The role of mineralogy on the impact of temperature cycling on the mechanical and transport properties of porous sandstones

Implications for CO_2 storage in depleted gas reservoirs

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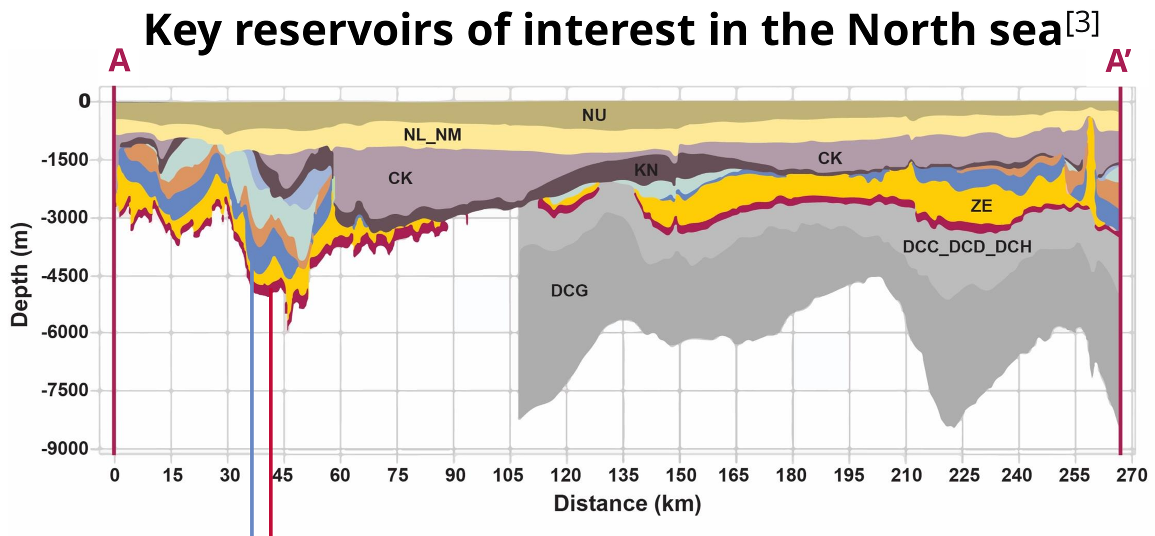
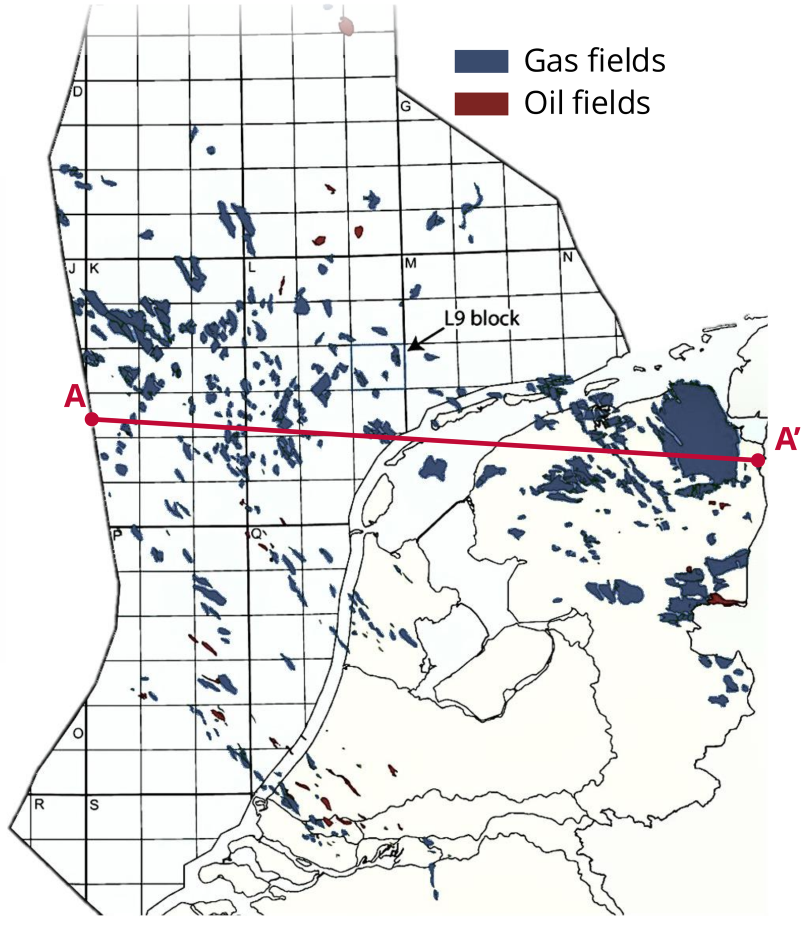
Introduction

