netherlands: offshore storage in depleted gas field
  - Quantify effects of carbonate content and temperature on frictional & transport properties of simulated caprock fault-gouge
  - Experimental method: Direct shear friction experiments on gouge at 20˚C - 120˚C , Velocity stepping plus permeability tests





Long term fault sealing integrity

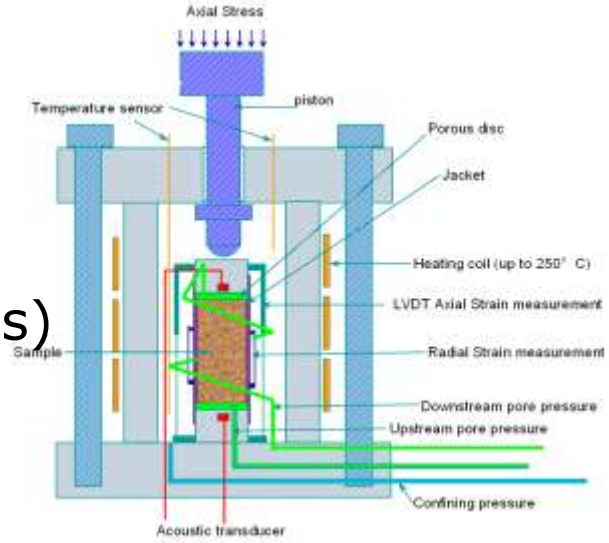
- Fracture caprock: examination of flow
- Monitored parameters (at steady-state):
  - Pore pressure, Pp, on the fracture plane
  - Applied stresses (σN and σS)
  - Fracture dilation
  - Fracture transmissivity: for different permeants
  - Fracture roughness: pre- and post-testing (3D laser scanner)
  - Post-test petrological/mineralogical analysis
  - examine potential for geochemical changes



Long term fault sealing integrity

- Fractured caprock: chemical effect on mechanics
  - Derivation of elastic parameters of intact material
  - Cyclic loading & strain gauges
  - Ultra-sonic velocity measurements

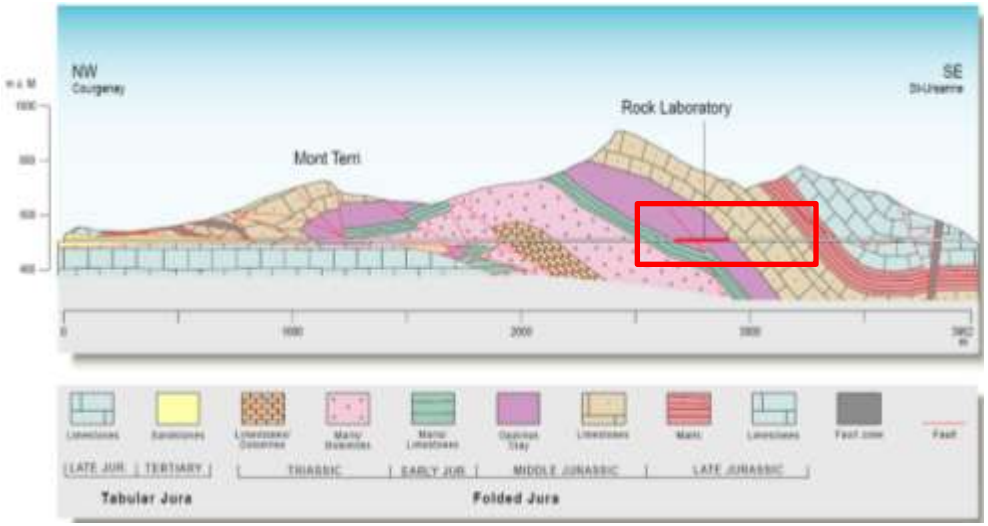
- Pre-damaging techniques used:
  - Tri-axial loading to failure
  - Drying in oven (105 C° during 5 days)
  - Freezing water content (~1.4%)



