3DHR Seismic Acquisition for CCS and considerations for Windfarm UHR

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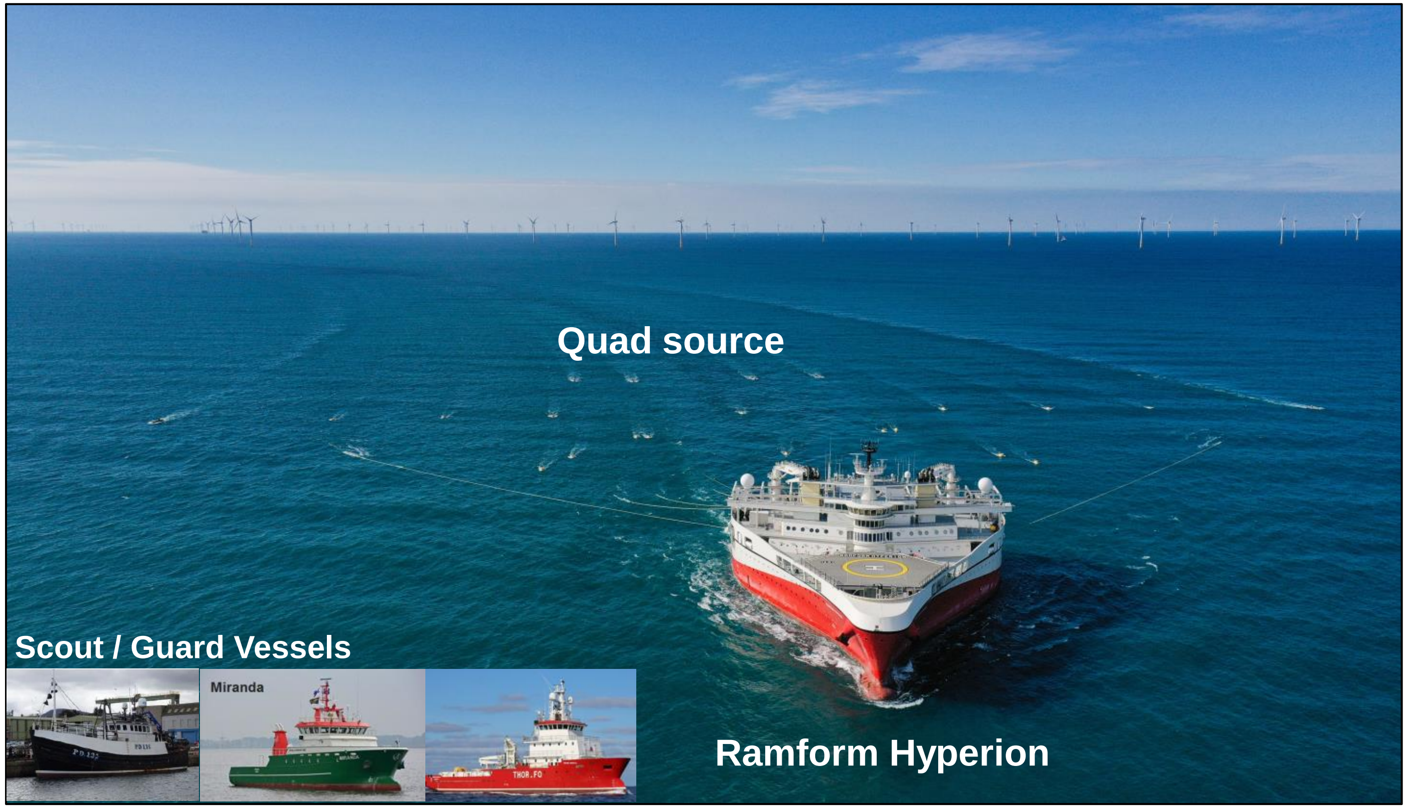
Introduction

The Northern Endurance Partnership (NEP) acquired a survey with PGS in 2022 using a novel quad source configuration, in order to image three CCS structures in the Southern North Sea, as part of one of the largest offshore CCS surveys to date. **bp is also increasingly involved in the offshore wind sector** which requires UHR data on large scales.

