Development and application of a coupled ECLIPSE – GeoSys modelling system for simulation of CO_2 storage in saline aquifers

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TRONDHEIM CCS CONFERENCE

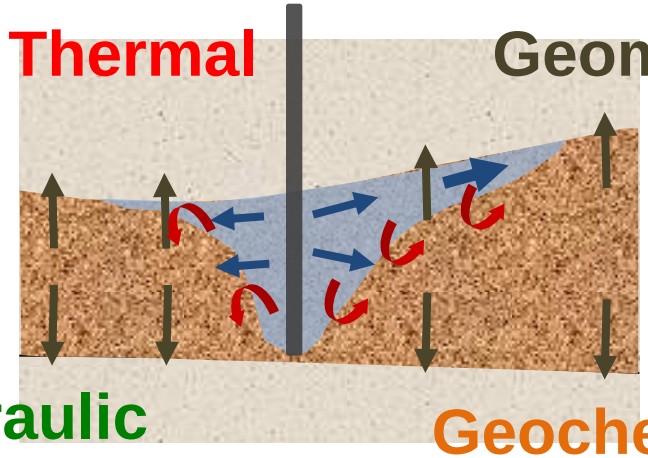
CO_2 CAPTURE, TRANSPORT AND STORAGE

Motivation

Simulation of CO_2 injection → THMC modelling system

Heat transport

$$\frac{\partial(u\varrho)}{\partial t} + \nabla \cdot (u\varrho \mathbf{v}) + \nabla \cdot (p\mathbf{v}) - \nabla \cdot (\lambda \nabla T)$$



Deformation

$$\nabla \vec{\sigma} - \rho \vec{g} = 0$$

Fluid dynamics

$$\frac{\partial(\rho_\alpha n S_\alpha)}{\partial t} - \nabla \cdot \left(\rho_\alpha \frac{k_{r\alpha} k}{\mu_\alpha} (\nabla p_\alpha - \rho_\alpha g) \right) - q_\alpha \rho_\alpha = 0$$

$$\sum_{\alpha=1}^{\alpha=n_{phase}} S_\alpha = 1$$

$$p_{c\alpha\beta} = p_\alpha - p_\beta = f(S_1, ..., S_{n_{phase}})$$

Transport und Reactions

$$\frac{\partial(n S_\alpha \rho_\alpha X_\alpha^\kappa)}{\partial t} + \nabla \left(v_\alpha \rho_\alpha X_\alpha^\kappa - n S_\alpha D_{DD,\,\alpha}^\kappa \nabla(\rho_\alpha X_\alpha^\kappa) \right)$$

$$x_\alpha^\kappa = H_\alpha^\kappa p_g^\kappa \qquad - q_\alpha^\kappa = 0$$

$$K_m = \prod_i a_i^{\nu_i} = exp(\frac{-\Delta G_0}{RT})$$

$$r_m = k_{m,T_0} \left(\frac{-E_a}{R} \left(\frac{1}{T} - \frac{1}{T_0} \right) \right) A_m \left[1 - \frac{Q_m}{K_m} \right]$$

OpenGeoSys (OGS)

= Scientific open-source code development for coupled **T**hermo-**H**ydro-**M**echanical-**C**hemical (**THMC**) systems in the environment

→ Object-oriented programming

→ Using Finite-Element-Method

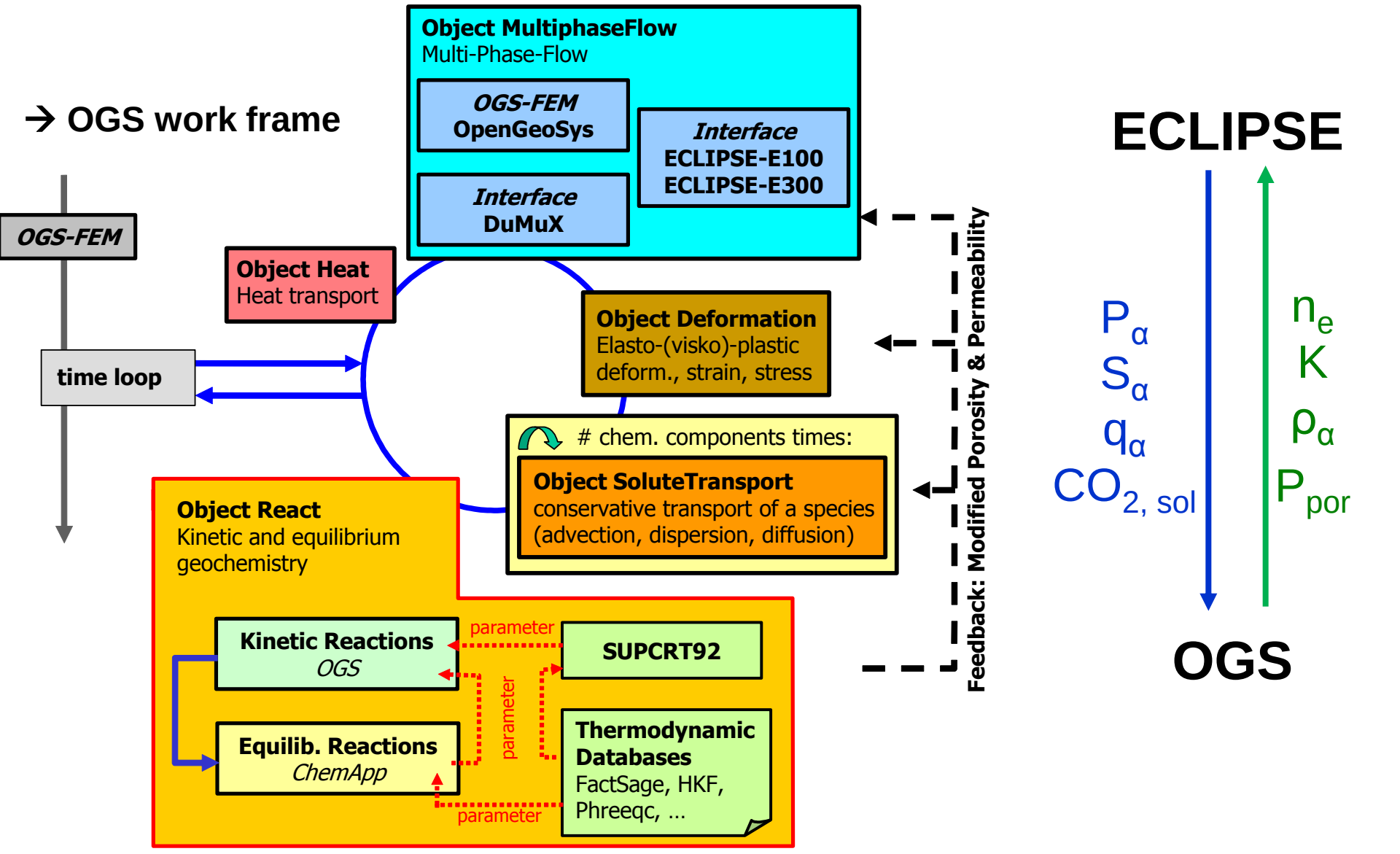
Schlumberger ©**ECLIPSE**

- widely used multiphase simulator
- Finite-Difference-Method
- CO_2Store option

Benefits of the OpenGeoSys-ECLIPSE coupling:

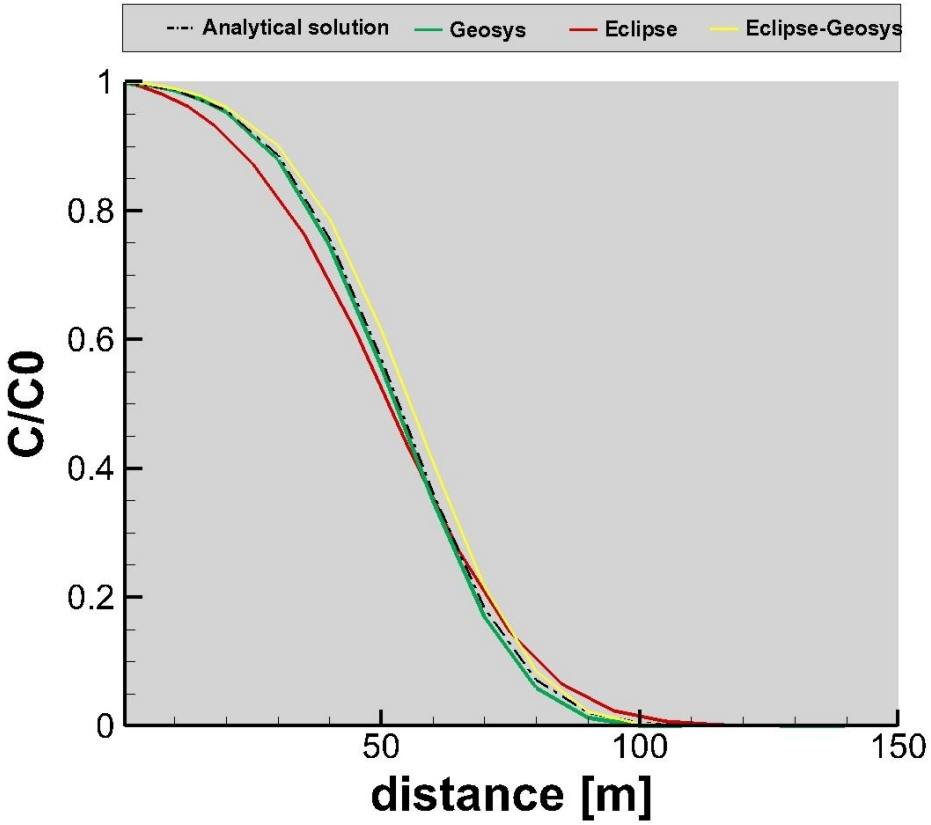
- benefit from the fast computation time of ECLIPSE
- Extend the capabilites of the ECLIPSE simulator for modelling CO_2 injection regarding Geochemistry and Geomechanics
- Using already existing fluid flow models build in ECLIPSE

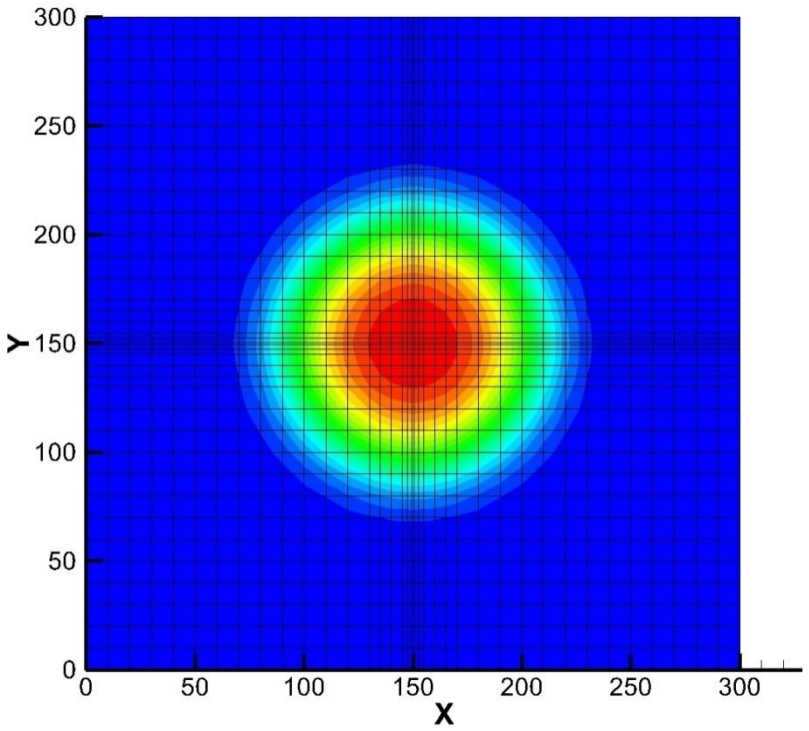
Implementation of the coupled code



Benchmark 1:

2D Tracer Transport in a 1Phase radial flow field (after Moench and Ogata,1981)