ALL MECHANICAL EXPERIMENTS CONDUCTED ON OPALINUS CLAY FROM MONT TERRI UNDERGROUND ROCK LABORATORY

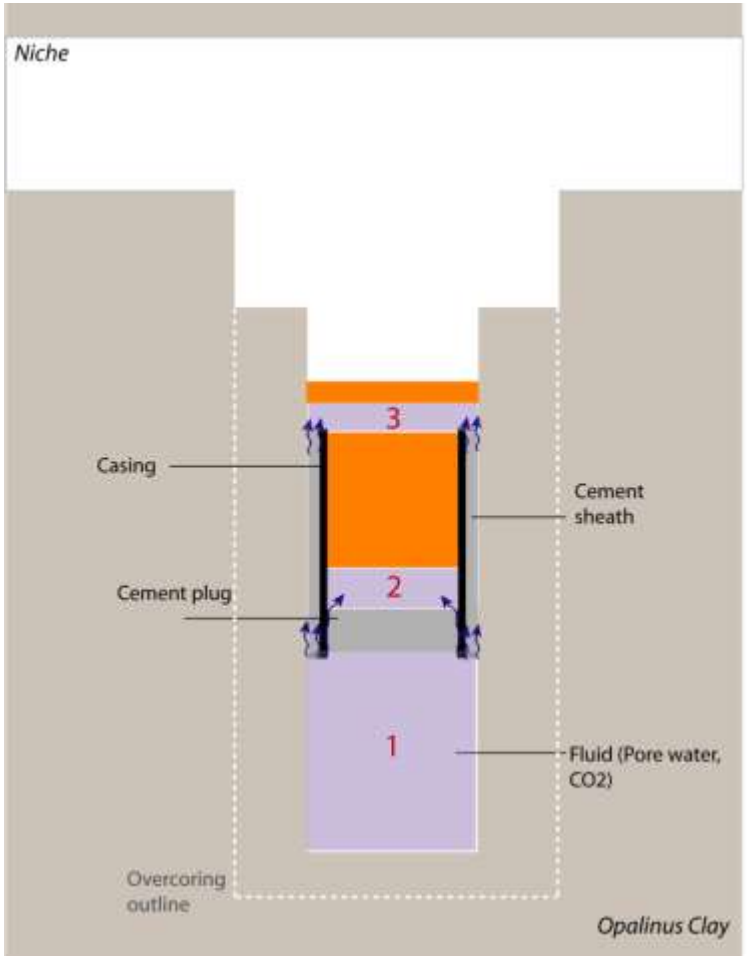
Long term wellbore sealing integrity

Use of Underground Rock laboratory, Mont Terri in Switzerland



after Mont Terri project website, 2013

Mont-Terri URL field experiment Concept



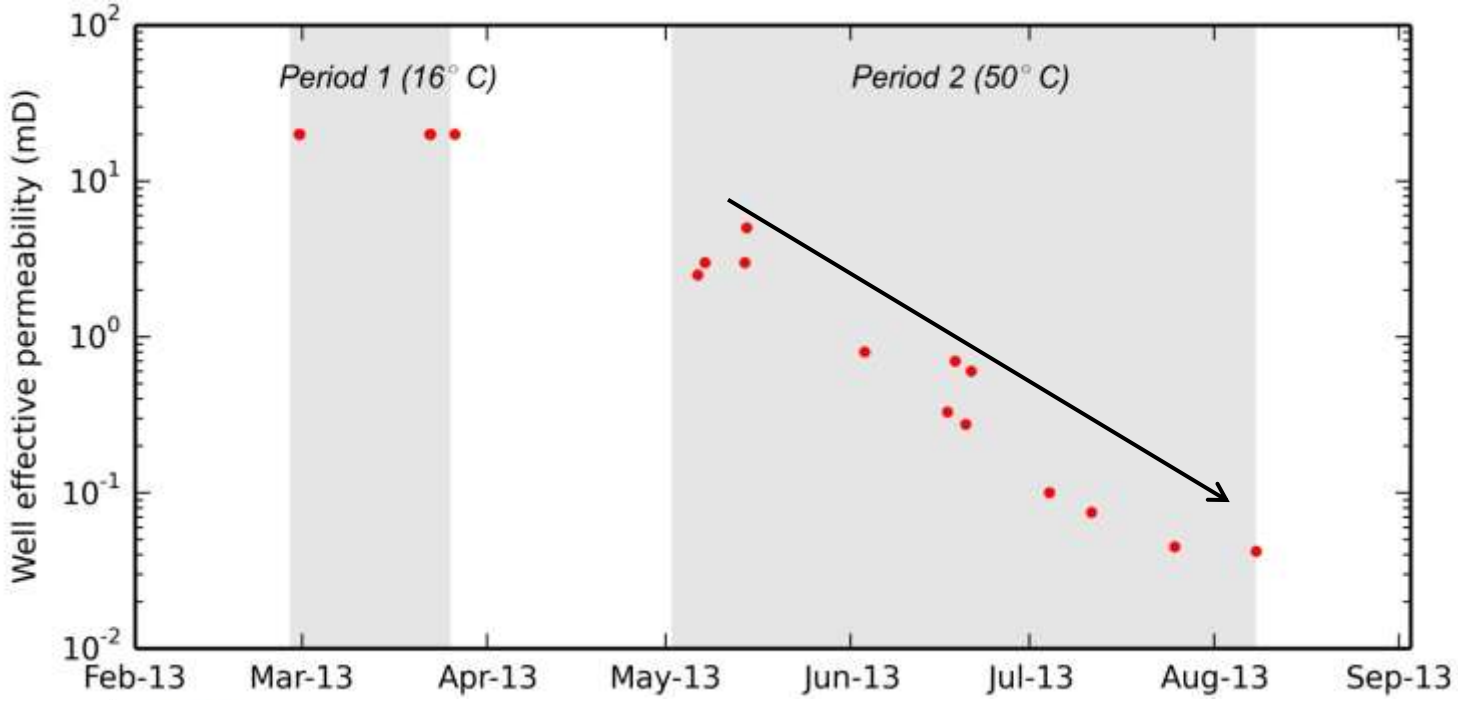
Not to scale

- Main Objectives
  - Build well components
  - Measure the permeability between chambers 1, 2 and 3
  - Inject CO2 at the bottom (Chamber 1)
  - Evaluate the chemical changes
  - Overcore the whole system (casing, cement, clay)
  - Measure permeability change and observe evidences of leakage

