Towards cost appropriate seismic monitoring of Carbon Stores

Will Bradbury
Director – New Energy Solutions
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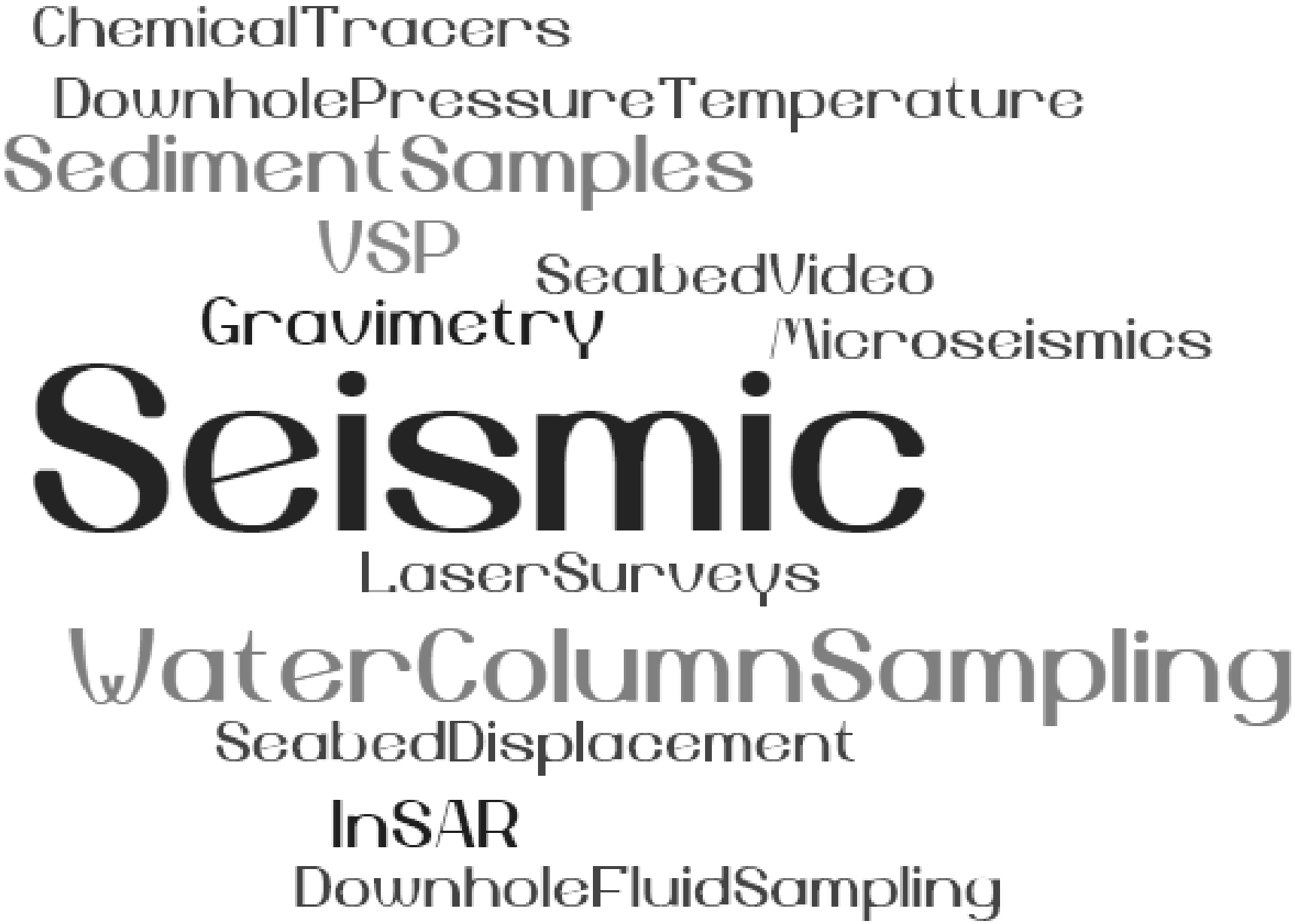
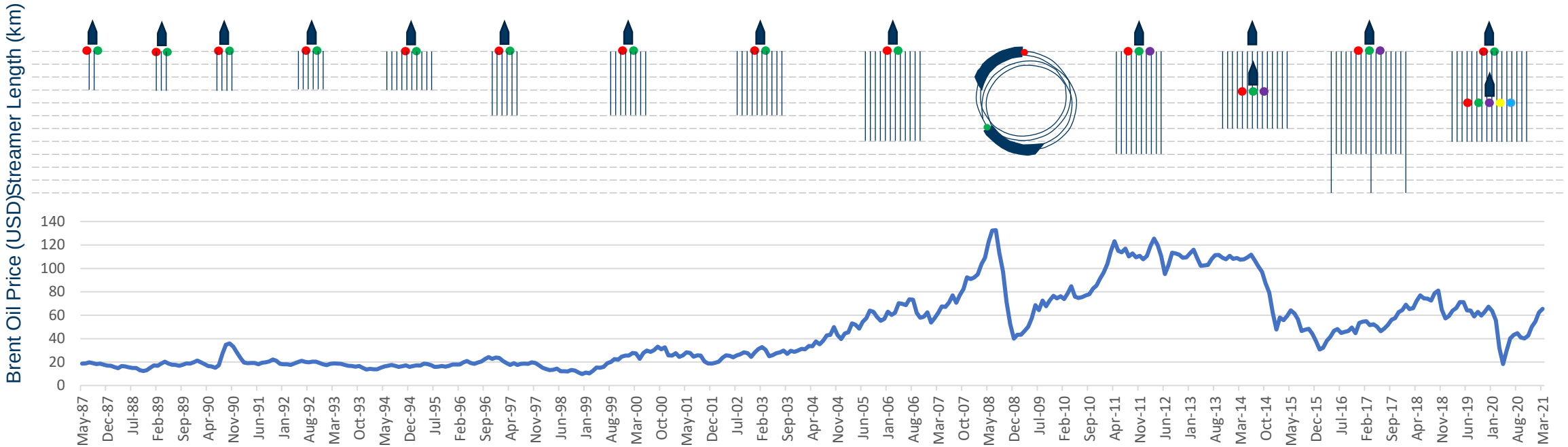

ChemicalTracers
DownholePressureTemperature
SedimentSamples
VSP
SeabedVideo
Gravimetry
Microseismics
Seismic
LaserSurveys
WaterColumnSampling
SeabedDisplacement
InSAR
DownholeFluidSampling

When it comes to applying technology for CCS we need to ask ourselves why?

- Containment & Conformance
  - What is needed to demonstrate containment of CO_2?
  - Image of the CO_2 in the reservoir, the lack of CO_2 elsewhere (direct / indirect)?
  - What is needed to demonstrate conformance with model forecasts?



Overview – Seismic Technology for Carbon Storage Monitoring

Existing Seismic

Regional Screening
Site Suitability

Multiple Data Types

This can include geophysical datasets beyond O&G seismic (e.g. geotechnical data UHR data etc.)

