Experience from Natural Gas Operations: Offshore Norway

Statoil

CSLF Mid-Year Meeting, Regina

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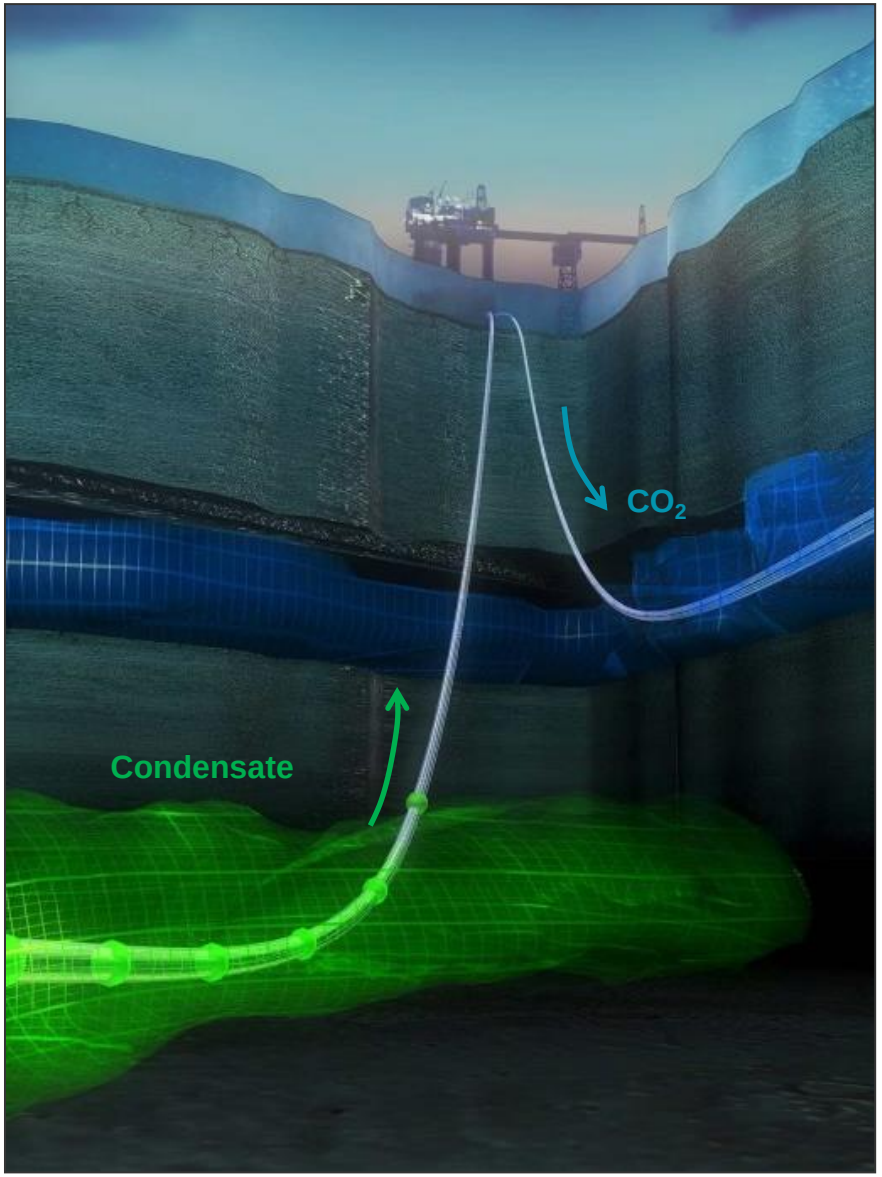
Presented by Britta Paasch

Statoil ASA, Norway

Overview

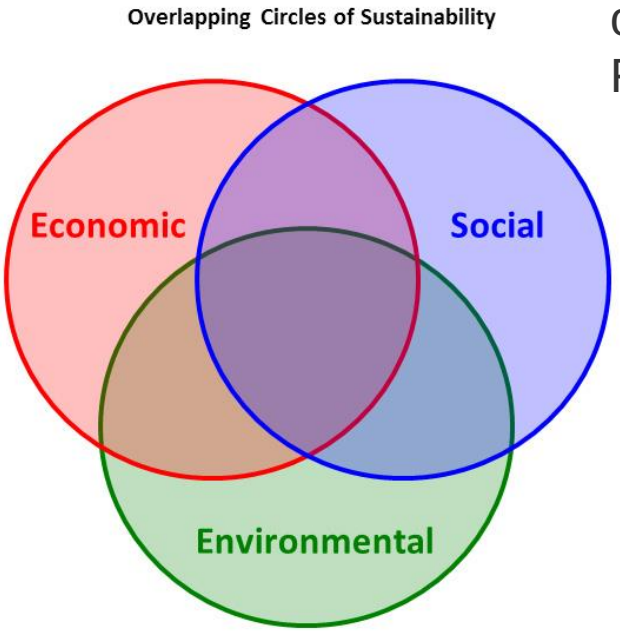
- History
- Sleipner
- Snøhvit
- What have we learned?



Intro

Our common future (1987)

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs« (Our Common Future, 1987)



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Norwegian CO2 Tax

1991

CCS Operations at Statoil

- Statoil is a world leading operator of CCS sites
- The pioneering Sleipner project started in 1996
- Unique blend of experience from several operations
- 22 Mt CO_2 stored safely underground

