An Overview of Monitoring Techniques for CO_2 Storage sites

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British Geological Survey

Monitoring – why?

SITE PERFORMANCE: CURRENT AND FUTURE (EC Storage Directive)

- Image CO_2 in the reservoir
- Monitor containment risks
- Show site is currently performing as expected
  - Identify deviations and remediate
- Constrain predictions of long-term site behaviour
- Enable site closure

→ **Principally deep - focussed technologies**

EMISSIONS ACCOUNTING (EU ETS / National Inventories)

- Monitor outer envelope of the storage complex
  - Measure emissions

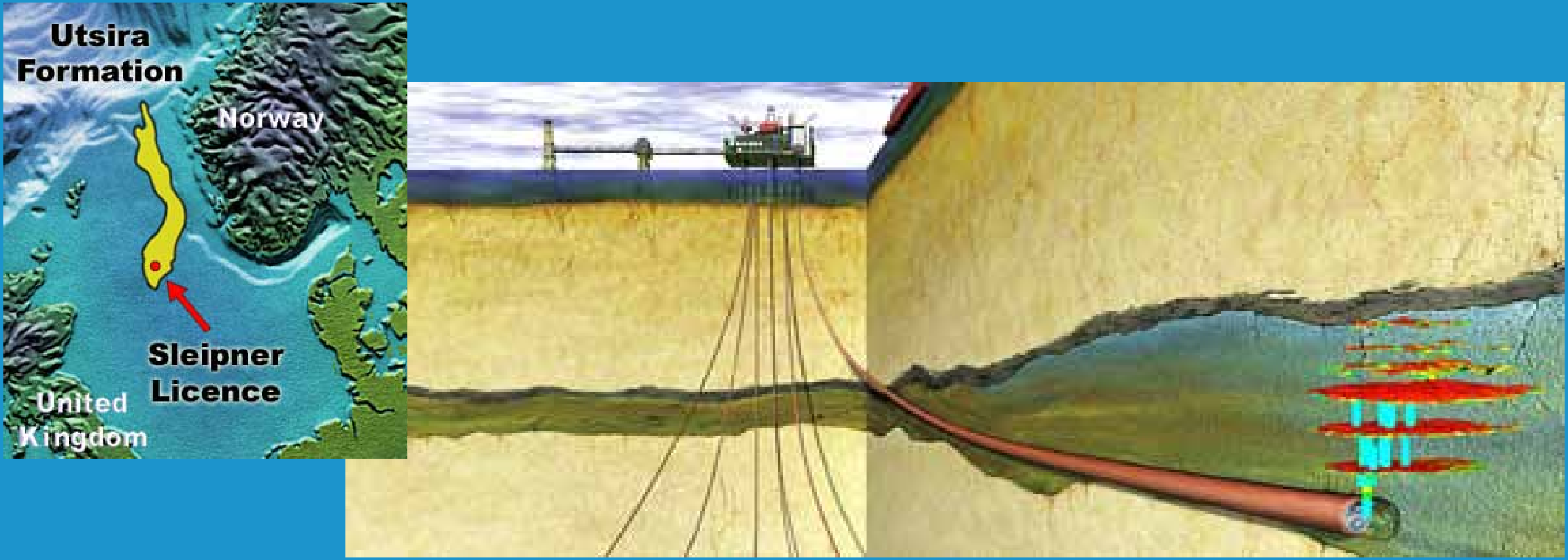
→ **Principally shallow - focussed technologies**

CO2ReMoVe site monitoring

4 industrial sites **3 pilot-scale sites**

3 offshore sites, 4 onshore

Deep-focussed monitoring at Sleipner (1)



CO_2 injection commenced 1996

~ 1 Mt CO_2 injected per annum

> 13 Mt currently *in situ*

Time-lapse 3D (4D) seismic

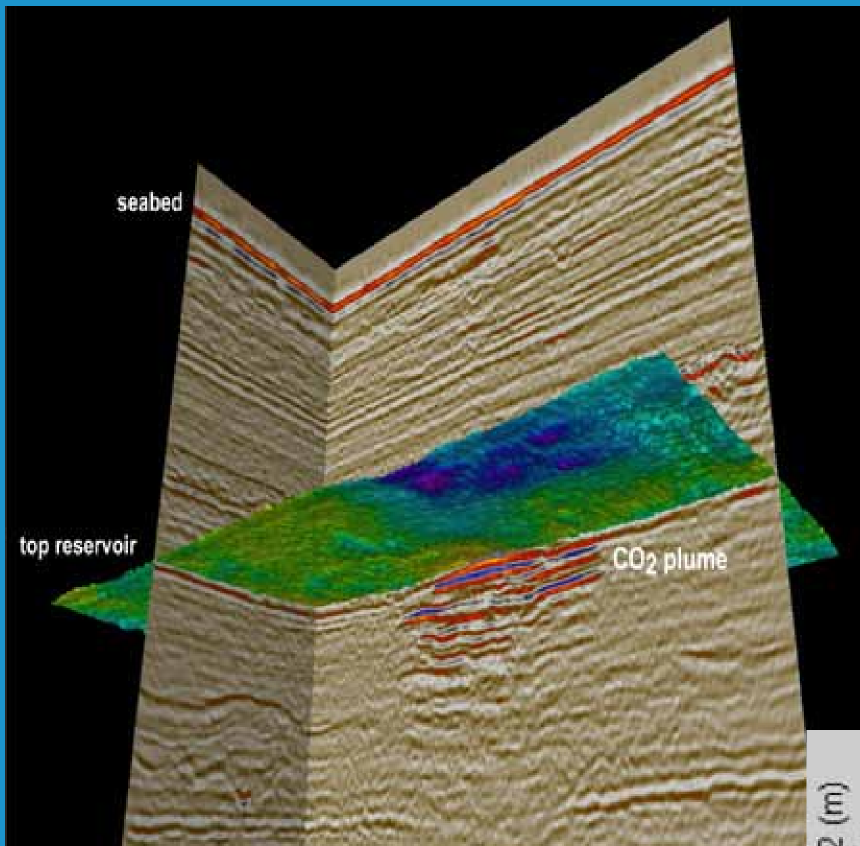
2D seismic

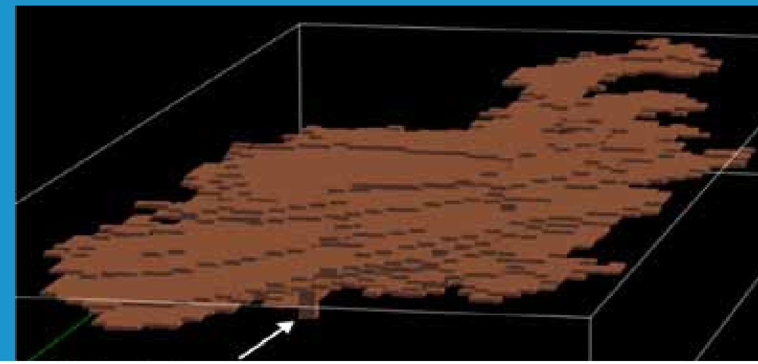
Time-lapse seabed gravimetry

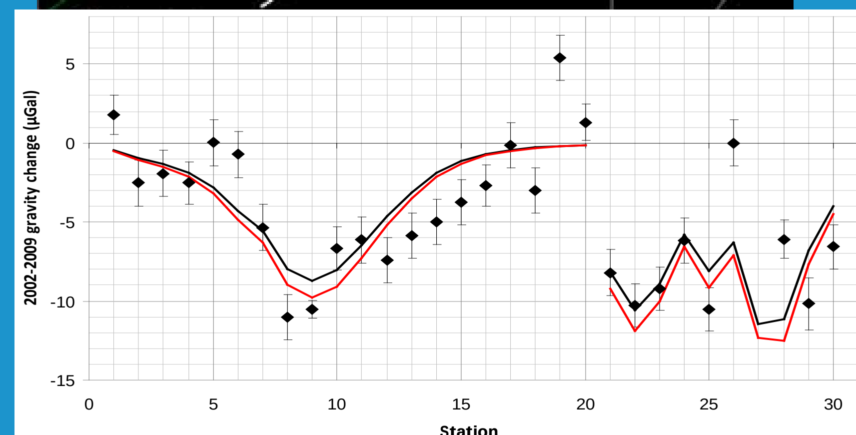
CSEM

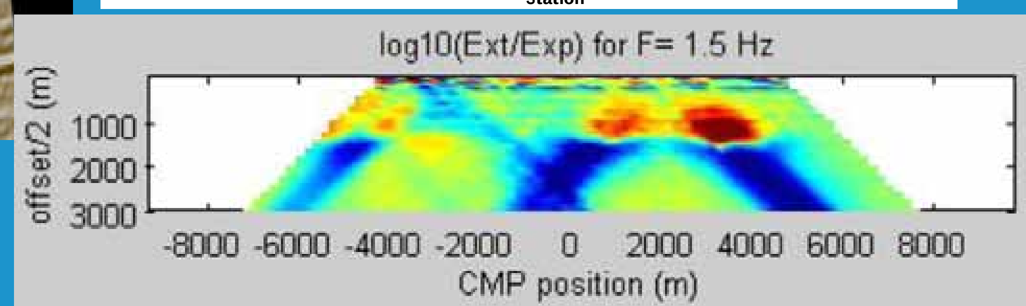
Seabed imaging

Deep-focussed monitoring at Sleipner (2)





