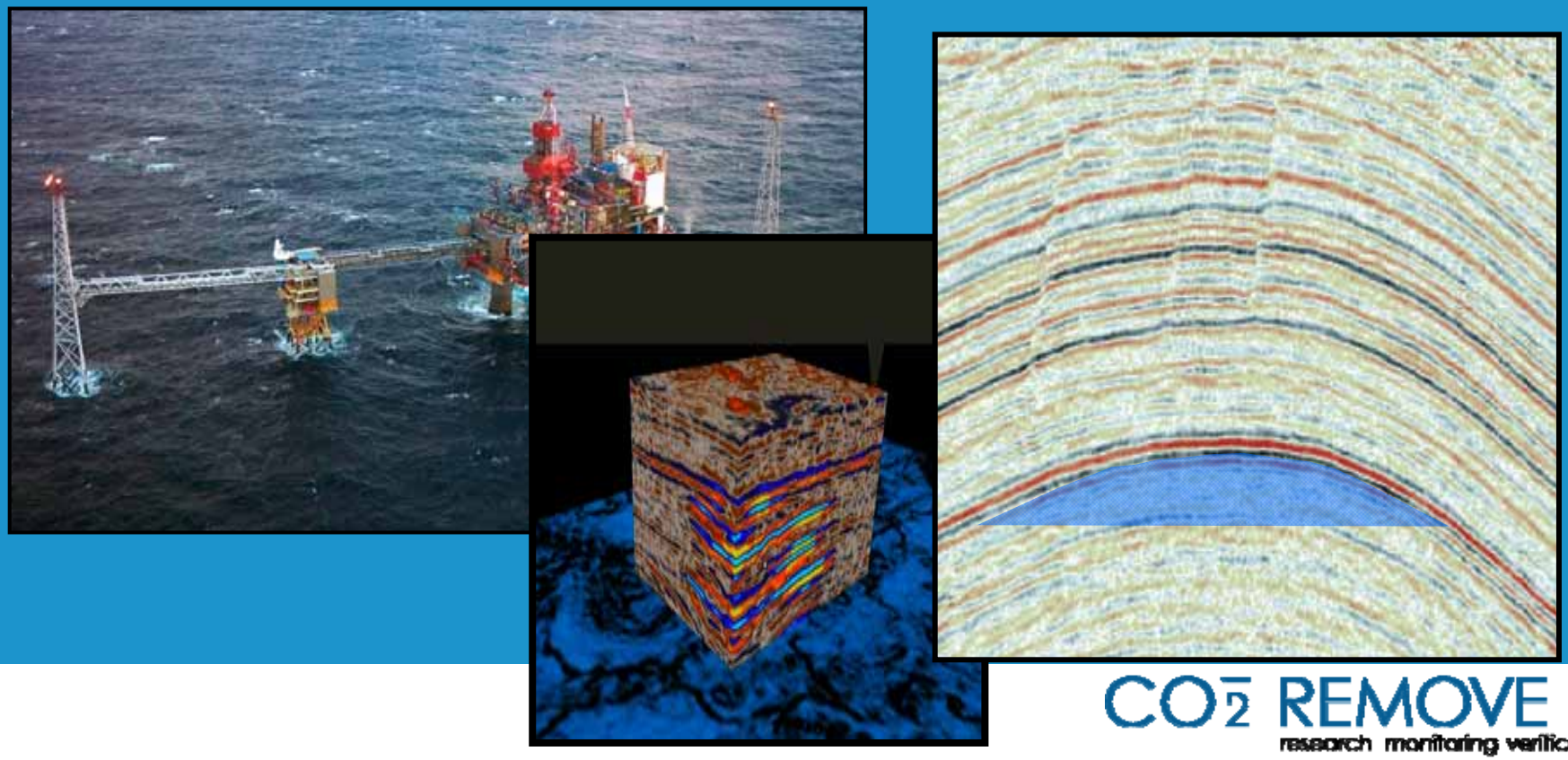
CO2 REMOVE
research monitoring verification

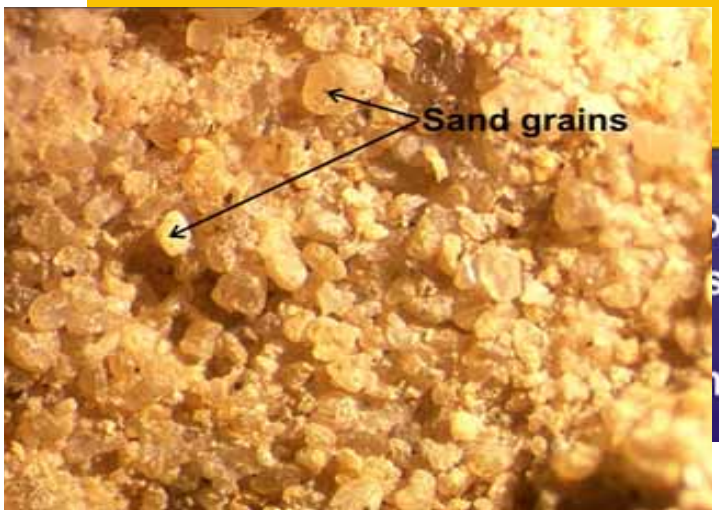
CO_2 storage site monitoring: can we meet the regulatory requirements?

Andy Chadwick (British Geological Survey)



CO2 REMOVE
research monitoring verification

Storage concept



Fossil fuel fired power

CO_2 extracted compressed & piped to disposal area

Pipeline

Cap Rock (impermeable shale or mudstone)