Note: Potential input to velocity models (i.e. XHR input)

Note: Relevance (e.g. Depletion since acquisition)

Cost: Data Purchase
Ops Duration: N/A
Env. Footprint: N/A

New Baseline Surveys

To establish a seabed to base reservoir/aquifer high resolution image

- DAS (VSP) +/- XHR
- XHR
  - +/- Sparse Nodes Or existing vel model
- 3D Conv.
  - + XHR
- Dense Nodes

Cost: Higher run rate
Ops Duration: short duration
Env. Footprint: higher

Early Warning Systems

(Optional based on risk assessment)

Risk focused Monitors
Well / Caprock Integrity / Plume Migration

- DAS Fiber
- DAS (VSP) +/- XHR
- *1-100 Nodes*

Cost: Low cost run rate
Ops Duration: long period (20+yrs)
Env. Footprint: Lower – Low - 0

Triggered / Scheduled Surveys

Full Field 4D Repeats

- DAS (VSP) +/- XHR
- XHR
- 4D Conv.
- Dense Nodes

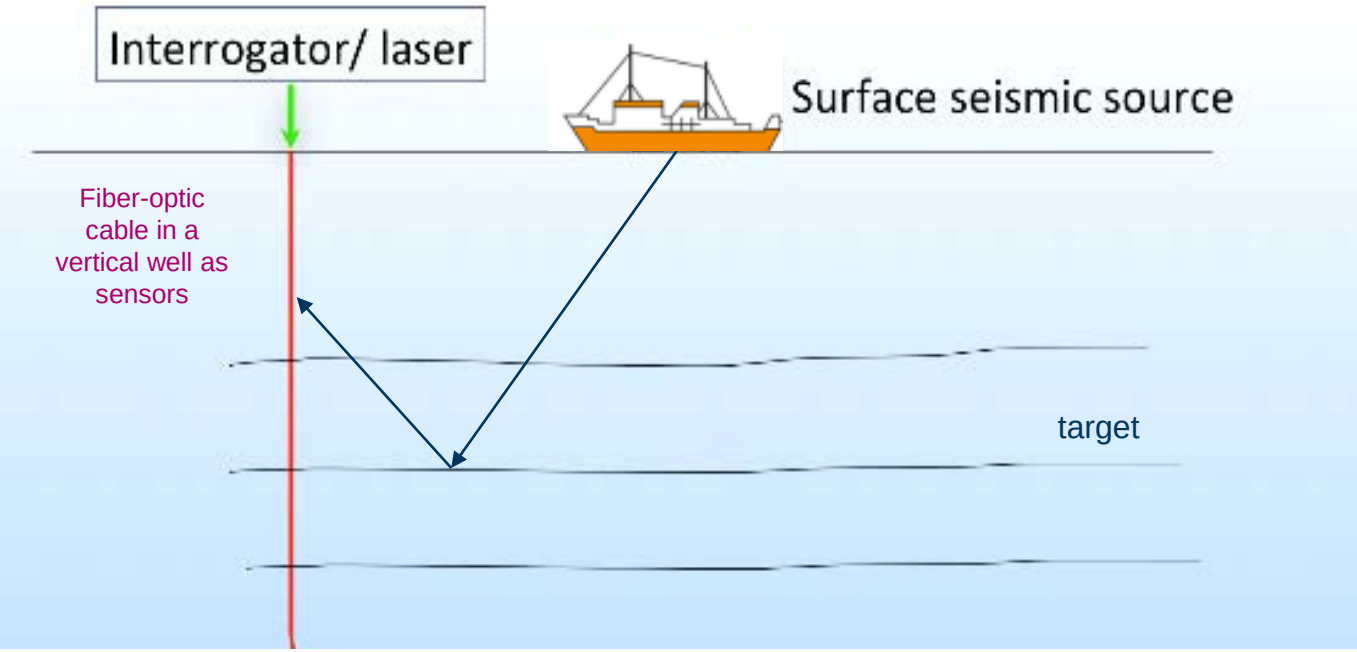
Cost: Higher run rate
Ops Duration: Short
Env. Footprint: Higher

DAS (VSP)

What is DAS?

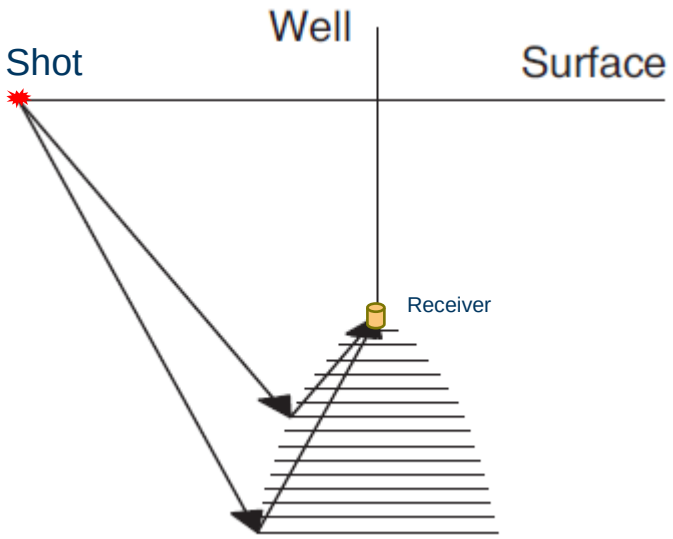
- DAS stands for Distributed Acoustic Sensing, a method that uses a fiber-optic cable as a sensor to record seismic data
- DAS applications in seismic imaging and monitoring

DAS VSP



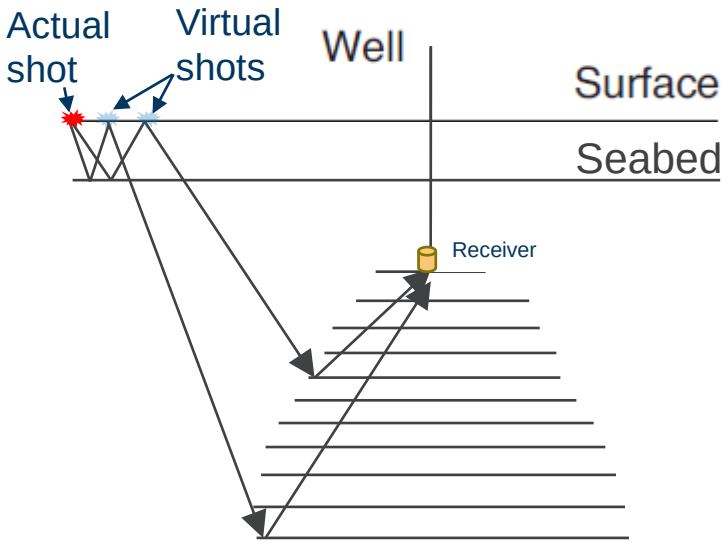
Extended Illumination Provided by Free Surface Multiples

VSP primary imaging
(using upgoing reflections)



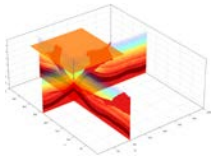
Limited primary illumination around well

VSP multiple imaging
(using 1st-order upgoing multiple reflections)

