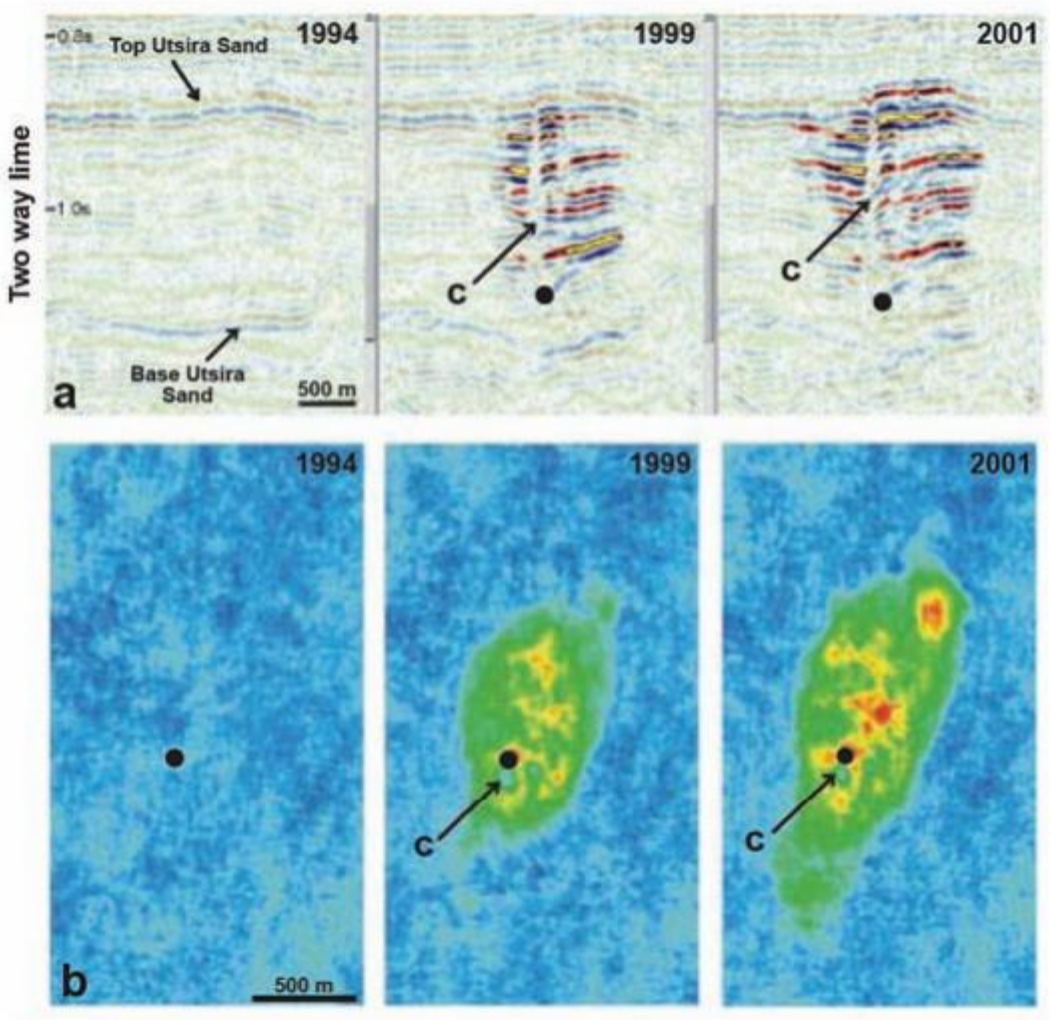
Making a plan to monitor CO2 storage

Robert Hines
Principal Advisor - CCUS, Inosys

Thinking Deeper. Going Further.