Sleipner

1996

In Salah

2004

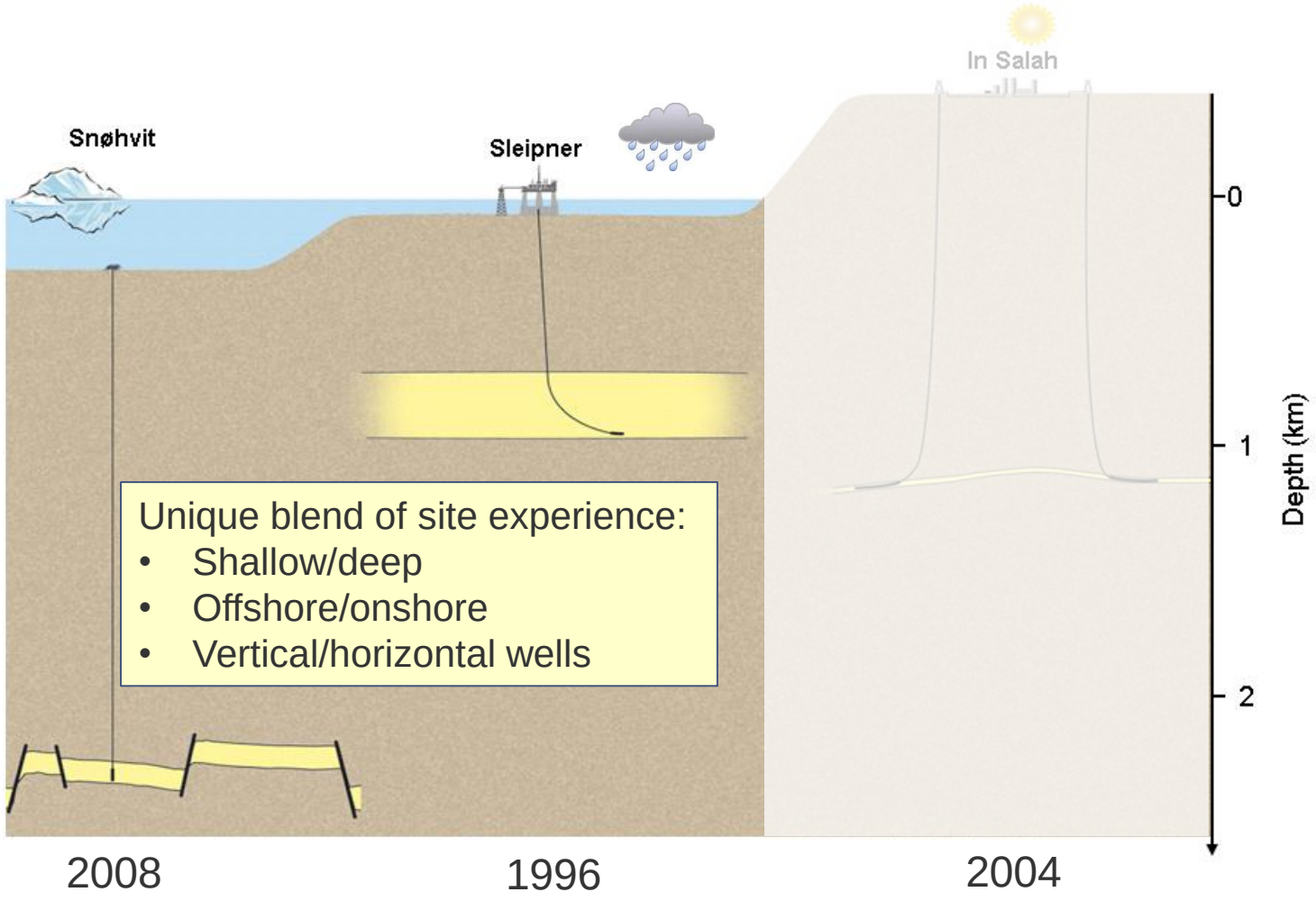
Snøhvit LNG

2008

Test Centre Mongstad

2012

Statoil storage projects



Eiken et al., 2011

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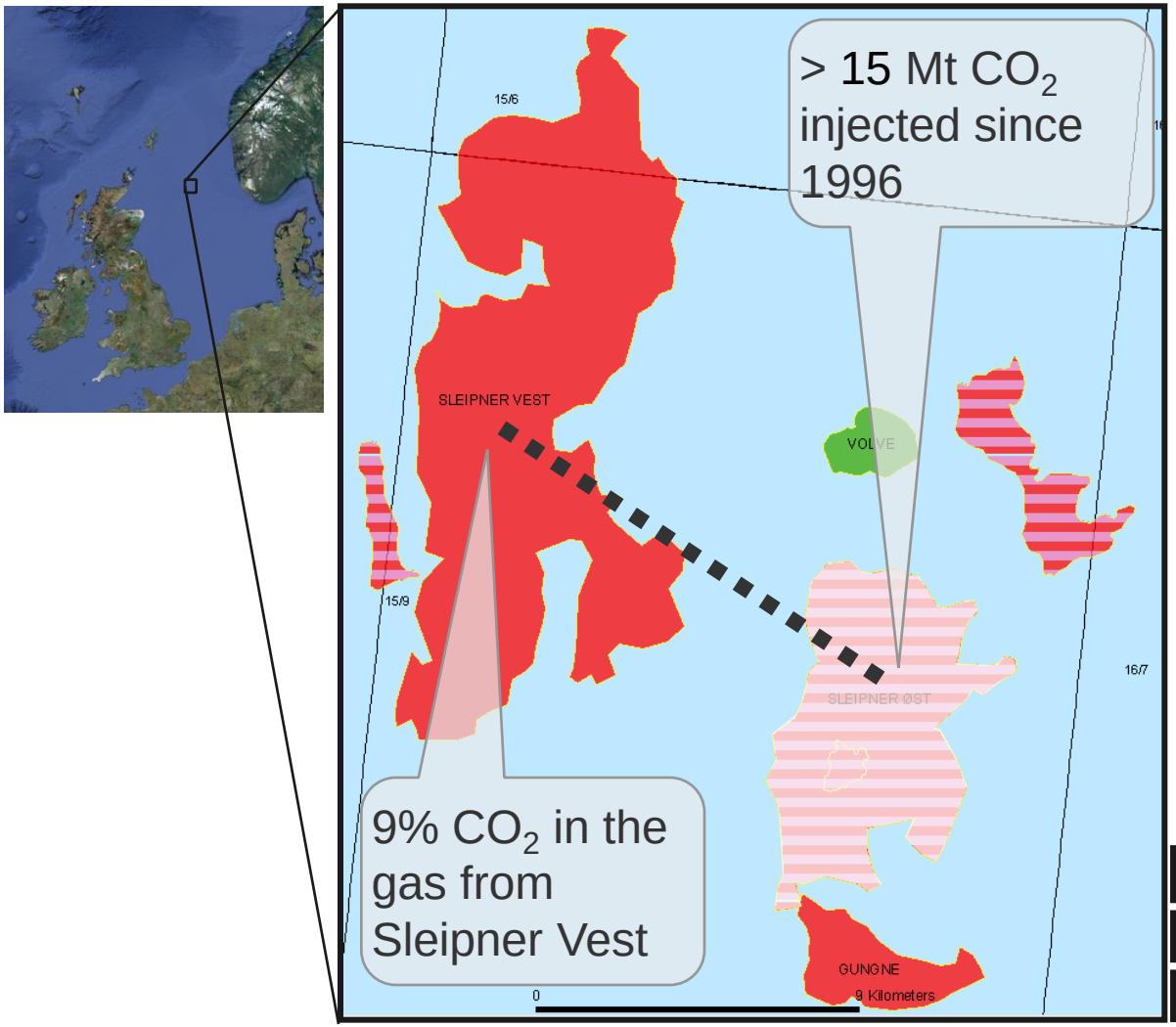
Brief introduction to the Sleipner fields



Sleipner West: Gas field with high CO_2 content.

Sleipner East: CO_2 is stripped off the gas and injected in the Utsira Fm at ~ 900 m depth (above the condensate reservoir).

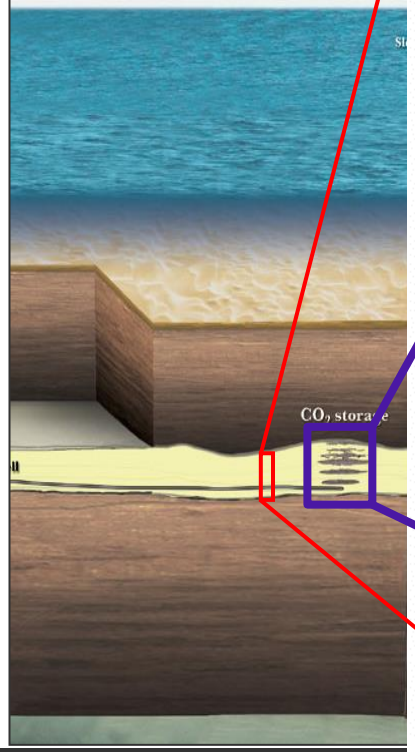
The Utsira Formation.

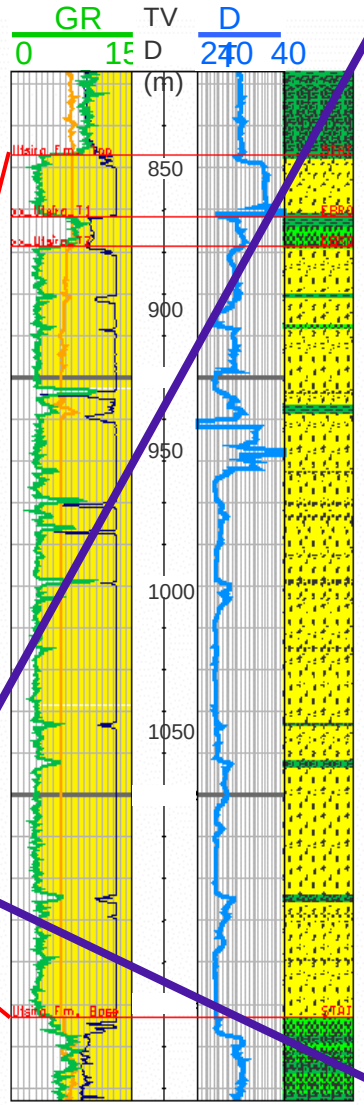
Net/gross: 0.98

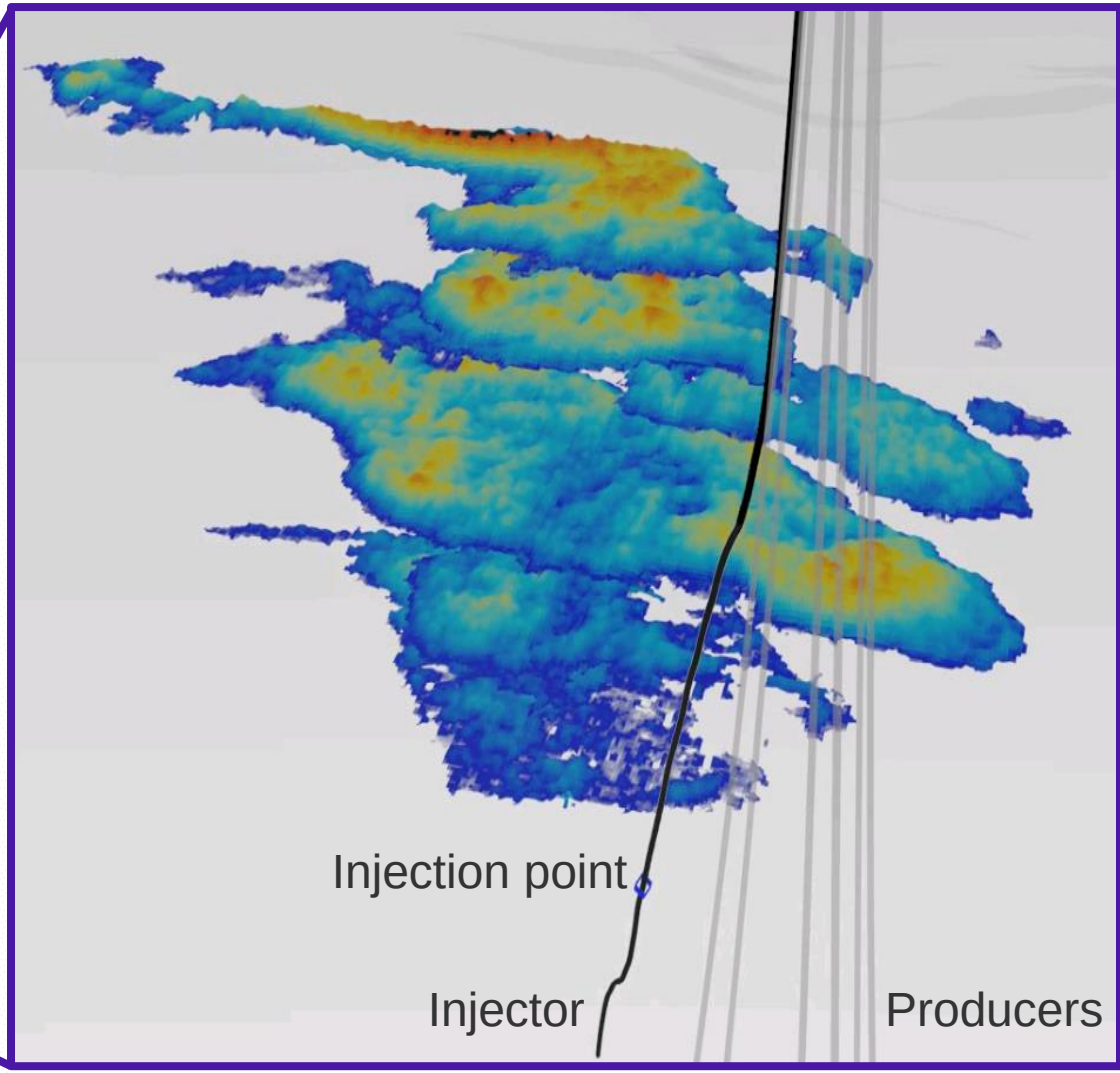
Porosity: 35-40 %

Permeability > 1 D

~ 200 m thick

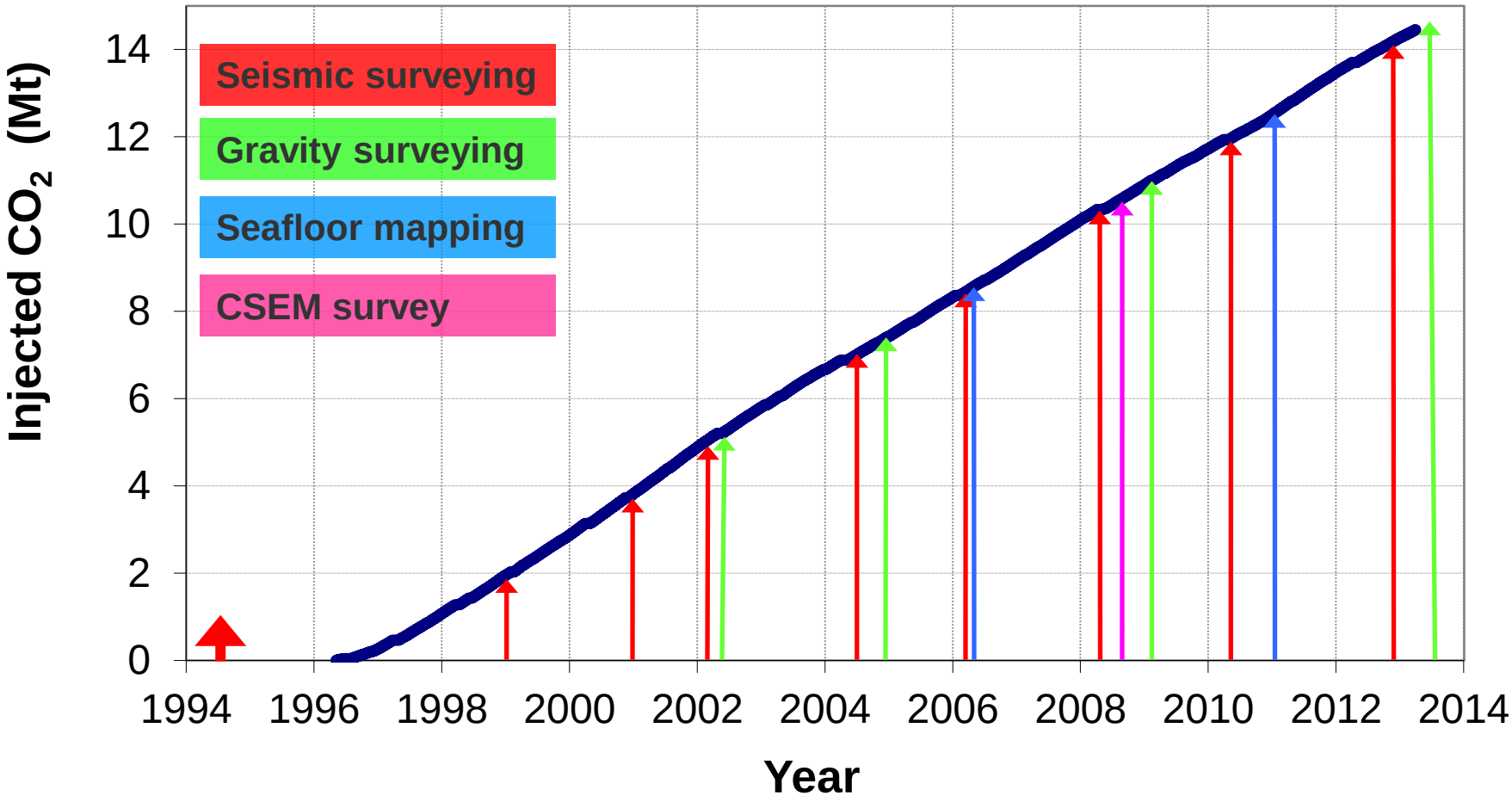






Sleipner injection and monitoring history

- *Cost-effective monitoring and geophysical portfolio design*



Time-lapse (4D) seismic:

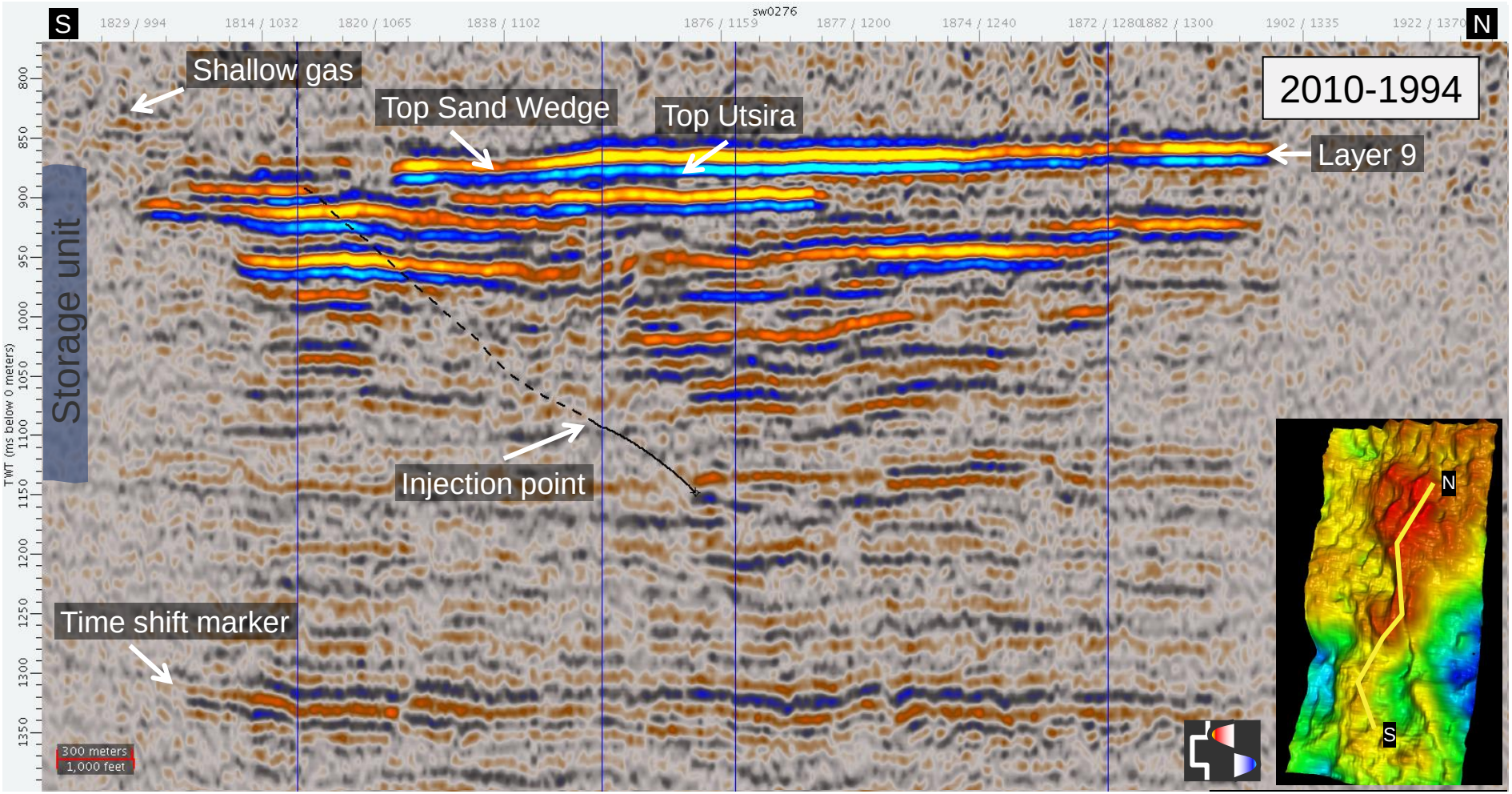
1996

New technology

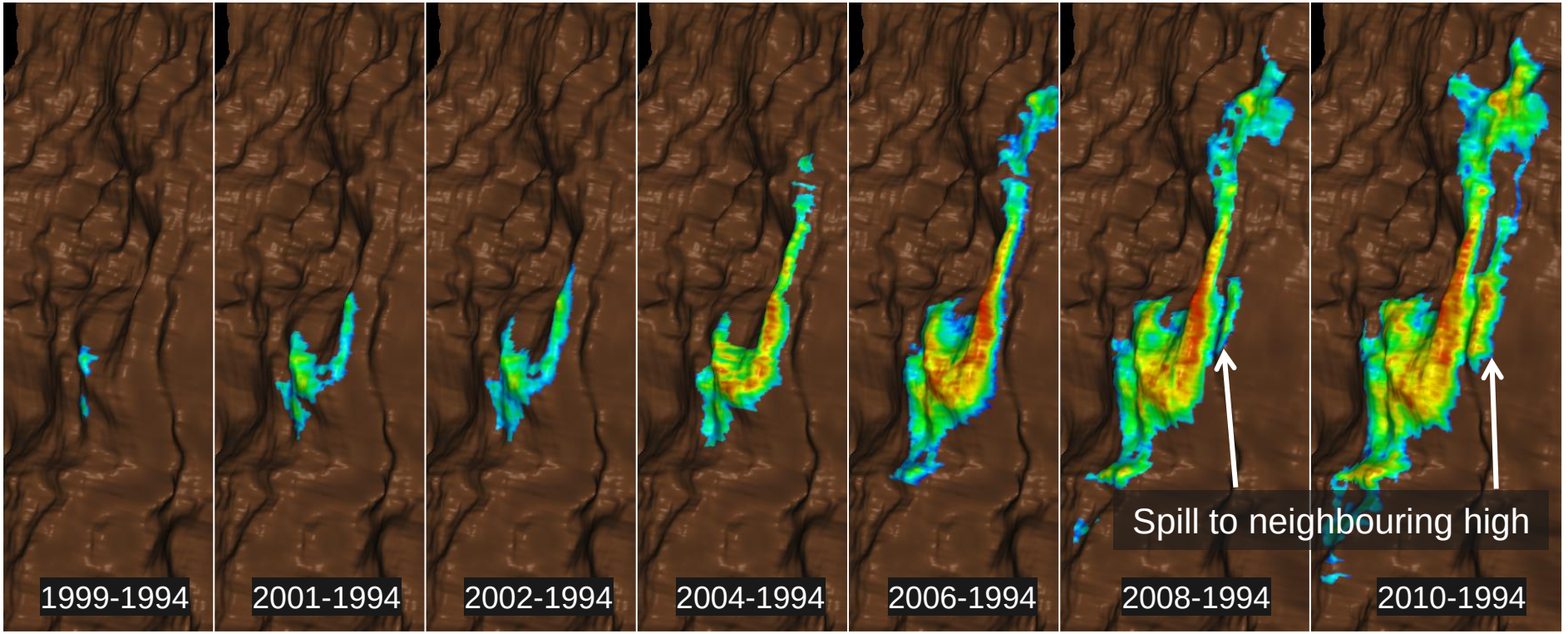
- Now: Old, well-tested technique
  - Gullfaks
  - Statfjord
  - Heidrun
  - Norne
  - Snorre
  - Troll
  - Veslefrikk
  - Njord
  - Sleipner

  - Oseberg
  - Grane
  - Kristin
  - Glitne
  - Snøhvit…

Time-lapse difference



Development of layer 9 draped on Top Utsira TWT
(exaggerated relief)