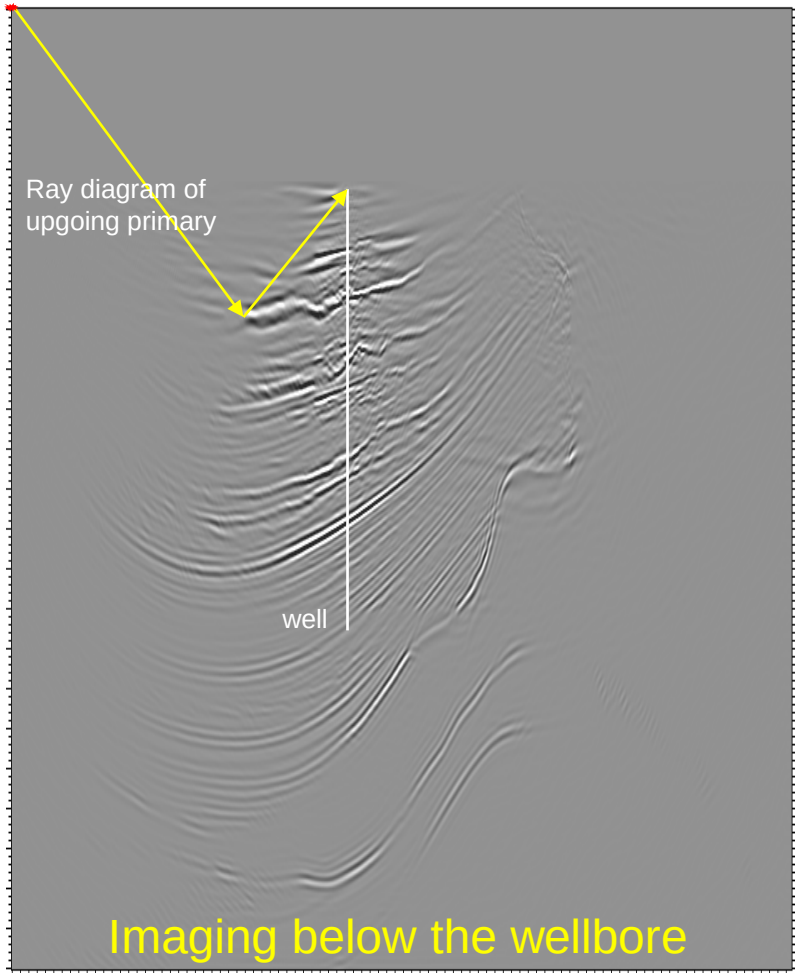


Extended multiple illumination

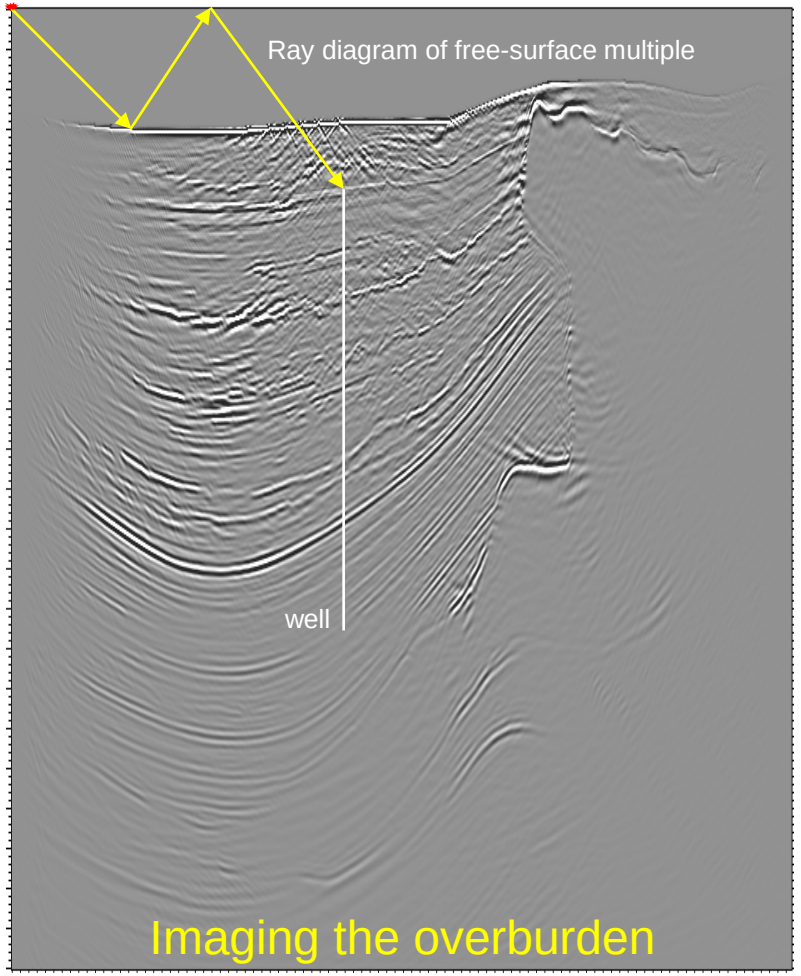
DAS least-squares joint imaging of multiples and primaries
- synthetic example