Key takeaways from talk:

- **Why seismic is critical for CCS and windfarm developments**
- **An understanding of the challenges** associated with CCS and windfarm survey planning and design
- **How these challenges can be addressed** in planning and implementation
- **Transferrable learnings** for other surveys

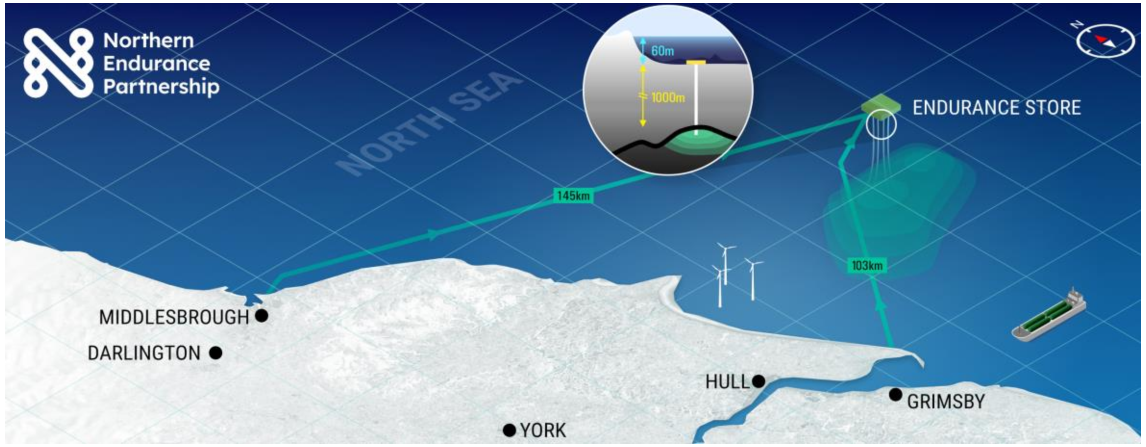


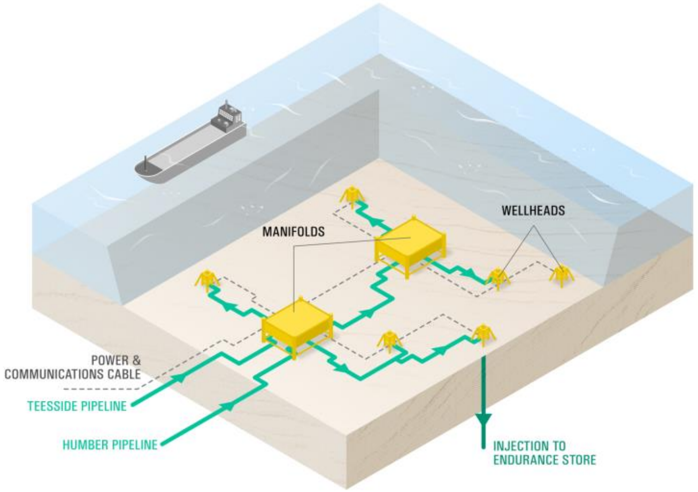
Content

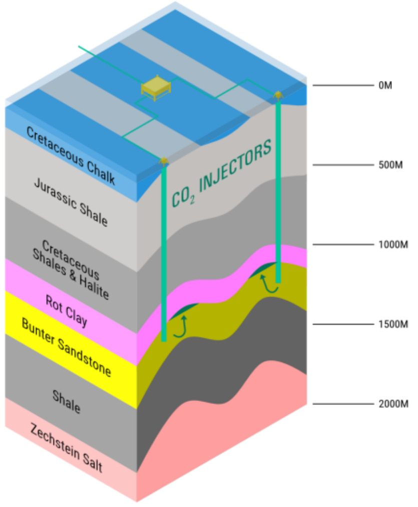
- Why acquire new 3D seismic data at the NEP CCS site?
  - Business and technical context
- CCS/NEP focus:
  - Survey Design Process
    - Objectives and challenges
    - Configurations
  - Operational implementation and preliminary results
  - Conclusions and Recommendations
- Considerations for Wind Acquisition

The Endurance Carbon Store

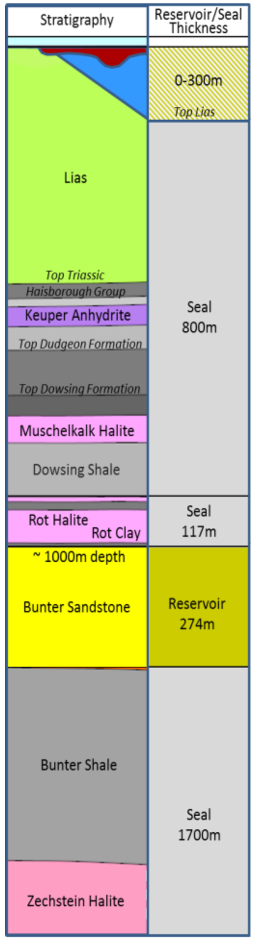
- First-of-a-kind offshore low carbon CCS infrastructure in the UK
- CO_2 injection into a saline aquifer is a worldwide proven concept
- Largest saline aquifer in Southern North Sea – capacity to store several hundred million tonnes of CO_2
- CO_2 pipelines from Teesside and the Humber
- Compression and pumping systems to a common subsea manifold and well injection site at the Endurance store
- Phase 1 injection of 4MTPA for 25 years

