Seismic2022

SEISMIC 2022 AND BEYOND – THE CONTINUING ROLE OF SEISMIC IN THE ENERGY INDUSTRY

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SPE - Seismic 2022

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‘An emerging solution for an emerging CCS market: Fugro’s Seismic Resolution Uplift – A Cost Effective Shallow CO_2 Monitoring Strategy?’

Benedict Robbins & Sanket Bhattachatya

Today's presenter

Benedict Robbins

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)

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Outline – 20 mins

01 (2 mins)

CO_2 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?

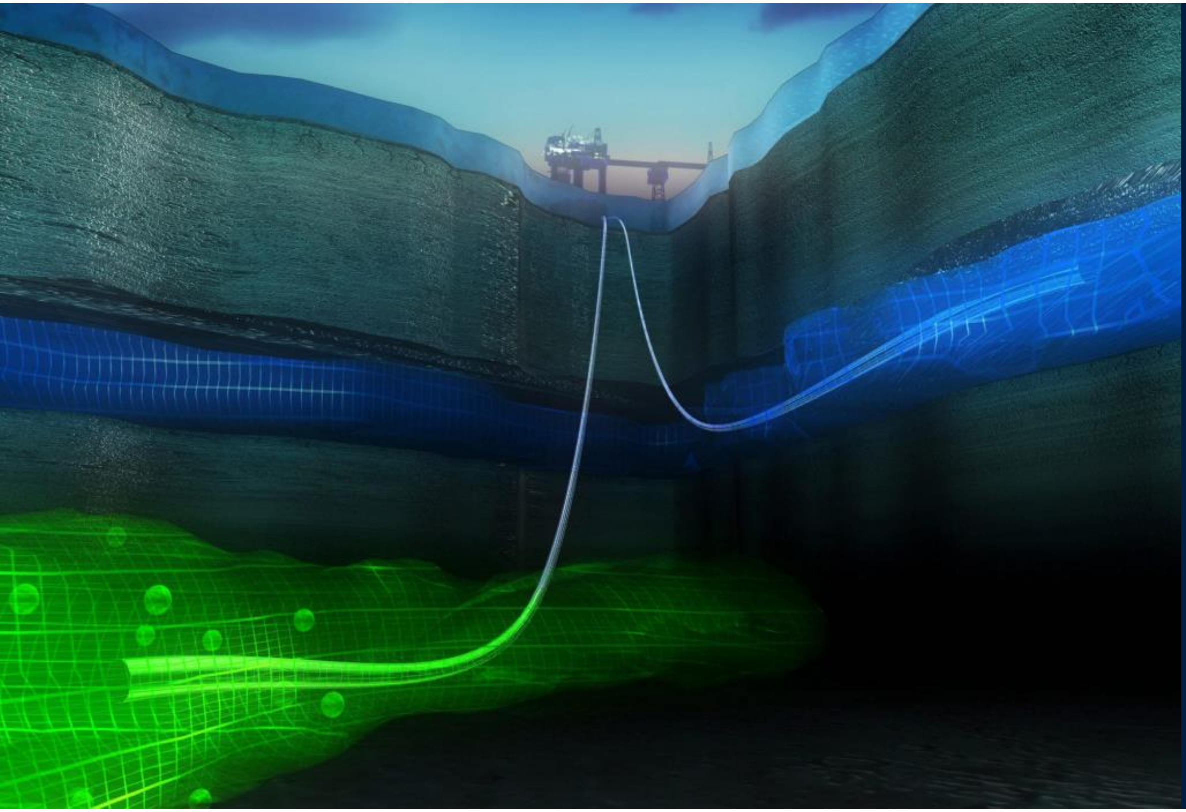
07 (1 mins)

Cost effectiveness of a near surface approach

08 (2 mins)

Summary

Unlocking Insights from Geo-data



1. CO_2 storage project development lifecycle

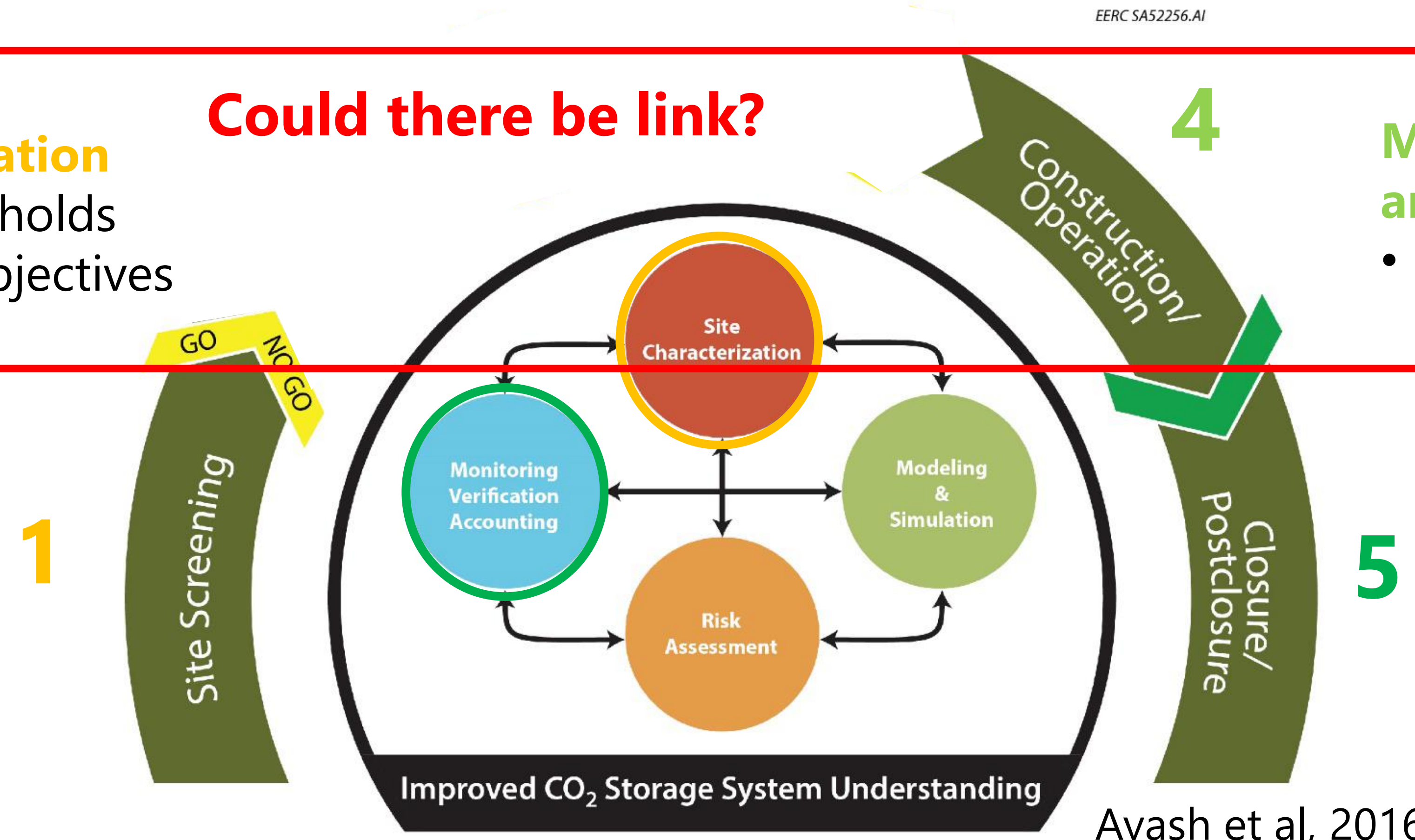
CO_2 storage project development lifecycle

Conventional approach to CCS monitoring

Site Characterisation

- Baseline thresholds
- Monitoring objectives

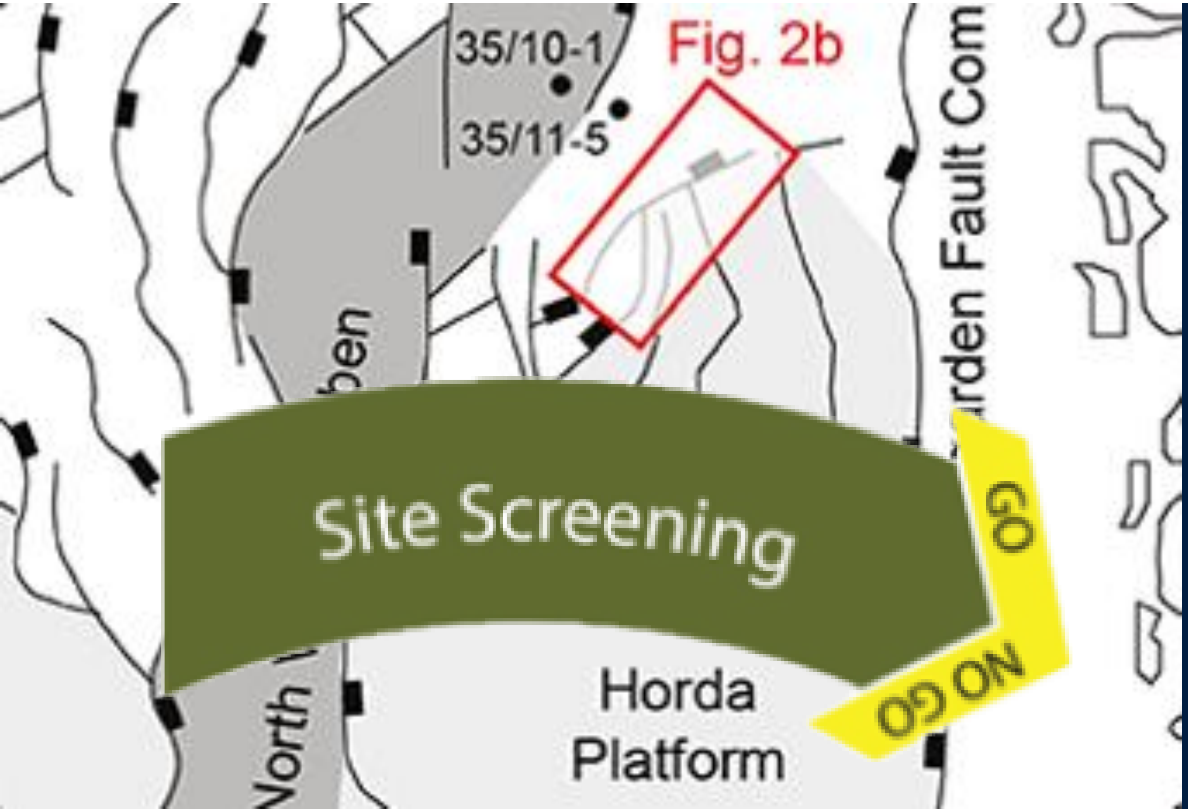
Could there be link?