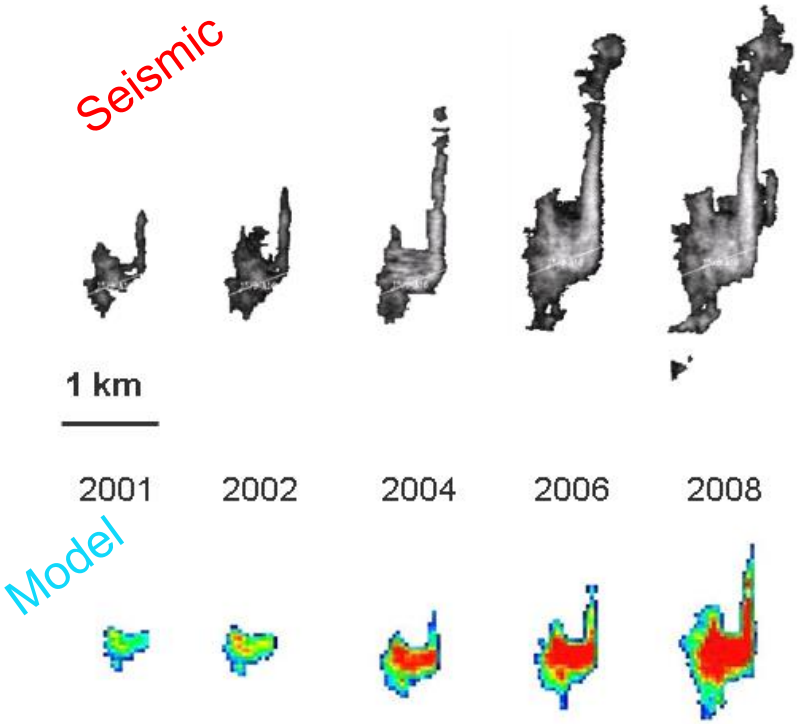


Low — High

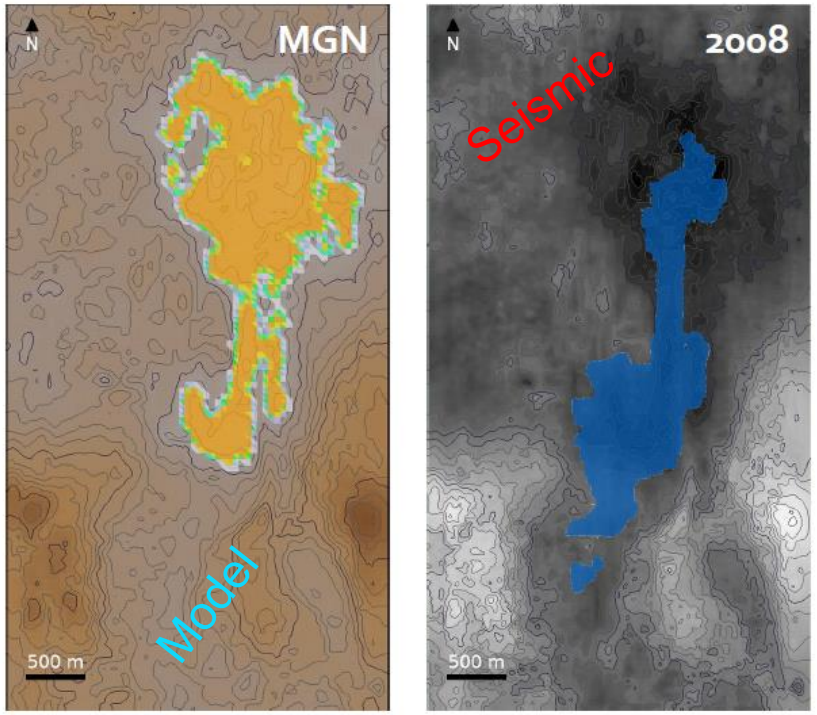
Amplitude

Modeling the CO_2 plume at Sleipner

- *Understanding CO_2 plume dynamics with benchmark simulations*

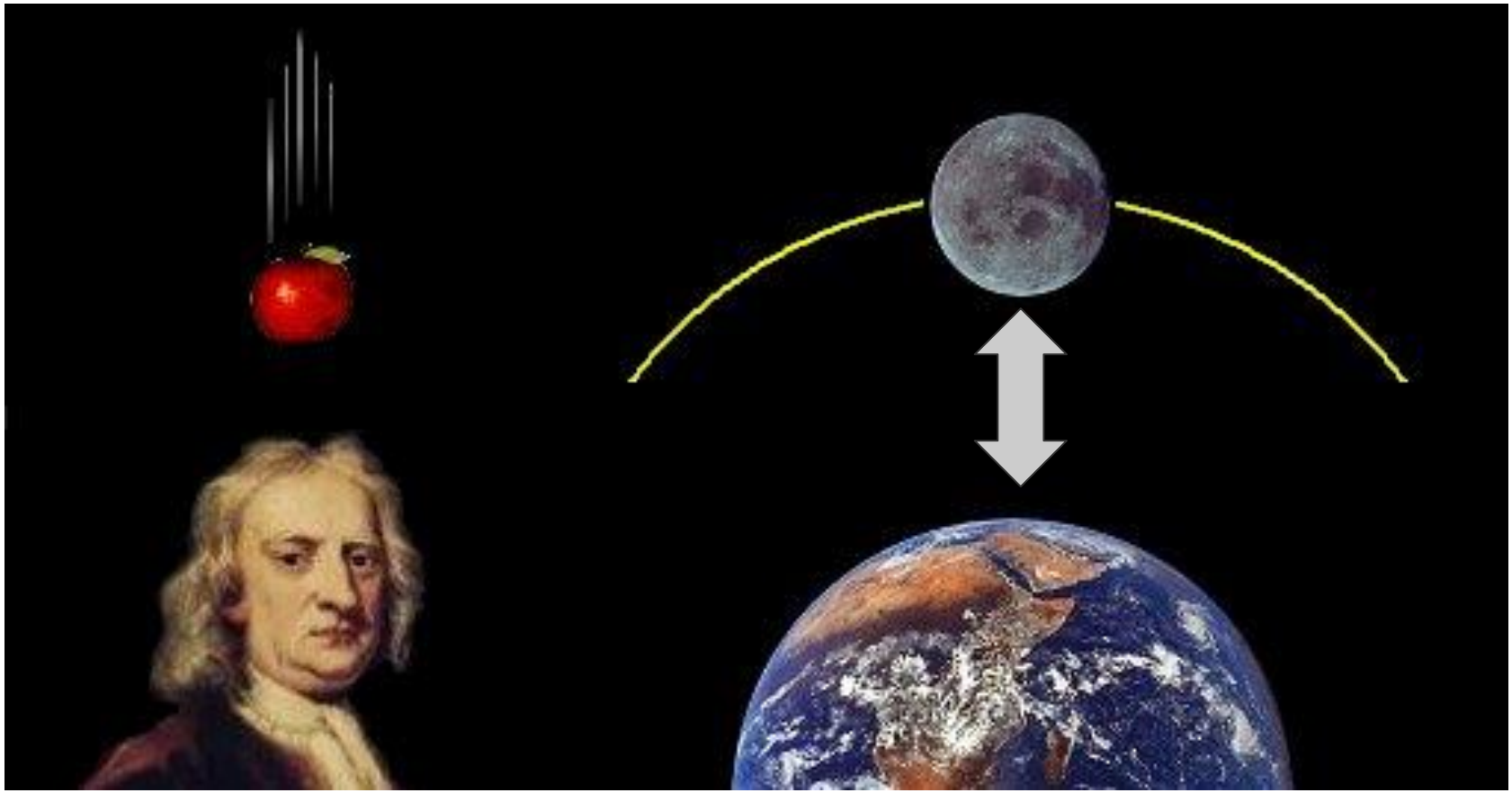


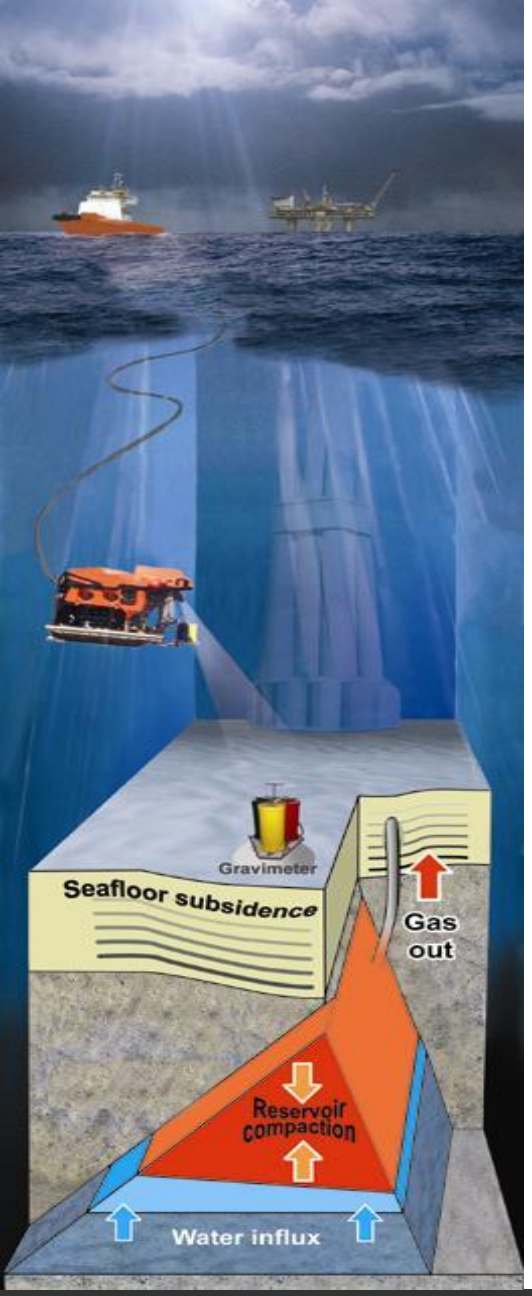
Darcy flow method
(Singh et al., 2010)



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

Gravimetric monitoring





Methodology

- Permanently deployed concrete benchmarks on the seafloor
- Mobile instrument carried by ROV, measuring 10-20 minutes at each site
- Measure changes in the gravity field at the seafloor using relative gravimeters (2-3 µGal accuracy)
- Measure vertical movement of benchmarks using water pressure (2-3 mm accuracy)
- The method has so far been used successfully for monitoring several gas reservoirs offshore Norway.

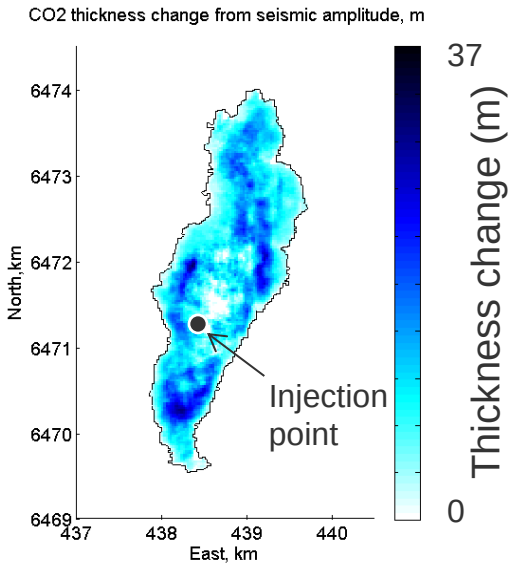
CO_2 thickness change 2002-2013

- How does the CO_2 plume develop over time?

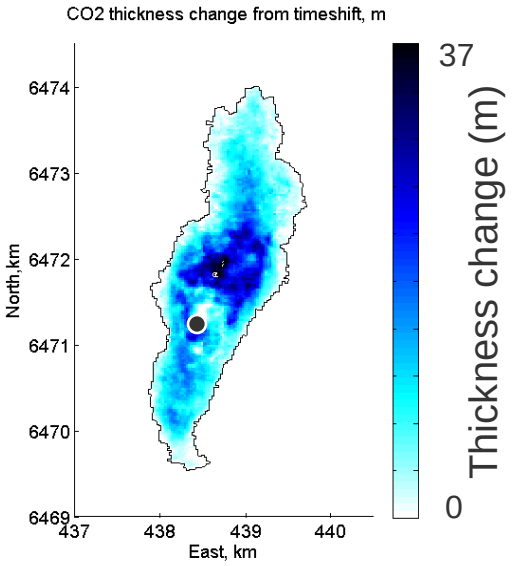
  4D seismic gives two very different pictures!

- After removing the signal from water influx to the Ty Fm., the gravity signal from CO_2 is visible
- Inversion of gravity data indicates that the plume is growing mainly in the centre, similar to the 4D timeshift picture.