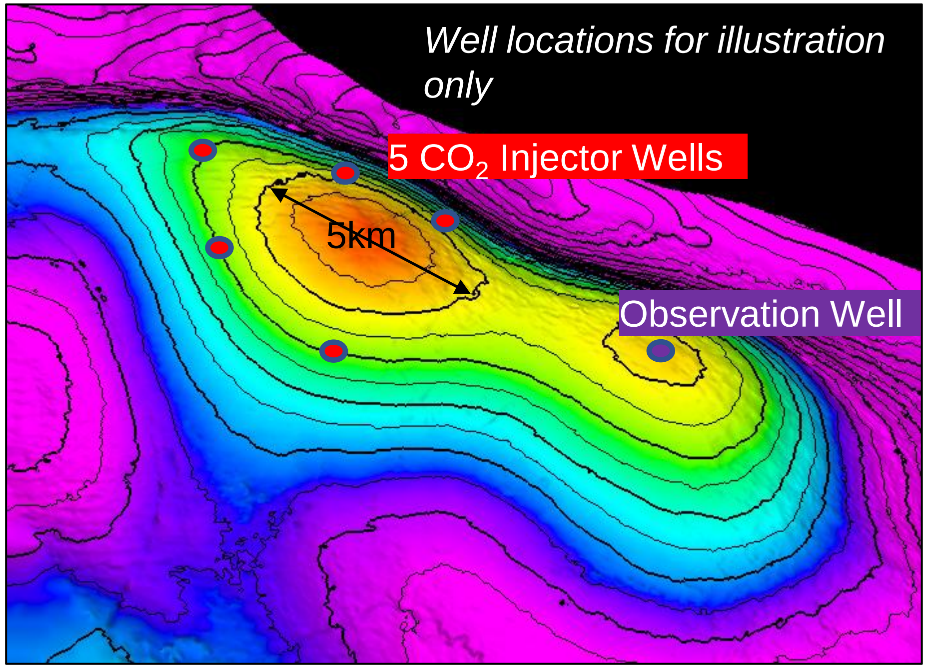


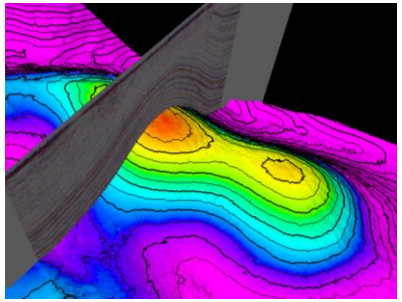


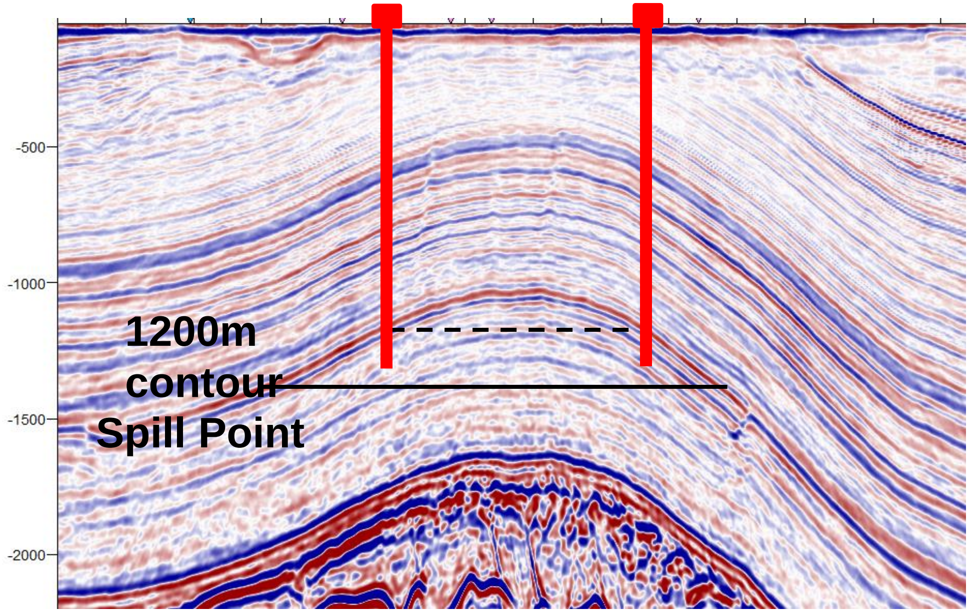


Phase 1 development

