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Statoil CO_2 storage experience: 20 years and 20 million tonnes

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CO_2GeoNet 10th Anniversary Open Forum, 2015

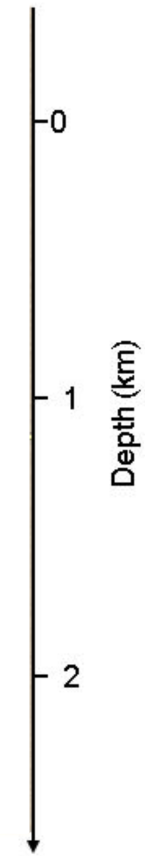
Statoil storage projects

2.9

15.2

1996

3.9



The pioneering CCS project, Sleipner

➢ *Main learning: CO_2 storage is feasible*

The World's first commercial-scale offshore storage project

- Driver: Norwegian carbon tax
- Storage unit: 800-1000 m depth, 200 m thick, high permeability
- More than 15 Mt CO_2 have been injected

➢ **Challenges:**

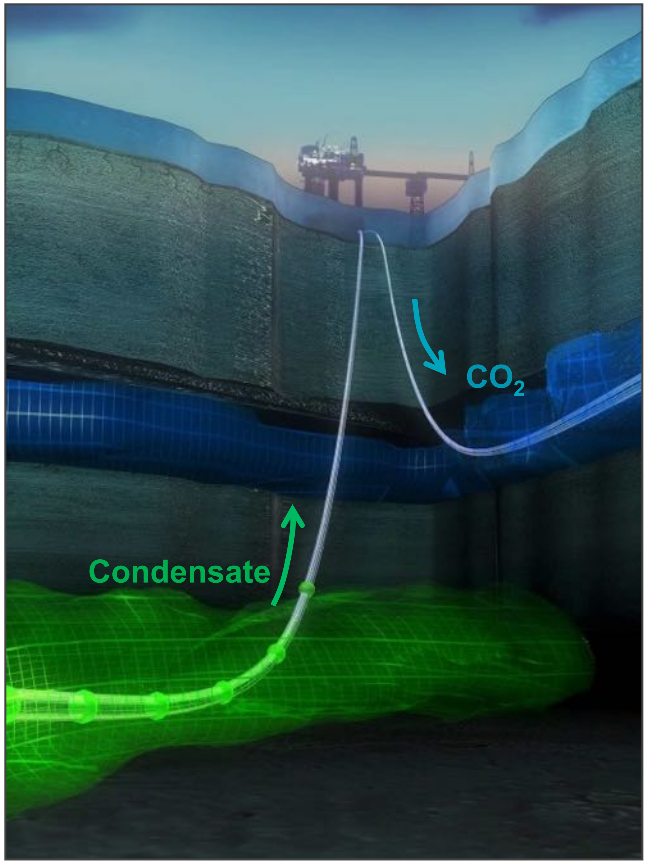
  - Role of internal shale layers on plume movement
  - Predicting CO_2 flow properties

➢ **Take-aways:**

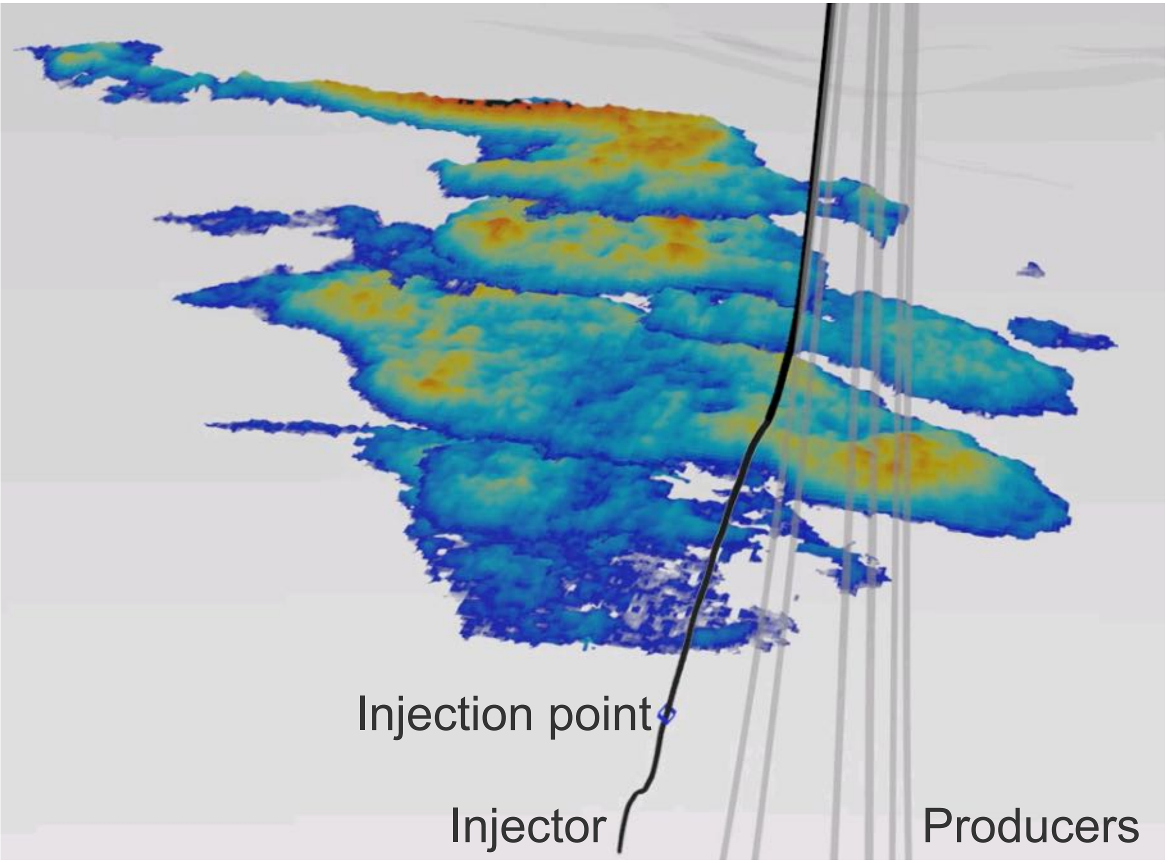
  - CO_2 plume can be monitored by seismic and gravimetric methods
  - Down-hole monitoring would improve models

