# Improved $CO_2$ storage capacity estimates from injection simulations

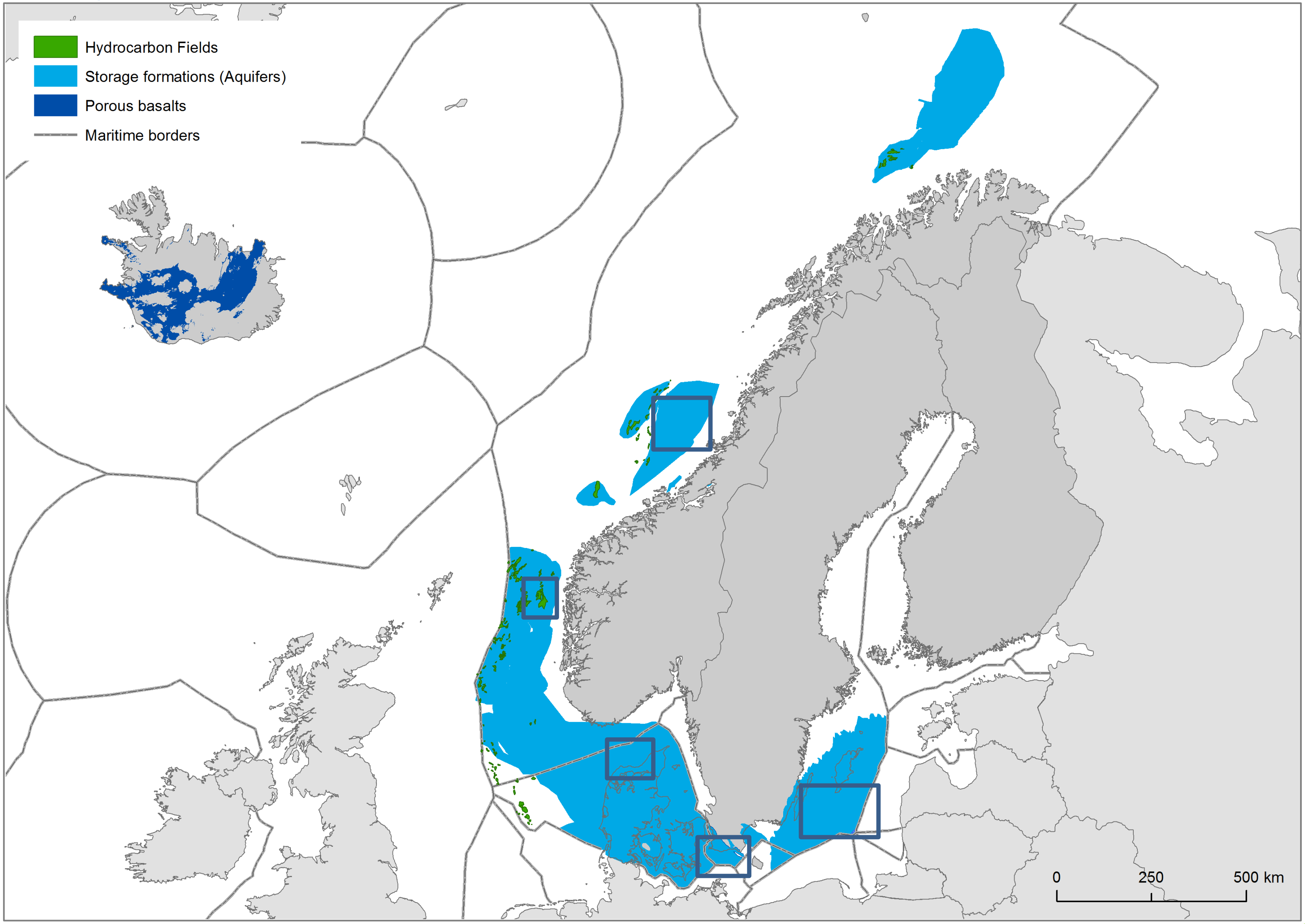
Ane Lothe

SINTEF Petroleum Research

norden
Top-level Research Initiative

nordiccs
Nordic CCS Competence Centre

# Key areas for modelling in the NORDICCS




Anthonsen et al. (2014)

# Objective:

- Introduction – NORDICCS
- Methods to estimate storage capacity:
  - Theoretical capacity
  - Structural storage capacity using basin modelling approach
  - Dynamic modelling
- Results from different case studies:
  - Gassum Formation, Skagerrak area (Norway and Denmark)
  - Gassum Formation, Vedsted (on-shore), Hanstholm (offshore)
  - Arnager Greensand Formation in south-west Scania (Sweden)
  - Johanssen Formation, North Sea (Norway)
  - Garn Formation, Trøndelag Platform (Norway)
  - Faludden Sandstone, south-east Baltic Sea (Sweden)
- Comparison of result from Garn Formation and Faludden Sandstone
- Conclusions

nordiccs $CO_2$

# Methods used to estimate storage capacities:

## Theoretical volumes

by introducing an efficiency factor which represent the assumed fraction of pore volume that will be occupied by $CO_2$. The U.S. Department of Energy has proposed an equation to calculate the mass of $CO_2$ that can be stored:

