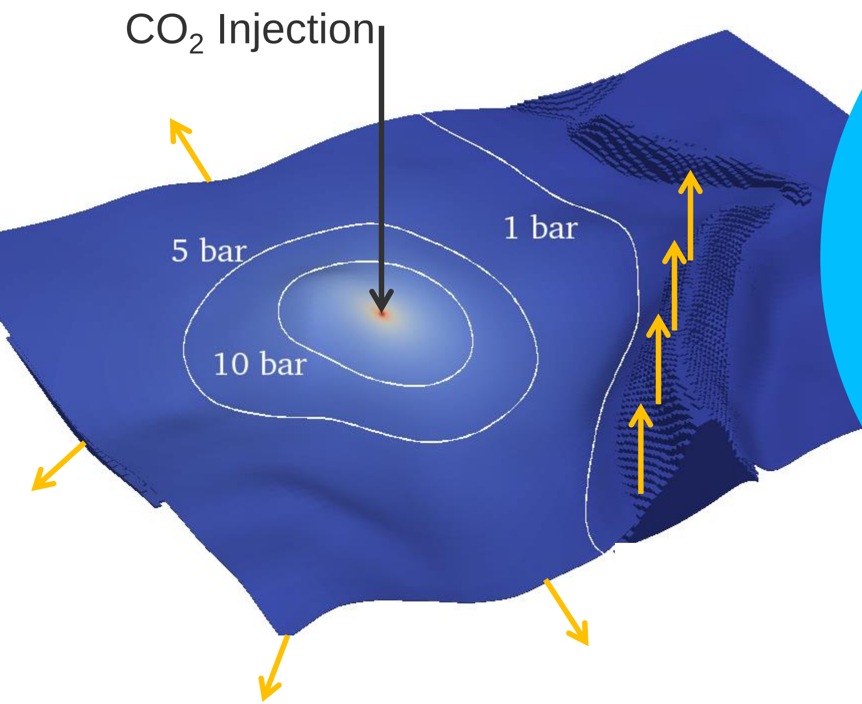
University of Stuttgart
Institute for Modelling Hydraulic and Environmental Systems
Department of Hydromechanics and Modelling of Hydrosystems



Assessment of brine migration along vertical pathways due to CO_2 injection

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GEOTECHNOLOGIEN
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Bundesministerium für Bildung und Forschung

Motivation

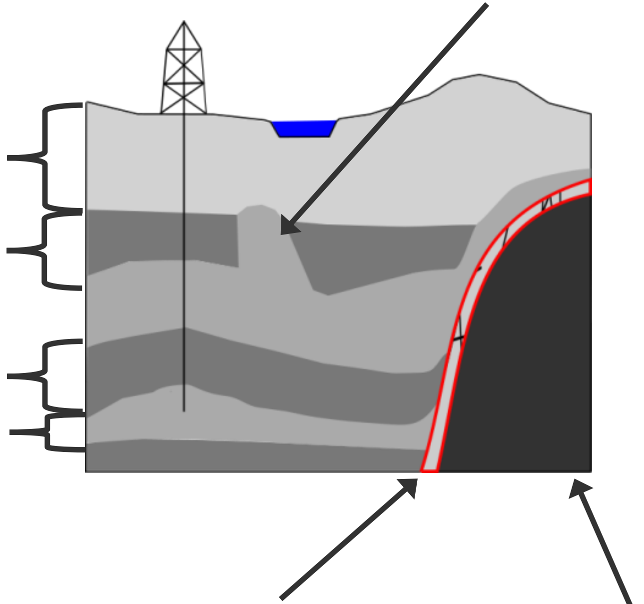
- Deep saline aquifers are an option for the storage of CO_2 or the disposal of waste water
- The injection of fluids causes an increase in pressure reaching far beyond the radius of the plume of the injected fluid

→ The prediction of leakage or pressure evolution requires the consideration of both **large horizontal** and **vertical scales**

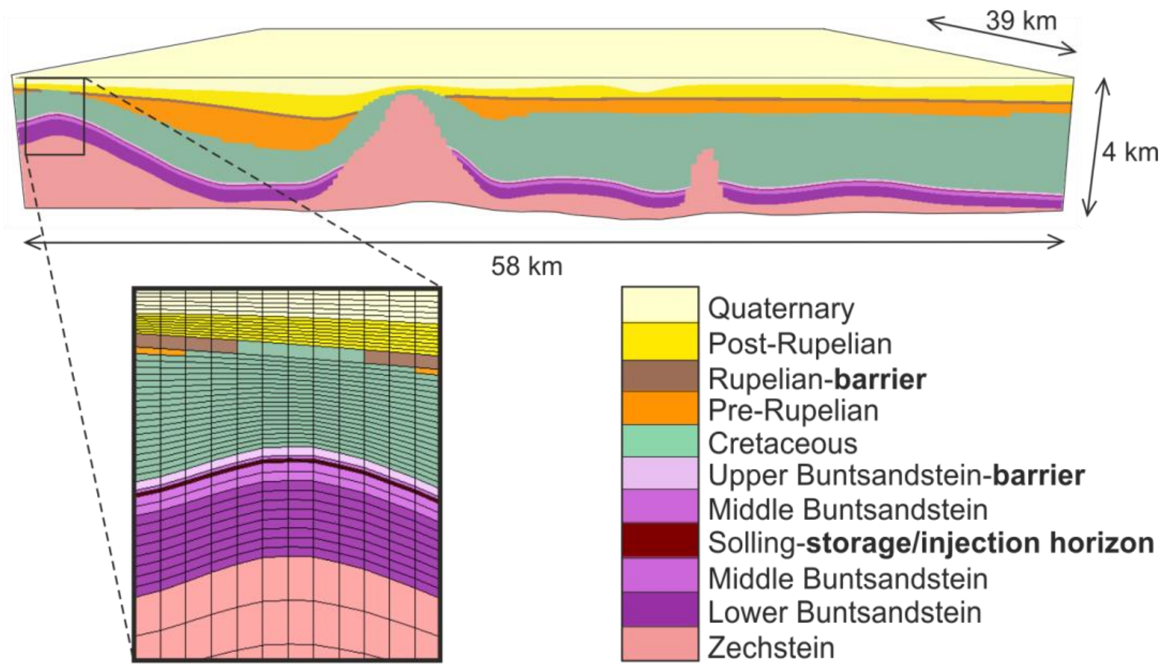
What is the appropriate level of model complexity for describing brine displacement due to CO_2 injection?