The pioneering CCS project, Sleipner

- *Main learning: CO_2 storage is feasible*



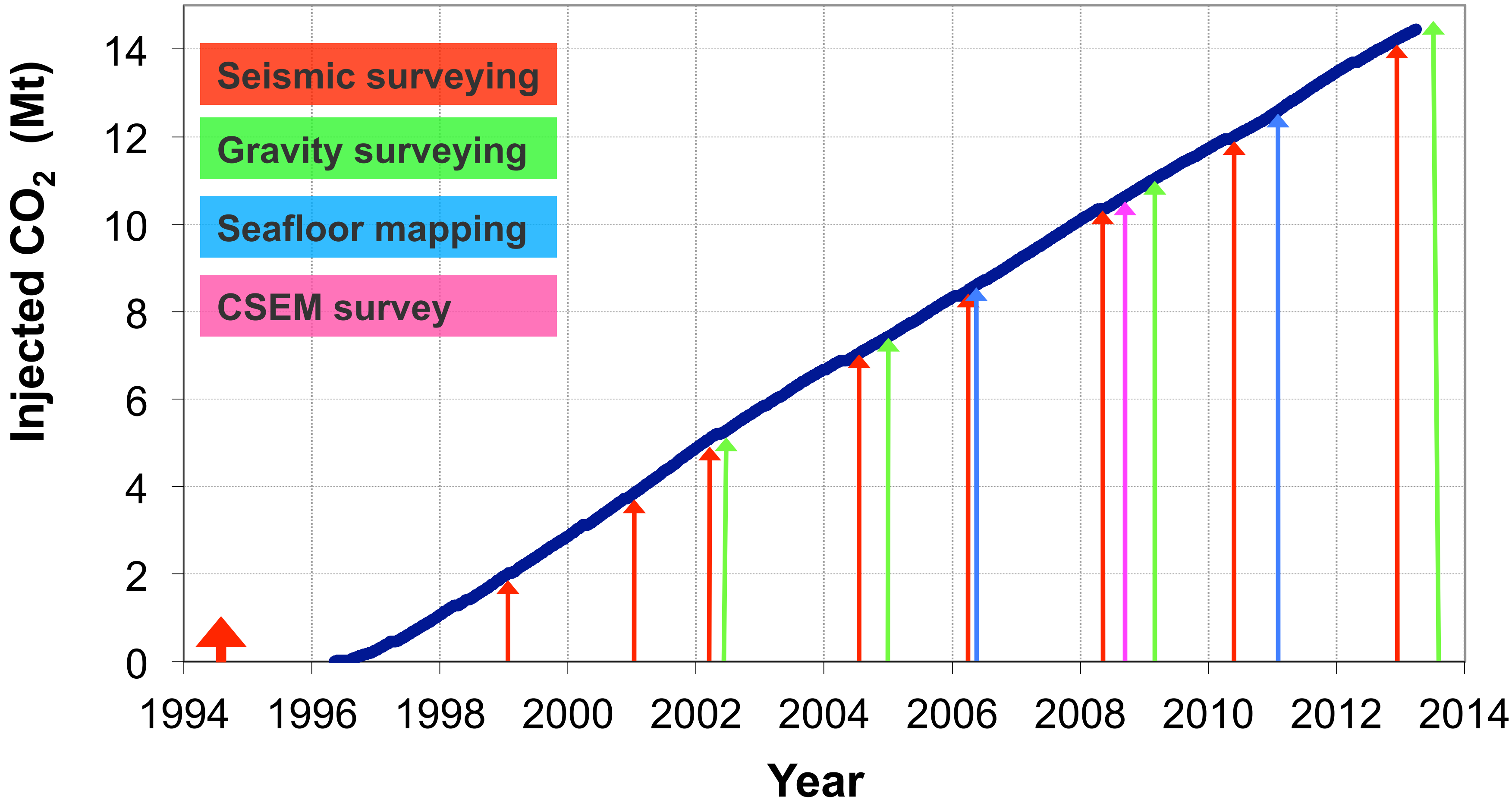
(T. Torp, 2000)



(A. Kiær, 2014)