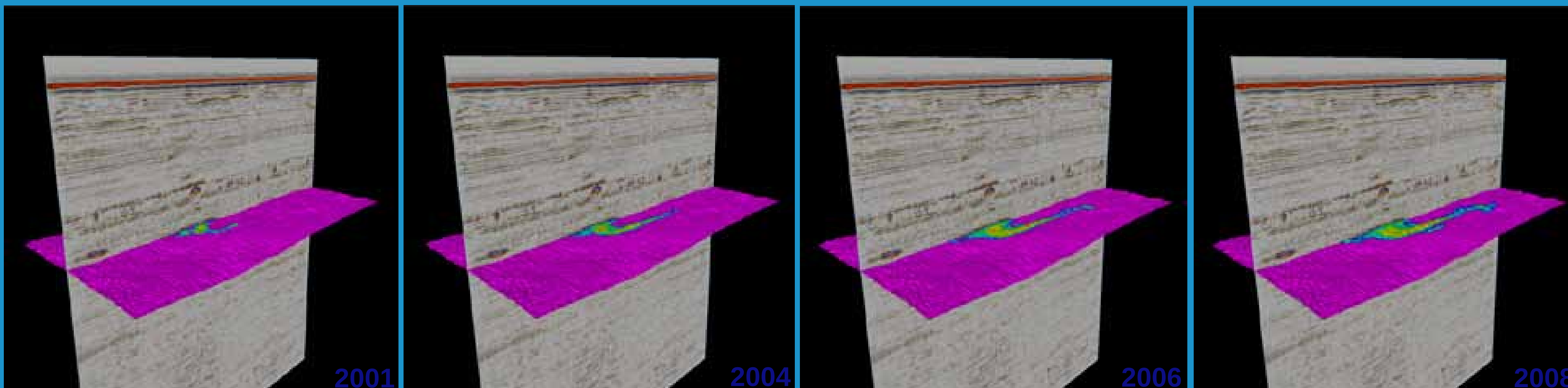


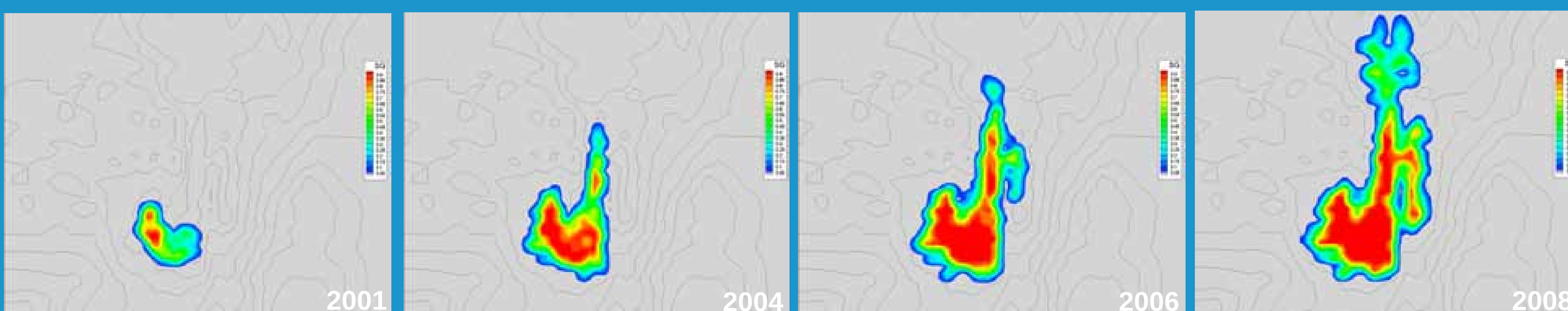


Seismic: key plume imaging tool
Gravimetry: complementary constraints on density and dissolution
CSEM: Possible constraints on saturation (in progress)

Deep-focussed monitoring at Sleipner (3)

observed layer growth

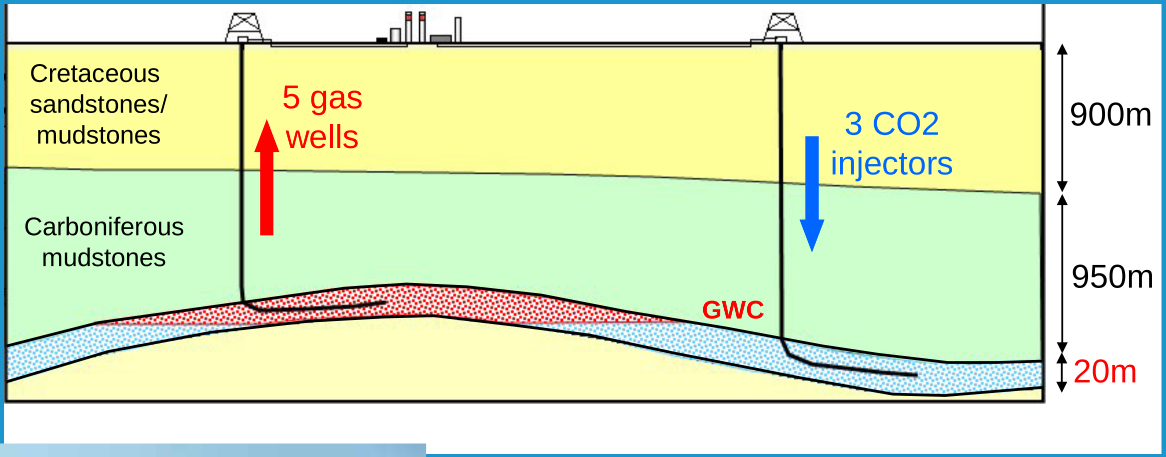


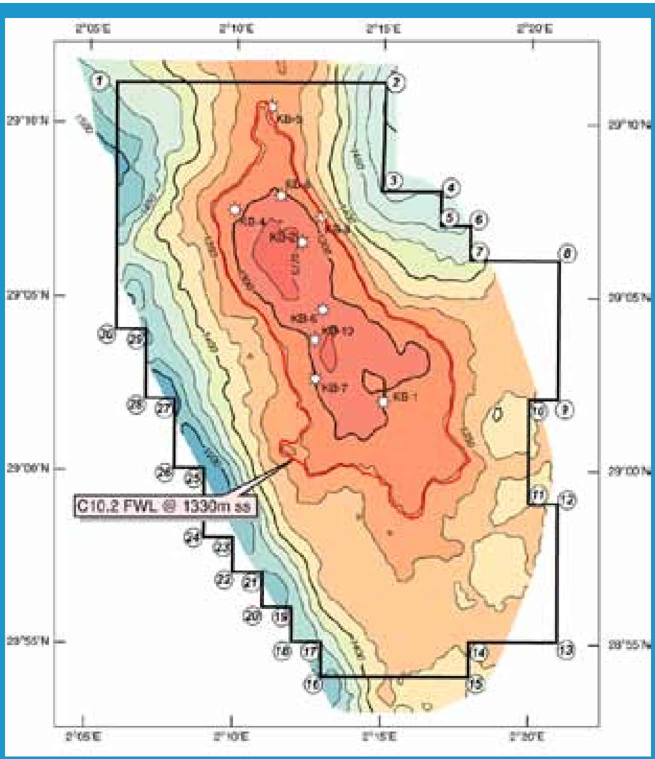


simulated layer growth

Detailed history-matching of growth of topmost layer
Some uncertainties – CO_2 mobility, feeder distribution topseal topography

Mixed Monitoring at In Salah (1)



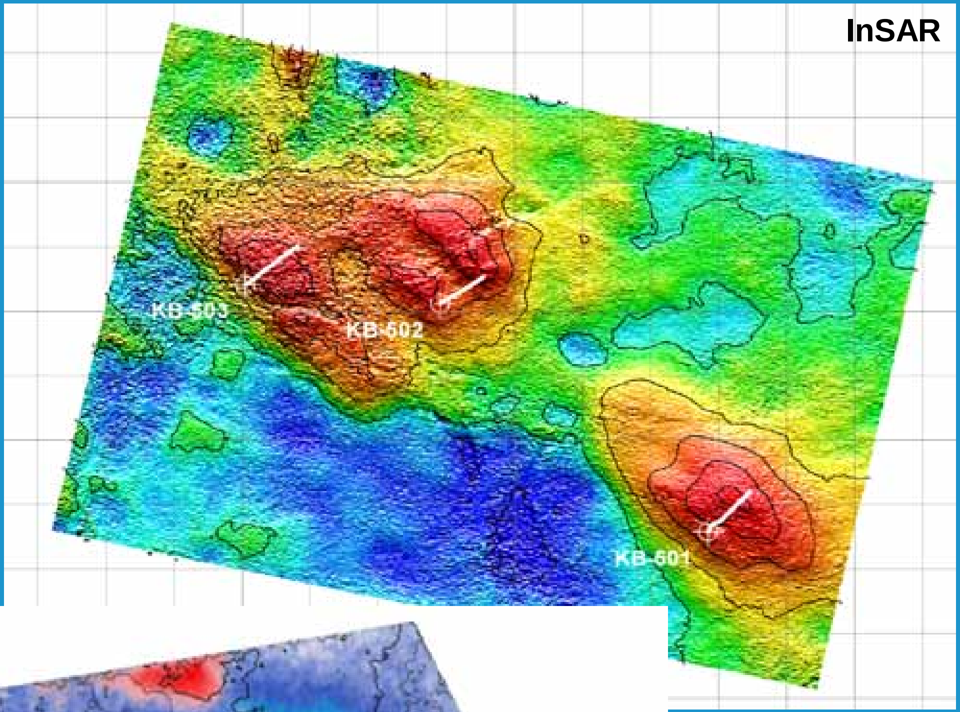


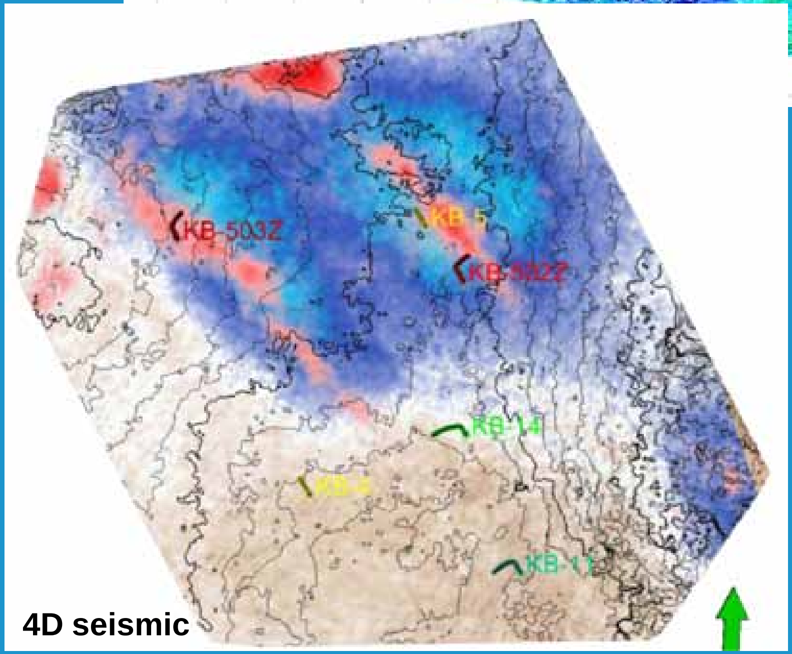
Three CO_2 injectors: Kb-501, 502 and 503

3 Mt CO_2 have been injected since 2004

Multiple deep and shallow-focussed tools

Mixed Monitoring at In Salah (2)