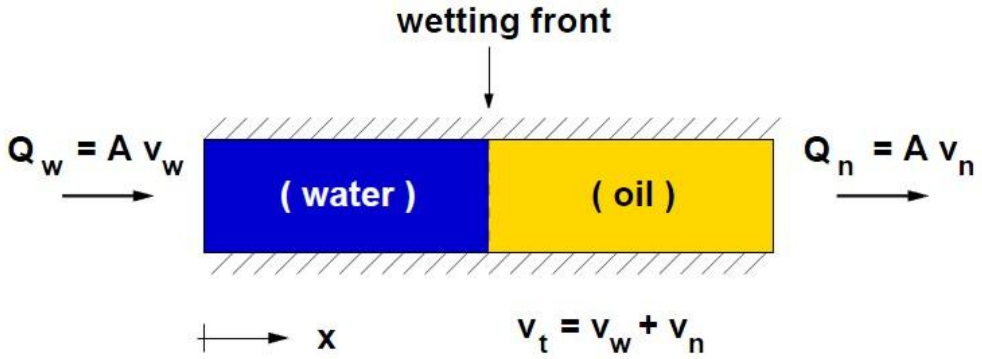




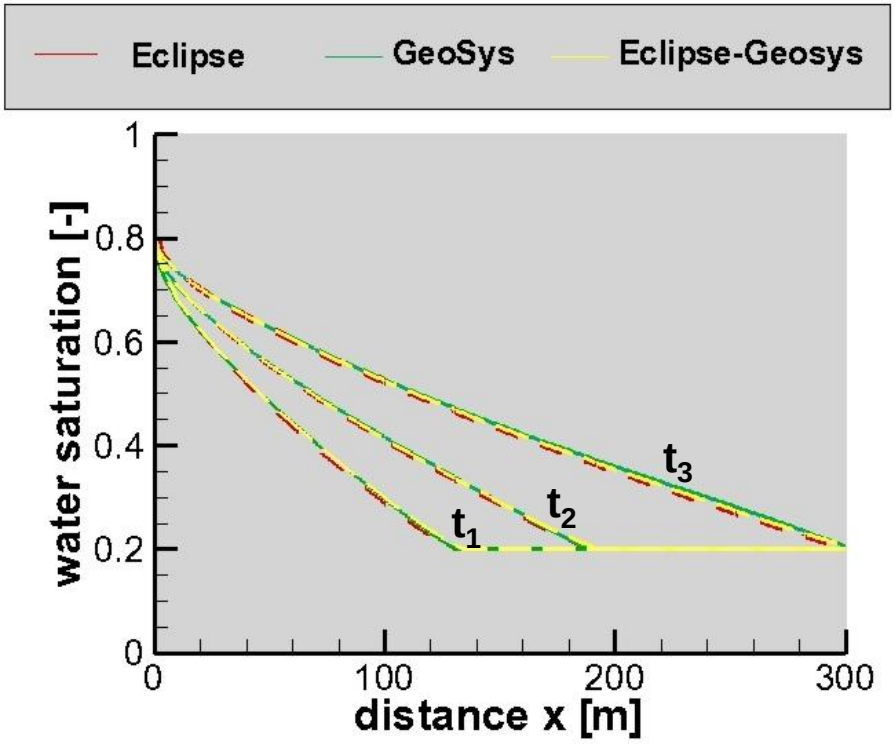
Good agreement of the coupled ECLIPSE-GeoSys code with the analytical solution.
Differences between the tracer fronts result from different mathematical methods which are used within the codes.

Benchmark 2:

Advective-dominated two phase flow in a homogeneous system (after Buckley and Leverett, 1942)



(Paul, 2003)

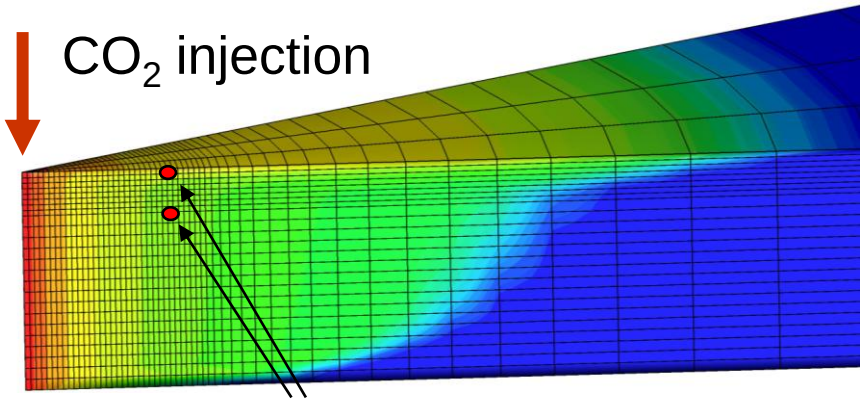


→ Linear k_r-S_w-function and p_c-S_w-function
→ GeoSys: PP formulation
→ ECLIPSE: PS formulation

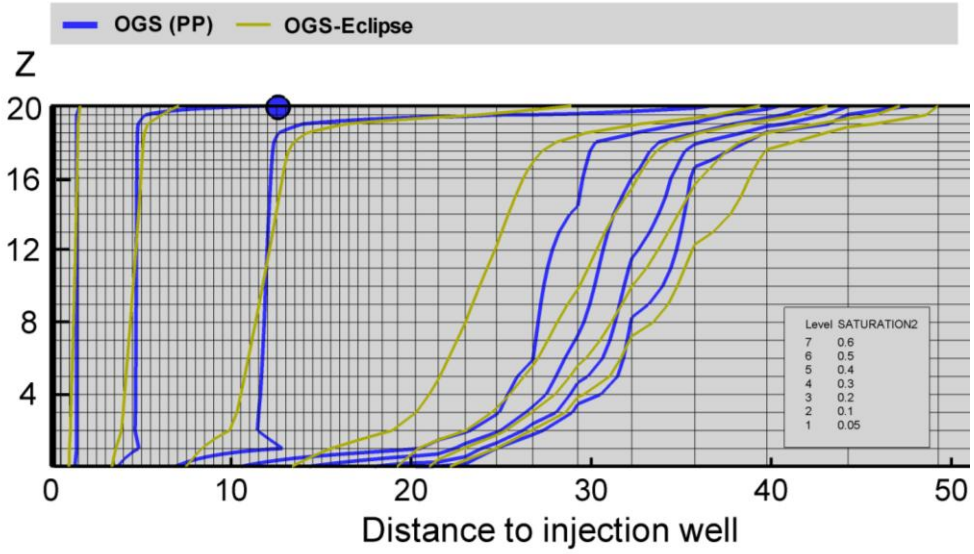
Benchmark 3:

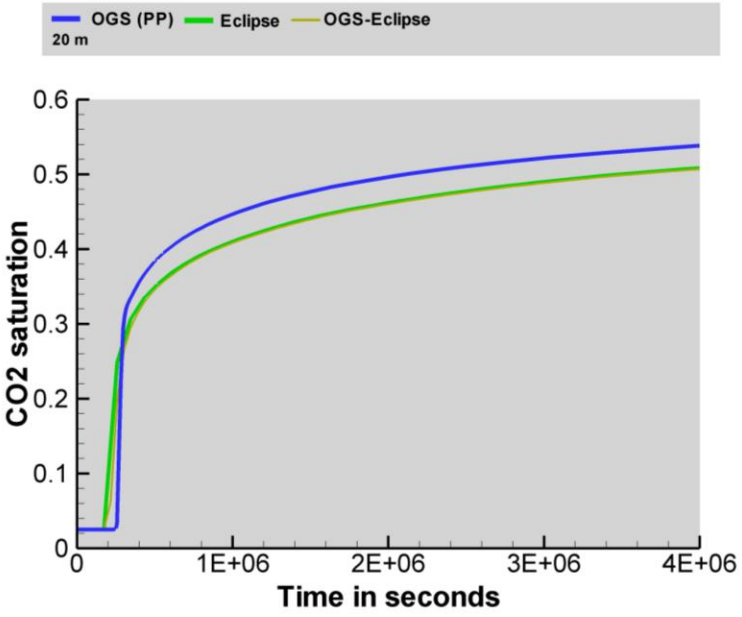
3D multiphase flow field with CO_2 injection