CO_2

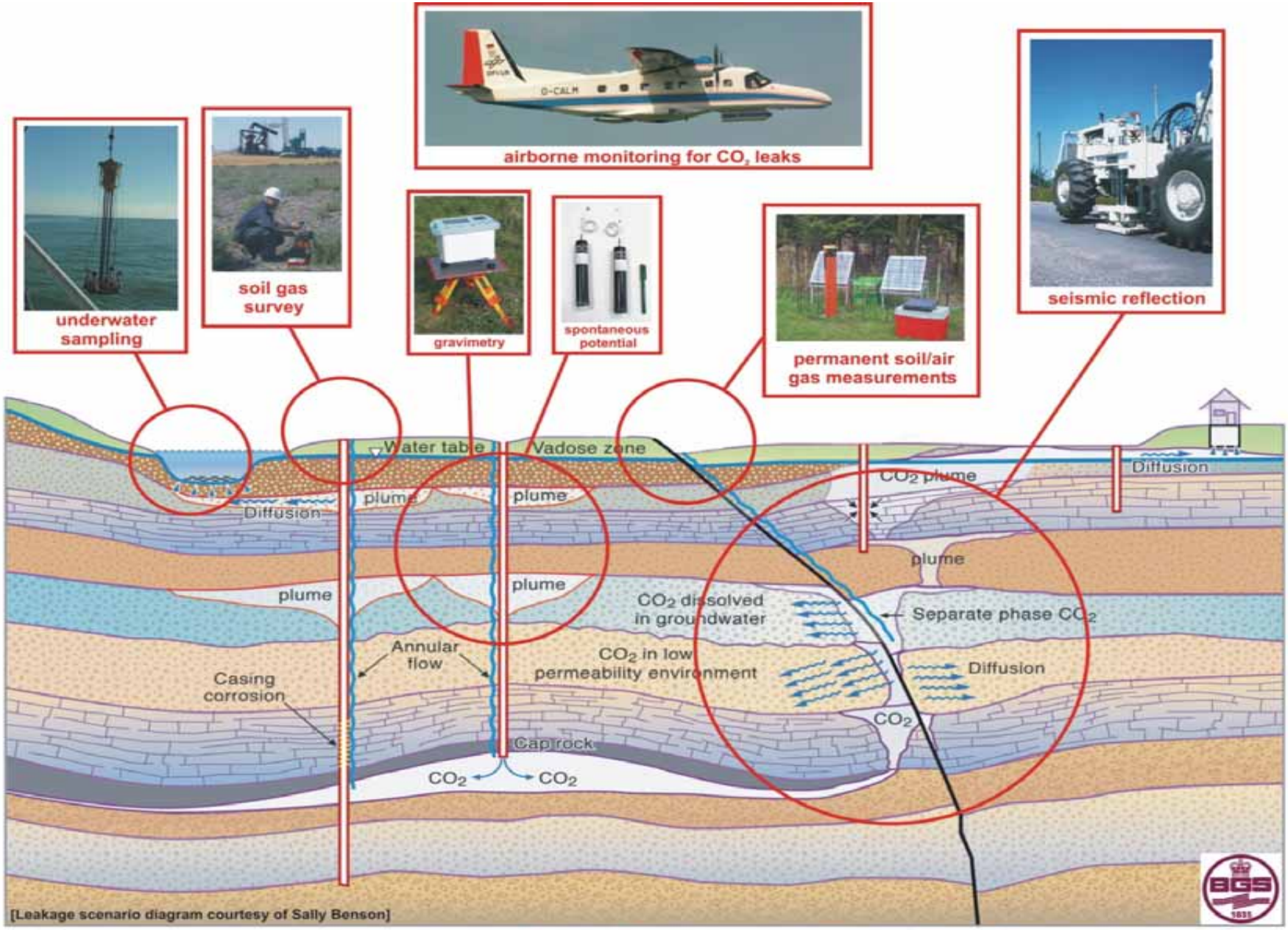
ormation water

silicate minerals to

reservoir

CO_2 fills pore spaces in sandstone, displacing the water which was originally present

Monitoring technologies



Monitoring and Regulation

SITE PERFORMANCE: CURRENT AND FUTURE (EC Directive)

- Image / measure CO_2 in the reservoir
- Monitor containment risks / no detected leakage
- Show site is currently performing as expected
  - Identify & remediate non-conformances
- Constrain predictions of long-term site behaviour
  - Calibrate flow simulations
- Enable site closure
  - Long term stability

EMISSIONS ACCOUNTING (EU ETS / National Inventories)

- Monitor outer envelope of the storage complex

HEALTH AND SAFETY (National legislations)

- Detect potentially hazardous leakages / accumulations at or near - surface

Monitoring and Regulation

SITE PERFORMANCE: CURRENT AND FUTURE (EC Directive)

- Image / measure CO_2 in the reservoir
- Monitor containment risks / no detected leakage
- Show site is currently performing as expected
  - Identify & remediate non-conformances
- Constrain predictions of long-term site behaviour
  - Calibrate flow simulations
- Enable site closure
  - Long term stability

EMISSIONS ACCOUNTING (EU ETS / National Inventories)

- Monitor outer envelope of the storage complex

HEALTH AND SAFETY (National legislations)

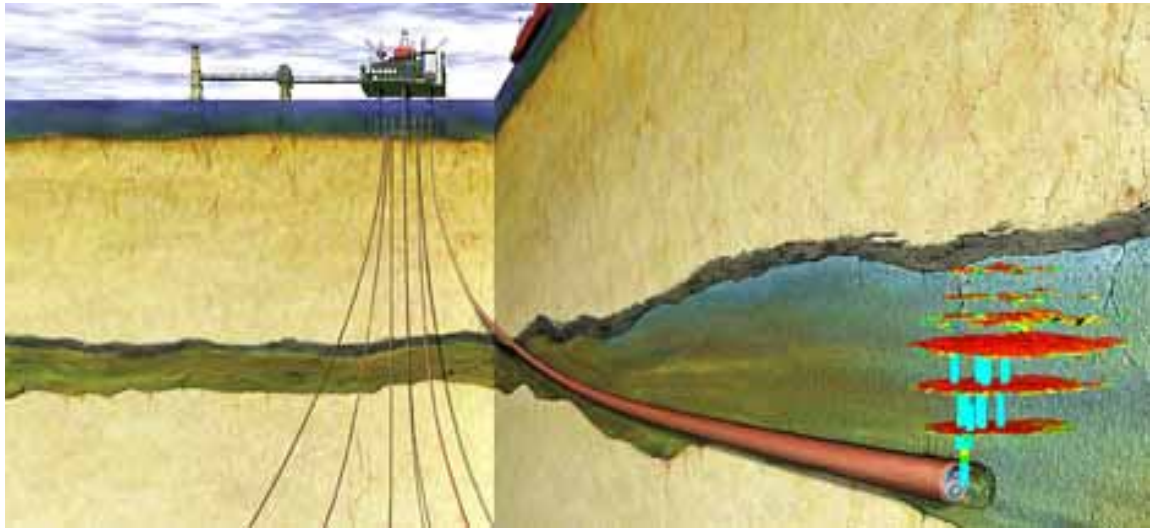
- Detect potentially hazardous leakages / accumulations at or near - surface