- Challenges: Relevant physical processes, data uncertainty, and computational demand
- Different numerical and analytical approaches of varying complexity
- Approach: Investigate the effect of different model simplifications on **large-scale leakage** and **pressure evolution** due to CO_2 injection in a realistic geological model based on the North German Basin

Important features of the system characteristic to the North German Basin



Geological model

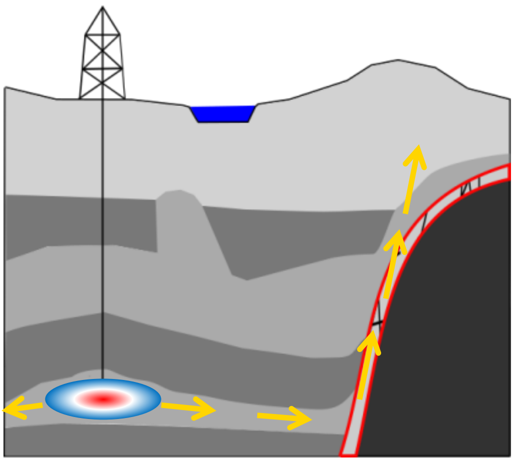


Data for layers

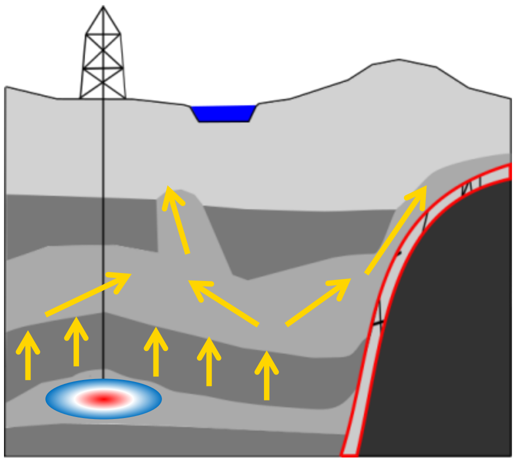
Layer	Lithology	Thickness [m]	Porosity [%]	Permeability [m^2]	
Quaternary 1	sand, gravel	100	20	6×10^{-11}	shallow aquifers
Quaternary 2	sand, gravel	200	20	1×10^{-12}	
Tertiary post-Rupelian	sand, silt	400	15	1×10^{-13}	
Tertiary Rupelian	clay	80	10	1×10^{-18}	barrier
Tertiary pre-Rupelian	sand, sandstone	350	10	1×10^{-13}	intermediate aquifers
Cretaceous	chalk, claystone	900	7	1×10^{-14}	
Upper Buntsandstein	salt, anhydrite, claystone	50	4	1×10^{-18}	barrier
Upper Middle Buntsandstein	siltstone	20	4	1×10^{-16}	
Solling	sandstone	20	20	1.1×10^{-13}	injection
Lower Middle Buntsandstein	siltstone	110	4	1×10^{-16}	semi-permeable layers
Lower Buntsandstein	clay- and siltstone	350	4	1×10^{-16}	
Permian Zechstein	rock salt	-	0	0	
Fault zone	-	50	30	1×10^{-12}	

