Modeling and parameterization of CO_2 storage in deep saline formations for dimensions and risk analysis

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Combined seismic and geoelectric modeling of CO_2 plumes in deep saline reservoirs (example Wagrien, North German Basin)

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Objectives / approach

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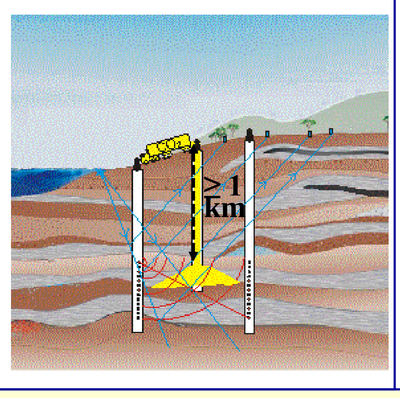
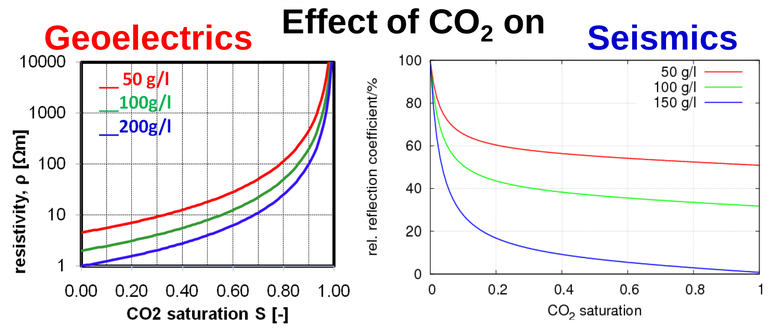
1) Analysing changes in seismic and electrical rock properties due to CO_2 injections and migrations based on petro-physico-chemical parameters and rock models, and CO_2 migration scenarios in subsurface structures
2) Investigating sensitivity/resolution of reflection seismics and electrical resistivity tomography (ERT) in boreholes (BRT) for monitoring development of an artificial CO_2 reservoir
3) Developing a geophysical monitoring strategy

Approach

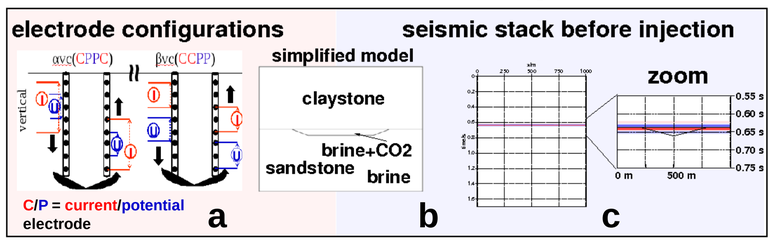
- Seismic time-lapse measurements at large time intervals (years?)
- Monitoring using BRT to estimate changes in intrinsic physico-chemical property changes of reservoir/ caprock and CO_2 plume with a priori seismic and log data in the constrained Inversion
- Possibly deriving bulk CO_2 amount and risk from determining CO_2 saturation (BRT) and the plume volume (seismic)



Introduction

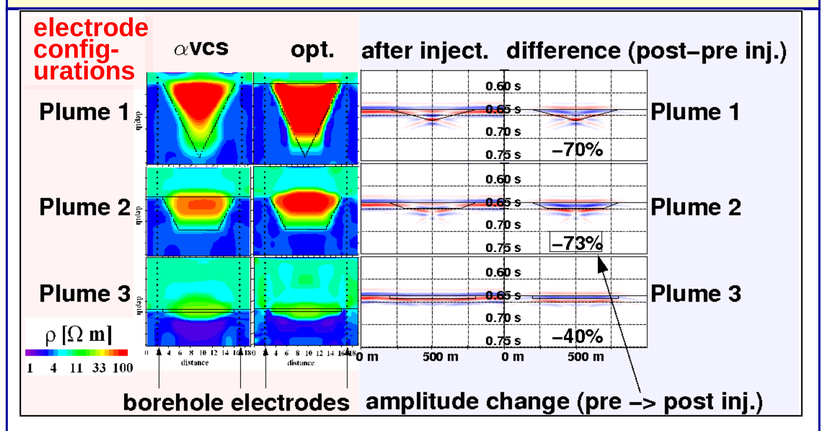


➡ BRT and seismics are suitable for monitoring of injected CO_2 in saline formations



a) αvcs and βvcs (v=vertical, c=circulating, s=symmetrical) are some of the possible applied electrode configurations.
b) Simplified model used in electric and seismic modeling
c) Seismic model before CO_2 injection. Only the boundary between caprock and hostrock causes a reflection. The zoom shows the location of the CO_2 reservoir filled with brine only.