M +44 7778 475873 | **E** robert.hines@inosys.co.uk | **W** inosys.co.uk
A 11 Laura Place, Bath, BA2 4BL

Goal of Monitoring, Measurement and Verification

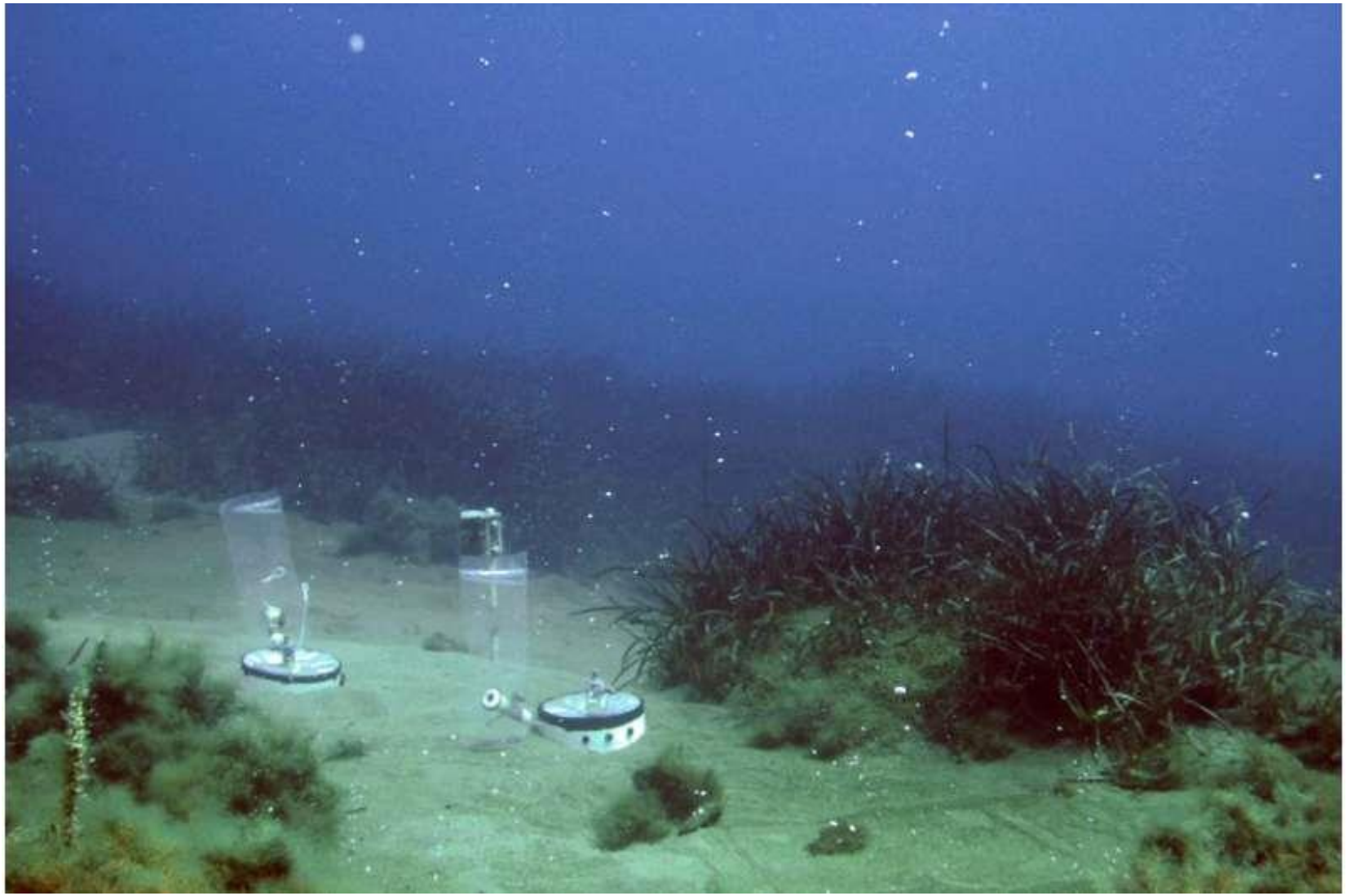


Plume migration at Sleipnir, Arts et al, (2004)

The main goals of a MMV plan can be summarised using the terms **containment, conformance**, and **confidence.**

- **Containment:** provide evidence for the absence of containment issues to stakeholders or trigger early intervention if needed.
- **Conformance:** forward models are consistent with monitoring data to demonstrate the long-term behaviour of the CO_2 is understood.
- **Confidence:** provide data for emission accounting, support storage transfer of long-term liabilities and maintain License to Operate (LtO).