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

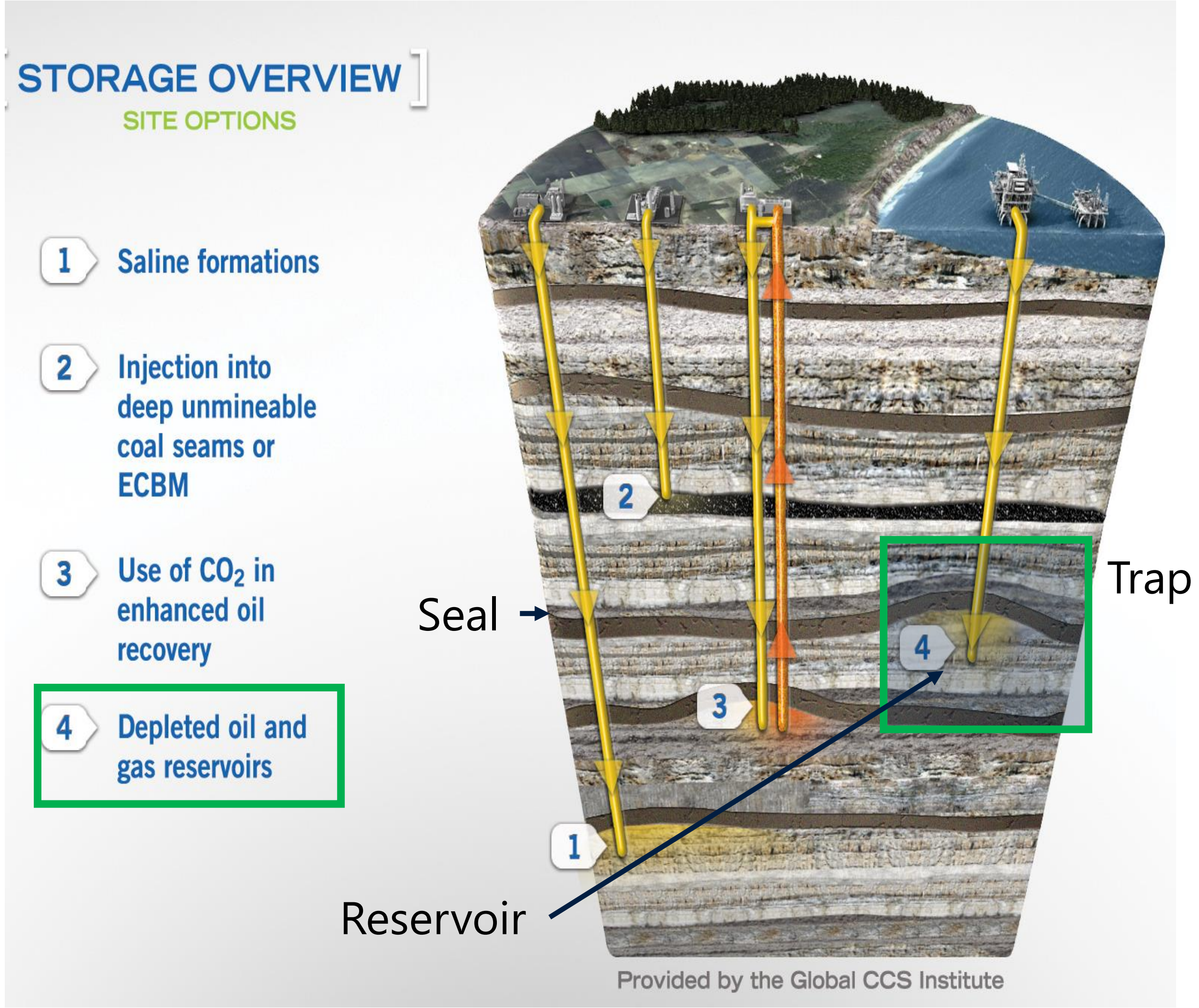
Aim to identify <1 candidate

site characterization (informs RA's and modelling simulations)

CO_2 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 <u>small scale features.</u>

Past fluid migration / future potential routes for CO_2 escape maybe below the resolvable limit & overlooked



Screening for SBS's

Seal bypass systems

Joe Cartwright, Mads Huuse, and Andrew Aplin

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?

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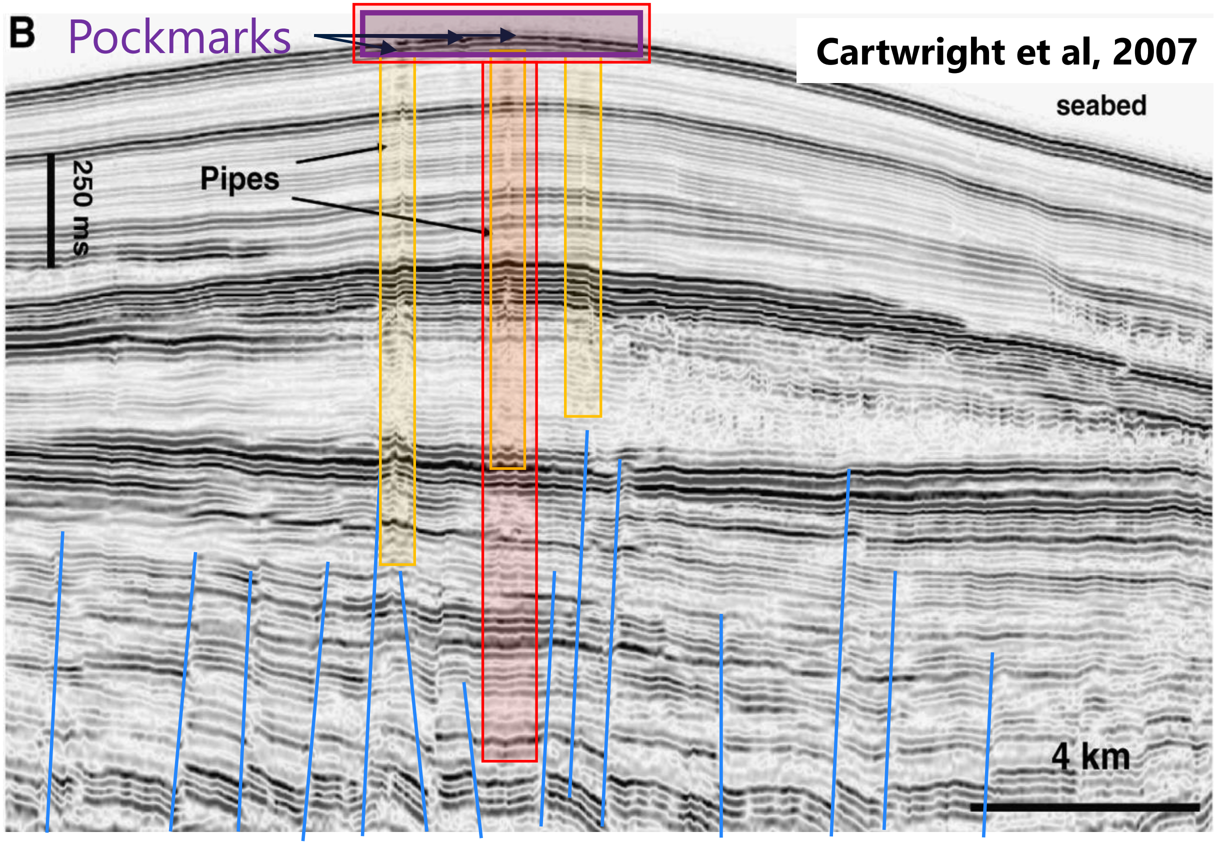
Seal Bypass Systems require resolution uplift

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)

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Polygonal Faulting Data Example

3D → screen & monitor CO_2 injection within the reservoir. However, seismic resolution has near-surfac resolution limits.

3D Survey: MN9201_R05

36-fold coverage with a line spacing of 25 m

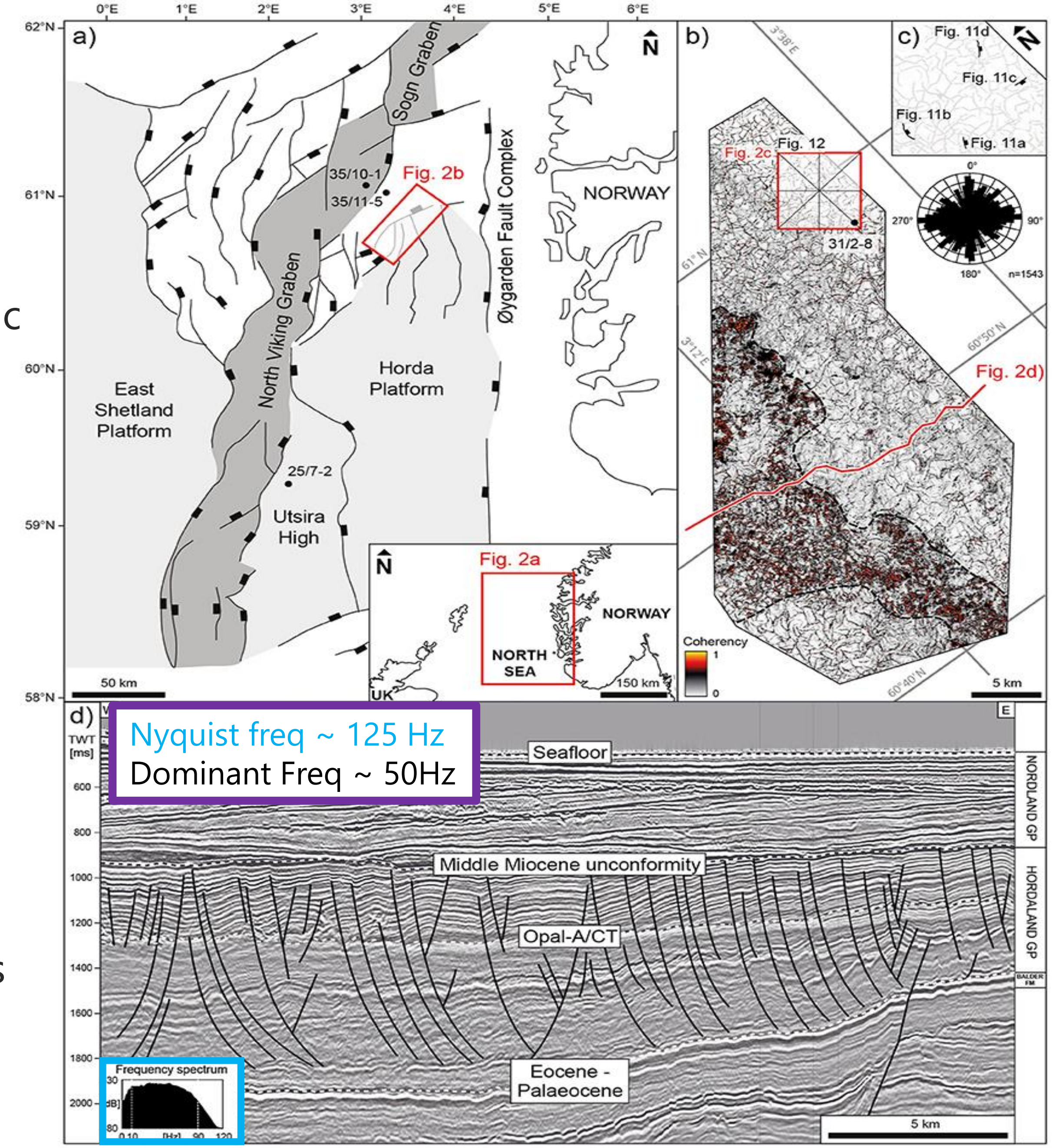
Sampling ~ 4ms

(Yilmaz, 2001)

