‘An emerging solution for an emerging CCS market: Fugro’s Seismic Resolution Uplift – A Cost Effective Shallow CO₂ Monitoring Strategy?’

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Today’s presenter

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Education
• 2010 - BSc Geophysics - Edinburgh Uni
• 2011 – MSc Carbon Capture and Storage - Edinburgh Uni

Supervisory Geophysicist (Fugro - GeoConsultancy)
• PO Fugro Joint Seismic inversion Initiative
• Fugro-Delphi Near Surface Advisory Committee

GeolSoc Careers/Industry Day Panel advisor (2020 – present)
• (2020-21) Renewables panellist (CCS & OWF)
Outline – 20 mins

01 (2 mins)
CO₂ storage project development lifecycle

02 (3 mins)
What should CCS sites screen for and how to screen for it?

03 (3 mins)
Conventional approach to CCS monitoring & case studies

04 (3 mins)
Does 2D have its place in Best – Practice Monitoring?

05 (3 min)
How can this be achieved?

06 (3 mins)
How do Fugro approach near-surface?

07 (1 mins)
Cost effectiveness of a near surface approach

08 (2 mins)
Summary
Unlocking Insights from Geo-data
1. CO$_2$ storage project development lifecycle
CO\textsubscript{2} storage project development lifecycle

Conventional approach to CCS monitoring

Site Characterisation
- Baseline thresholds
- Monitoring objectives

Could there be link?

Monitor, Verification and Analysis (MVA)
- Conducting monitoring

Ayash et al, 2016
2. What should CCS sites screen for and how to screen for it?
Stage 1 – Site Screening Context

Aim to identify <1 candidate site characterization (informs RA's and modelling simulations)

CO₂ storage sites likely to be (4) depleted oil and gas reservoirs.

Full characterisation/baseline → 3D survey, processing largely focussed on deep target not near-surface small scale features.

Past fluid migration / future potential routes for CO₂ escape maybe below the resolvable limit & overlooked
The most vulnerable parts of the seal are those that can act as fluid migration pathways,

Cartwright et al’s (2007) classified SBS’s as ‘small - large scale seismically resolvable geological features embedded within sealing sequences that promote cross-stratal fluid migration and allow fluids to bypass the pore network’.

Q: Does resolution effect the screening criteria?
Seal Bypass Systems (SBS’s) are historical expressions within seismic data (Cartwright et al, 2007):

- Faults / Damage Fault zones
- Gas-Chimneys and Pipes
- Intrusions (& channel features)
- Pockmarks and depressions

Data courtesy of Equinor AS

- SBS’s not easily resolvable within the shallow section → Implications for CO$_2$ migration.
- Channel features that intersect Faults (1) → horizontal component to lateral migration (Robbins, 2011)
3D $\rightarrow$ screen & monitor CO$_2$ injection within the reservoir. However, seismic resolution has near-surface resolution limits.

3D Survey: MN9201_R05
36-fold coverage with a line spacing of 25 m
Sampling $\sim$ 4 ms

(Yilmaz, 2001)

Vertical resolution$= 1/4\lambda$ & \[ \frac{\text{Velocity}}{\text{Central Frequency}} = \lambda \]

2000 (m/s) / 50 Hz = 50 m $\rightarrow$ $\sim$ 10 m Resolution
Fault Displacement maps

Nyquist freq $\sim$ 125 Hz
Dominant Freq $\sim$ 50Hz

(Wrona et al, 2017)
• SBS’s are common in most proliferous basins, unreported and may act as fluid flow conduits.

• Seismic based classification - restricted to resolution – not intended to excluded bypass systems that fall beneath this arbitrary scale limit.

• Sub seismic scale bypass systems > effective than larger features.

• Q: If we could resolve more does this offer the potential to also impact monitoring?
3. Conventional approach to CCS monitoring & case studies
Characterisation & monitoring typically 4D time-lapse Deep-focus

1) Deep-focused techniques
   - Demonstrate that CO$_2$ is securely contained within reservoir & storage complex
   - Calibrate predictive simulations “history matching”
   - Post closure monitoring (Deep & Shallow)

Characterisation & monitoring typically largely reliant on 4D time-lapse and largely ignores detailed monitoring in the shallow
Characterisation & monitoring typically 4D time-lapse (2003 & 2009)

Conventional approach to CCS monitoring

Snovit

High amplitude anomalies in a NW-SE trending path.

Injection well F2

The 4D anomalies stops along the detected ridge.

Bohloli et al, 2018

Seismic 2022 – SPE 4-5th May
Deep technical risks to CCS

Conventional approach to CCS monitoring

- **Injectivity**
- **Reservoir/storage formation capacity**
- **Wellbore integrity**
- **Induced seismicity** - CO$_2$ injection generating seismic activity.
- **Vertical containment** - Injected CO$_2$ should remain within the storage complex.
- **Lateral migration** - physical boundaries within the reservoir may prevent lateral flow of CO$_2$ beyond a certain distances.
4. Does 2D have its place in Best – Practice Monitoring?
CCS largely driven by the **upside & large investment from Oil and Gas majors** (In Salah, Snovit and Sleipner) to facilitate monitoring using 3D.

**Environmental concerns** → moving the industry towards smaller seismic sources

**Q:** is not just how deep you can go, but how small (source) & cost -effective you can go and still penetrate to depth?
Can future monitoring strategies will rely on expensive 3D (Time-lapse seismic)?

CCS experience has been driven by gas targets that had large financial drivers for 3D monitoring solutions.