- Radial settings
  (injection left, boundary condition right)
- Adequate for model development
  and testing



Breakthrough





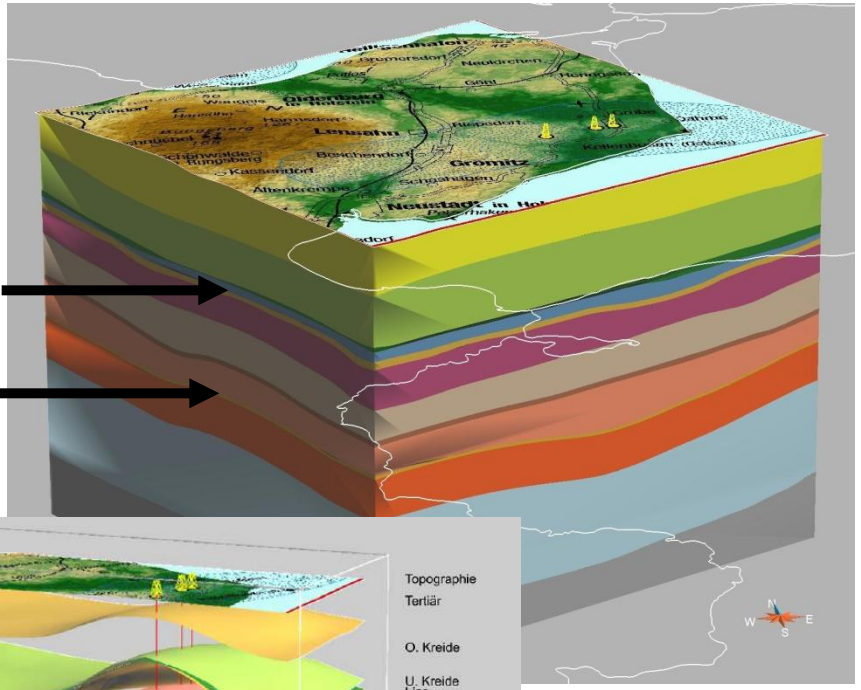
Field site application

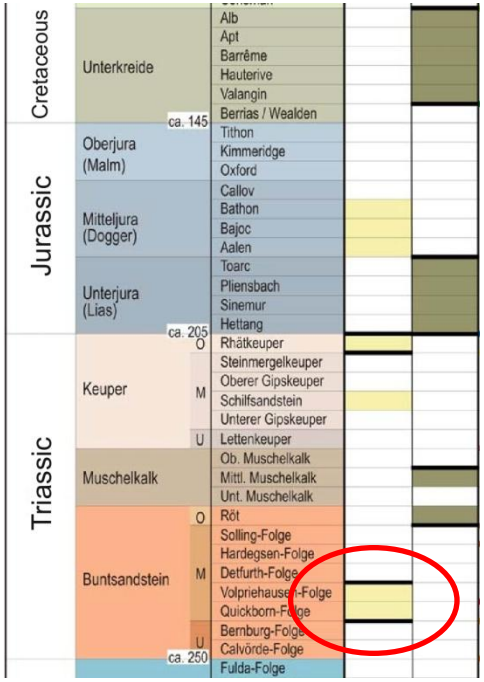
Geological Model:

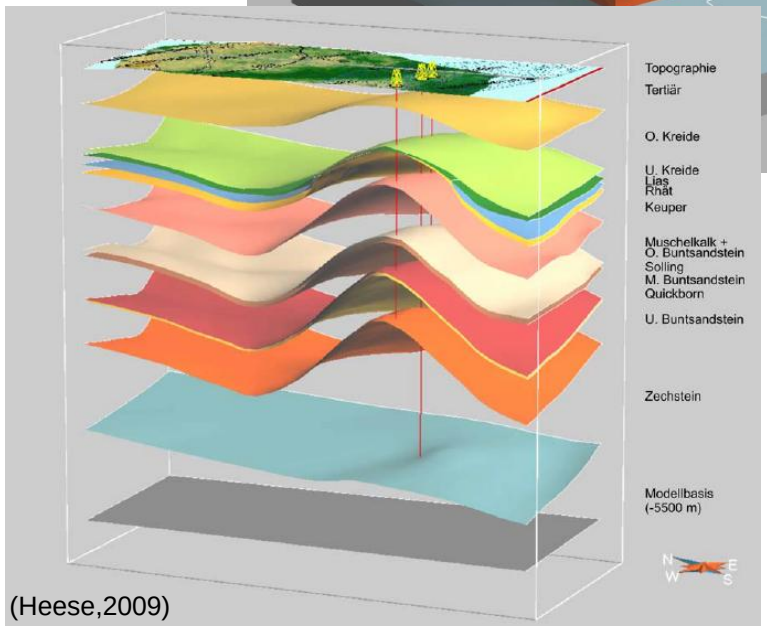
Extend: 29 x 28 km
Entire thickness ~ 5000 m

<u>Possible Storage Formations:</u>

1) Rhät Sandstone
2) middle Bunter Sandstone







(Heese,2009)