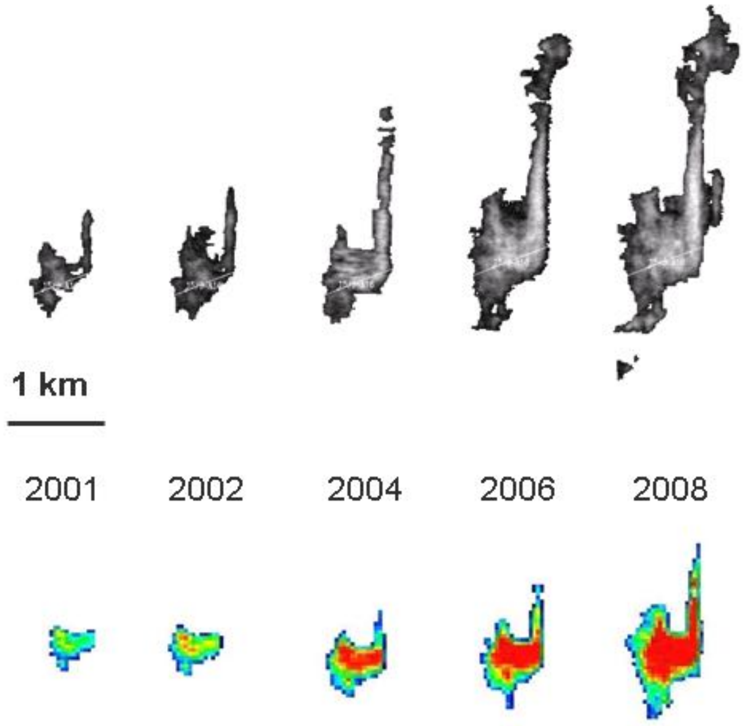
Sleipner monitoring

- *Cost-effective geophysical portfolio design*

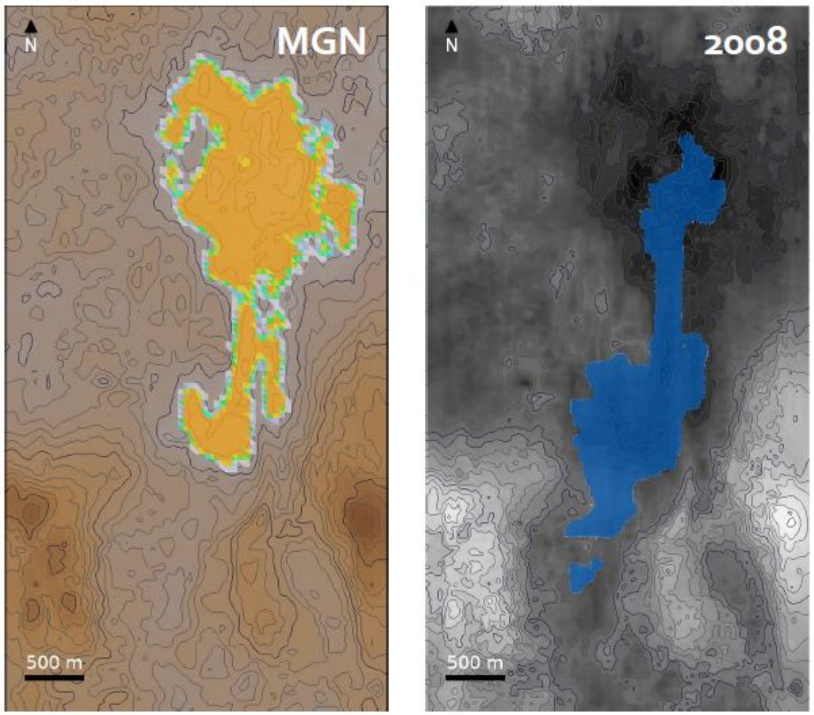


Sleipner model

➢ *Understanding CO_2 plume dynamics*



Darcy flow method
(Singh et al., 2010)



Percolating flow method
(Cavanagh, 2013; Cavanagh & Haszeldine, 2014)

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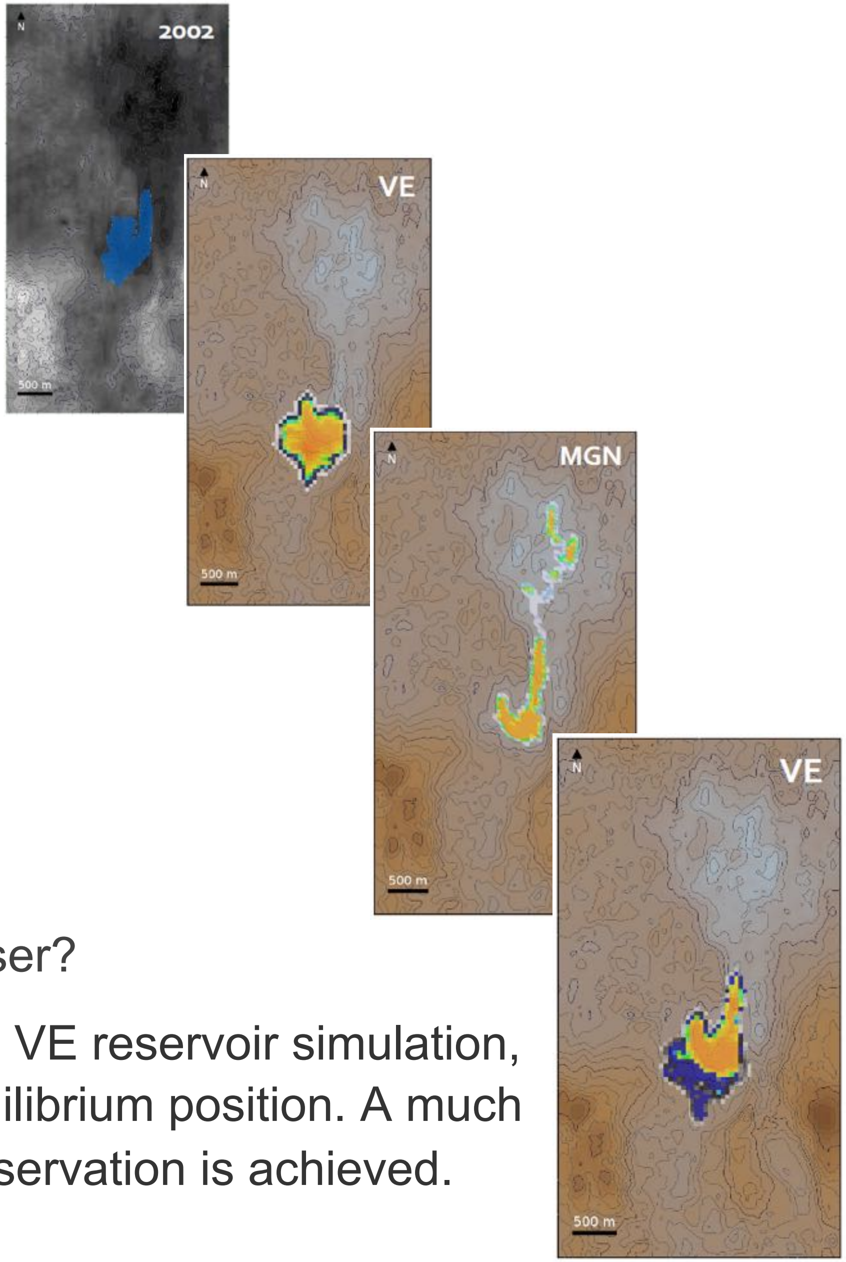
Sleipner model

➢ *Plume calibration based on seismic*

- Darcy flow approach:
  - Viscous forces, reservoir simulation
  - Vertical equilibrium assumption (VE)
  - Poor match, strong pressure artifact
- Percolating flow approach:
  - Capillary forces, basin modeling
  - Gravity assumption for migration (MGN)
  - Equally poor match, but is buoyancy closer?
- We then allow the pressure to dissipate in the VE reservoir simulation, and the plume redistributes to its buoyant equilibrium position. A much better match to the footprint of the seismic observation is achieved.