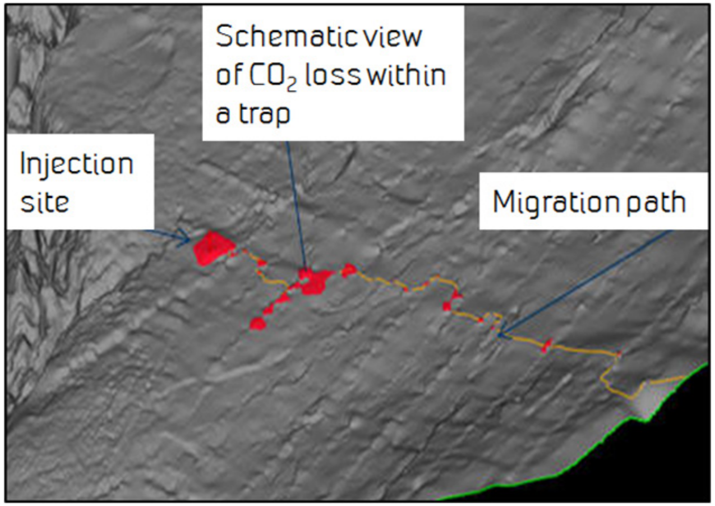
$$M_{CO_2} = Ah\phi\rho_{CO_2}E$$

Where $M_{CO_2}$ is the mass of $CO_2$, $A$ is the area of interest, $h$ is net height of storage formation, $\phi$ is the porosity, $\rho_{CO_2}$ is the density of $CO_2$ at storage conditions and $E$ is the storage efficiency factor.

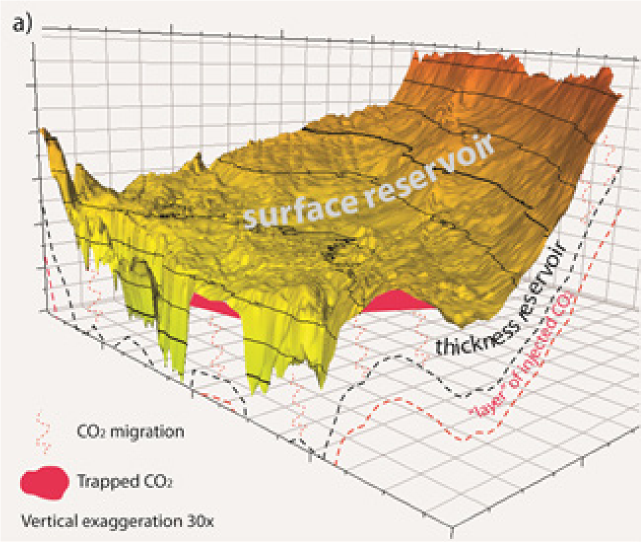
# Methods for estimating storage capacities:

## Structural trapping

- The SEMI basin modelling software tool models migration, losses, leakage and spill of $CO_2$.
- It uses a ray-tracing technique to migrate $CO_2$ within the reservoir.
- The dip of the top reservoir surface will determine the pathway directions.
- The total trap storage capacity was estimated by flooding the reservoir with $CO_2$. This is technically done by adding a "layer" of $CO_2$ under the reservoir unit.




From Grøver et al. (2013)



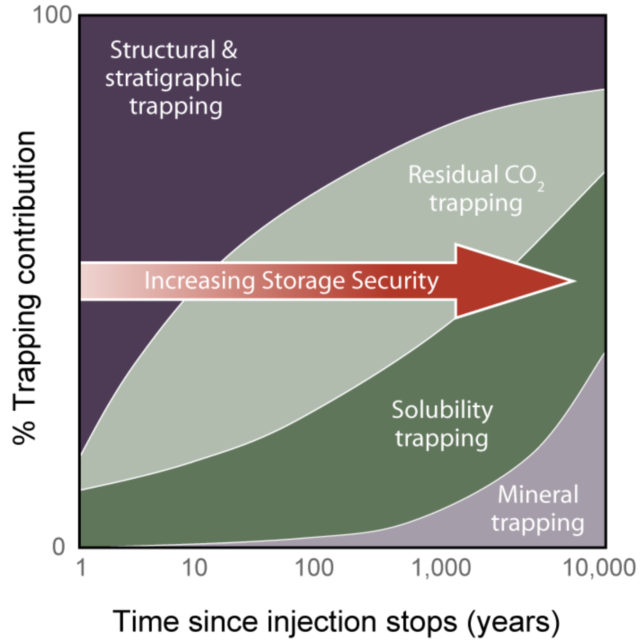

From Lothe et al. (2014)