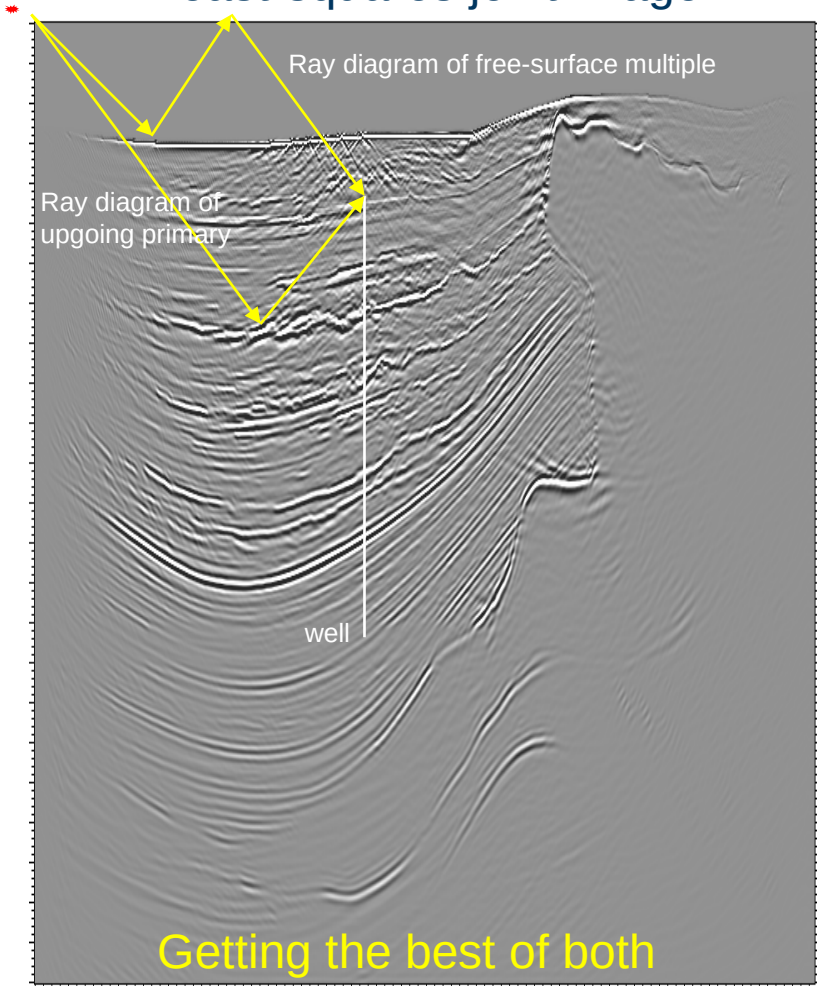
Upgoing primary image



Downgoing multiple image

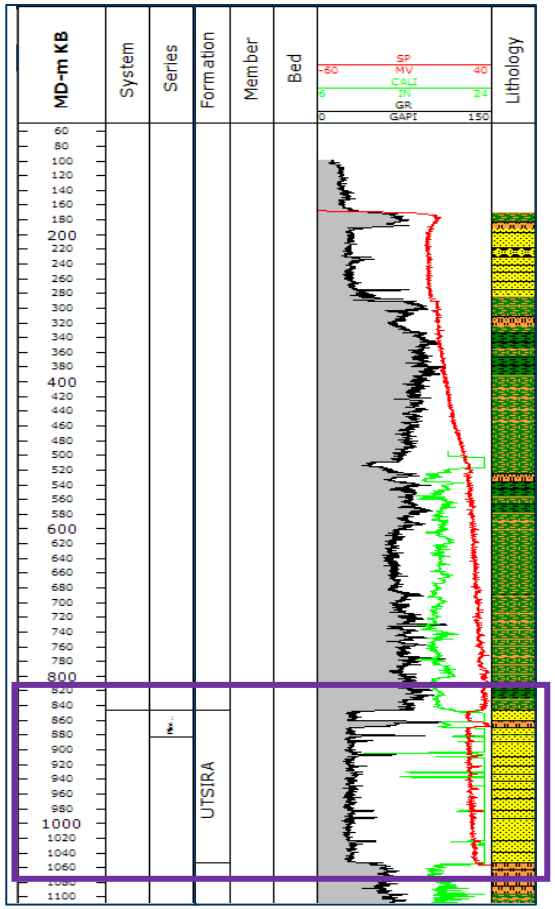


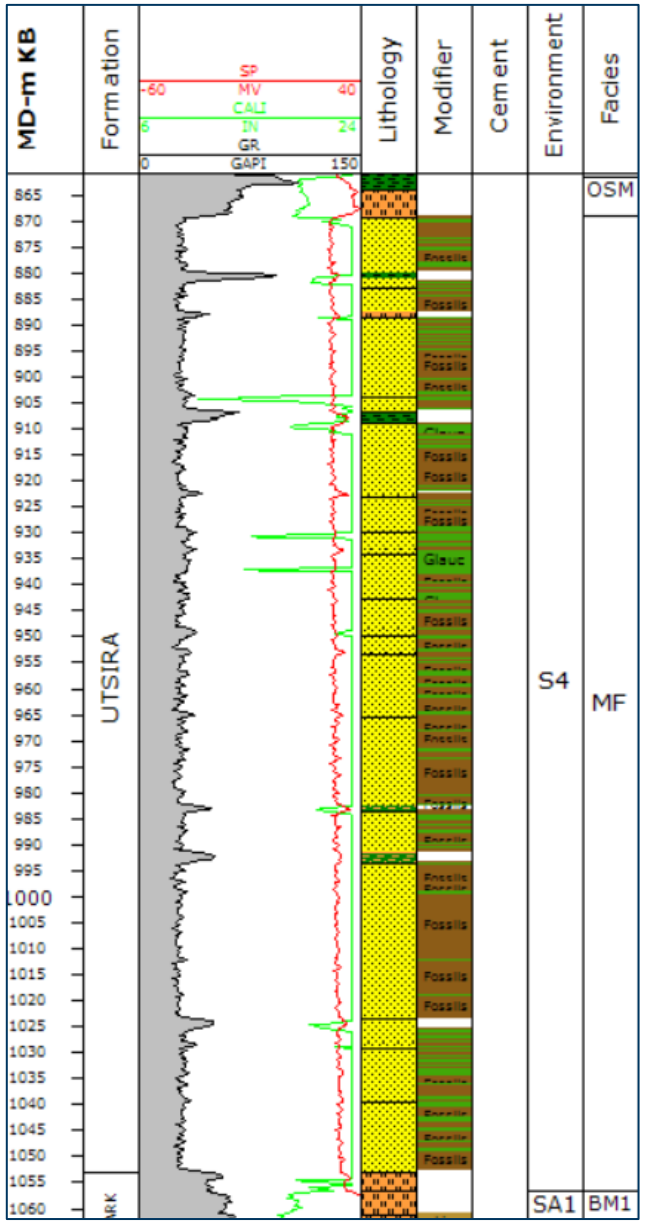
Least-squares joint image

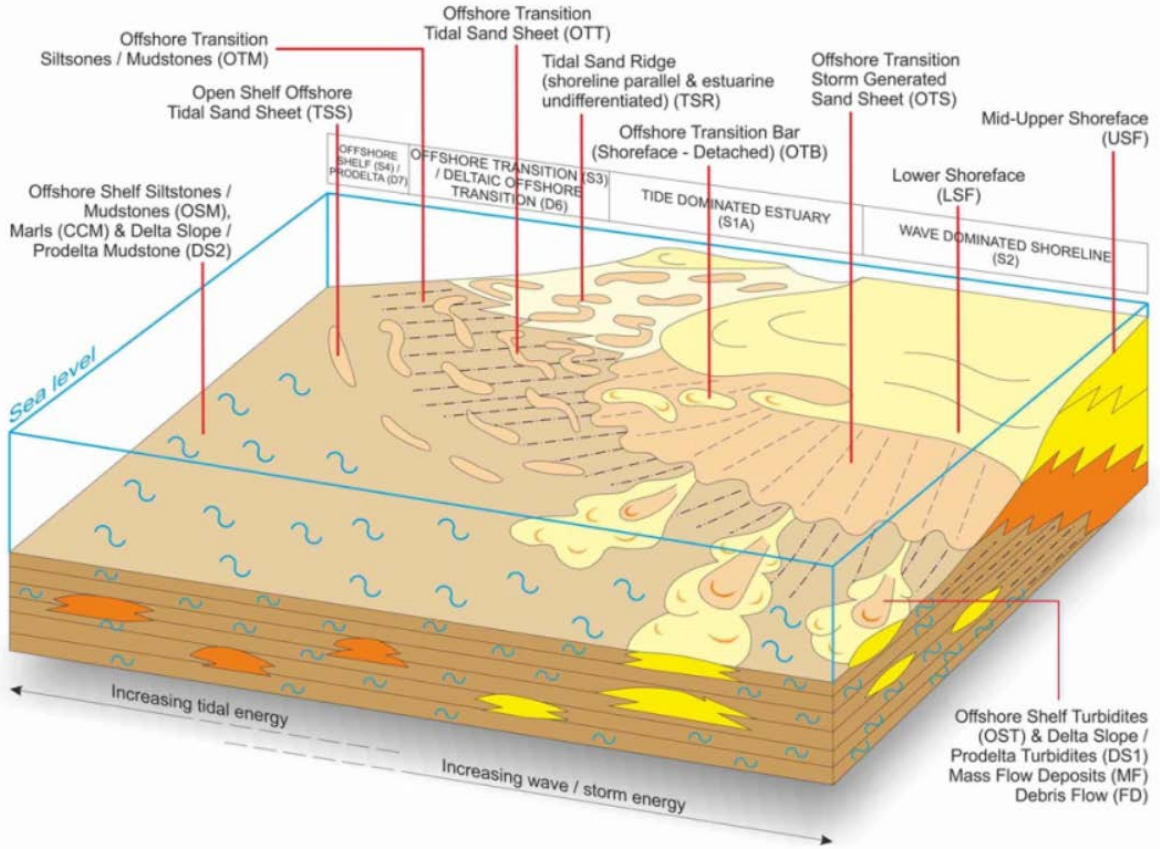


Sleipner Carbon Store
~ 2022 acquisition data

Sleipner 2022 Pilot – Geology