Mont-Terri URL field experiment

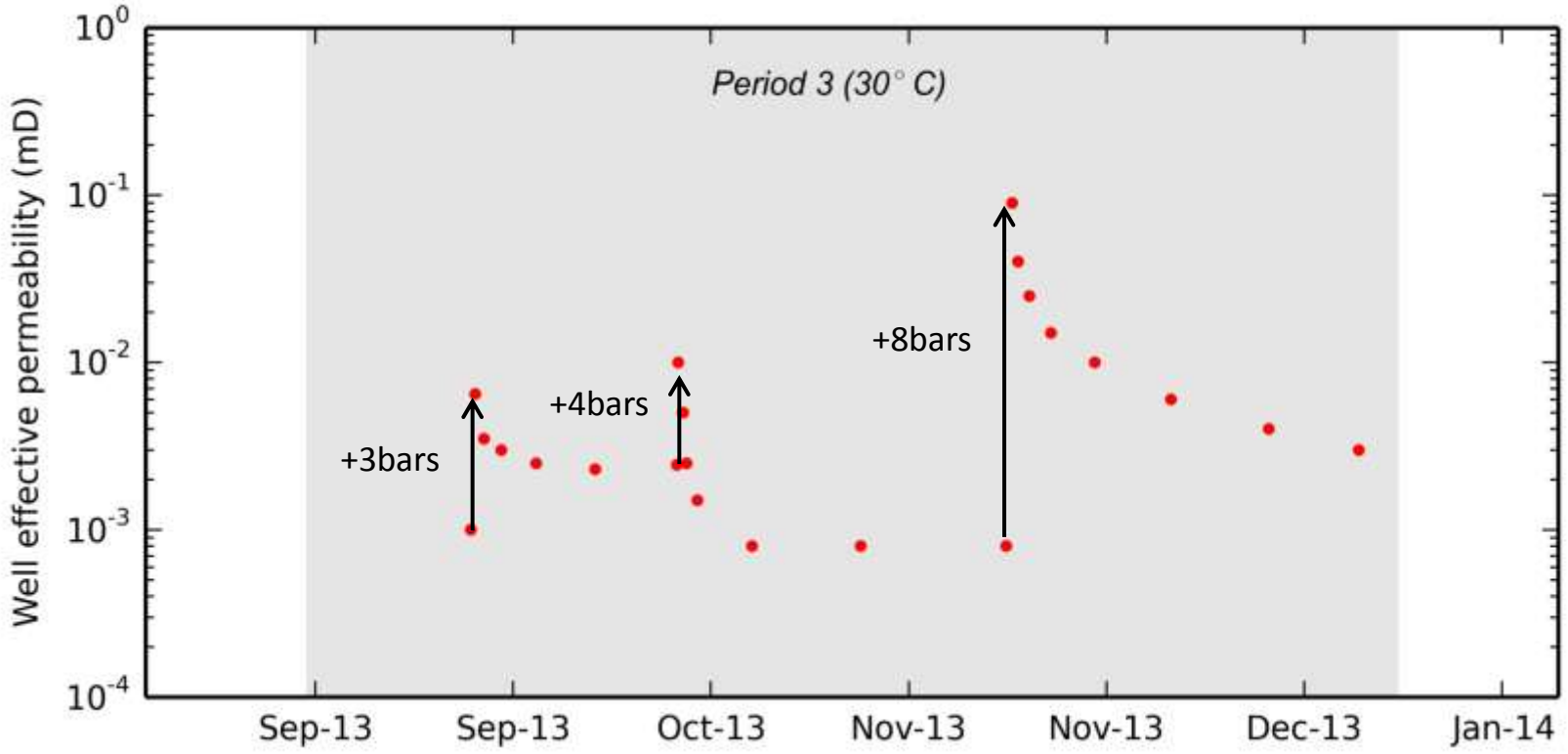
Results: effects of temperature

- A **large decrease of K_{eff}** is observed.
- The model shows that the **K_{eff} decrease** seems to occur **in the lower part of the well** (where **larger T increase** occurs)
- Hypotheses:
  - **Rock/material thermal expansion**
  - But also **mineral precipitations**, **clogging by fine particles**, or **natural borehole convergence**



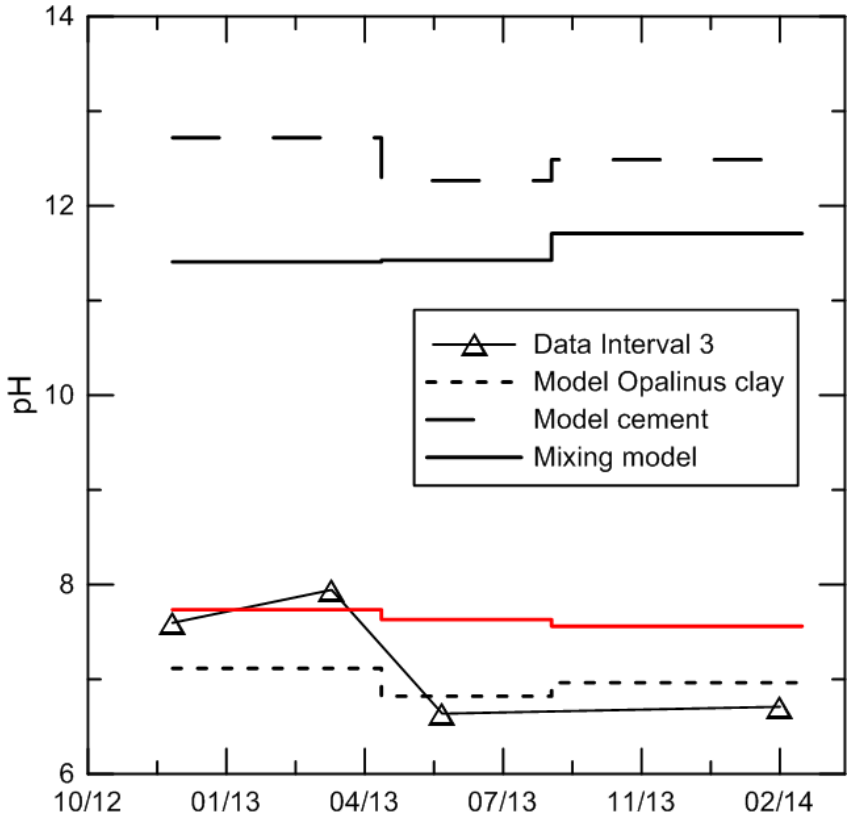
Results: effect of P_{bottom} increase

- **K_{eff} dependant on P_{bottom}**: could be a sign of flow through annuli/interfaces