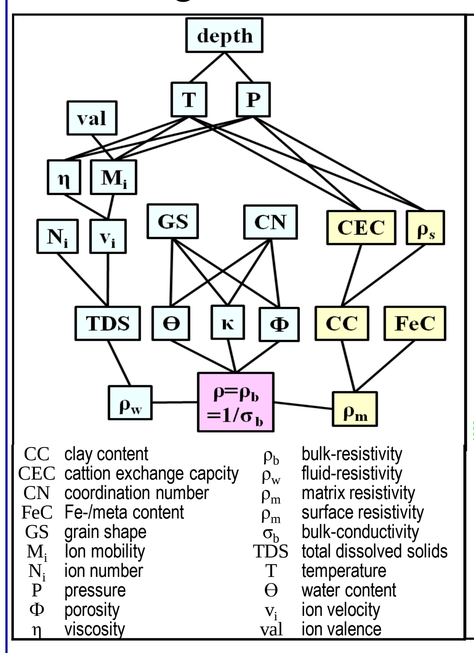
Study of basic parameters



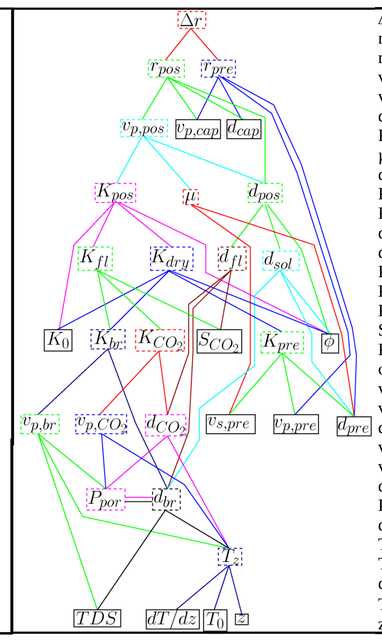
- Electric (left) and seismic (right) modeling of three different plume forms at 80% CO_2 saturation in the pore water and at 1000 m depth.
- Two electrode configurations: αvcs and optimized (opt) were used. Opt includes the dataset with the highest resolution of all possible comprehensive configurations, thus increasing spatial and temporal resolution.
- Seismic modeling: seismic (zero offset) section after CO_2 injection (left of the two columns) and difference between the pre- and post-injection sections (right). The maximum decrease of the reflection amplitude is indicated.
- The three plume forms are resolved but with smearing effects and blurred edges. Plume 3 is most problematic of them (limited thickness).
- 30% CO_2 saturation (not shown here) causes significantly weaker geoelectric contrasts. Seismic results: only minor changes.

