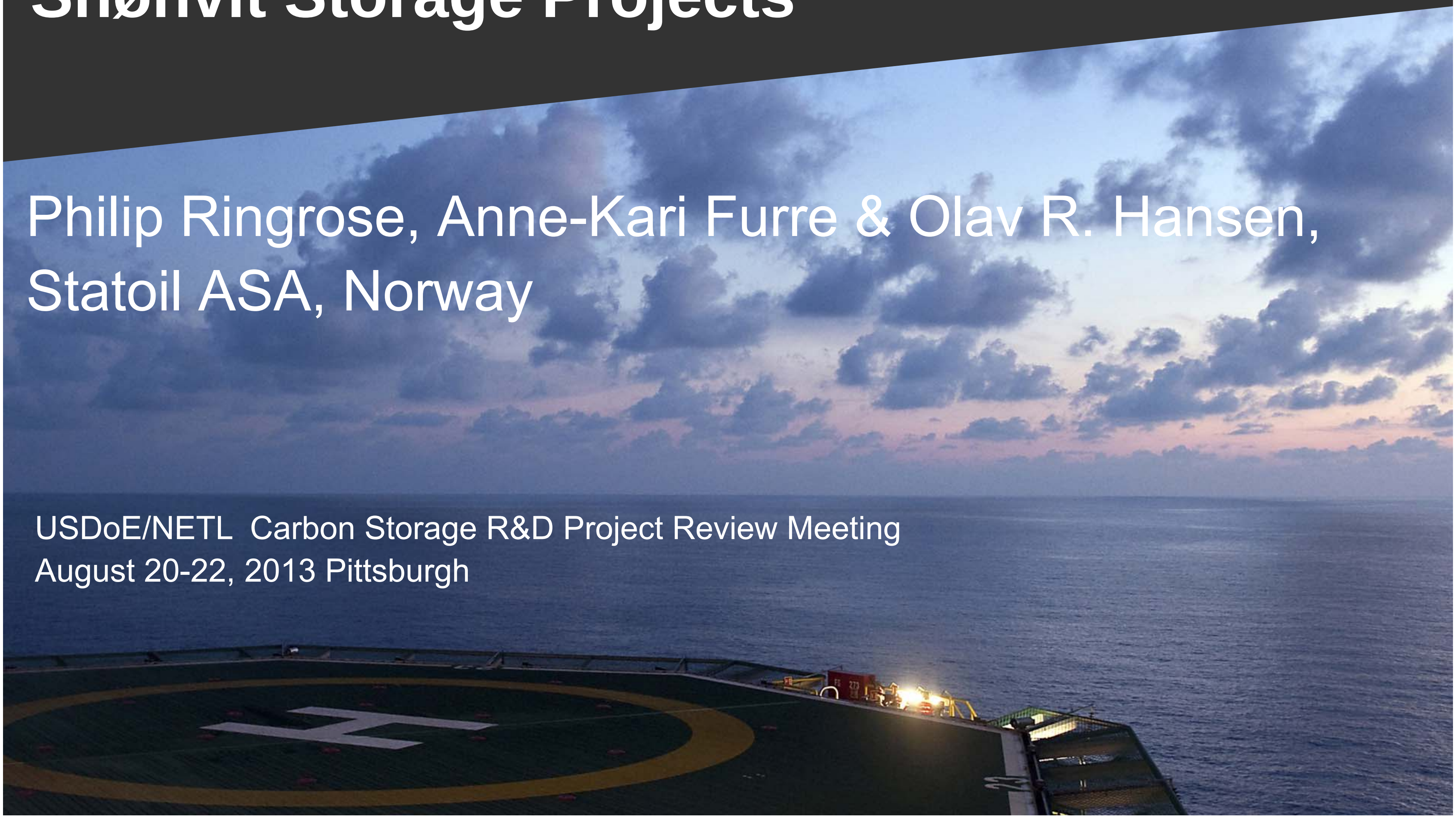
Offshore Monitoring Lessons Learned: Sleipner and Snøhvit Storage Projects



Philip Ringrose, Anne-Kari Furre & Olav R. Hansen, Statoil ASA, Norway

USDoE/NETL Carbon Storage R&D Project Review Meeting
August 20-22, 2013 Pittsburgh

The big questions for CO_2 monitoring

- What type of monitoring is really necessary?
- Several stakeholder viewpoints:
    1. What monitoring is important from an operational point of view?
    2. What monitoring is required from a regulatory perspective?
    3. What monitoring is in the public interest?
- In response to these questions CO_2 storage projects have tried to develop fit-for-purpose approaches to monitoring.
- The biggest technical challenge is that projects need to monitor:

  The reservoir (saline aquifer)

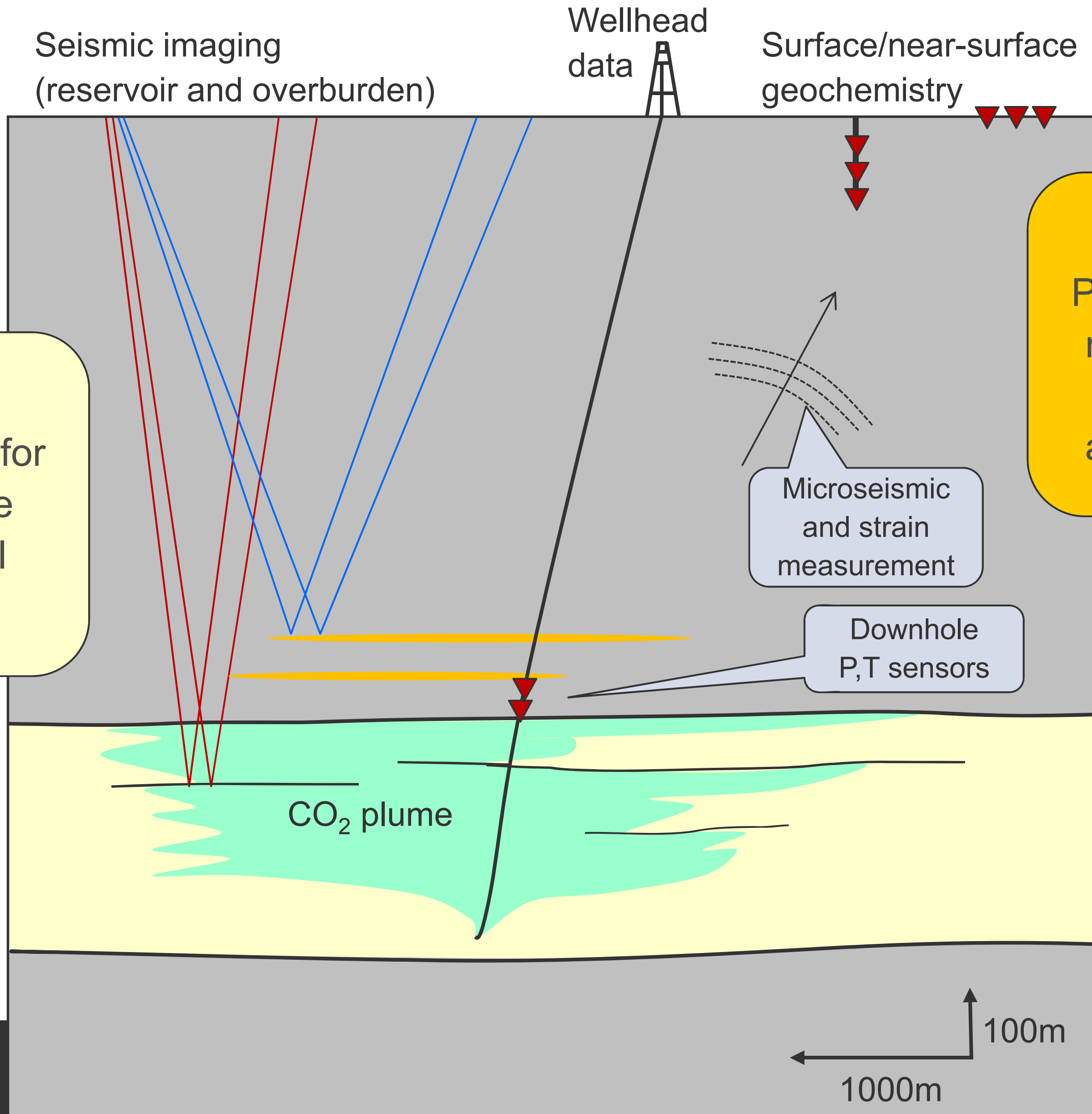
  … and the overburden

  … and the surface

  … and the facilities

CO_2 storage site monitoring portfolio

Offshore
Proven value for non-invasive geophysical monitoring



Onshore
Proven value for monitoring gas geochemistry and rock strain

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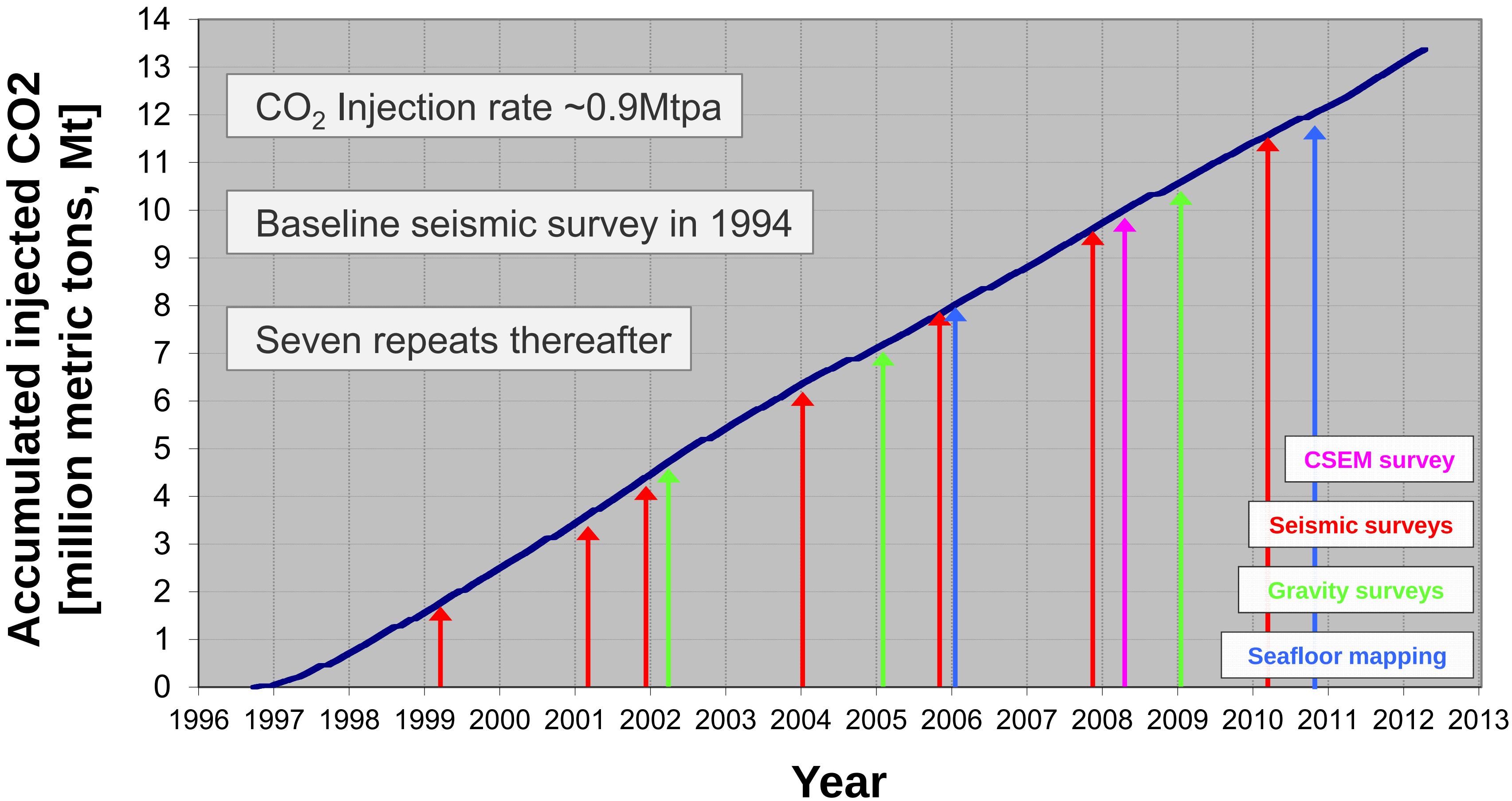
Monitoring applied at 3 large-scale CO_2 storage projects