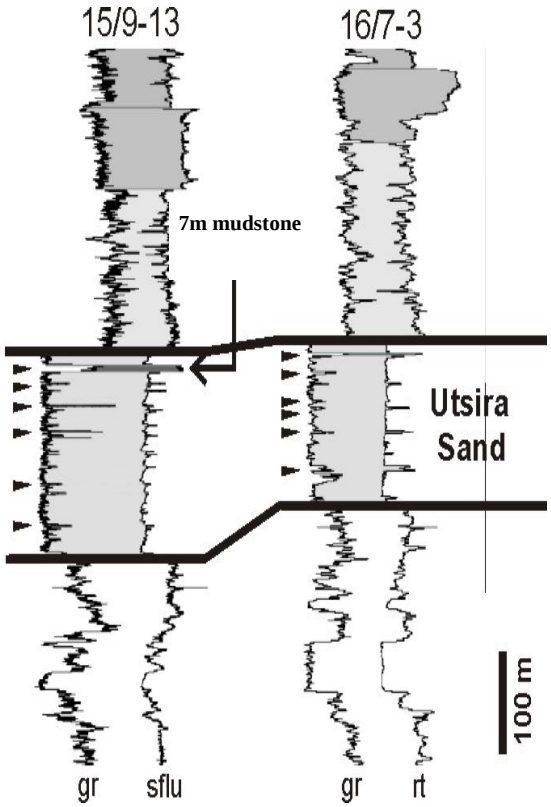
Monitoring at Sleipner

CO_2 injection commenced 1996

~ 1 Mt CO_2 injected per annum

>12 Mt currently *in situ*



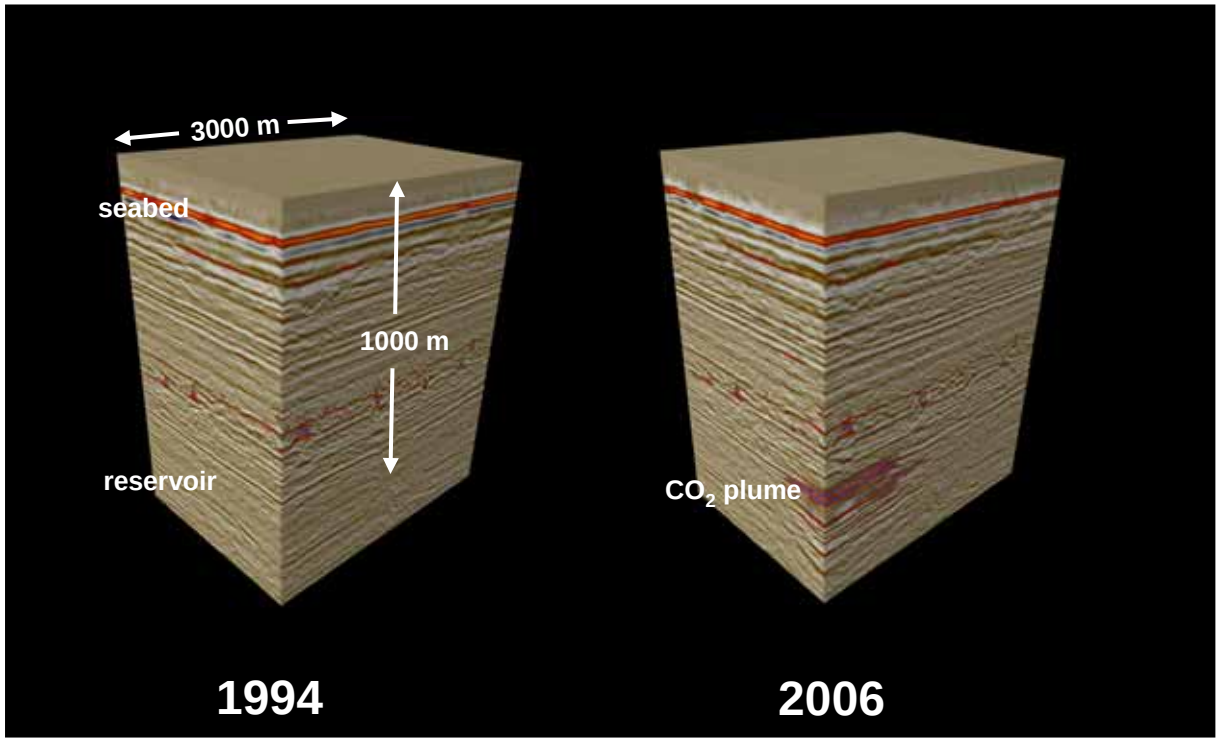


Sleipner Monitoring Programme

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
3D surface seismic	✓					✓		✓	✓		✓		✓		✓	
2D surface seismic (hi-res)													✓			
Seabed imaging (ss sonar, multibeam)													✓			
Seabed gravity									✓			✓				✓
CSEM															✓	
Wellhead pressure			**continuous**													
Cumulative CO_2 injected at TL surveys (Mt)	0.00		injection starts			2.35		4.25	4.97(s) 5.19(g)		6.84	7.74	8.40		10.15 (s) 10.38 (em)	11.05

N.B. No invasive (well based) monitoring

Sleipner: 3D time-lapse (4D) seismic



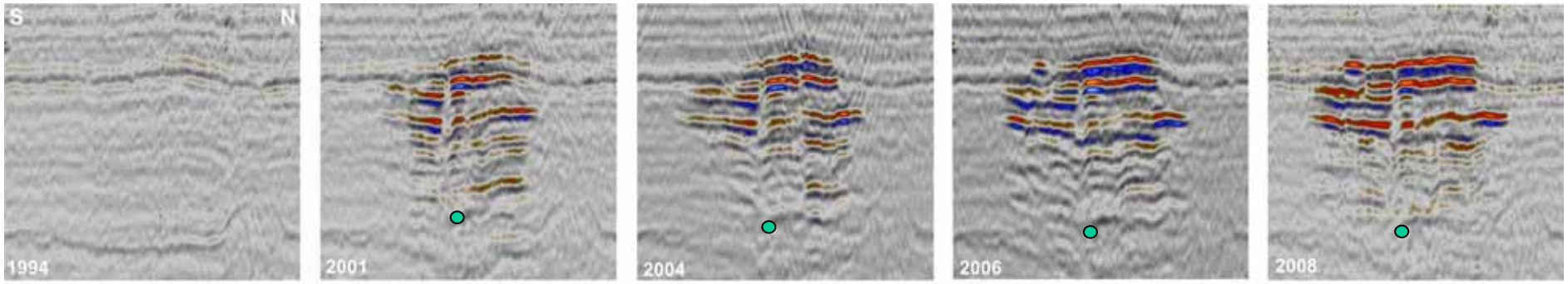
3D time-lapse surveys

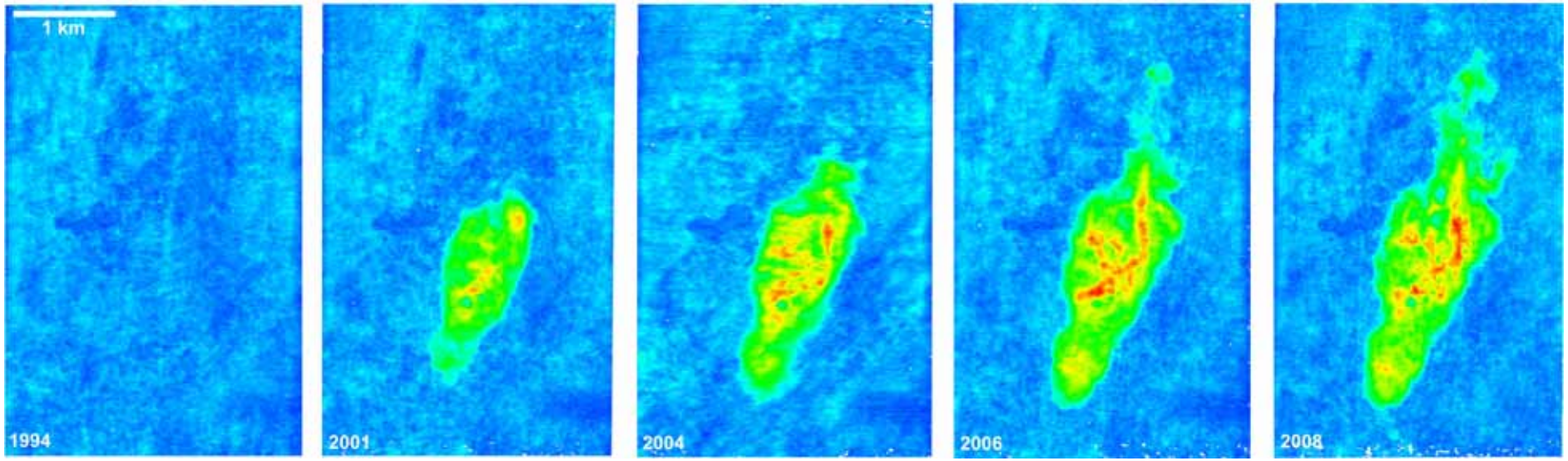
1994	baseline
1999	
2001	
2002	
2004	
2006	
2008	

Provides spatially continuous and uniform coverage of the subsurface volume of the storage site / complex

Sleipner: Imaging CO_2 in the reservoir

vertical section





plan view

Monitoring and Regulation

SITE PERFORMANCE: CURRENT AND FUTURE (EC Directive)

- Image / measure CO_2 in the reservoir
- Monitor containment risks / no detected leakage
- Show site is currently performing as expected
  - Identify & remediate non-conformances
- Constrain predictions of long-term site behaviour
  - Calibrate flow simulations
- Enable site closure
  - Long term stability

EMISSIONS ACCOUNTING (EU ETS / National Inventories)