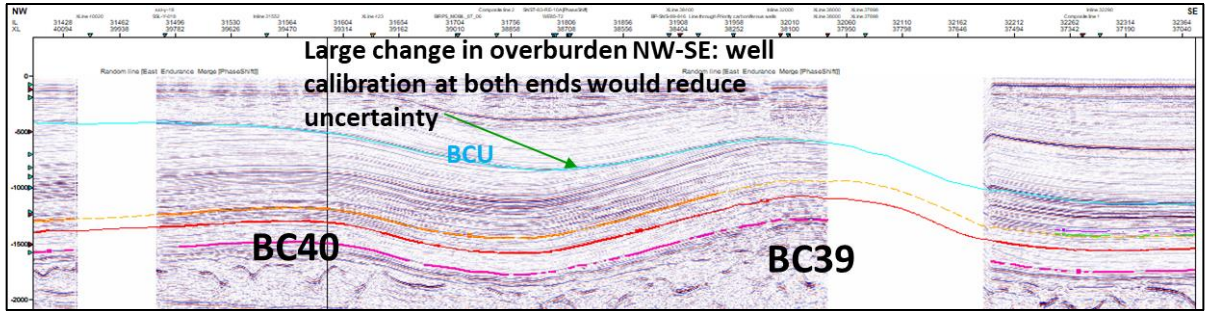


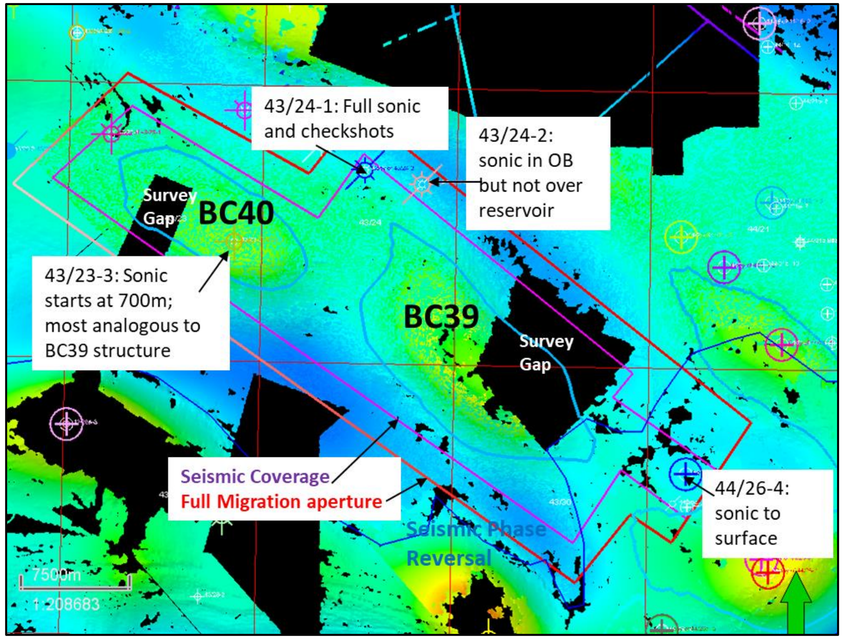






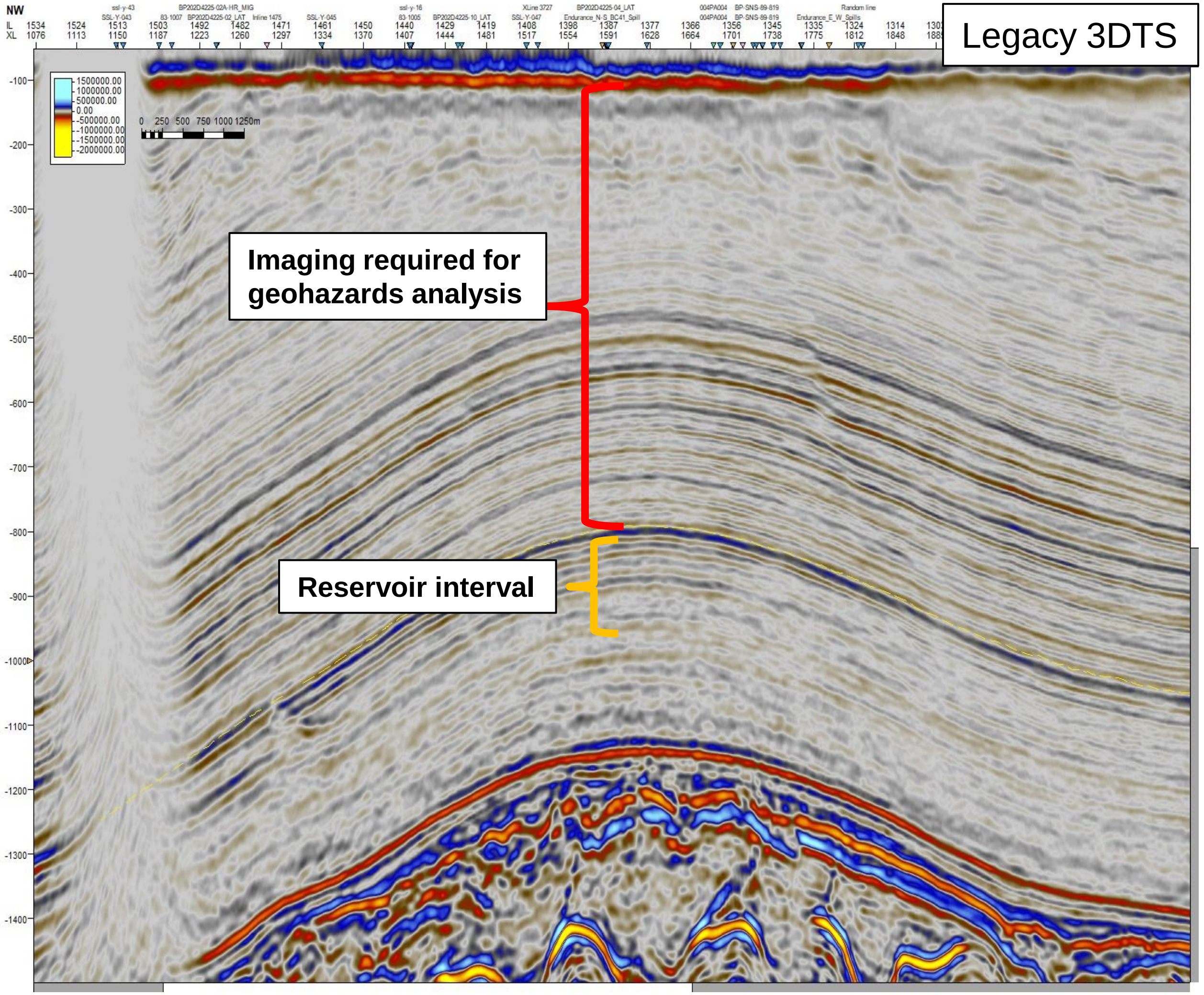
BC39 and BC40 (Expansion)