Vertical resolution= 1/4λ & $\frac{Velocity}{Central\ Frequncy} = \lambda$

2000 (m/s) / 50 Hz = 50 m → ~ 10 m Resolution

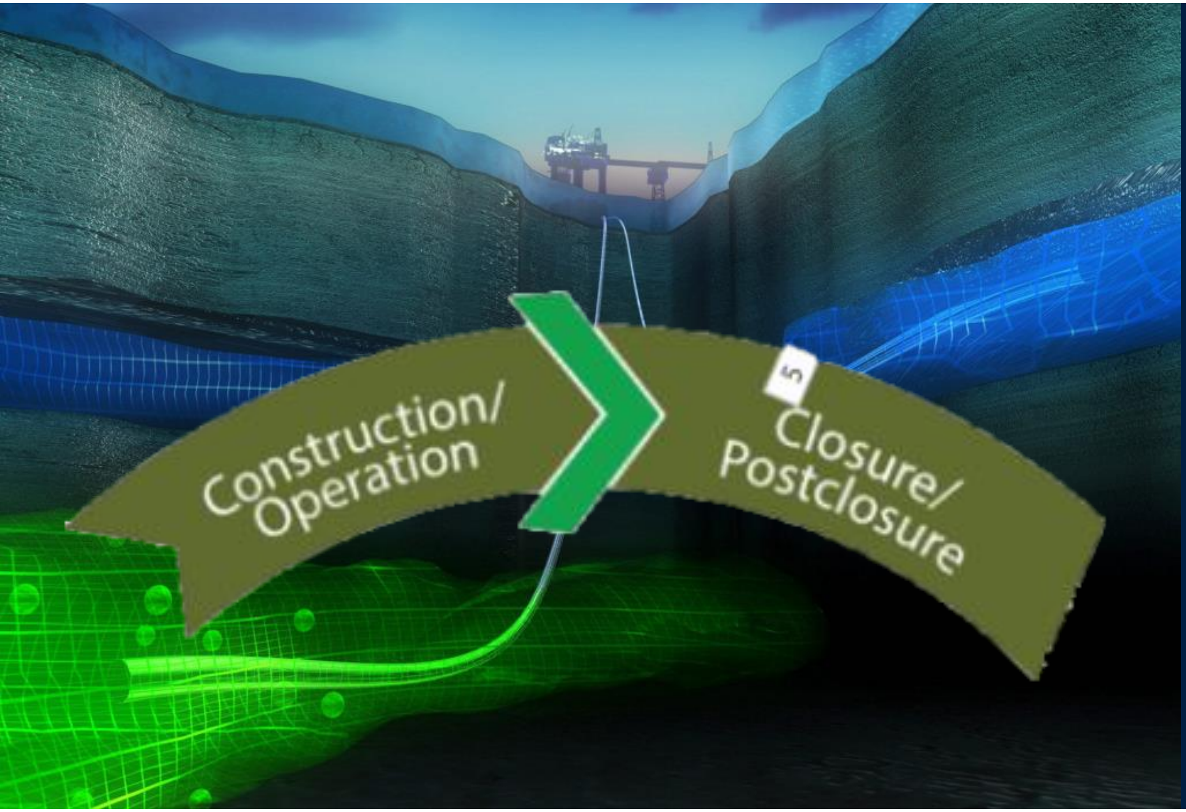
Fault Displacement maps



(Wrona et al, 2017)

SBS's summary and impact to screening / monitoring

- 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

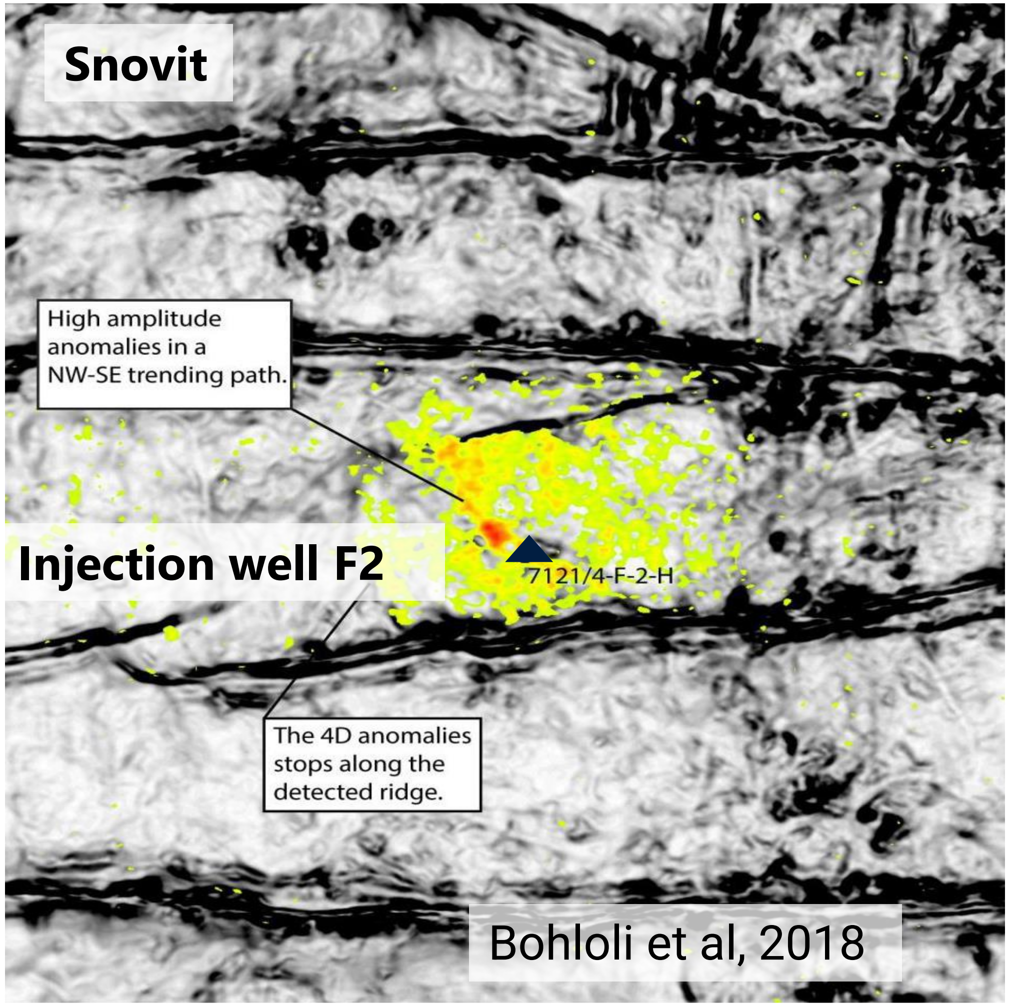
Characterisation & monitoring typically 4D time-lapse Deep-focus

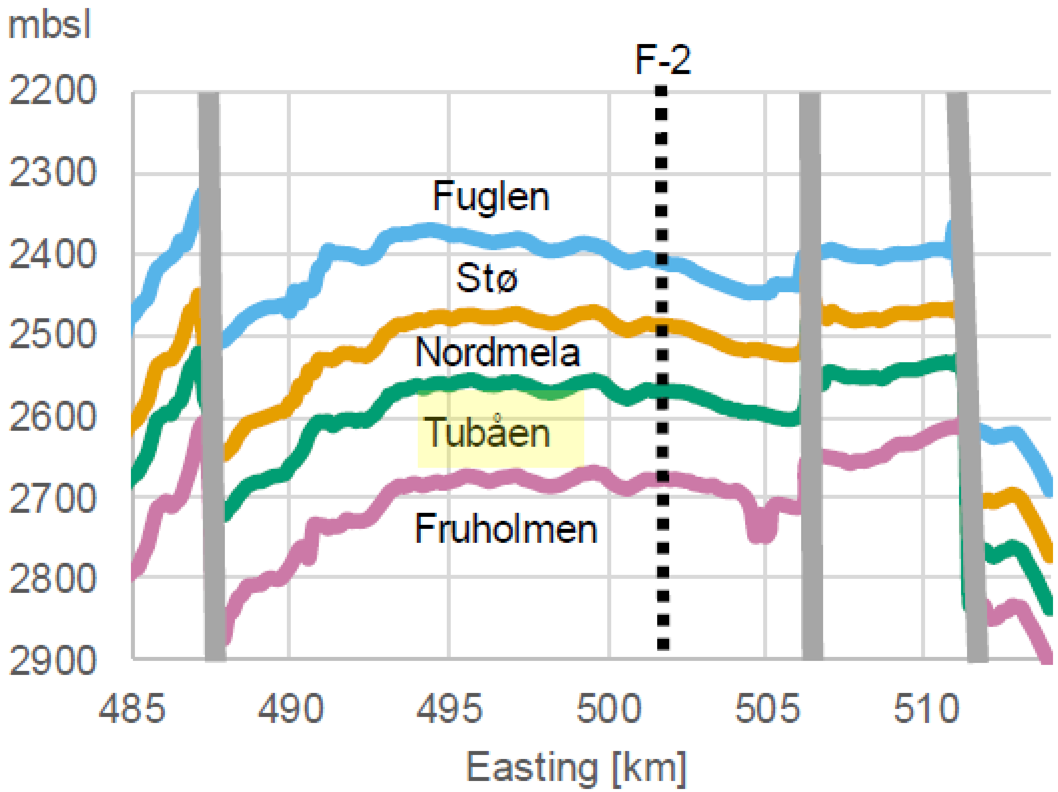
1) **Deep-focused techniques**
   - Demonstrate that CO_2 is securely contained within reservoir & storage complex
   - Calibrate predictive simulations “history matching”
   - Post closure monitoring (Deep & Shallow)

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





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.

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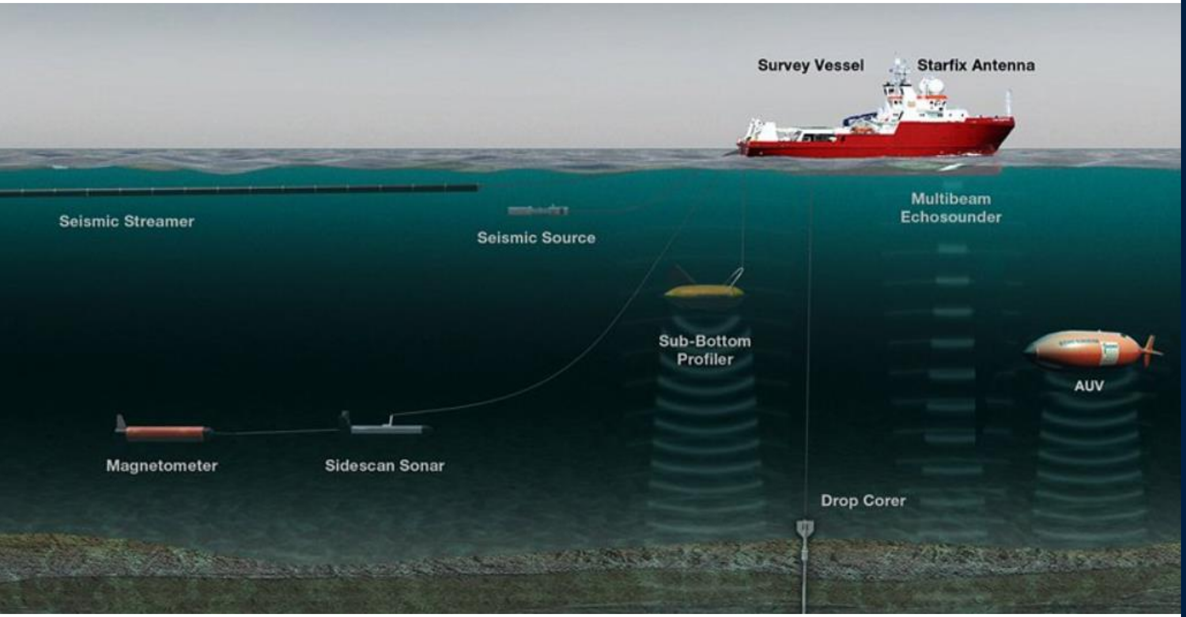