Vertical pathways

Focused leakage over fault zone



Diffuse leakage over barrier

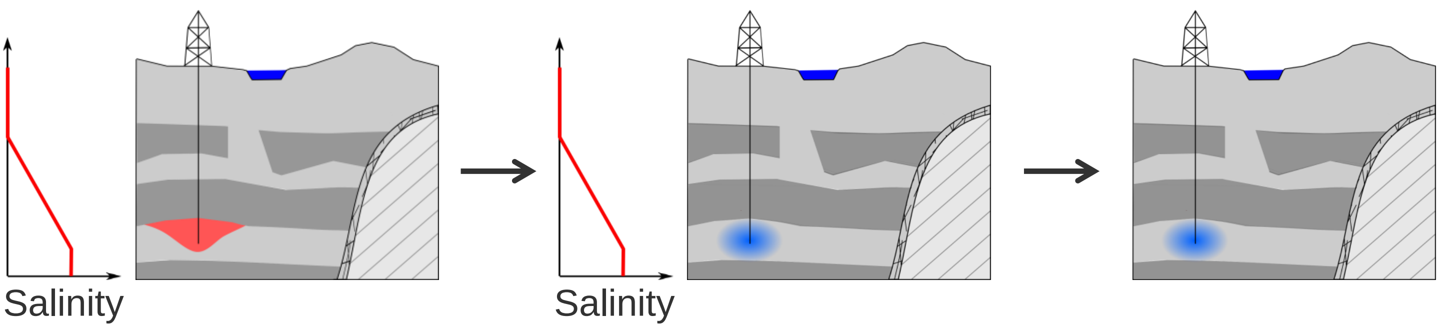


Reducing complexity

CO_2 injection
- Two phase flow
- Salt transport

Reference
- Water injection
- Salt transport

No salt transport
- Water injection

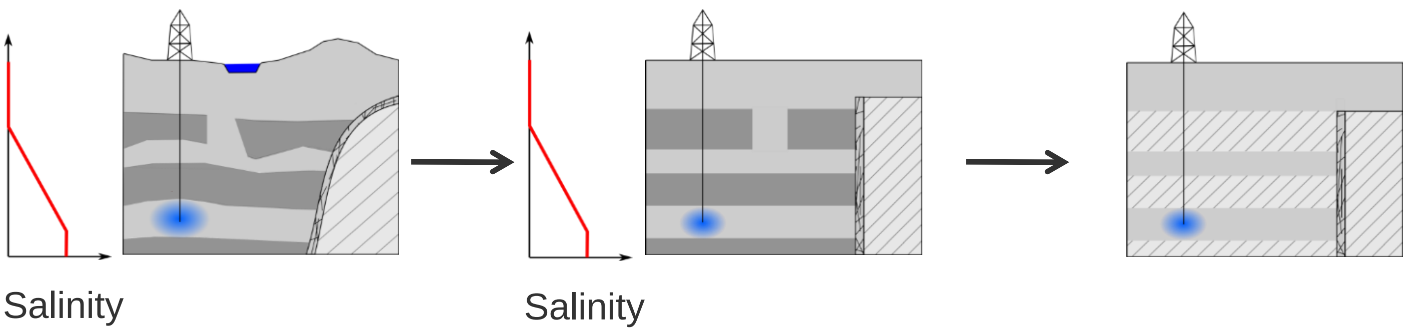


Reducing complexity

Reference
- Realistic geometry
- Water injection
- Salt transport

Simplified geometry
- Stratified geometry
- Water injection
- Salt transport

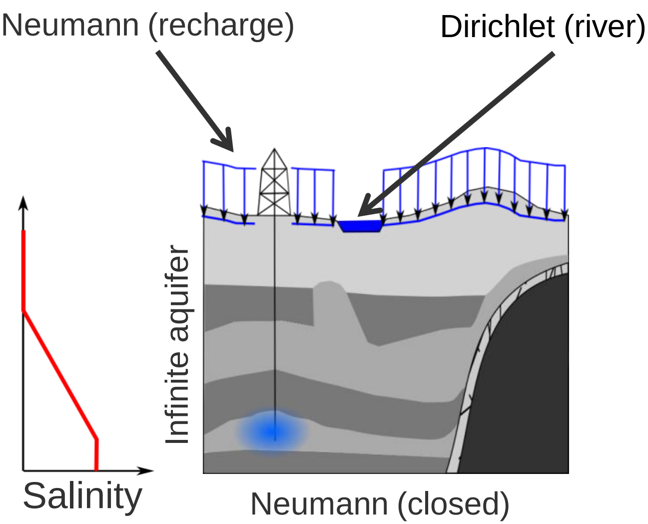
Analytical solution
- after Zeidouni (2012)
- Water injection
- No salt transport
- No diffuse leakage



Zeidouni, M. (2012). Analytical model of leakage through fault to overlying formations. Water Resources Research, 48(12). http://doi.org/10.1029/2012WR012582

Numerical models: boundary and initial conditions

- **Injection period 100 years**
  50 years injection + 50 years post-injection
- **Constant injection rate of 0.5 Mt per year**