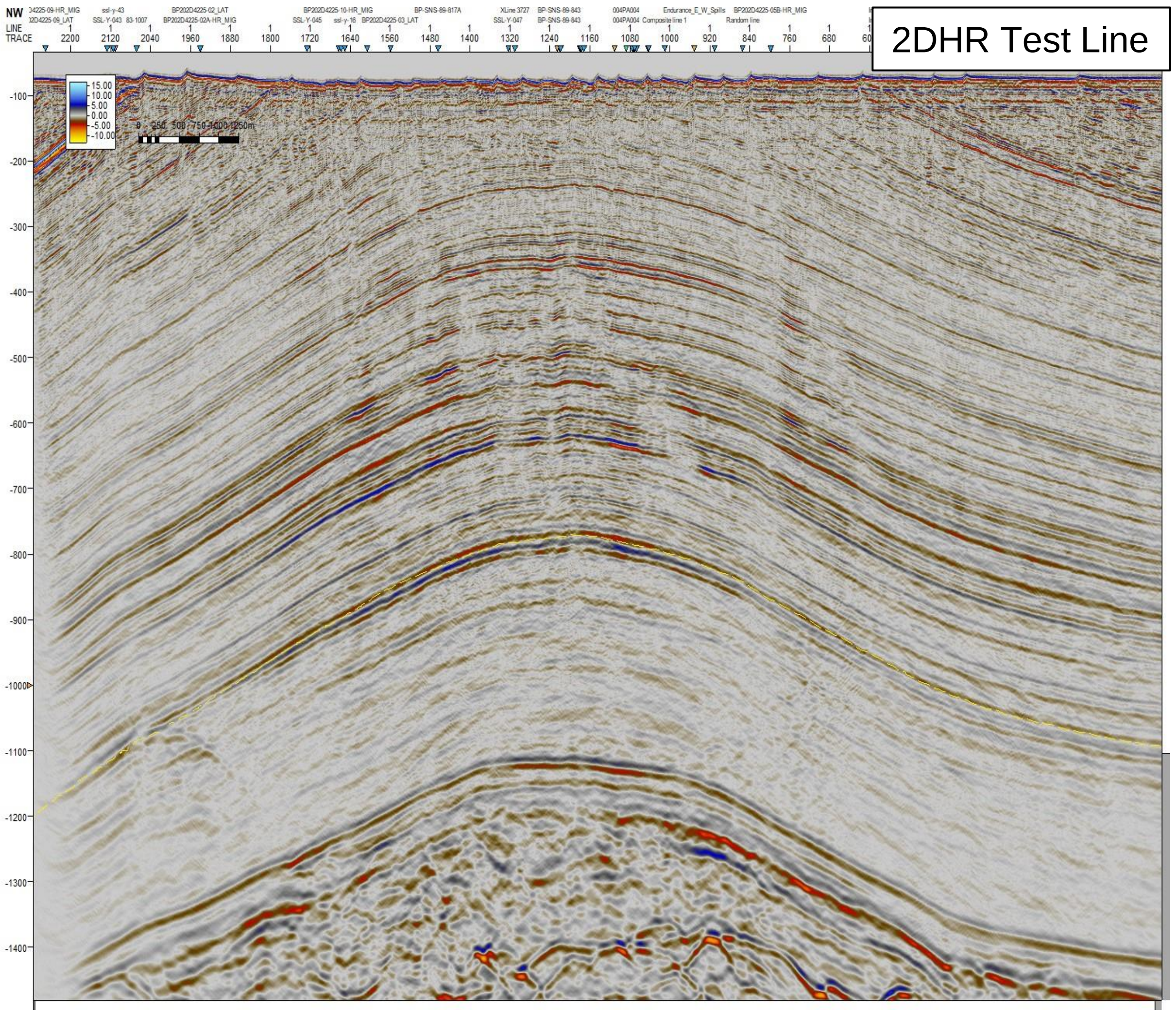




- BC39 and BC40 are both missing portions of seismic coverage: a new 3D is required ahead of a BC39 appraisal well in 2024
- The structures are very similar to Endurance so a similar 3D seismic survey would be appropriate
- No well on BC39 - the acquisition area should cover existing wells to calibrate
- Acquiring the same seismic survey over both structures would mean that appraisal well results from BC39 are much easier to extrapolate to BC40
- BC40 has a shallow structural closure and spill point uncertainty could change capacity estimates significantly.