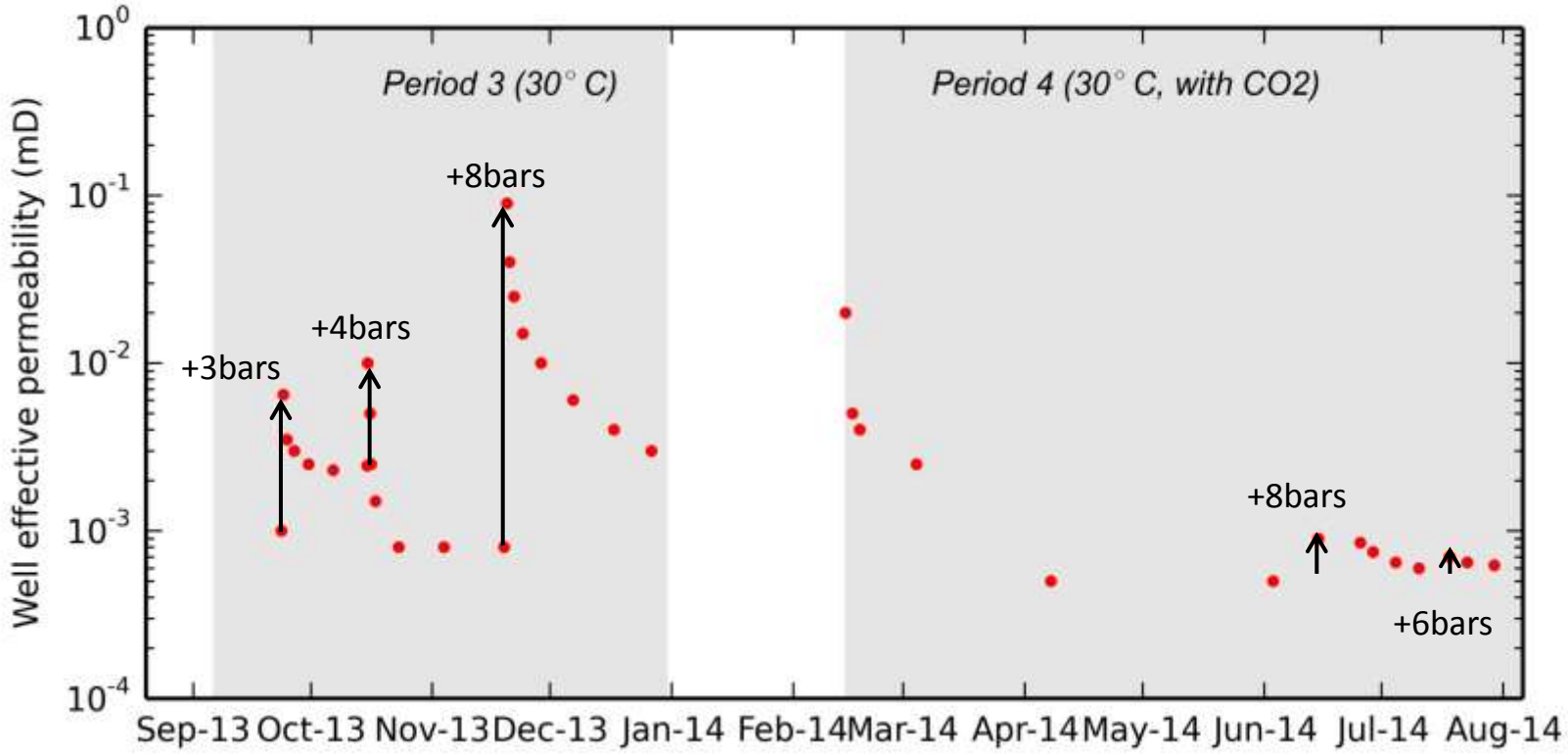
Flow through annuli/interfaces: insights from water chemistry

- Solutions from intervals sampled over time
- Geochemical model using PhreeqC v3 which simulates the **water/cement/clay interactions** and the **transport**
- Solution composition in top interval could be explained by a **channelized flow** without passing through the cement porosity



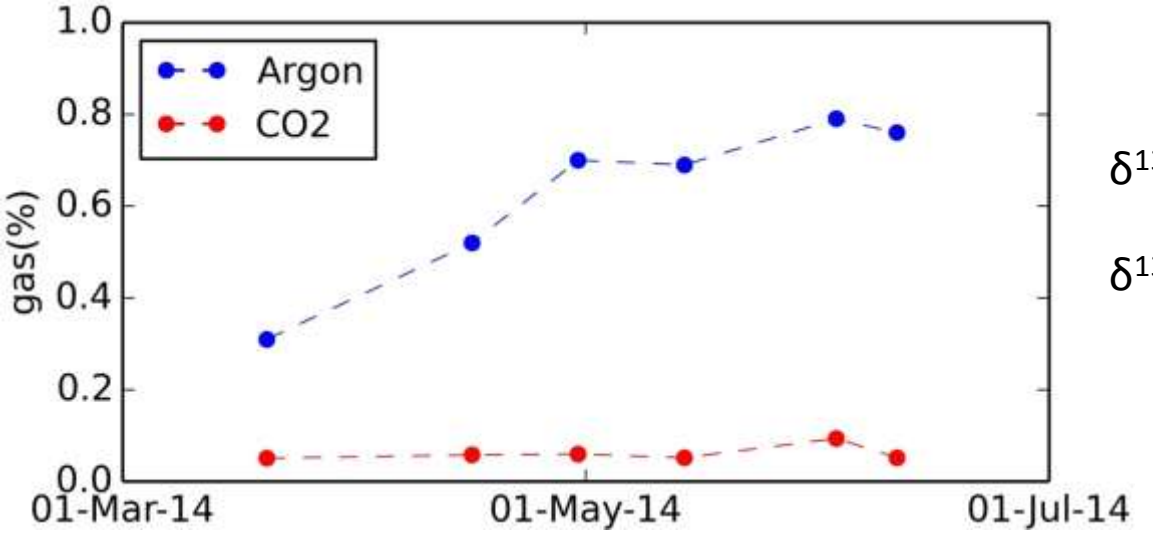
Results: effects of CO_2

- Lower effect of pressure increase: sign of **carbonation** at annuli/interfaces ?