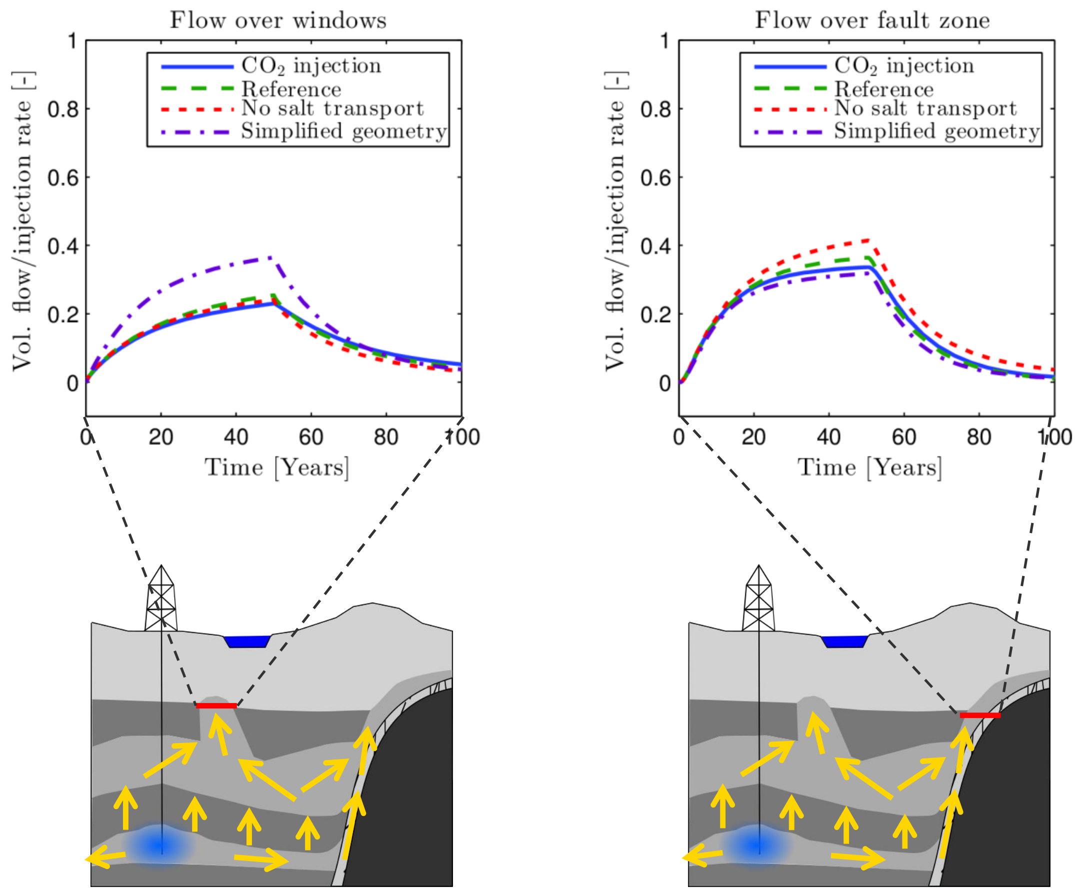


Implementation in DuMuX

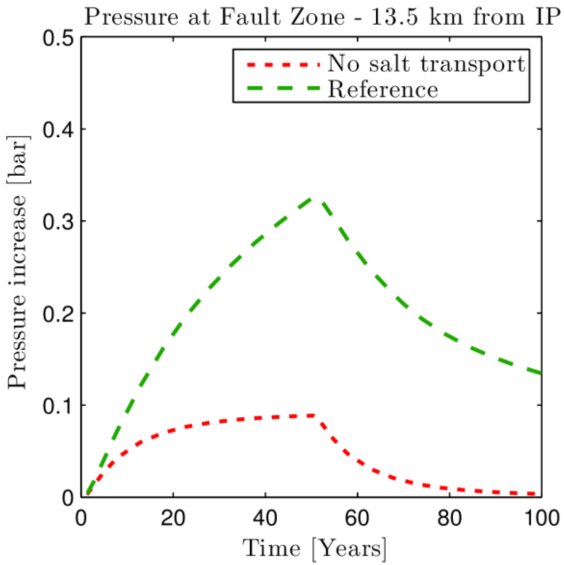
Schwenck, N., Beck, M., Becker, B., Class, H., Fetzer, T., Flemisch, B., … Weishaupt, K. (2015, September). DuMuX 2.8.0. doi:10.5281/zenodo.31611

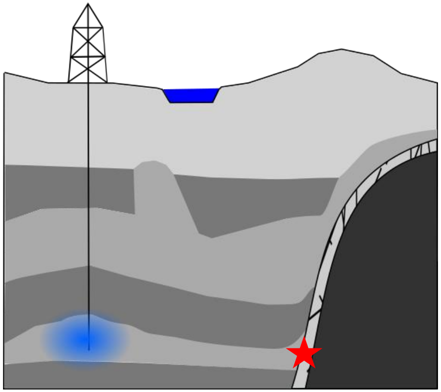
Diffuse and focused leakage scenario

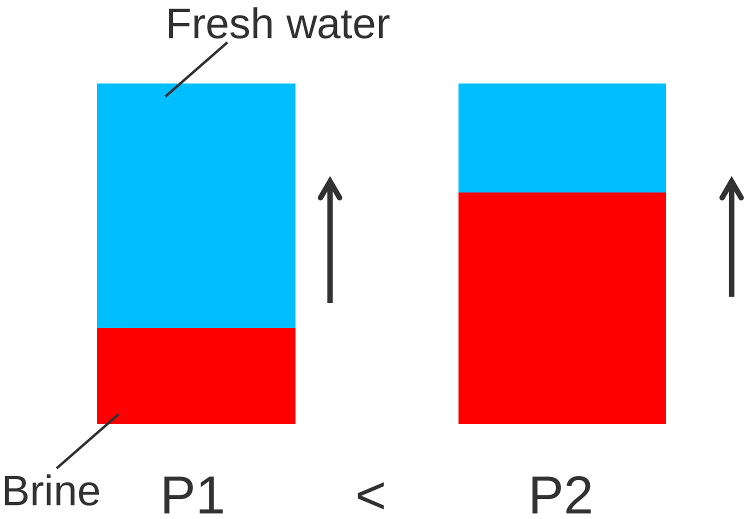
Upper Buntsandstein barrier permeability: $k = 10^{-18}\ \mathrm{m}^2$