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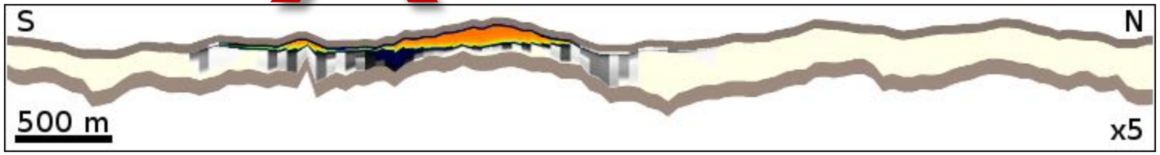
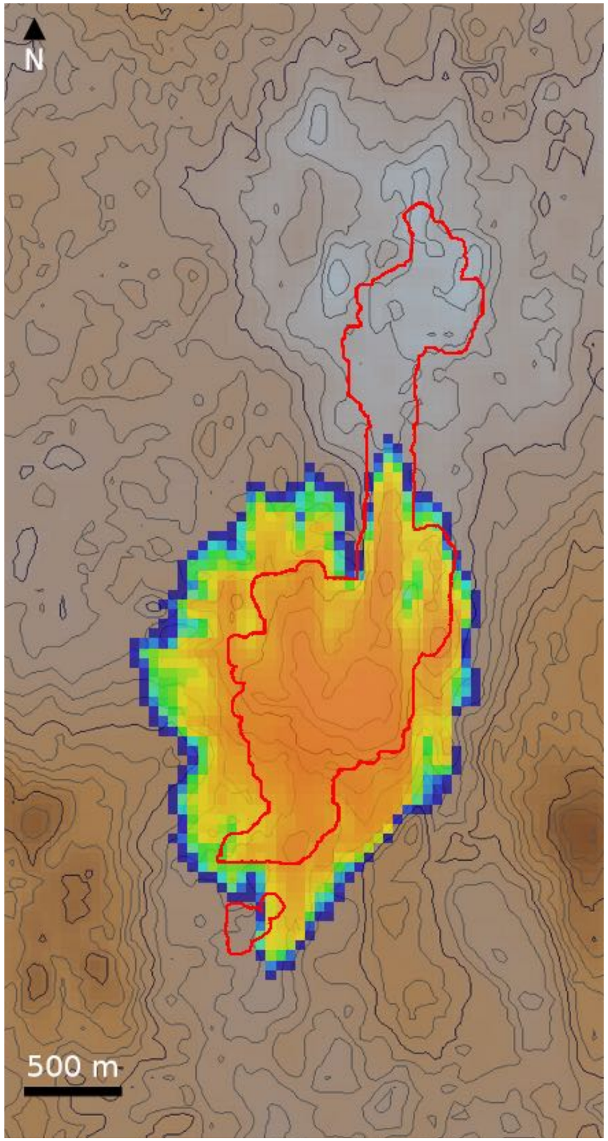
Sleipner model

- *2-phase black oil reservoir simulation*

- Calibrating for 2008 seismic footprint based on pressure equilibrium
- *Simulation time in years: 100*
- *Pressure field at the end of injection:*
  ~ 460 to 710 kPa (65-100 psi) overpressure
  ~ 250 kPa (36 psi) drop over 3 km





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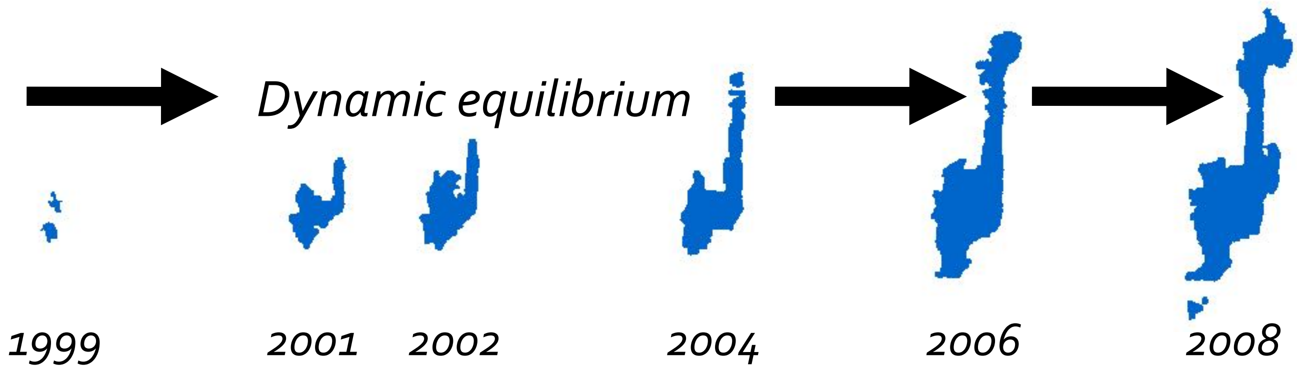
Sleipner model

- *Flow modelling favours near-equilibrium interpretation*



The simulation results clearly indicate that the plume beneath the caprock is gravity-dominated, and close to equilibrium at every observation point (Cavanagh, Energy Procedia, 2013)

Reservoir simulations for CO_2 storage may be susceptible to significant pressure artefacts that distort the model outcome.

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Testing the boundaries at In Salah

➢ *Main learning: the role of geomechanics and monitoring*

Storage limits in a challenging environment

- Driver: Joint Venture for technology development with BP and Sonatrach
- Storage unit: 1880 m depth, 20 m thick, low permeability
- 3.8 Mt CO_2 injected from 2004 to 2011

➢ **Challenges:**

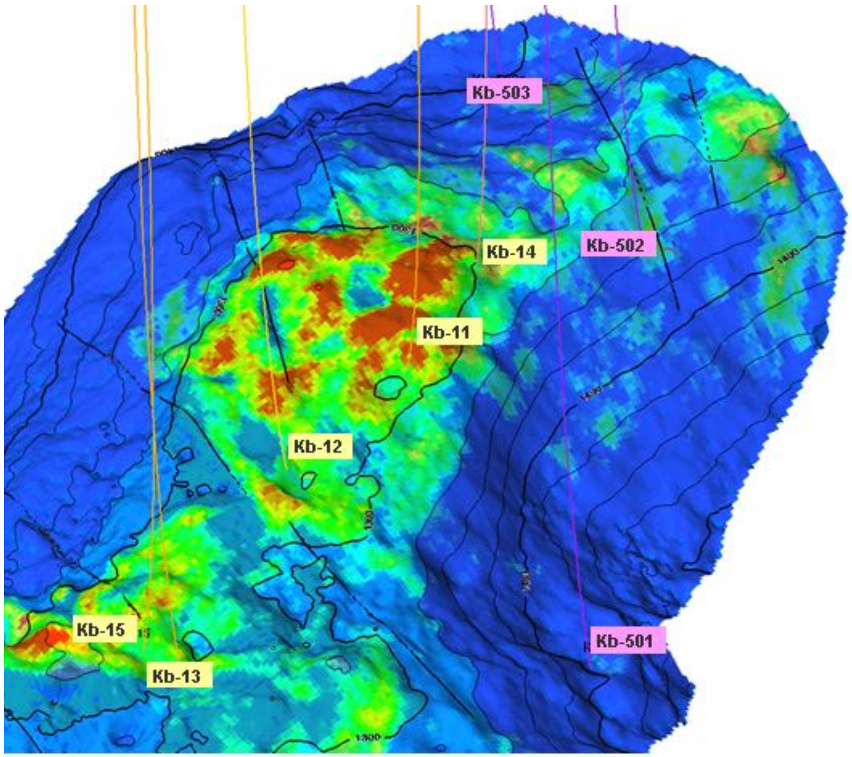
- Injectivity: low permeability formation limited injectivity and capacity
- Geo-mechanics: integrating monitoring techniques and modelling

➢ **Take-aways:**

- Developed pioneering onshore monitoring portfolio
- Inclusive research approach resulted in many peer-reviewed papers