Results

Complex relationships controlling geoelectric and seismic attributes



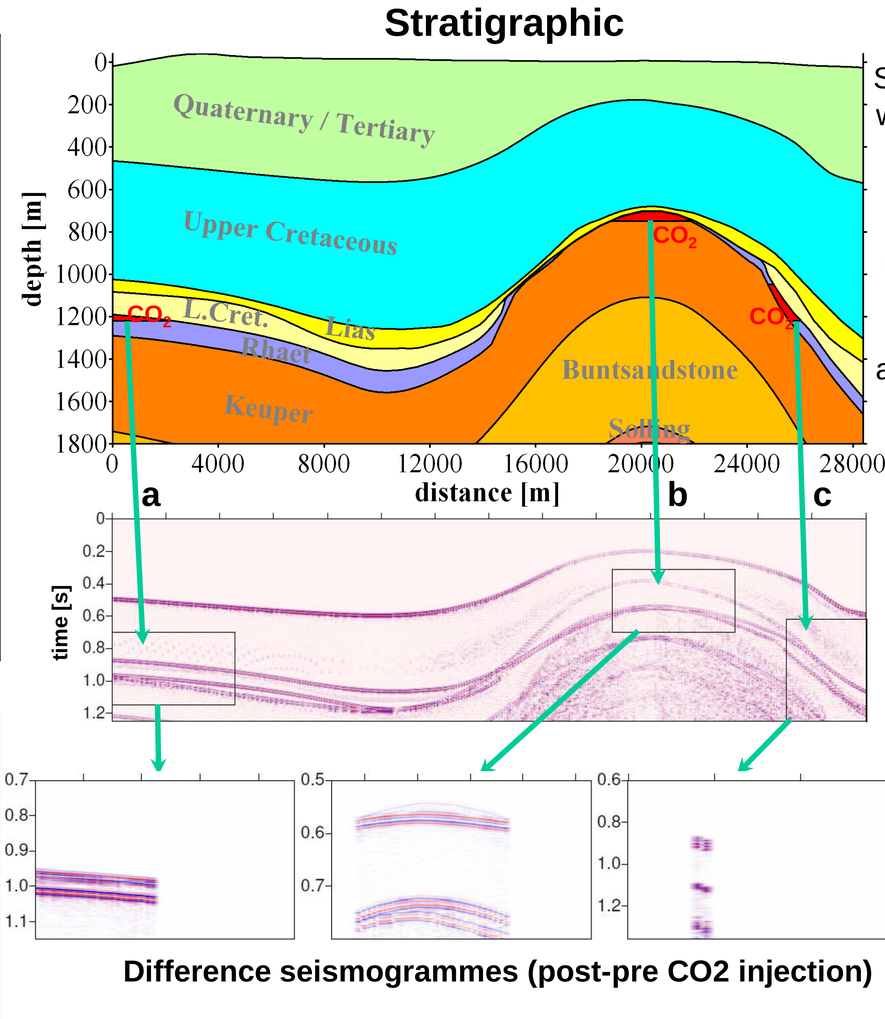
CC	clay content	ρ_b	bulk-resistivity
CEC	cattion exchange capcity	ρ_w	fluid-resistivity
CN	coordination number	ρ_m	matrix resistivity
FeC	Fe-/meta content	ρ_m	surface resistivity
GS	grain shape	σ_b	bulk-conductivity
M_i	Ion mobility	TDS	total dissolved solids
N_i	ion number	T	temperature
P	pressure	Θ	water content
Φ	porosity	v_i	ion velocity
η	viscosity	val	ion valence



Δr	relative change of reflection coefficient (post-pre injection)
r_{pos}	reflection coefficient (post injection)
r_{pre}	reflection coefficient (pre injection)
$v_{p,pos}$	p wave velocity (reservoir, post injection)
$v_{p,cap}$	p wave velocity (caprock)
d_{cap}	density (caprock)
K_{pos}	bulk modulus (reservoir, post injection)
μ	shear modulus (reservoir)
d_{pos}	density (reservoir, post injection)
K_{fl}	bulk modulus (brine-CO_2 mixture in pores)
K_{dry}	bulk modulus (reservoir, rock matrix)
d_{fl}	density (brine-CO_2 mixture in pores)
d_{sol}	density (rock matrix)
K_0	bulk modulus (quartz)
K_{br}	bulk modulus (brine)
K_{CO2}	bulk modulus (CO_2)
S_{CO2}	CO_2saturation (in pores)
K_{pre}	bulk modulus (reservoir, pre injection)
φ	porosity (reservoir)
$v_{p,br}$	P wave velocity (brine)
$v_{p,CO2}$	P wave velocity (CO_2)
d_{CO2}	density (CO_2)
$v_{s,pre}$	P wave velocity (reservoir, pre injection)
$v_{p,pre}$	P wave velocity (reservoir, pre injection)
d_{pre}	density (reservoir, pre injection)
P_{por}	(hydrostatic) pore pressure
d_{br}	density (brine)
T_z	temperature (reservoir)
TDS	salinity (total dissolved solids)
dT /dz	temperature gradient
T_0	temperature at surface
z	depth

Wagrien

Stratigraphic

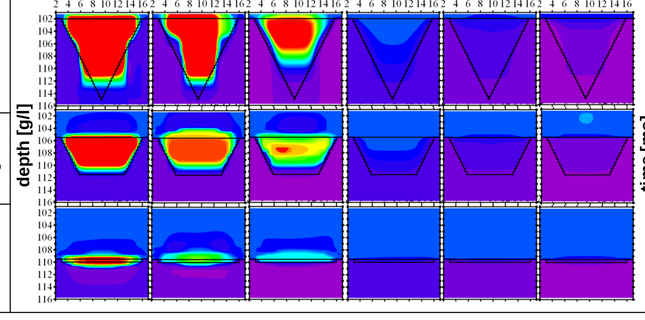
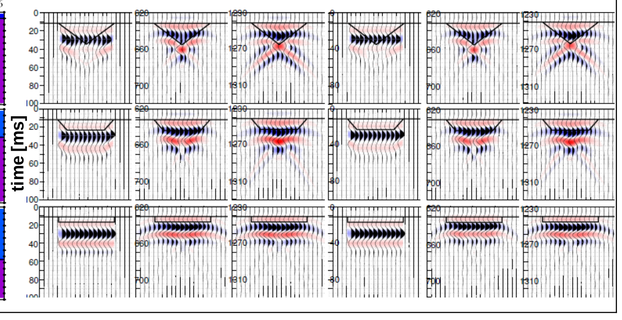