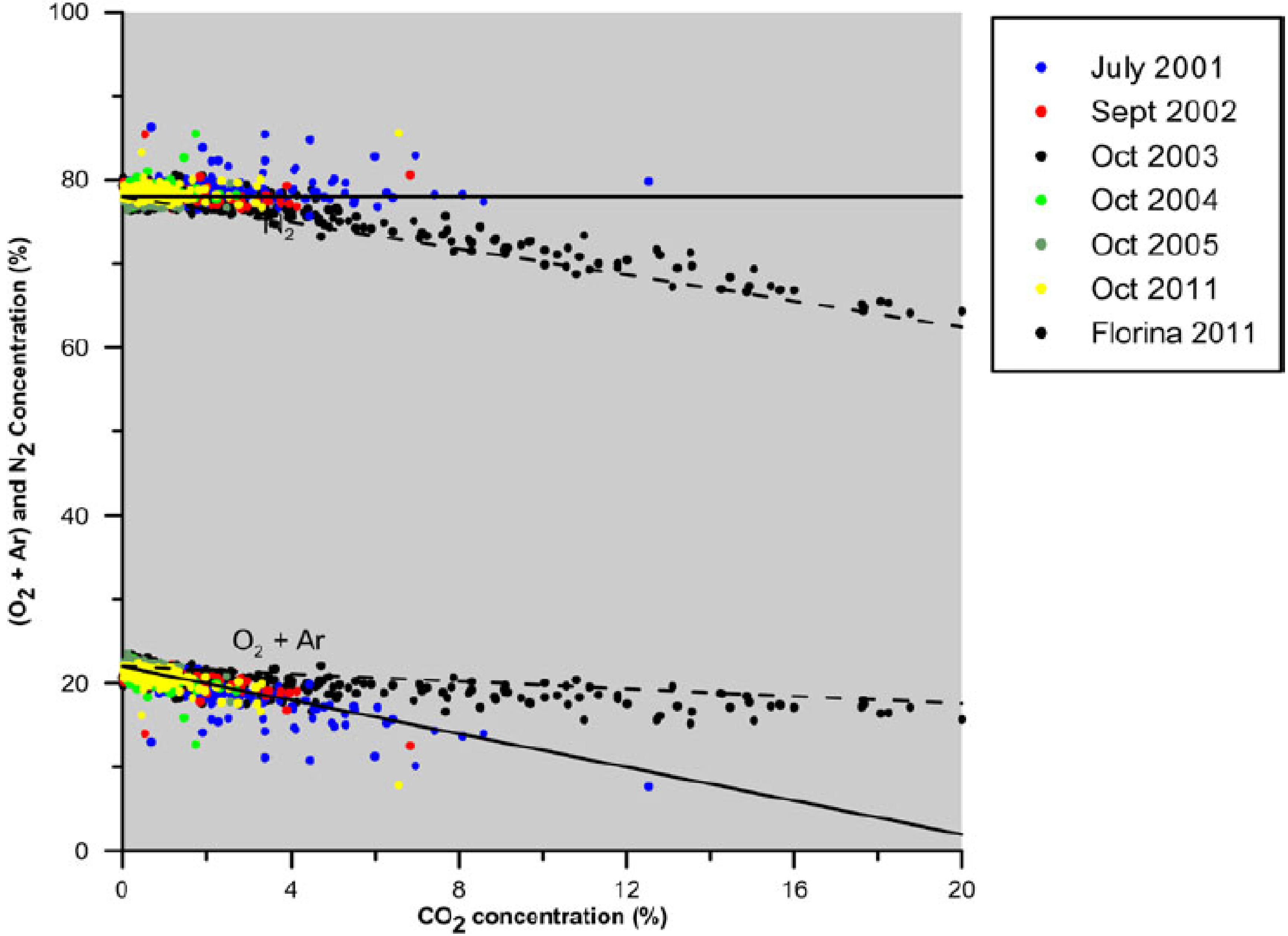
Correlation between surface displacements (mm-scale) and seismic changes at depth

Mixed Monitoring at In Salah (3)

ecosystems

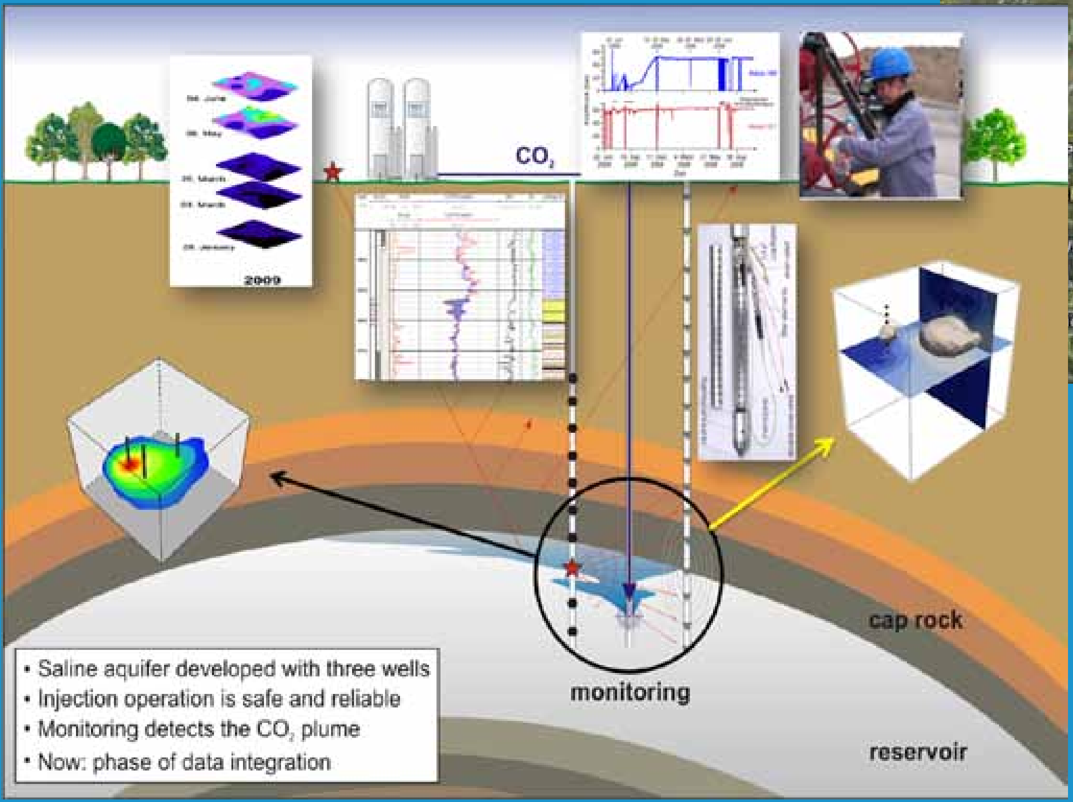
surface gas flux and soil gas

atmospheric concentrations



100
80
60
40
20
0
0
4
8
12
16
20
CO2 concentration (%)
(O2 + Ar) and N2 Concentration (%)
N2
O2 + Ar
July 2001
Sept 2002
Oct 2003
Oct 2004
Oct 2005
Oct 2011
Florina 2011

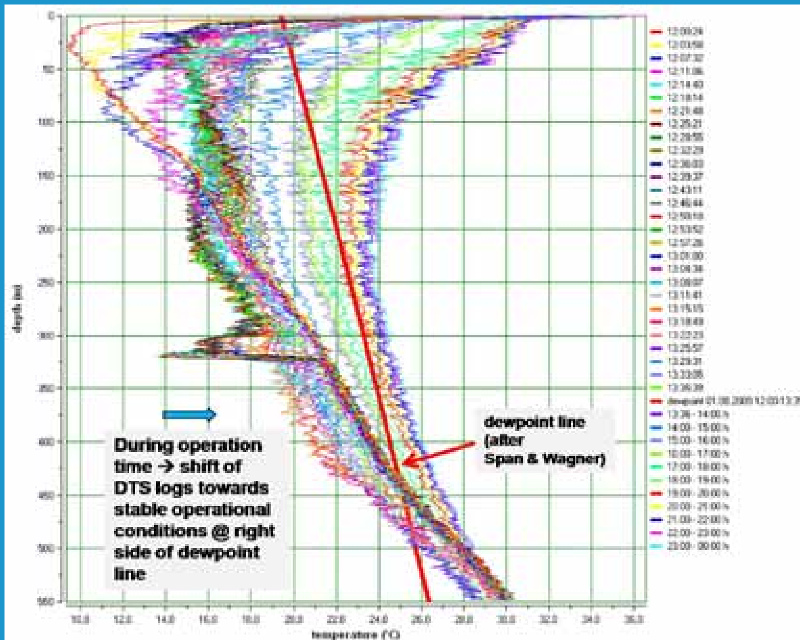
Pilot-scale laboratories: Ketzin (1)



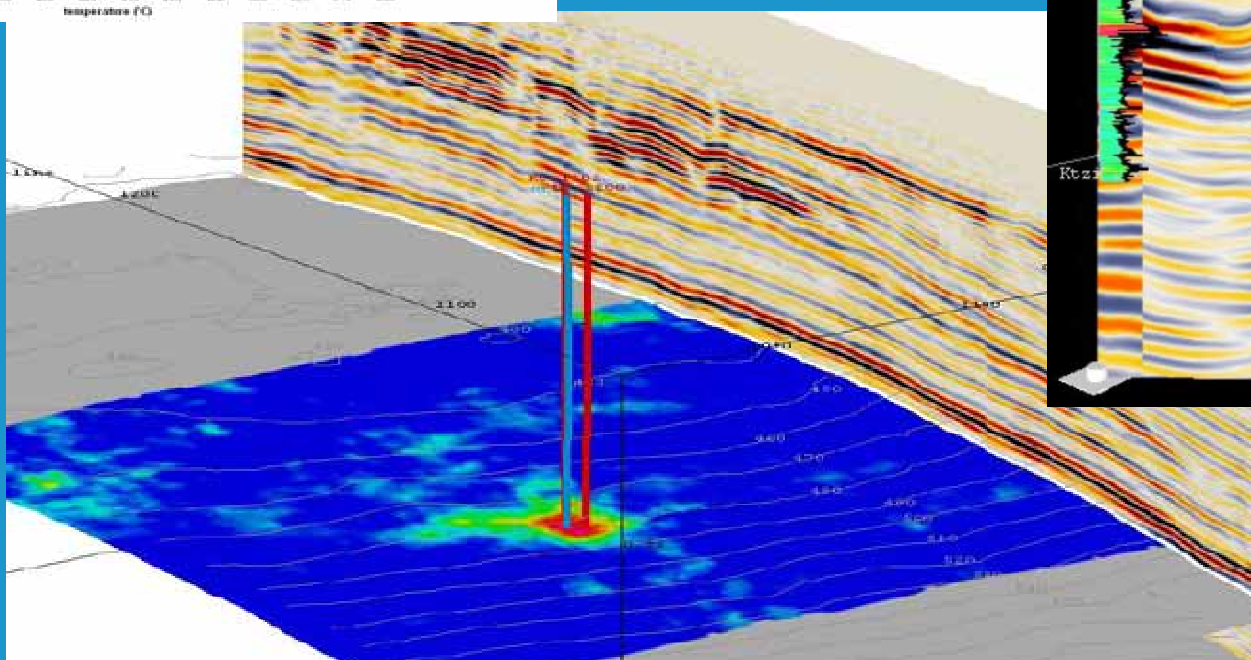
Multiple tools from other projects

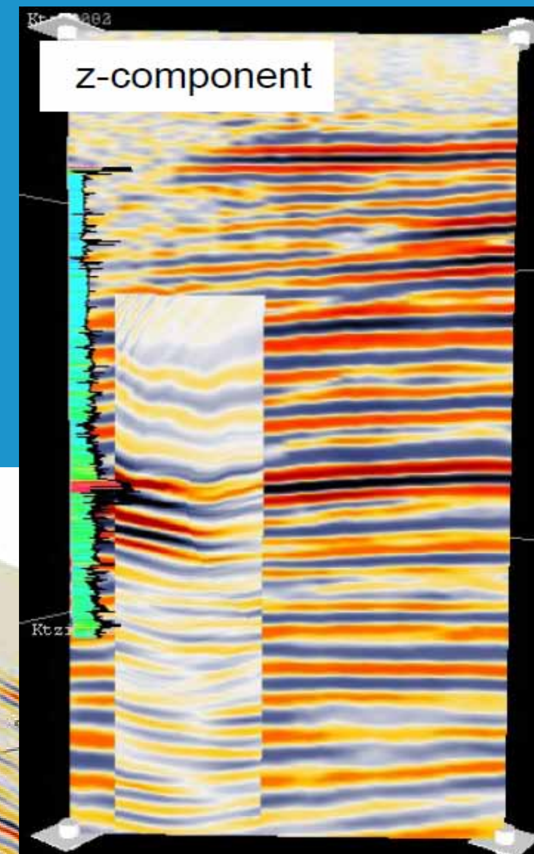
- *2D & 3D surface seismic*
- *VSP*
- *2D-MSP*
- *3D- MSP*
- *Cross – hole*
- *Electrical Resistance Tomography*
- *Borehole-surface EM*
- *Surface monitoring ……*