# Methods used to estimate storage capacities:

## Dynamic modelling

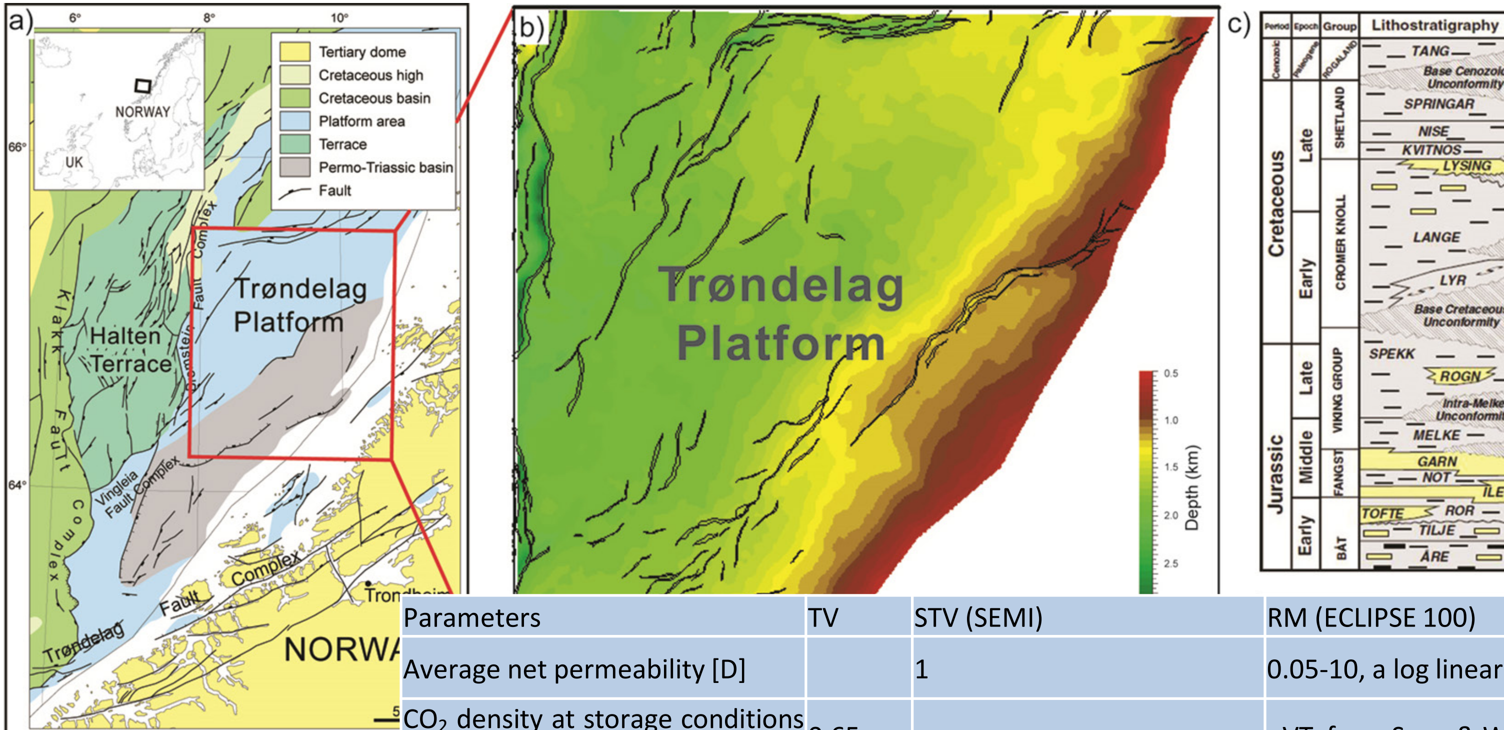
- Dynamic modelling of $CO_2$ injection into deep saline aquifers is performed using the industry standard reservoir simulator ECLIPSE 100.

- ECLIPSE 100 is a fully implicit, three phase, three dimensional simulator which accounts for all trapping mechanisms involved in $CO_2$ storage except mineral trapping




Mixed trapping mechanisms for geological storage of $CO_2$ (from CO2CRC homepage)

# Case study: the Middle Jurassic Garn Formation



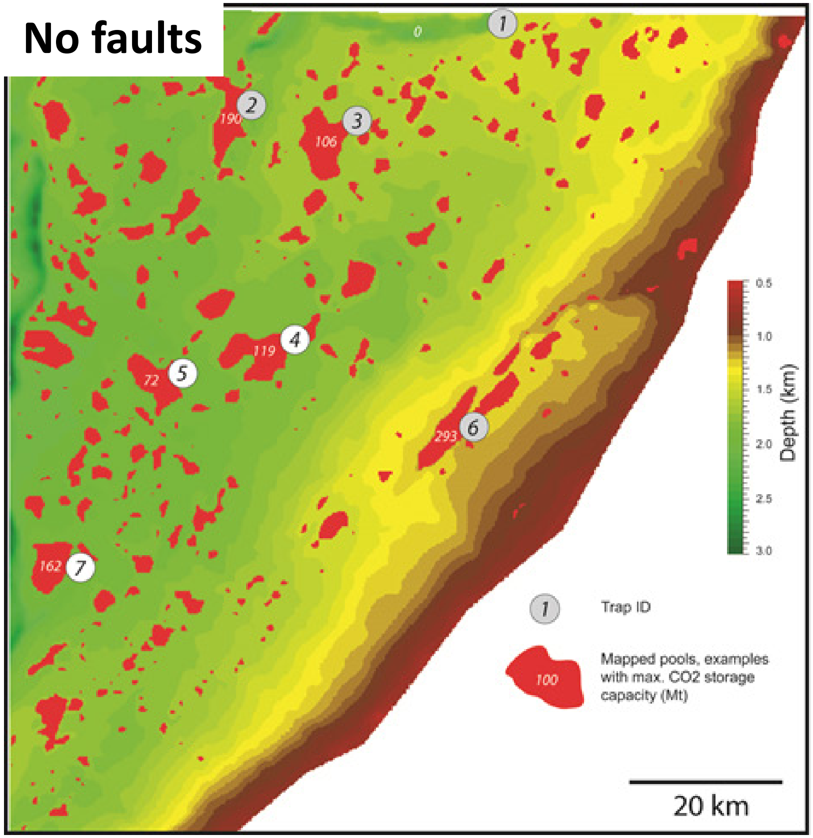

| Parameters | TV | STV (SEMI) | RM (ECLIPSE 100) |
|---|---|---|---|
| Average net permeability [D] | | 1 | 0.05-10, a log linear rel. por. and perm. |
| $CO_2$ density at storage conditions [g/cm$^3$] | 0.65 | | pVT from Span & Wagner (1996) |
| Polygon fault map | | Fault map at top Garn Fm. | Fault map at top Garn Fm. |
| Porosity [%] | 34 | Compaction curves | 15-41%; Ehrenberg (1990) |
| Pressure [MPa] | | Hydrostatic conditions | Hydrostatic conditions |
| Storage efficiency [%] | 0.5 - 2.0 | | |
| Surface temperature [ºC] | | 4 | 4 |
| Thermal gradient [ºC/km] | | 40 | 40 |
| Thickness maps* [m] | 127 | 127 | 127 |
| Top reservoir map | | Top Garn Fm. seismic map | Top Garn Fm. seismic map |
| Total injected CO2 [Mt] | | Infinte | 3500 - 7000 |
| Water depth [m] | | Present day seabed | Present day seabed |