Key prior datasets – Legacy 3DTS and 2DHR





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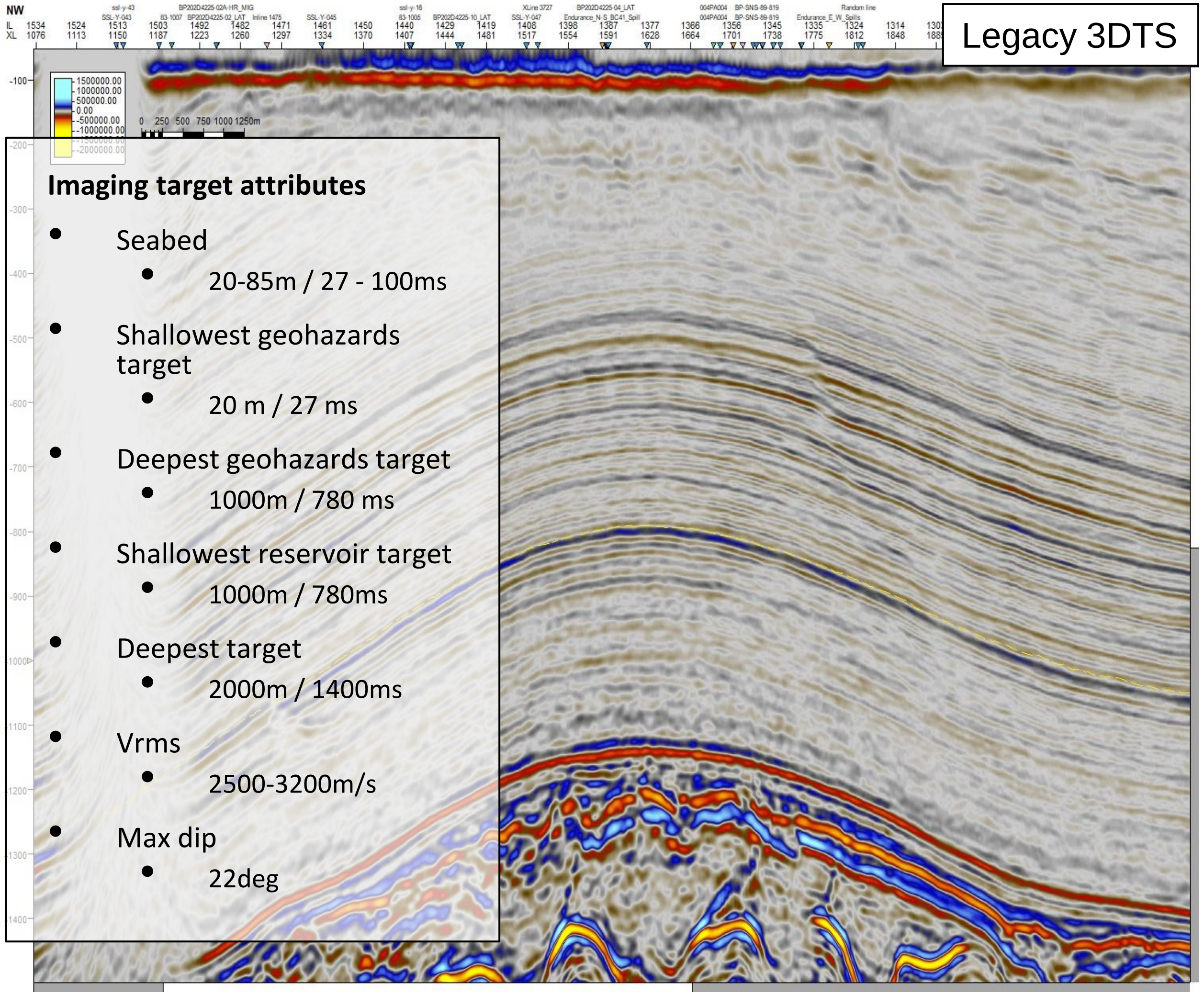
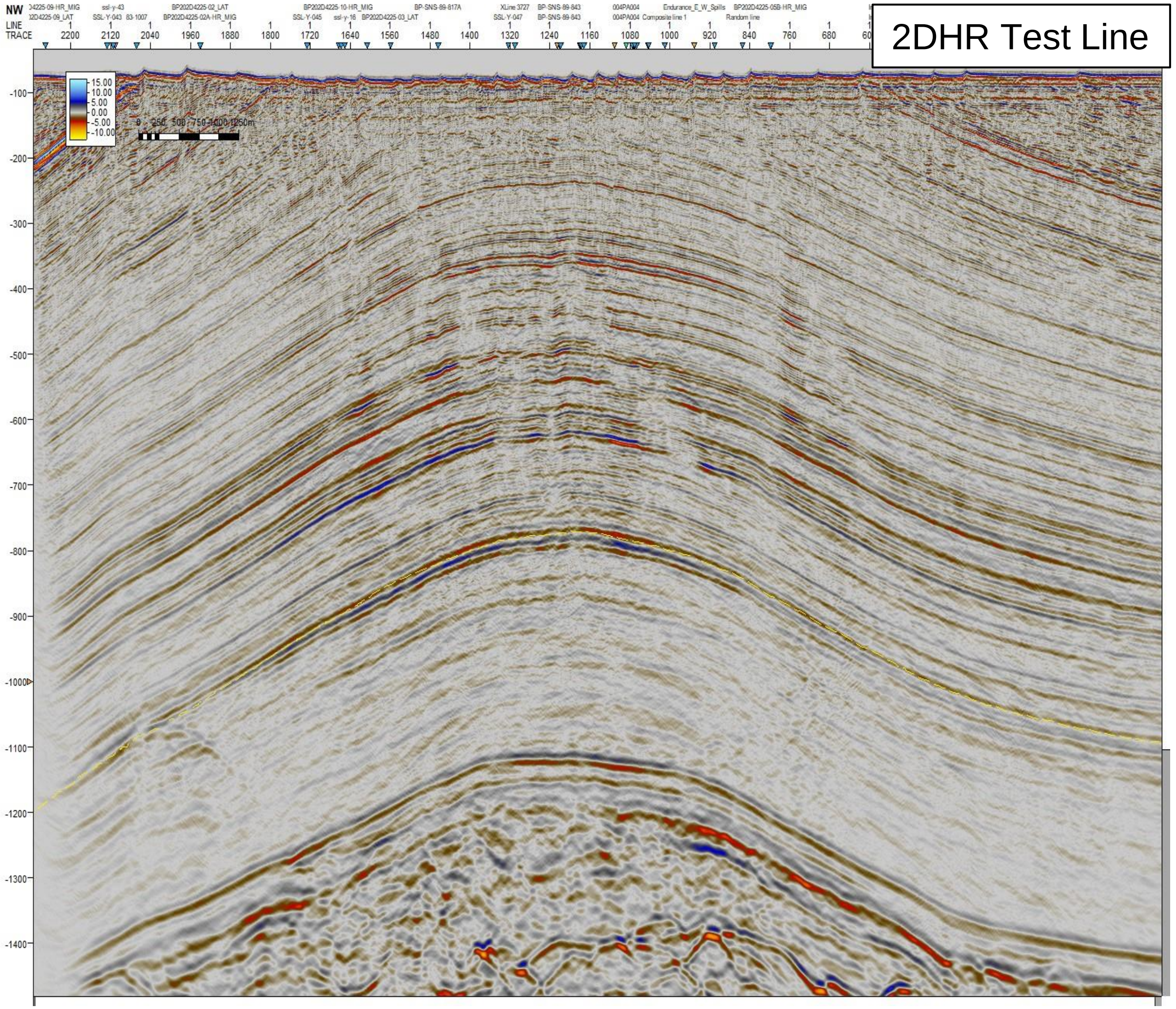