Pilot-scale laboratories: Ketzin (2)



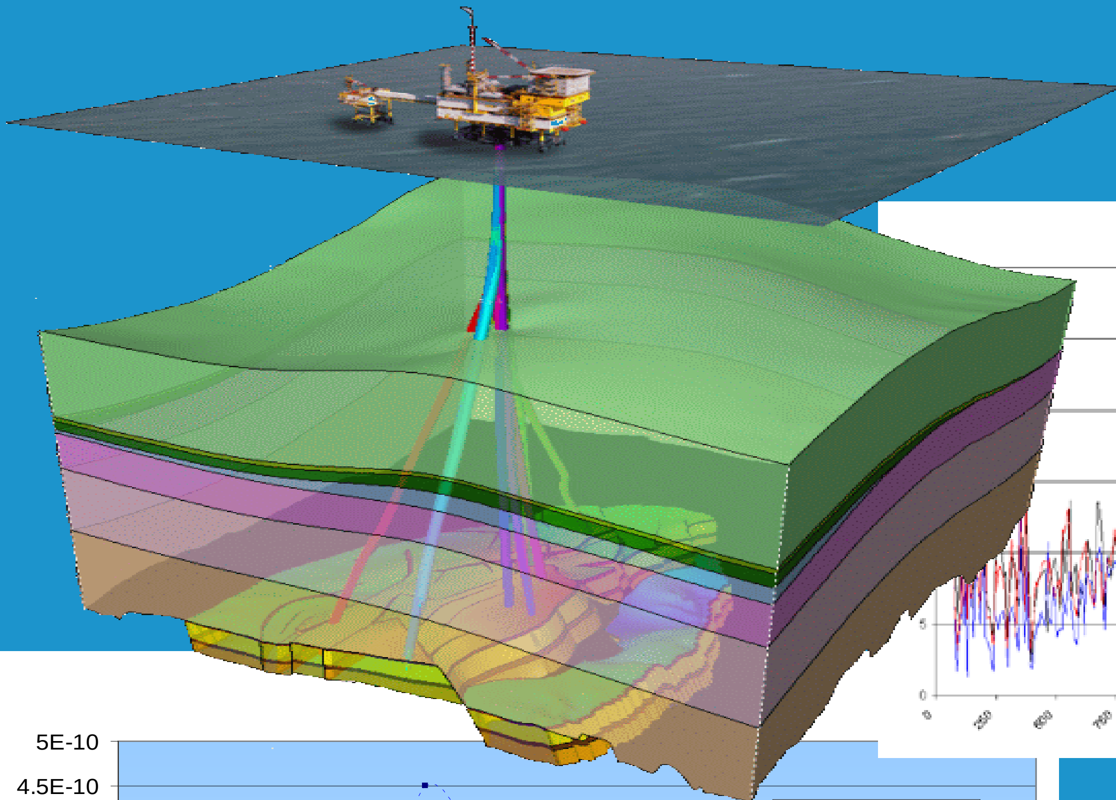
Distributed (downhole) temperature sensor