Note: Large area modelled; 15,000 k

# Modelling results Garn Formation (structural trapping)

- Basin modelling
- Assume no migration loss, low dissolution rate in the traps

**No faults**

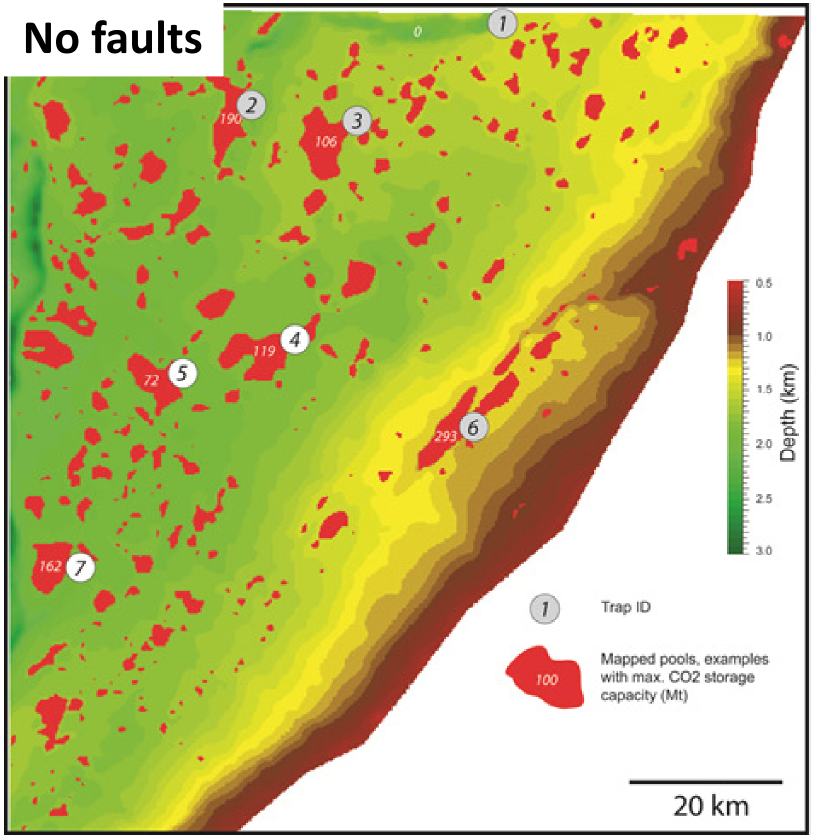


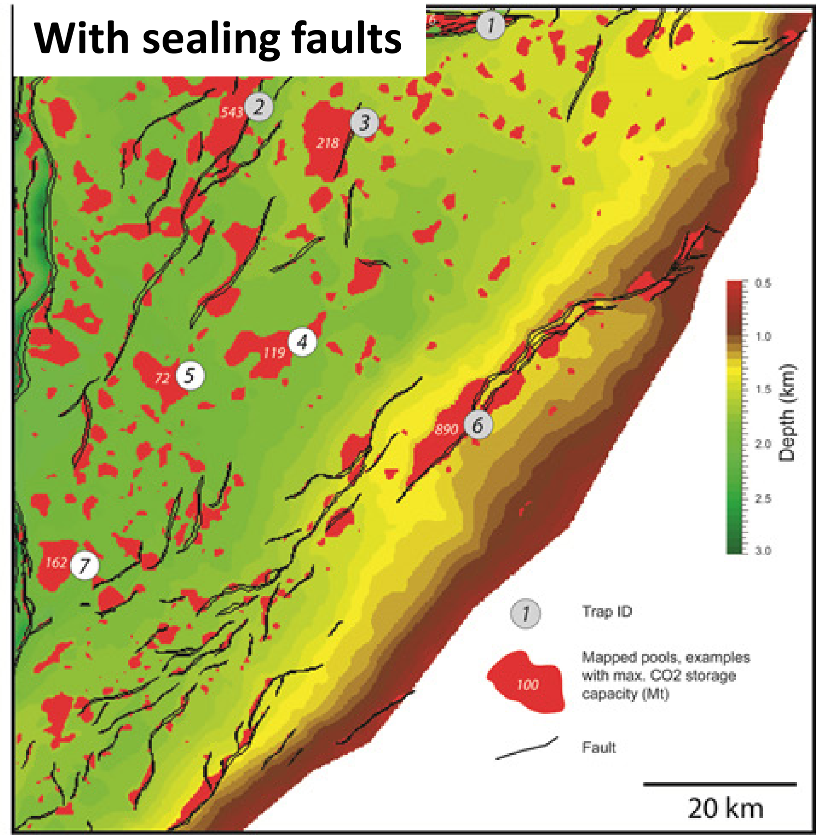

Structural storage capacity of 2.0 Gt

nordiccs $CO_2$

# Modelling results Garn Formation (structural trapping)

- Basin modelling