Carbonation at interfaces ?

- During period 4, in the **bottom interval:**
  - dissolved CO_2 ($\delta^{13}C>0$ different from the formation where $\delta^{13}C<0$)
  - tracers (2.5% Ar + 2.5% Xe)
- Observations in the **top interval:**



$\delta^{13}C_{bottom}$= 19.2 ‰

$\delta^{13}C_{top}$= - 4.1 ‰

⇒ The injected **CO_2 did not reach the top** and might have been **consumed by the cement**

What are the impact of the regional scale on the storage complex?

- Model initialisation
  - Traditional hydrostatic initialisation (because only few informations)
  - How to take into account gradient of salinity, temperature?
  - How to take into account water income/outcome from outcrops?
    - This generate flux
- Model Boundary conditions
  - Vary with time
  - Where does water « produced » at boundary go?

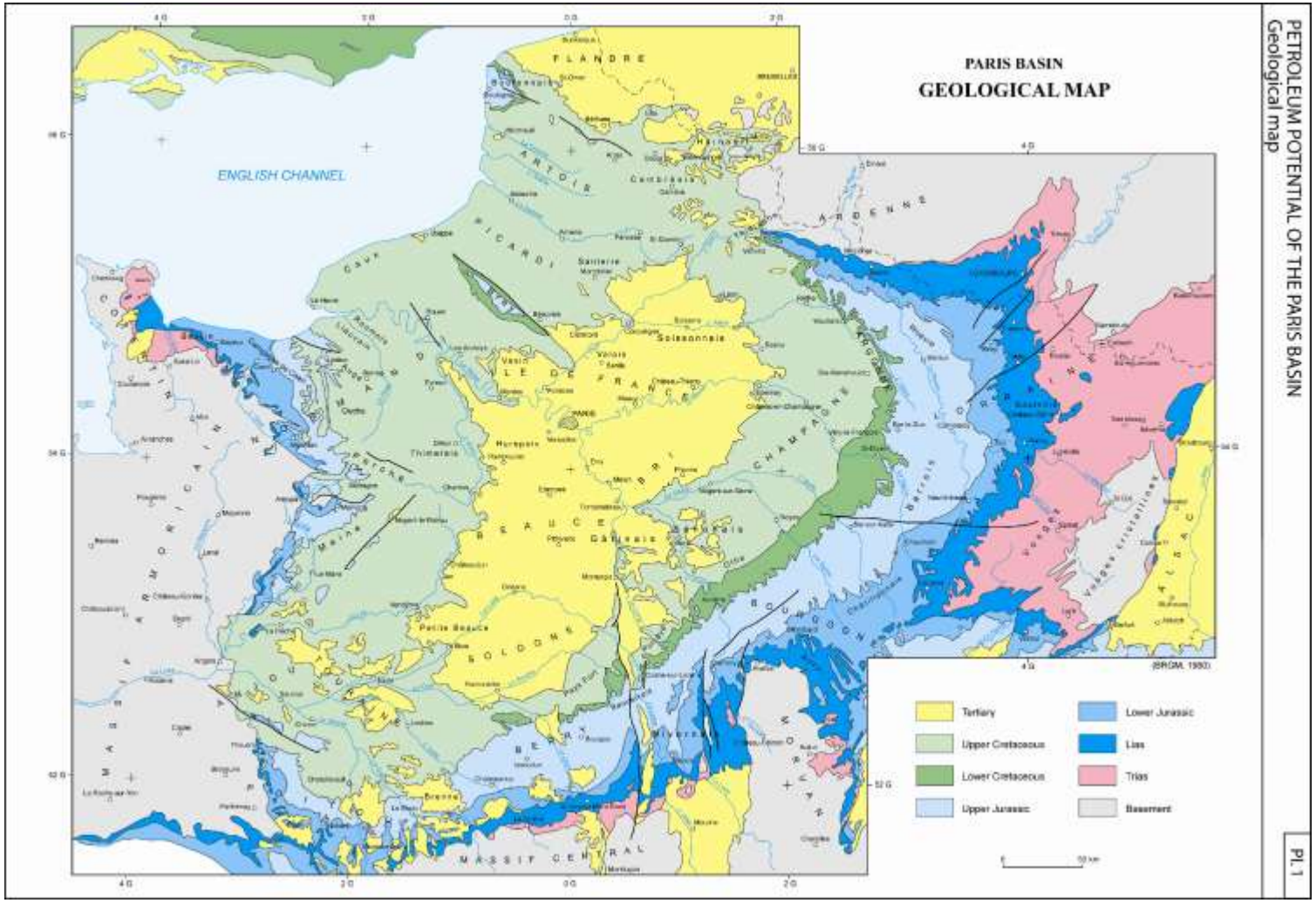
Basin modelling

- Study and model the formation and evolution of sedimentary basins
- To assess the burial and thermal history of a basin
- Tool widely used in Petroleum industry :
  - To get burial and thermal history of source rocks as well as timing of hydrocarbons generation and migration paths of expelled hydrocarbons.