- Achieving net-zero CO_2 emissions requires large-scale carbon capture and storage[1].
- Depleted oil and gas fields are excellent candidates for geological storage[2].
- Injecting cold, high-pressure CO_2 into high temperature, depleted reservoirs can cause significant cooling, potential freezing, and temperature cycling due to both temperature differences between the CO_2 and the reservoir, and the Joule-Thomson cooling effect[4].
- The impacts of these temperature variations on injectivity and near-wellbore formation integrity remain poorly quantified.

Key reservoirs of interest in the North sea[3]





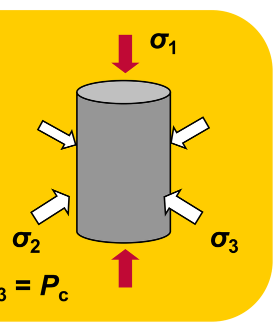
Methods

Sample selection:

- Bleurswiller sandstone (a Rotliegend analogue) containing ≈7% pore-lining clay content, $\varphi \approx 24\%$.
- Bunter reservoir sandstone containing up to ≈14.4 wt% halite cement, $\varphi \approx 5$ to 22%.

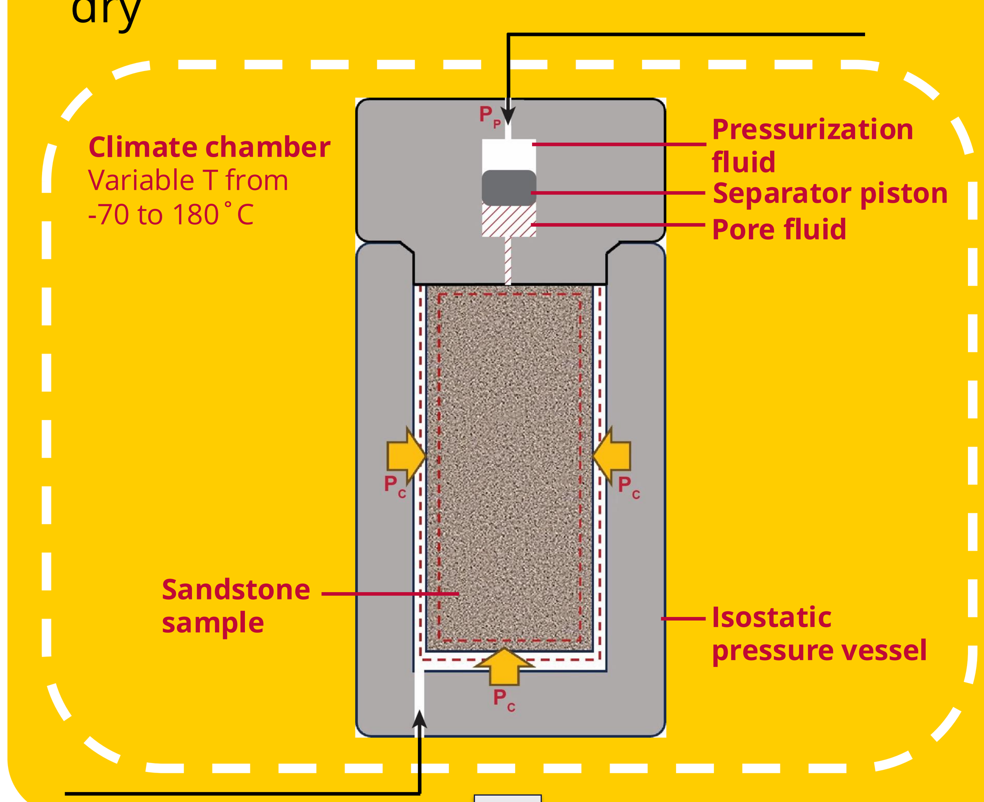
Triaxial experiment:

- Permeability measurement
- Mechanical properties



Temperature cycling

- 1-20 cycles
- ΔT : 100 ⟶ +40, +5 , -20°C or −35°C
- Cooling rate (≈2-10°C/min)
- Saturation level: fully or partially saturated, dry



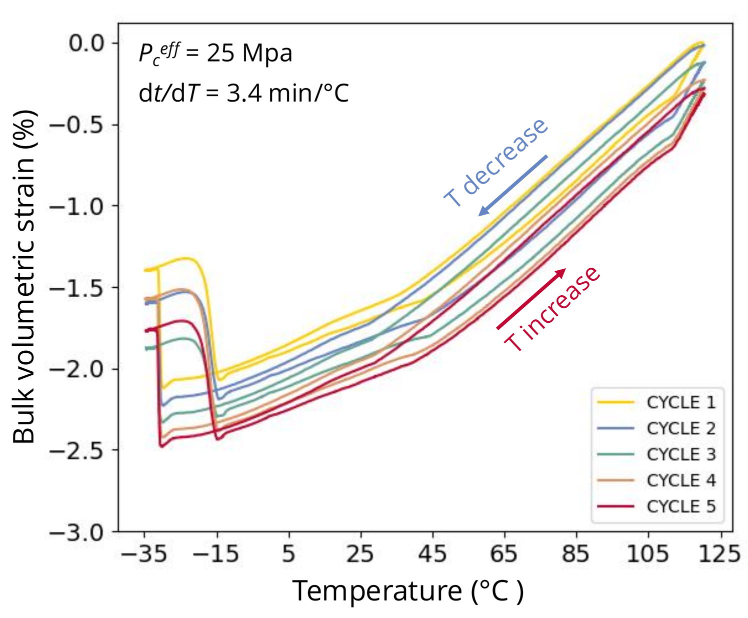
Post thermal treatment triaxial experiment:

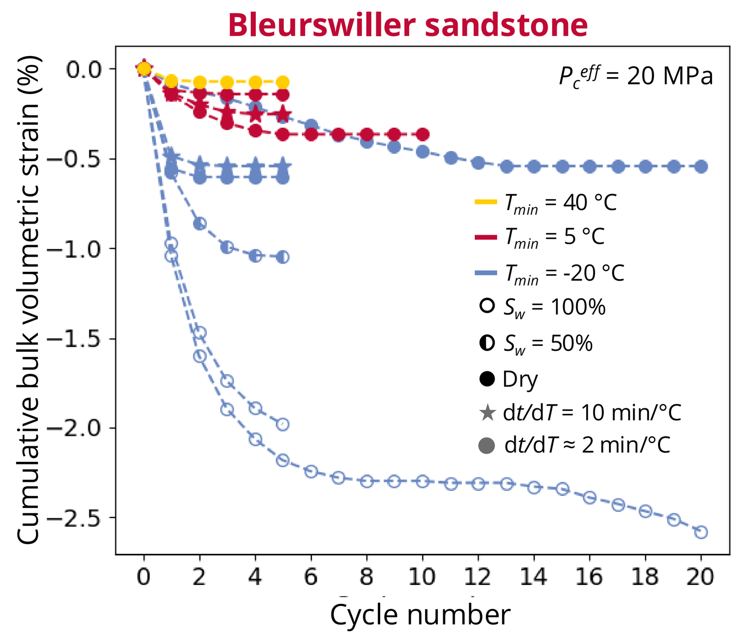
- Permeability measurement
- Mechanical properties