Monitoring Technology	Sleipner (Offshore platform)	In Salah (Onshore)	Snøhvit (Offshore subsea)
4D seismic	✓	✓	✓
4D Gravity	✓		✓
CSEM	✓		
Microseismic		✓	
Down-hole gauges			✓
Tracers		✓	
Satellite (InSAR)		✓	
Surface/shallow gas	✓	✓	
Groundwater		✓	

- What was the value of these chosen technologies?
- How could we improve the monitoring portfolio?

Sleipner Example (Offshore)

- Proven value of geophysical monitoring for site management

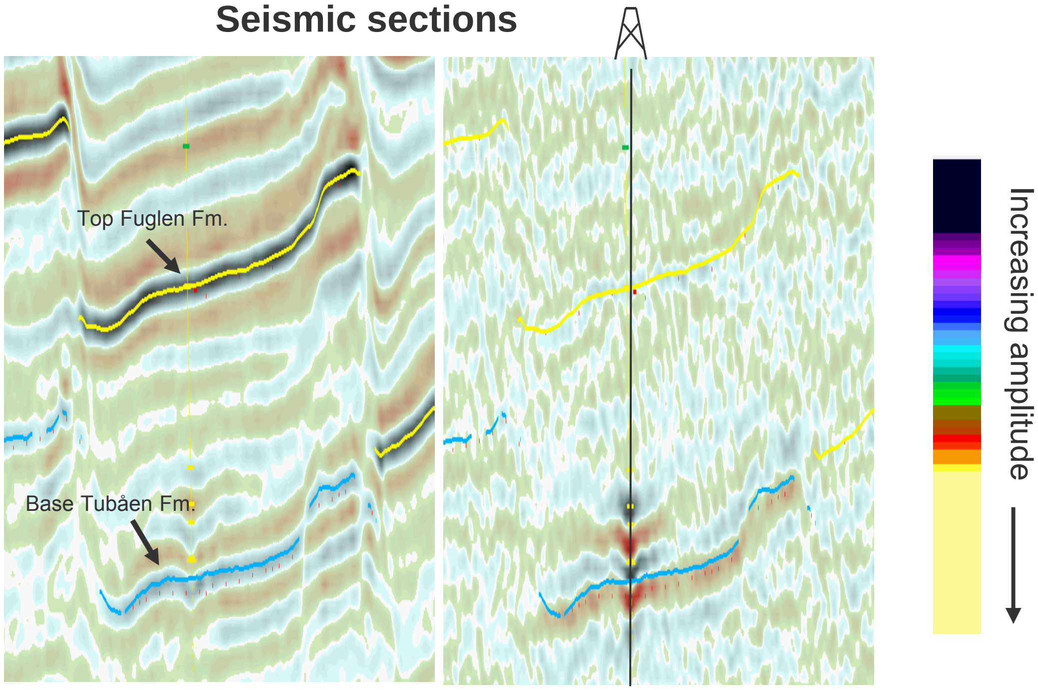


Eiken et al., 2010; Furre & Eiken, 2012

Snøhvit Example (Offshore)

- Proven value of geophysical monitoring for site management
- Proven value of down-hole pressure gauges
- Successful well intervention guided by monitoring data

Seismic sections



2009 Seismic Survey 4D (Amplitude difference)

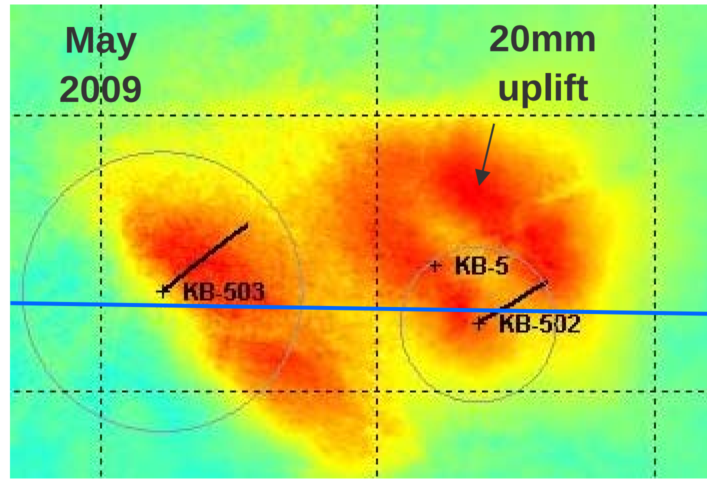
First offshore CO_2 injection well intervention April 2011

Hansen et al., 2012

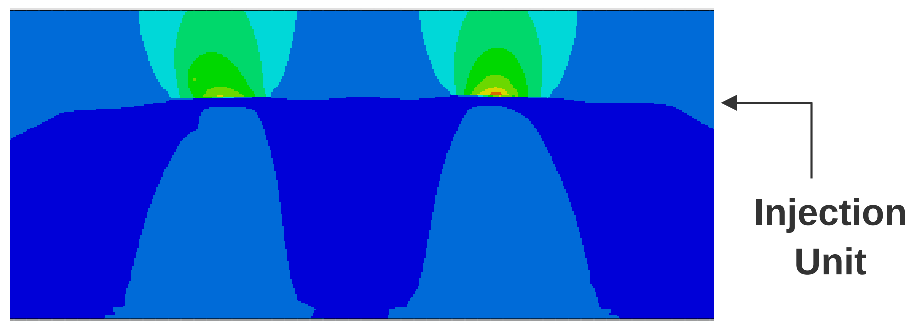
In Salah Example (onshore)

- Proven value of geomechanical monitoring using:
  - InSAR (Interferometric Synthetic Aperture Radar)
  - Microseismic monitoring
  - 3D/4D seismic
- Addresses a key question for CO_2 Storage – pressure management

Map of surface uplift



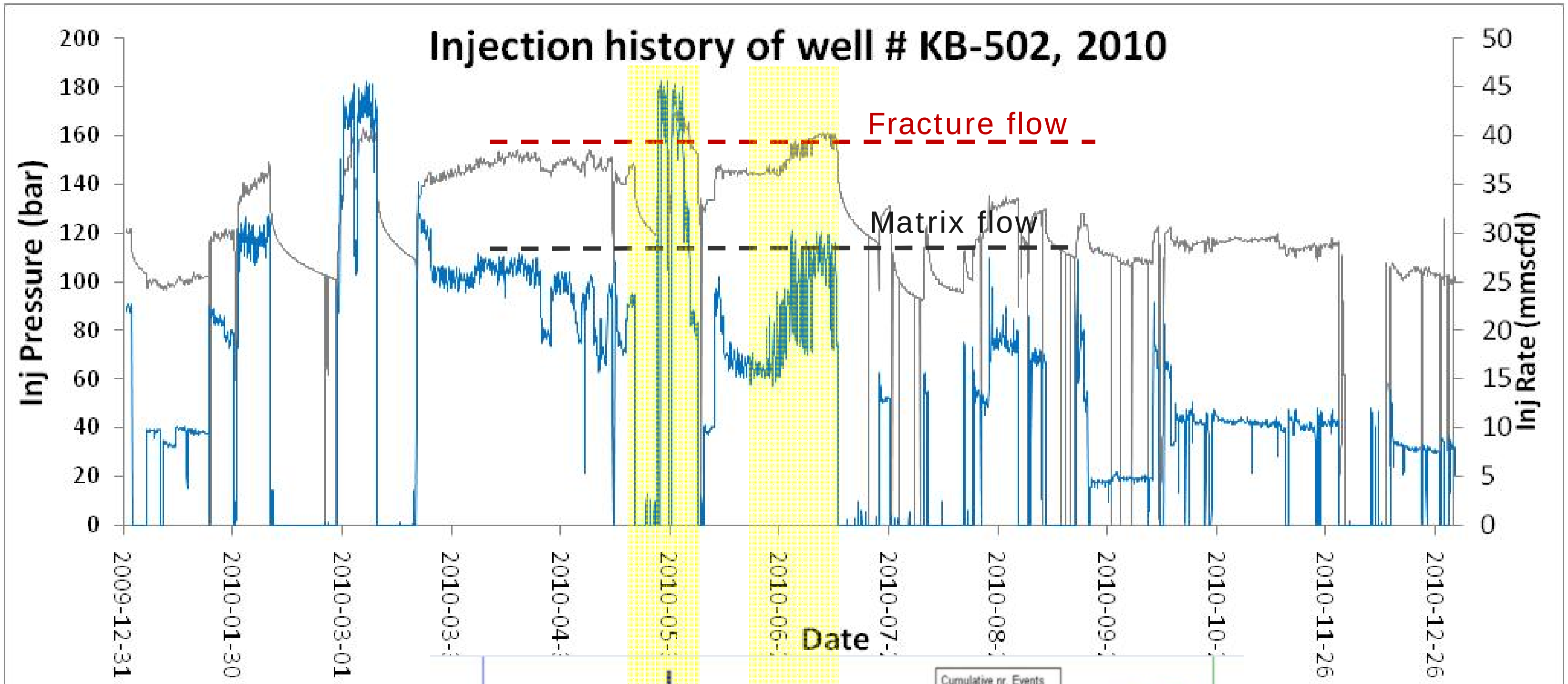
Modelled rock strain (section)