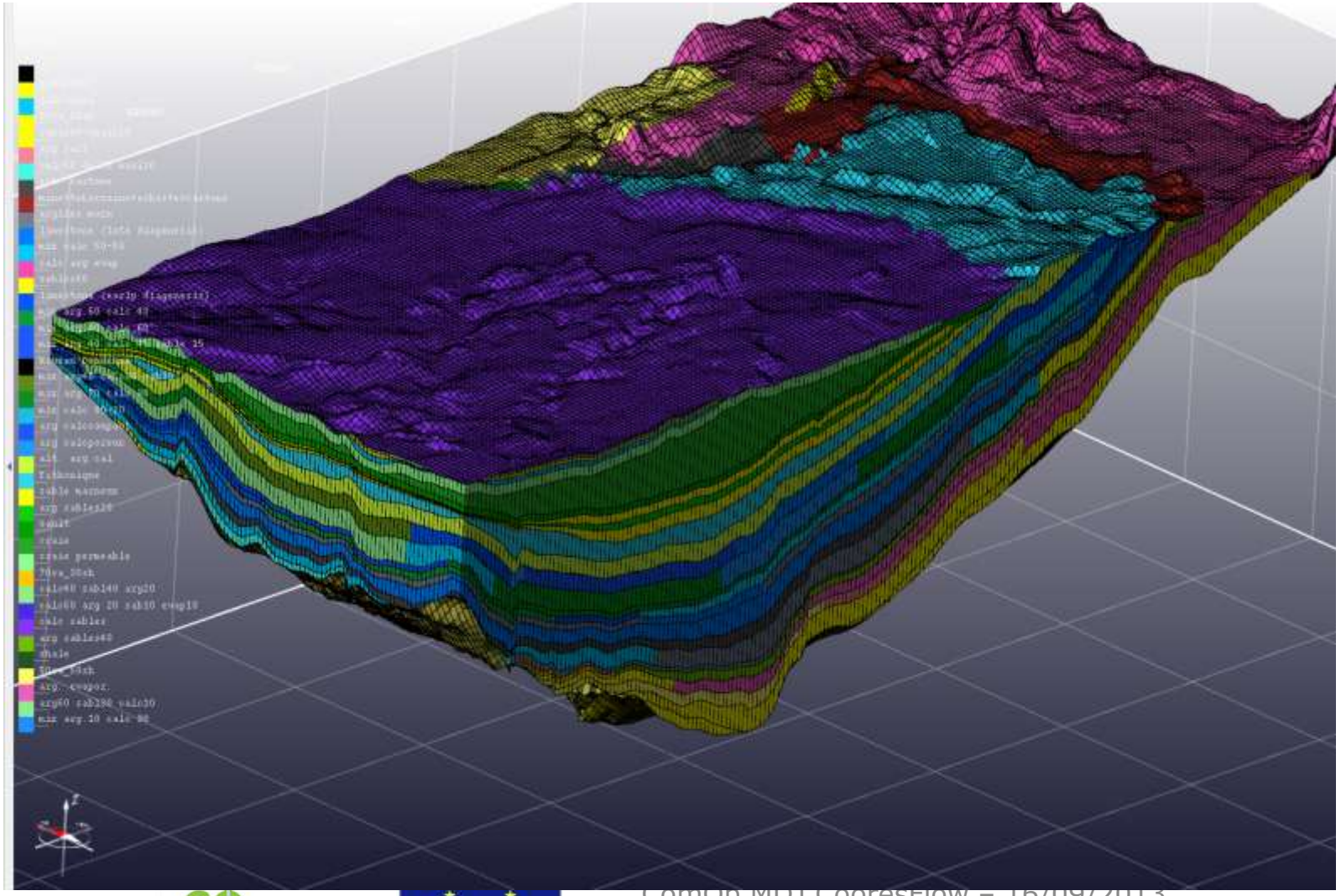
Basin modelling pinciples

- Reliable geological framework describing the present day geometry and lithology
  - Structural/Geometrical definition (well data, seismic, faults)
  - Stratigraphic sequence (porous/sealing layers, lithologies)
  - Constraining subsurface information (logs, pressures, fluid properties)
- Reconstruct the evolution through time
  - Sequence stratigraphy (geological scenario)
  - Geodynamical information (faults movements, uplift, erosion)
  - Backstripping method
- Simulate the basin history with fully-coupled physical equations
  - Forward modelling of fully-coupled equations (flow, compaction, HC craking, migration)

