Sixth Annual Conference on Carbon Capture & Sequestration

Evaluation of Geological Formations

Long Term Prediction of CO_2 Migration and Fluid Rock Interaction during CO_2-Geological-Storage

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Summary

- Introduction BRGM activities in terms of numerical modelling of CO_2 geological storage

- Physical processes involved and numerical tools associated.

- 4 Case studies :
  - 1D Diffusion model through Sleipner (North Sea, Norway) cap rock
  - 1D radial near well desiccation model during CO_2 injection into the Dogger aquifer (Paris basin, France)
  - 2D model of CO_2 injection and post injection at Sleipner (North Sea, Norway)
  - 3D model of CO_2 injection into the nearly depleted K12-B gas reservoir (North Sea, Netherlands)

- Limitations of numerical tools, future works…

CO2 Capture and Storage Projects

- BRGM (French Geological Survey) is involved in several European Research Projects (funded by the EC) and National Project (ANR, National Agency of Research) since beginning of 90's

- Among these projects: WEYBURN (Canada), CO2STORE (Sleipner, North Sea), CASTOR (*Pierre Le Thiez, IFP*), NASCENT (Natural Analogues, France and Greece), CO2GEONET (Excellence Network), PICOR (France), ANR/INJECTIVITY, ANR/INTEGRITY

CO_2 Capture and Storage Projects:

- Initially, BRGM was solicited for geochemical reactivity modelling impact of CO_2 injection into geological formations

- Today, Geo-mechanical and Risk assessment projects (ANR/CSCO2, CRISCO2, *Olivier Bouc, BRGM*) are under going as well as Monitoring aspects of CO_2 geological storage (CO2REMOVE, *Hubert Fabriol, BRGM*).

Trapping Processes

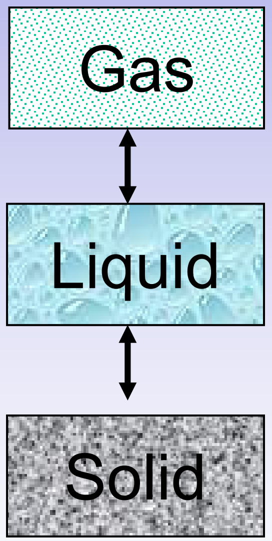
- Three processes have been identified as the most important for modelling consideration:

  – STRUCTURAL TRAPPING
    - Multiphase flow: $CO_2 + CH_4 + H_2S$…

    (Residual trapping)

  – SOLUBILITY TRAPPING
    - Dissolution of CO_2 in the liquid phase: brine, oil…

  – MINERAL TRAPPING
    - CO_2 chemical reactions with formation minerals and waters



Available numerical tools

- In house and commercial codes are used for modelling these 3 processes
  - **House codes:**
    - **MARTHE** : 3D fluid flow simulator developed at BRGM for hydrological modelling (Thierry et al.)
    - **SCALE2000** (Azaroual et al.) and **RTAFF** (Sbai et al.) : two geo-chemical codes offering opportunity to treat high salinity and 3D models respectively. They are still under development.
  - **Commercial codes:**
    - **PHREEQC** (USGS, Parkhurst and Appelo) for aqueous geochemical reactions, batch and 1D transport calculations, i.e. mineral trapping characterisation,
    - **TOUGH2** (LBNL, Pruess et al.) : for structural trapping characterisation, dissolution of gaseous CO_2 in the liquid phase i.e. solubility trapping with temperature and salinity coupling, 3D media.
    - **TOUGHREACT** (LBNL, Xu et al.) : an adaptation of TOUGH2 to reactive transport modelling for CO_2 injection i.e. mineral trapping

Sleipner, 1D diffusion in cap rock

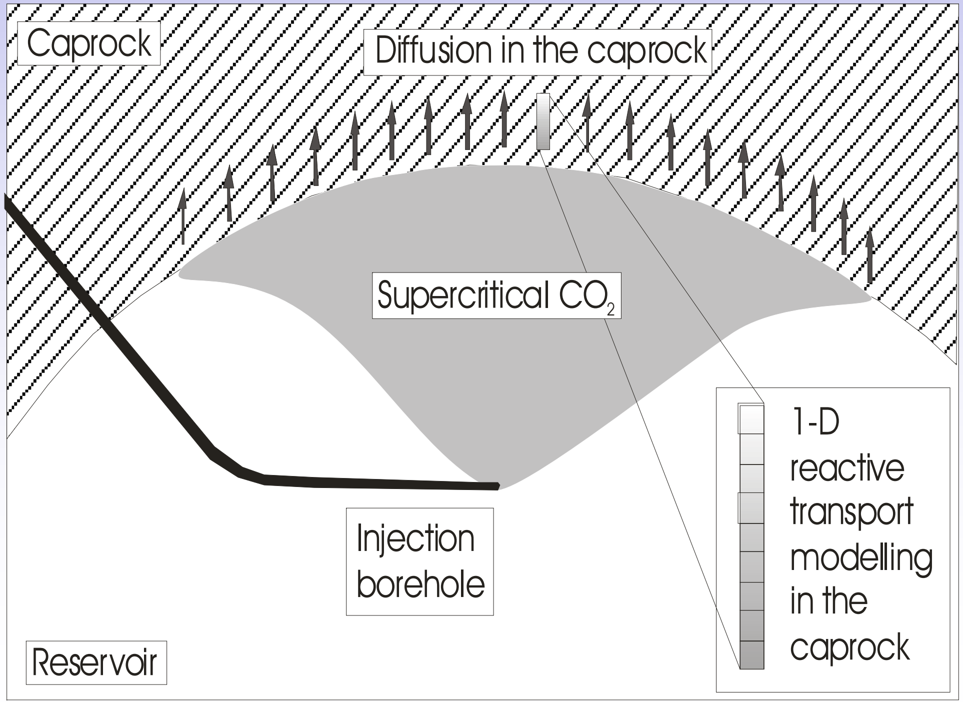
(Gaus et al. 2005, Chem. Geol, 217, 319-337)

At Sleipner (North Sea), the CO_2 (extracted from a gas platform emission) is injected in the Utsira sand formation underlying the Nordland shale caprock from one horizontal well.