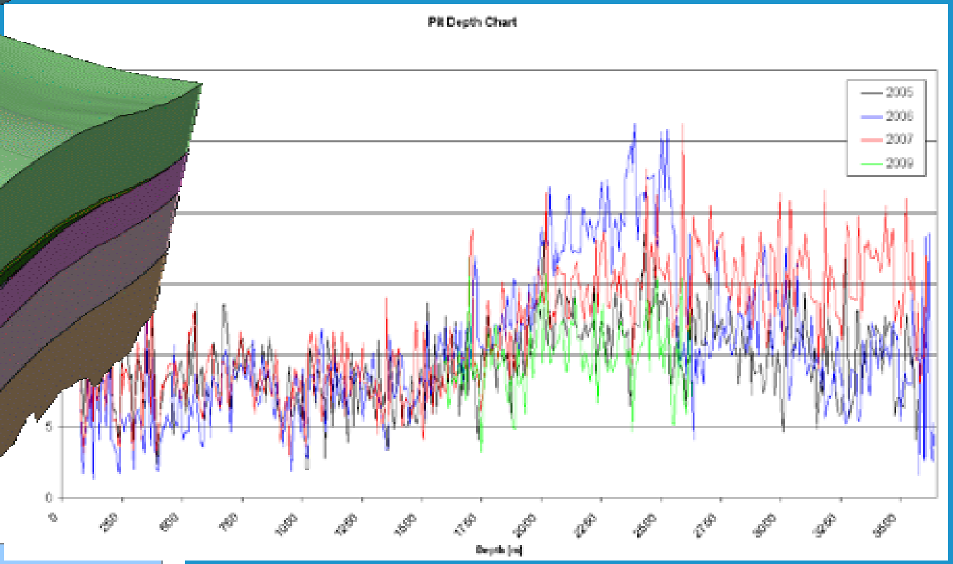




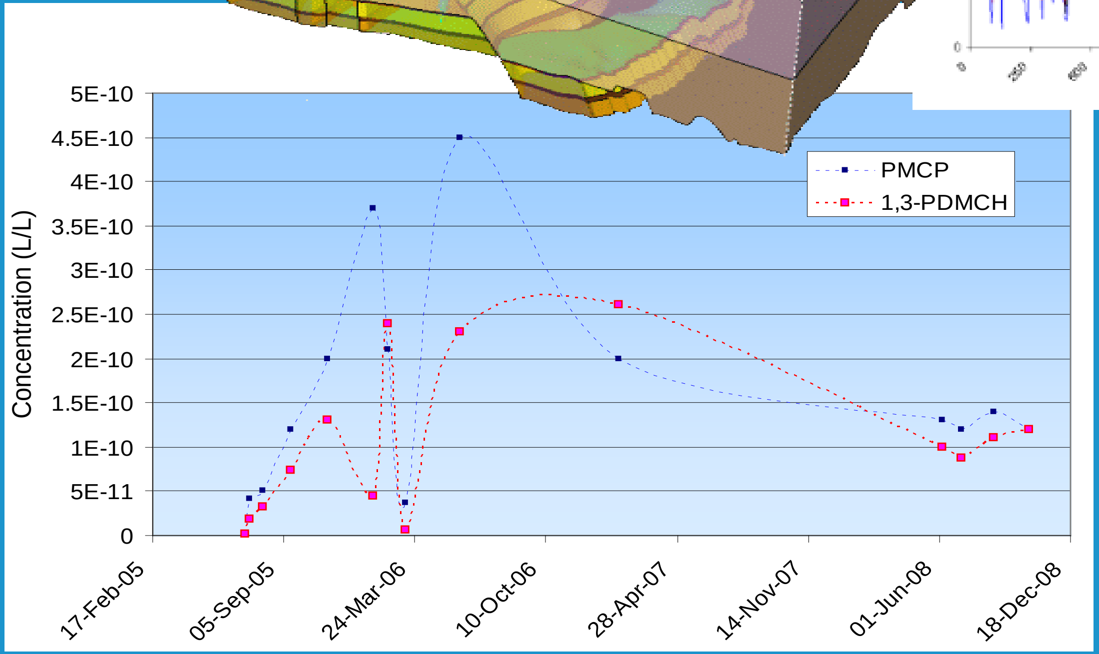
VSP

Pilot-scale laboratories: K12-B



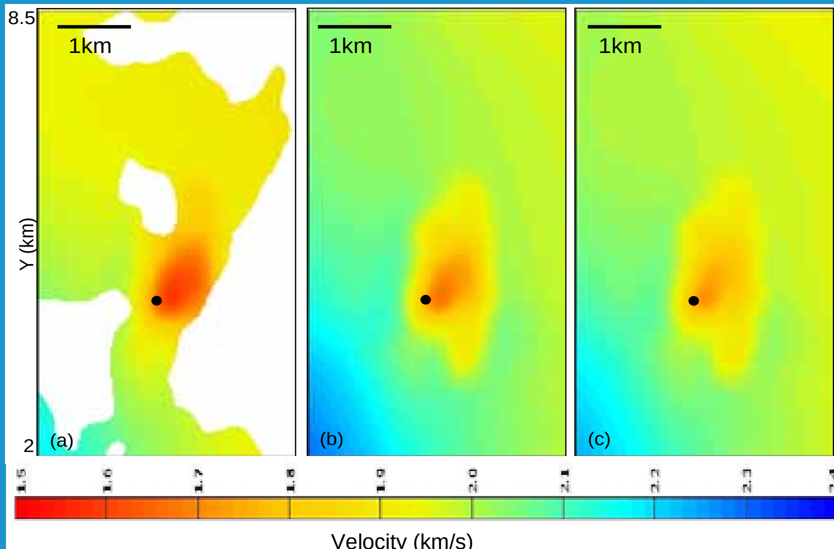


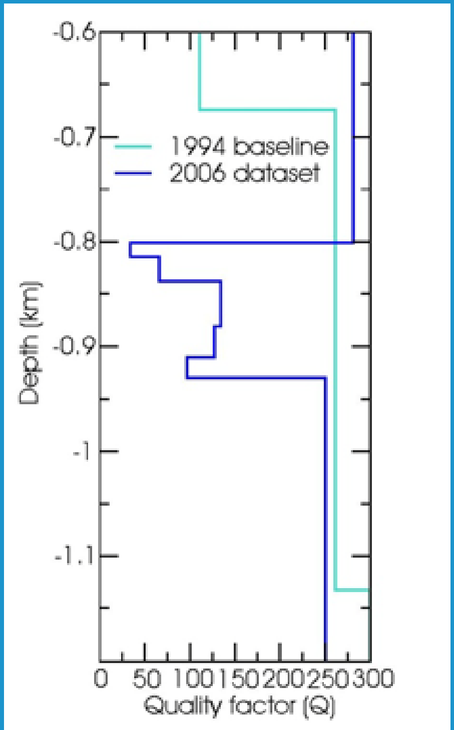
Wellbore integrity

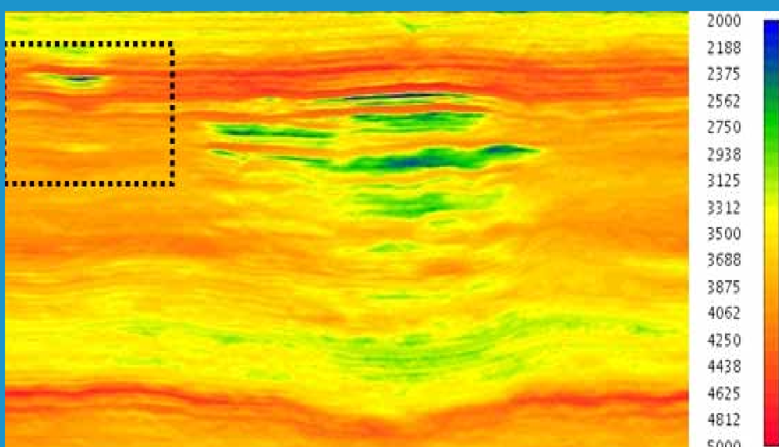


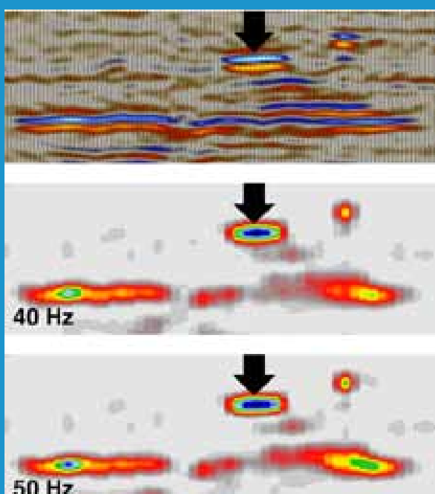
History-matching from tracer breakthrough

Innovative tools (1): Seismic methods





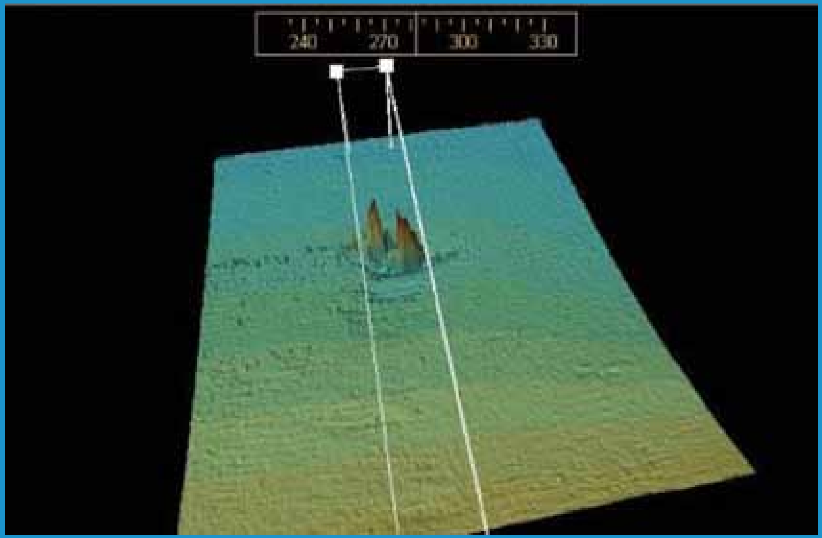




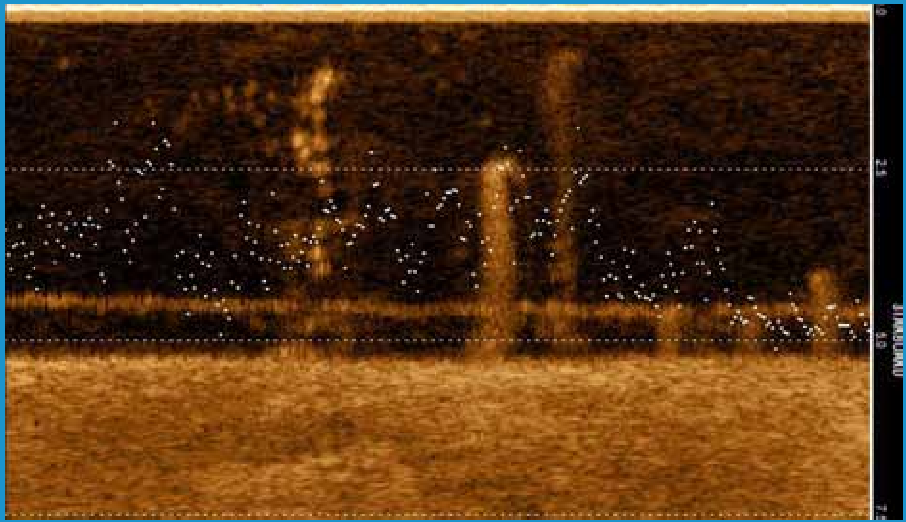
Trace inversion, amplitude-offset studies , thin layer tuning, velocity and attenuation tomography

Also research into passive seismics and electrical methods

Innovative Tools (2): Emissions monitoring (offshore)



seawater chemistry



CO_2 bubble-stream imaging

seabed gas sampling

Monitoring Strategies

Importance of baselines

Key tools

Cost-effective monitoring programmes

Key Monitoring Messages

Baselines – Weyburn

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IN PICTURES

Carbon capture leak forces Saskatchewan couple to leave farm

Published Tuesday, Jan. 11, 2011 6:12PM EST

Pair abandon Saskatchewan farm because of blowouts, dead animals and algae

CO2 leaks worry Sask. farmers

Last Updated: Tuesday, January 11, 2011 | 8:45 PM ET The Canadian Press

A Saskatchewan farm couple says greenhouse gases that were supposed to be stored permanently underground are leaking out, killing animals and sending groundwater foaming to the surface like shaken-up soda pop.

Cameron and Jane Kerr took this picture of what they say is gas bubbling from water on their property.

Couple says CO2 leaking 1:49

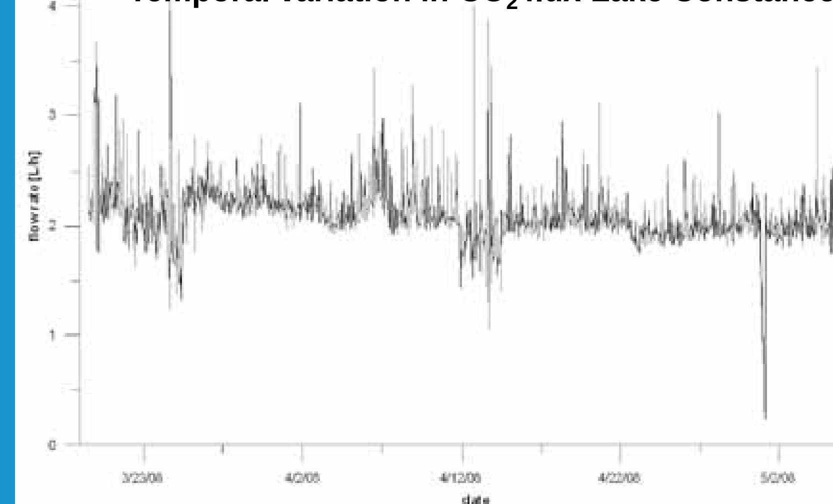
Cameron and Jane Kerr, who own land above the Weyburn oilfield in eastern Saskatchewan, have released a consultant's report that claims to link high concentrations of carbon dioxide in their soil to gas injected underground every day.

"We've lost a home, we've got a back yard full of sand and gravel that we don't think we can sell," Cameron Kerr told CBC News Tuesday.

Energy giant Cenovus injects 8,000 tonnes of the gas every day in an attempt to enhance oil recovery and fight climate change.

Cameron Kerr says ponds on his land have developed algae blooms, clots of foam and scum, while small animals have been found dead a few metres away.

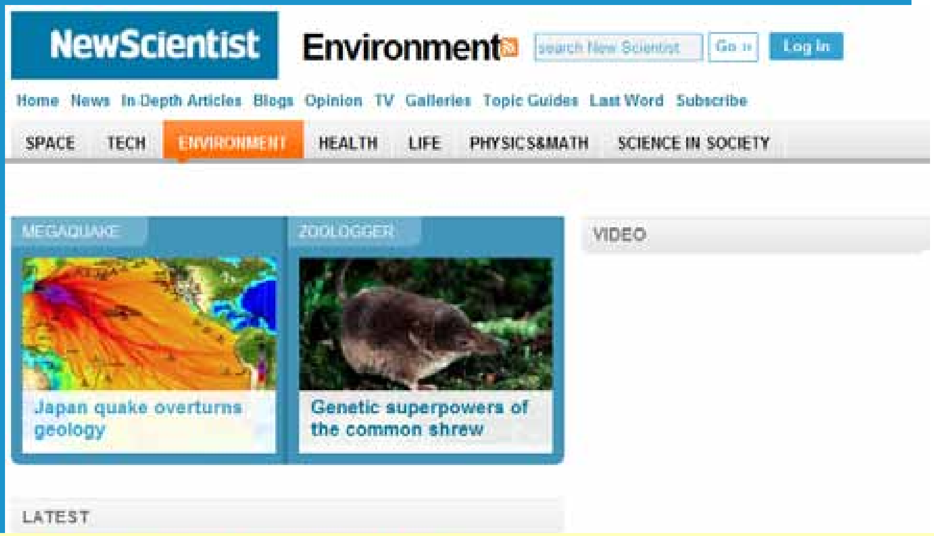
A consultant found high concentrations of carbon dioxide in the soil that matches the carbon dioxide Cenovus has been injecting, he says.