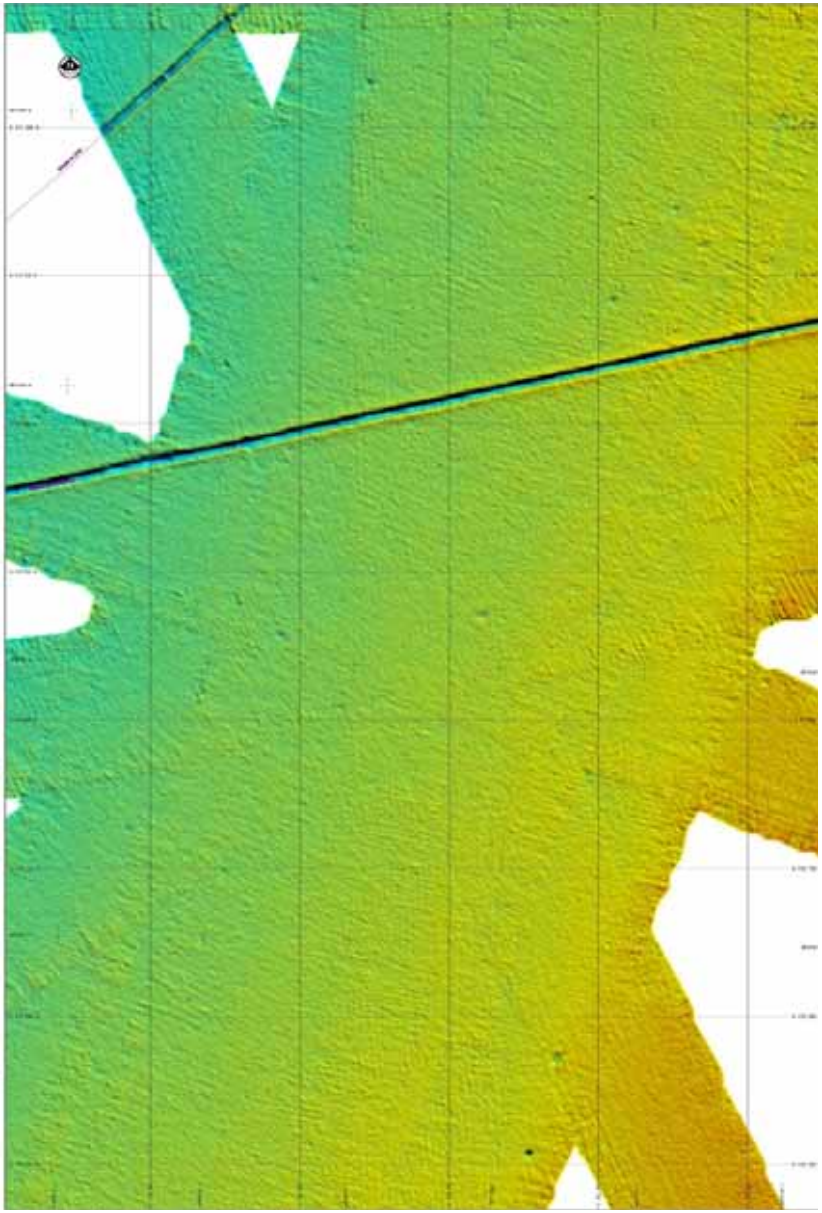
- Monitor outer envelope of the storage complex

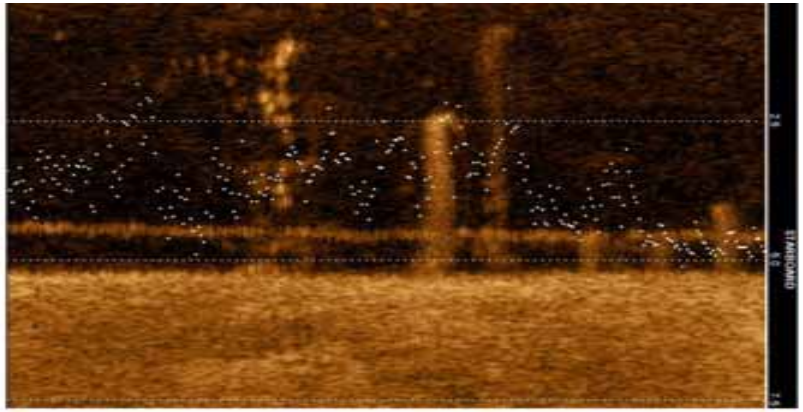
HEALTH AND SAFETY (National legislations)

- Detect potentially hazardous leakages / accumulations at or near - surface

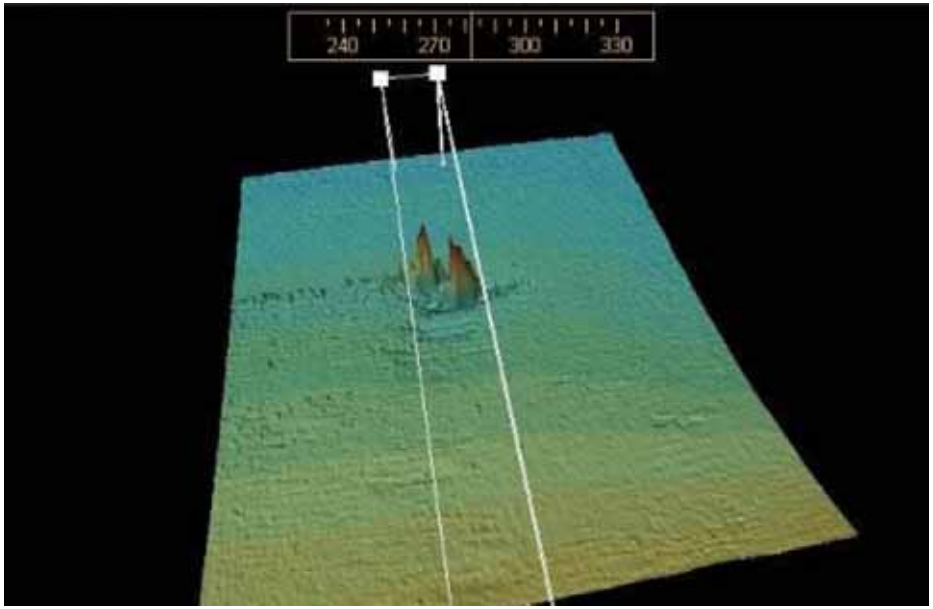
Emissions monitoring: seabed imaging

Multibeam echosounding – seabed at Sleipner



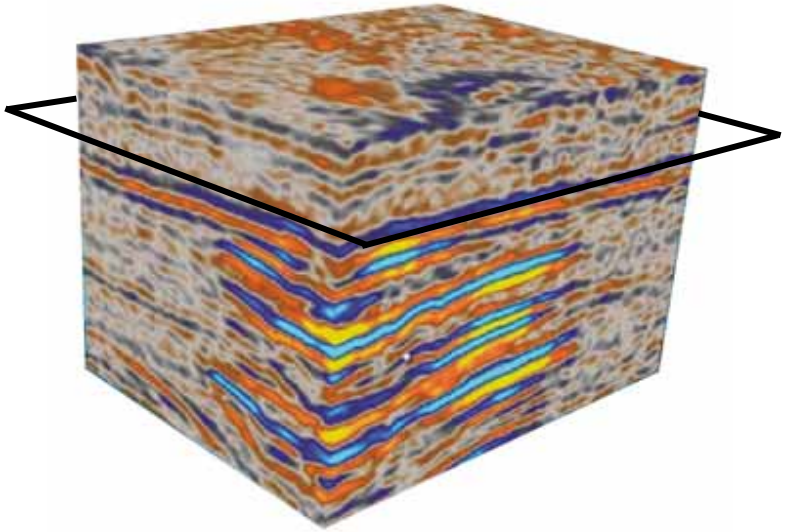


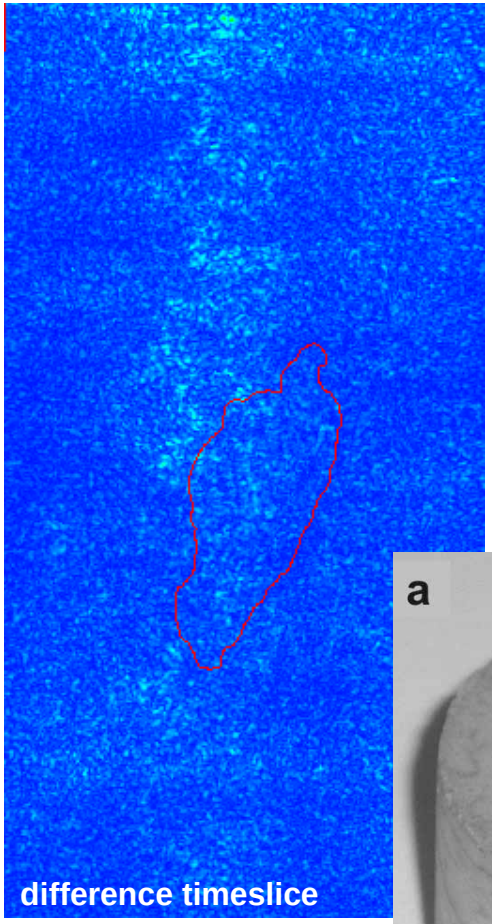
Sidescan sonar – emissions imaging
(Figure from CO2ReMoVe / BGR)