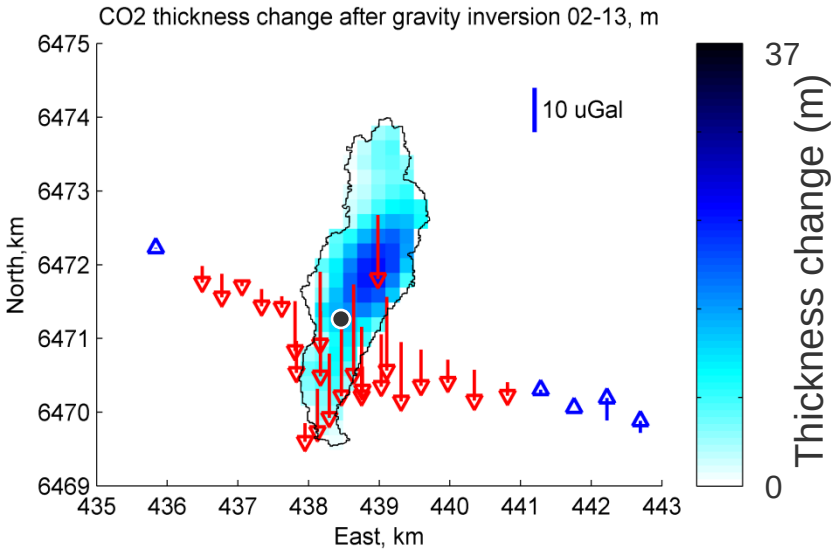
4D seismic amplitudes



4D timeshift



Gravity inversion:



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Summary - Gravimetry

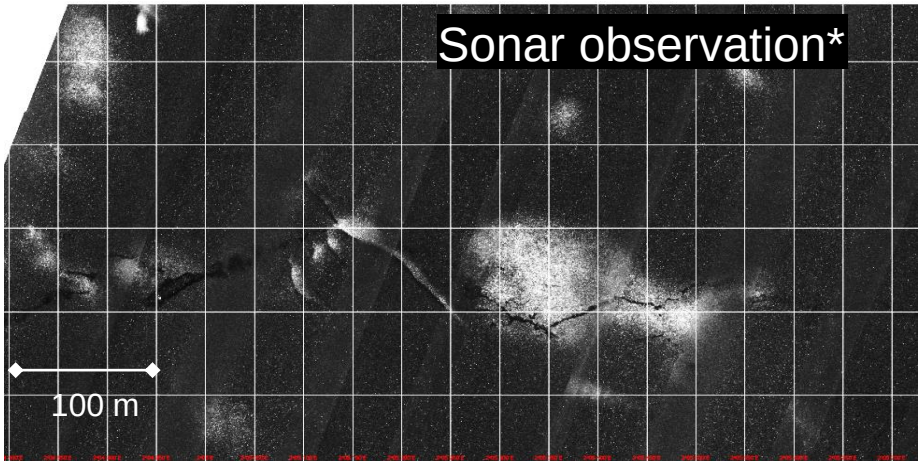
- Time-lapse gravity is useful for quantitative monitoring of subsurface CO_2 storage (and even more useful for monitoring water influx to gas fields)
- Current instrument accuracy corresponds to a sensitivity of ± 1 MT CO_2 at 800m depth
- Gravity surveys over Sleipner prove that the CO_2 is stored in the Utsira Fm. and puts an upper limit on CO_2 absorption into brine of 2.7% per year

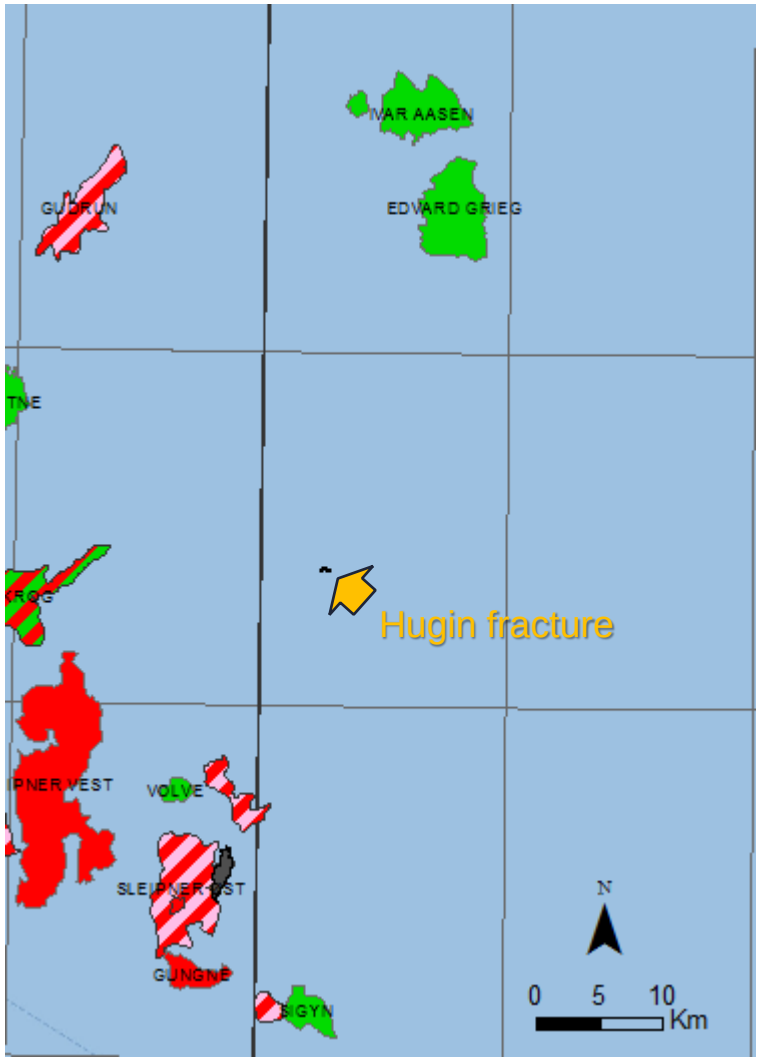
The views expressed in this presentation reflect Statoil's understanding

Acknowledgement: We would like to thank the Sleipner license partners (ExxonMobil and Total E&P Norge AS) for permission to share this work.

Public interest in seabed feature

- Considerable public interest in a sea-bed glacial feature in the greater Sleipner area
- Natural gas leakage was observed at the Hugin fracture, one of many on the NCS
- Unrelated to CO_2 injection
- Probably related to glacial processes
- Further analysis of this by Furre et al, 2014





*ECO_2 consortium

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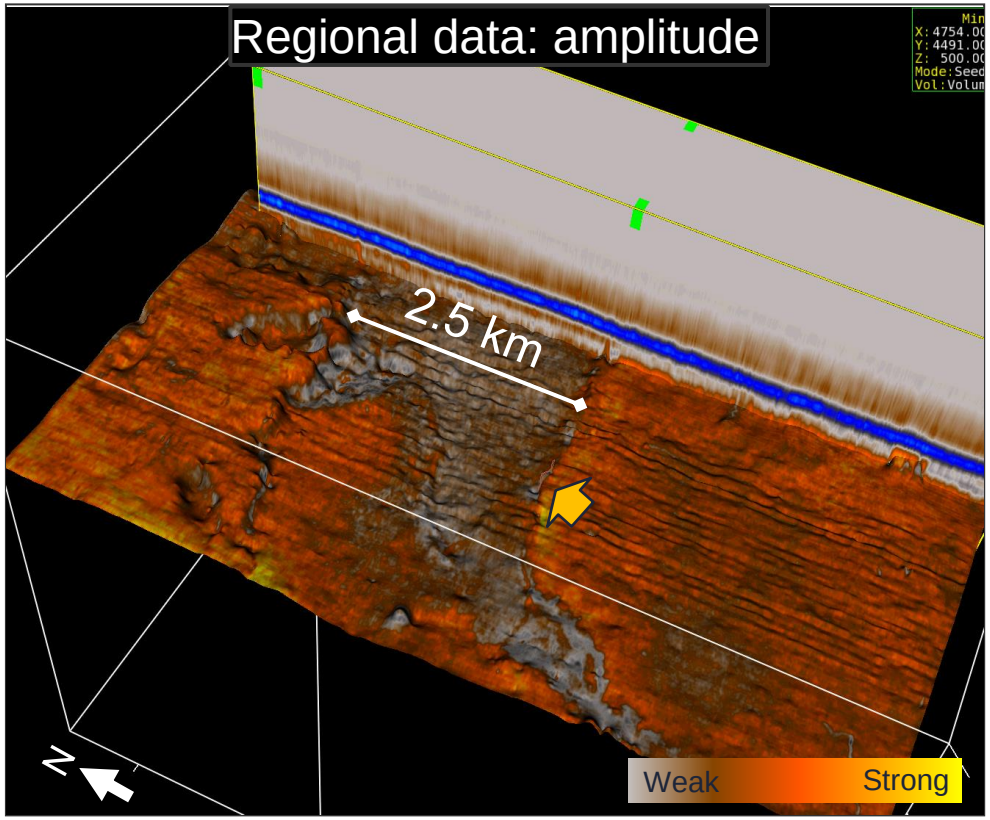
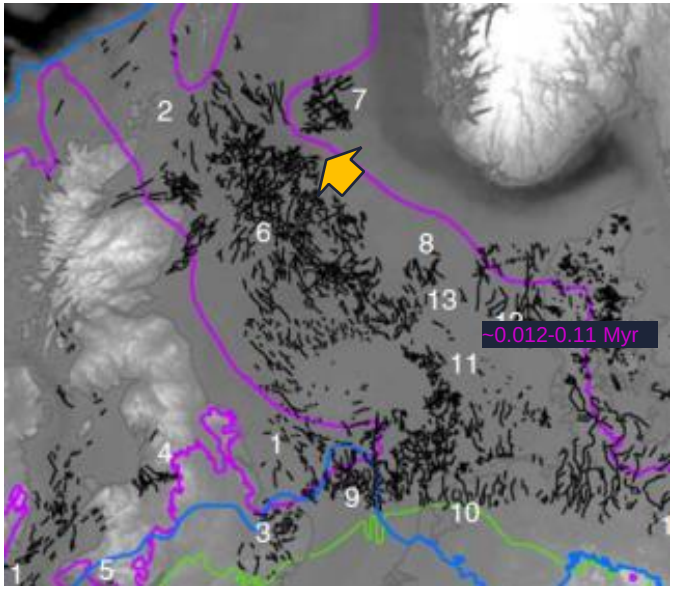
Regional mapping of shallow seismic features

- Regional mapping work is needed to understand glacial processes and their impact on the shallow rock system(see Furre et al., 2013)



Regional observations on glacial valleys and channels (van der Vegt et al., 2012)