4. Does 2D have its place in Best – Practice Monitoring?

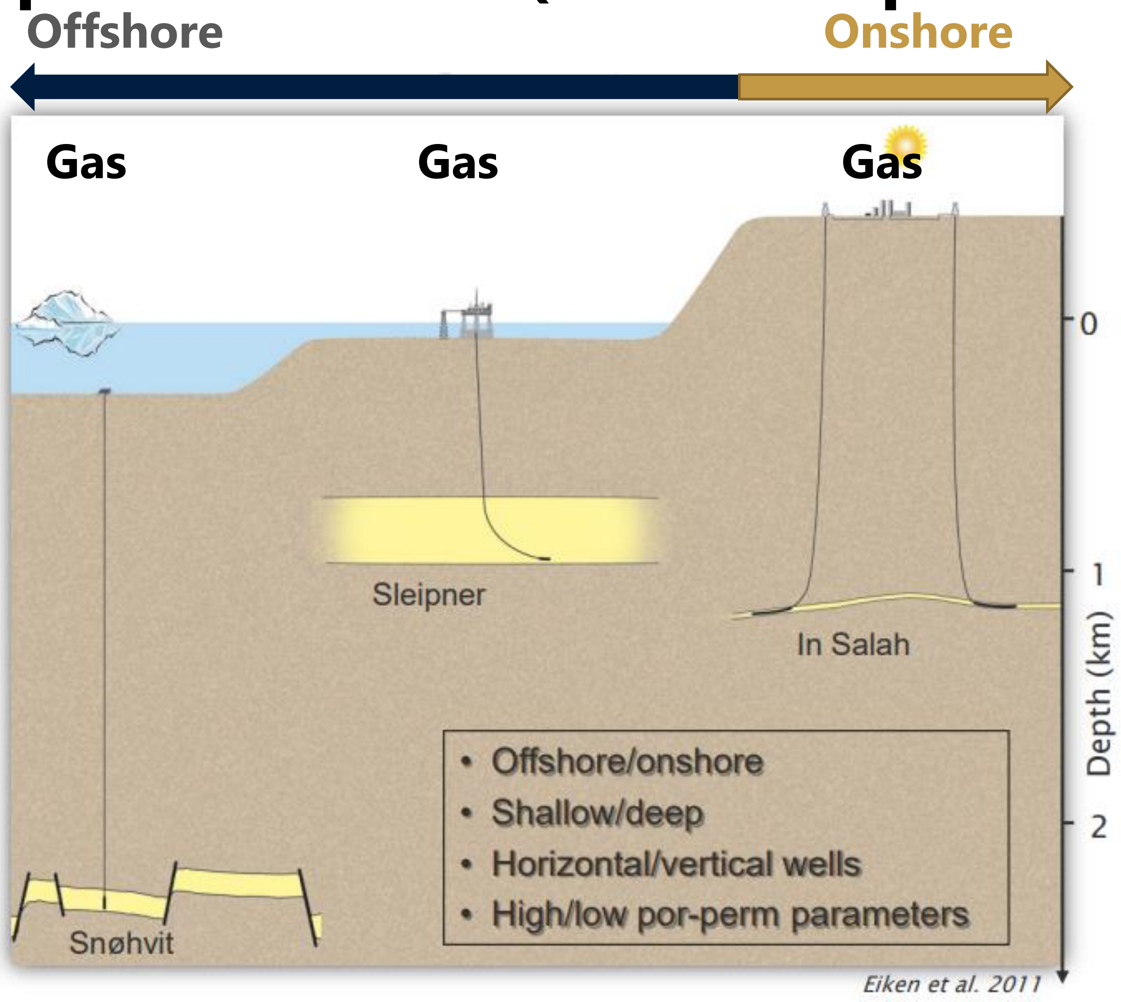
Drivers

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

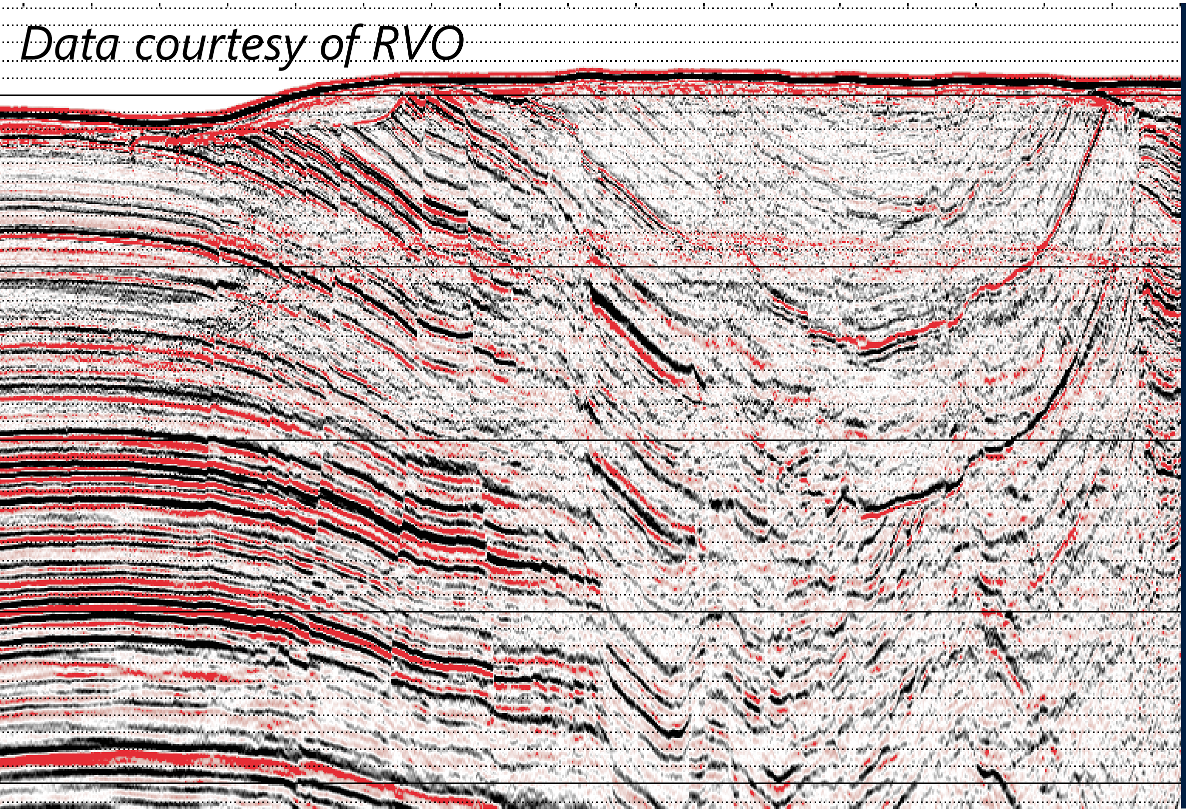
Best practices manual – Monitoring for CO_2 storage. Plains CO_2 Reduction (PCOR) Partnership Phase III *- Glazewski et al, 2017*

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: 3 D 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.

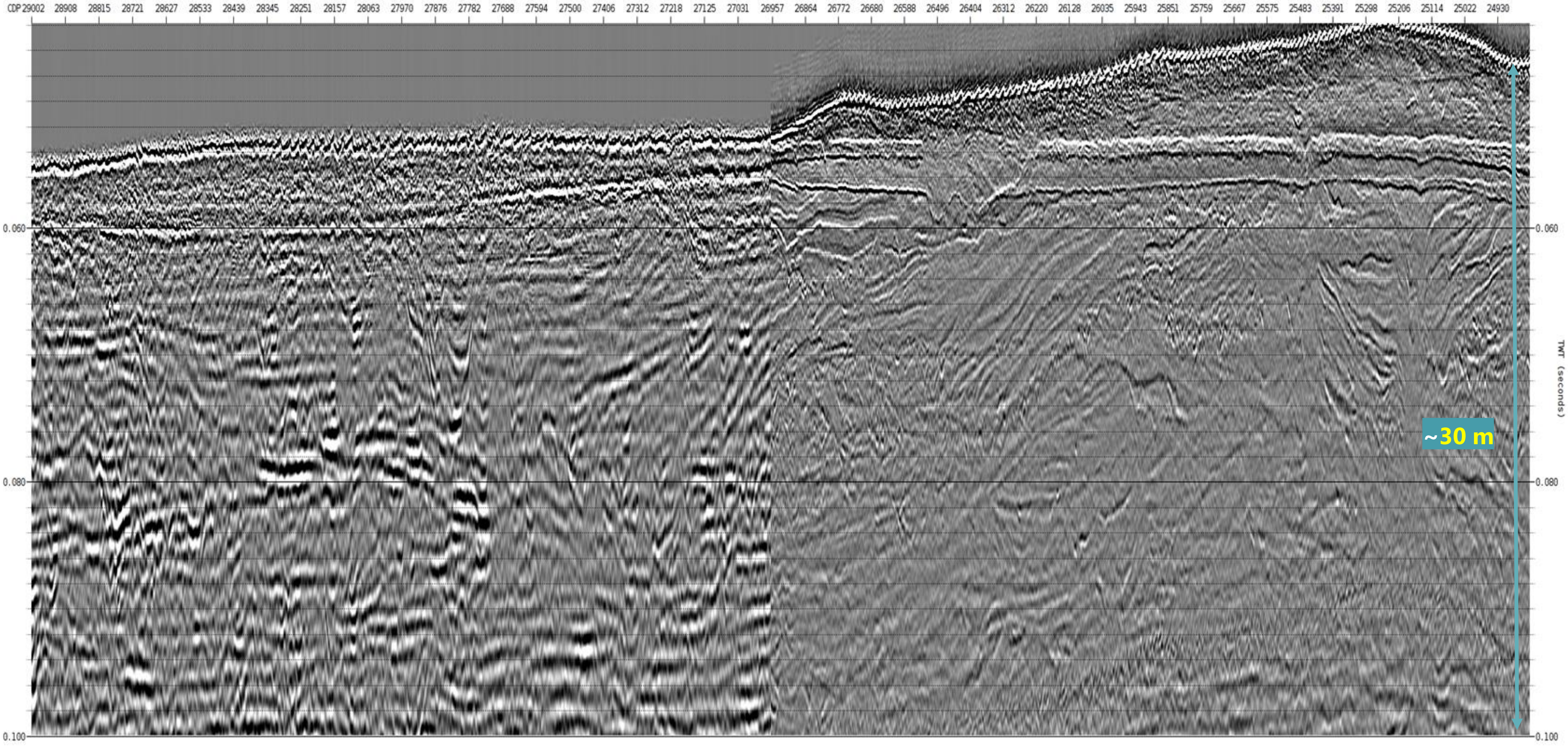
Recommended Best Practice – Ensure Baseline–Monitoring Data Comparability

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)