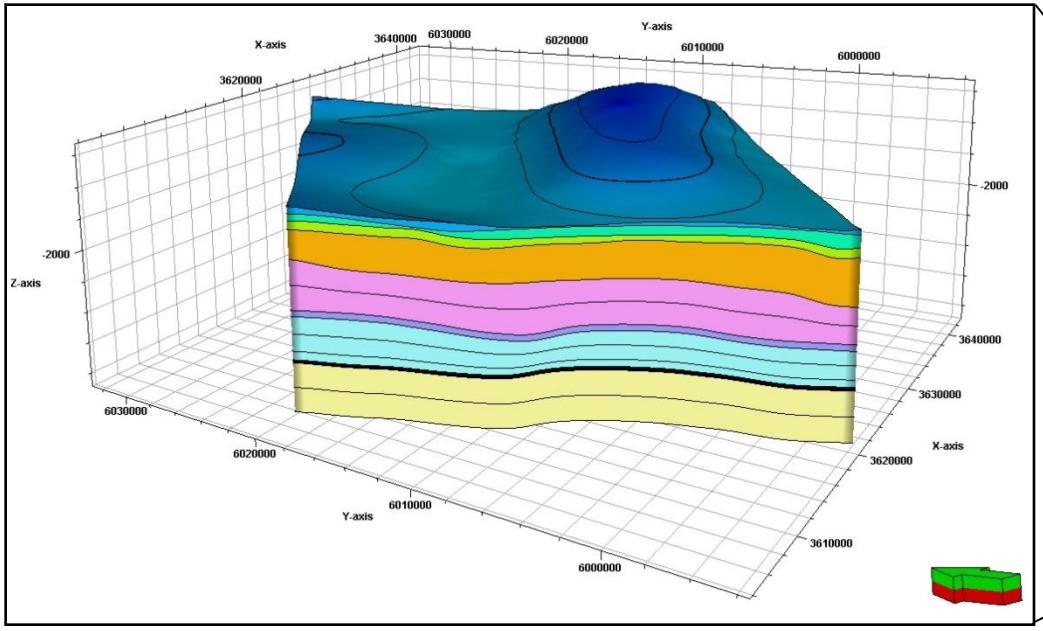
Field site application

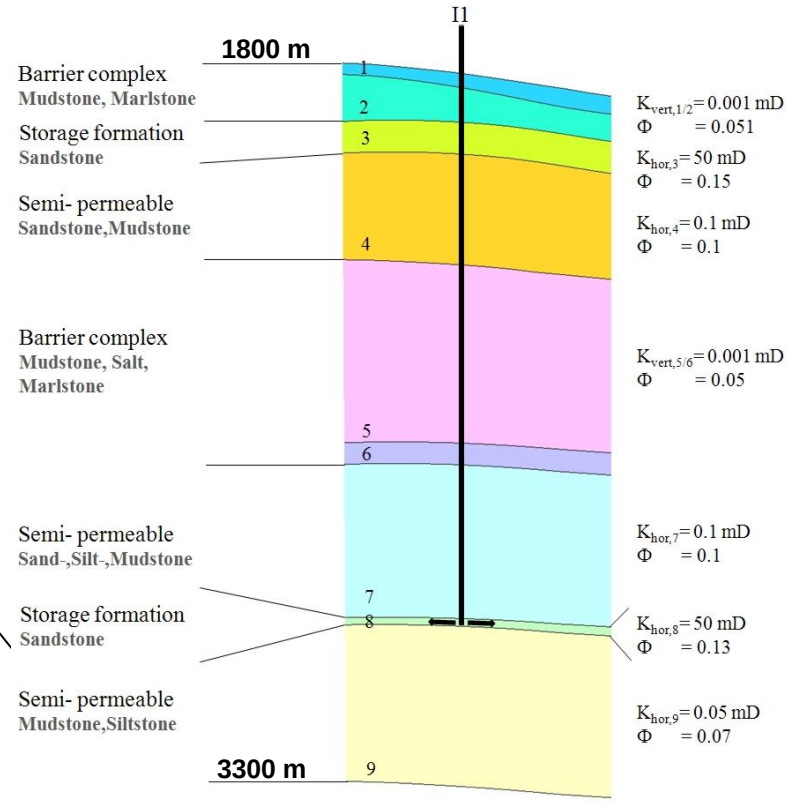
Simulation model

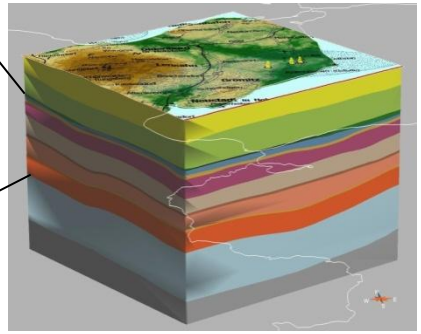
Entire thickness ~ 1500 m
Discretization: 65 x 111 x 23 cells

Szenario:

- CO_2 injection into the lower storage formation over a period of 20 years (1 Mio tons per year)
- 70 years post-injective simulation