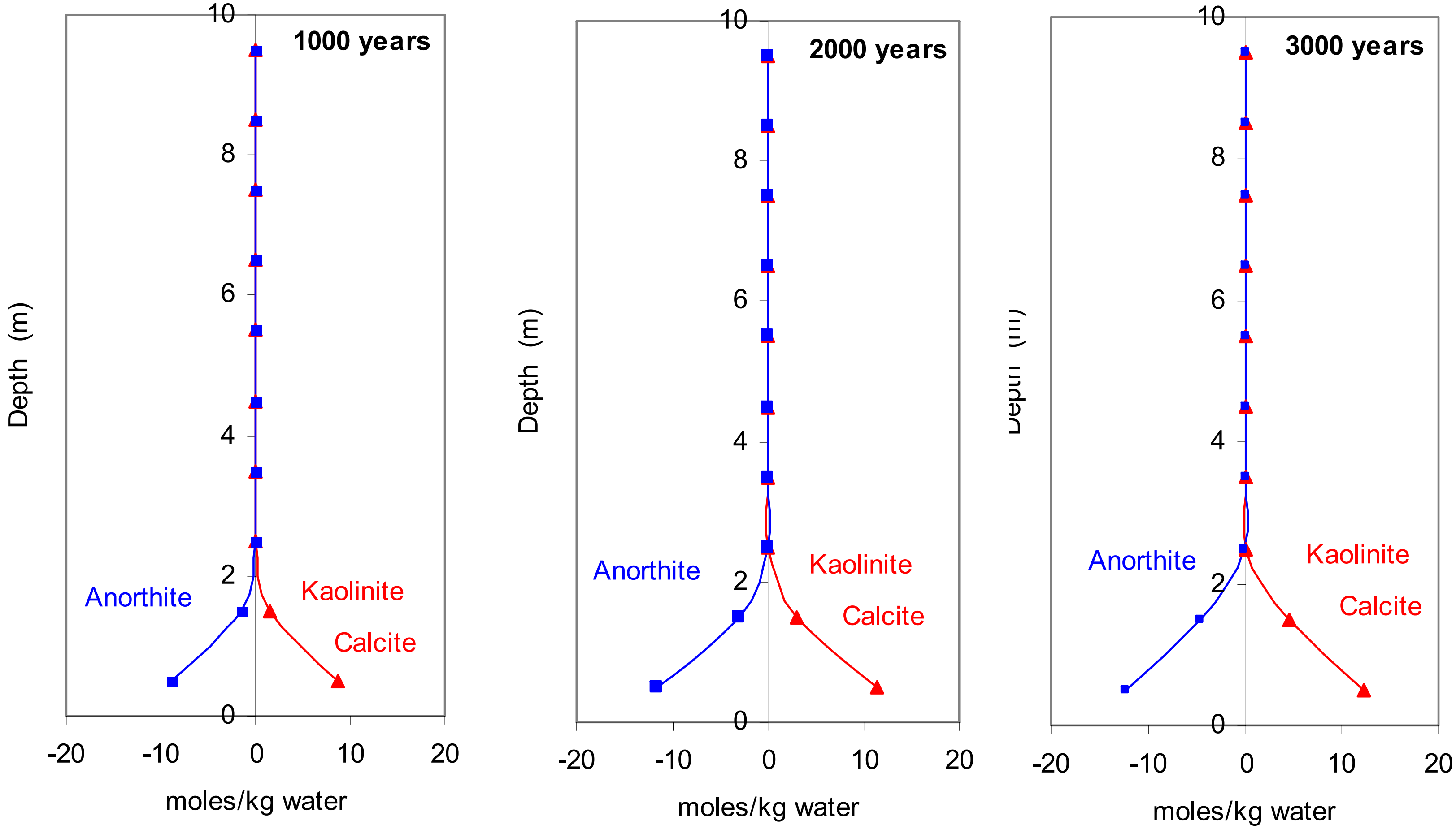
This work focuses on the geochemical aspect of the CO_2 injection with special attention to the long term integrity of the cap rock preventing upward migration of CO_2.

Geochemical reactions between dissolved CO_2 and the minerals present in the cap rock can lead to porosity and permeability changes compromising cap rock integrity.

The case of diffusion of dissolved CO_2 through the base of the cap rock after injection is treated using **PHREEQC**.



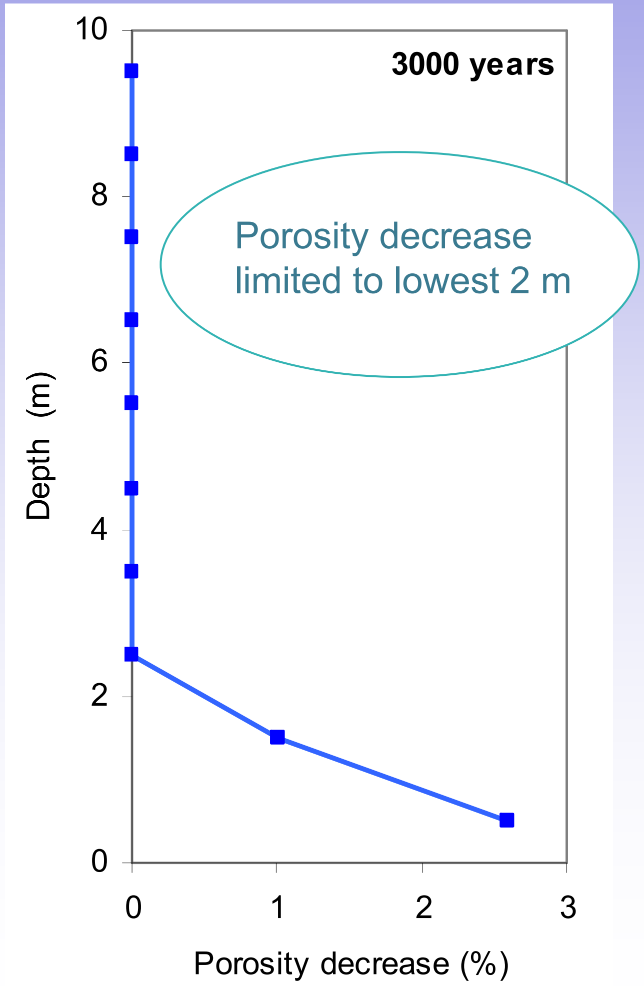
Reaction profiles: 50/50 albite/anorthite