Subsurface model with sequestrated CO_2. scenario for: (a) nearly horizontal layering, (b) anticline structure und (c) steep flank

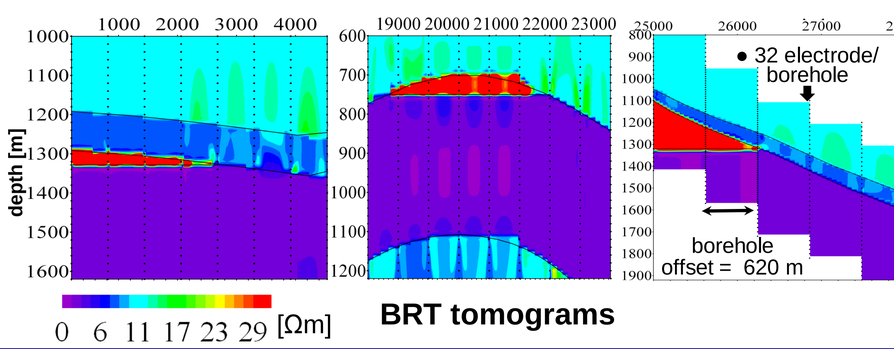
CO_2 thickness ≤25 m

Vp [m/s]	d [kg/m³]	Formation
1930-3470	2050-2500	caprock (L.Cret.-Lias-Quat.)
4260	2525	saline reservoir
4170	2450	CO_2 reservoir

Effect of CO_2 saturation and water salinity, North German Basin

	Geoelectrics (BRT) models						Seismic zero-offset difference sections					
CO_2 sat.	80 %			30 %			80 %			30 %		
depth	10 m	1000 m	2000 m	10 m	1000 m	2000 m	10 m	1000 m	2000 m	10 m	1000 m	2000 m
TDS	40 g/l	100 g/l	200 g/l	40 g/l	100 g/l	200 g/l	40 g/l	100 g/l	200 g/l	40 g/l	100 g/l	200 g/l
ρ (pre / post, CO_2)	3 / 80	2 / 50	1 / 25	3 / 6.5	2 / 4	1 / 2 Ωm	V_p(pre / post)	3614/ 3502	3656 / 3399	3812 / 3370	3614 / 3428	3656 / 3368	3812 / 3364 m/s
wedge model, **plume1** (v.length ↑, width ↑)												
plume 2 (v.length ↖, width ↑)												
plume 3 (v.length ↓, width ↑												

Difference seismogrammes (post-pre CO2 injection)



BRT tomograms

ρ Ωm	Formation
12	caprock (L.Cret.→Quat.)
8	caprock (Lias)
3	saline reservoir (Rhaet),100g/l
50	CO_2 reservoir (Rhaet), 80%

Electrode spacing, a = 20 m

Summary and conclusion

- Continuing fundamental studies of diverse basic parmeters related to data acquisition, inversion, geological/petrophysical setting and CO_2 plumes affecting seismic and BRT modeling
- Applications on simple schematic models and also on realistic subsurface scenarios (Wagrien)
- Developing a new geoelectric algorithm to generate an optimised electrode array for any survey
- Variations of depth (0-3km), temperature (30°C/km), pressure, (<70 MPa), petrophysics (porosity =0.2-0.25, TDS=100 g/l per 1km depth) and CO_2 plume parameters (dimension= 0.5➡10a, saturation=30-80%)
- Strong effects with increasing brine salinity, plume thickness, porosity and CO_2 saturation
- Increasing depth ➡ decreases the frequency of seismic signals and thus resolution
- Resolution decreases with decreasing CO_2 dimensions and saturations
- **Wagrien**: CO_2 plume with thickness ≤20m (a=20m) is well mapped in BRT at 1 km depth and for TDS=100 g/l ➡ seismics: problematic due to long wavelength
- **BRT**: a priori information from seismics/logs (interfaces) in constrained inversion ➡ more reliable tomograms, better derivation of intrinsic properties of geologic formations and CO_2 plumes. Further improvements are anticipated for monitoring results since the resistivity distribution is partly known from previous time-lapses

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