Importance of variable-density flow on pressure increase at the fault zone

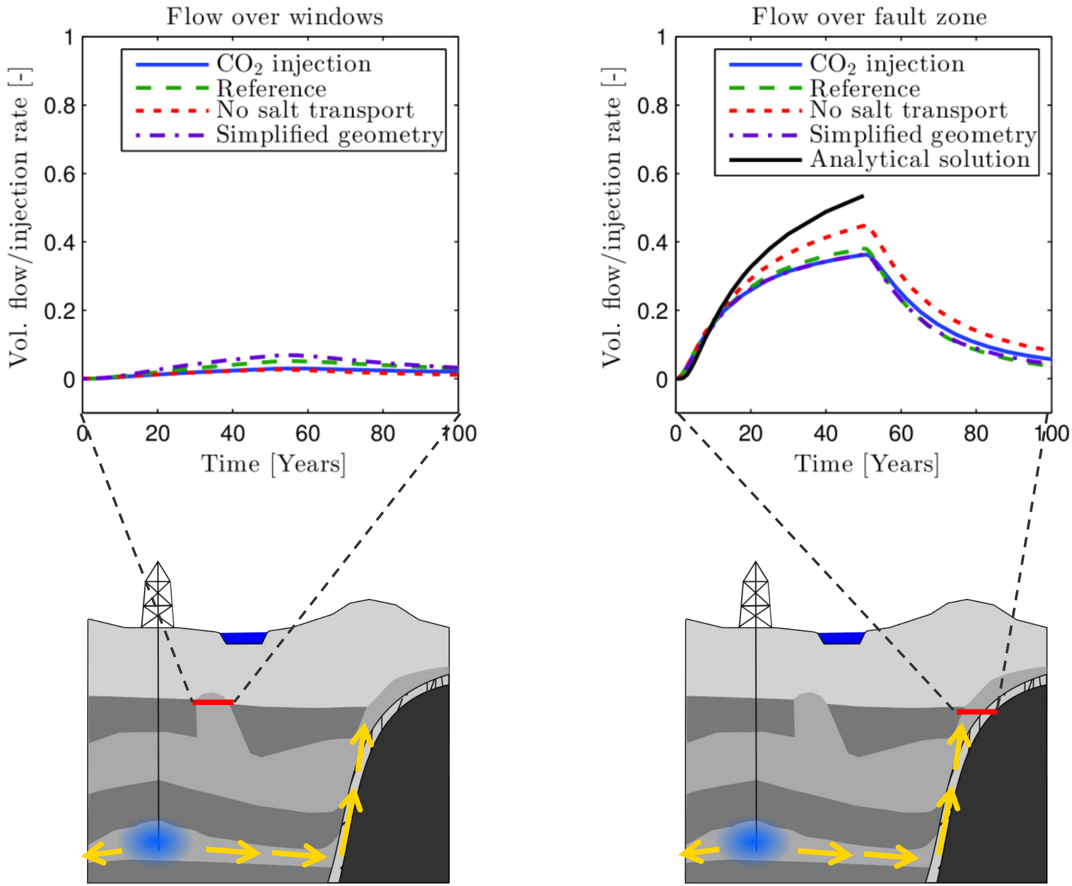




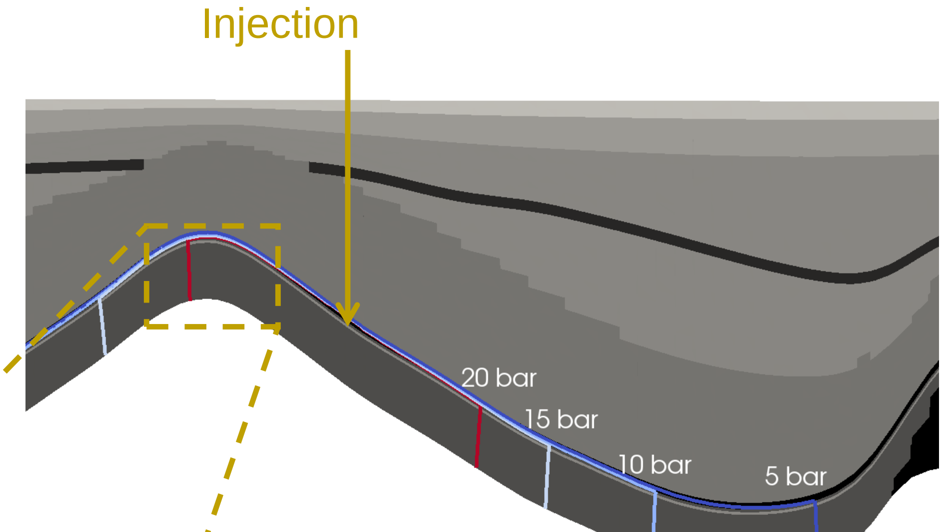


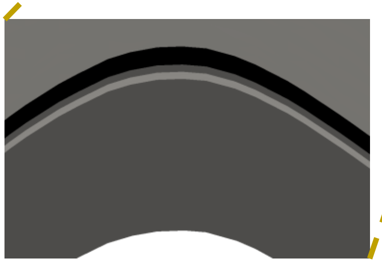
Focused leakage scenario

Upper Buntsandstein barrier permeability: $k = 10^{-20}\ \mathrm{m}^2$



Importance of semi-permeable layers on leakage





Injection horizon Solling:

$$L_{Sol} = 20 \text{ m}$$
$$k_{Sol} = 1.1 \cdot 10^{-13} \text{ m}^2$$
$$\phi_{Sol} = 0.2$$