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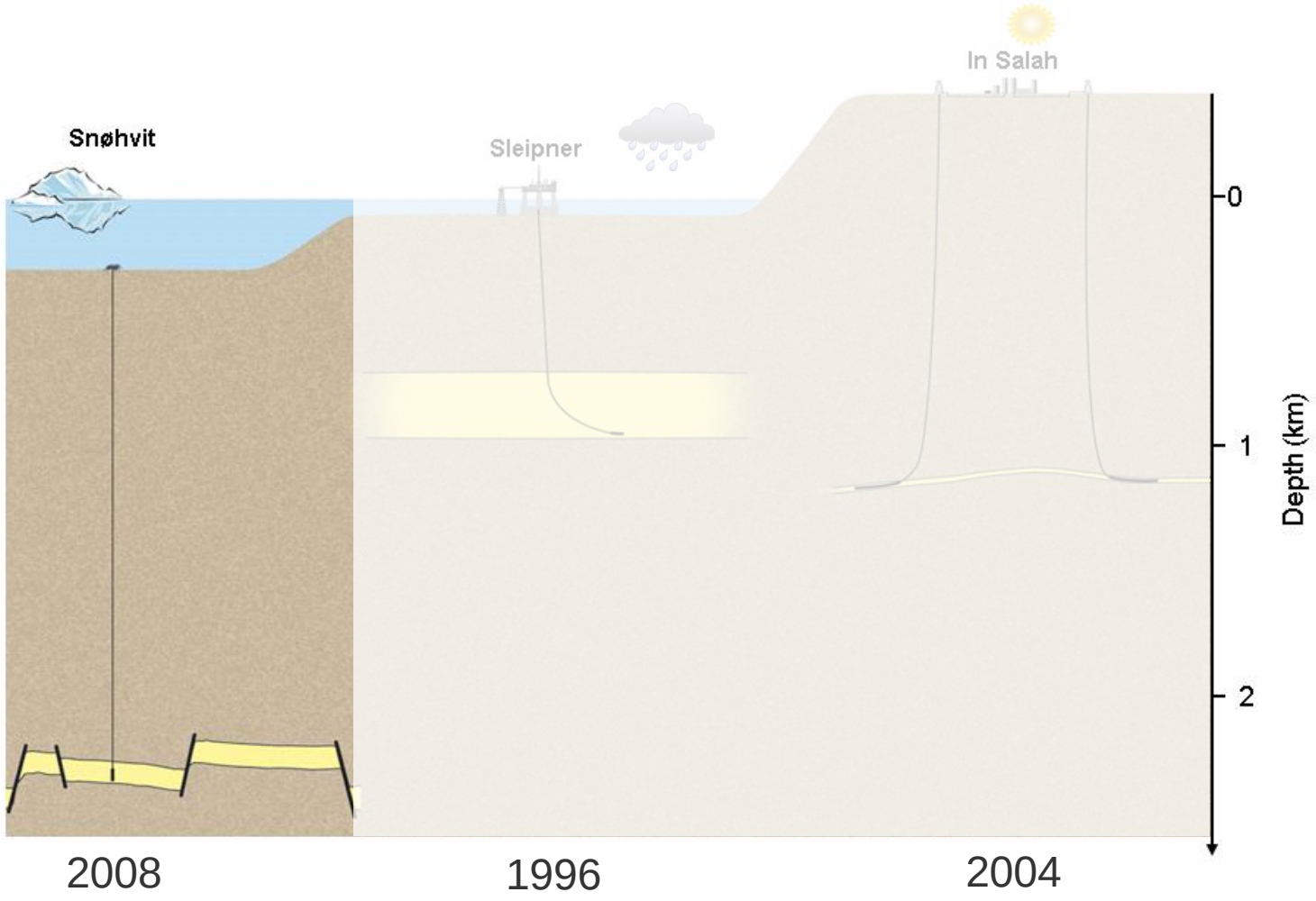
Sleipner Summary

- *Main learning: CO_2 storage is technically feasible*

- **The World's first commercial-scale offshore storage project**
  - Storage unit: 800-1000 m depth, 200 m thick, high permeability
  - More than 15 Mt CO_2 has been injected since 1996
- **Challenges:**
  - Role of internal shale layers on plume movement
  - Predicting CO_2 plume flow properties
- **Take-aways:**
  - CO_2 plume can be monitored by seismic and gravimetric methods
  - Significantly improved understanding of CO_2 storage processes

Statoil storage projects



Eiken et al., 2011

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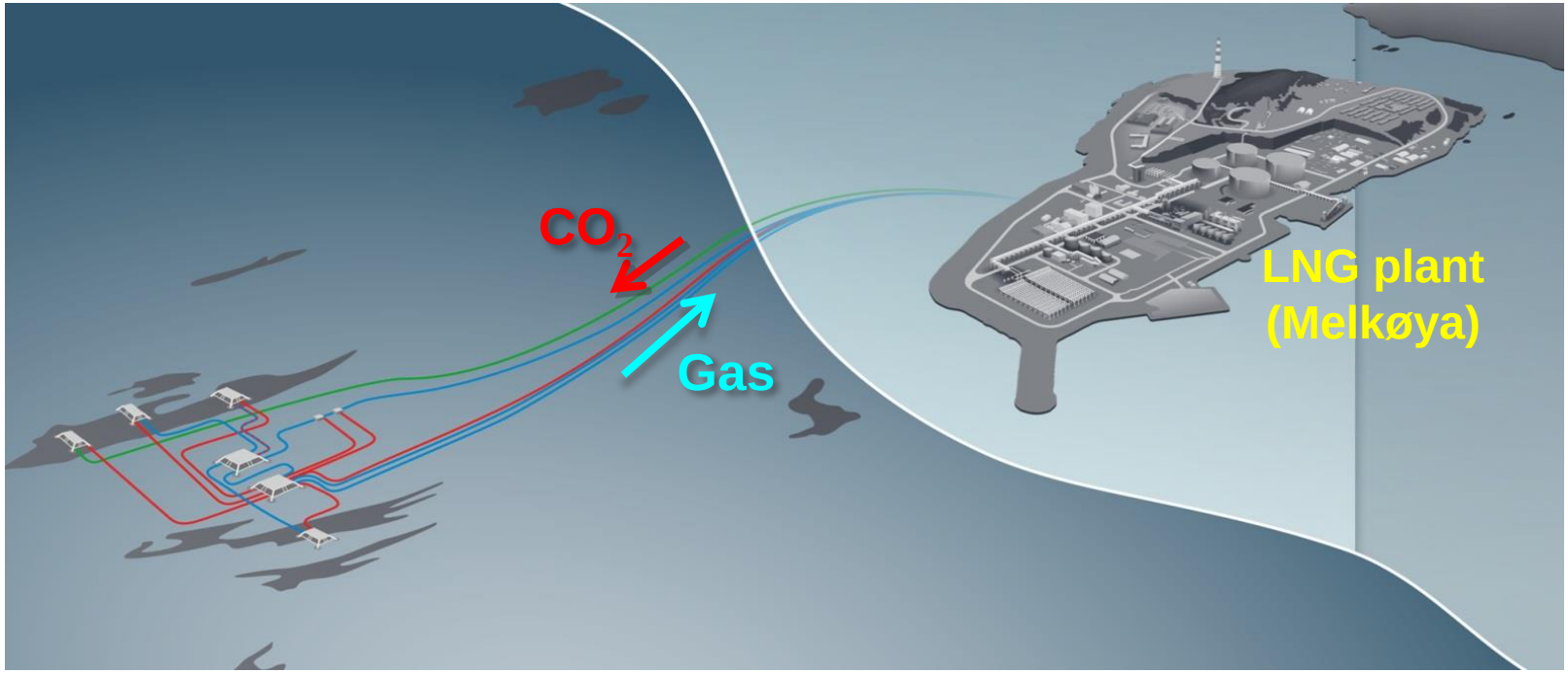
Snøhvit CO_2 capture and storage

- *First onshore capture - offshore storage project (combined with LNG)*
  - 150km seabed CO_2 transport pipeline
  - Saline aquifers c. 2.5km deep adjacent to gas field
  - CO_2 stored initially in the Tubåen Fm. and then in the Stø Fm. (2011-)



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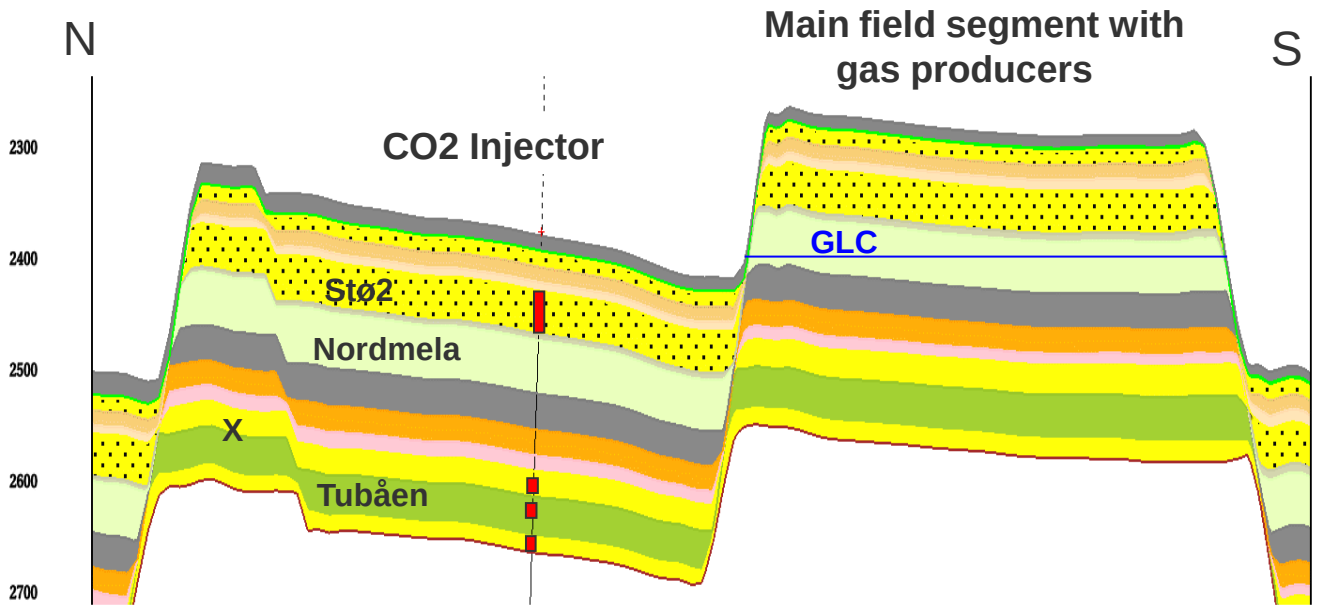
Snøhvit CO_2 injection history and status

➢ Continuing stable injection of CO_2

- CO_2 injection into the Tubåen Formation until April 2011
- Injection then diverted into the Stø Formation following well intervention
- 2.9 Mt injected by end 2014 (1.1 Mt injected into Tubåen)