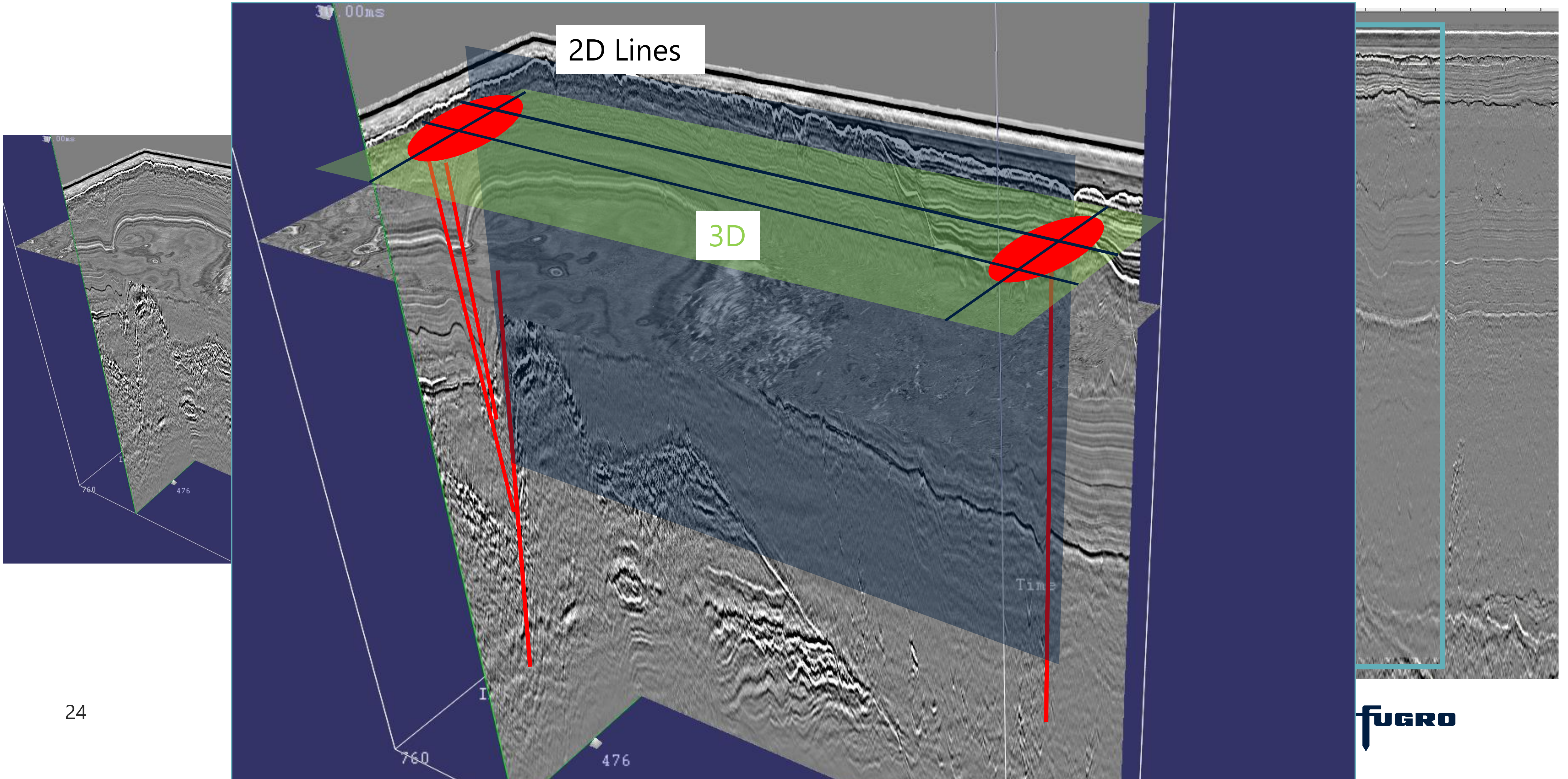
Data courtesy of RVO

Legacy Dataset	Fugro Reprocessed



3 D Characterisation & 2D repeat localised Coincidental 2D & 3D UUHR Example

Data courtesy of Energinet



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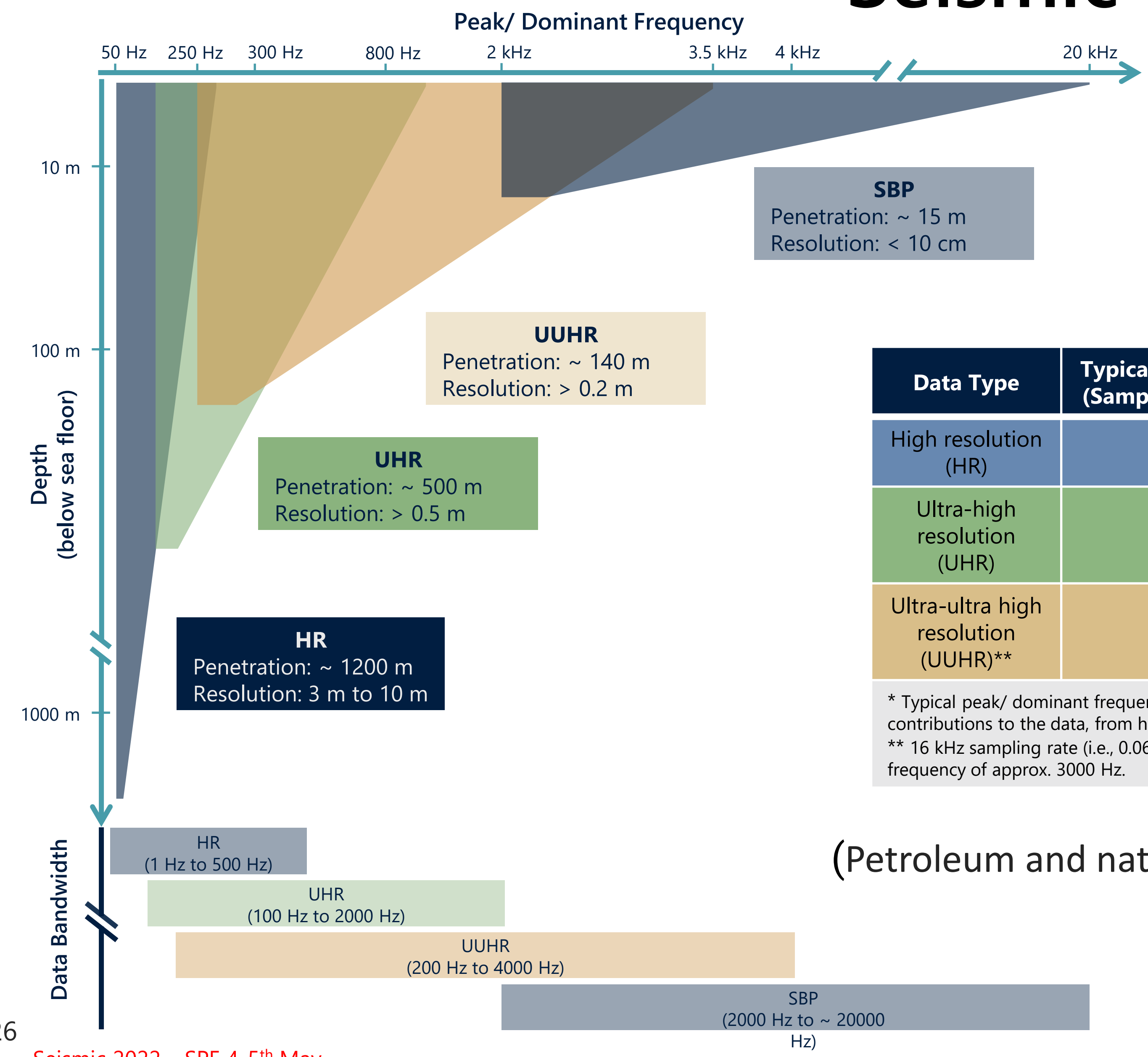
6. How do Fugro approach near-surface?

Seismic Resolution Bandwidth



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

* 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.

(Petroleum and natural gas industries, ISO 19901-10)

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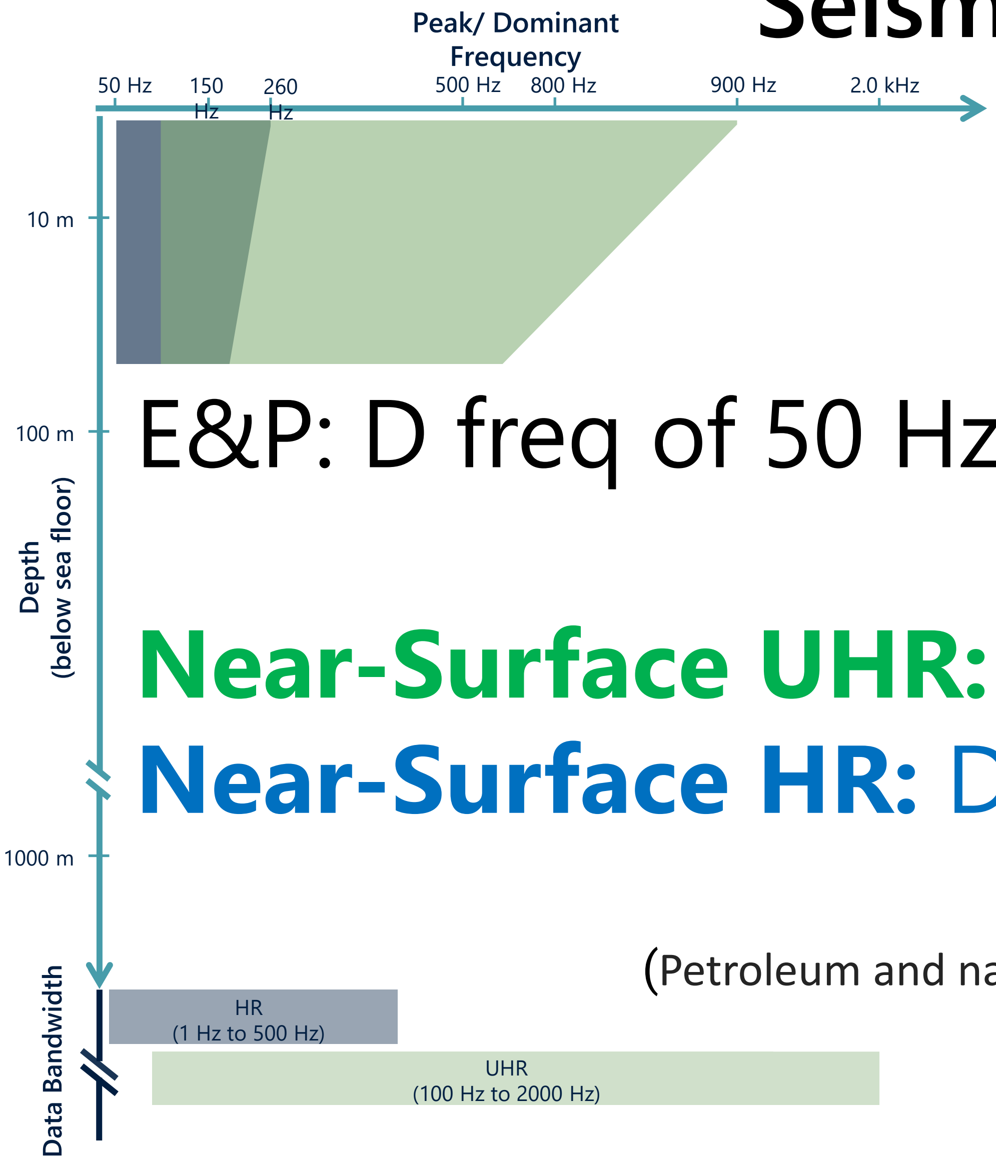
Dual Source & Penetration Depth Seismic Resolution Bandwidth



Data Type	Typical Sampling Rate (Sampling Frequency)	Nyquist Frequency (Data bandwidth)	Typical Peak/ Dominant Frequency*
High resolution (HR)	1 ms (1000 Hz)	500 Hz	~ 260 Hz
Ultra-high resolution (UHR)	0.250 ms (4000 Hz)	2000 Hz	~ 900 Hz

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)