Industry standard sources typically using

**Sources:** < 600 Cuin
- Sleipner 1994 – 2006 ~ < 3000 cuin

**Shotput intervals:** 12.5 – 18.75m

**Group intervals:** 12.5 m
**Sample intervals:** typically ~2 ms

**Nyquists frequencies:** 250 Hz
**Central frequency:** ~100 Hz
**Vertical resolution:** ~5-6 m
Near-surface monitoring required to **provide further assurance to stakeholders/regulators and provide a warning system in the unlikely event of a significant leak.**

The absence of any evidence of leakage can build confidence during monitoring of the operational phase, **with the potential to decrease costs through reduced survey locations and frequency.**

**What is needed**

1) **Identify** fluid migration pathways,

2) **Monitor** identified fluid migration pathways, and

3) **Limitations awareness:** sensitivities/detection limits associated with monitoring approaches and technologies.
5. How can this be achieved?
Stage 1: 3D Characterisation, Seismic Audit & Re-Processing

Source: Glazewski et al, 2017 - Best practice for the commercial deployment of carbon dioxide geologic storage

Recommended Best Practice – Review Existing Subsurface Data

While these historical data may be invaluable for initial site screening and feasibility studies, using these data to establish baseline conditions for a monitoring program should be subject to quality assurance review.

Recommended Best Practice – Ensure Baseline–Monitoring Data Comparability

Poor comparability between the techniques and parameters used to establish baselines and the subsequent operational monitoring could result in difficulties interpreting the operational monitoring results.
Reprocessing Data Example (UHR Data, North Sea)

Data courtesy of RVO
3D Characterisation & 2D repeat localised Coincidental 2D & 3D UUHR Example

Data courtesy of Energinet
6. How do Fugro approach near-surface?
## Seismic Resolution Bandwidth

### Data Type

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Typical Sampling Rate (Sampling Frequency)</th>
<th>Nyquist Frequency (Data bandwidth)</th>
<th>Typical Peak/Dominant Frequency*</th>
</tr>
</thead>
<tbody>
<tr>
<td>High resolution (HR)</td>
<td>1 ms (1000 Hz)</td>
<td>500 Hz</td>
<td>~ 260 Hz</td>
</tr>
<tr>
<td>Ultra-high resolution (UHR)</td>
<td>0.250 ms (4000 Hz)</td>
<td>2000 Hz</td>
<td>~ 900 Hz</td>
</tr>
<tr>
<td>Ultra-ultra high resolution (UUHR)**</td>
<td>0.125 ms (8000 Hz)</td>
<td>4000 Hz</td>
<td>~ 1500 Hz</td>
</tr>
</tbody>
</table>

* Typical peak/dominant frequencies refer to frequencies in the final processed dataset. Also note, there are contributions to the data, from higher frequency ranges, at or near the seabed.

** 16 kHz sampling rate (i.e., 0.0625 ms) is also possible, resulting in a Nyquist frequency of 8000 Hz and dominant frequency of approx. 3000 Hz.

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**Seismic 2022 – SPE 4-5th May**

**Petroleum and natural gas industries, ISO 19901-10**
Dual Source & Penetration Depth Seismic Resolution Bandwidth

E&P: D freq of 50 Hz ~ 10 m

Near-Surface UHR: D freq of 900 Hz ~ 0.5 m
Near-Surface HR: D freq of 260 Hz ~ 2.5 - 9 m

(Petroleum and natural gas industries, ISO 19901-10)
A 2D shallow monitoring approach

“Several avenues are being explored for integrated acquisition techniques, the current setup being one of them, and we look forward to have more updates in the near future – this is a two-source set up – other alternatives do exist”
Shooting Deep & Shallow at the same time

Offshore

Gas

~1600 m

Onshore

Gas

~1200 m

~1600 m

Gas

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HR Example: Client: Total; Area: North Sea

Channelling

~4300 m

~500 m

~1600 m

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Coincidental HR & UHR Example: Client: Total; Area: North Sea

Immediate uplift in data resolution is noticed.

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HR Example – showing “faults”: Client: Shell; Area: Southern North Sea + Hypothetical scenario

~1600 m

~27500 m
HR Example – showing “near seabed - faults”:
Client: Shell; Area: Southern North Sea

~ 27500 m

~ 500 m

~ 1600 m
7. Cost effectiveness of 2D vs 3D approach?
A hypothetical scenario: Cost of repeat 3D

For most prospective CO₂ storage sites, reservoir area is >100 sq kms

Budgetary estimate for 3D > £3 million + processing @10% + infil etc

Imagine a 5-year CCUS seismic package (3 x 3D surveys & processing) = ~£10 million

If you can identify key areas that pose the highest risk from the initial 3D base line characterisation....

Q: Wouldn’t repeat 2D at localised focussed monitoring points massively reduce the costs?
8. Summary

Data courtesy of Energinet
Best Practice: Seismic Audit & re-process legacy data.

Sub seismic scale bypass systems > larger features on leakage.

Higher resolution \(\rightarrow\) resolve smaller features. Near-surface experts should perform data acquisition & interpretation.

Near-surface monitoring a future requirement to assure stakeholders.

Initial 3D for characterisation, 2D Time lapse seismic offers a cheap alternative for ongoing monitoring.

Ability to acquire deep / shallow simultaneously & monitor within the shallow overburden (<1200 m) to seabed.

Is 2D a Cost Effective Shallow CO\textsubscript{2} Monitoring Strategy?..... You decide
Still have questions?

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Thank you

Q&A

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