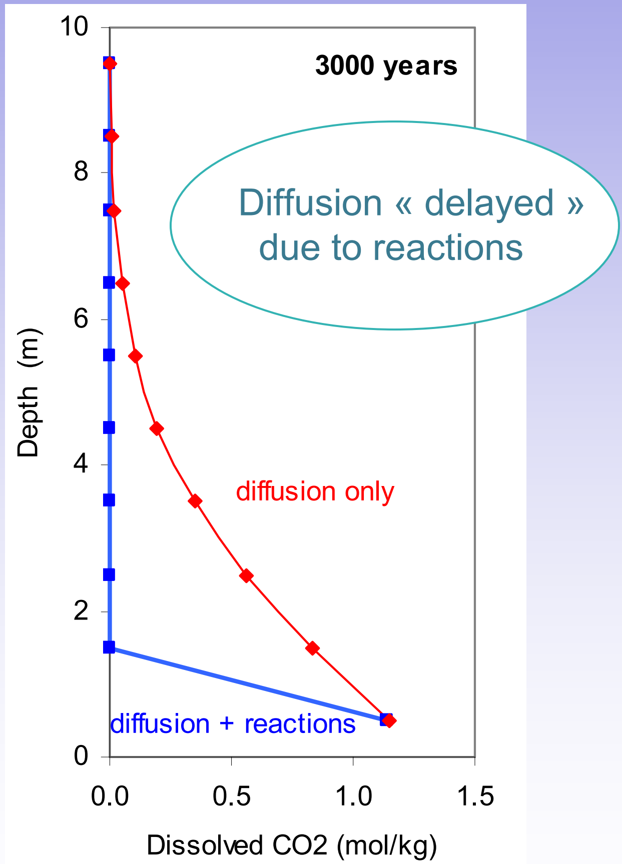
Dominant reaction only

Porosity and diffusion profiles after 3000 years

Porosity change profile

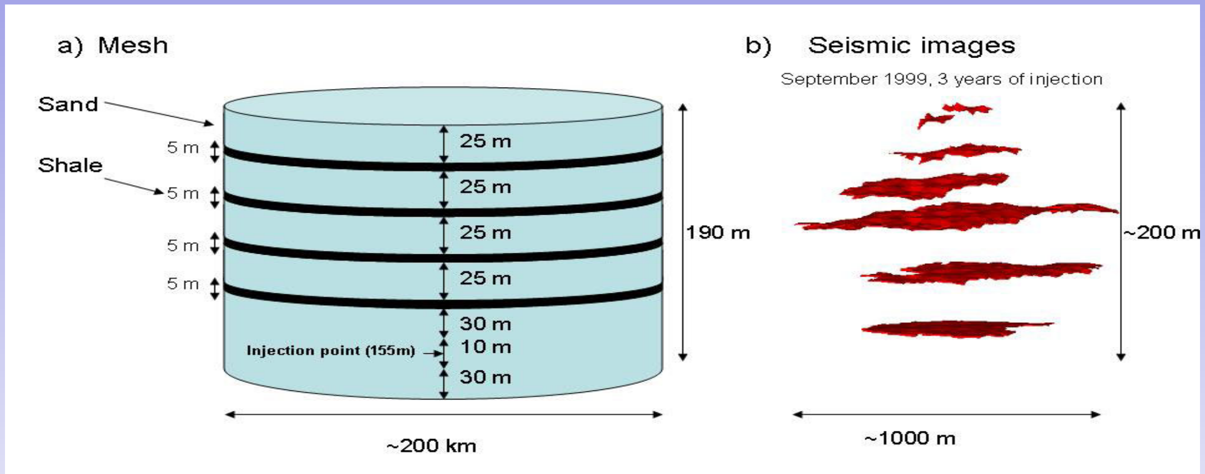


Diffusion profile



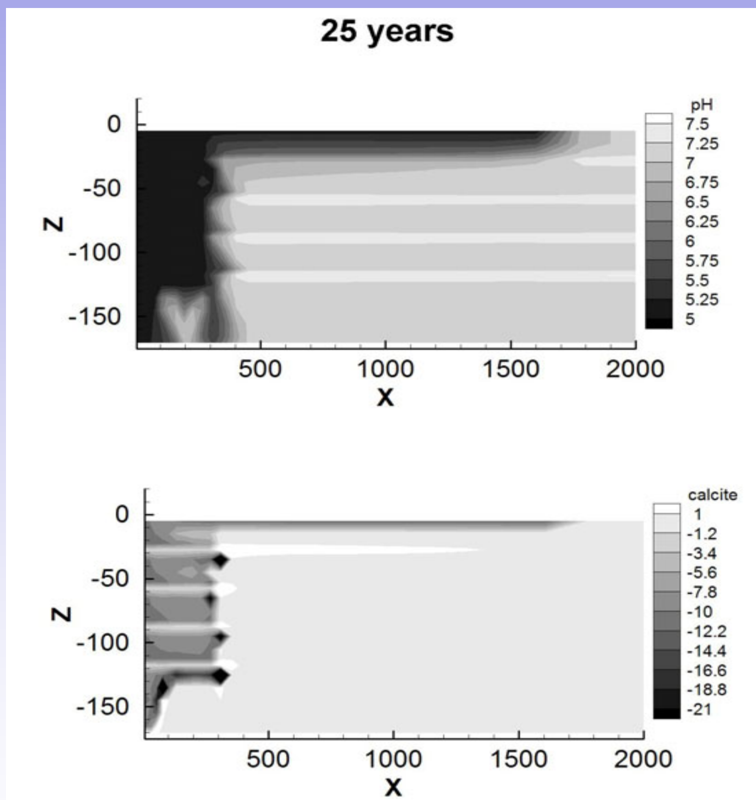
2D model of CO_2 injection at Sleipner

(Audigane et al., 2007a, Am. J. of Sc., In Press)



- vertical 2D mesh with a cylindrical geometrical configuration, centered around an injection point located 155 m beneath the top, 184 m thick formation
- Four sand layers of 25 m thickness separated by shale layers of 5 m thickness
- At the bottom : sand layer of 70 m thickness into which the CO_2 is injected
- Mesh: 22 layers in the vertical and 52 cells in the radial direction
- The first cell has a radius of 10 m, and is followed by 20 cells with radial increments increasing in logarithmic progression out to 100 km from the injection point, so that the model system would be infinite acting.
- Numerical tool: **TOUGHREACT**