Semi-permeable surrounding layers of Middle Buntsandstein:

$$L_{Semi} = 480 \text{ m}$$
$$k_{Semi} = 1.0 \cdot 10^{-16} \text{ m}^2$$
$$\phi_{Semi} = 0.04$$

Importance of semi-permeable layers on leakage

Injection horizon diffusivity:

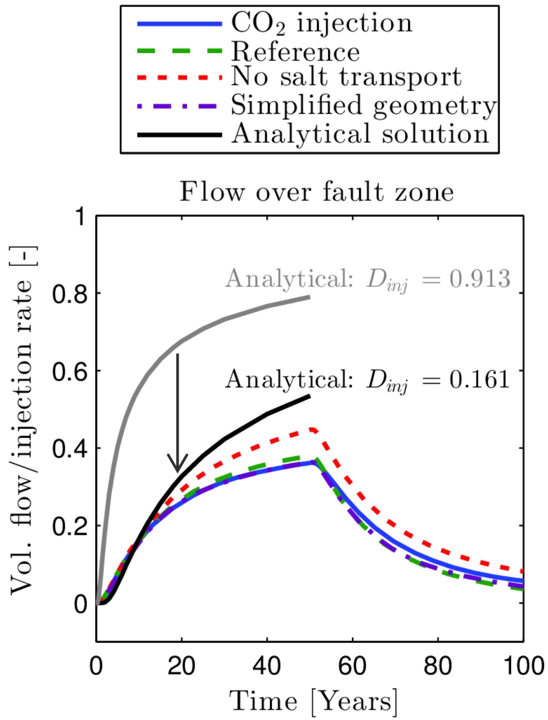
$$D_{inj} = \frac{k}{\mu \phi C_{tot}}$$

Considering **only** the 20m thick Solling:

$$D_{inj} = 0.913$$

Vertical averaging of surrounding semi-permeable layers with the injection horizon Solling:

$$D_{inj} = 0.161$$



Summary and outlook

- If **leakage** into shallow aquifers is the target variable the model simplifications show acceptable agreement, especially when considering the uncertainty inherent to the hydrogeological parametrization
- The **semi-permeable layers** embedding the injection horizon Solling are an important component of the system significantly influencing the leakage rates
- The prediction of **pressure increase** near the fault zone is very sensitive to model assumptions, especially variable-density flow

- **Outlook:** Results can give valuable input for the design of a **basin-scale model** of the North German Basin including multiple CO_2 injection sites

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CO_2BRIM

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This work was funded by the German Federal Ministry of Education and Research **(BMBF)** and the German Research Foundation **(DFG)** within the geoscientific research and development program **GEOTECHNOLOGIEN.**

Thank you!

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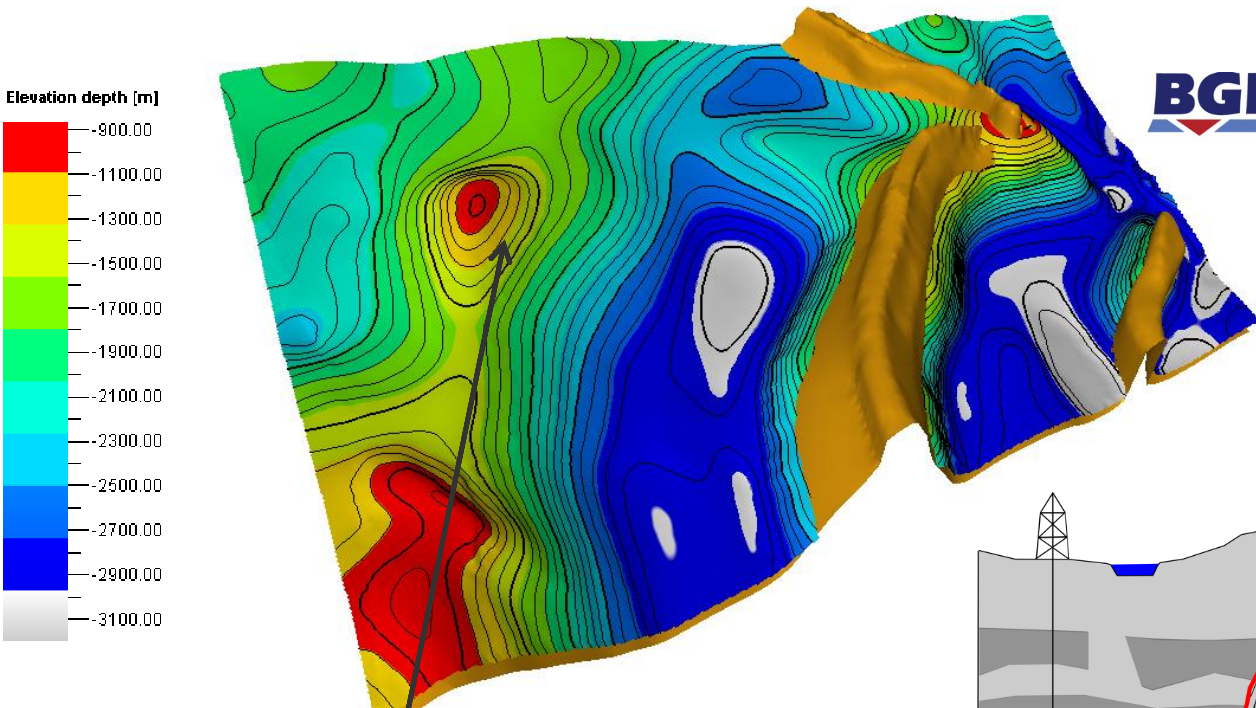
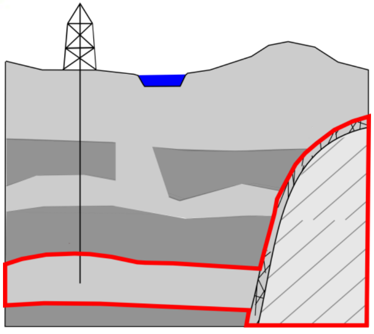
Injection layer