Shallow Monitoring

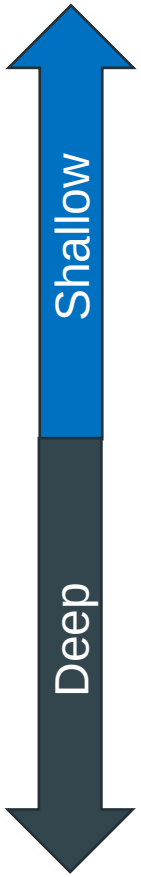


Natural CO2-venting sites off the coast of Panarea, Italy.
Credit: HYDRA/C. Lott (via phys.org)

Making a plan to monitor CO2 storage

Contents

Development and In-Service techniques



Site Characterisation

Integrity Monitoring

Oceanographic

- EIA
- Metocean
- Water column baseline
  - Dissolved CO2
  - pH
  - Phosphates
- MBES – Pockmarks, natural seeps

- Monitoring landers
  - Water chemistry
  - Acoustic leak detection
- EIA
  - Monitor wildlife changes
- Repeat MBES surveys
- Sediment sampling

Geological

- Construction survey
- Deep seismic
  - Appraisal
  - Containment
- Outcropping identification
- Plume modelling
- Risk profile

- 4D seismic
  - Towed arrays > OBNs
  - Plume migration
- Risk areas/features

UK Development Programmes – Shallow Monitoring

2012

Quantifying and Monitoring Potential Ecosystem Impacts of Geological Carbon Storage

- Academic first look at CO2 behaviour in a marine environment
- 4200 kg of CO2 over 37 days
- 10 - 210 kg/day
- Inshore, injected 11m below seafloor

A novel sub-seabed CO2 release experiment informing monitoring and impact assessment for geological carbon storage, Taylor et al., 2015

Strategies for Environmental Monitoring of Marine Carbon Capture and Storage

- Academic/ applied research in a representative environment (Goldeneye)
- 675 kg of CO2
- 6 – 143 kg/day
- Injected 3m below seafloor

Towards improved monitoring of offshore carbon storage: A real-world field experiment detecting a controlled sub-seafloor CO2 release, Flohr et al., 2021

Energy Technologies Institute – Measuring Monitoring and Verification

- Commercial system development for CCS competition
- 10 – 50 L/min ~ 27 – 136 kg/day
- Released via a nozzle so a very ‘clean’ plume

Insights and guidance for offshore CO2 storage monitoring based on the QICS, ETI MMV, and STEMM-CCS projects, Dean et al., 2020

UK Development Programmes - Comments

Confident in water column monitoring system performance

Good gaseous phase detection

Reasonably unconvinced about areal search chemical detection application for site monitoring.

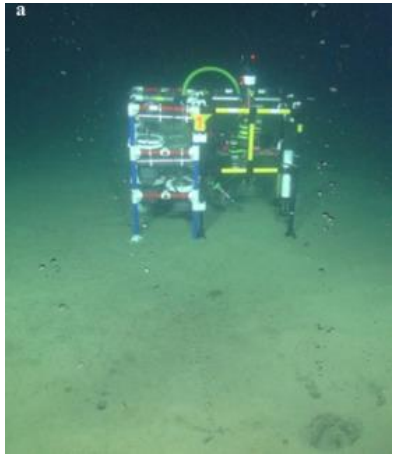
- QICS ‘During the release phase, CO2 enriched pore waters were observed close to the sediment–water interface (Lichtschlag et al., 2014)’
- ETI, inconclusive – detections could be inferred after the fact but did not cross automatic detection thresholds
- STEMM-CCS, not detected on an AUV search but targeted sampling did show differences across measured parameters

Lots of water, not much CO2. 2.7 tonnes/day allowable under legislation

CO2 is highly dissolvable

It provokes ‘natural damping’ such as photosynthesis

QICS. Taylor et al., 2015.