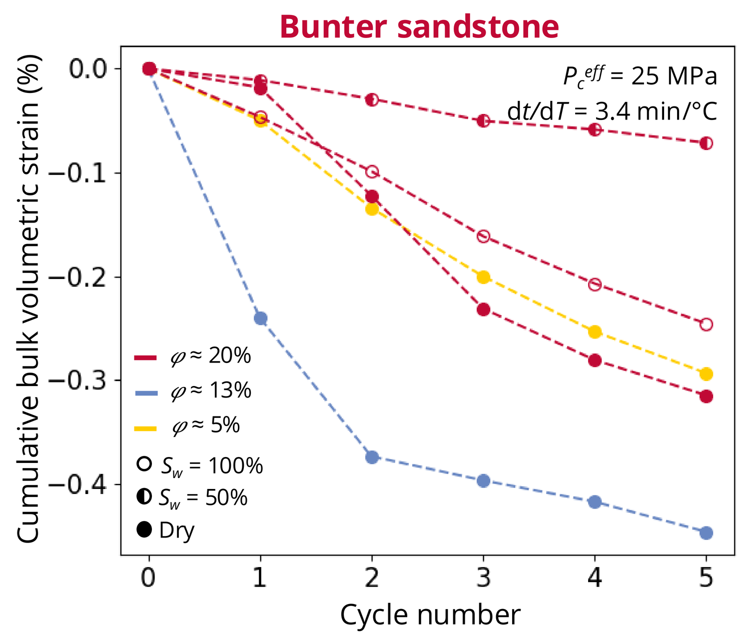
Microstructural analysis

Results

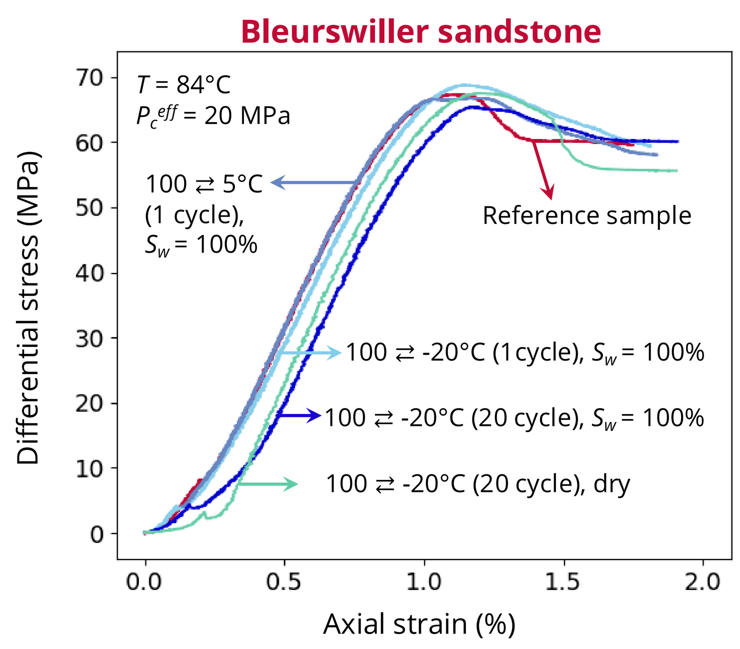
- Permanent compaction during temperature cycling.