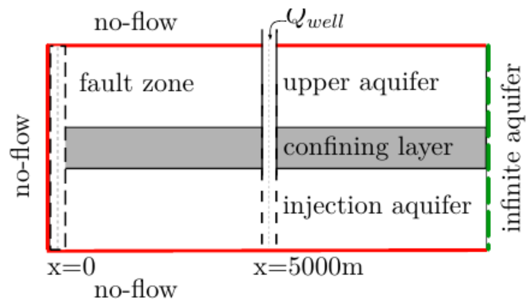
Bundesanstalt für Geowissenschaften und Rohstoffe

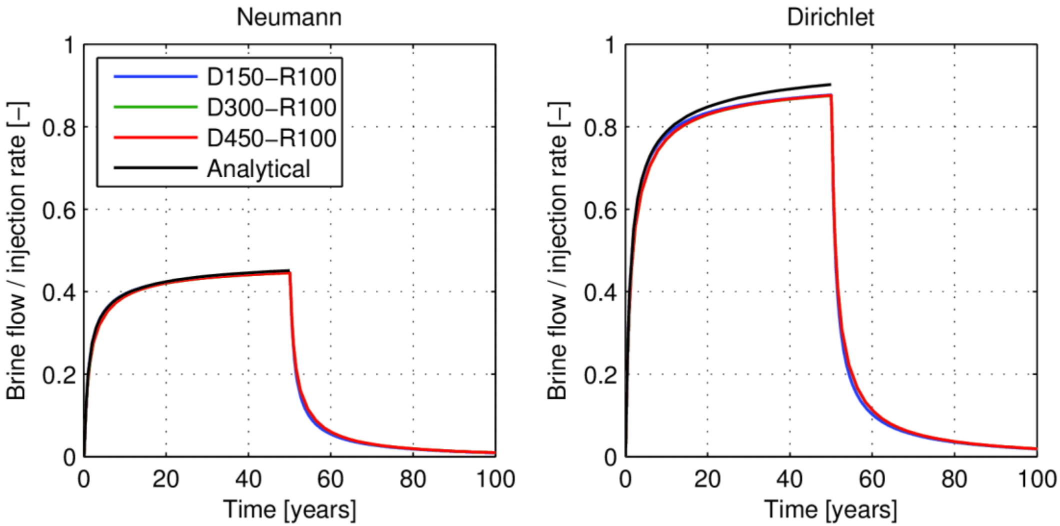


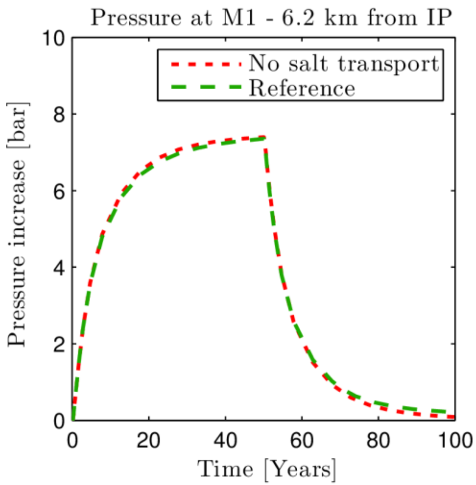


Injection point at ca. 1500 m depth
at the flank of the anticline

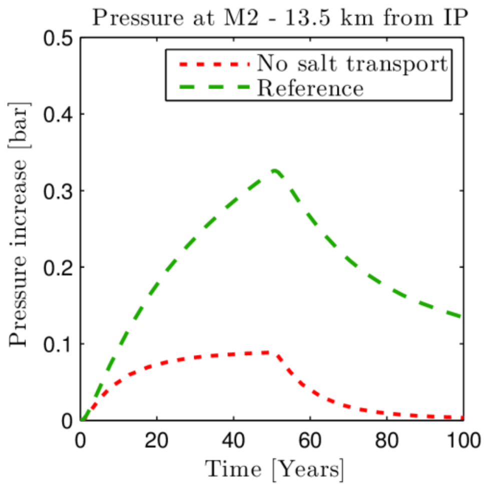
Backup: Analytical solution



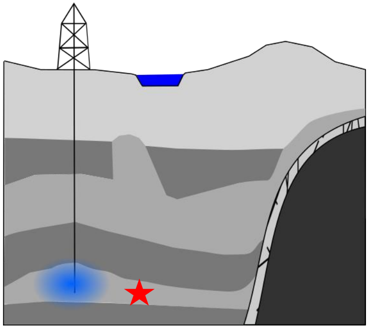


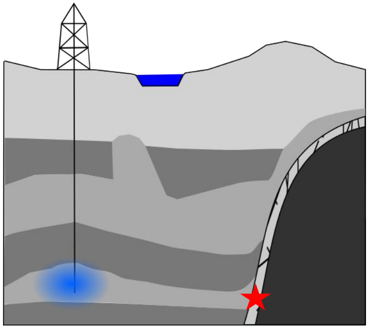


Pressure at M1 - 6.2 km from IP
No salt transport
Reference
Pressure increase [bar]
Time [Years]
0
20
40
60
80
100
0
2
4
6
8
10



Pressure at M2 - 13.5 km from IP
No salt transport
Reference
Pressure increase [bar]