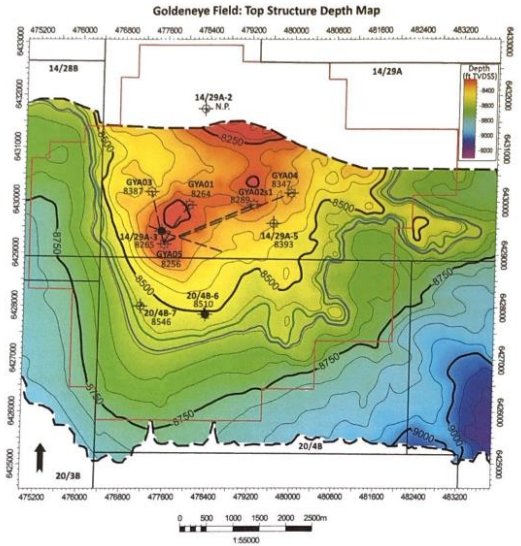


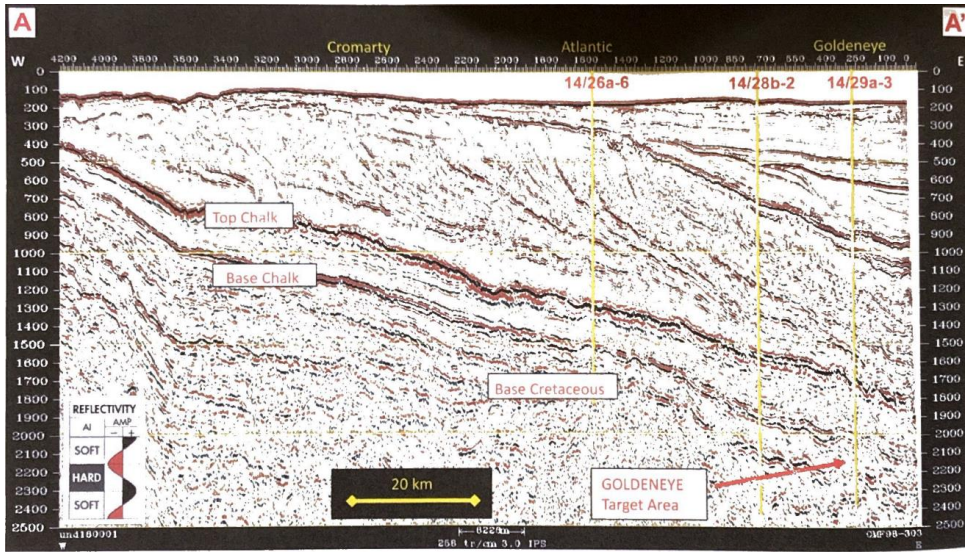
STEMM-CCS. Flohr et al., 2021
Leak rate of 86 kg/day

UK Development Programmes - Comments

Will we see gaseous phase at all? Will we be looking in the right area?

QICS observed only 15% of CO2 emerging from the seafloor, the rest staying in the sediment (Berges et al., 2014)





Both from. The Goldeneye Field, Blocks 14/29a and 20/4b, UK North Sea. Stewart and Marshall, 2020

- **Ch**aracteri**s**ation of **m**ajor overburde**n** l**e**akage pathwa**y**s 'CHIMNEY' - Large-scale chimneys (~100−1000 m wide) are therefore hypothesised to represent a series of interconnected sub-vertical or radial fractures, which allow the vertical flow of gas in the shallow subsurface (Bull et al., 2018)

- 'No Continuous pathways for the escape of CO2 to surface have been identified', (Marshall et al., 2017)

Issues with Shallow Monitoring

Questions not yet answered through trials

- **What advantages are there over deep monitoring that gives an earlier indication of problems?**
- **How much confidence is there in gaseous phase CO2 being present at the seabed given the supercritical phase in the store and diffusion/dissolution in overburden?**
- **How much confidence is there in chemical detection given no conclusive experimental evidence of success yet?**

Is it even fit for purpose?

Monitoring Options – Deep Monitoring

Sub-bottom options may be more suitable for wide area monitoring……

- Sleipner - ‘The Utsira Formation is a 200-250 meters thick massive sandstone. It is estimated that the Utsira Formation is capable of storing 600 billion tons of CO2. 3D seismic monitoring of the CO2 injection into the Utsira Formation shows that there is no leakage of the CO2 into other horizons.’
- Towed arrays
- Ocean-Bottom Nodes
- Gravimetric Monitoring