Temporal variation in CO_2 flux Lake Constance

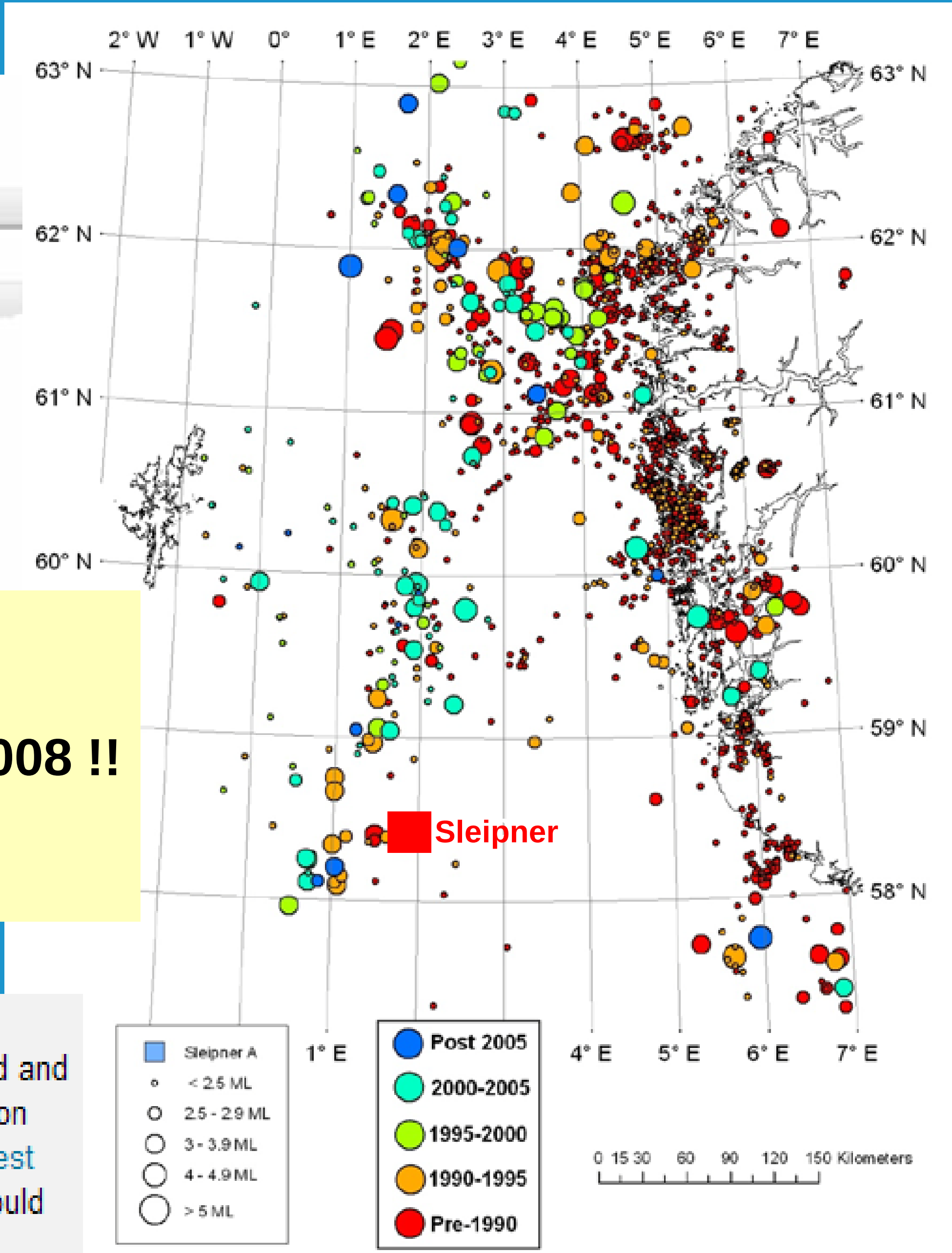
Need to capture full natural variation/range

Baselines – Sleipner



New Scientist …… September 2009

Induced earthquake at Sleipner in 2008 !!
Magnitude 4
Tsunami risk ??



Bury the carbon, set off a quake?

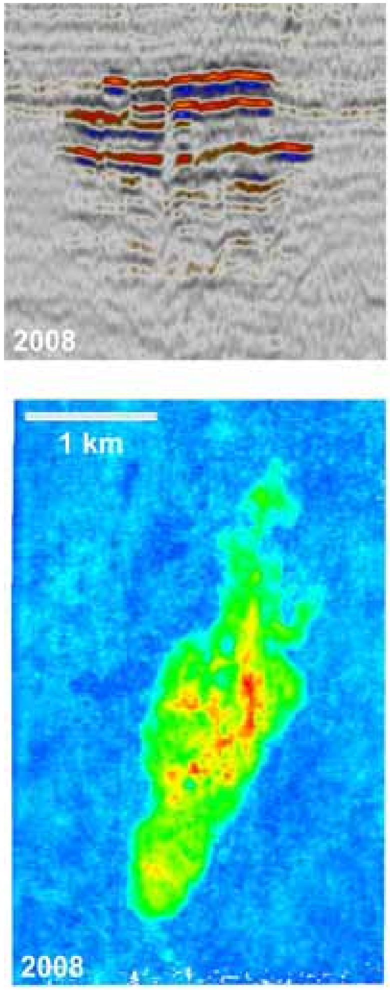
It all looked so promising - tidy carbon dioxide away underground and forget about it. But even as the US's first large-scale sequestration operation is getting off the ground at the Mountaineer plant in West Virginia, geophysicists are concerned that burying the carbon could trigger earthquakes and tsunamis.

Potential monitoring tools: world deployments

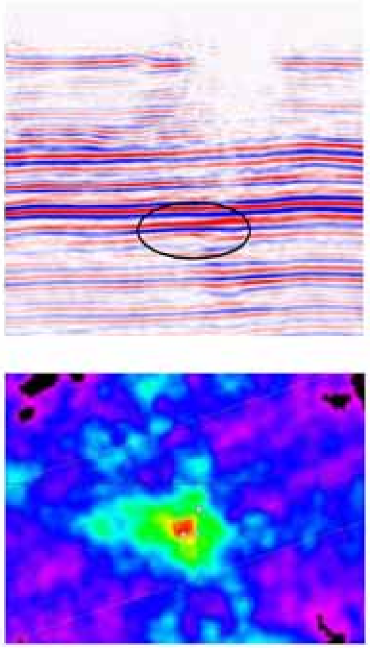
	Sleipner	Snovit	K12-B	In Salah	Ketzin	Kaniow	Weyburn	Innovative tools	Nagaoka	Otway	Frio	Cranfield
	offshore (~900m)	offshore (~2700m)	offshore (~3800 m)	onshore (~1900m)	onshore (~600m)	onshore (~1100m)	onshore (~1400m)	onshore and offshore	onshore (~1100m)	onshore (~2100 m)	onshore (~1500m)	onshore (~3100 m)
Deep-focussed												
3D/4D surface seismic	■	■		■	□		□	■	□	□		
2D surface seismic	■	■						■				
Gravity surface	■											
Seabed CSEM	■											
Wellhead P,T	■		■		□		□		□			
Wellhead/annulus sampling				■								
Downhole P,T		■	■	■	□		□		□	□		□
Continuous temperature (DTS)		■	■		■							
Geophysical logs			■	□	□		□		□			
Crosshole seismics							□		□		□	□
Downhole fluid chemistry			■		□		□	■	□	□	□	□
Micro (passive) seismics				■	■		□			□		□
Electromagnetic wellbore					■						□	
Electromagnetic surface					■							
Spontaneous potential								■				
Tracers			■	□	□					□	□	□
Monitoring shallow aquifers				■				■		□		
Downhole well integrity			■							□		
VSP / MSP					■		□			□		
Electrical Resistivity Tomography					■							□
InSAR				■								
Shallow-focussed												
Multibeam echosounding	■							■				
Sidescan sonar	■											
Tiltmeters				■								
Bubble-stream detection								■				
Bubble-stream chemistry								■				
Soil gas/surface flux				■			■	■		□		□
Flux towers (eddy covariance)							■	■		□		
Passive detectors				■			■	■		□		
Ecosystem (including biomarkers)	■			■								
Microbiology				■	□							
Seabottom ROV video	■											
Deployed/analysed in CO2ReMoVe	■											
Deployed/analysed in other projects	□											

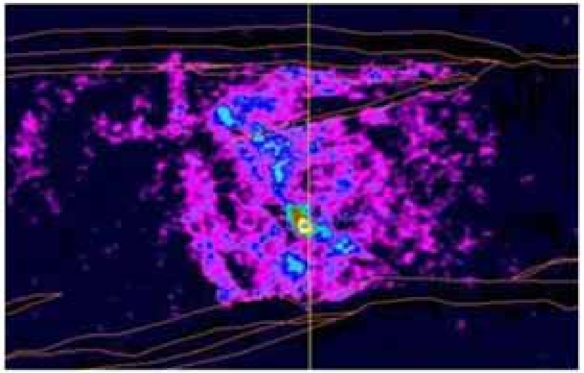
- Some tools are effective, some are not
- Some tools require dedicated infrastructure (e.g instrumented wellbores)
- Can verify performance predictions at pilot-scale
- Many not realistic / viable at industrial scale

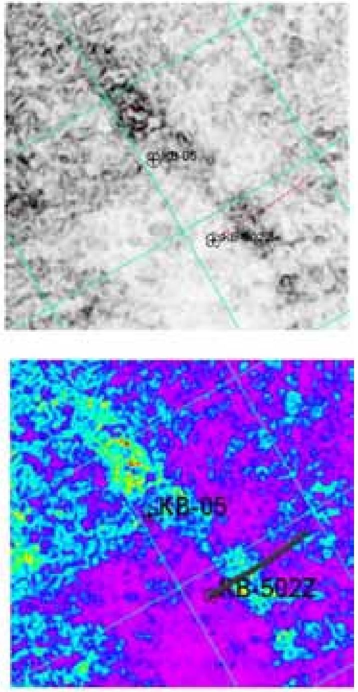
Key deep-focussed tools (3D time-lapse seismic)