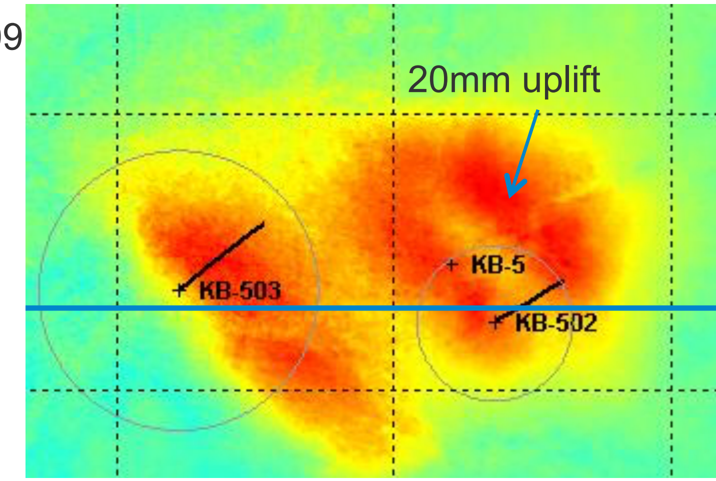
Testing the boundaries at In Salah

- *Main learning: the role of geomechanics and monitoring*

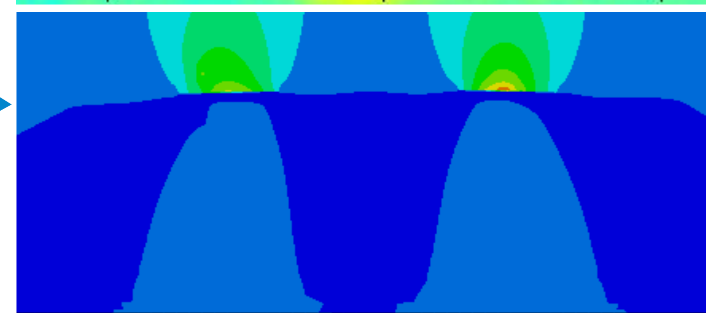


Map of surface uplift

May 2009



Injection unit

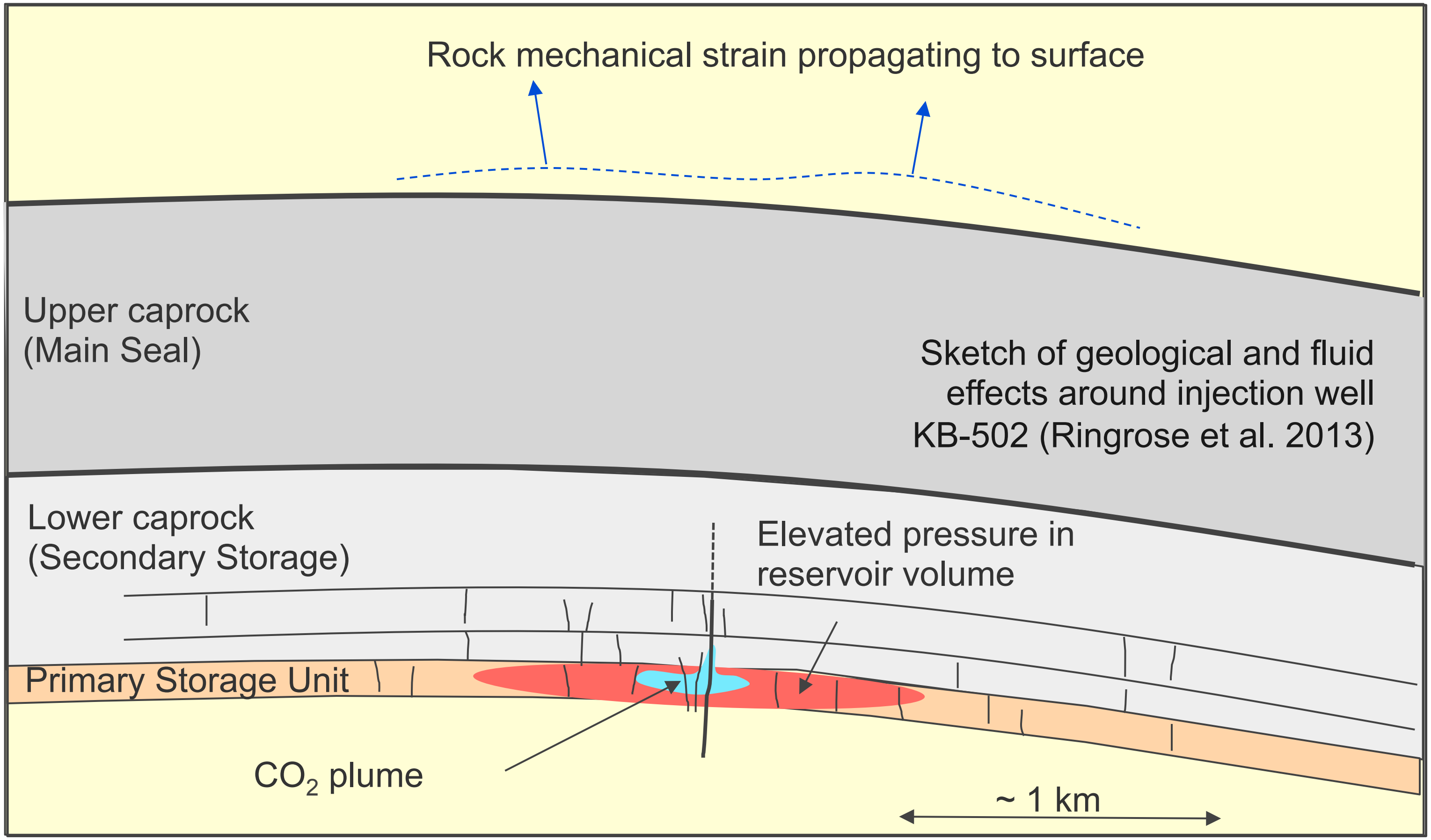


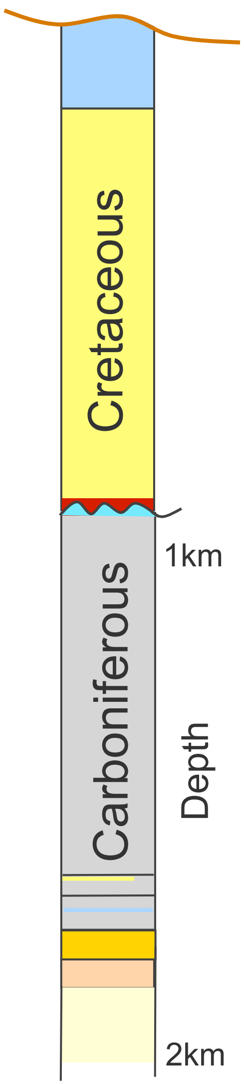
Modelled rock strain (section)