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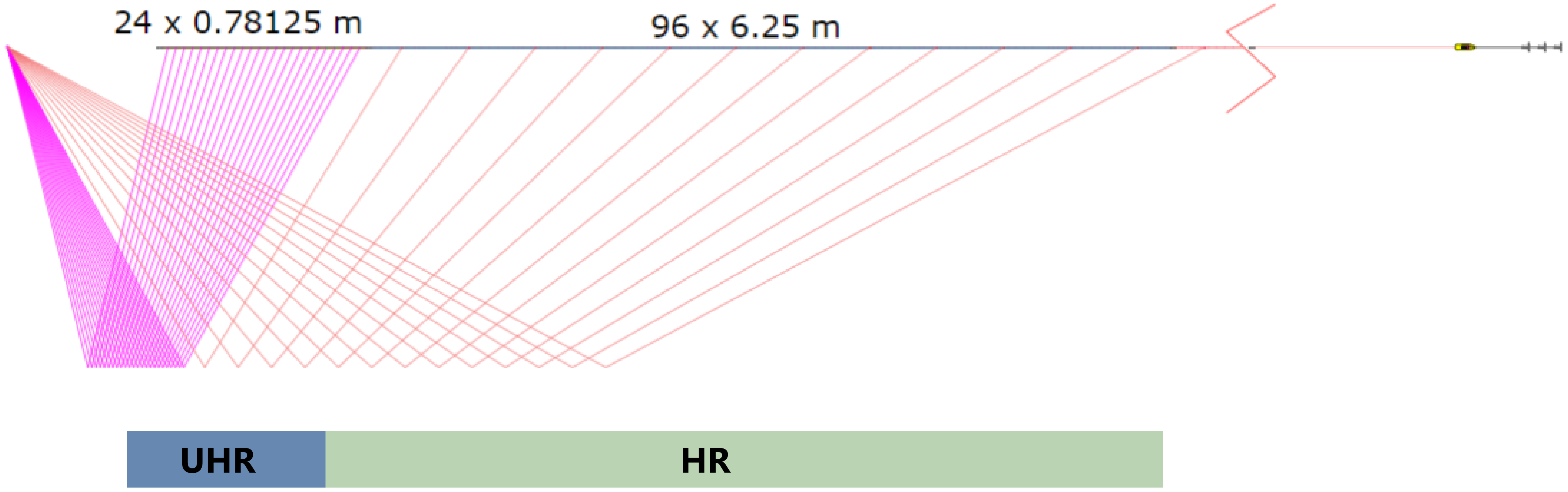
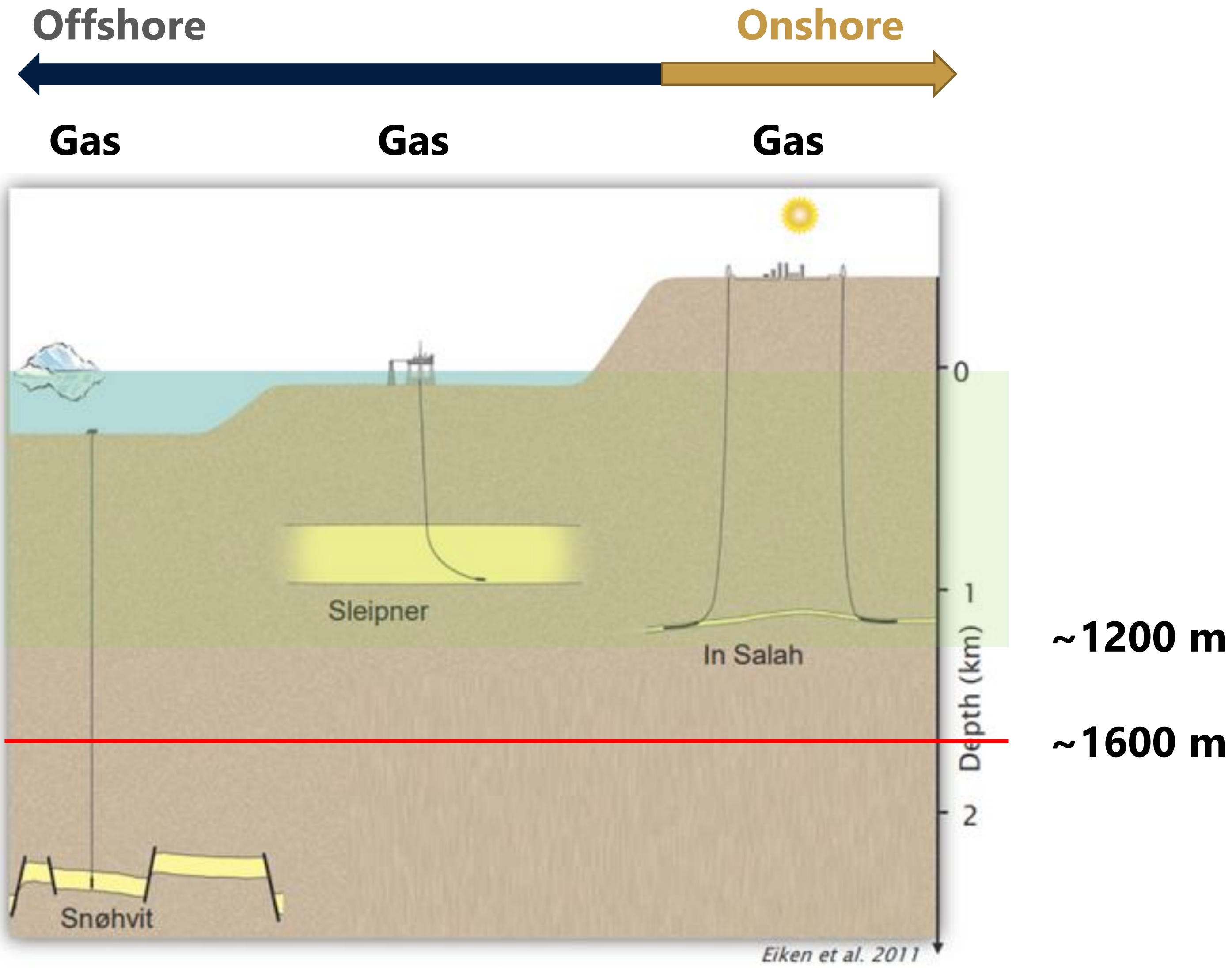
A 2D shallow monitoring approach

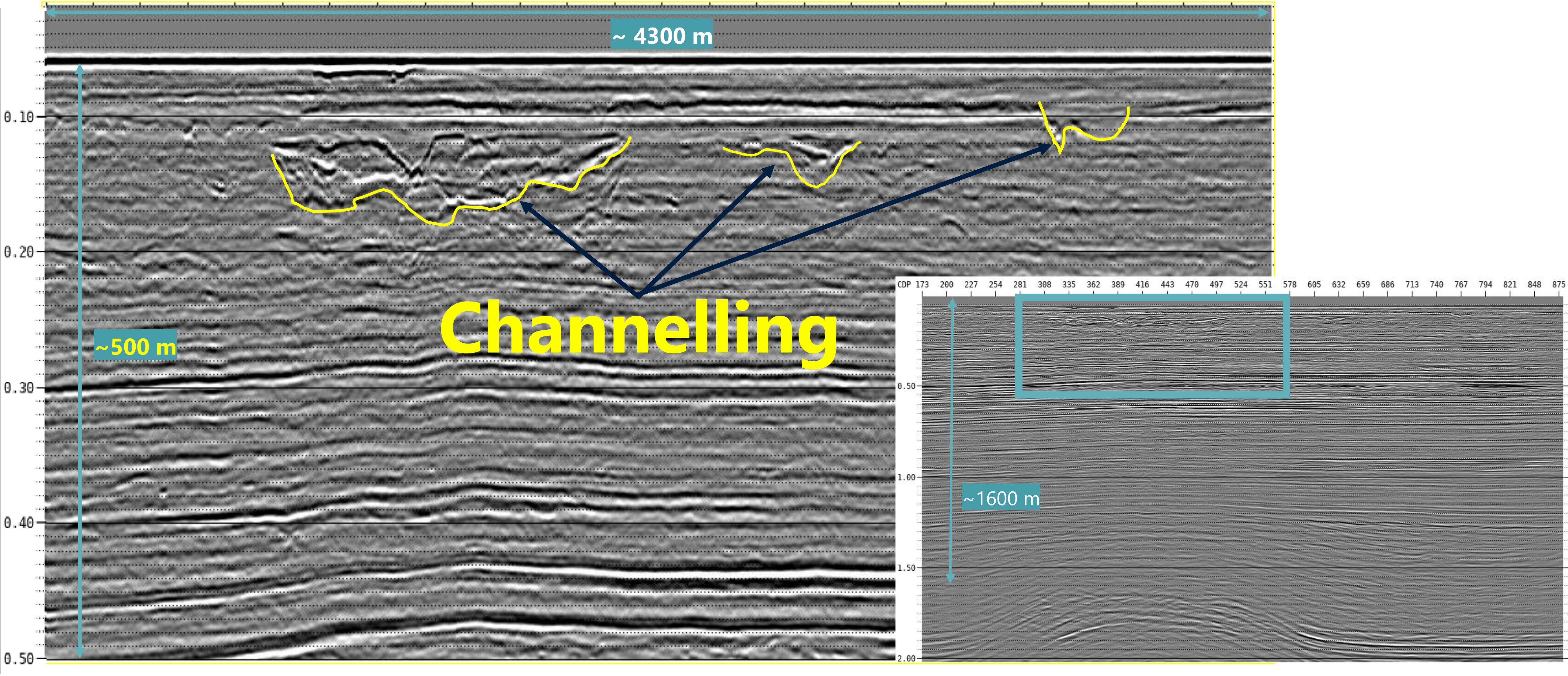
"**several avenues** are being explored for integrated acquisition techniques, the current setup being one of them, and we look forward to have more updates in the near future – this is a two-source set up – other alternatives do exist"