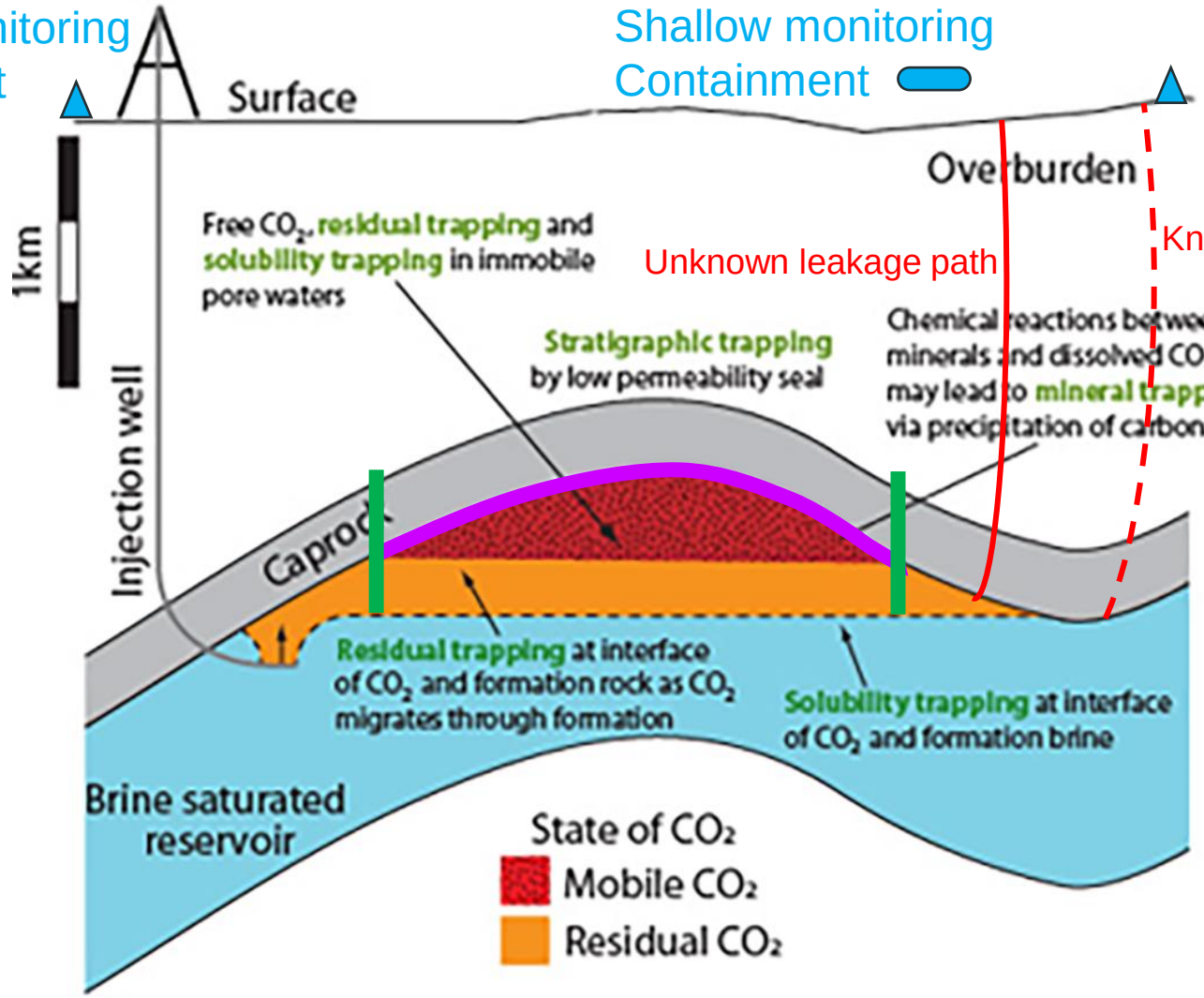
Monitoring Options

Trade-off and Layered Capabilities

Shallow monitoring
Containment

Shallow monitoring
Containment

Shallow monitoring
Containment/Conformance



Deep monitoring
Containment

Deep monitoring
Conformance

Credit: UKCCSRC

Conclusions

There are a number of technically mature options for monitoring offshore CO2 storage sites, which will be able to support operations in the near future.

Due to the differences between each store the monitoring approach will need to be matched to the risk profile of the store.

Water column monitoring may be used for continuous monitoring of infrastructure and high risk areas, but is unlikely to be the solution for wide area monitoring of the store.

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