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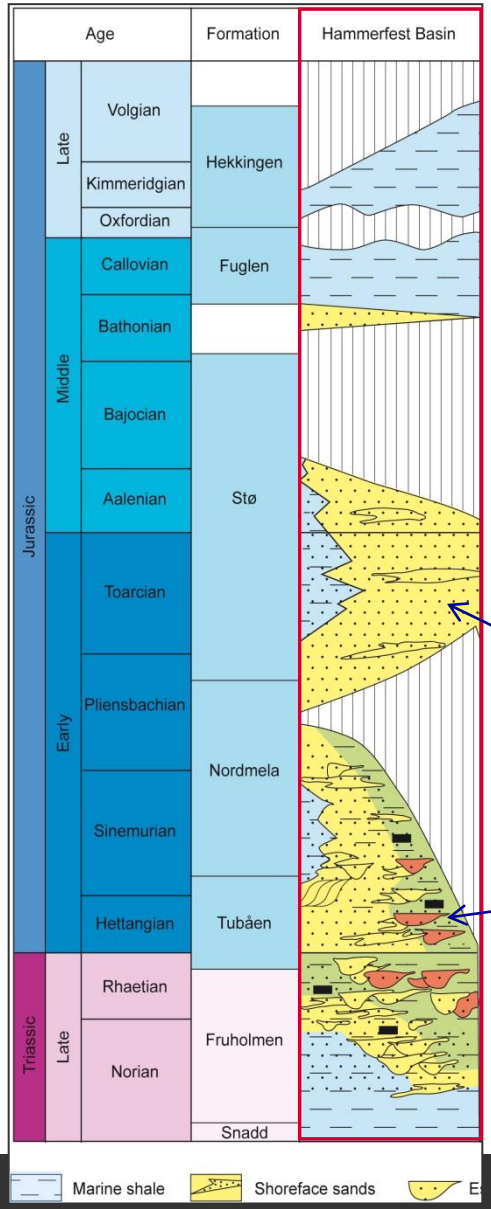
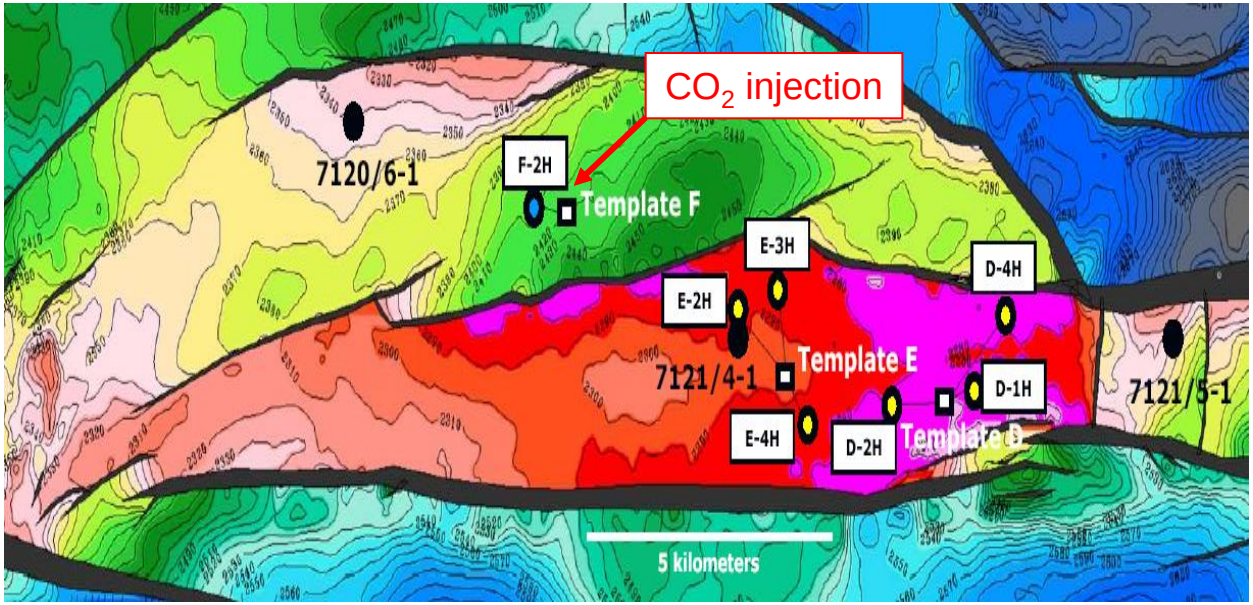
Stratigraphy and Depositional Environment





Stø (main reservoir)

- Shallow-marine environment
- Good lateral and vertical communication

Tubåen

- Densely stacked fluvial channels
- Poor lateral and vertical communication

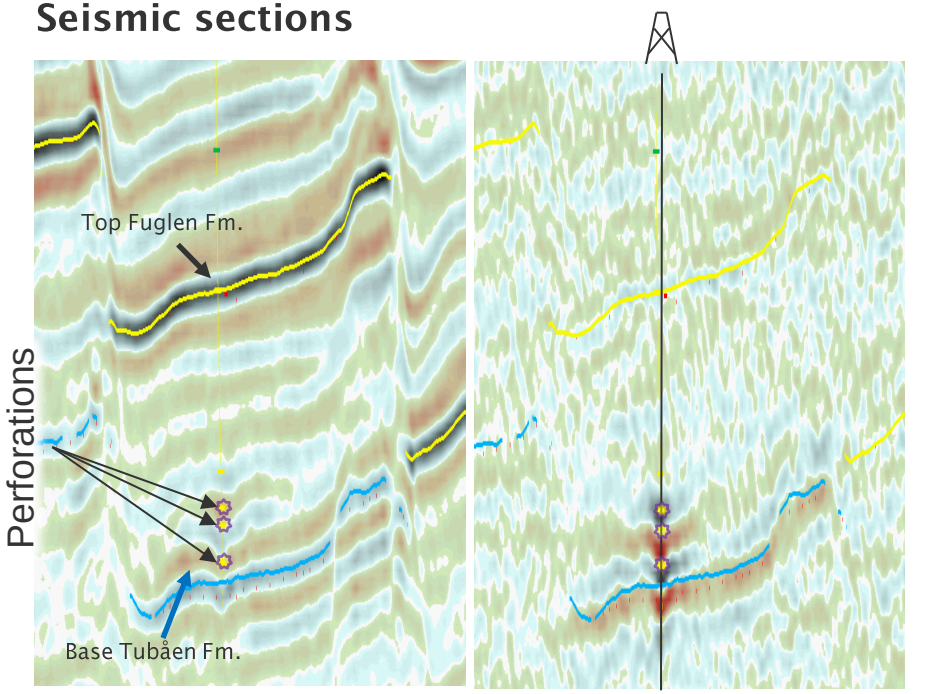
Depth map at top of Fuglen Fm. (upper right) and stratigraphic section (left) [from Wennberg et al., 2008]

Snøhvit well intervention in 2011

➢ Successful well intervention guided by monitoring data

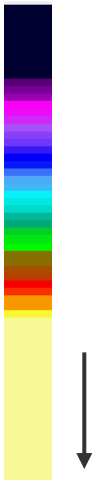
- Rising pressure due to geological barriers led to well intervention
- Integrated use of geophysical monitoring and down-hole gauges

Seismic sections



2009 Seismic Survey

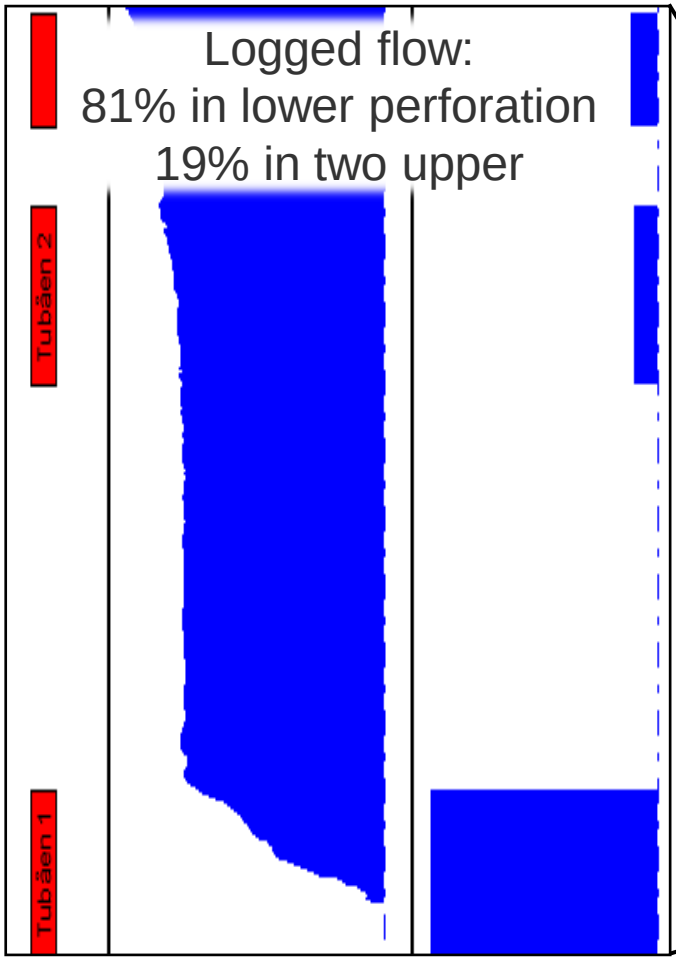
4D (Amplitude difference)