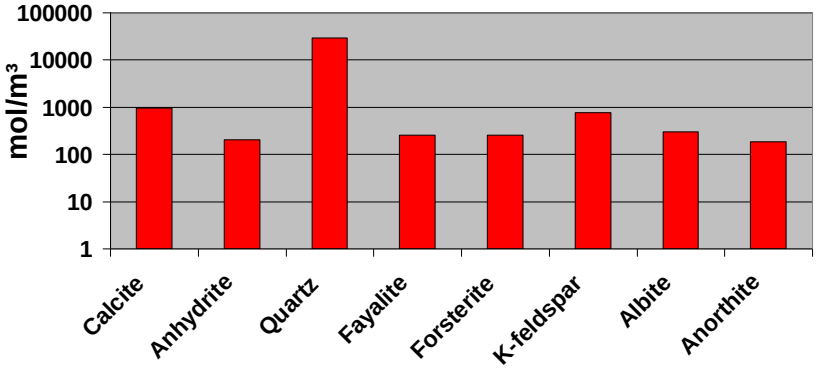




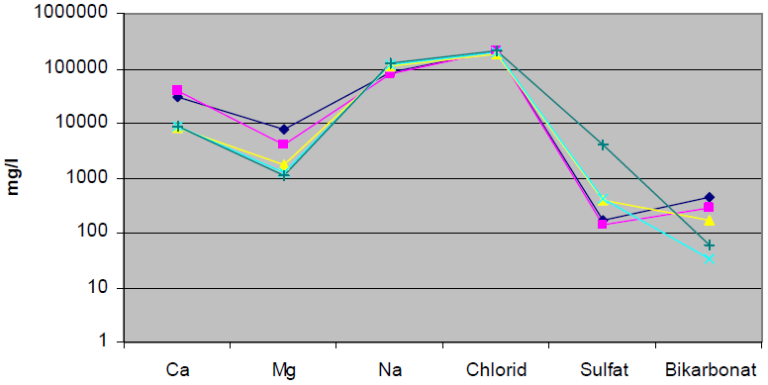
Field site application

Geochemical modelling:
Characterisation of the storage rock and formation water

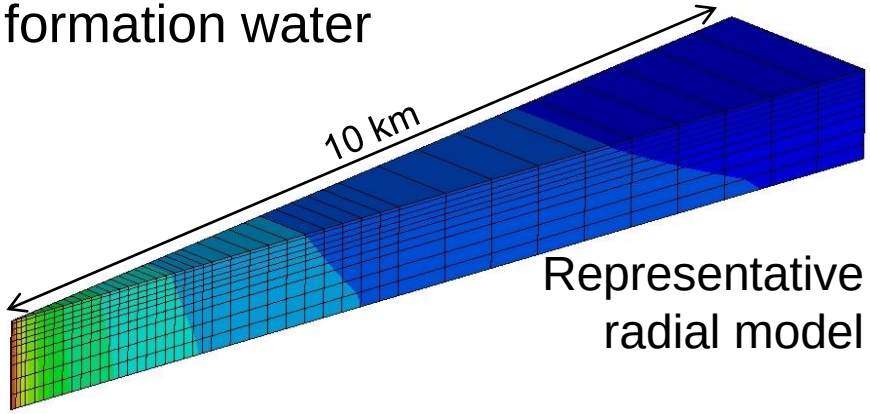
Mineral composition



Brine composition

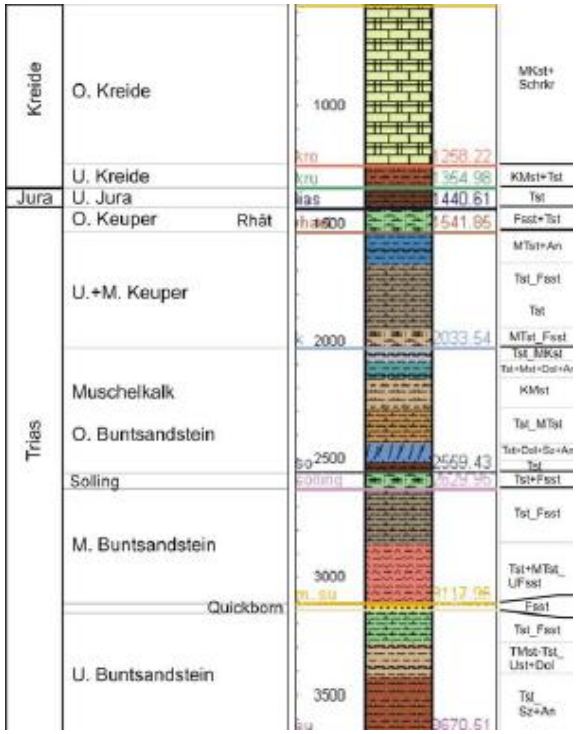


(Heese,2009)



Representative radial model

Lithology information

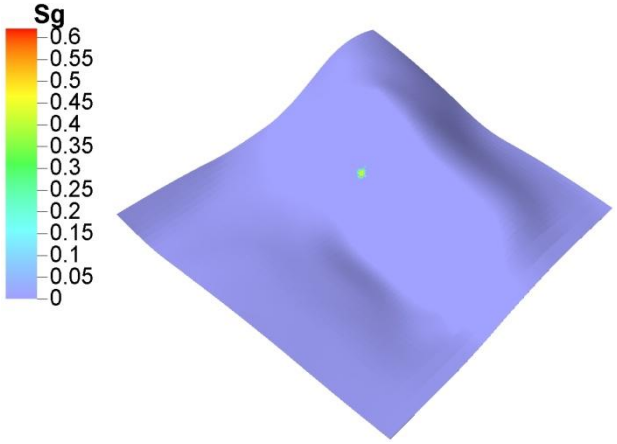


(Heese,2009)

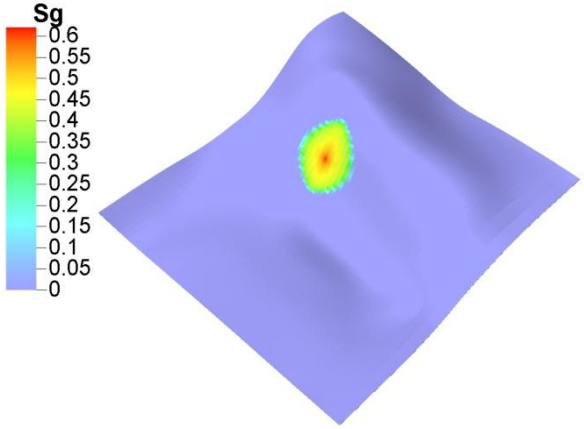
Simulation results of the coupled code:
1) Pressure build up and phase propagation

Phase propagation after:

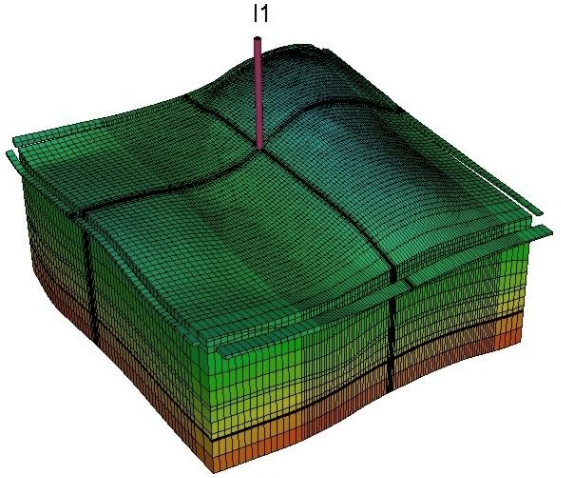
a) Injection start



b) Injection stop

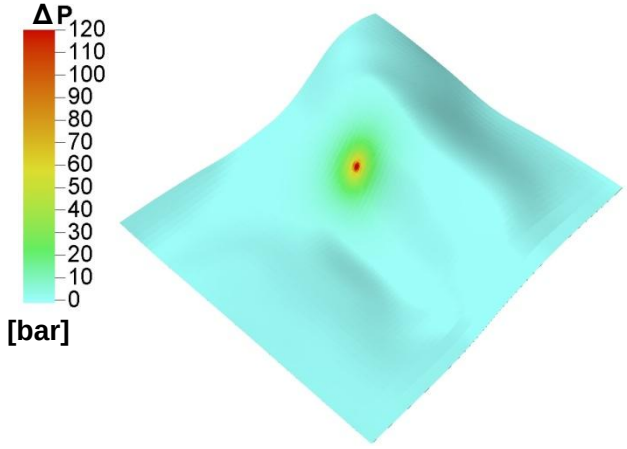


Simulation grid
(4 times exaggerated)