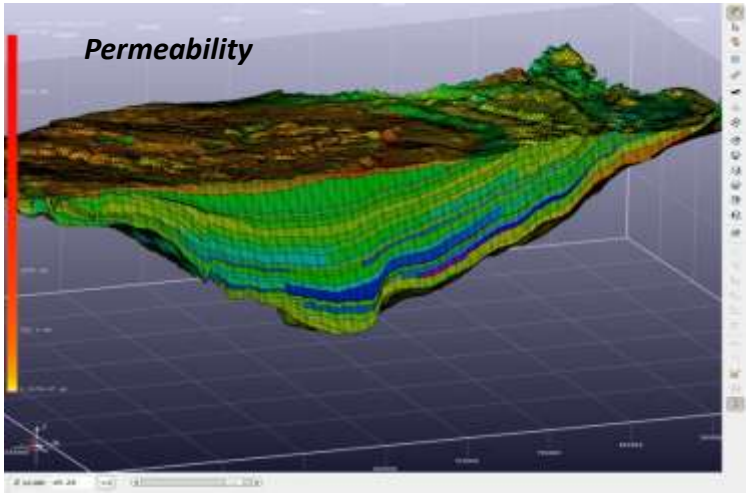
Paris basin

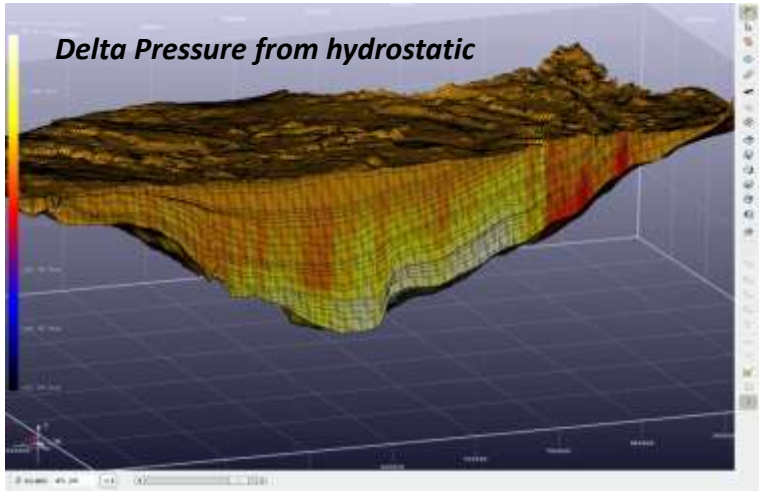

PARIS BASIN
GEOLOGICAL MAP
ENGLISH CHANNEL
FLANDRE
ARTOIS
PICARDIE
ARDENNE
VEXIN
ILE DE FRANCE
CHAMPAGNE
BRIE
BEAUCE
GATINAIS
SOLOGNE
PERCHE
NORMANDIE
MAINE
ORLEANAIS
BERRY
LIMOUSIN
MASSIF CENTRAL
BOURGOGNE
VOSGES
ALSACE
Tertiary
Upper Cretaceous
Lower Cretaceous
Upper Jurassic
Lower Jurassic
Lias
Trias
Basement
(BRGM, 1980)
PETROLEUM POTENTIAL OF THE PARIS BASIN
Geological map
PL.1