Shooting Deep & Shallow at the same time



HR Example: Client: Total; Area: North Sea



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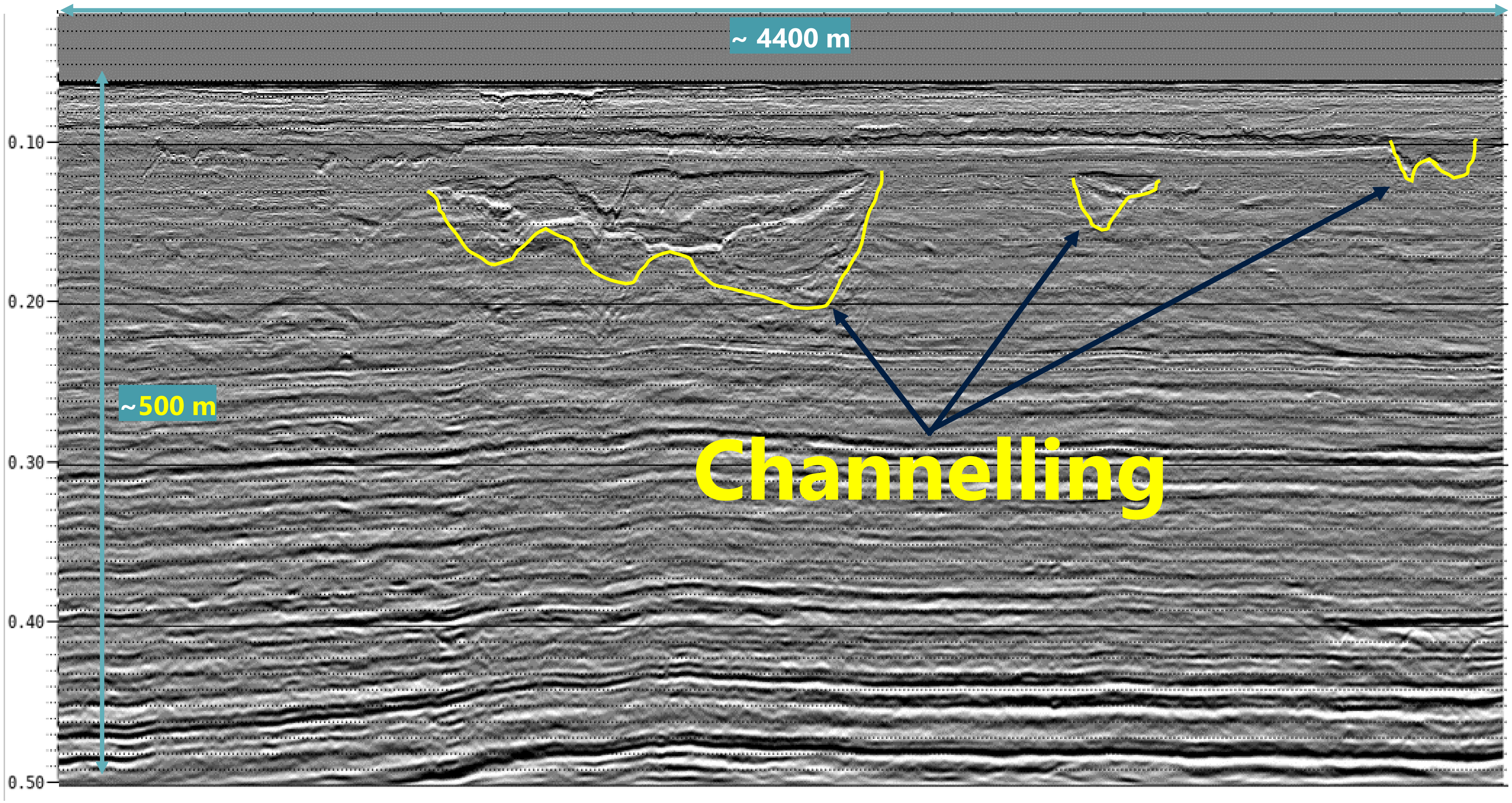
UHR Example: Client: Total; Area: North Sea



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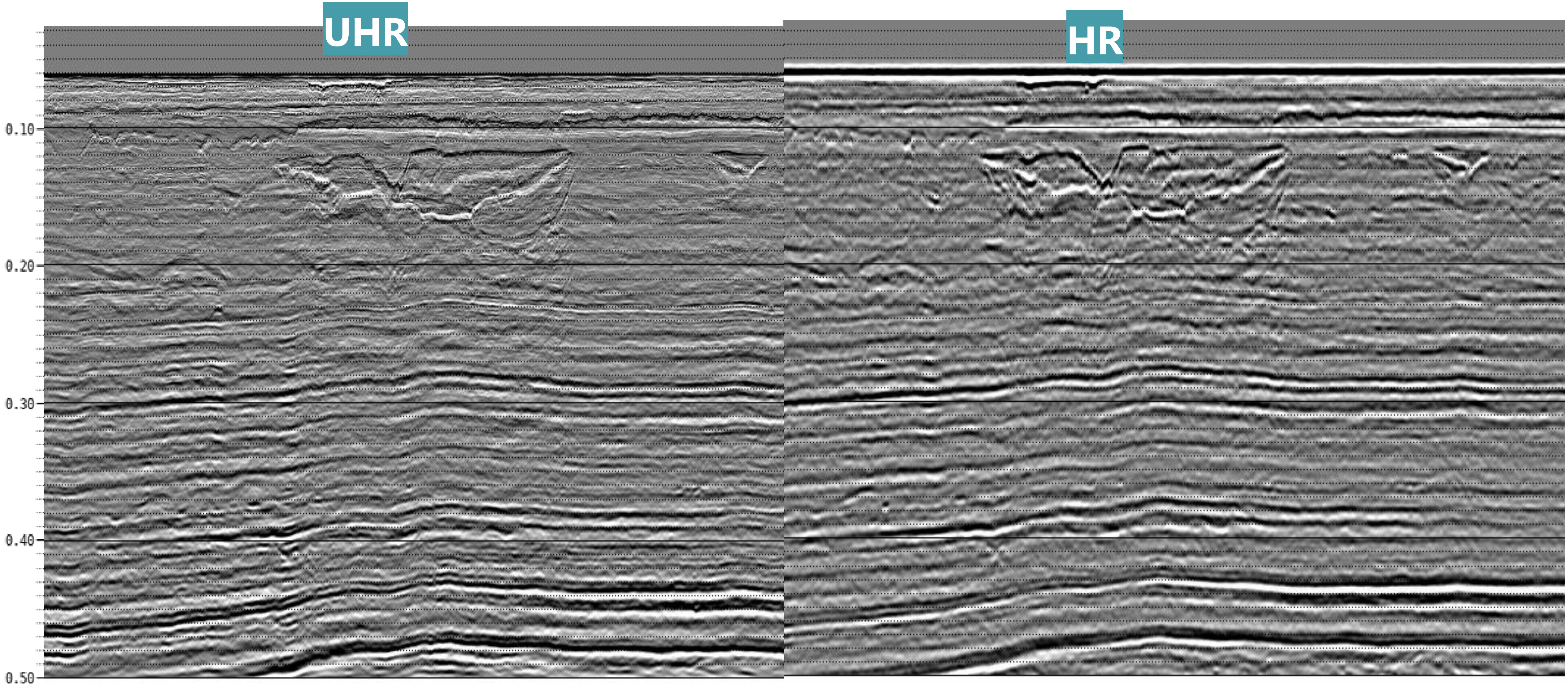
Coincidental HR & UHR Example: Client: Total; Area: North Sea



Immediate uplift in data resolution is noticed

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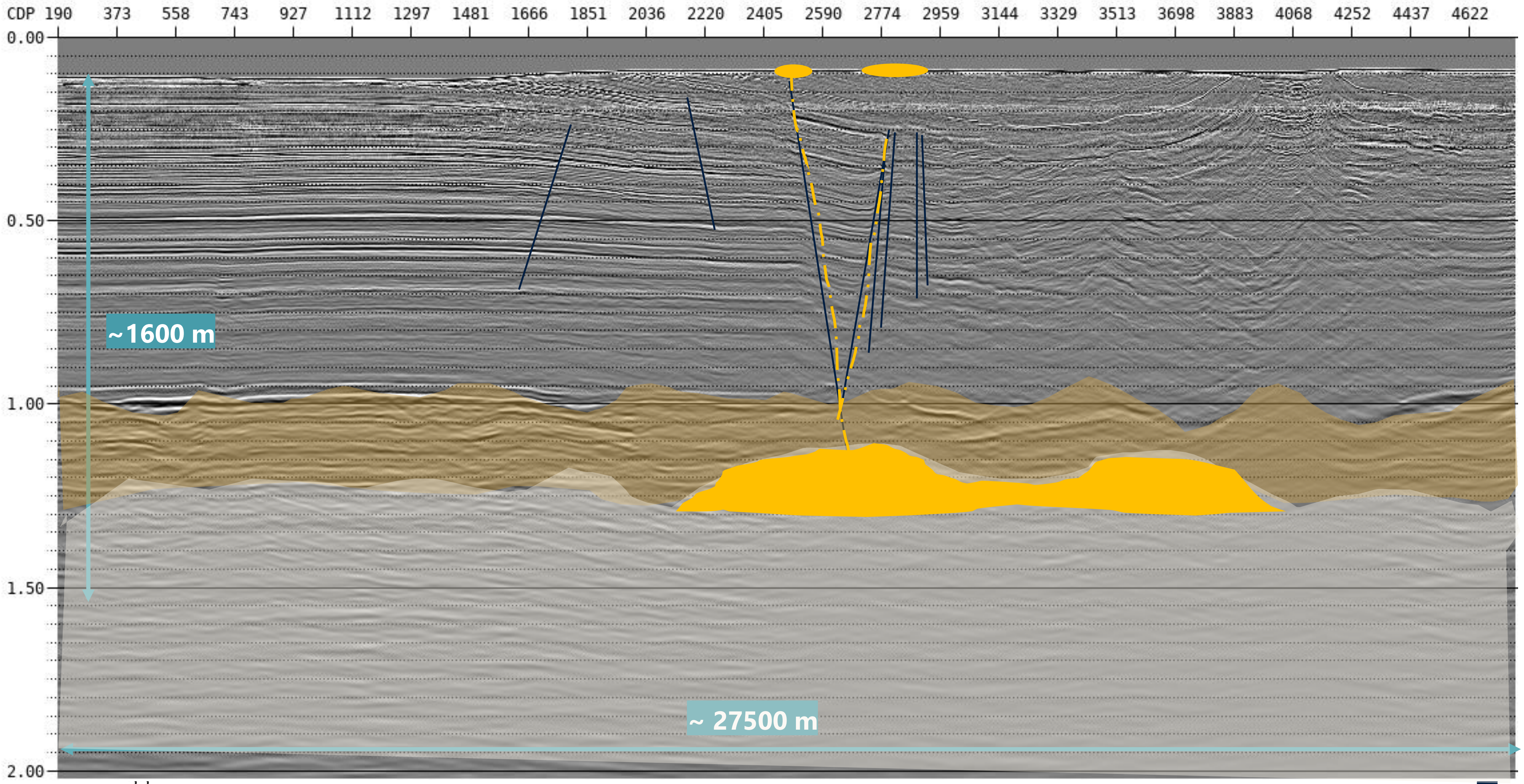
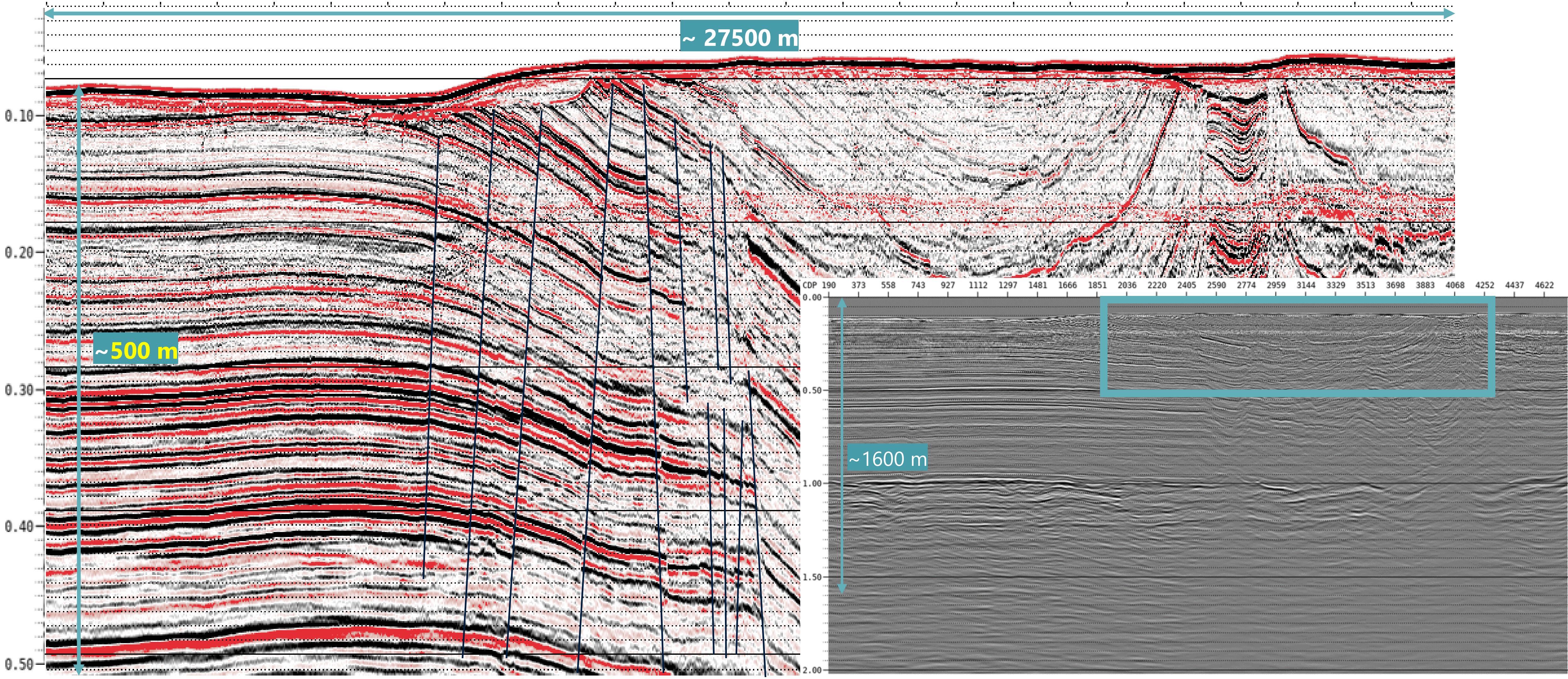
HR Example – showing "faults": Client: Shell; Area: Southern North Sea + Hypothetical scenario