Time [Years]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5





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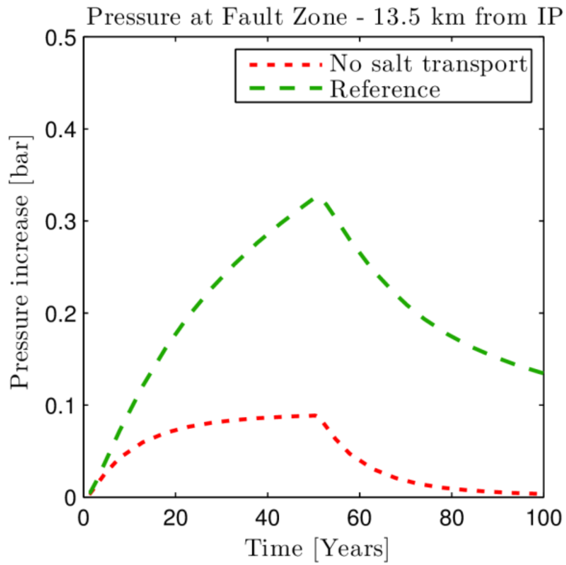

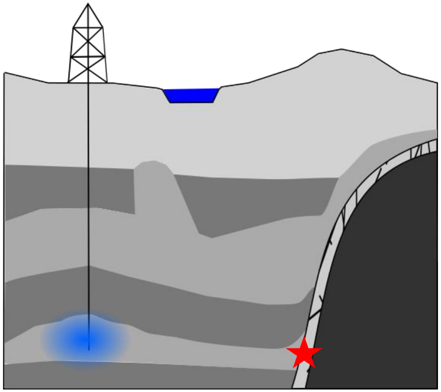

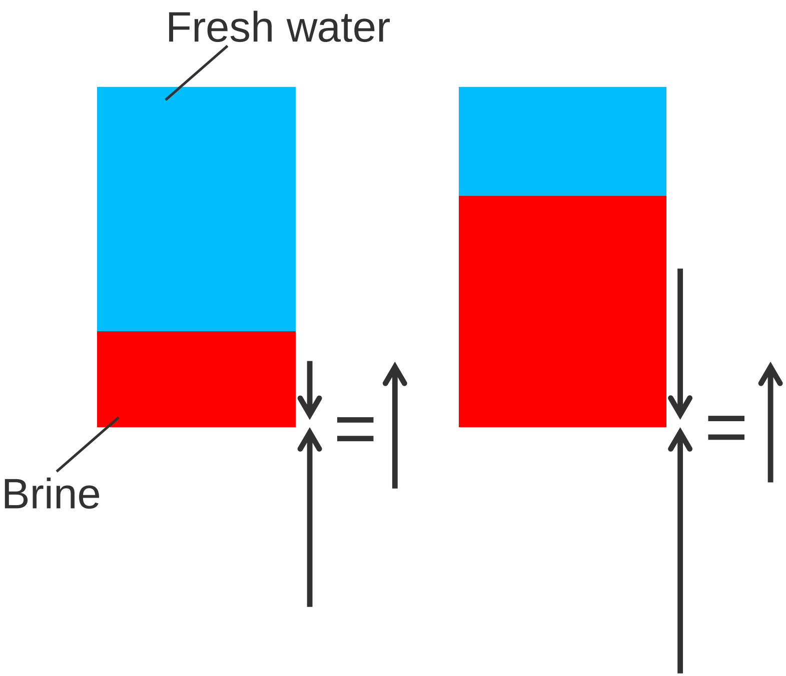

Diffusivity

Injection horizon diffusivity:

$$D_{inj} = \frac{k}{\mu \phi C_{tot}}$$

Considering **only** the 20m thick Solling:

$$D_{inj} = 0.913$$

Vertical averaging of surrounding semi-permeable layers with the injection horizon Solling:

$$\bar{\phi}_{inj} = \frac{\phi_{Sol} L_{Sol} + \phi_{Semi} L_{Semi}}{L_{Tot}}$$

$$\bar{k}_{inj} = \frac{k_{Sol} L_{Sol} + k_{Semi} L_{Semi}}{L_{Tot}}$$

$$D_{inj} = 0.161$$