SHORT TERM SIMULATION RESULTS



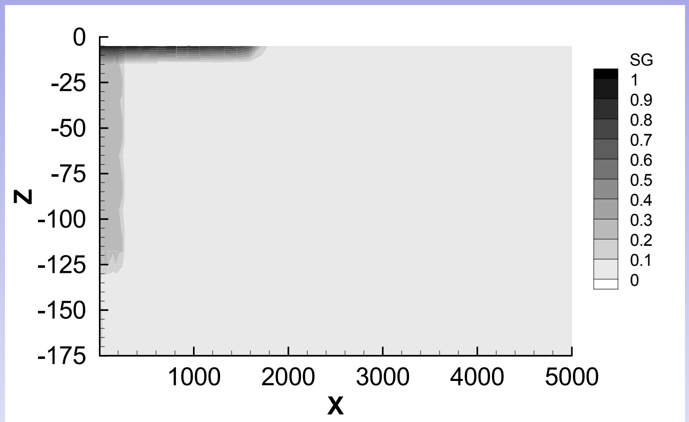
pH and calcite dissolution (in mol/kg of medium) at the end of 25 year CO_2 injection period. The negative sign corresponds to mineral dissolution

- Dissolution of CO_2 makes the brine more acidic. **pH drops** to a value of 5.13 inside the gas bubble, which results from buffering due to calcite dissolution (Figure 3).

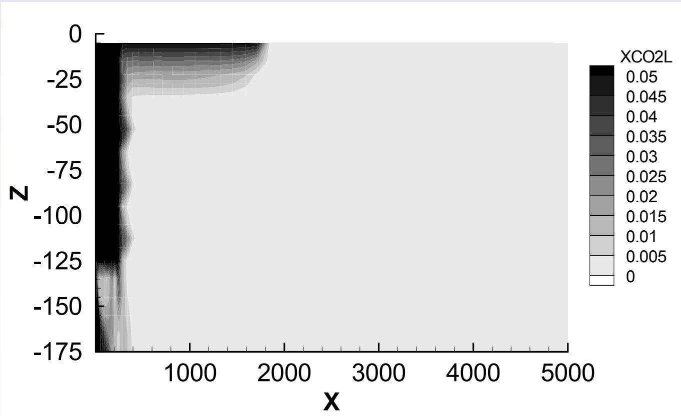
- The **dissolution of calcite** is less pronounced in the shales (~5 moles per m^3 of rock) than in the sands (up to 20 moles). Calcite precipitates below each shale layer at the interface between the CO_2 saturated brine and the initial brine, due to mixing of different waters in these regions.

LONG TERM SIMULATION RESULTS

50 years



Supercritical CO2

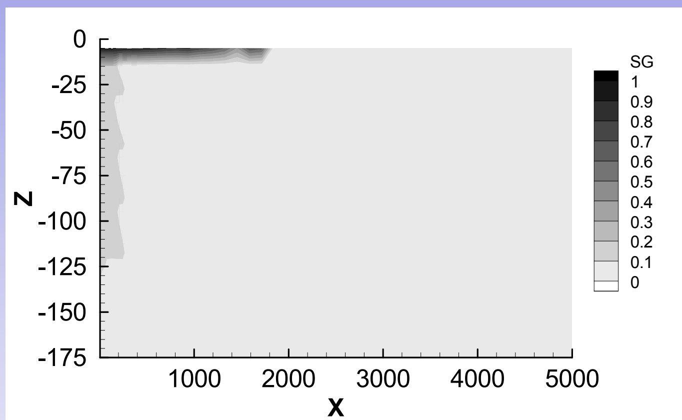


Dissolved CO2

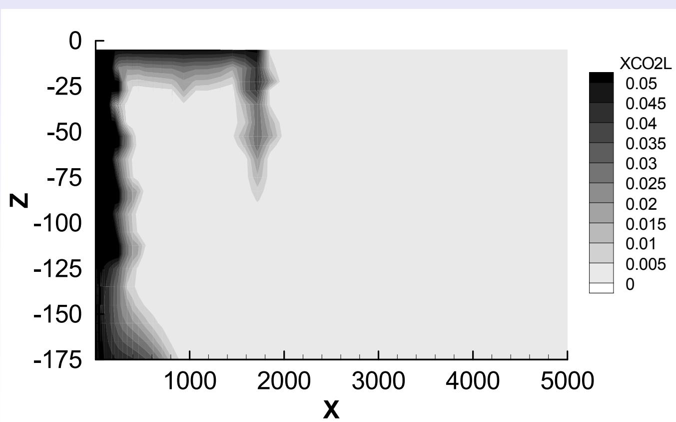
- After injection, the **upward migration of the supercritical CO_2** occurs quickly, and most of the supercritical CO_2 accumulates just below the cap rock, except for the residual CO_2 that is trapped in sediments.
- The **CO_2 plume** extends to a maximum radius of 2,000 m around the injection point.
- CO_2 starts to **dissolve in the brine**, and the free gas is completely dissolved after 6,000 years.
- The **brine** with dissolved CO_2 tends to **migrate downward** as it has approximately 10 kg/m3 larger denser than brine without CO_2. The brine containing dissolved CO_2 is carried downward and is replaced by brine with less CO_2. After 10,000 years, a large volume near the **bottom of the formation contains brine with dissolved CO_2 out to a radius of 4,000 m**.

LONG TERM SIMULATION RESULTS

1,000 years



Supercritical CO2



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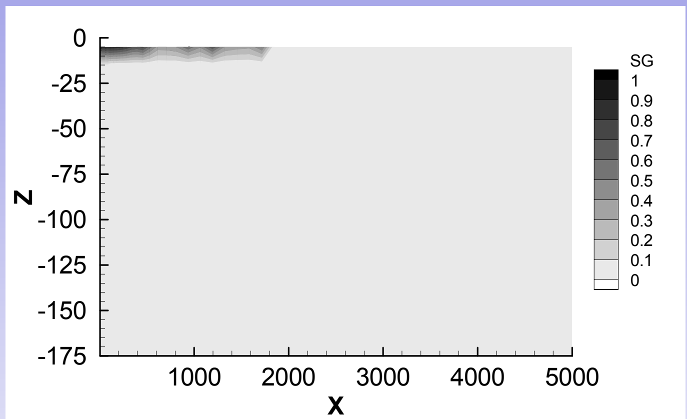
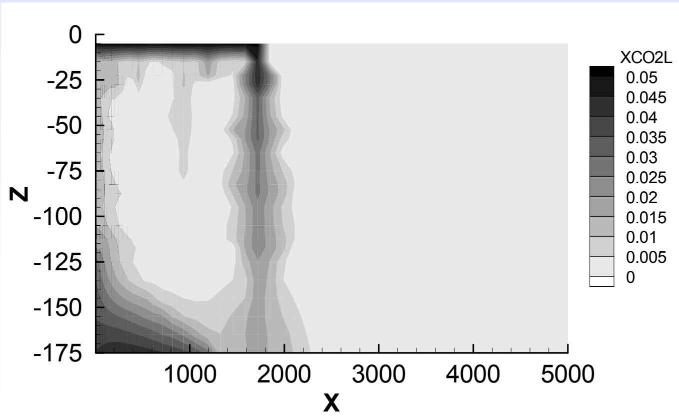
LONG TERM SIMULATION RESULTS