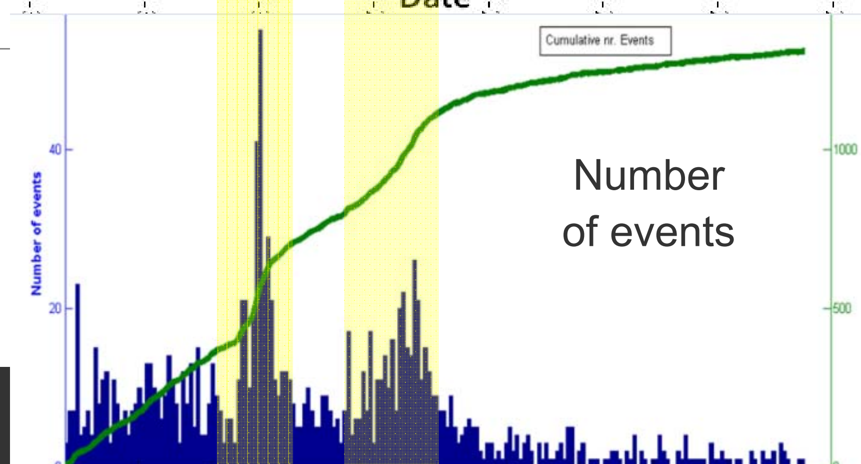


Vasco et al., 2010; Gemmer et al 2012

In Salah Gas Stockage de CO_2

Monitoring Highlight – Microseismic





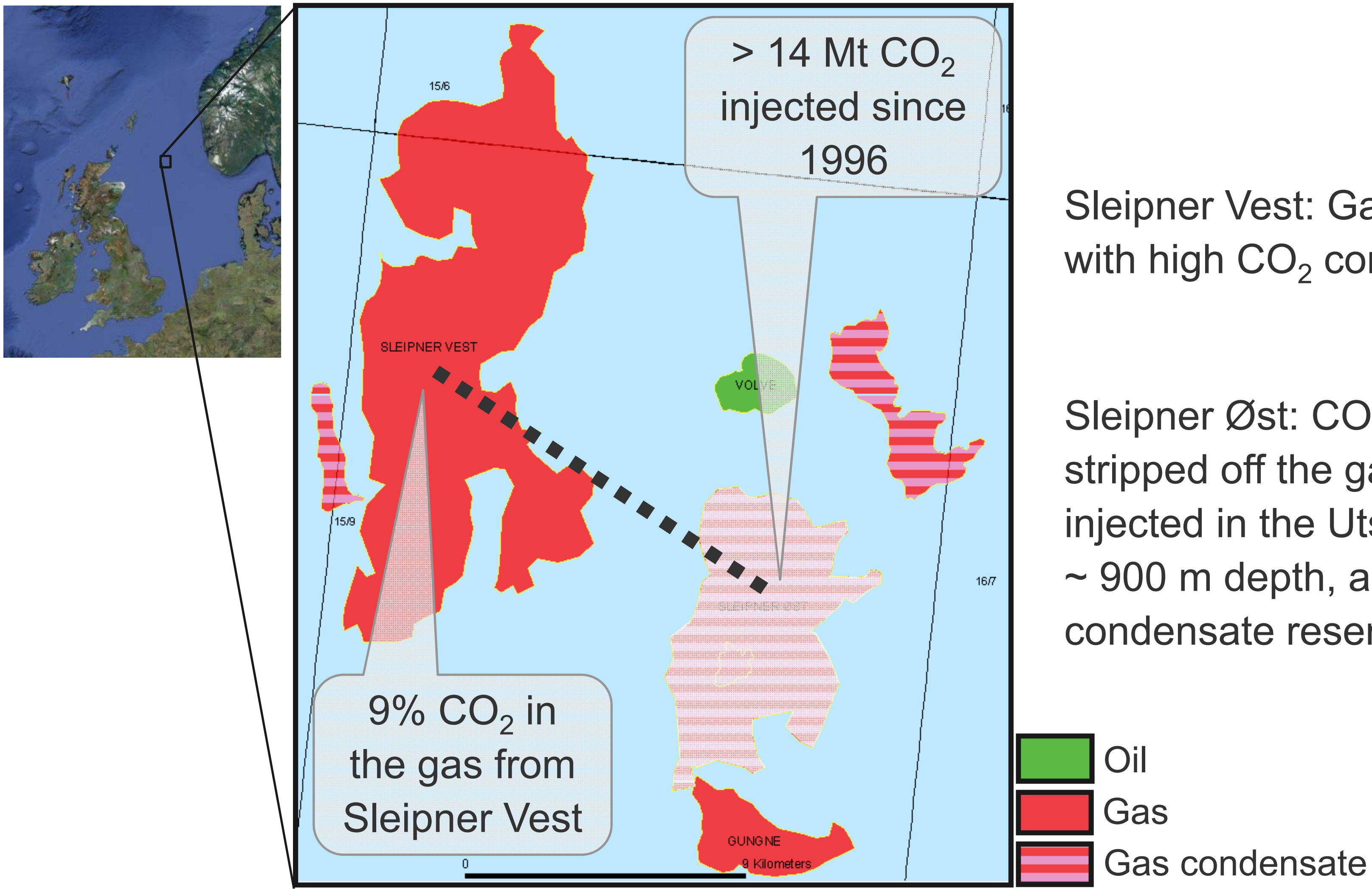
Pilot well with 3-C geophones recording since 2009

Event clusters correlate with injection

Oye et al., 2013

In Salah Gas Stockage de CO_2

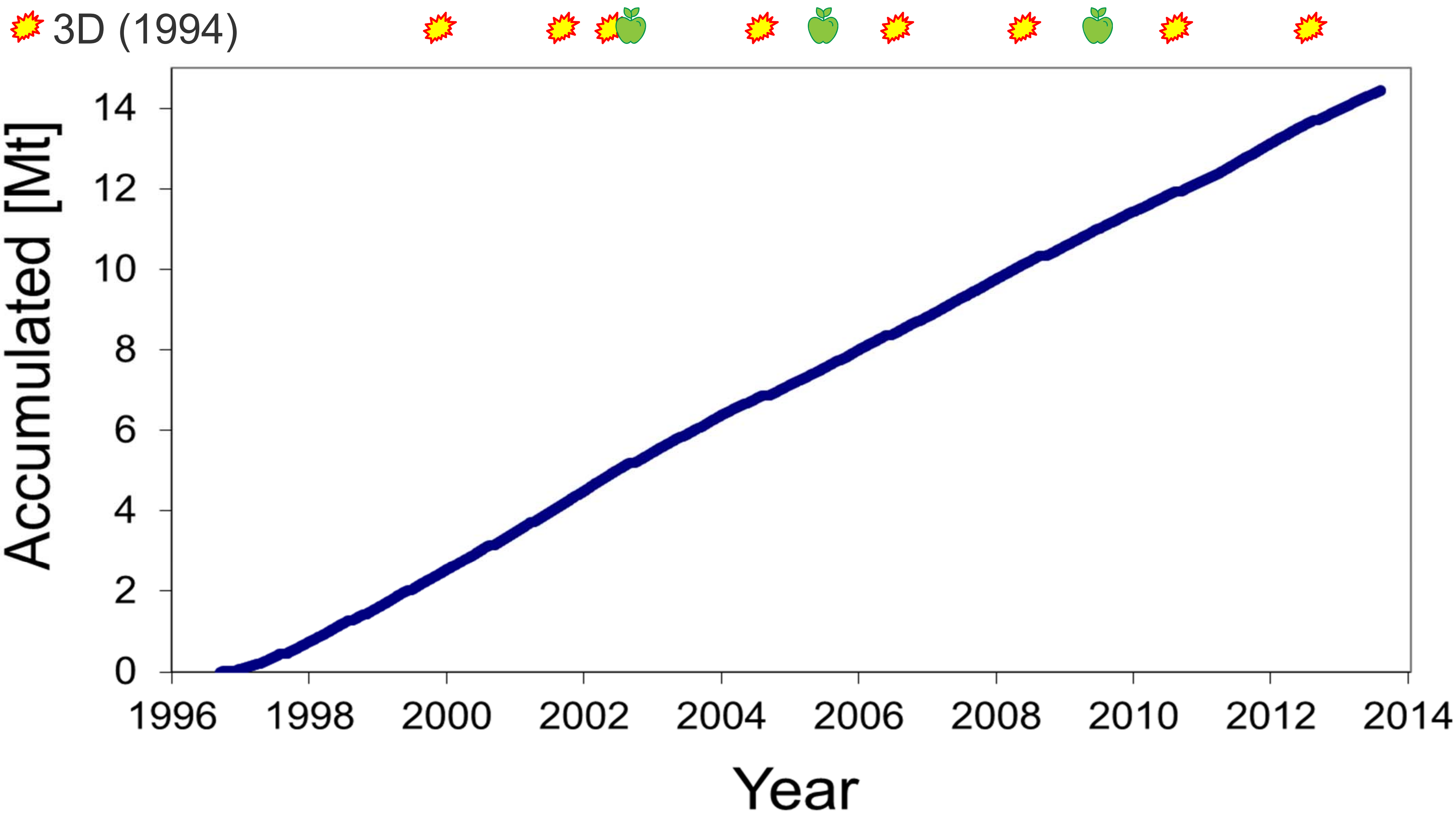
Brief introduction to the Sleipner fields



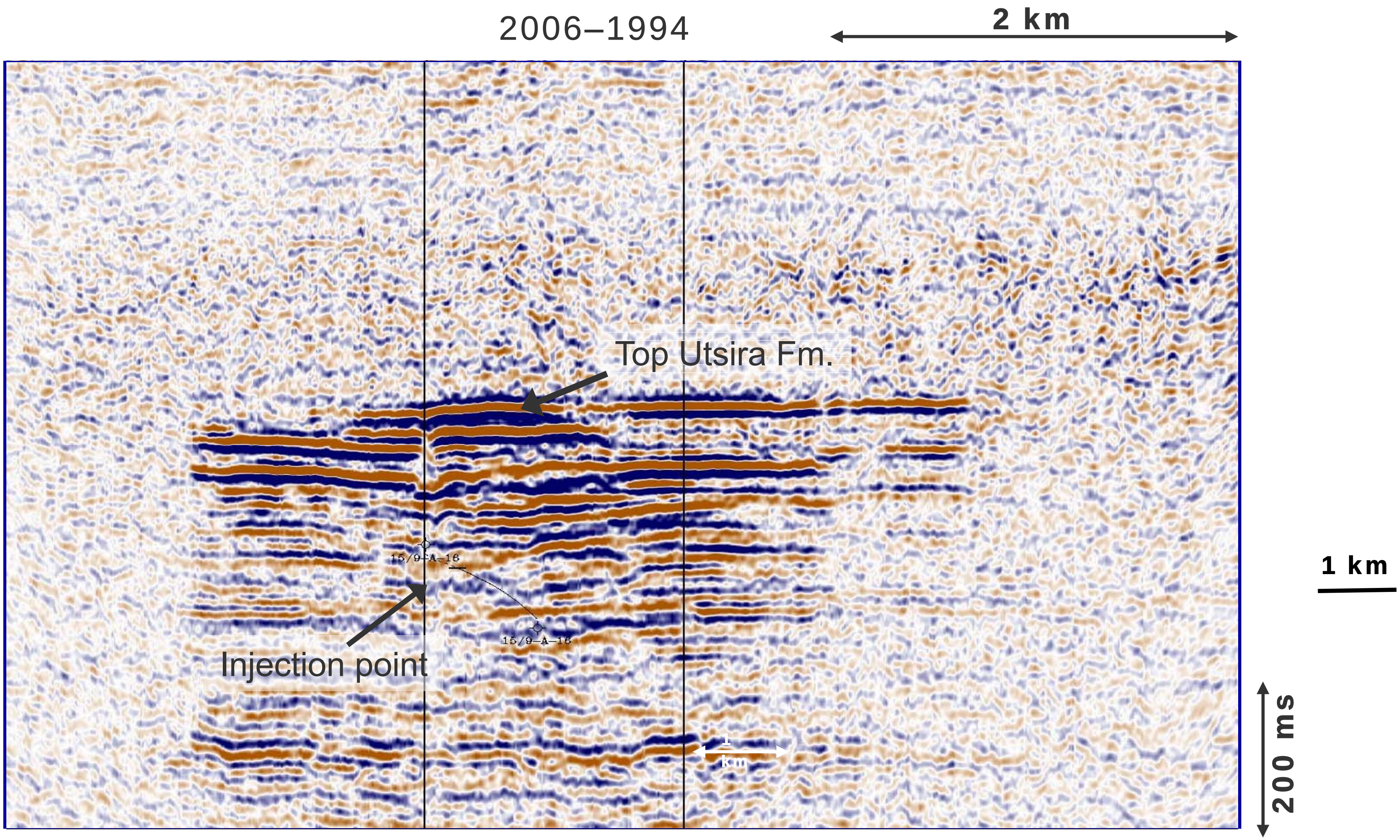
Sleipner Vest: Gas field with high CO_2 content