(Gemmer et al., 2012)

In Salah geomechanics

- *Simple linear elastics not sufficient to explain observations*
- *Hydro-fractures and fracture flow observed*

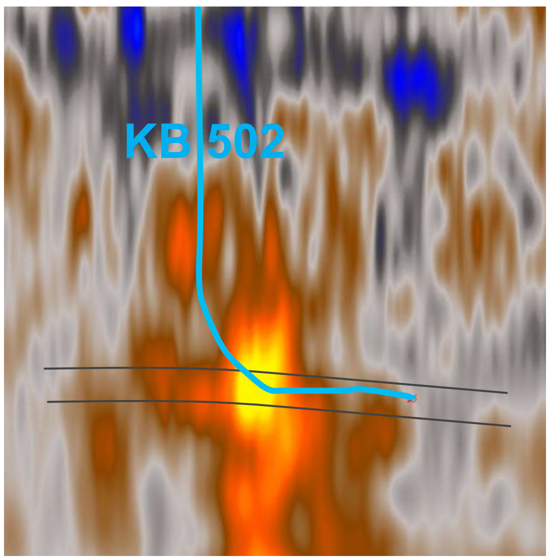




In Salah geomechanics

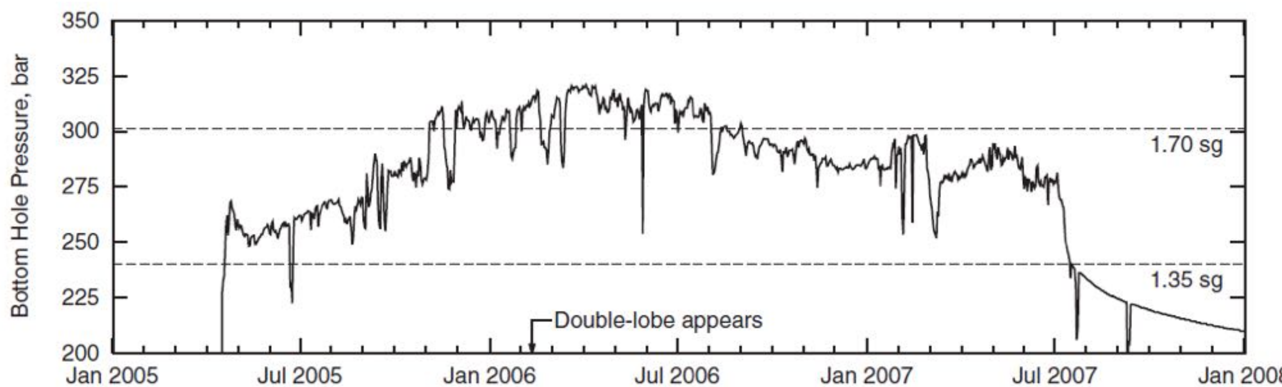
- *All hydro-fracture hypotheses reviewed by White et al. 2014 (PNAS)*

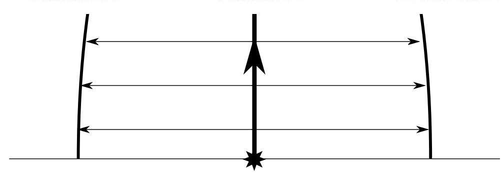
4D seismic:
Time-delay feature
(reprocessed seismic)



Well-head pressure:
Monitoring reservoir response

Modelling:
Example analytical model





integrity

Applying the knowledge to Snøhvit

➢ *Main learning: integrating geophysics and injectivity*

The world's first offshore CO_2 transport pipeline

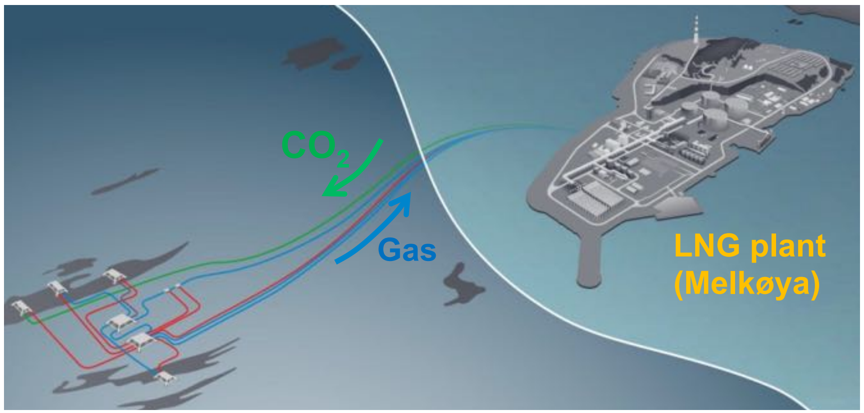
- Driver: Regulator license-to-operate (& carbon tax)
- Distance: field-to-onshore facility is 150 km
- Storage unit: 2600 m depth
- Over 3 Mt CO_2 has been injected since 2008

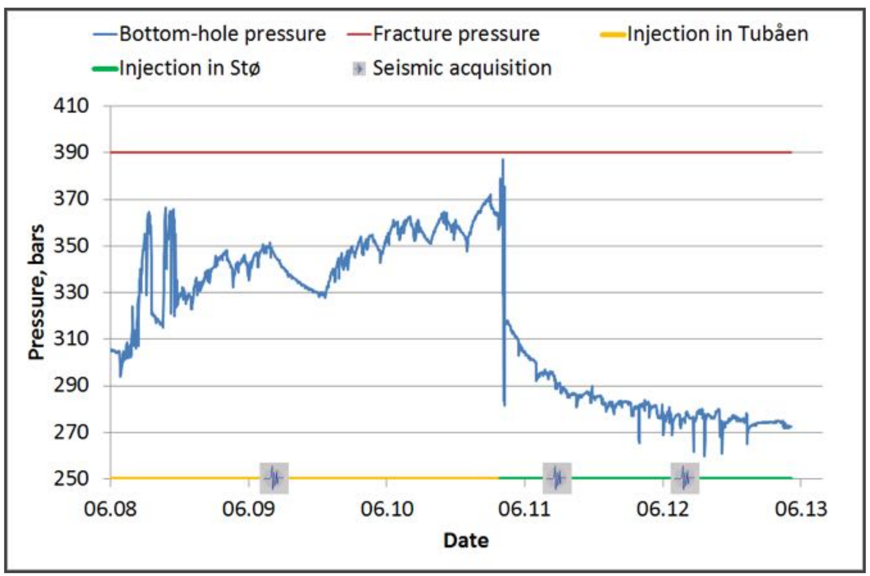
➢ **Challenges:**
  - Reservoir heterogeneity
  - Near-well flow limits