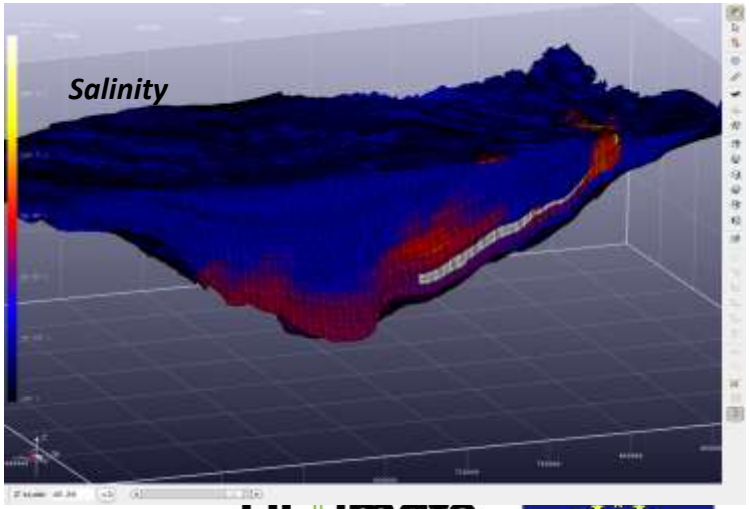
Basin modelling

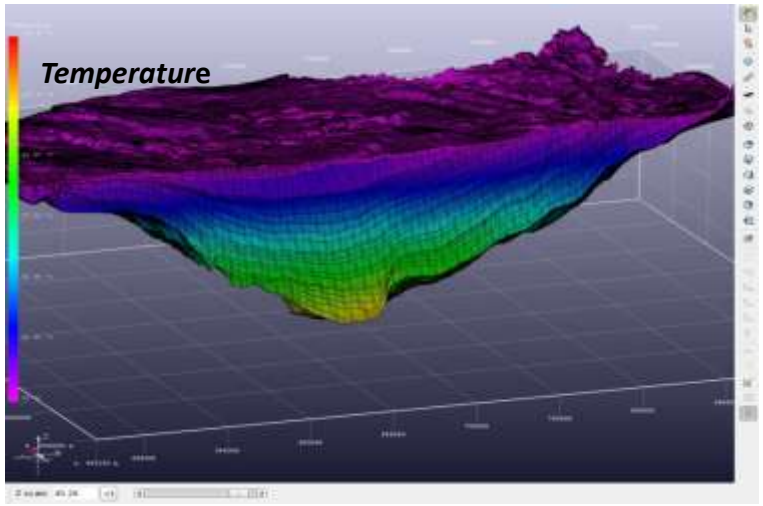


Basin modelling



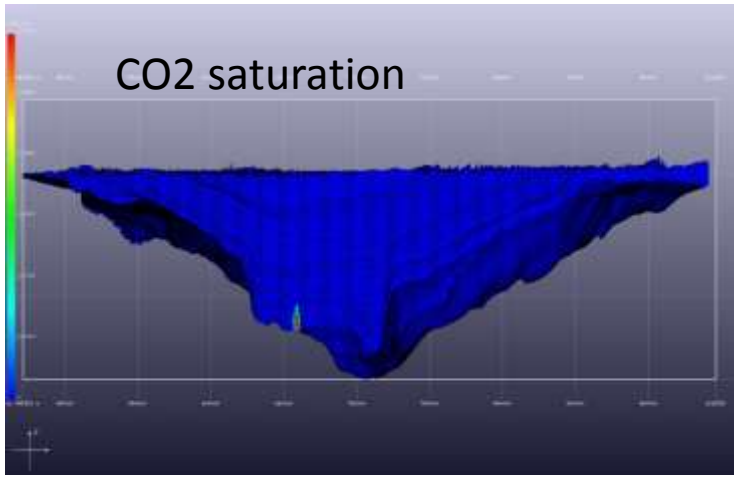


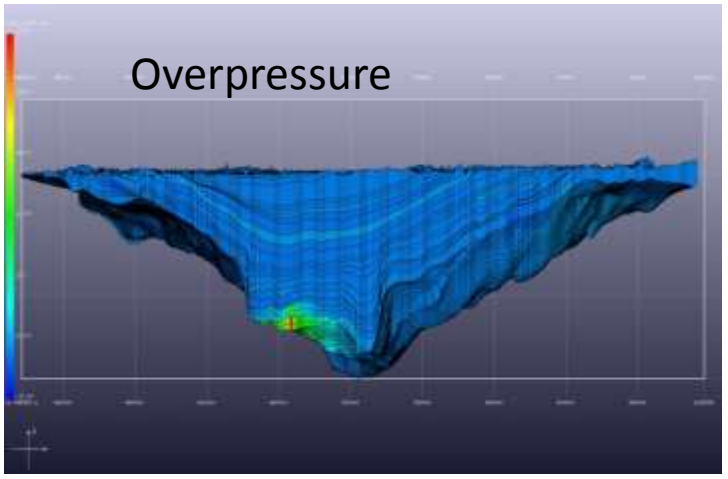




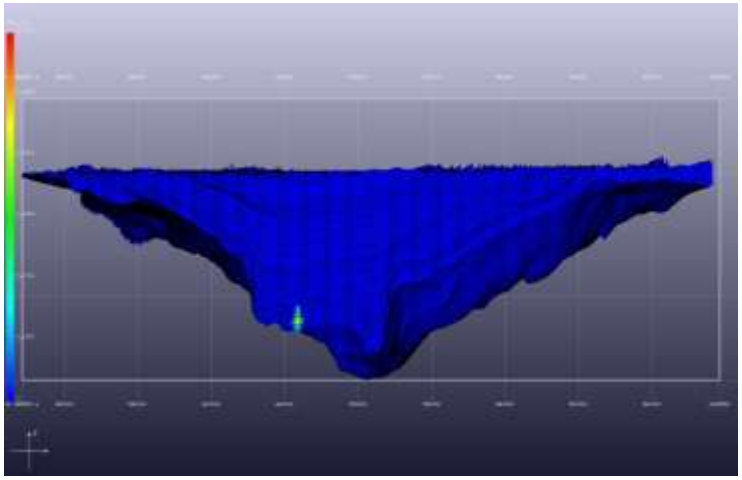
CO2 injection

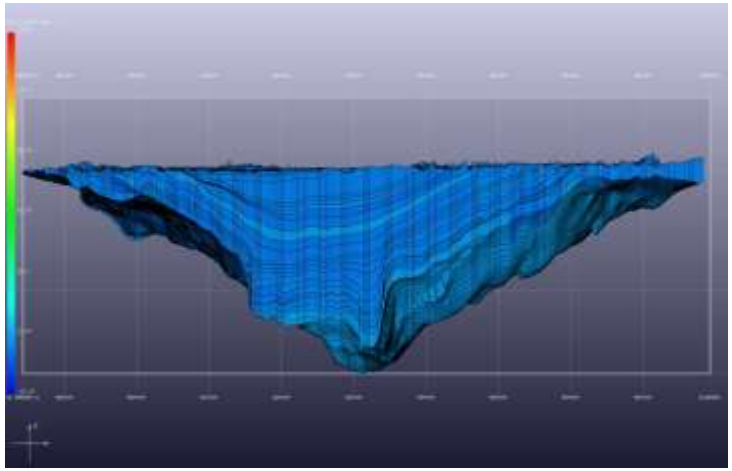
@ 50y





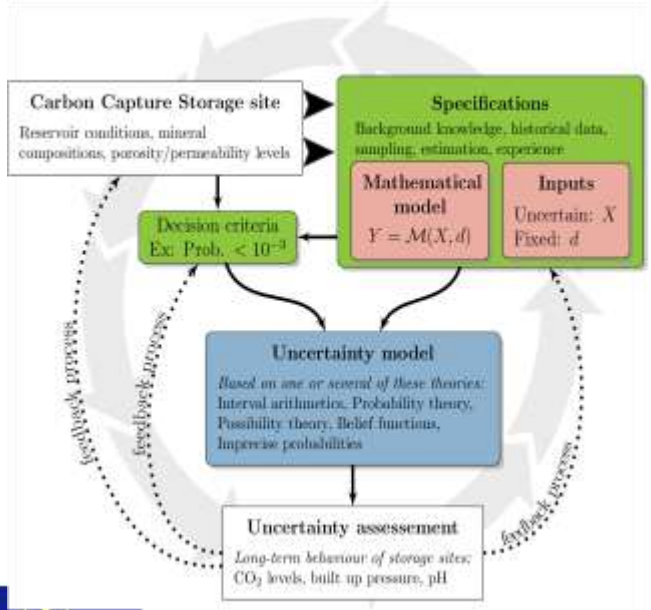
@ 1000y





Uncertainty analysis

- How confident can we be with our predictions, evaluations, measurements, observations?
- Long term issue increases the level of uncertainty
- Is there any methodology coming from other application that could be used for CCS?



Conclusion & Perspectives

- ULTimateCO2 suffers from the difficulties encountered in Europe for CCS site deployment:
  - NER300 European funds did not finance new sites; ULCOS French project is abandoned (industrial plants closure)

- Does not prevent ULTimateCO2 team to progress and provide new insights on coupled processes of long term CO2 storage, with specific focus on
  - the role of chemistry on trapping, and
  - efficiency processes associated with CCS and at several scales

- More to come in 2015:
  - End of injection of CO2 in Mont Terri
  - Regional scale study
  - Experimental program
  - Uncertainty methodology