Sleipner Øst: CO_2 is stripped off the gas and injected in the Utsira Fm at ~ 900 m depth, above the condensate reservoir

CO_2 injection to date



Seismic time-lapse monitoring



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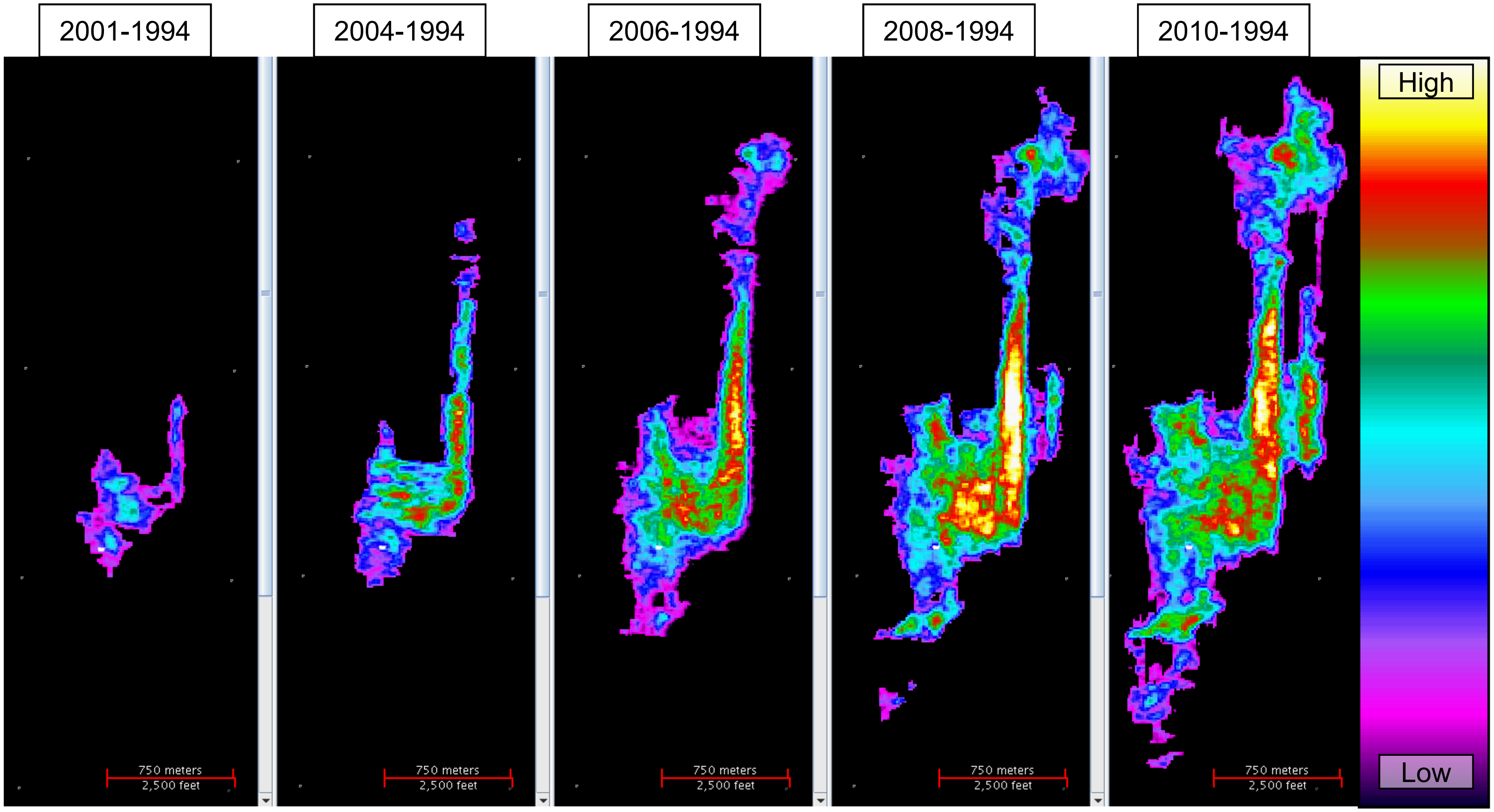
Development of layer 9



Seismic time-lapse monitoring shows that CO_2 stays in place in the Utsira Fm at Sleipner and gives a detailed description of where the CO_2 is

Furre & Eiken, 2012

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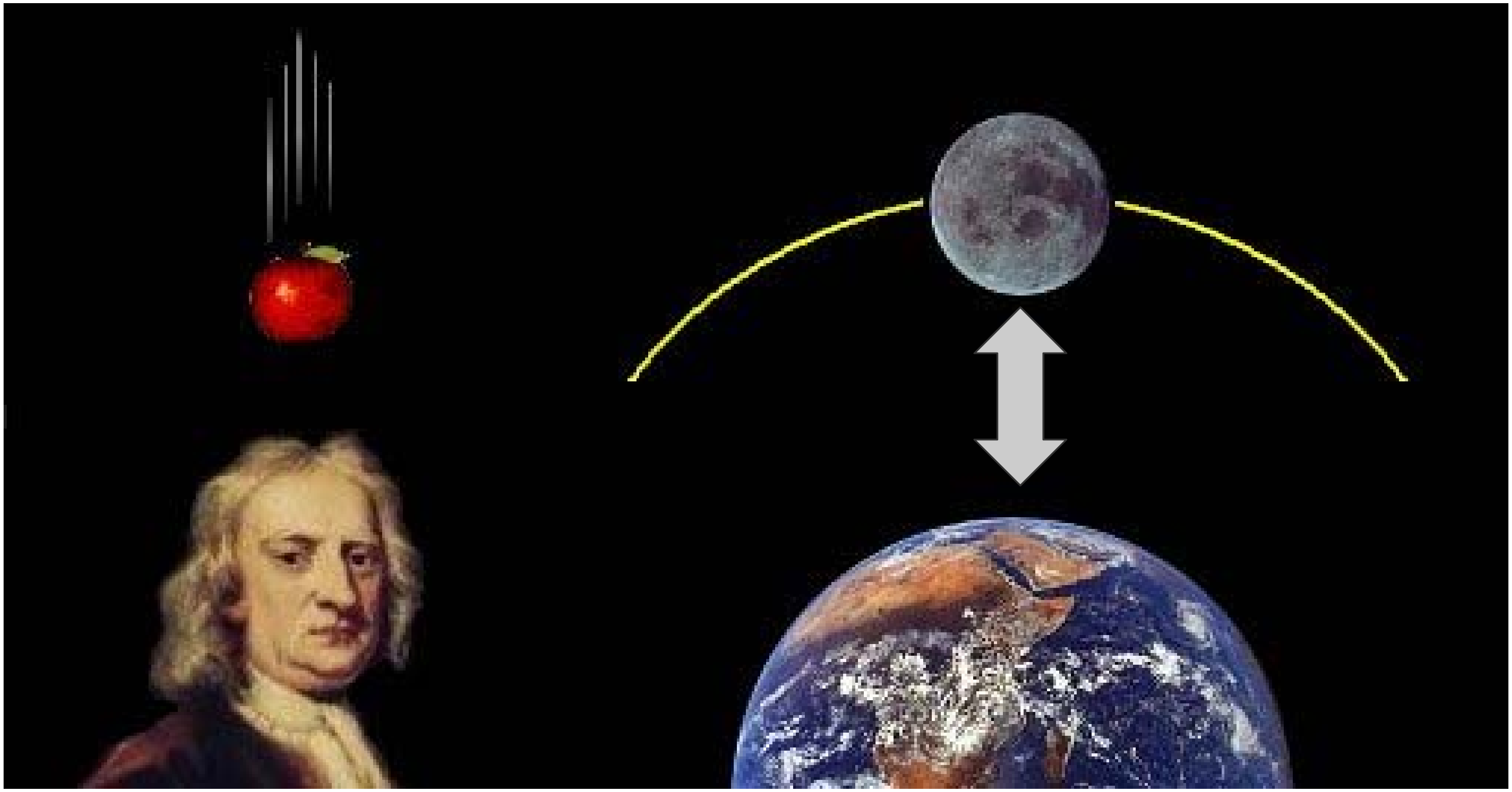
Gravimetric monitoring