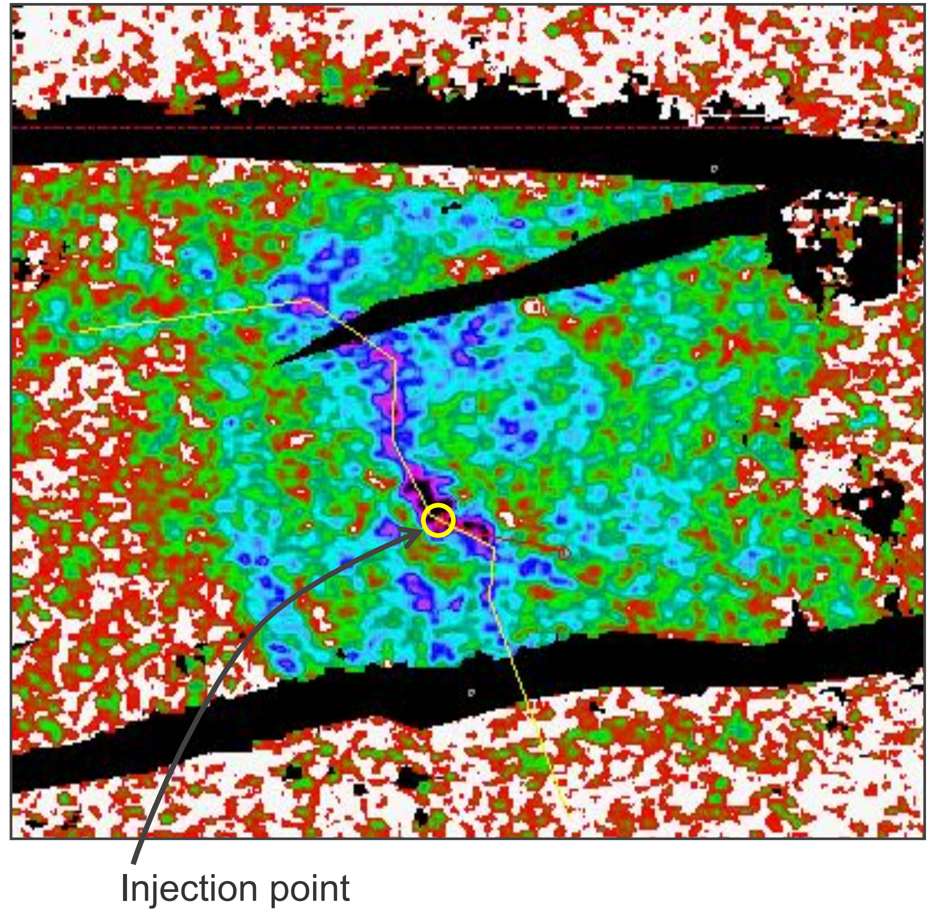
➢ **Take-aways:**
  - Need for robust design of injection system in heterogeneous reservoirs
  - A good 'Plan B' is invaluable when reservoir uncertainties are large

Applying the knowledge to Snøhvit

- *Main learning: integrating geophysics and injectivity*



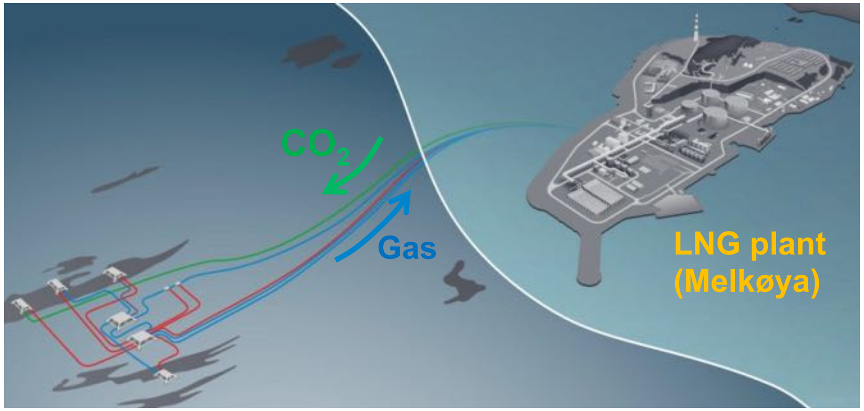


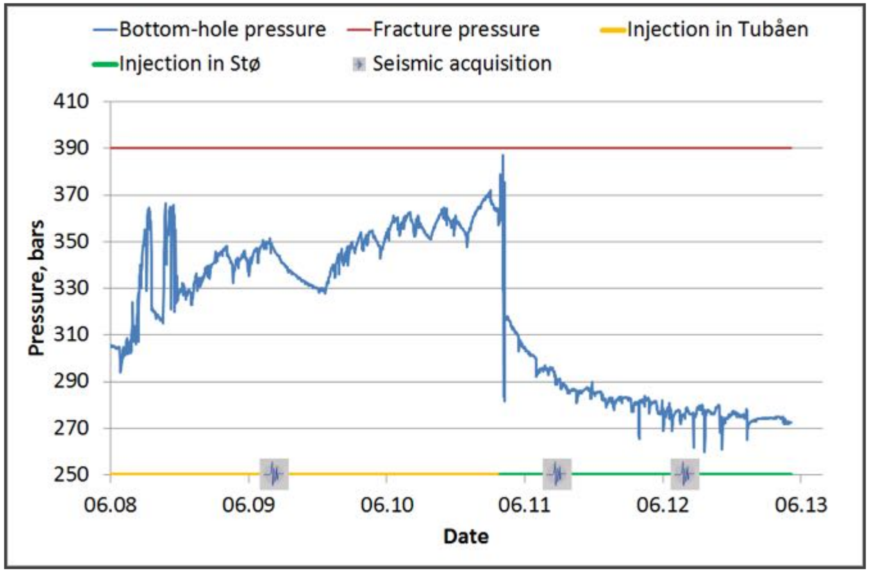


(Osdal et al., 2014)