- Assume no migration loss, low dissolution rate in the traps



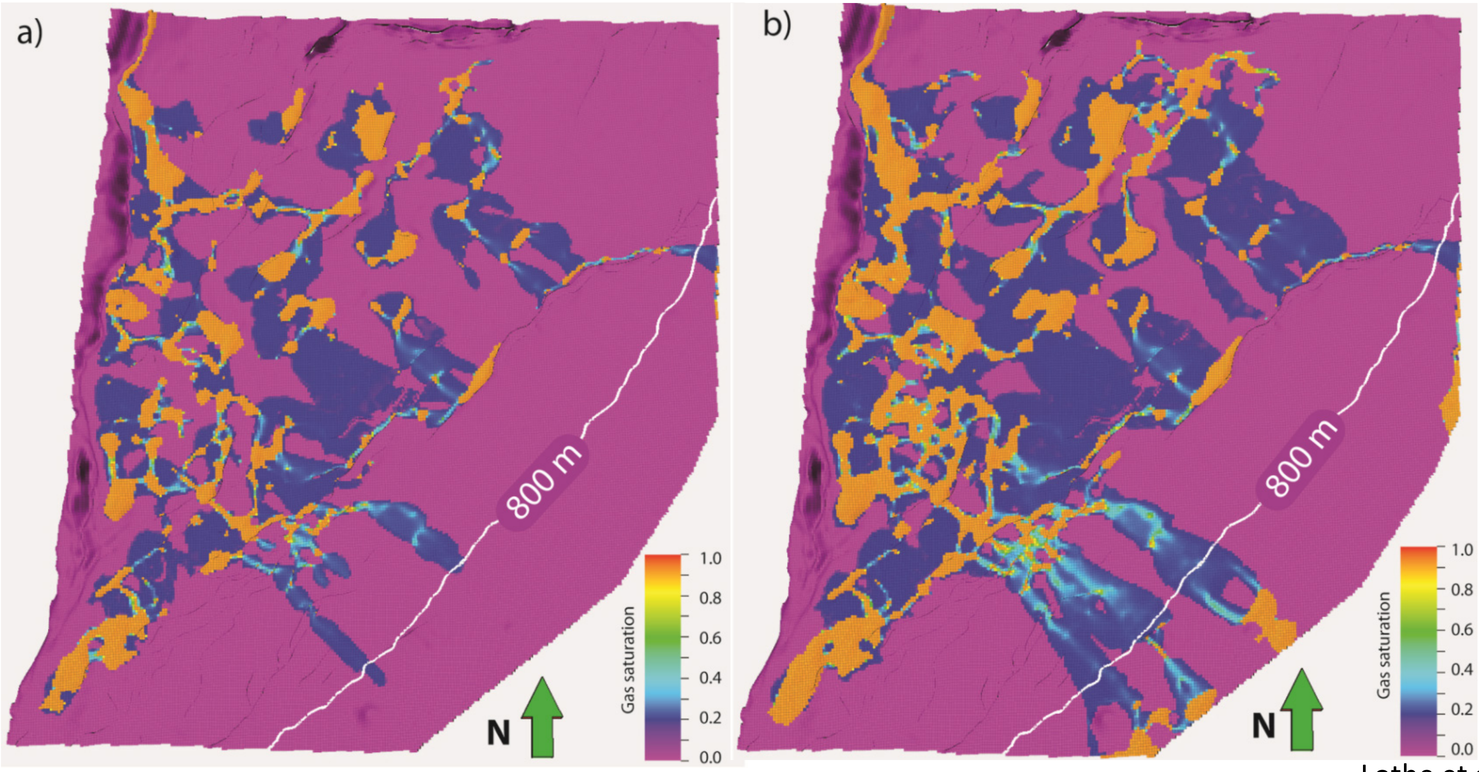

Lothe et al. (2014)

Structural storage capacity of 2.0 Gt

Structural storage capacity of 5.2 Gt

# Modelling results Garn Formation

- Dynamic modelling
- No sealing faults
- Results of the reservoir models for the Garn Fm. 3000 years after $CO_2$ injection.