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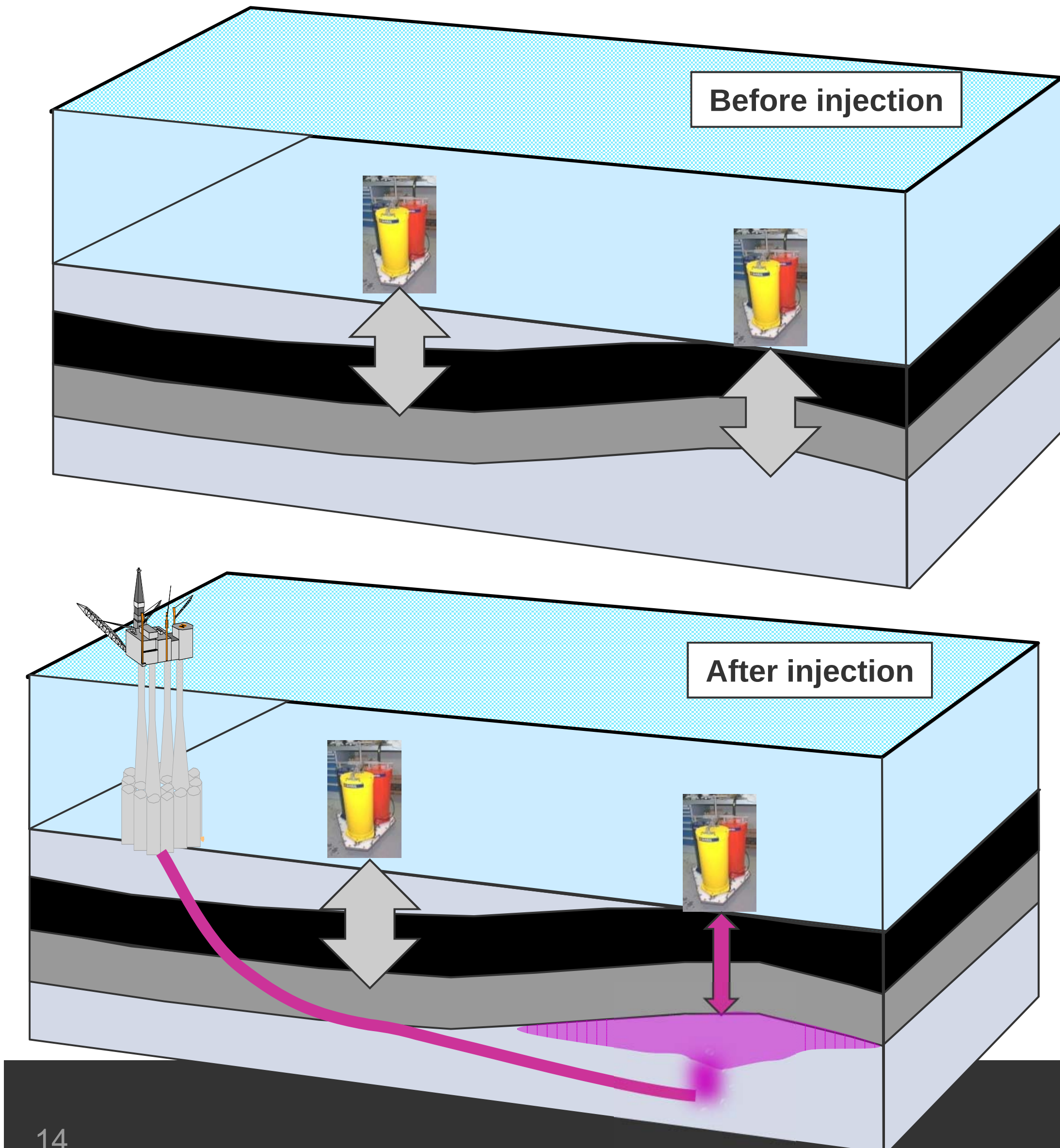
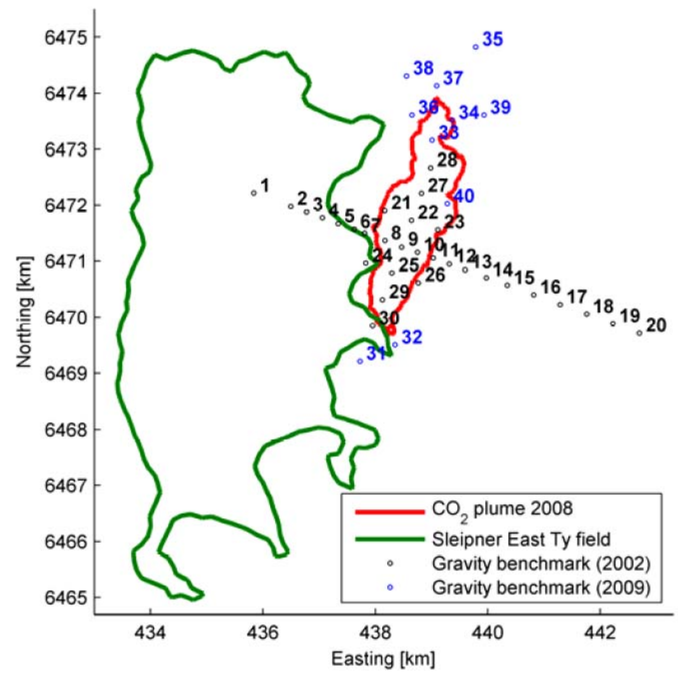
Gravimetric monitoring



Outline



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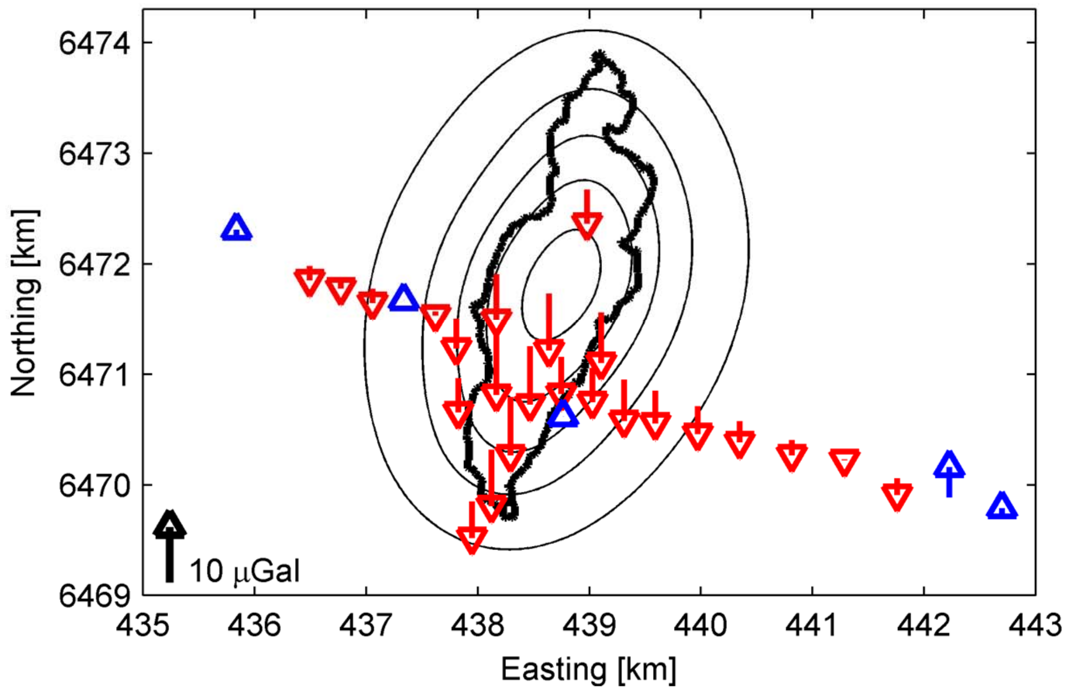
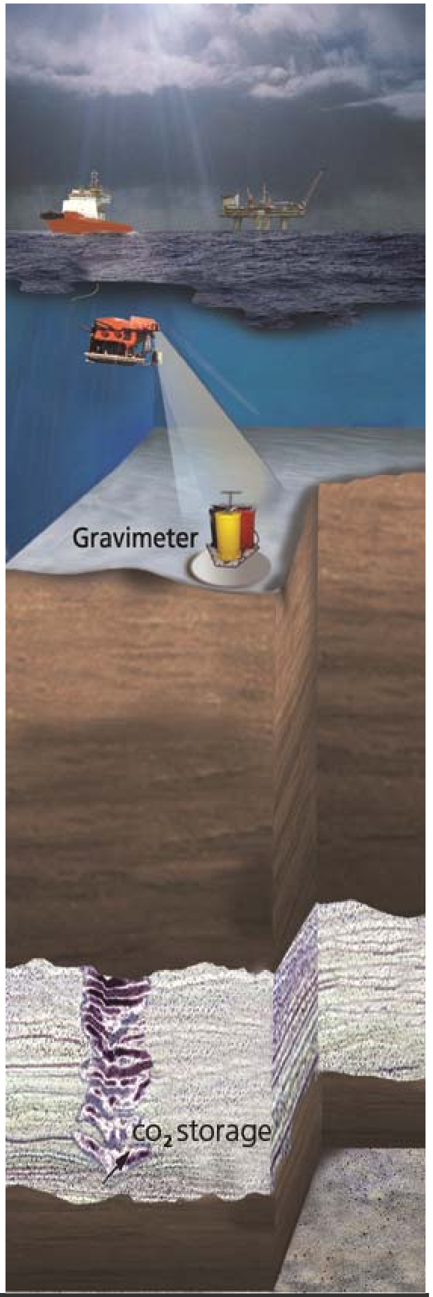
Gravimetric monitoring 2009-2002





Observed in-situ CO_2 density from gravity measurements:
720 +/- 80 kg/m^3

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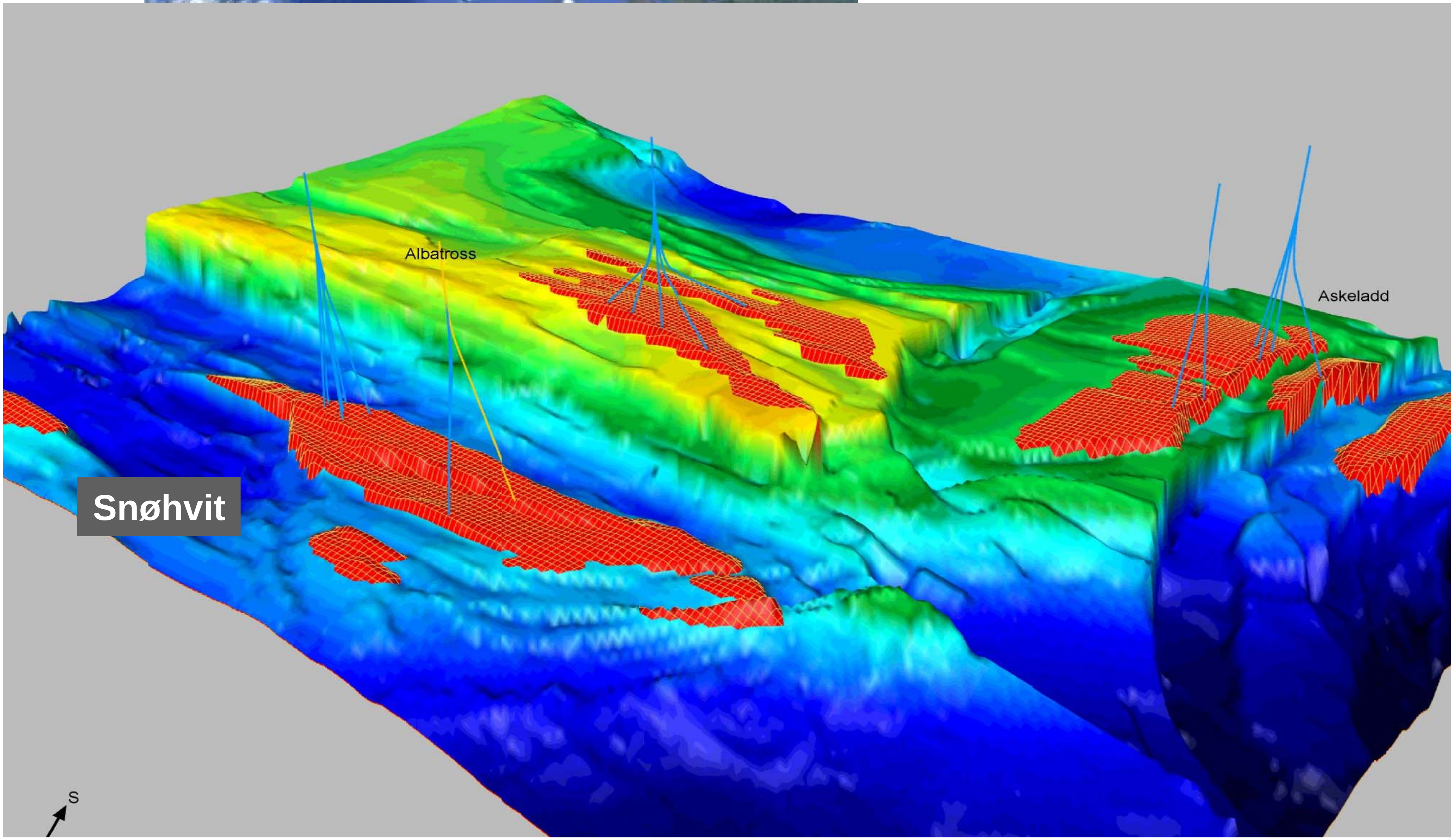
Snøhvit facts