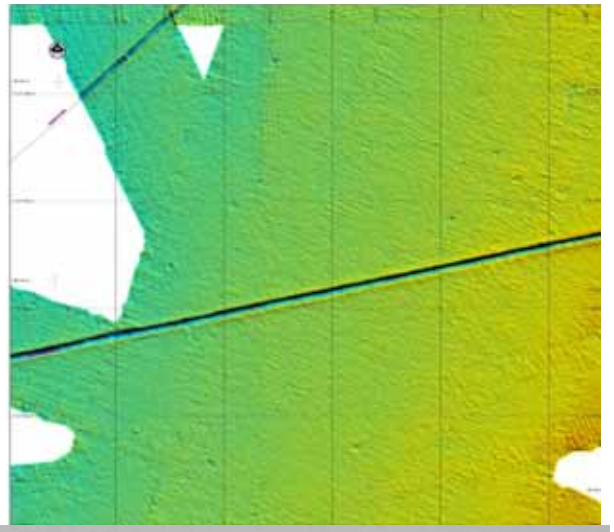


Multibeam echosounding – emissions characterisation
(Figure from CO2ReMoVe / BGR)

No current detected leakage in overburden or at seabed





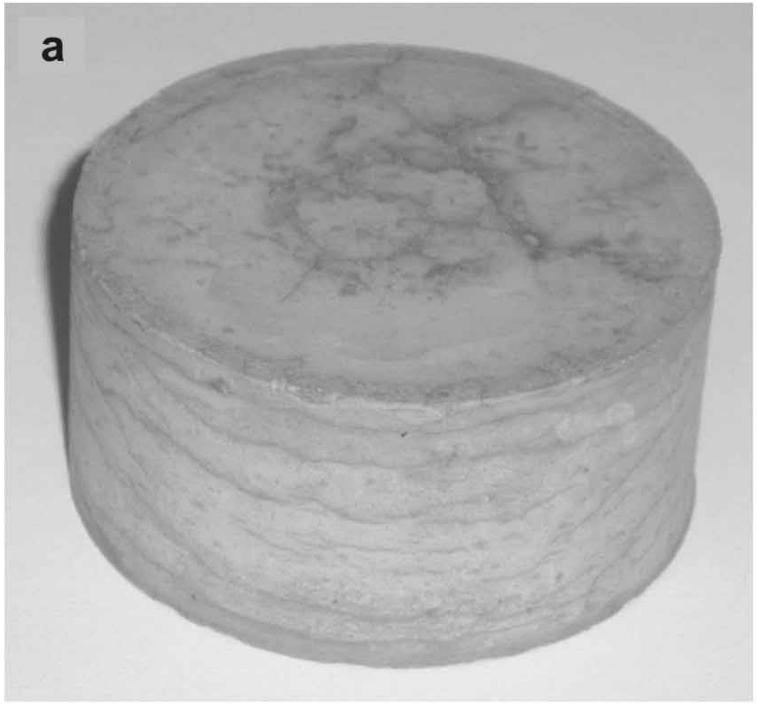


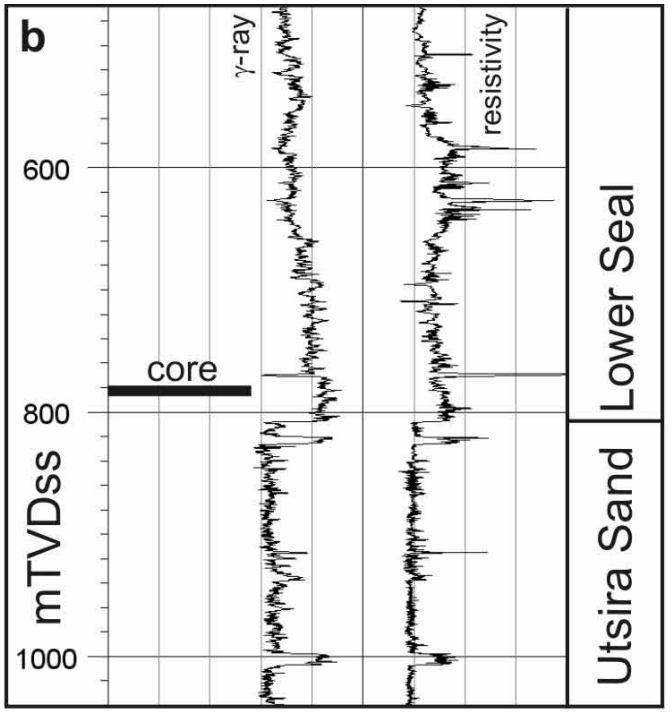
Detection limit for Sleipner data:

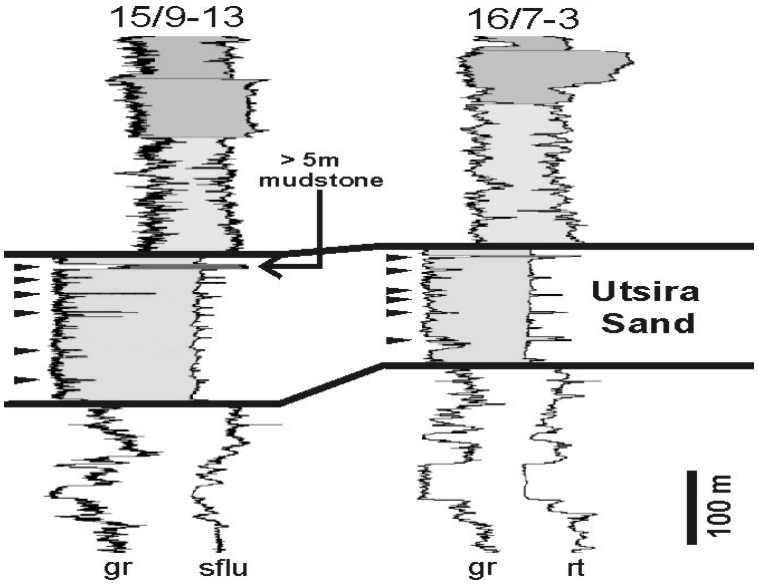
~ 4000 m³

~ 2500 tonnes at top reservoir (~0.01% of projected total)

Demonstrable capillary seal







→ no leakage

Monitoring and Regulation

SITE PERFORMANCE: CURRENT AND FUTURE (EC Directive)

- Image / measure CO_2 in the reservoir
- Monitor containment risks
- Show site is currently performing as expected
  - Identify & remediate non-conformances
- Constrain predictions of long-term site behaviour
  - Calibrate flow simulations
- Enable site closure
  - Long term stability