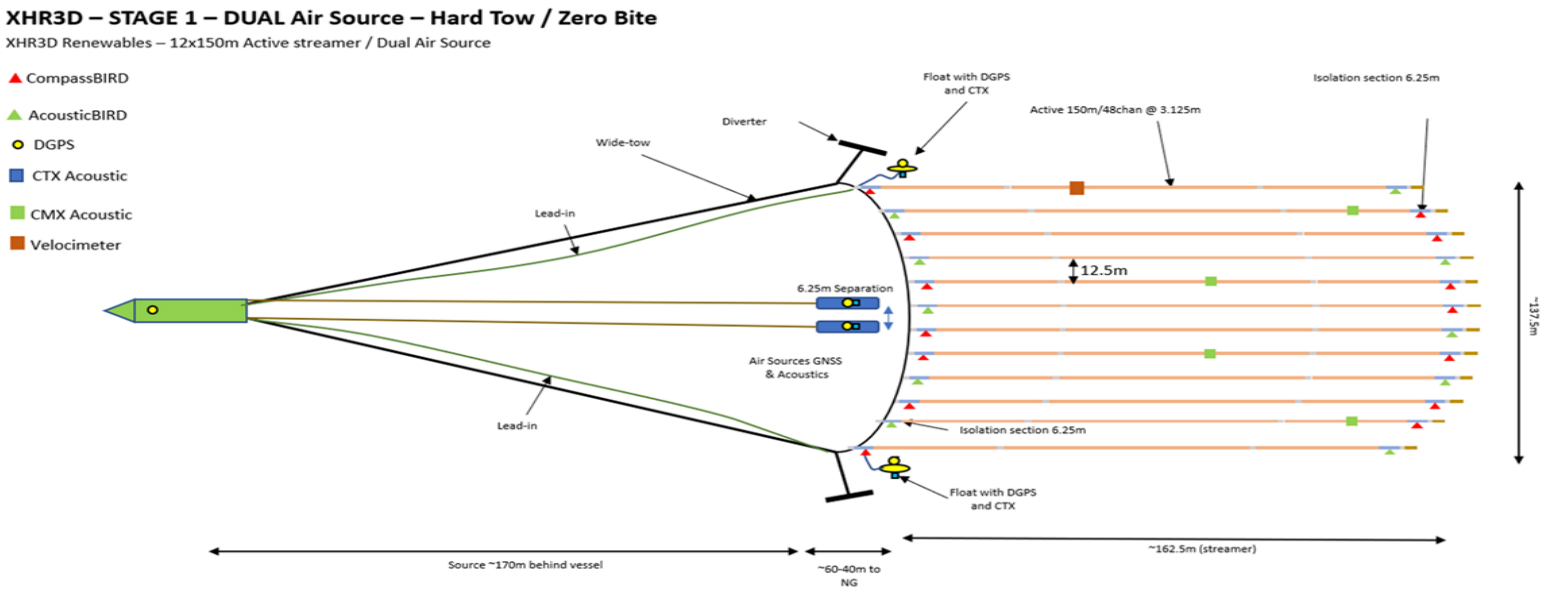


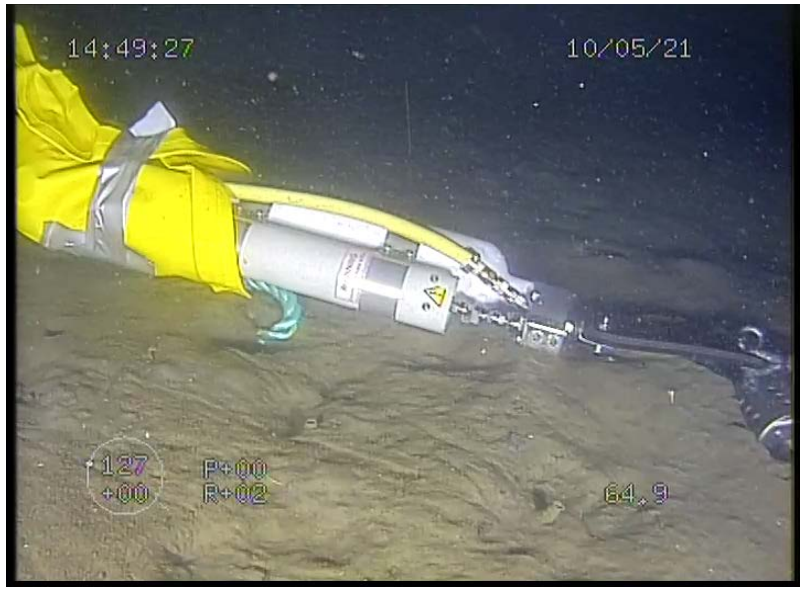


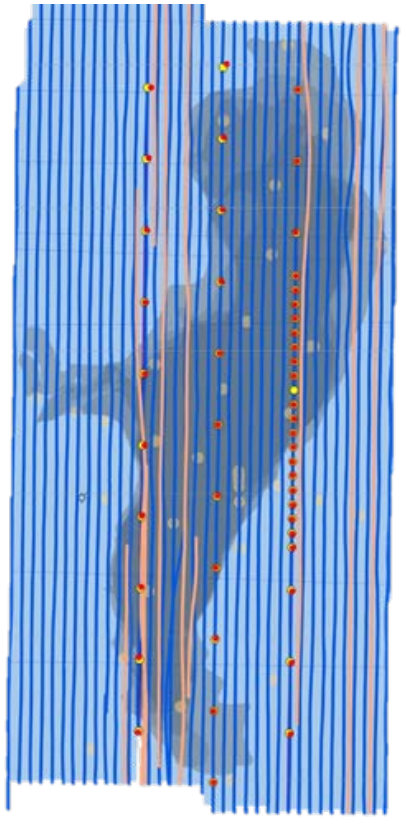
Offshore Transition (S3) / Deltaic Offshore Transition (D6)
& Clastic Shelf (S4) / Prodelta (D7)

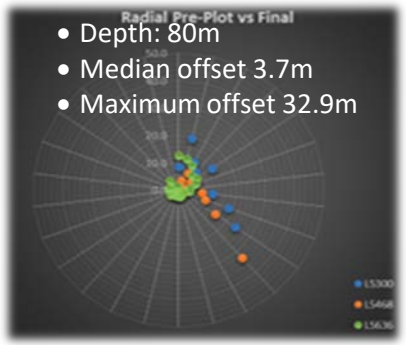
200m interbedded sandstones overlain by 600m sealing lithologies