Sleipner
Offshore: 800m

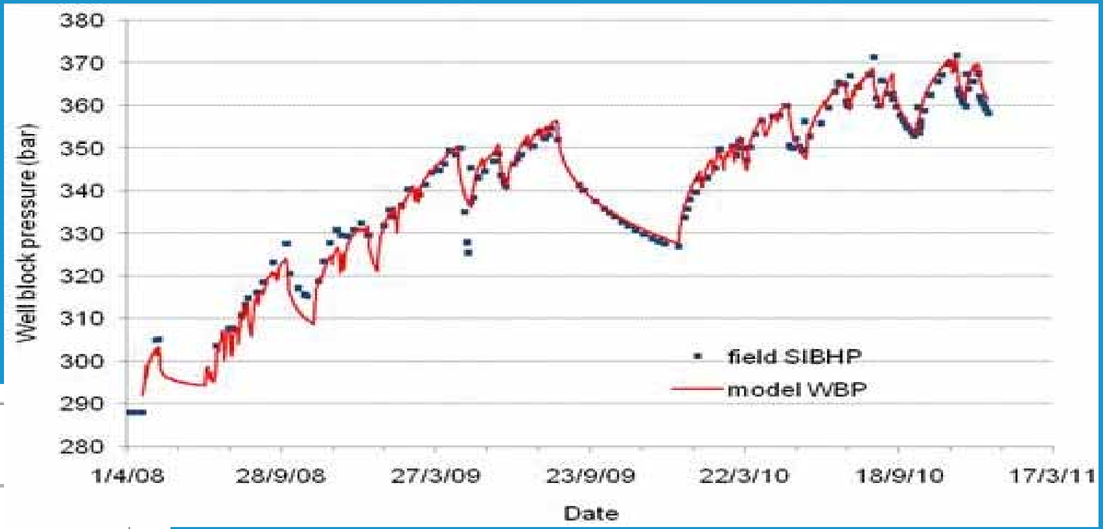

Ketzin
Onshore: 630m


Snohvit
Offshore: 2700 m

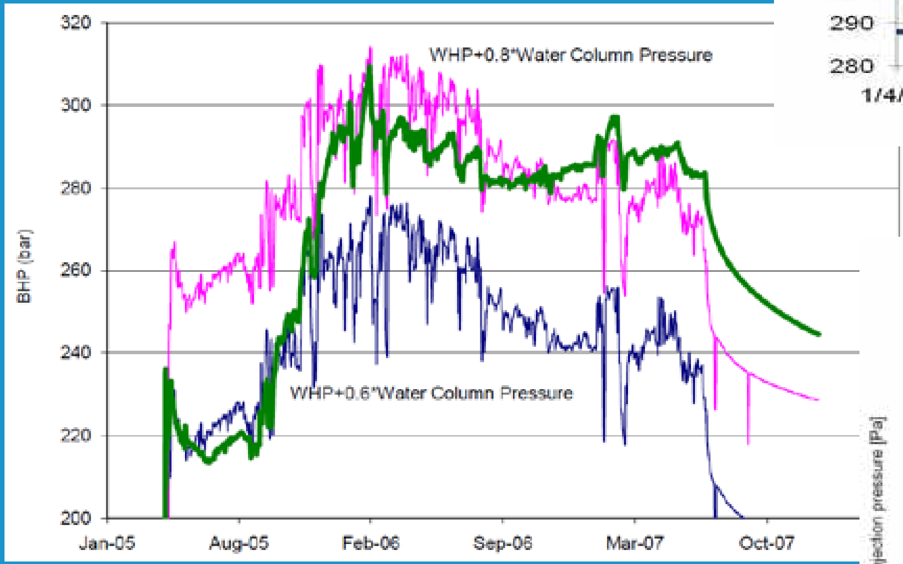


In Salah
Onshore: 1950m

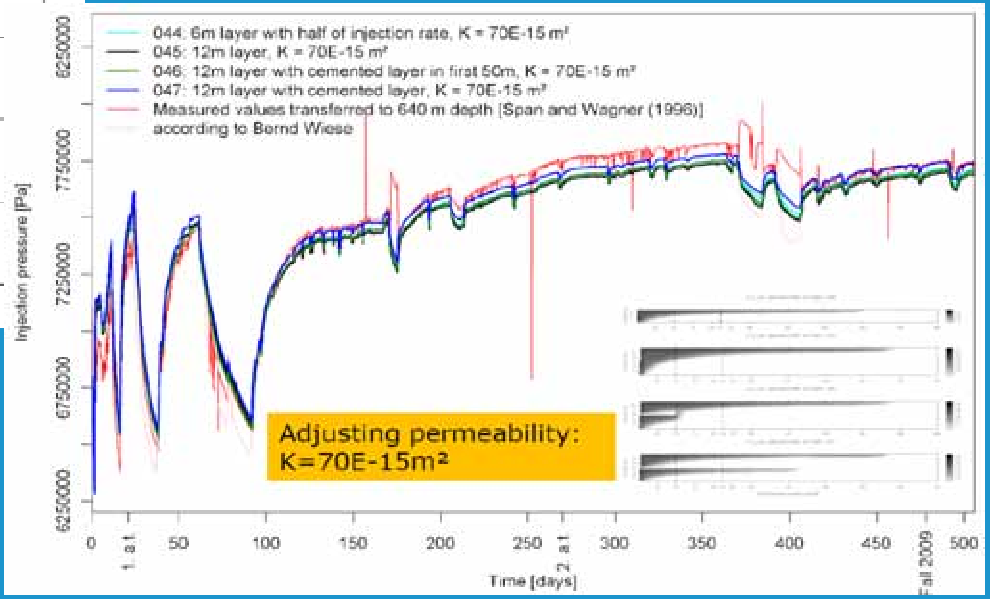
Key deep-focussed tools (reservoir pressure)



Snohvit (downhole)



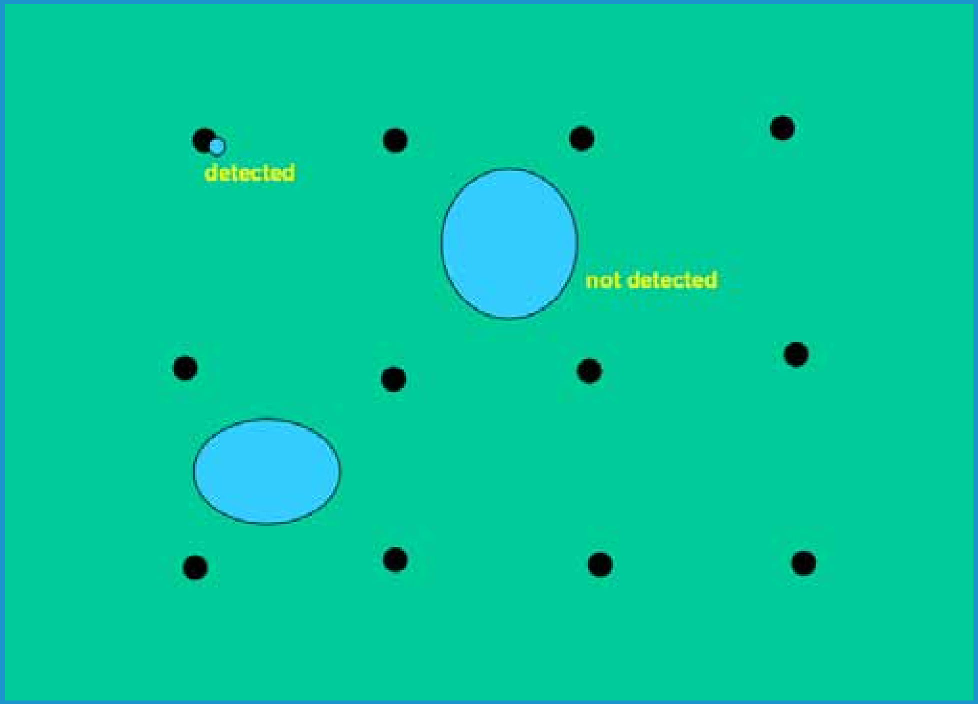
In Salah (wellhead)



Ketzin (downhole)

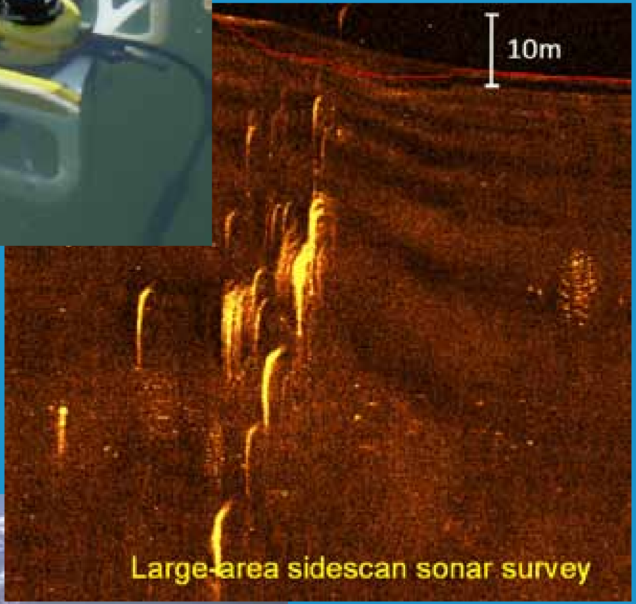
Plus e.g. Cranfield (reservoir + overburden)

Shallow-focussed methodologies (1)



Need pointwise + spatial measurements

Shallow-focussed methodologies (2)



Spatial and point measurements

Cost-effective monitoring systems

HIGH-LEVEL OBJECTIVES

- Assurance of integrity and safety
- Address identified risks
- Verify (predictive) performance models
- Detect leakage (from the Storage Complex)
- Confirm permanent containment within the Storage Complex
- Quantify emissions if leakage detected

SPECIFIC OBJECTIVES

- Plume imaging in the reservoir
- CO_2 migration in the overburden (storage complex)
- Predictive model calibration and verification
- Storage processes and efficiency
- Topseal integrity
- Leakage warning and detection
- Emissions measurement
- Public acceptance

The Core Monitoring Programme

To meet the regulatory requirements of a conforming site (i.e. one that behaves as expected during its lifetime).

It is aimed at performance verification, the monitoring and management of any site-specific containment risks identified in the Framework for Risk Assessment and Management (FRAM) and the detection of performance irregularities including early warning of potential leakage.