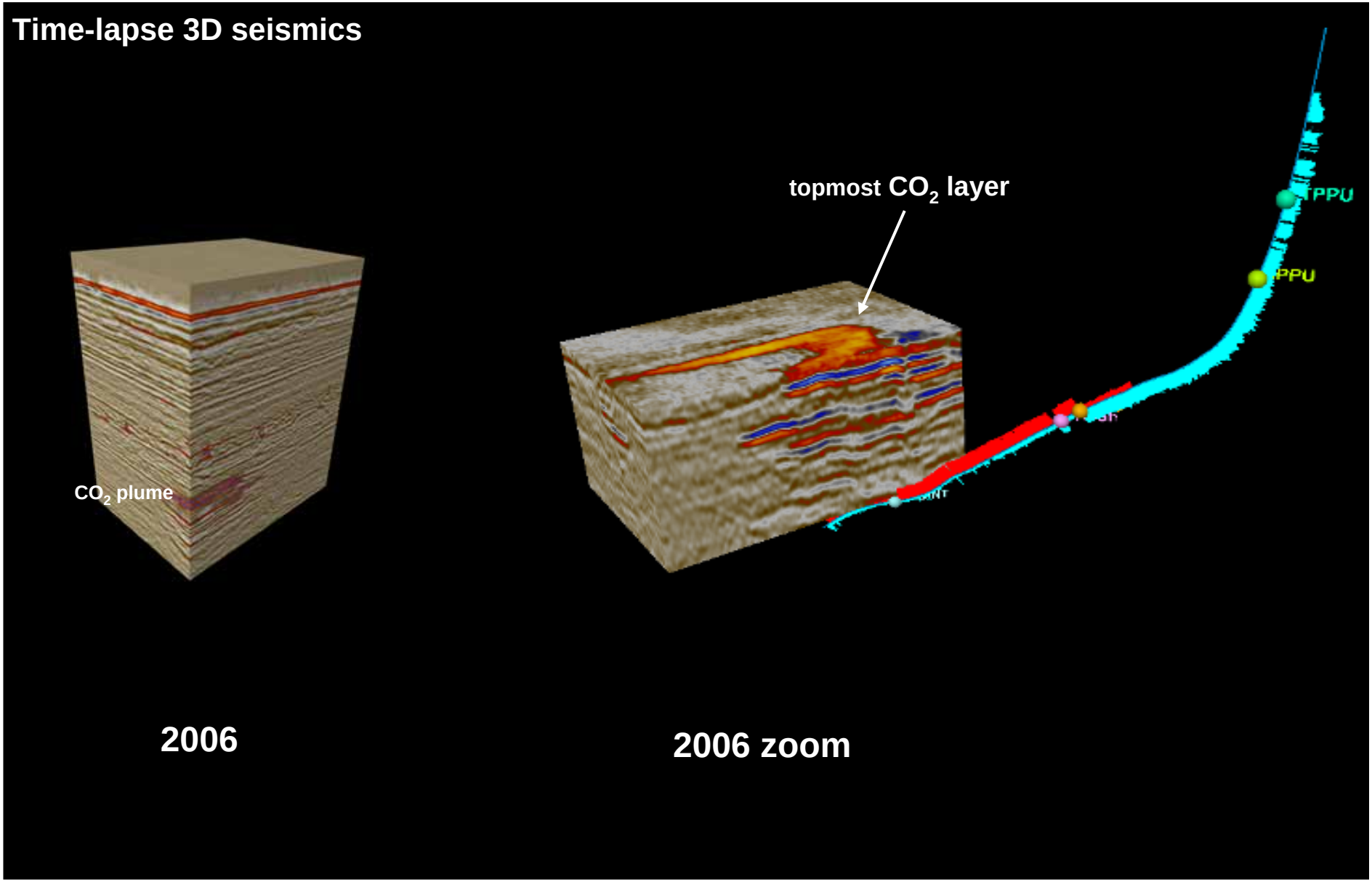
EMISSIONS ACCOUNTING (EU ETS / National Inventories)

- Monitor outer envelope of the storage complex

HEALTH AND SAFETY (National legislations)

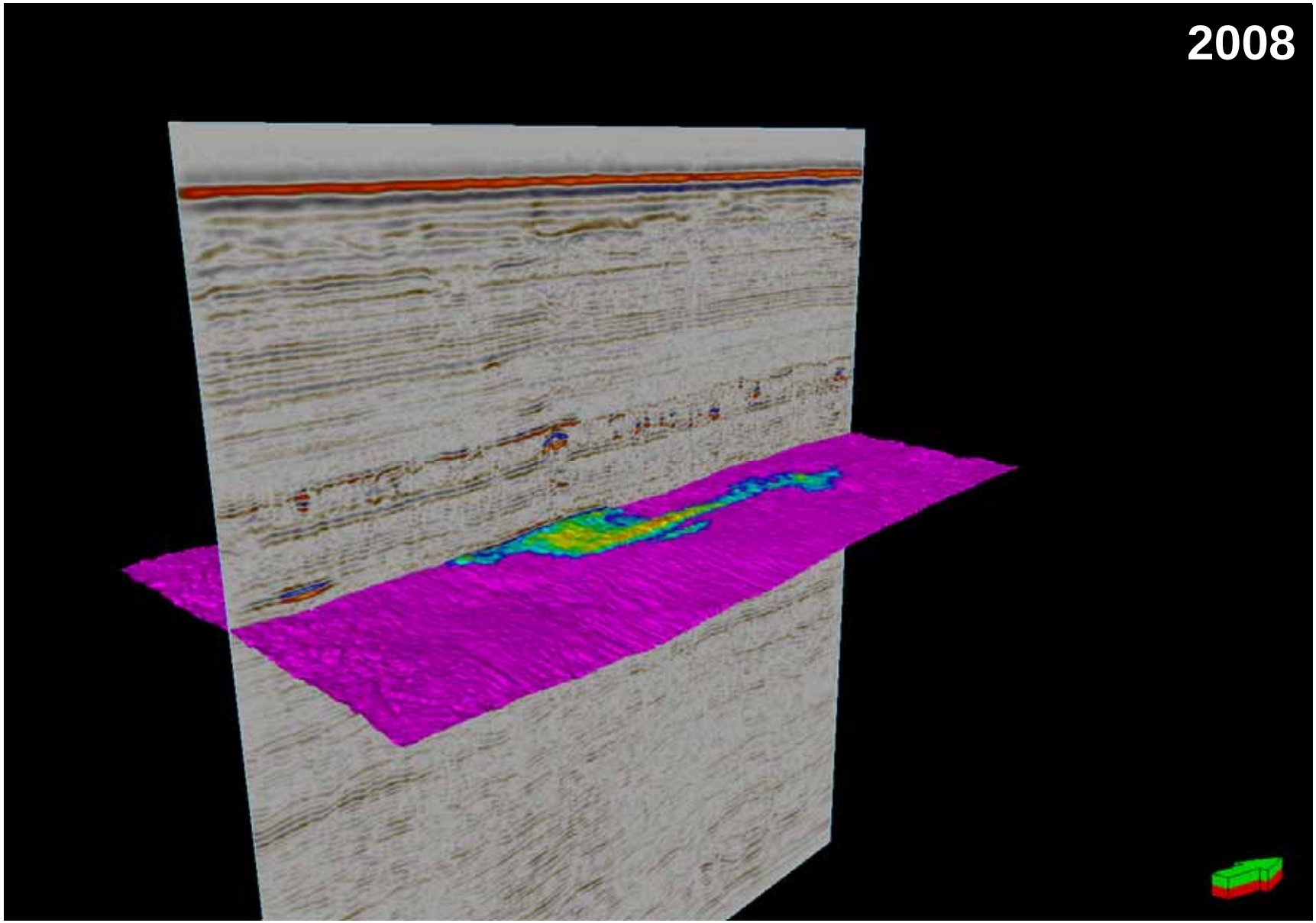
- Detect potentially hazardous leakages / accumulations at or near - surface