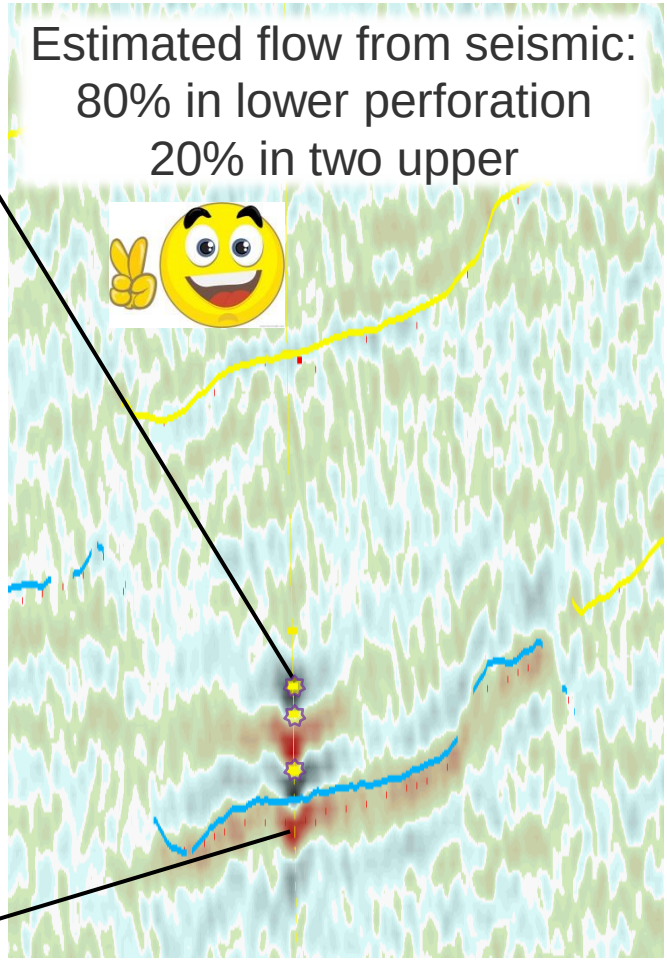
Hansen et al., 2013

Tubåen reservoir zone monitoring

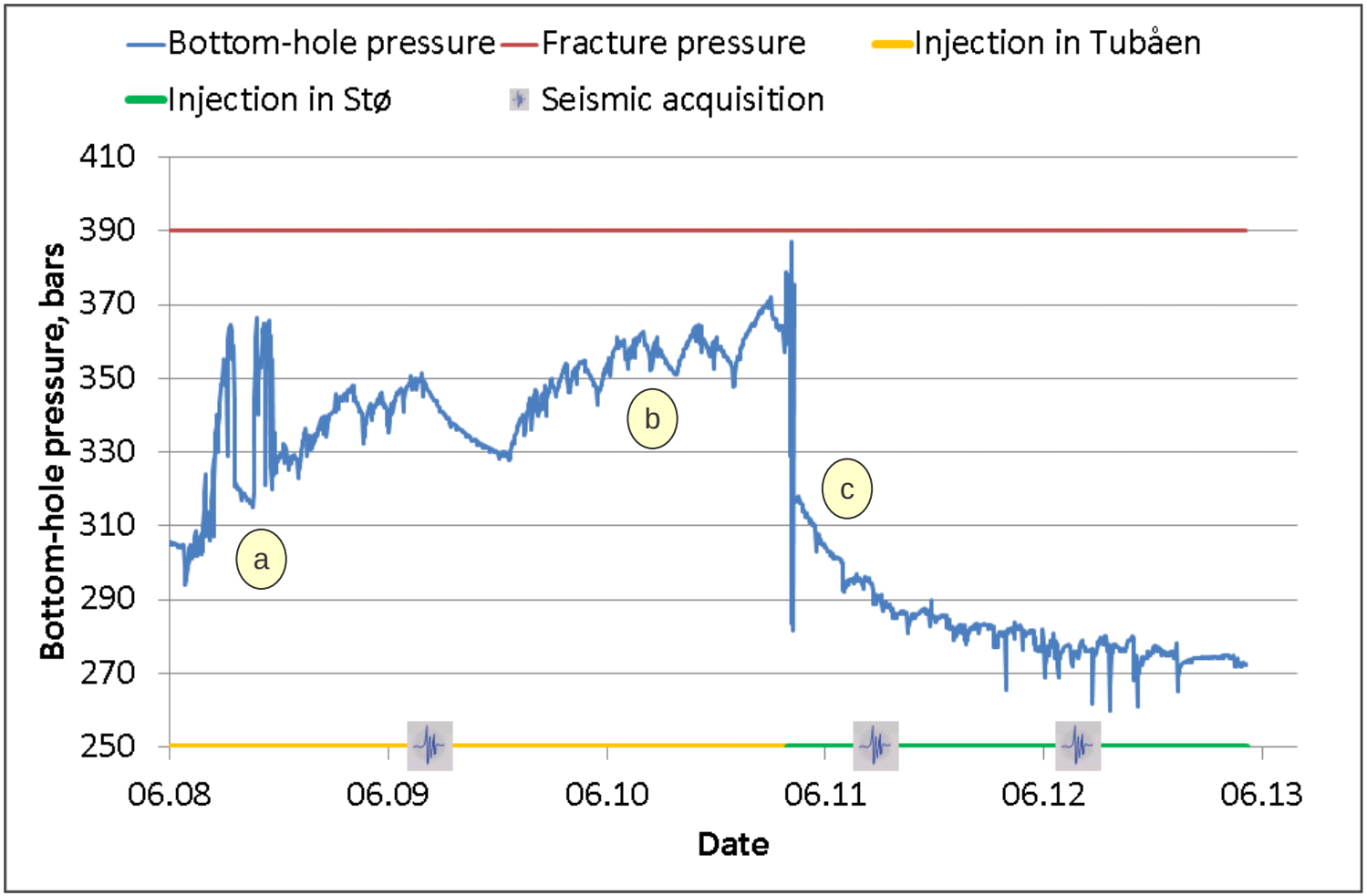
Production logging



Difference seismic



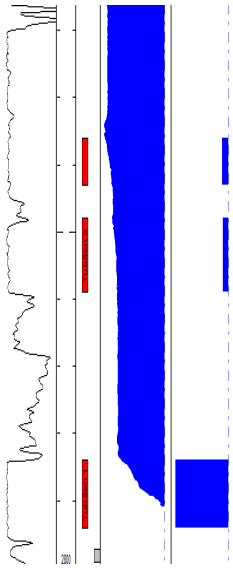
Snøhvit Injection pressure
(2008-2013)



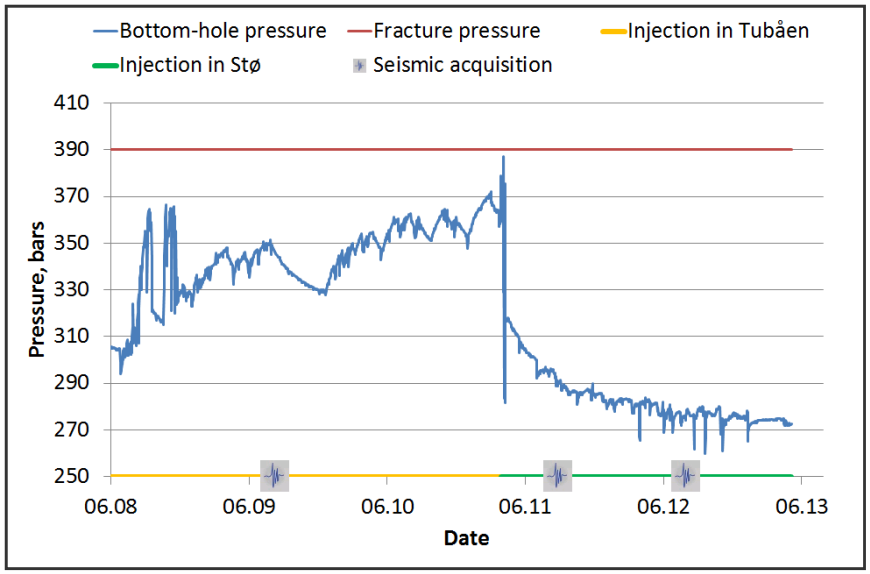
Monitoring Techniques applied at Snøhvit

- 4D Seismic
- Downhole P/T gauges and flow logging
- Gravity surveys

Down-hole data:
P, T, Q



Down-hole pressure data



Snøhvit Summary

- Main learning: integrating geophysics and reservoir management

- **The world's first offshore CO_2 transport pipeline**
  - Distance: field-to-onshore facility is 150 km
  - Storage unit: 2600 m depth
  - 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

Main Lessons Learned

- 20-year track record in CO_2 storage operations
- Geophysical monitoring has proven essential for site management
  - ➢ Safe CO_2 storage confirmed
- Practical learnings about capacity and injectivity from well operations
- Improved understanding of CO_2 storage processes
  - ➢ Builds confidence in model forecasts
- Sharing experience is important for building confidence in CCS

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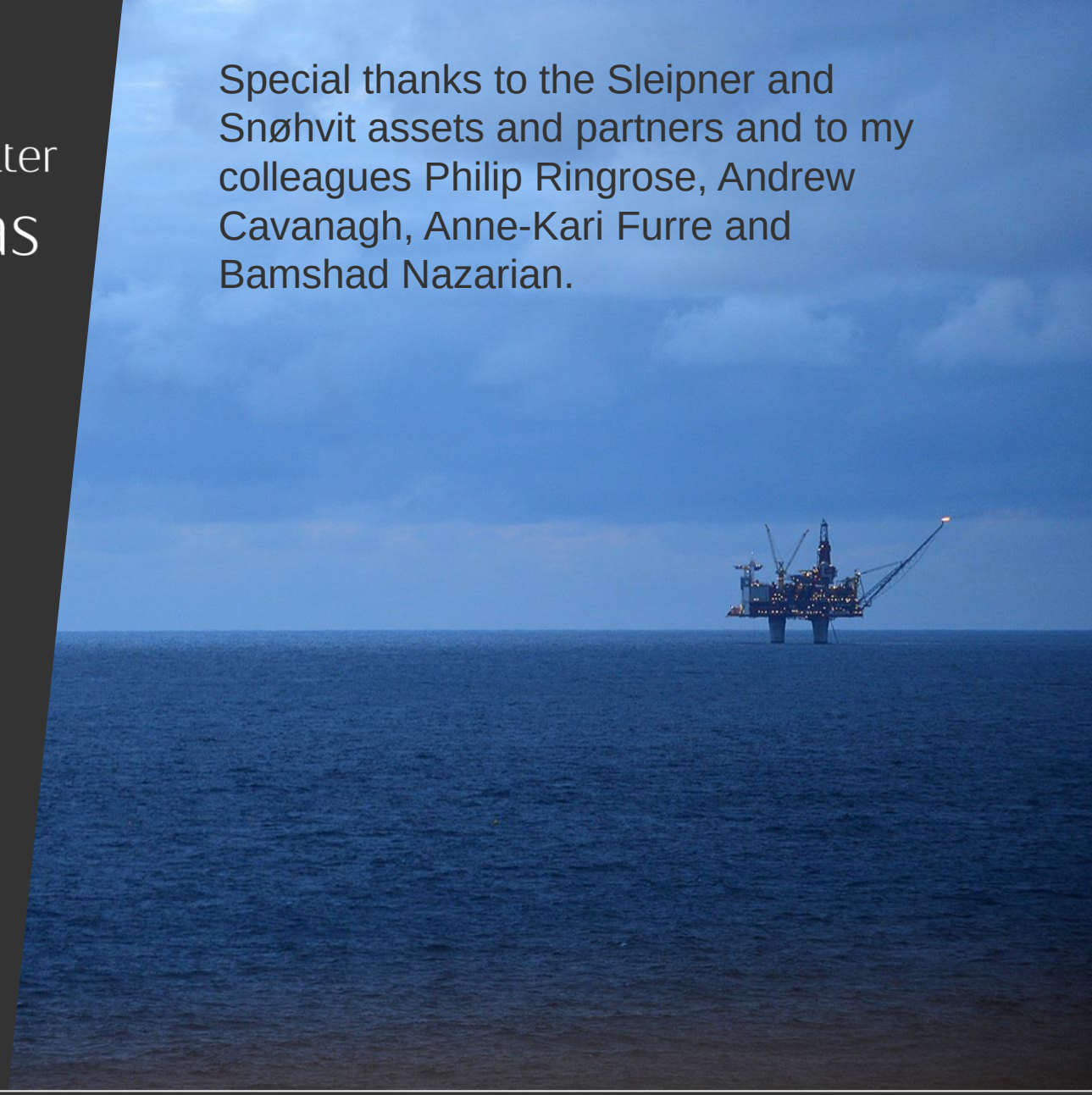
There's never been a better time for good ideas

Special thanks to the Sleipner and Snøhvit assets and partners and to my colleagues Philip Ringrose, Andrew Cavanagh, Anne-Kari Furre and Bamshad Nazarian.



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