2,000 years



Supercritical CO2



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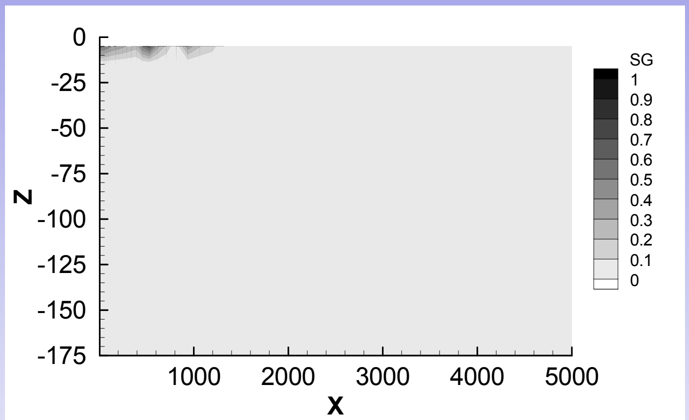
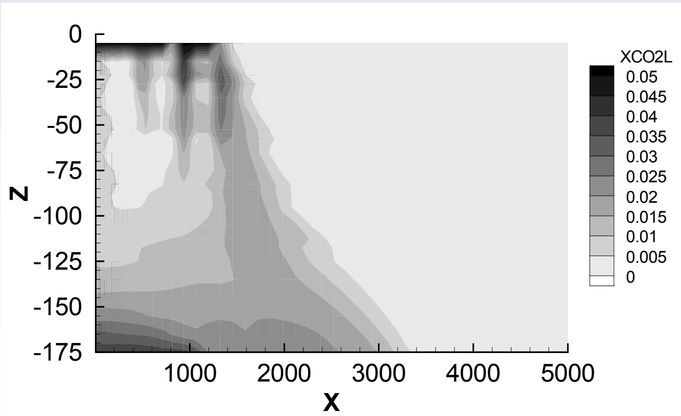
LONG TERM SIMULATION RESULTS

5,000 years



Supercritical CO2



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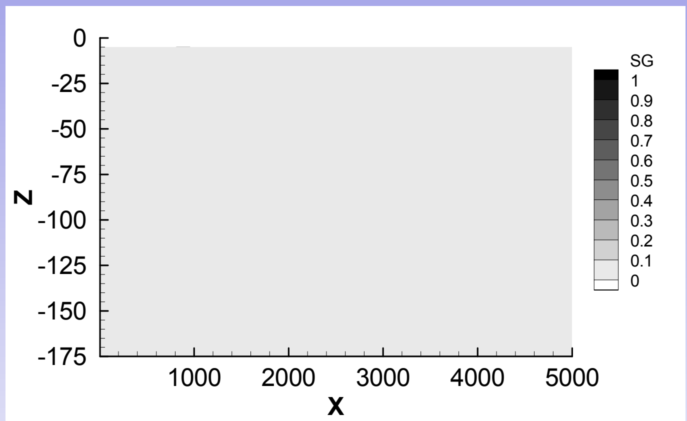
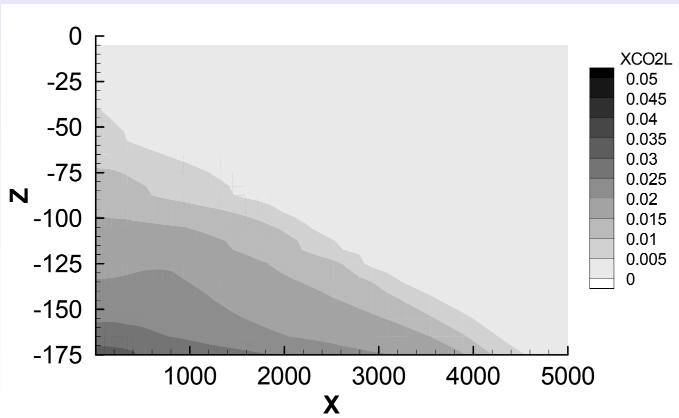
LONG TERM SIMULATION RESULTS

10,000 years



Supercritical CO2



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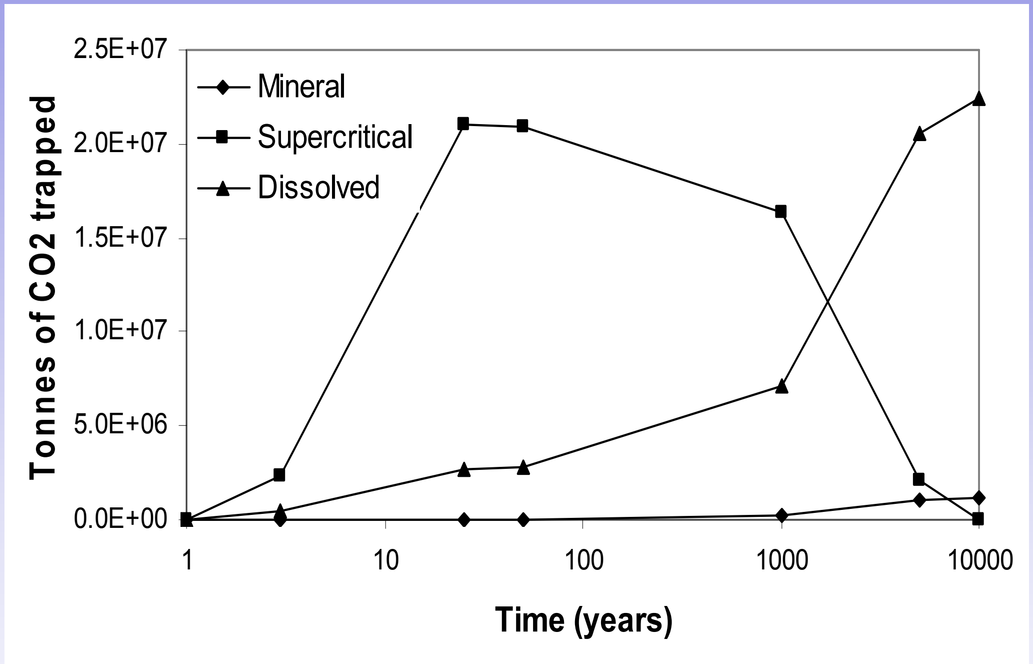
Amount of CO_2 stored



Total amounts of carbon dioxide present as a **free (supercritical) gas phase**, **dissolved in the aqueous phase**, and sequestered in minerals.