Sleipner 2022 Pilot - Combining XHR with OBN

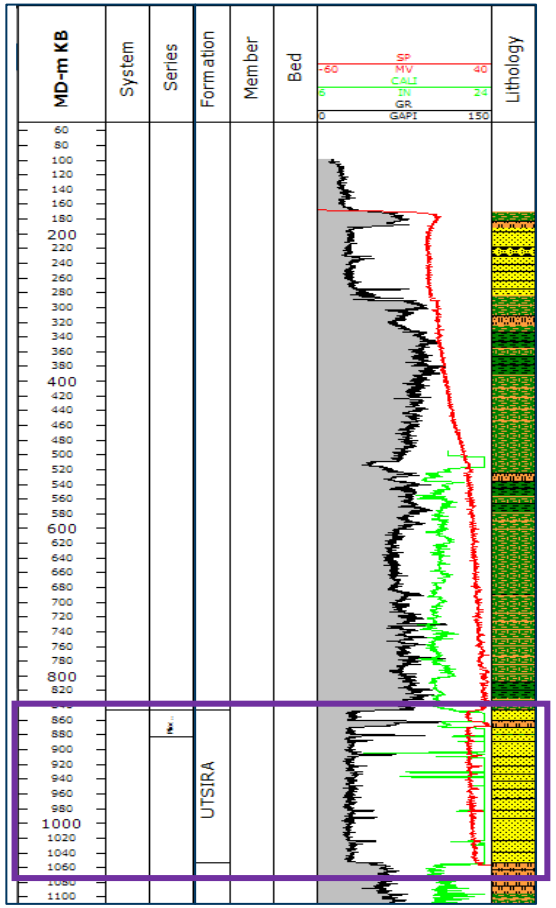


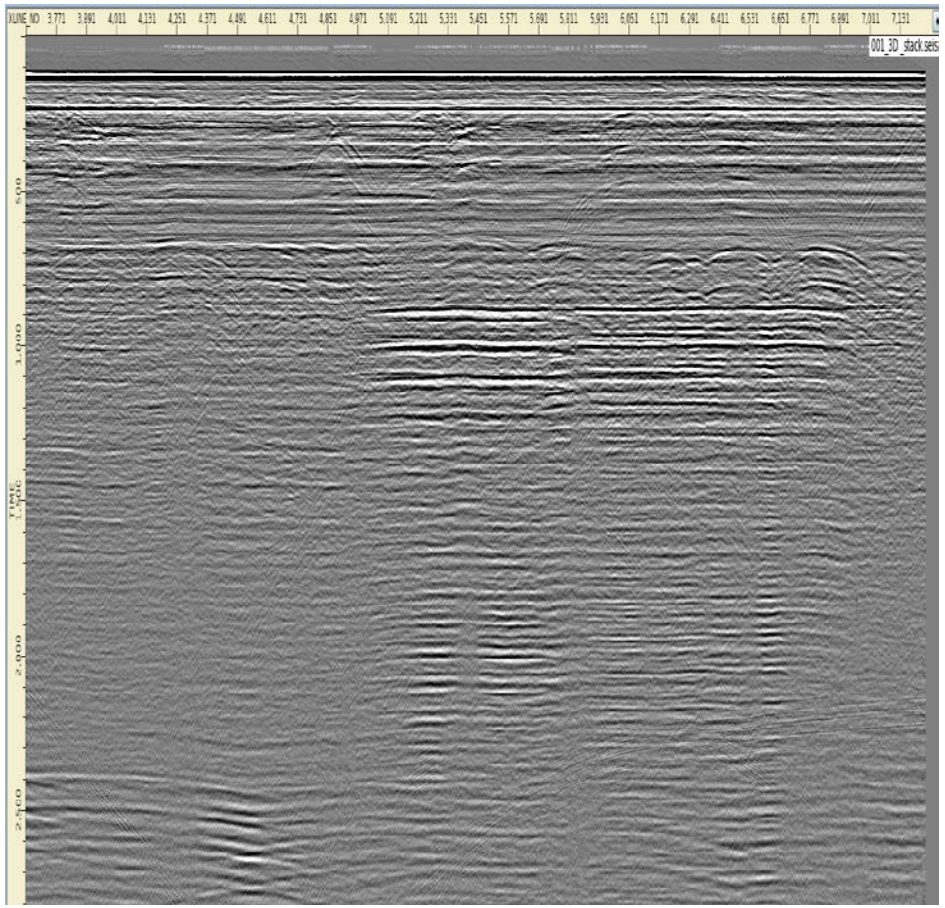


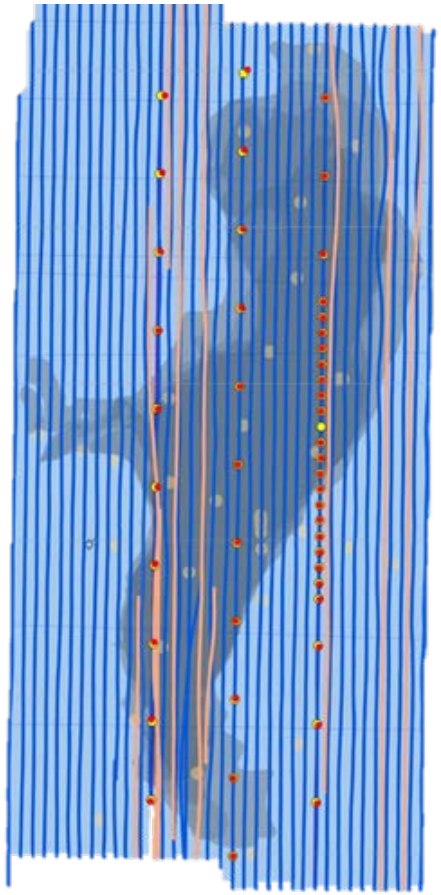




Sleipner 2022 Pilot – A look at the raw data



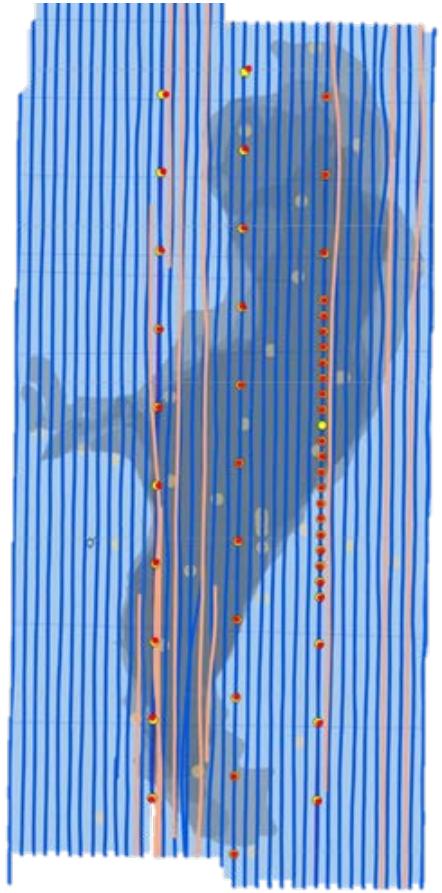


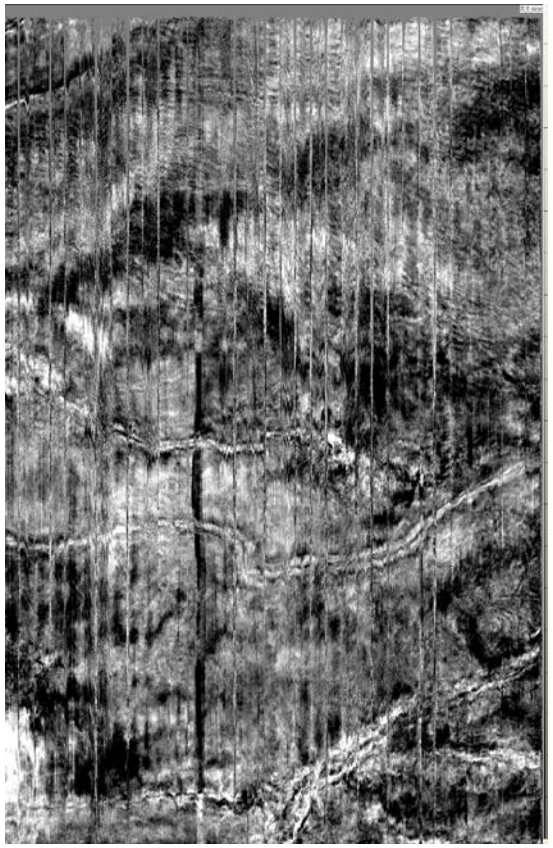


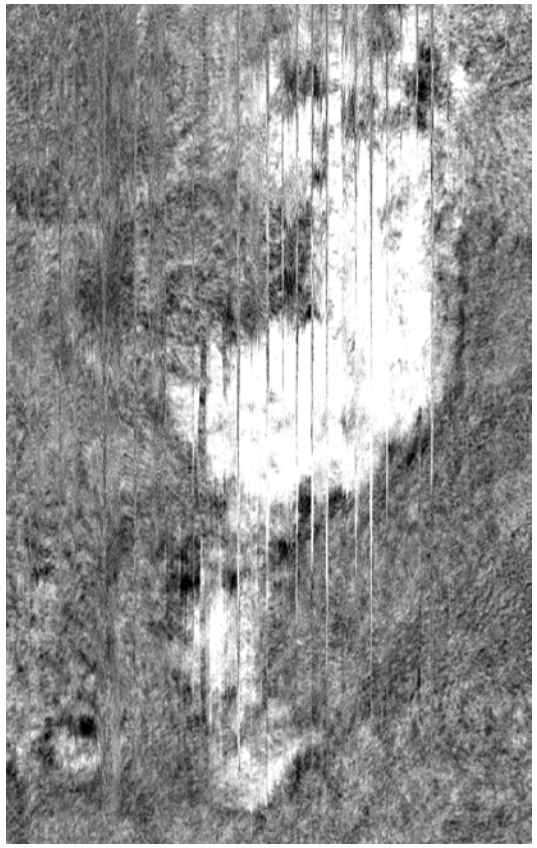
RAW Stack showing depth of penetration and imaging of the vertical heterogeneity within the Utsira Formation as logged in the adjacent 15/9- 13

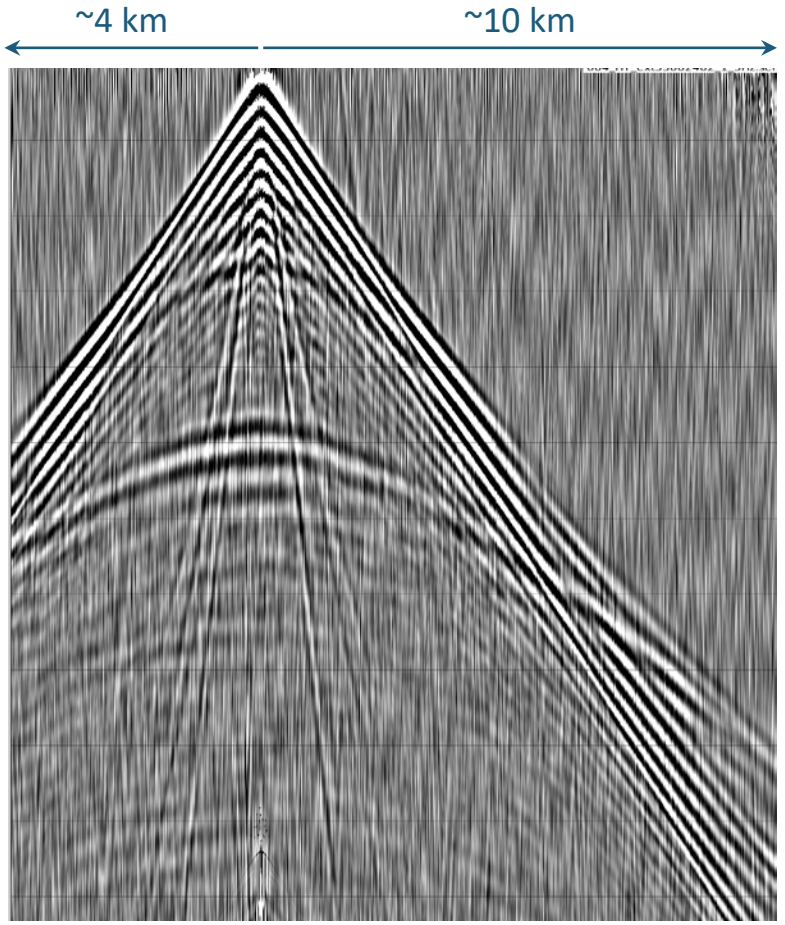
New phase of processing will take FWI VMB from Nodes