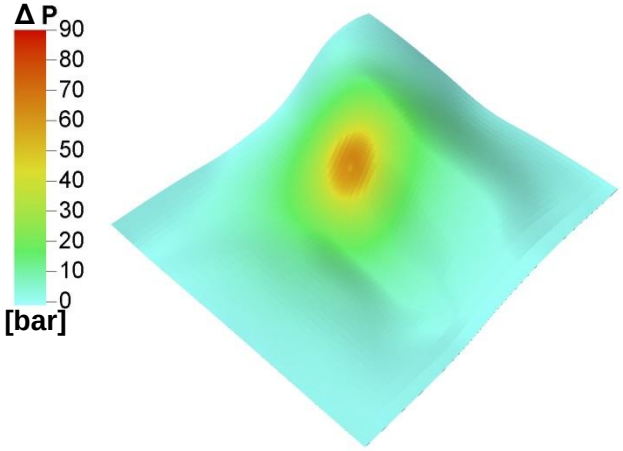


Pressure change after:

a) Injection start

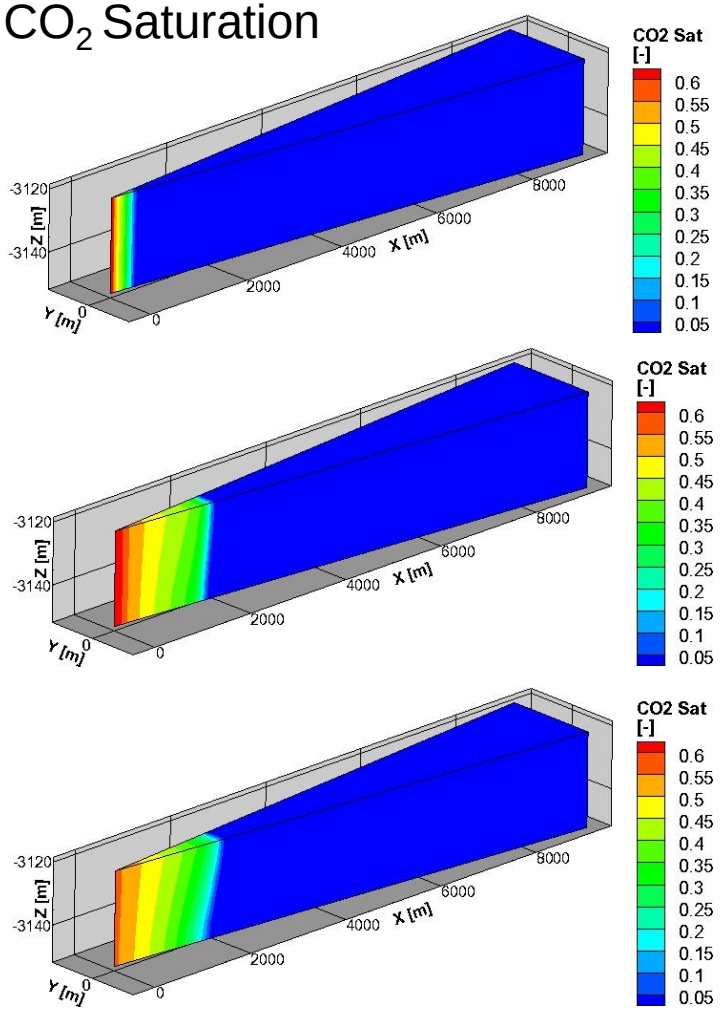


b) Injection stop

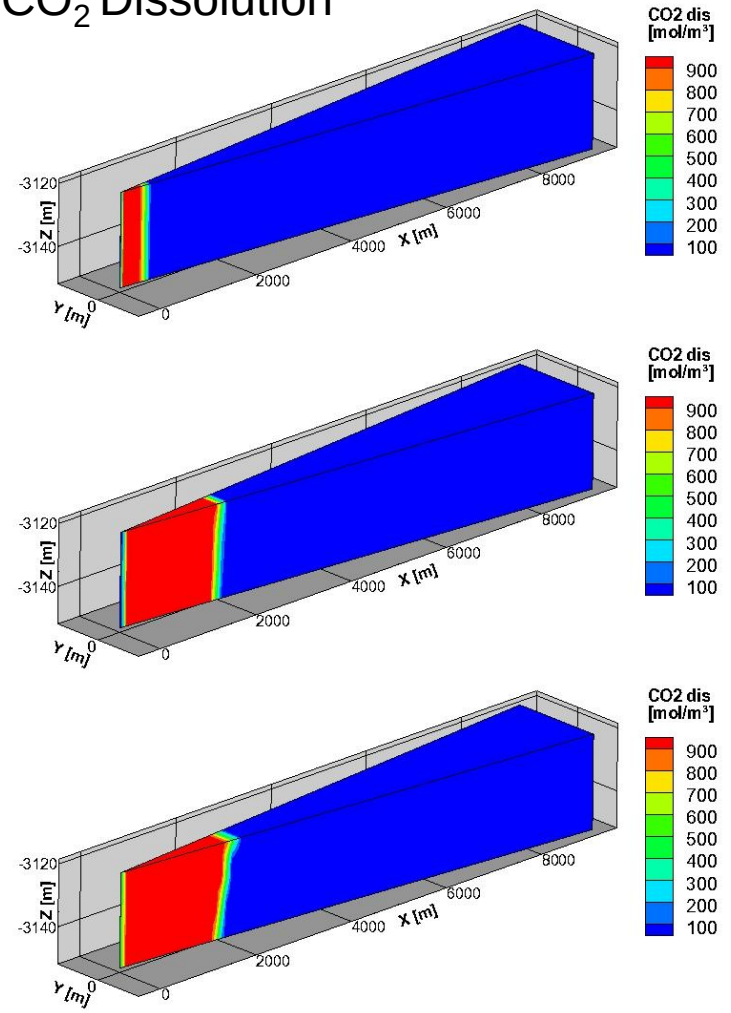


Simulation results of the coupled code: 2) Geochemical modelling

CO_2 Saturation



CO_2 Dissolution

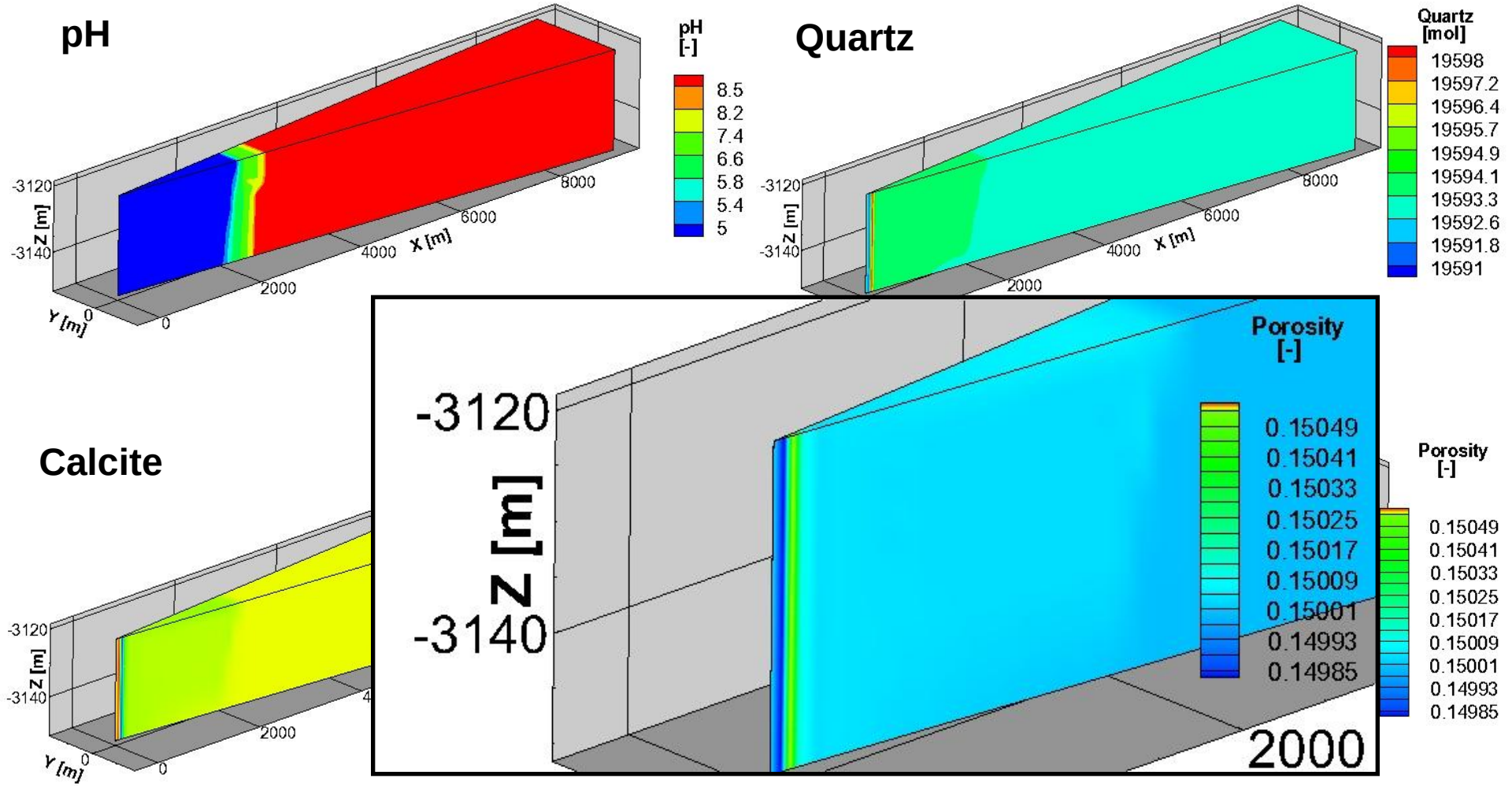


10 days

20 years

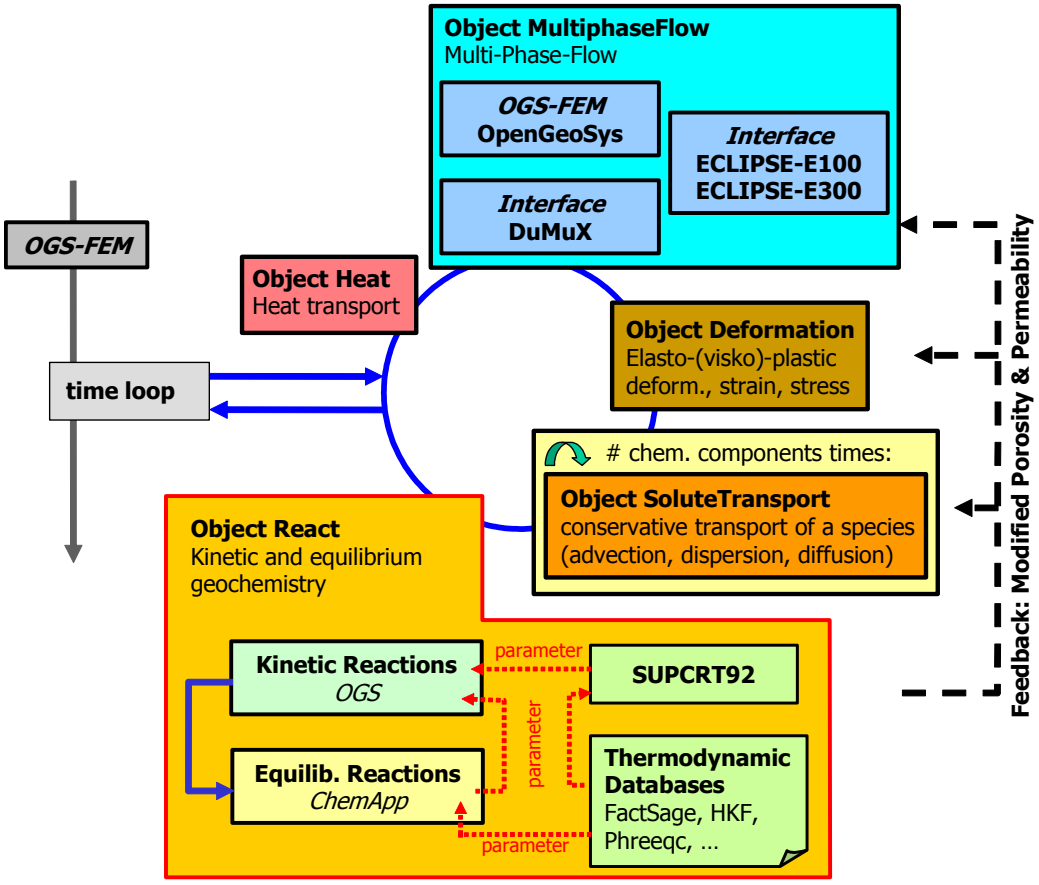
90 years

Simulation results of the coupled code:
2) Geochemical modelling after 90 years



Next steps

- Increasing computation efficiency
  → Multiphase flow
  → Geochemistry
- Mechanical feedback on multiphase flow (OGS→ECLIPSE)
- Further code verification
- More large scale applications
  → Geochemistry



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THANKS FOR YOUR ATTENTION

Greetings from Kiel