Mineral trapping plays only a minor role, although it increases slowly with time and therefore contributes to long-term stability of the storage process.

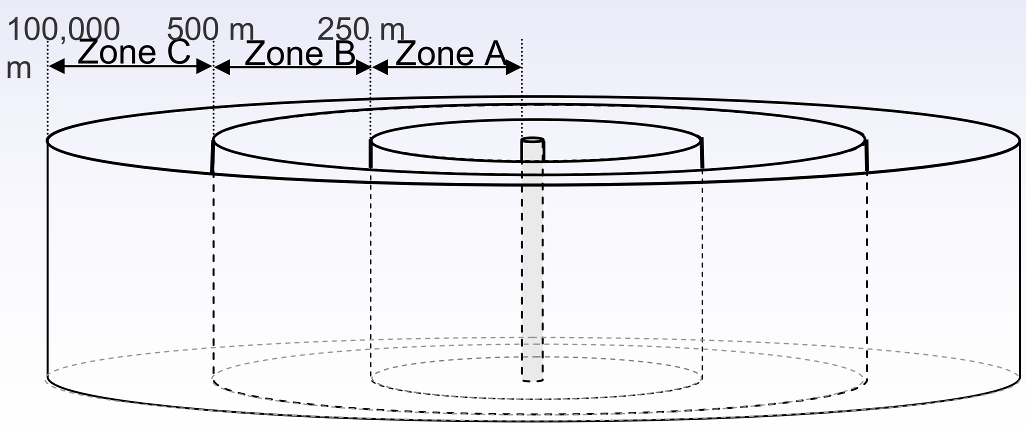
1D radial desiccation, Dogger, France

(André et al., 2007, En. Conv. Mgmt., Volume 48, Issue 6, 1782-1797)

- Assessment of the physical and chemical impact of CO_2 injection on the properties of the carbonated Dogger aquifer
- 1D radial injection model is proposed to evaluate the evolution of the geochemical reactivity induced by injection of CO_2
- Injection of pure supercritical CO_2
  - TOUGHREACT
- Near well dry out and desiccation phenomenon with high salinity
  - SCALE2000

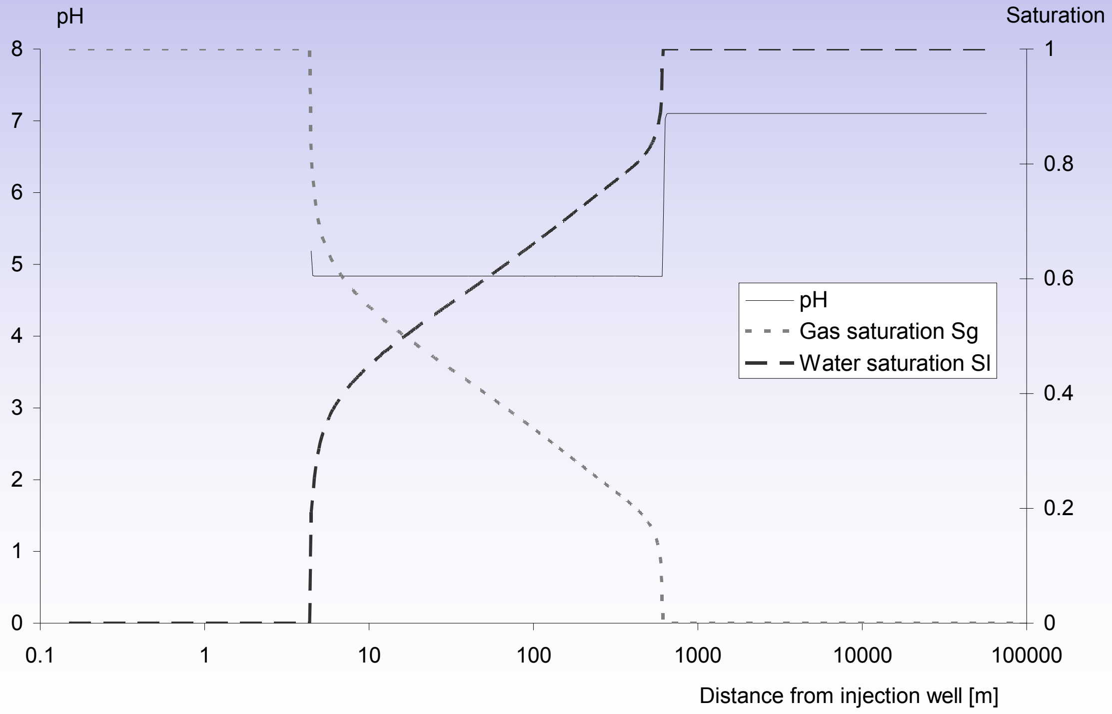
The Dogger aquifer

- Carbonated reservoir
- Represented by a cylindrical geometry centered around a vertical injection well
- One layer (no gravitational effect) with a thickness of 20 m and a maximal radial extension of 100 km
- 1610 co-centered cell elements
- First cell radius containing the injection well is equal to 0.3 m and next 500 cells radius is also constant and equal to 0.5 m
- Hydrostatic pressure is imposed in the outermost column of the mesh