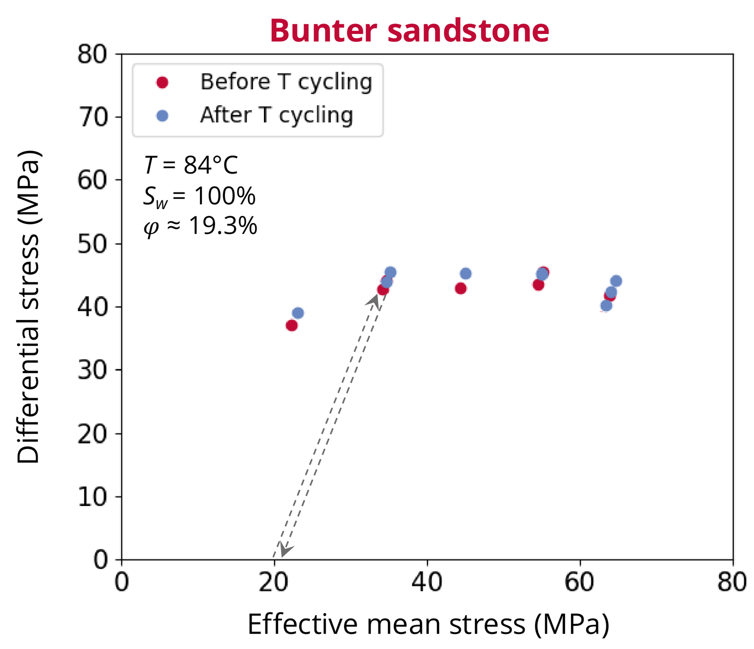


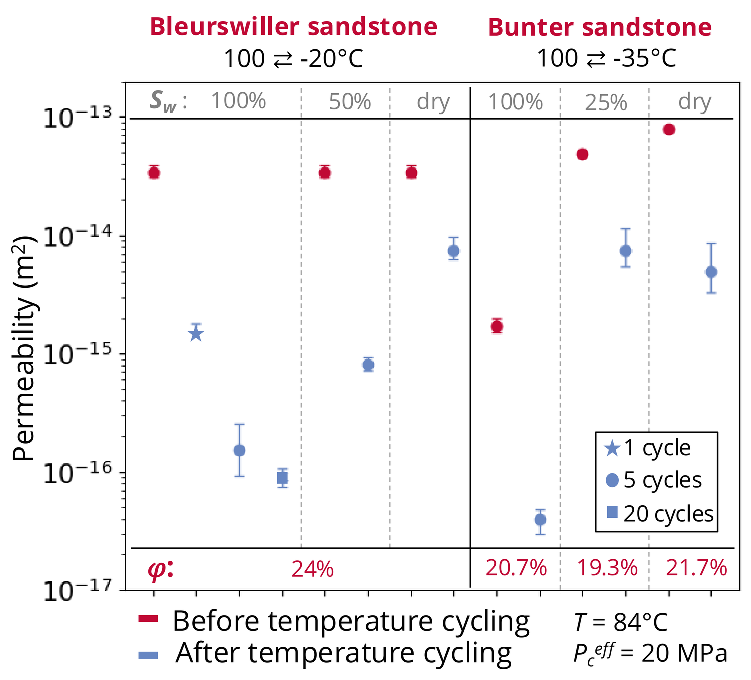




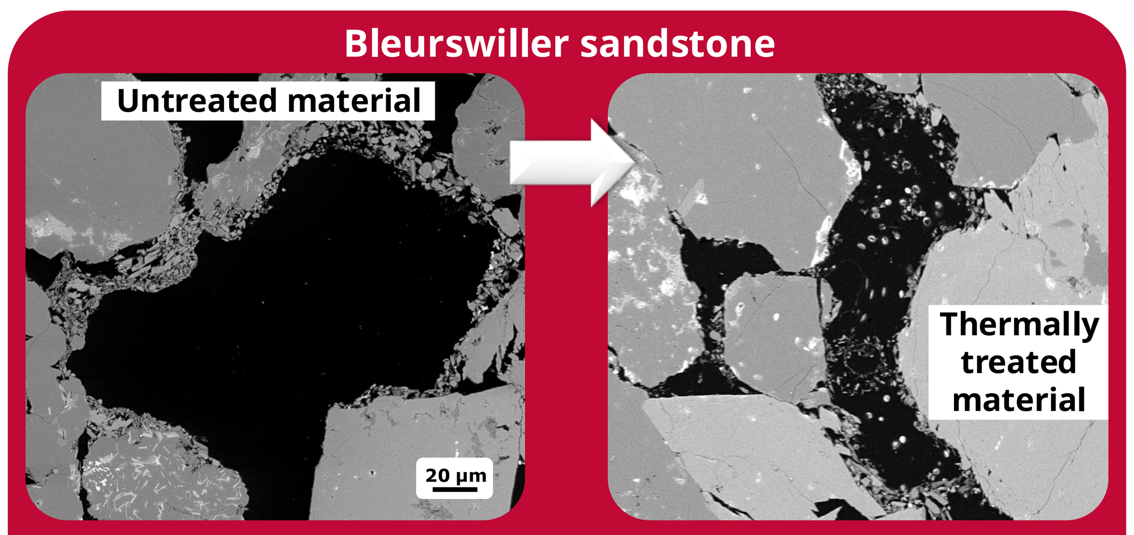
- Mechanical properties of both sandstones remained largely unaffected.
- Permeability reduction by 1–3 orders of magnitude.
- Under more reservoir-representative conditions (single cycle, partially saturated, above-zero temperatures), permeability reductions were less pronounced (< one order of magnitude).