Sleipner: Performance verification



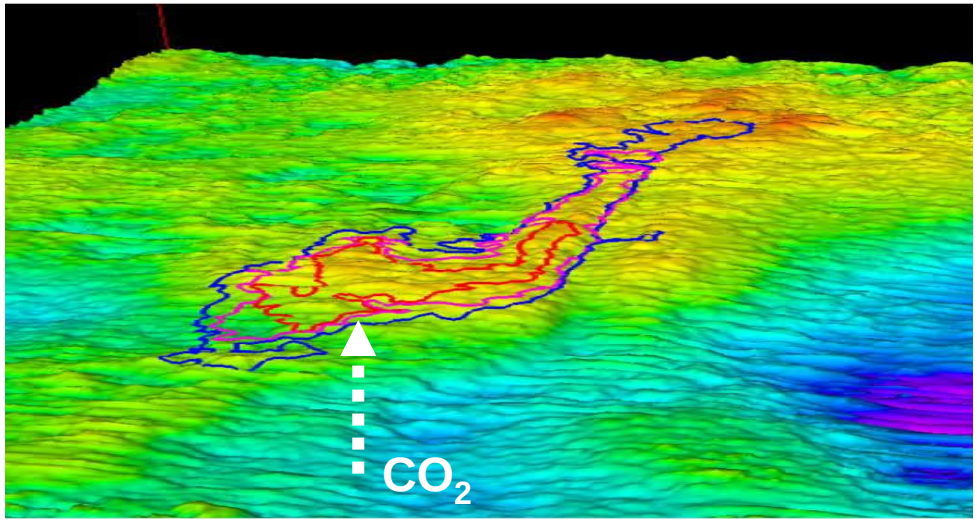
Sleipner: Performance verification

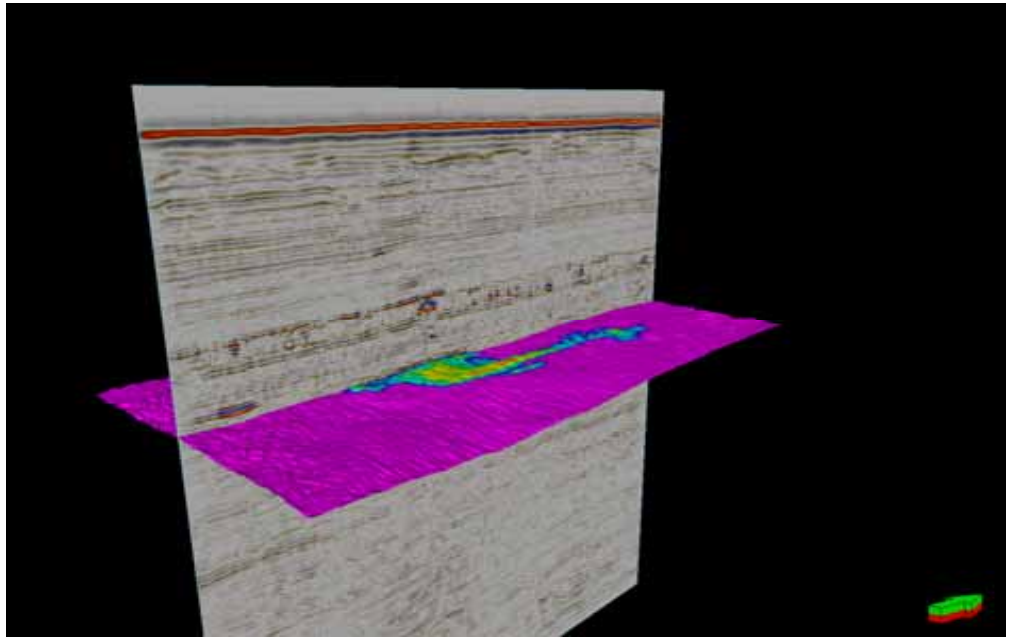
Plume migration (1)



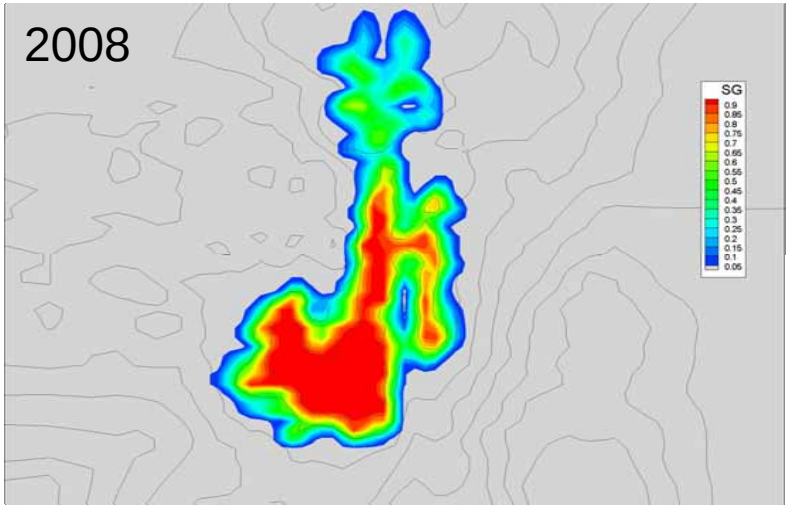
Sleipner: Performance verification

Plume migration (2)





observed layer growth



simulated layer growth

Monitoring and Regulation

SITE PERFORMANCE: CURRENT AND FUTURE (EC Directive)

- Image / measure CO_2 in the reservoir
- Monitor containment risks / no detected leakage
- Show site is currently performing as expected
  - Identify & remediate non-conformances
- Constrain predictions of long-term site behaviour
  - Calibrate flow simulations
- Enable site closure
  - Long term stabilisation

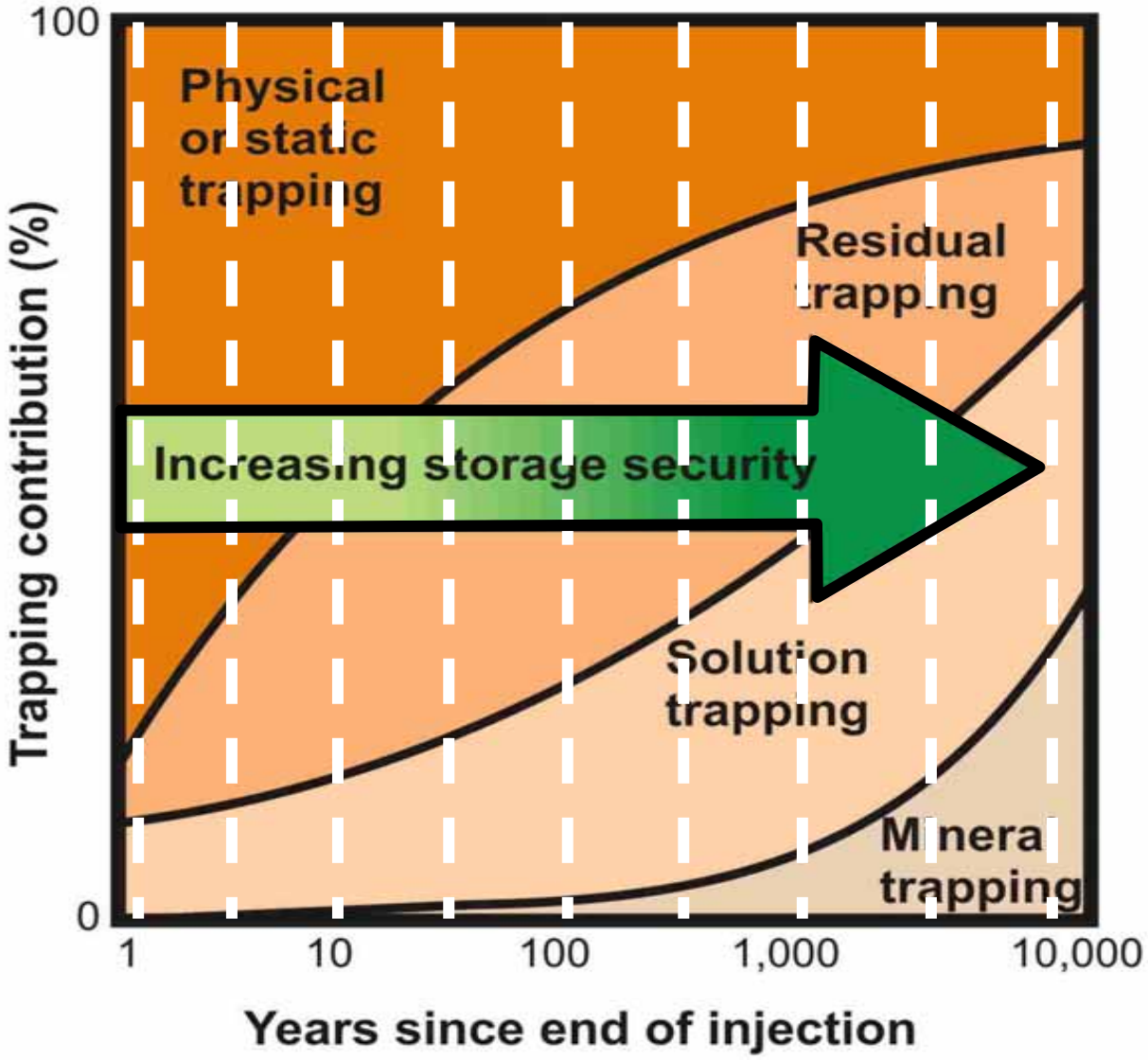
EMISSIONS ACCOUNTING (EU ETS / National Inventories)