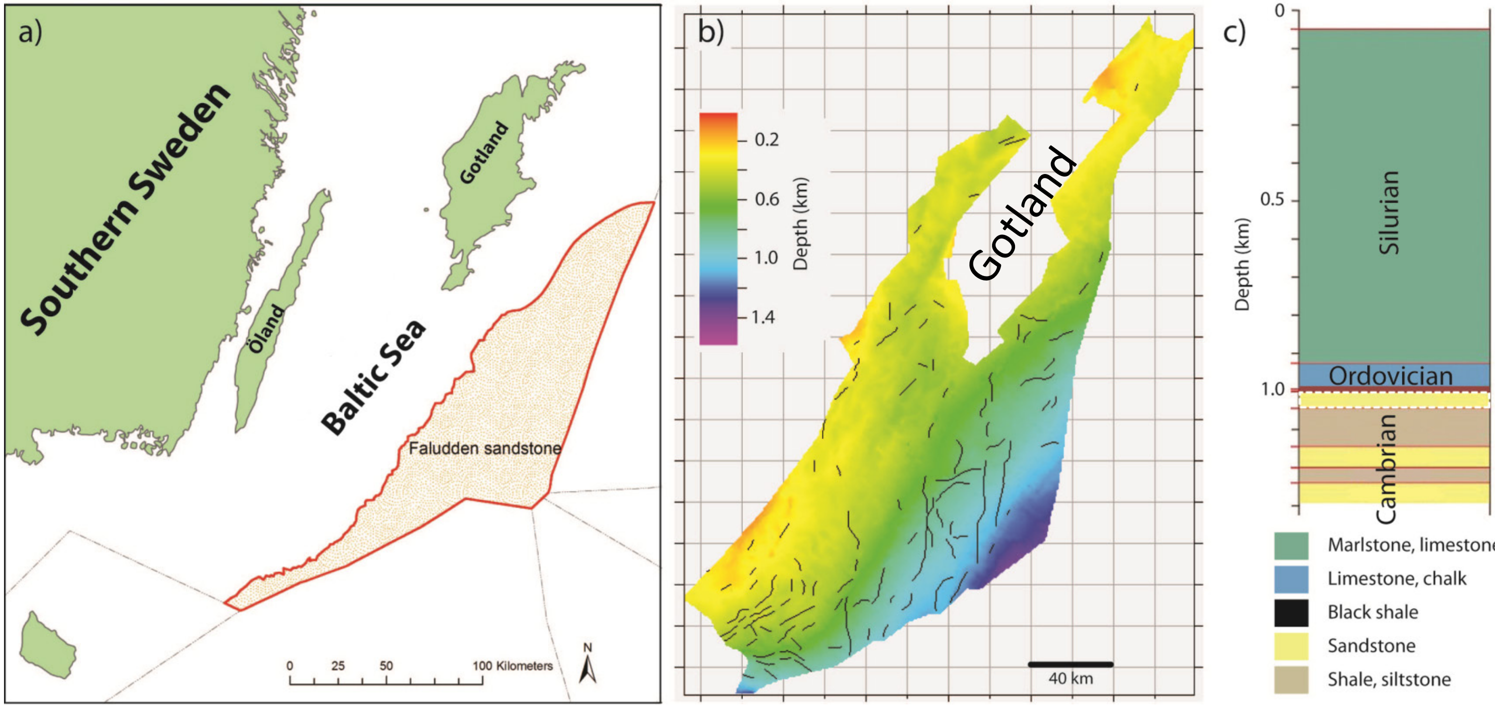



Lothe et al. (2016)

- The high permeability scenario (0.5-10 D) where 3.5 Gt of $CO_2$ were injected.
- 23.5% is dissolved, the rest is structural and residually trapped

- The low permeability scenario (0.05-1 D) with 7 Gt $CO_2$ injected.
- 22.1% is dissolved, the rest is structural and residually trapped.

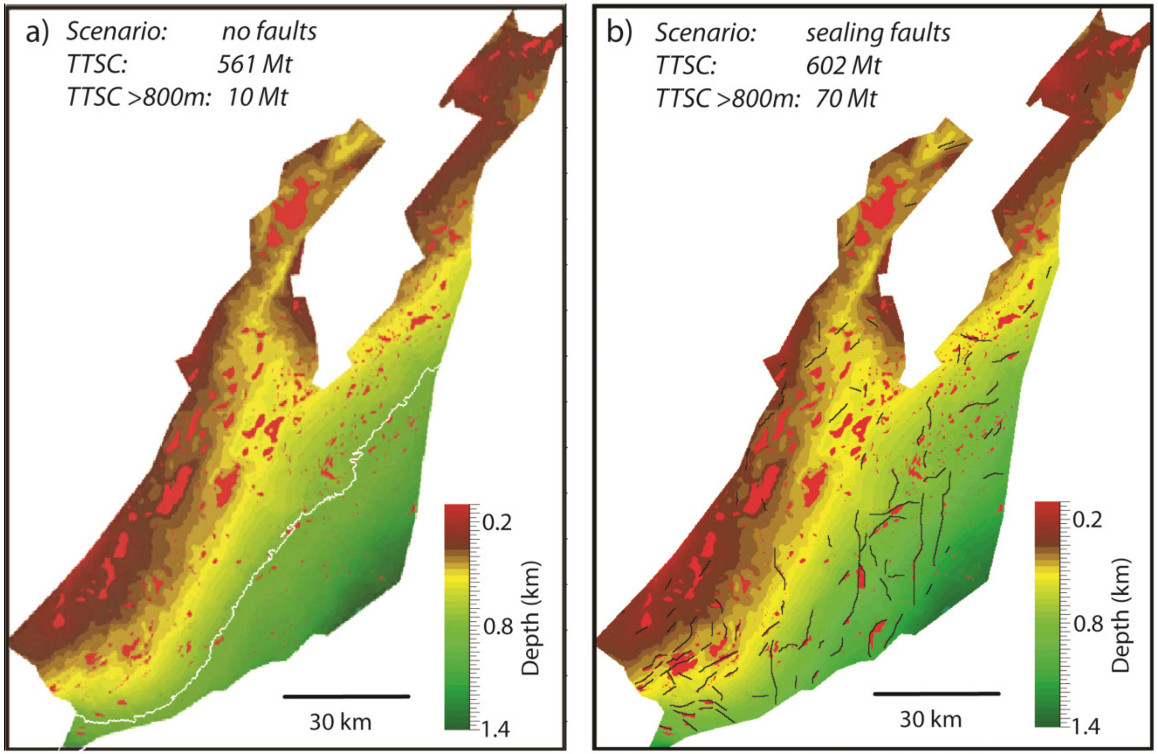
# Case study Cambrian Faludden sandstone, Baltic Sea