Bleurswiller sandstone

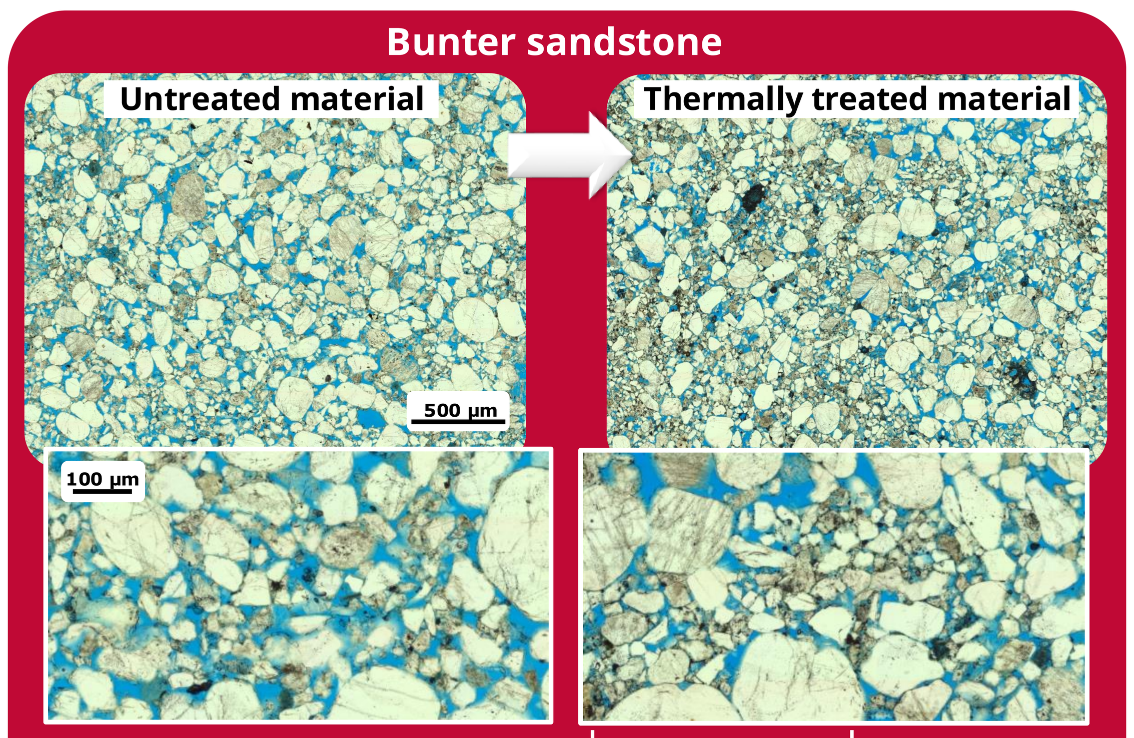


Chemical analysis ⟹ Fines, generated primarily by de-bonding and mobilization of pore-lining clays, clogged pore throats, leading to permeability reduction.

Mineral	Q	K-F	Clay
Bulk rock %	60.7	31.8	6.6
Fine particles %	20.0	27.6	52.4

$4R_{particle} > R_{pore\ throat}$[5]

Bunter sandstone



	Initial material	After treatment
Median equivalent pore diameter (µm) (Obtained from image-analysis segmentation)	27.85	24.44
Median pore throat radius (µm) (Measured on the pore skeleton maps)	7.48	6.56

Key Findings and Implications

- Cooling effects: permanent compaction, no impact on mechanical properties, permeability reduction ➞ increase in pressure gradients ➞ enhanced Joule-Thomson cooling ➞ reduced injectivity
- Saturation level, cooling amplitude, and the number of cycles (up to ≈5) play important roles in the extent of cooling effects (as reflected in permanent volumetric compaction and the reduction of permeability after temperature cycling).
- Despite comparable effects of temperature cycling on transport properties in both sandstones, mineralogical and textural characteristics exert strong influence: (i) pore-lining clays may lose cohesion, generate fines, and clog pore throats; and (ii) poor grain sorting can induce local porosity reduction and pore-throat narrowing.

References

1. Metz et al., 2005.
2. Cerasi et al., 2022.
3. TNO – GDN (2019) DGM-deep v5.0. TNO - Geological Survey of the Netherlands, https://www.dinoloket.nl
4. Oldenburg, 2007.
5. de Vries et al., 2022.

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