- Monitor outer envelope of the storage complex

HEALTH AND SAFETY (National legislations)

- Detect potentially hazardous leakages / accumulations at or near - surface

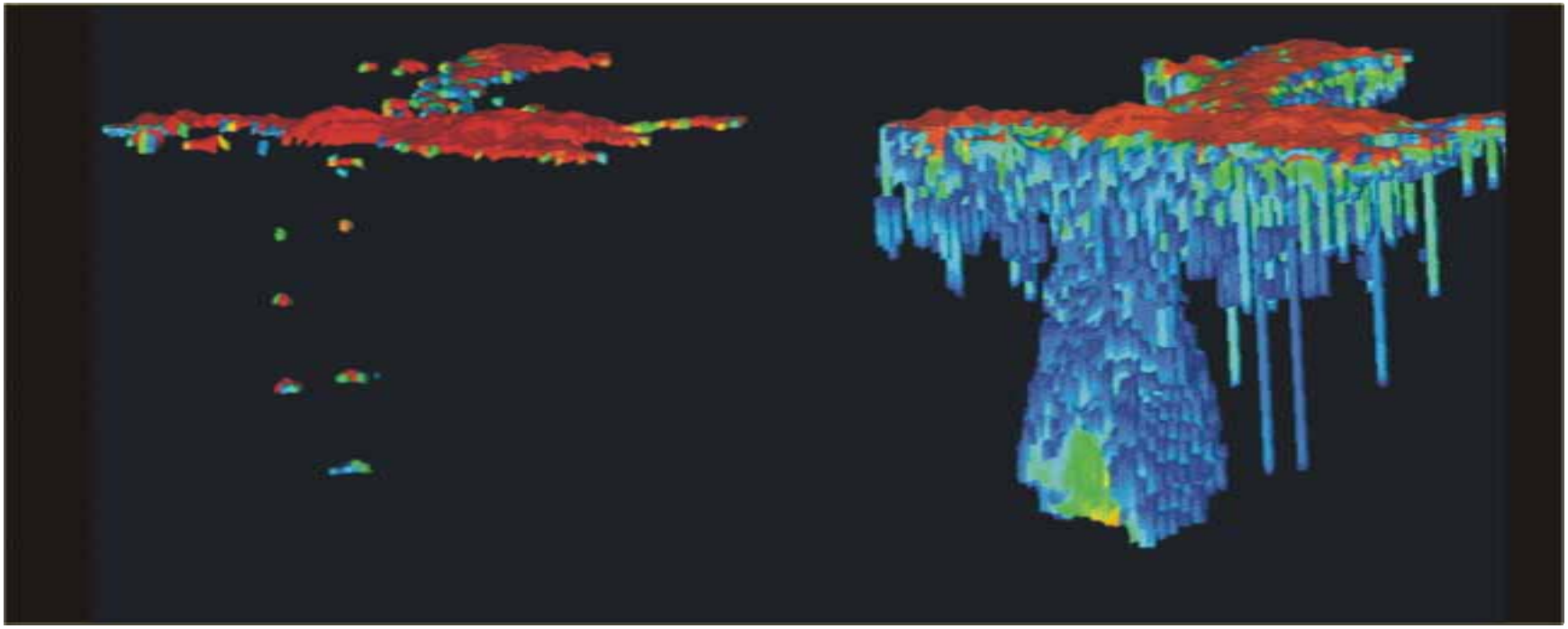
Long-term stabilisation



Sleipner stabilization: 275 years

Onset of dissolution: gravitational stabilization

free CO_2 **CO_2 in solution**

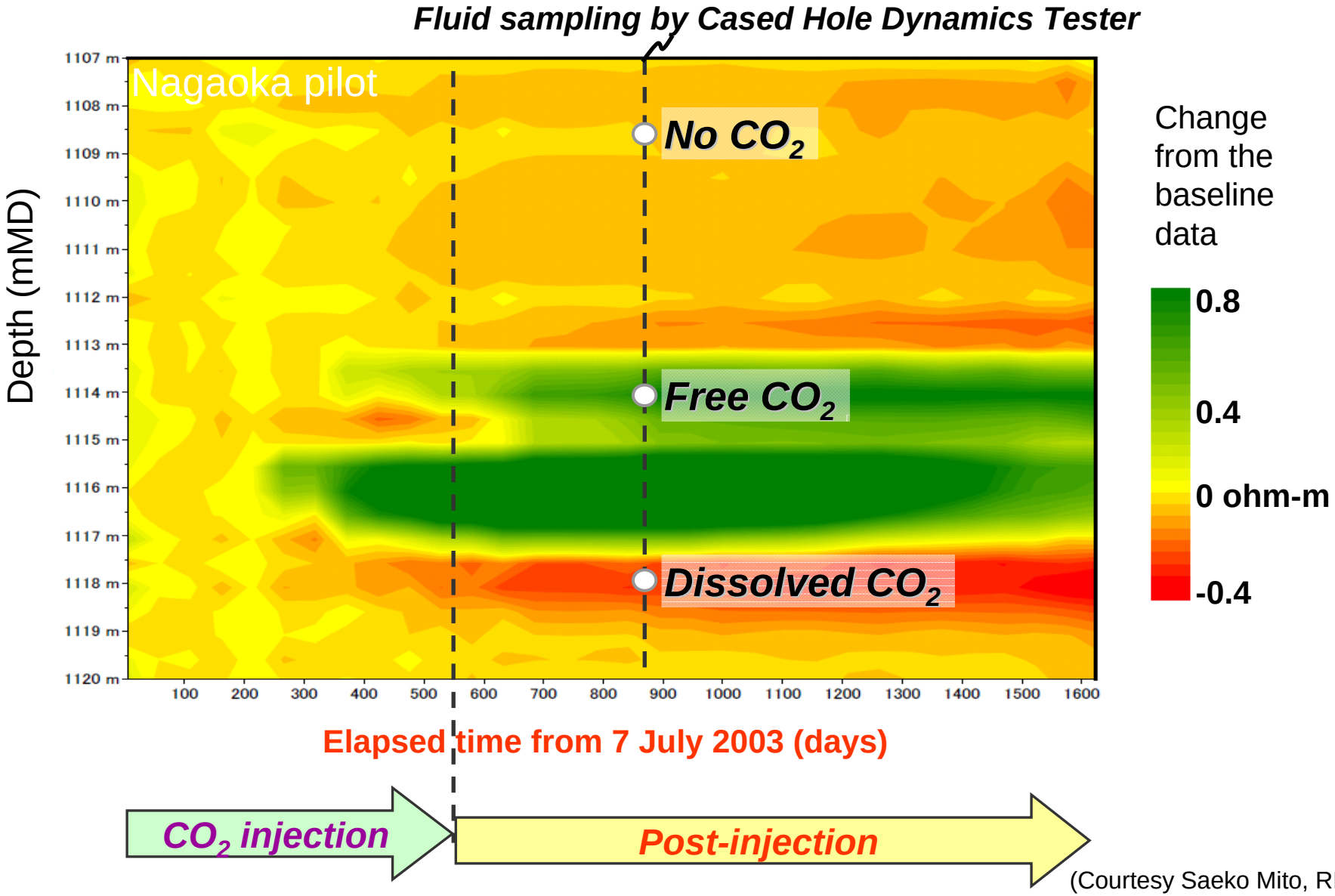


2270

[courtesy Erik Lindeberg, SINTEF]

Evidence for dissolution:

Field measurements from Nagaoka pilot project



(Courtesy Saeko Mito, RITE)

Conclusions

Technologies in place to address most aspects of the regulatory requirements (EU Directive)

Integrated monitoring methodologies under development

<u>Challenges</u>

Understanding / demonstrating long-term stabilization

Accurate emissions measurement (for ETS)

Acknowledgements

CO2ReMoVe project funded by the European Commission (FP6) and industry

CO2 REMOVE
research monitoring verification