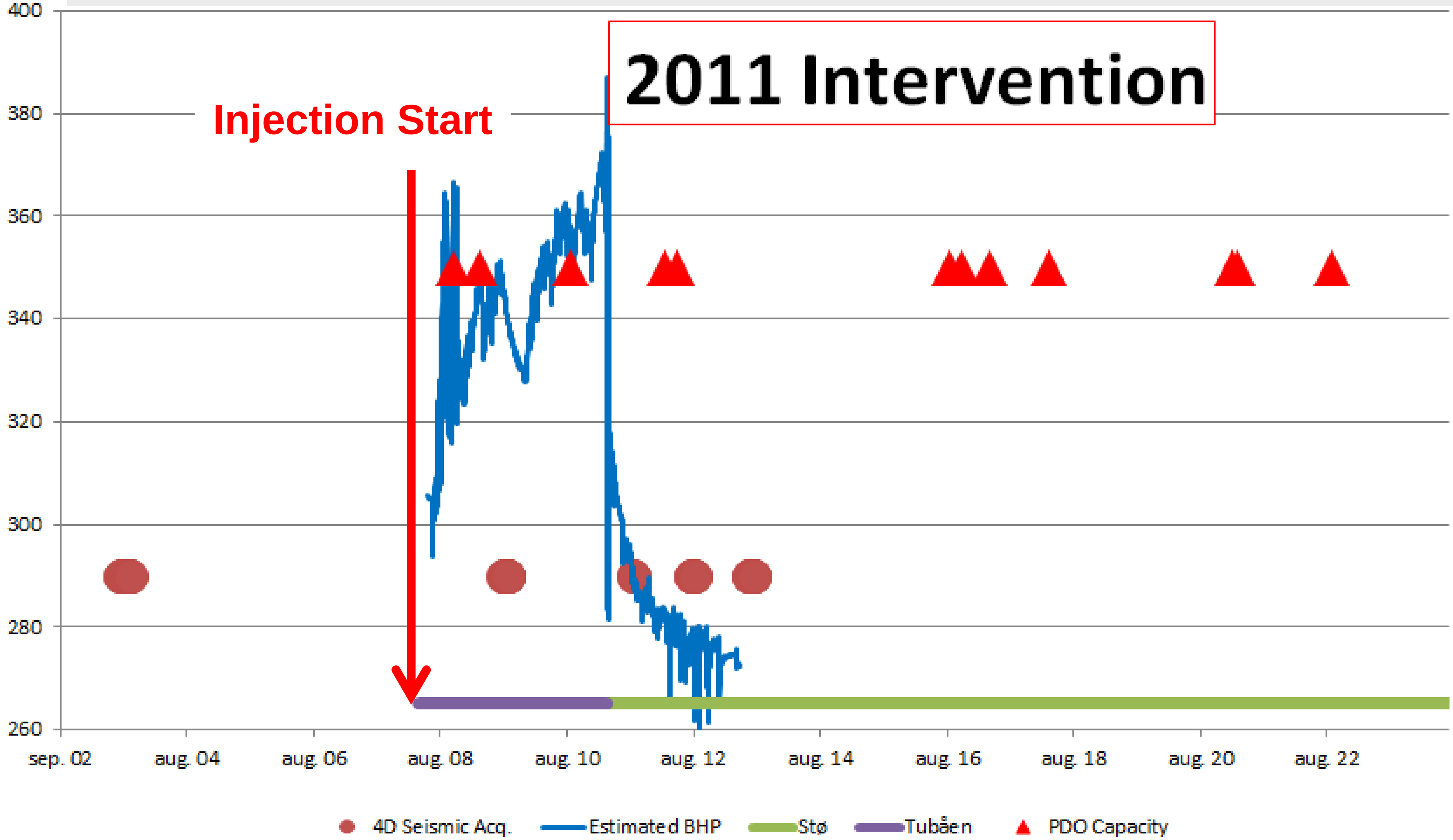
The first gas development project in the Barents Sea

✓ Discovered : 1981 – 84



Snøhvit

CO_2 monitoring – plan and performance



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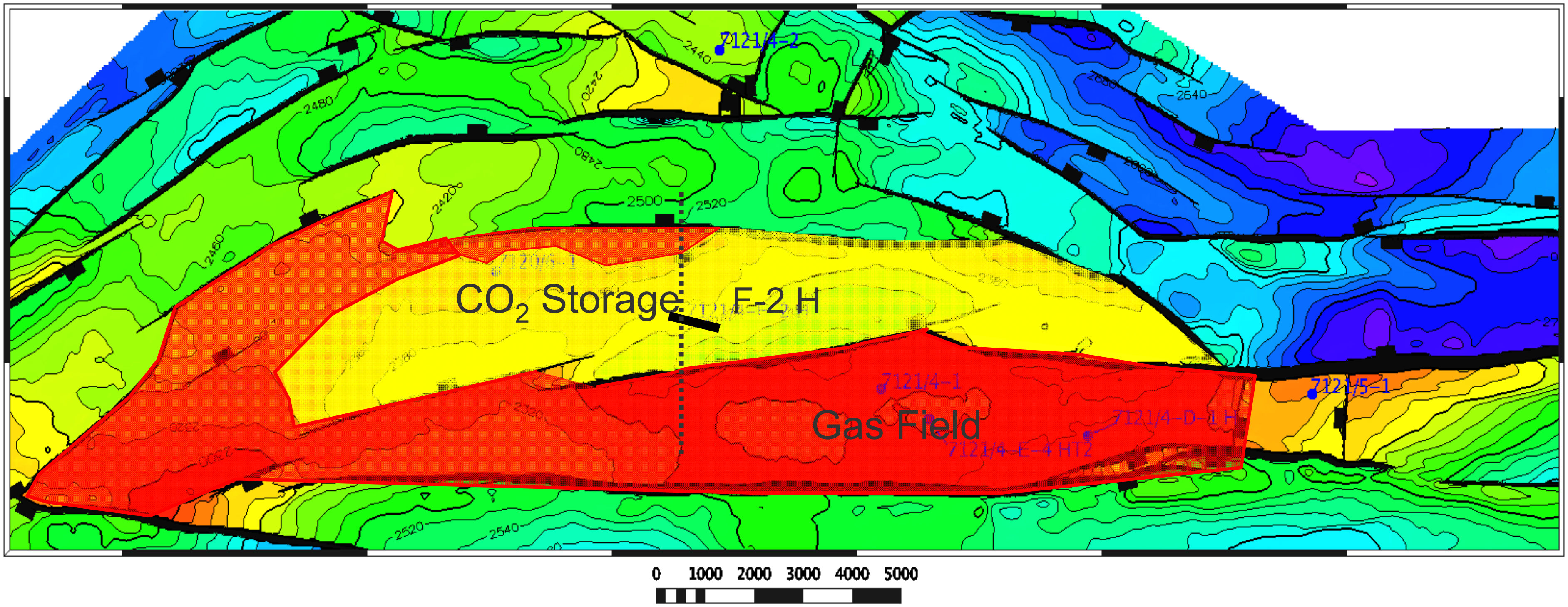
Structural Setting

Gas Field in Stø, Storage site in Tubåen
2400-2500 m below sea level



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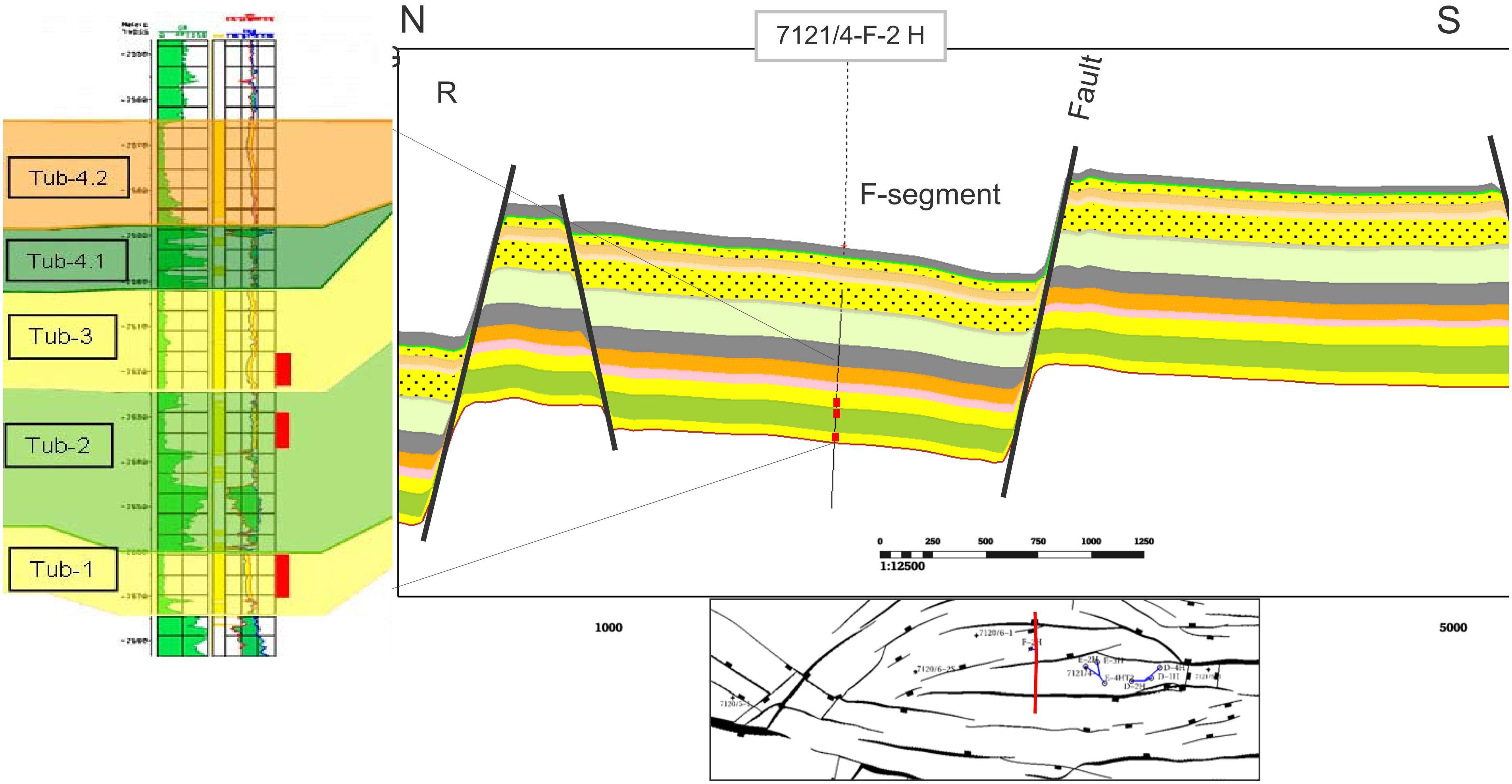
Geological X-section through CO2 injector