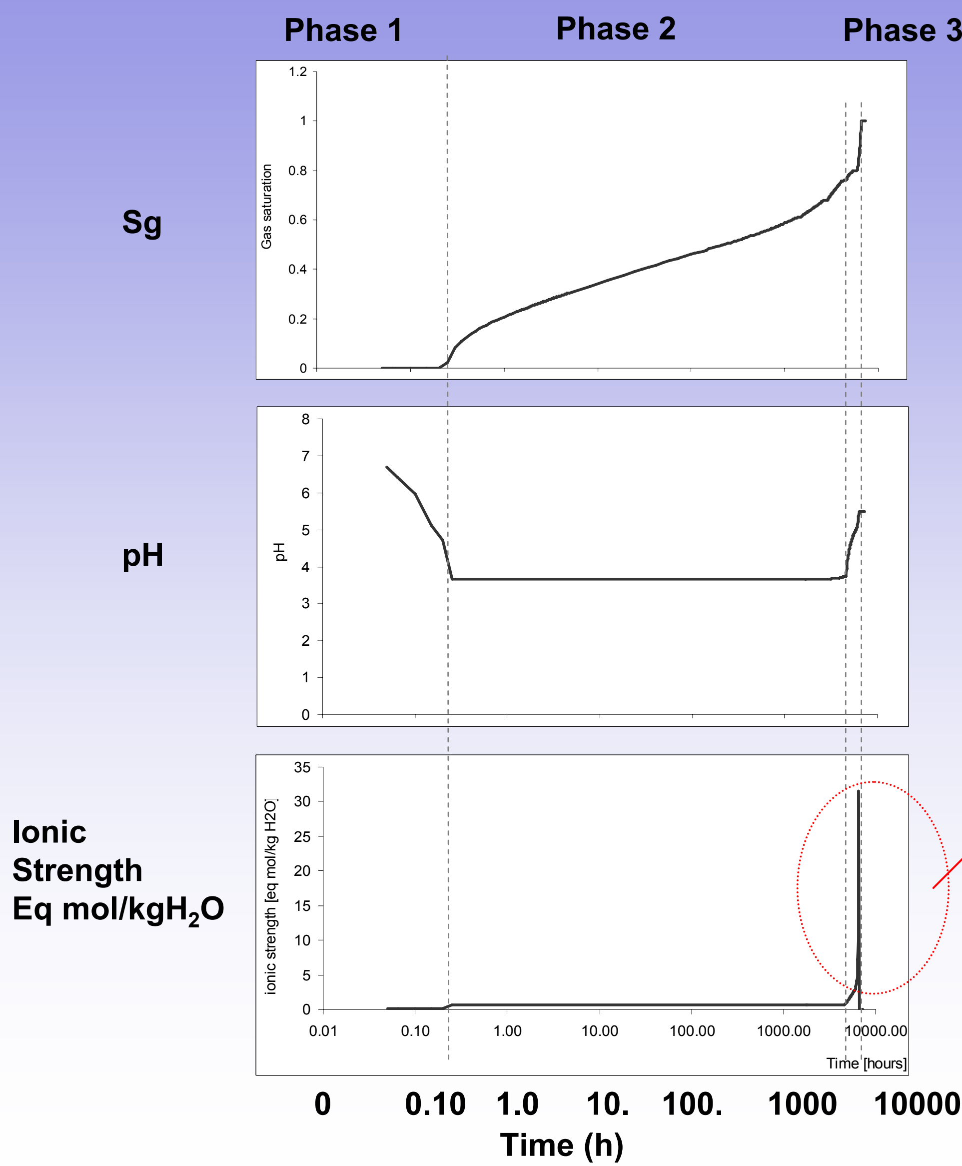


Simulation Results

- CO_2 supercritical and brine flow
- Buckley-Leverett profile



Dry out zone at 1 m from the well



- Historical evolution of the chemistry for a point located 1meter away from the well
- Three phases identified:
  - Mono phase : liquid
  - Two phases
  - Mono phase : supercritical (dry out)

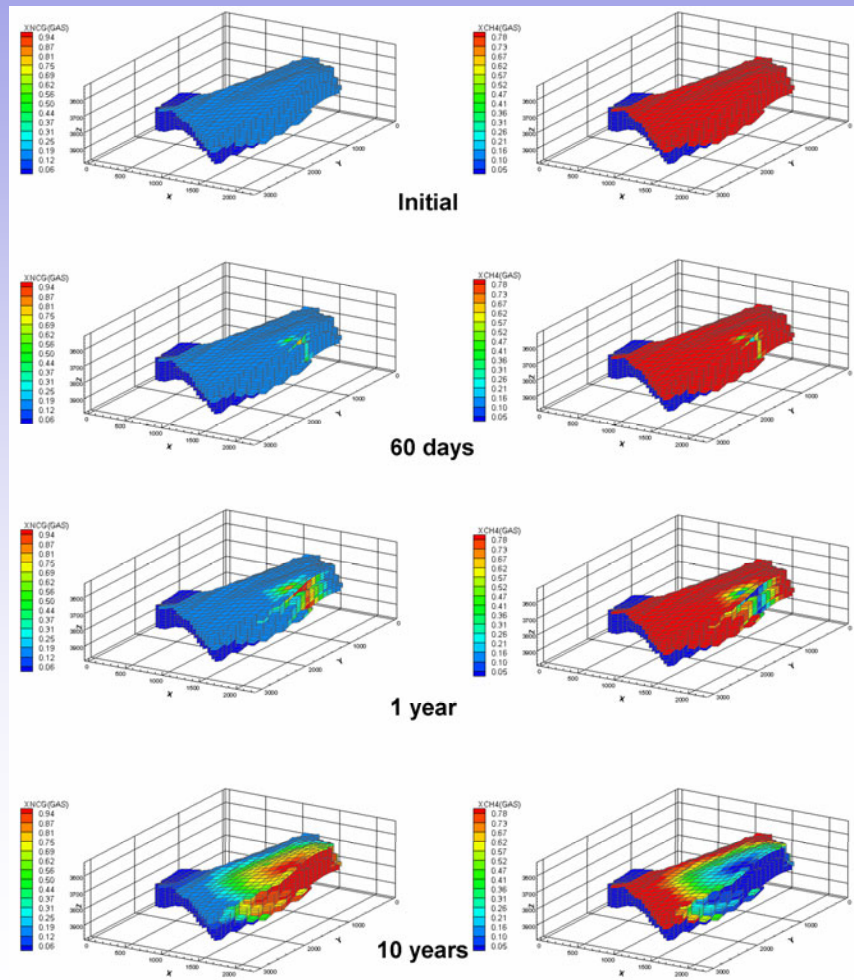
Out of the Debye Hückel Formalism: Ionic Strength >0.5

USE OF SCALE2000
To calculate correct Index of Saturation for precipitated minerals