HR Example – showing "near seabed - faults ": Client: Shell; Area: Southern North Sea



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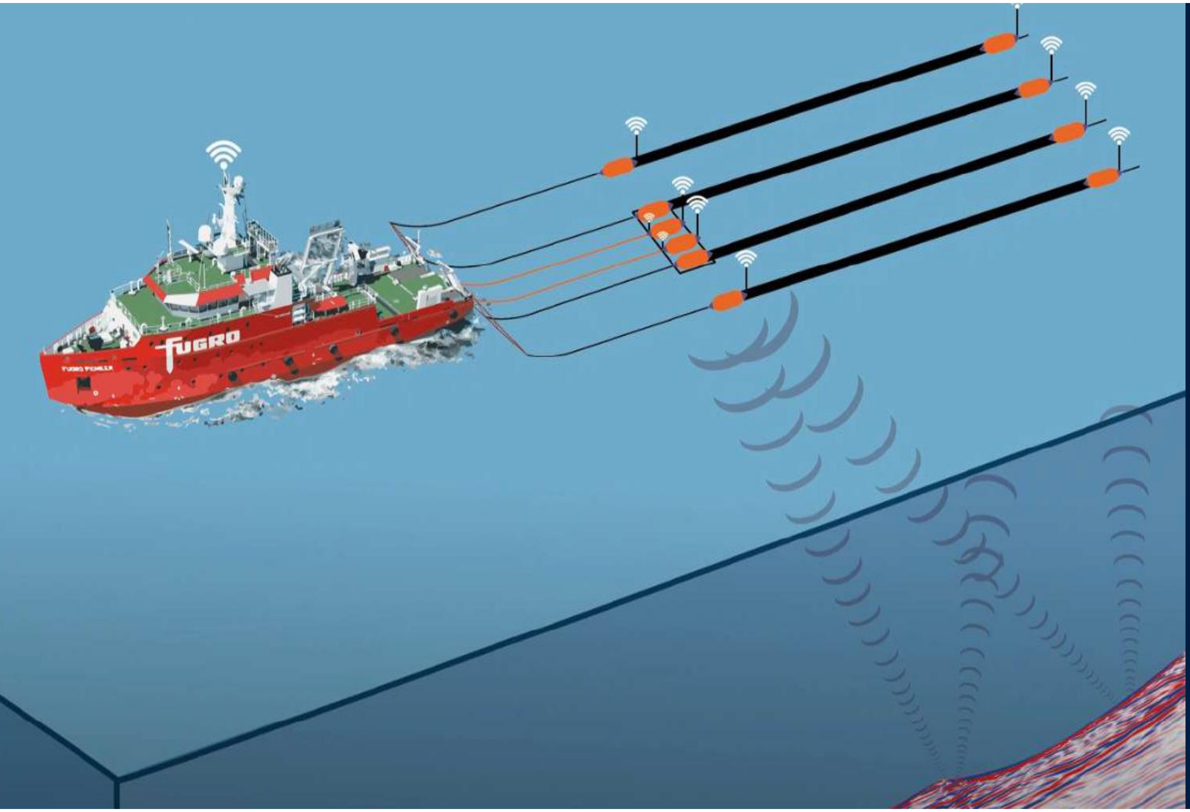


7. Cost effectiveness of 2D vs 3D approach?

A hypothetical scenario: Cost of repeat 3D

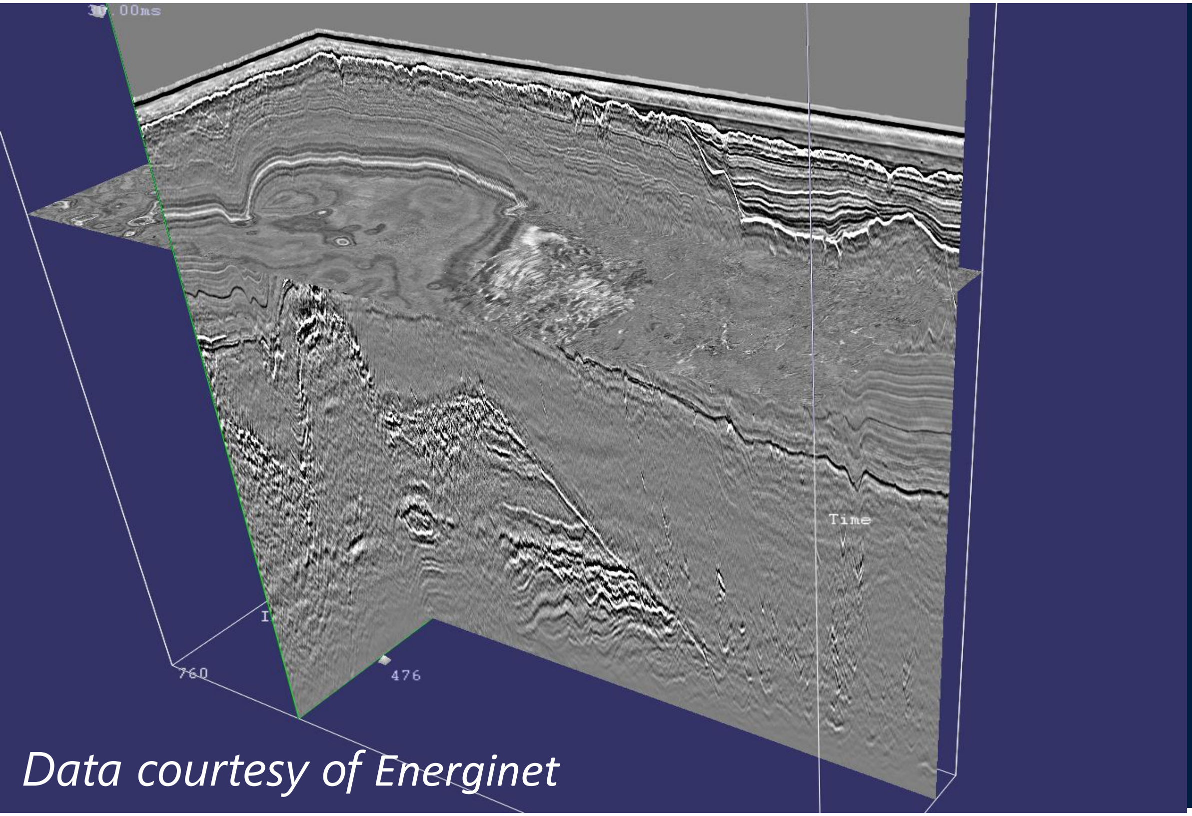
For most prospective CO_2 storage sites, reservoir area is >100 sq kms

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?



Data courtesy of Energinet

8. Summary

Is 2D a Cost Effective Shallow CO_2 Monitoring Strategy?..... You decide

- Best Practice: Seismic Audit & **re-process legacy data.**
- **Sub seismic scale bypass systems** > larger features on leakage.
- Higher resolution → 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.

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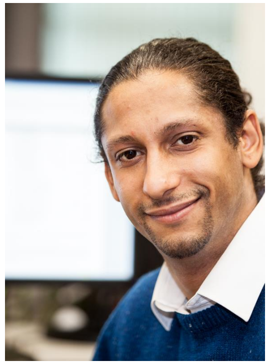
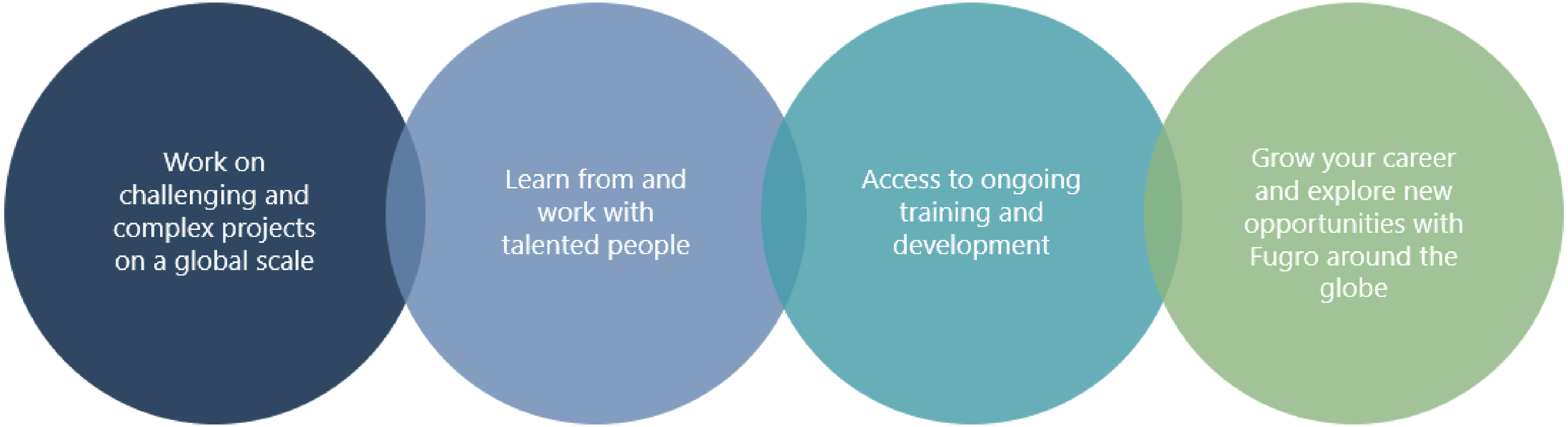
Still have questions?



Benedict Robbins
Supervisory Geophysicist
b.robbins@fugro.com
in Benedict Robbins

Sanket Bhattacharya
Seismic Business Development Manager
S.Bhattachacharya@fugro.com
in Sanket Bhattacharya



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Q&A

Thank you

+44 1491 820 800
b.robbins@fugro.com
fugro.com