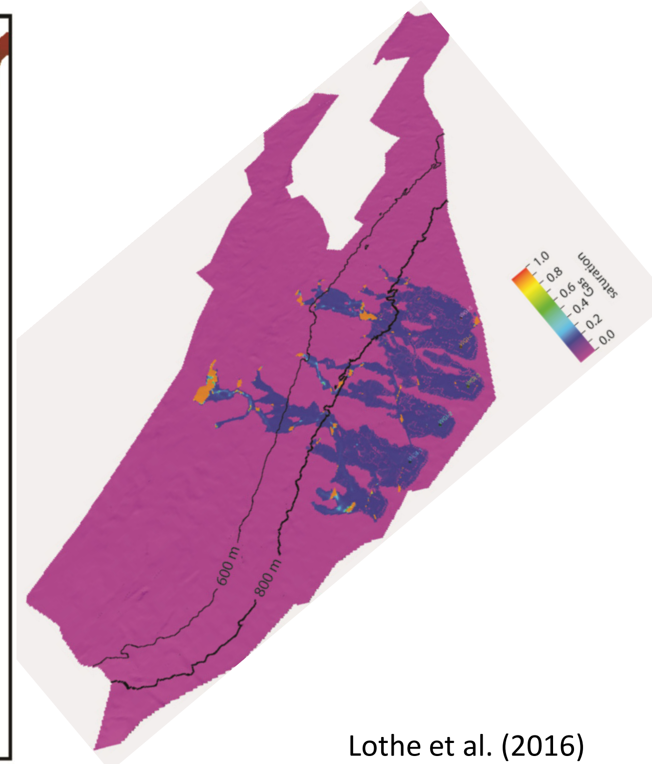



Mortensen et al. (in press)

- Gently dipping sandstone (<1°), few faults, few structures
- Dalder structure is not included in this study

# Modelling results Faludden sandstone, Baltic Sea



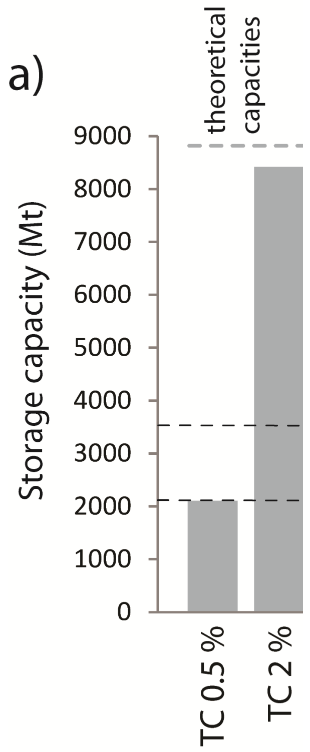

Lothe et al. (2016)
Mortensen et al. (in press)

- Structural storage capacity is low both with and without sealing faults
- Dynamic modelling show storage of 250 Mt $CO_2$. A large part of the injected $CO_2$ is captured as residual gas (4 % ends up in traps shallower than 600 m, 9 % in traps between 600-800 m depth)
- 39 % of the injected $CO_2$ is dissolved

nordiccs

# Capacity estimates

## Garn Formation (Trøndelag Platform)

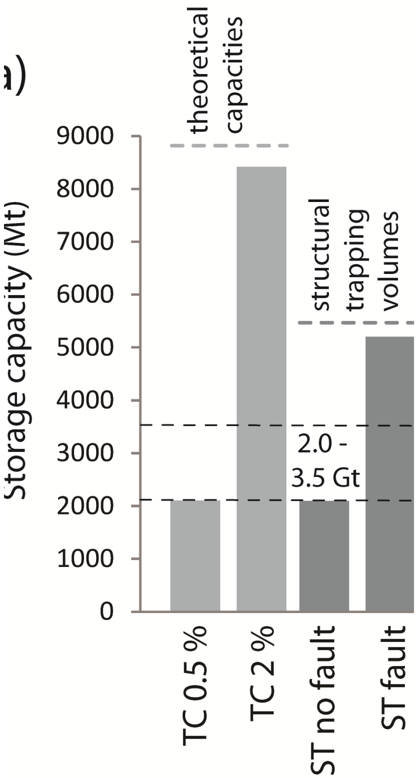



Lothe et al. (2016)

- The theoretical capacity is very much dependent on the efficiency factor

# Capacity estimates

## Garn Formation (Trøndelag Platform)



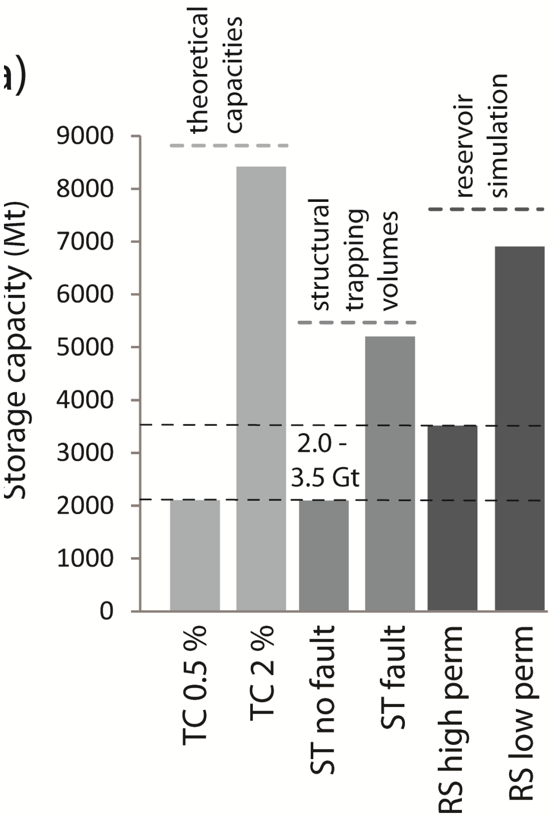

Lothe et al. (2016)