MONITORING THAT WILL BE CARRIED OUT AS PART OF ROUTINE SITE OPERATION

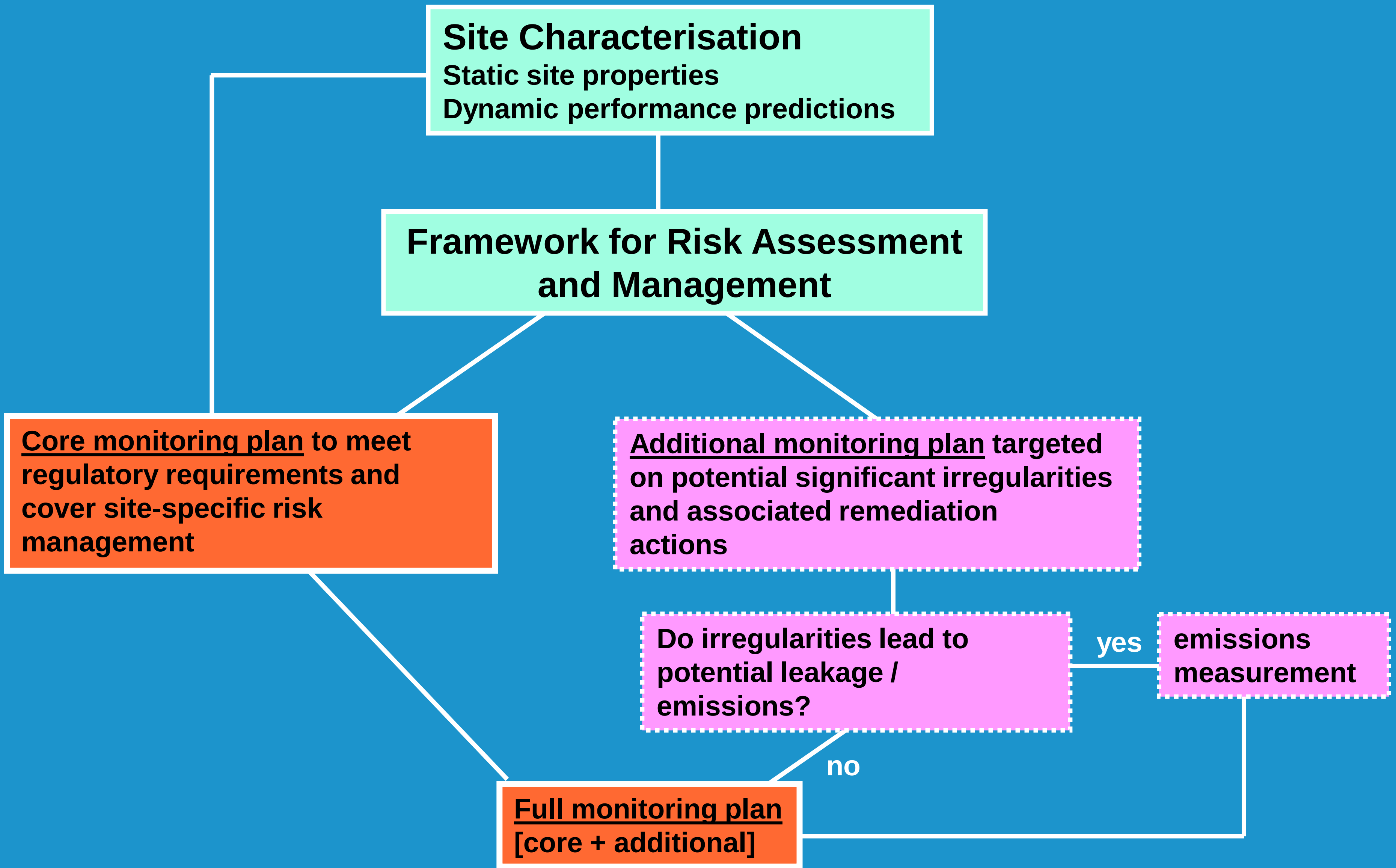
The Additional Monitoring Programme

To meet the requirements of a storage site that does not perform as expected i.e. one in which irregularities have become significant.

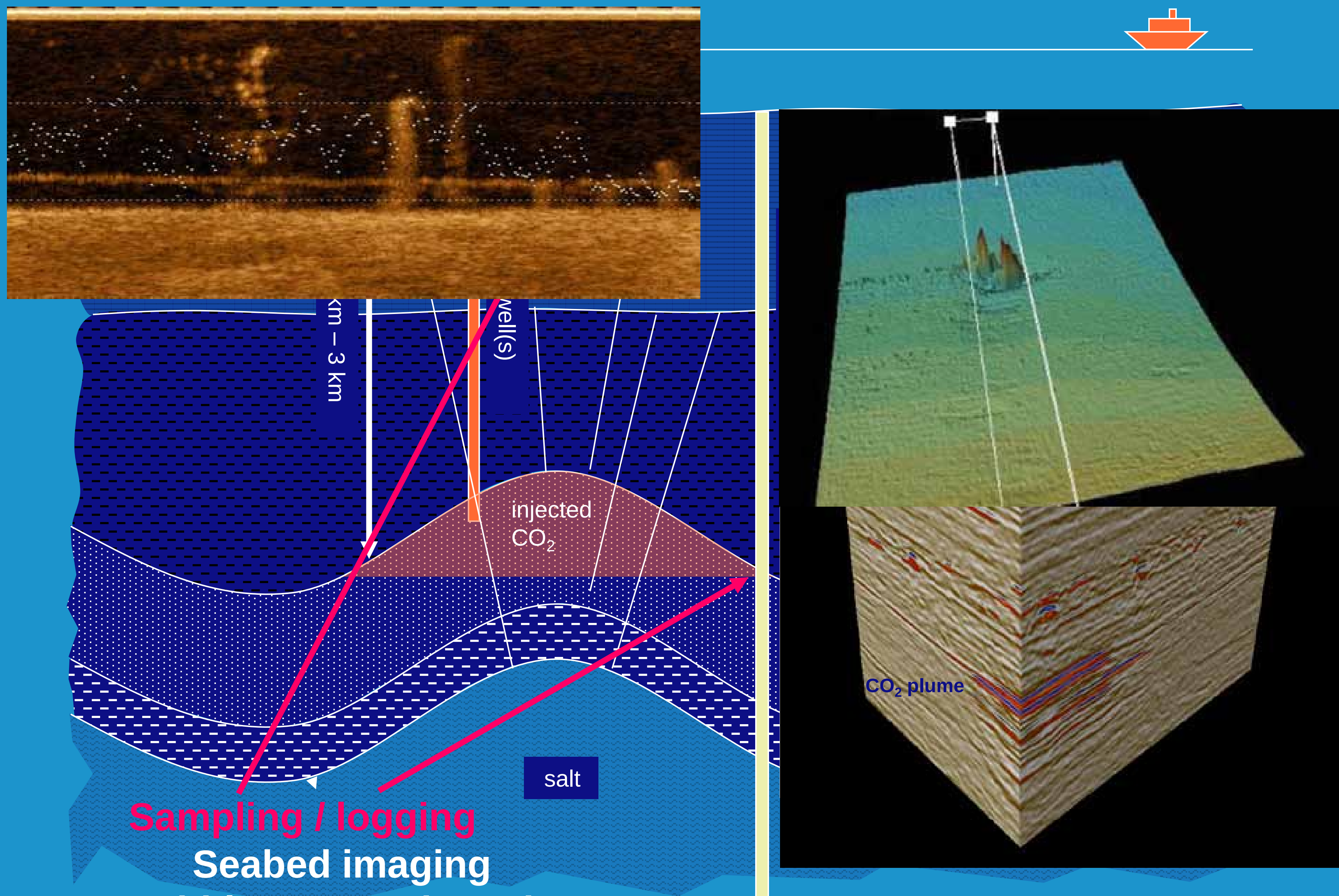
Address possible range of significant irregularities and the needs of any associated remediation actions.

PORTFOLIO OF TOOLS HELD IN RESERVE FOR USE IN THE EVENT OF A SIGNIFICANT IRREGULARITY

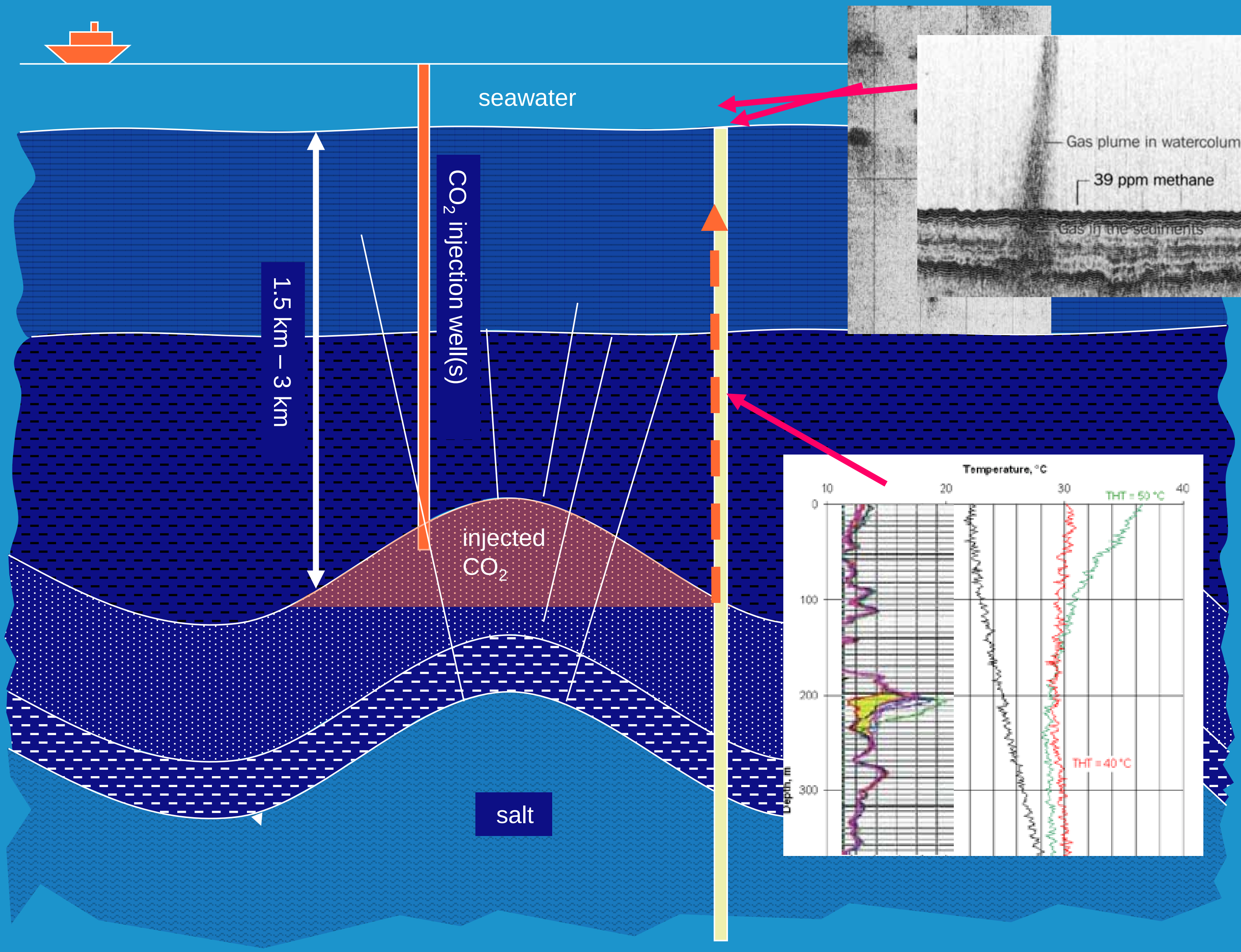
Monitoring Strategy flowchart



Typical offshore storage site - Core Monitoring



Typical offshore storage site - Additional Monitoring: Leakage



Typical offshore storage site - Additional Monitoring: Emissions

Key monitoring findings

Monitored site performance always deviates from predictions

- Key is to establish what constitutes an acceptable deviation and demonstrate convergence of prediction and observations with time

Robust monitoring baseline datasets key to effective performance verification.

- Weyburn (shallow monitoring baseline proved worth)
- In Salah (lack of satisfactory 3D seismic baseline significant drawback)

Different monitored parameters can be used to verify performance depending on site characteristics

- Sleipner – plume migration and overburden imaging
- In Salah – pressure and surface displacement
- Snohvit – pressure and plume migration

For deep-focussed assurance (particularly offshore) a limited portfolio of monitoring tools is likely to be required

- Sleipner – seismic, seabed imaging, but we need robust site characterisation
- Snohvit – pressure and seismic

Shallow-focussed assurance needs to establish emissions and also environmental baselines

Emissions measurement (if required) is very challenging

- Point and areal measurements
- Precise quantification likely to be impossible
- Integrate measurements with leakage models to provide quantification

Focussed wholly on regulatory requirements

Acknowledgements

- CO_2ReMoVe project (EC FP6)

http://www.co2remove.eu/

Project Reference: 518350
Contract Type: Integrated Project
Start Date: 2006-03-01
End Date: 2012-02-29