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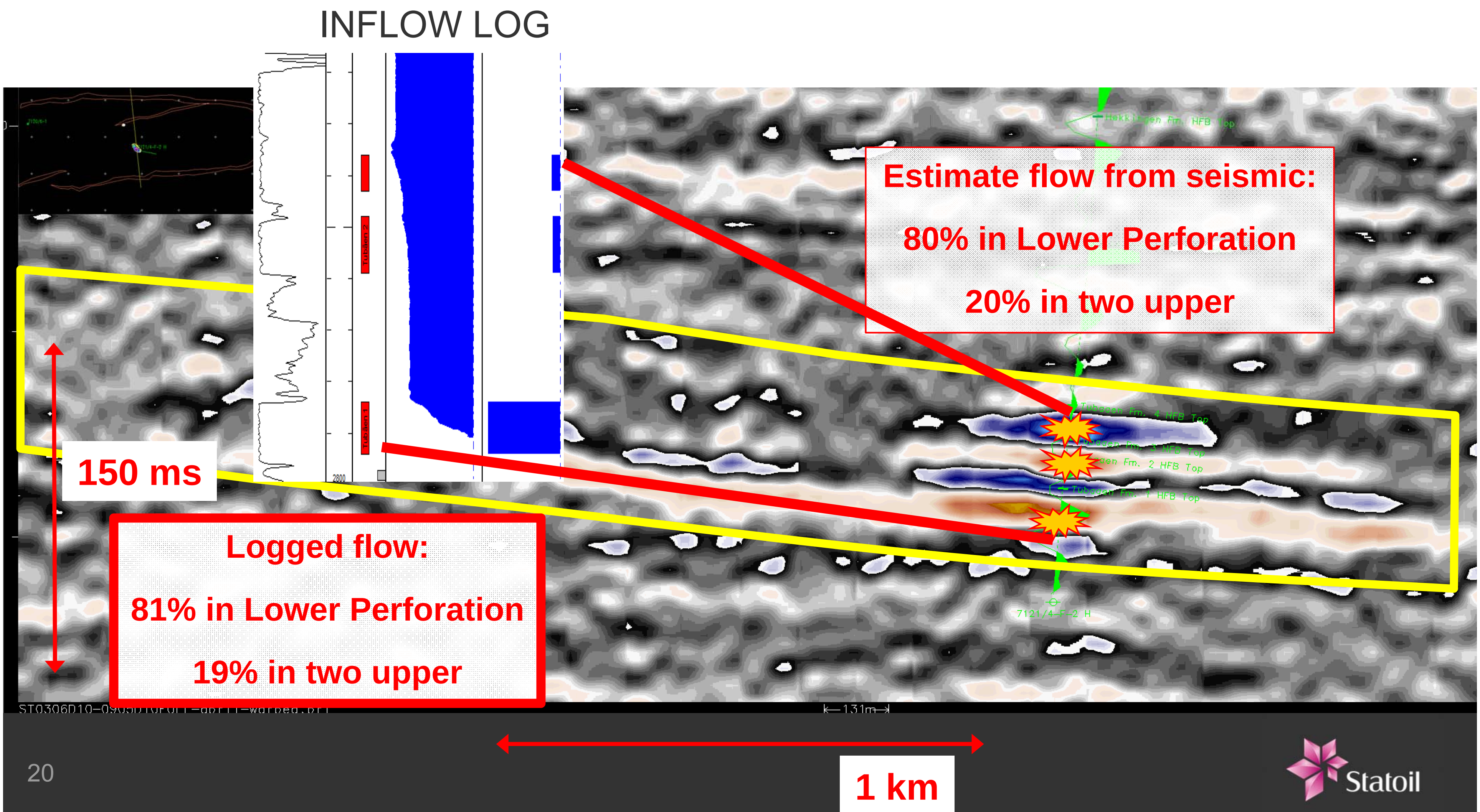
Tubåen Reservoir Zone



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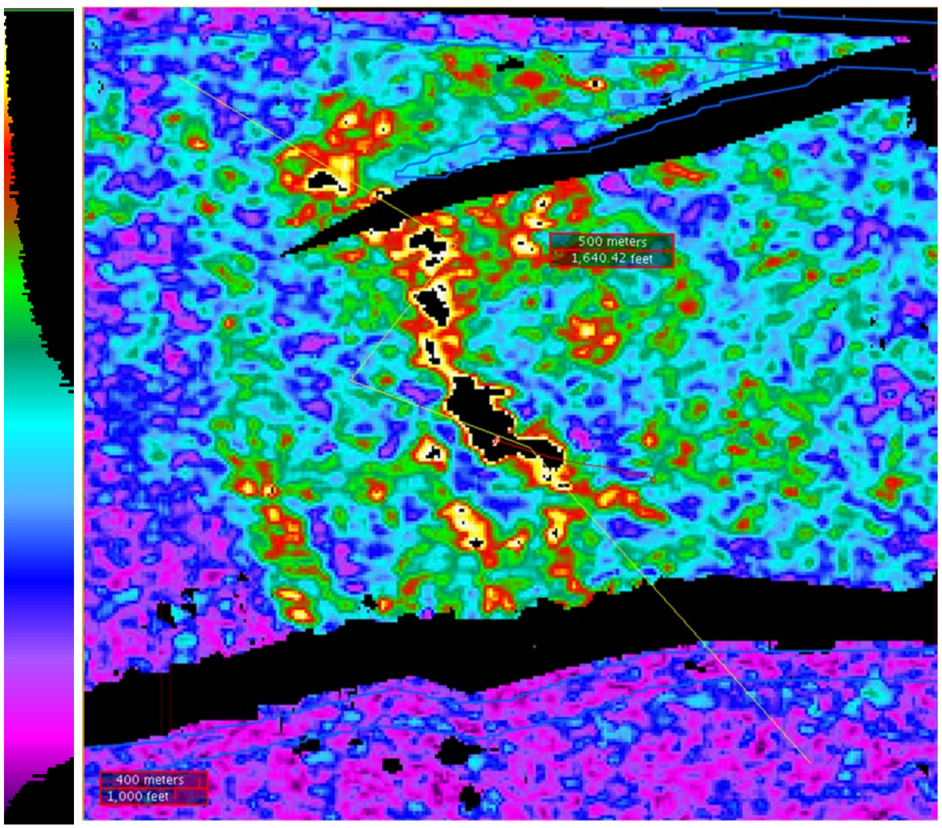
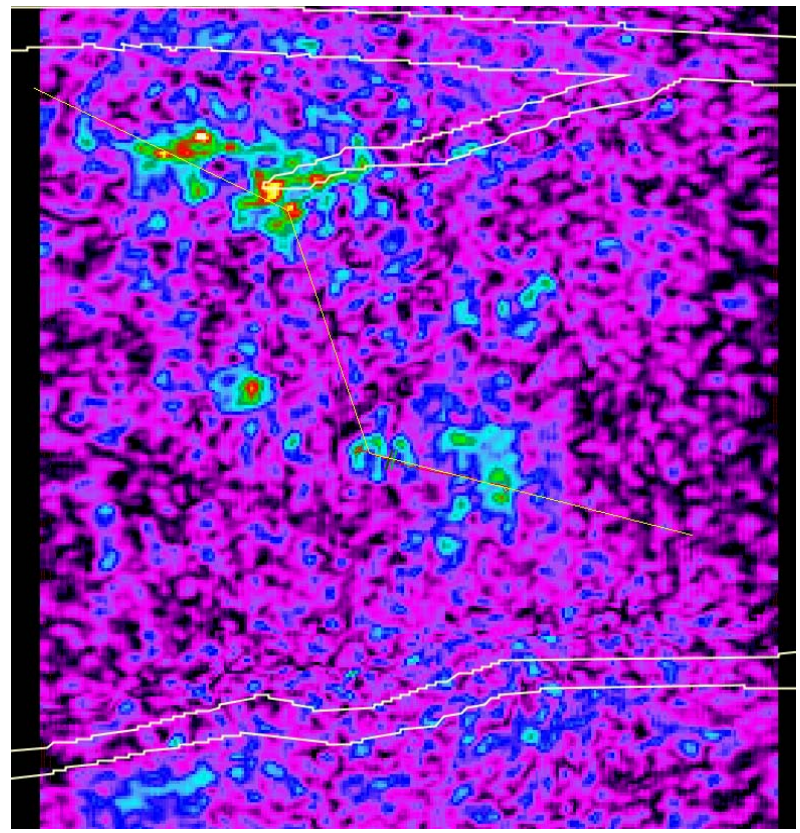
Map view
The Tubåen 4D anomaly
2003 -> 2009 -> 2011

2003-2009 Anomaly



2009-2011 Anomaly



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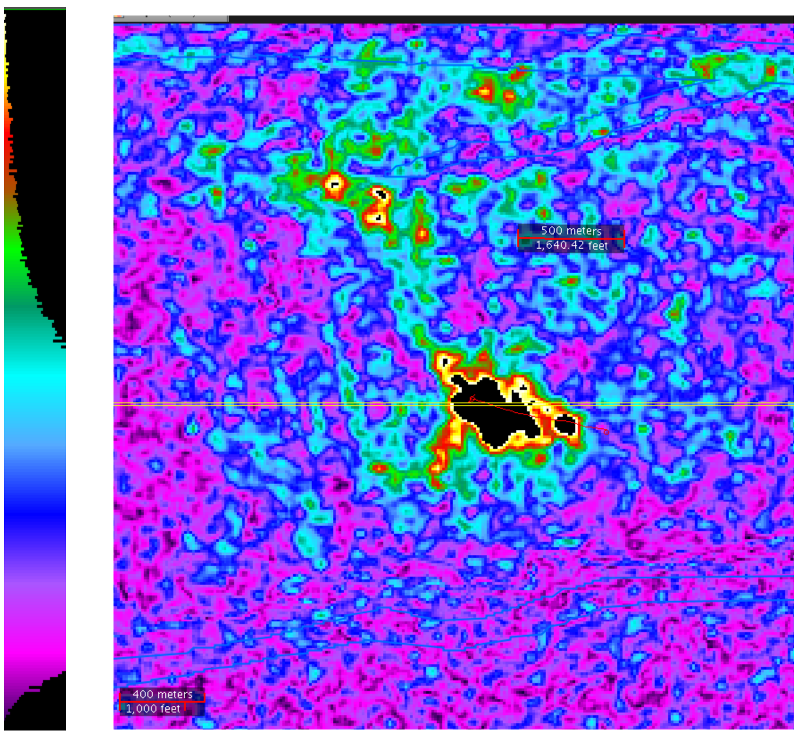
Horizontal / Areal view