Applying the knowledge to Snøhvit

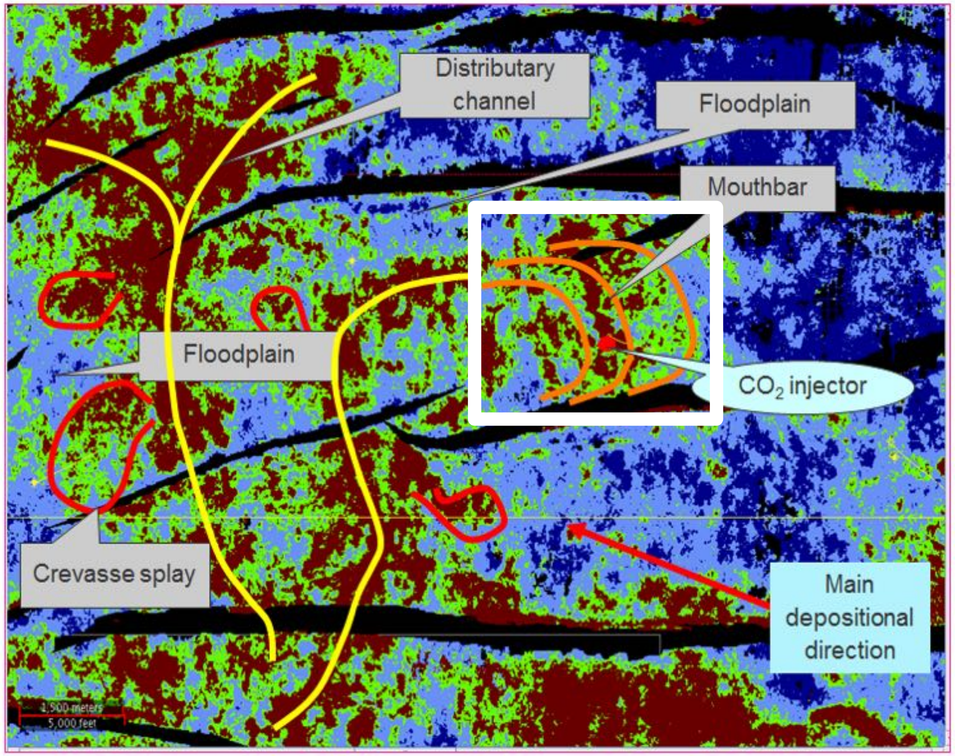
- *Main learning: integrating geophysics and injectivity*





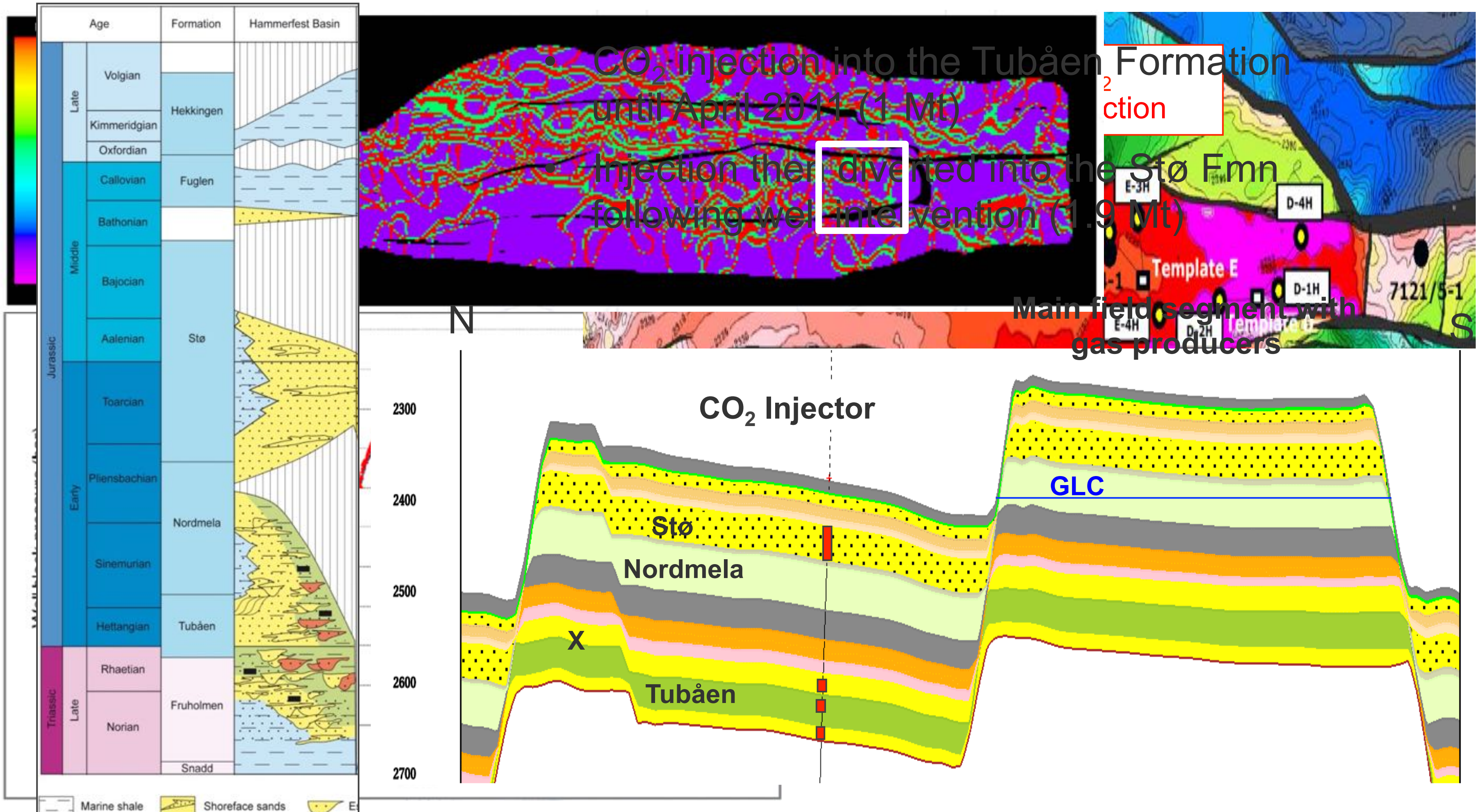
Tubåen reservoir quality

Detailed mapping based on 3D seismic



Applying the knowledge to Snøhvit

➢ *Response to pressure build-up in the Tubåen*



(Ji-Quan Shi et al., 2011)

Lessons learned from the last 20 years

1. Can injected CO_2 be monitored cost-effectively?	• Yes ☑ No ☐ Maybe ☐
2. Do we have enough storage capacity?	• Yes ☐ No ☐ Maybe ☑
3. Are we technically ready for very large projects?	• Yes ☐ No ☐ Maybe ☑
4. Is CO_2 storage safe?	• Yes ☑ No ☐ Maybe ☐

There's never been a better time for good ideas

Thanks to…
Anne-Kari Furre
Anders Kiær
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Bamshad Nazarian
Britta Paasch
Philip Ringrose

Statoil CO_2 storage experience: 20 years and 20 million tonnes

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