- The theoretical capacity is very much dependent on the efficiency factor
- Structural trapping with and without sealing faults

nordiccs $CO_2$

# Capacity estimates

## Garn Formation (Trøndelag Platform)



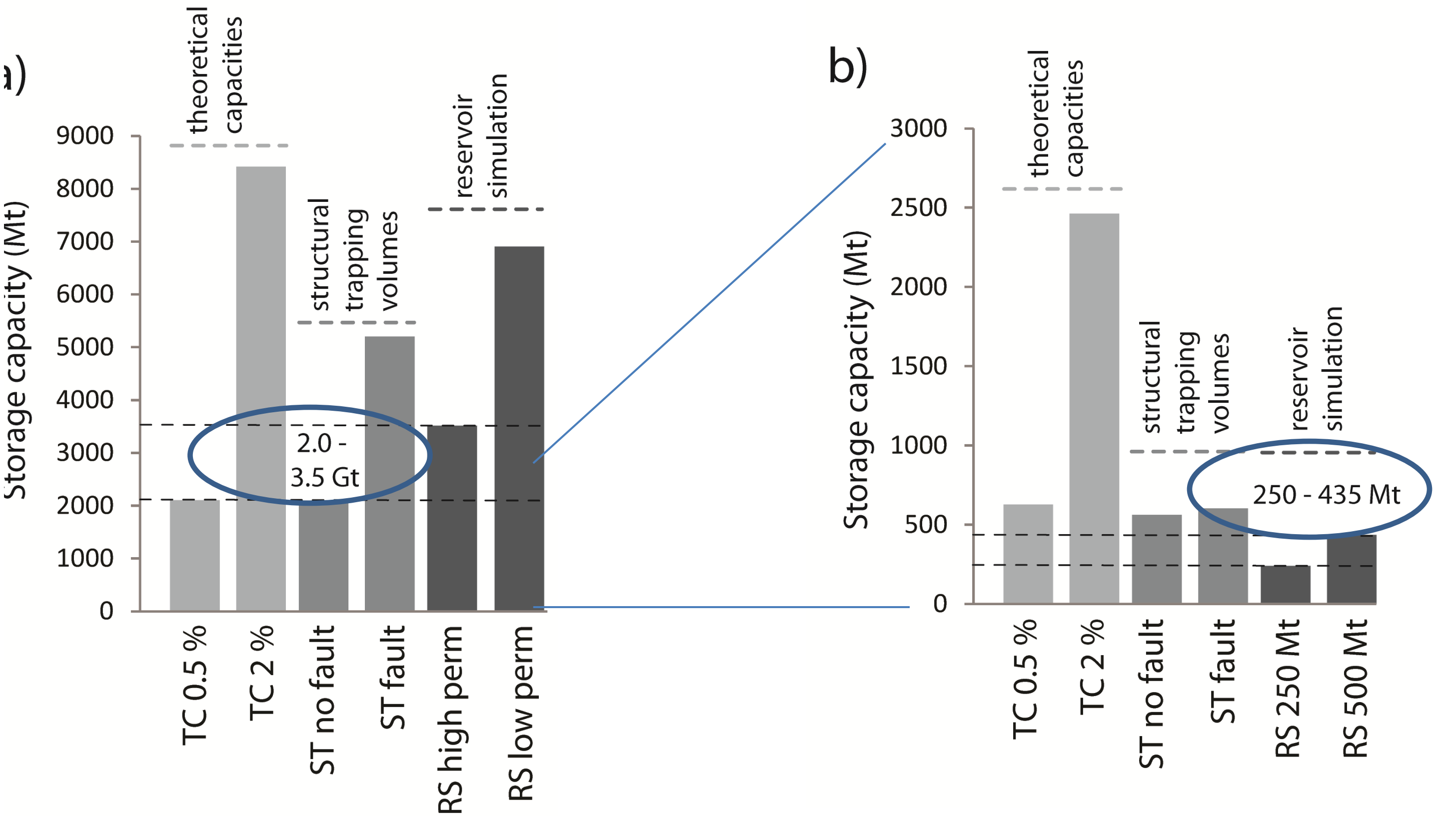

Lothe et al. (2016)

- The theoretical capacity is very much dependent on the efficiency factor
- Structural trapping with and without sealing faults
- Reservoir simulations assuming high and low permeability
- Residual trapping and dissolution are important!

nordiccs $CO_2$

# Capacity estimates

Garn Formation (Trøndelag Platform)　　Faludden Sandstone (Baltic Sea)




Lothe et al. (2016)

- The theoretical capacity is very much dependent on the efficiency factor
- Structural trapping will give more realistic volumes
- Reservoir simulations assuming high and low permeability

nordiccs $CO_2$

# Conclusions

The representative storage capacities are:

- The open dipping Garn Formation has the potential to store large volumes of $CO_2$ between 2.0-3.5 Gt. If assuming sealing faults the storage capacity is 5.2 Gt.

- Faludden Sandstone has the potential to store between 250-435 Mt

Residual trapping and dissolution are very important in areas with gentle dipping structures.

- **Important to perform dynamic capacity modelling**

- **Trapping mechanisms vary from site to site, not captured by theoretical capacity estimates**