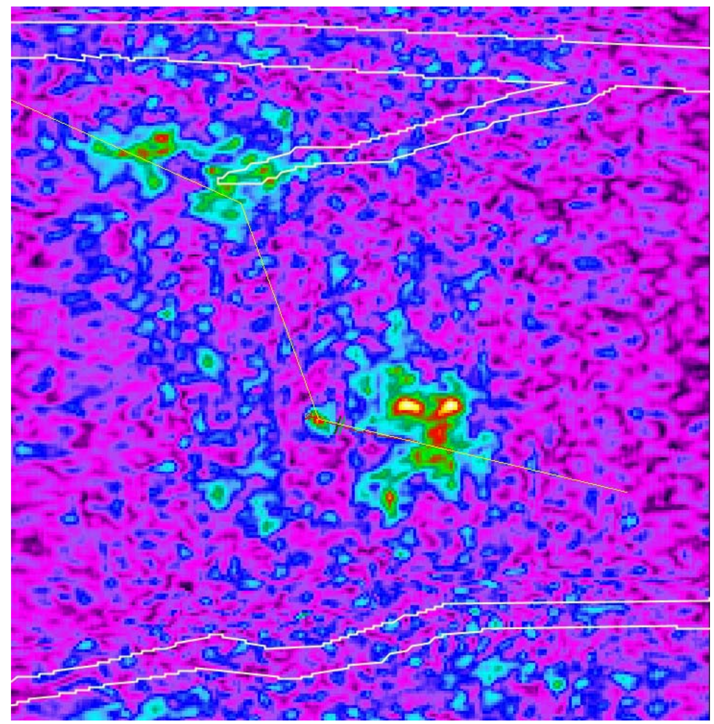
Upper 4D anomaly

2003 -> 2009 -> 2011

2003-2009 Final Full offset



2009-2011 Final full offset



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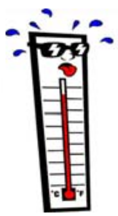
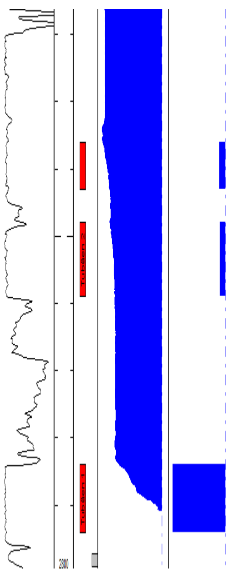
Monitoring Techniques applied at Snøhvit - a summary





- Seismic
  - 3D/4D repeats (so far 3 repeats)
  - 2D repeats (so far 1 repeat)
- Multiple Temperature / pressure Gauges
  - Continuous measurement
  - Weekly shut-in measurements
  - Long fall-off when feasible
- Well Logging
  - In-flow logging
  - Pressure & temperature

- Gravimetry
  - 86 bases positioned (1 repeat)

Main Lessons Learned

1. Never underestimate the challenge!
2. Monitoring all pressures and geomechanics is as important as saturation
3. The overburden is as important as the reservoir
4. The importance of a **good baseline datasets**
5. Time-lapse seismic imaging of CO_2 plume development has proven its value
6. Monitoring of gas geochemistry is important to assure site integrity
7. The combination of different monitoring methods brings added value

Oilfield Monitoring Experience

Technology breakthroughs in permanent systems

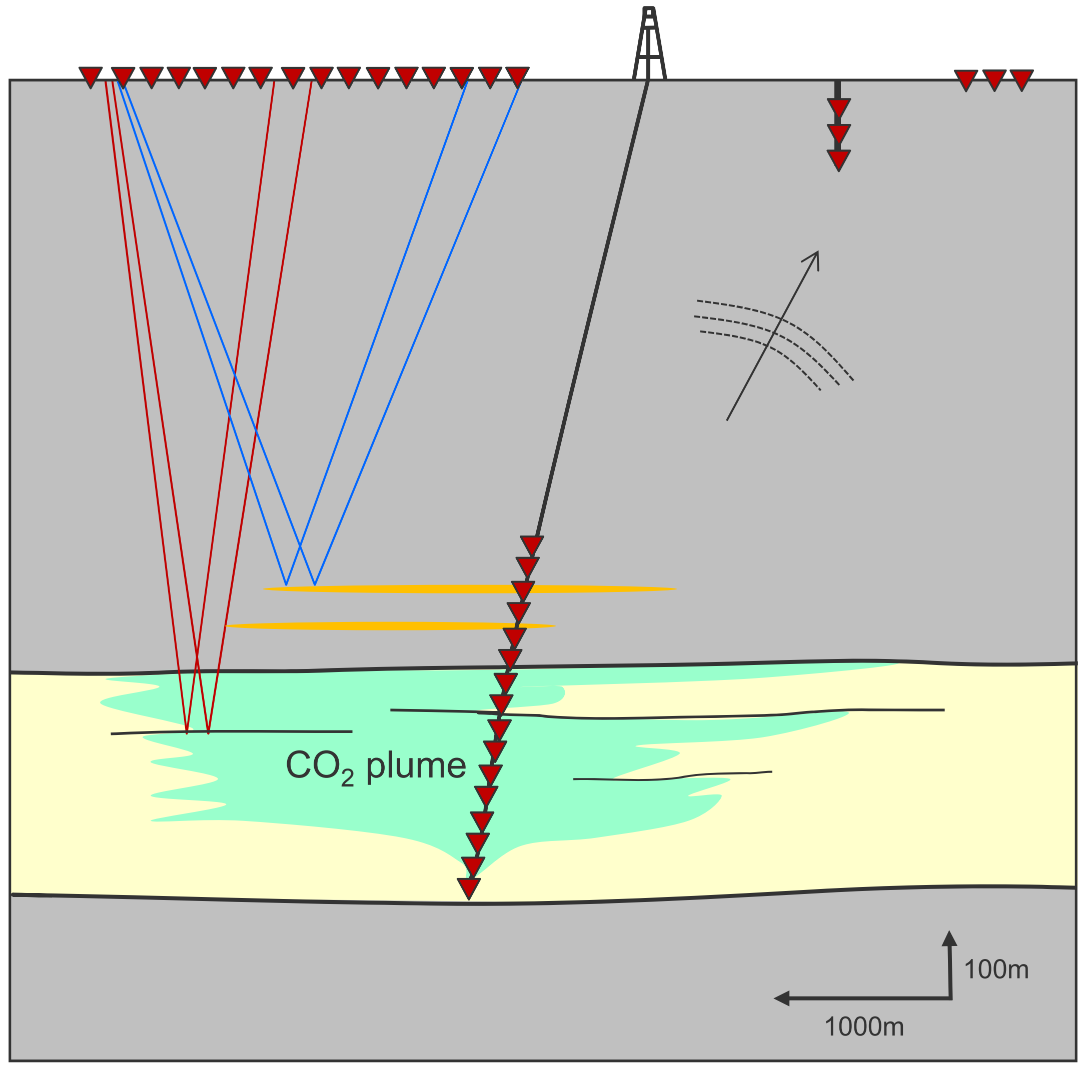
CO_2 Monitoring challenge

- Cost-effective combinations
- Geomechanics

Ideal CO_2 Storage Monitoring Portfolio

So what should future CO_2 monitoring look like?

- Reservoir Volume and Pressure Control
- Future Technologies
  - Dominated by non-invasive geophysical methods
  - Extensive use of permanent distributed fibre-optic P, T, acoustic gauges (e.g. DACS)
  - Satellite InSAR and/or sea-bottom sonar
- Significantly lower cost than today



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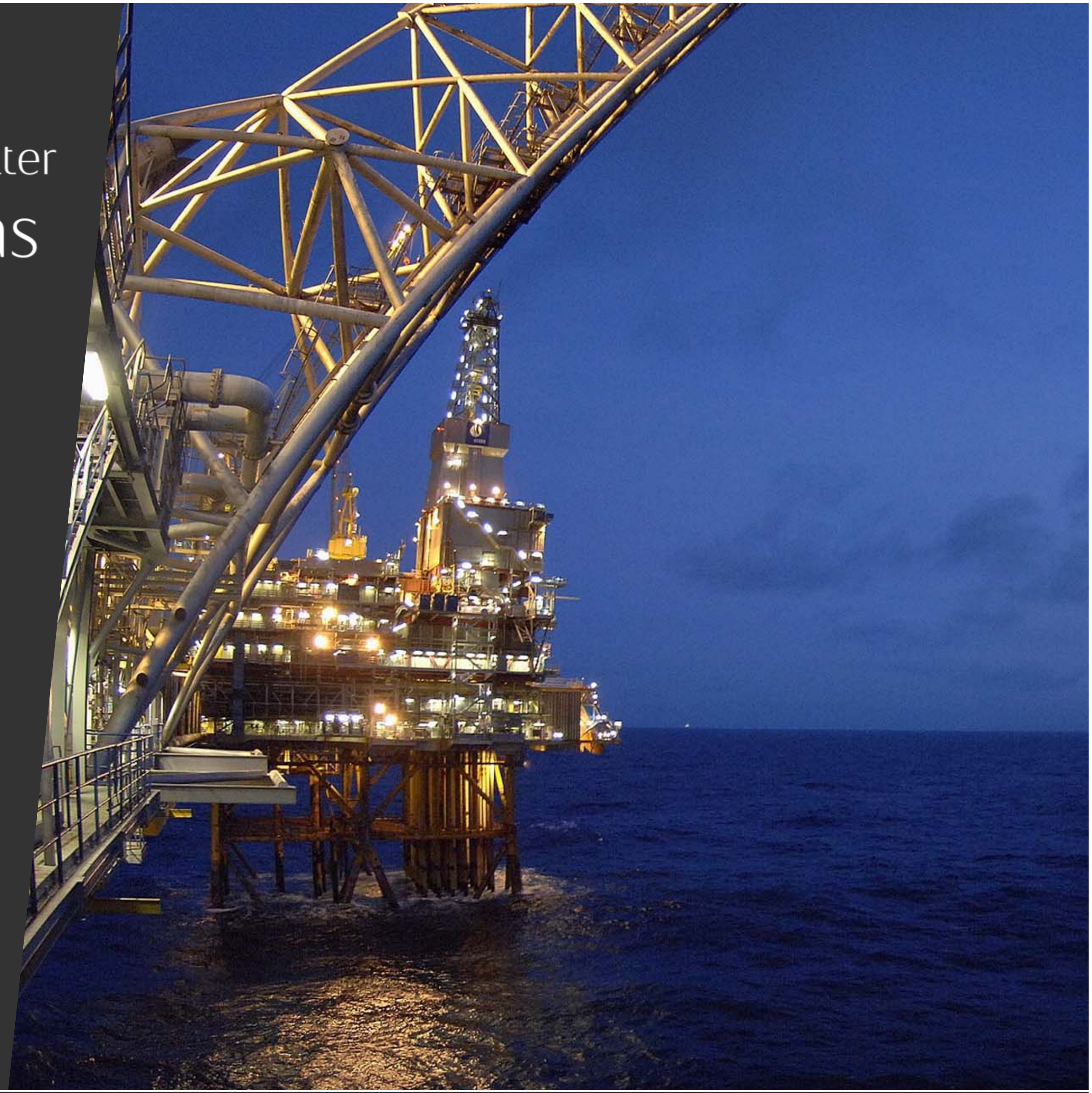
There's never been a better time for good ideas



Presented by:
P. Ringrose, A-K Furre, O. Hansen
Statoil RDI

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