Sleipner Initial 3D Results – RAW Data







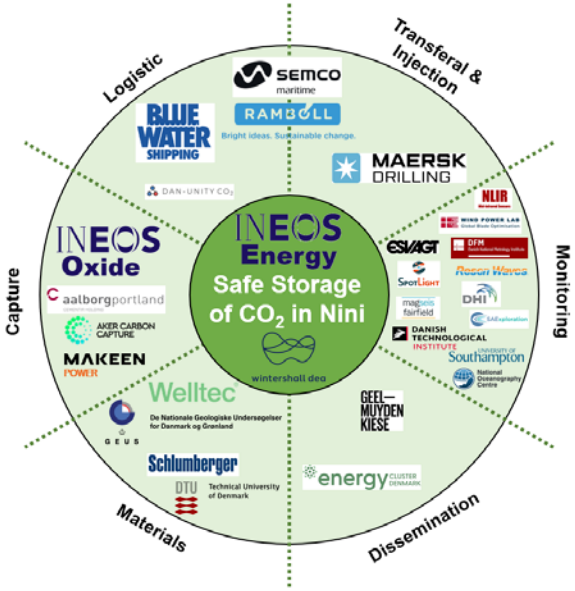


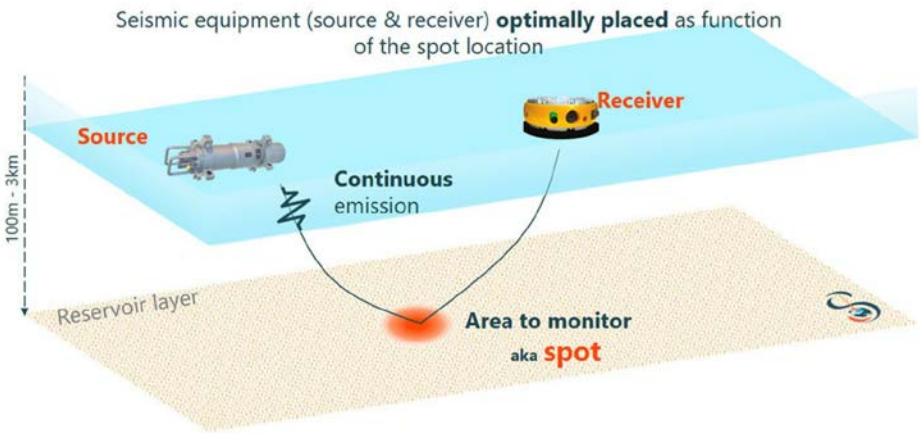
Long offset data on raw nodal hydrophone record (0-5 Hz) for Full Waveform Inversion

Nodes
- Testing a concept

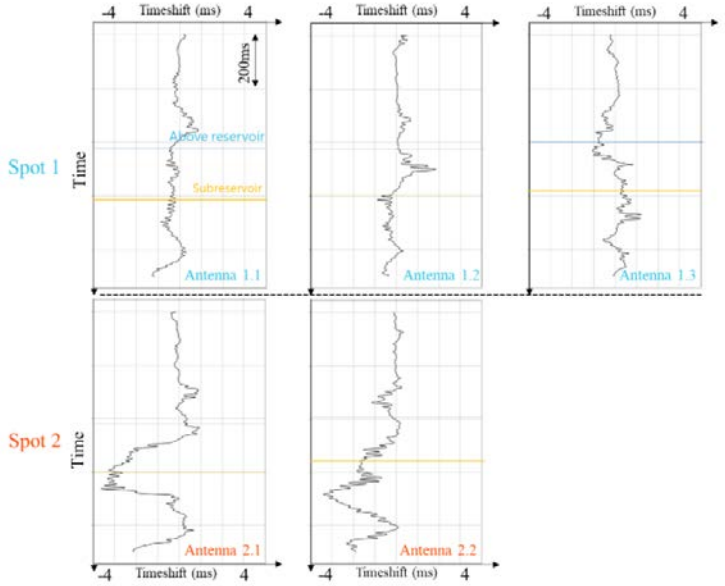
Testing the Spotlight concept at Greensand

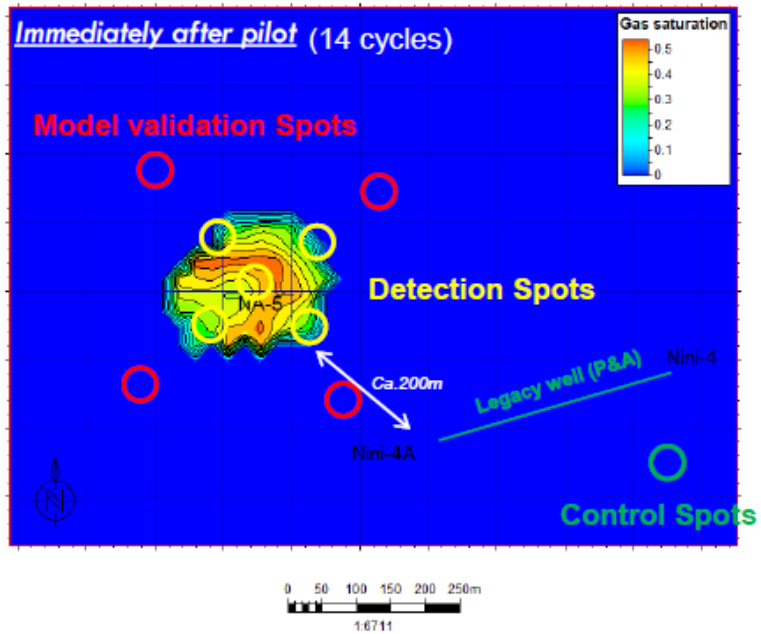
Greensand partners





CO2 related time shifts at Weyburn[2]



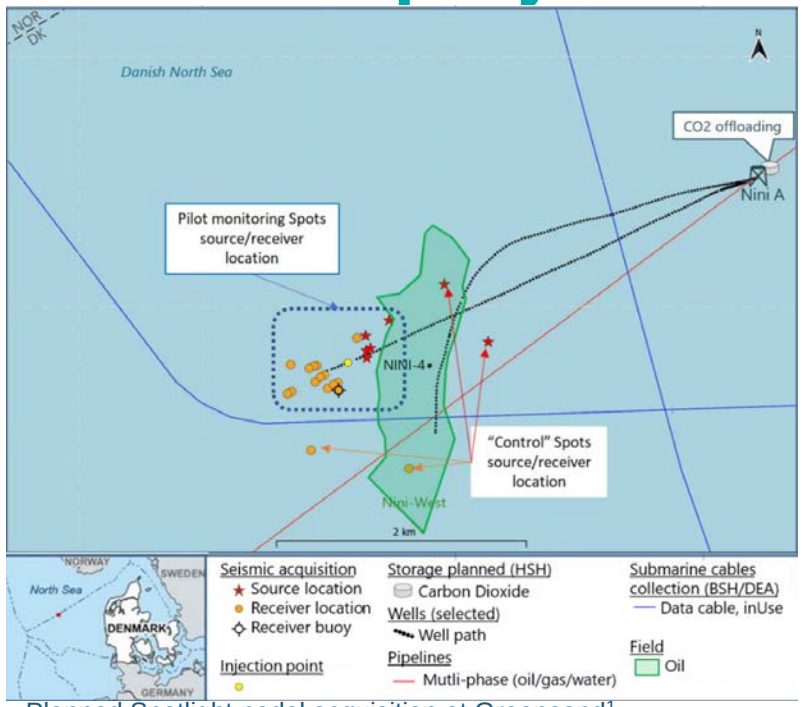


Spotlight concept[1]