3D model of CO_2 injection in K12-B

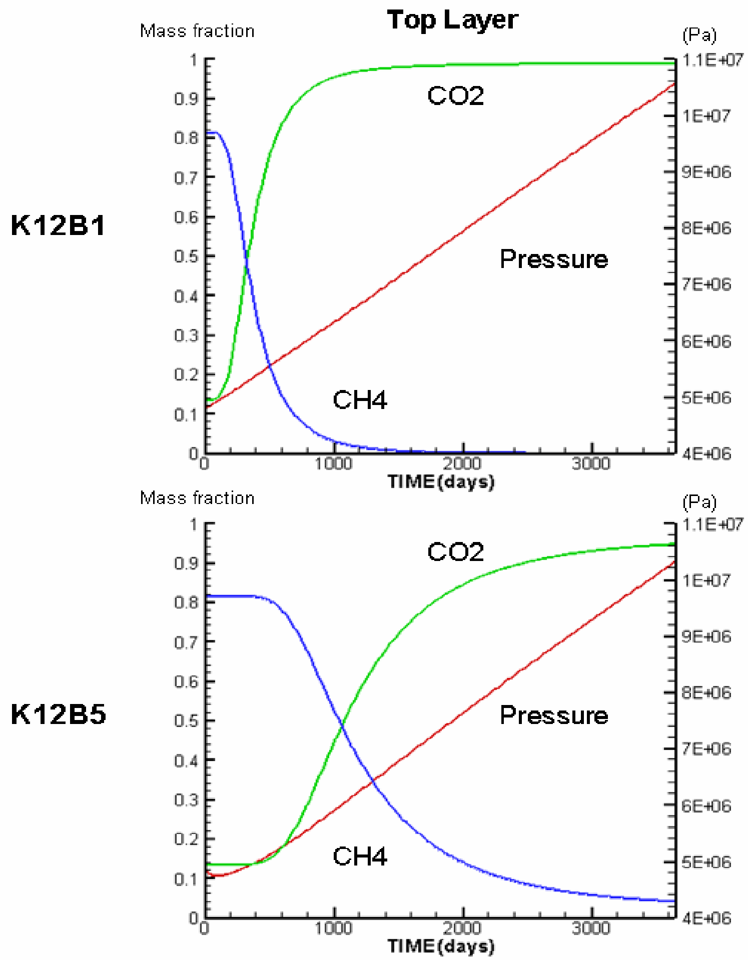
(Audigane et al. 2007b, AAPG special publication on Carbon Dioxide Sequestration in Geological Media)

- Enhanced Gas Recovery scenario envisaged
- CO_2 can flush CH_4 through permeable regions of the reservoir
- 10 kg/s injection
  - K12-B6
- 2 x 1 kg/s production
  - K12-B1 and K12-B5



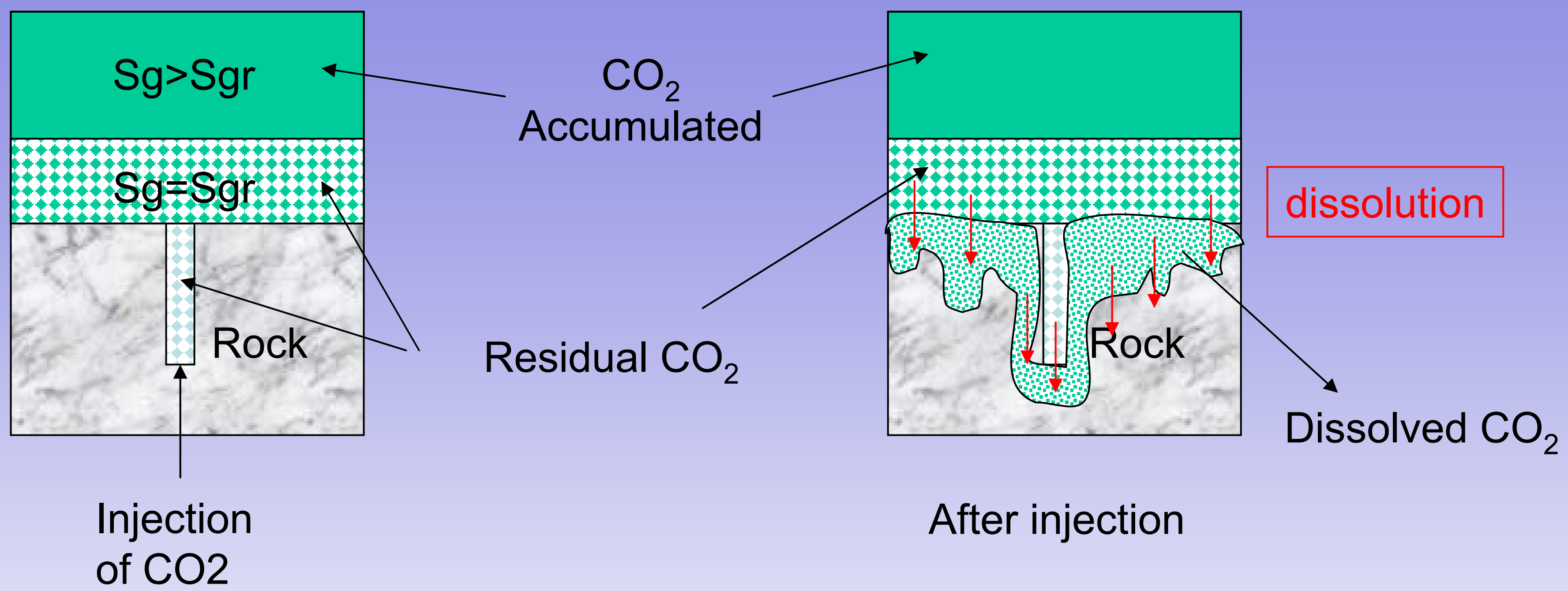
Breakthrough curves

- Breakthrough
  - K12-B1: 60 days (450 m away from B6)
  - K12-B5: 1 year (850 m from B6)
- 50% of CO_2
  - K12-B1: 1 year
  - K12-B5: 3 years
- End of injection
  - K12-B1: 100% CO_2
  - K12-B5: 95% CO_2
- Linear pressure increase
  - Closed system



Conclusions

- By combining in house and commercial codes BRGM is being able to provide modeling studies on geological storage of CO_2 focusing on different physical processes: trapping processes, injectivity efficiency and site integrity for short and long term predictions at different scales.
- Numerical modeling is a simplification of very complex systems. Interpretations of such modeling have to be supported by on site measurements for calibration.
- Limitations remain for specific cases:
  - Oil or gas field reservoir,
  - High saline aquifers
  - Desiccation
  - Coupling
  - CPU time and memory



- The residual gas part of CO_2 is not mobile
- But once dissolved, it does move because of gravity.
- Therefore the dissolution equilibrium is modified and does carry on to be equilibrated again.