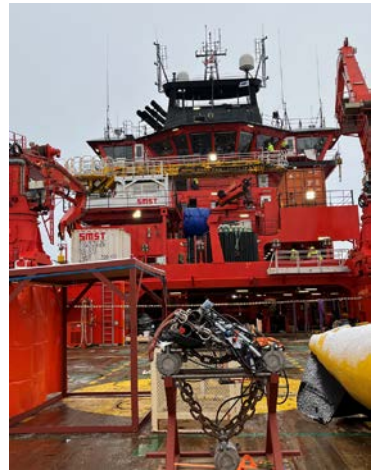
[1] https://jpt.spe.org/shaking-seismic-business-simple-idea
[2] Brun et al, CO2 injection detection using light time-lapse seismic Monitoring, EAGE 2022
[3] Szabados et al, *Greensand Focused Seismic Monitoring for Offshore CO2 Pilot Injection*, GET2022

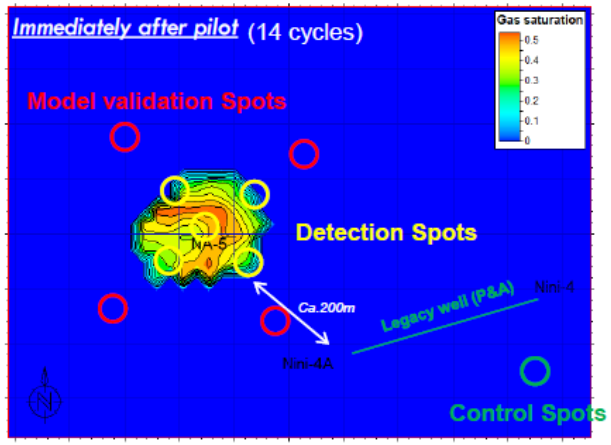
Testing the Spotlight concept in Greensand project

- Key Objectives[1]
  - Demonstrate detectability of CO_2 by means of focused seismic, 1st offshore trial
  - Low energy air gun (600 cu) selected
  - 16 receiver -, 7 source locations planned. 80 shots planned per source location
  - 3 seismic campaigns planned to monitor injection pilot (1-5 days each)
- How:
  - Seismic spots placed geometrically around the injection point to cover entire plume.
  - Detection Spots should confirm CO_2 presence.
  - Model validation Spots should confirm absence of CO_2 according to simulation model during project time.
  - Control Spots are measuring the noise level and repeatability out of reach of the plume.
- Why:
  - Perform full 4D monitoring when model is not confirmed by the spots.



Planned Spotlight nodal acquisition at Greensand[1]





[1] Szabados et al, *Greensand Focused Seismic Monitoring for Offshore CO2 Pilot Injection*, GET2022

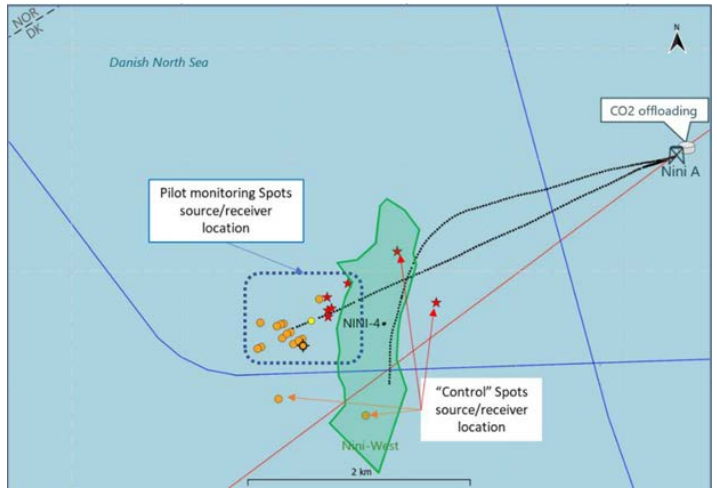
Conclusions

- Current geophysical technologies are very capable of supporting conformance requirements and delivering evidence of CO2 containment in offshore Carbon Stores
- In order to deliver a full monitor, integrated seismic solutions delivering both realtime and periodic data feeds have a role to play
- Seismic MMV plans should be developed in collaboration with drilling and O&M planning as synergies are available that can optimise cost and footprint of monitoring operations
- It is possible to optimise cost levels and environmental footprint of monitoring activities in line with operational duration and emissions intensity

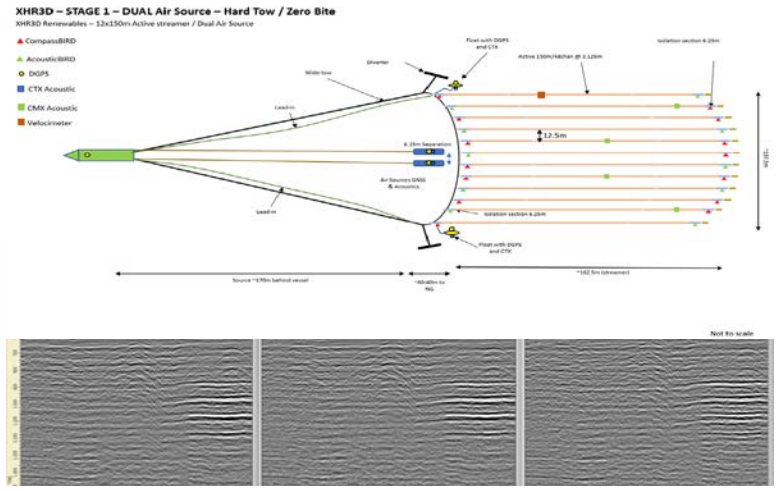
Acknowledgements

TGS is currently operating a node deployment program for “spot” monitoring together with SpotLight over the Greensand CCS site in Denmark as part of the consortium.

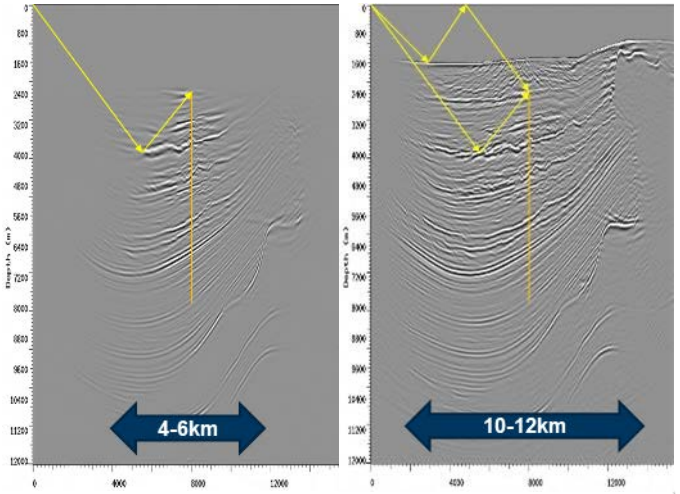
GREEN SAND



The recently completed XHR acquisition over the Sleipner field. The survey was designed to evaluate XHR 3D, sources and sparse to dense node lines for CO2 plume imaging. The program was conducted in collaboration with equinor and CLIMIT



TGS IMG has developed new approaches to DAS(VSP) imaging. TGS in collaboration with HALLIBURTON offers installation and processing of DAS data. TGS currently has a collaboration with to evaluate 3 and 4D monitoring technologies for C Horisont Energi



Will.Bradbury@tgs.com

Will.Bradbury@tgs.com