Imaging target attributes

- Seabed
  - 20-85m / 27 - 100ms
- Shallowest geohazards target
  - 20 m / 27 ms
- Deepest geohazards target
  - 1000m / 780 ms
- Shallowest reservoir target
  - 1000m / 780ms
- Deepest target
  - 2000m / 1400ms
- Vrms
  - 2500-3200m/s
- Max dip
  - 22deg



Why acquire new 3D seismic (CCS)?

Existing conventional towed-streamer seismic data inadequate:

- Gaps in 3D coverage
- Cannot image small scale reservoir features and faults
- Poor shallow imaging – missing near offsets
- Uncertainty on velocity model

All of this reduces NEP's ability to understand the following:

- CO_2 storage capacity
- Optimal injection well locations
- Reservoir distribution and baffles
- Shallow hazards
- Storage integrity
- Connectivity between CCS structures
- Baseline for future 4D monitoring

2D HR test lines were acquired in 2020 to inform the 3D acquisition parameters and the assess the benefits of HR data compared to standard TS

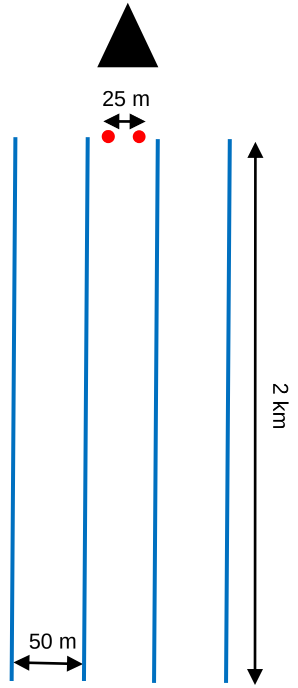
Key Challenges with survey design – NEP CCS

- HR data is generally acquired over small areas (i.e. several km^2) compared to 1600 km^2 for NEP
  - Standard HR solutions would take prohibitively long to acquire
- Imaging of seabed (20 m) to shallow reservoir requires ultra-near offsets over large area
  - While maintaining far offsets ~ 2000 m
- CCS seismic market not yet well developed – not many ‘off the shelf’ solutions
  - Useful analogues include in the Barents sea and in the site survey world
- Survey needed to be very cost-effective given CCS economics
- Large areas of shallow water (20-30m) can pose challengers

NEP CCS Survey Design Requirements / Example Configuration

- Design requirements were based on a 4 streamer solution that would:
  - Meet the near offset criteria
  - Be achievable / practical for a number of suppliers
- However, **it was left open to potential suppliers to offer different solutions as long as the key design criteria were met**

Key design solution constraints:
- **25 % of CMP lines to have near offsets of < 30 m**
- **50 % of CMP lines to have near offsets of < 60 m**
- **Minimum fold of 80, at 2 km max offset, 12.5 XL bin**
- **2 second clean record length**
- Max offset – at least 2 km
- Source – 300-500 cu.in



4 streamer example solution

Key design features:
- 4 streamers separated by 50 m
- Dual sources separated by 25 m
- 0 inline offset
- Fold of 80 at 12.5 m (XL) x 6.25 m (IL) bin size

NEP CCS Survey Final Configuration

- The final configuration illustrated below was proposed by PGS to meet the stringent near-offset requirements
- Note that a 5 % fan was implemented in the field to minimize infill

Key design features:
- 9 streamers separated by 50 m
- Quad sources (400 cu.in) separated by 62.5 m
- 6.25 m shot interval
- Source inset by 130 m in inline sense within streamers
- Coverage overlap between sail-lines to give 40 fold on a 6.25 m bin grid

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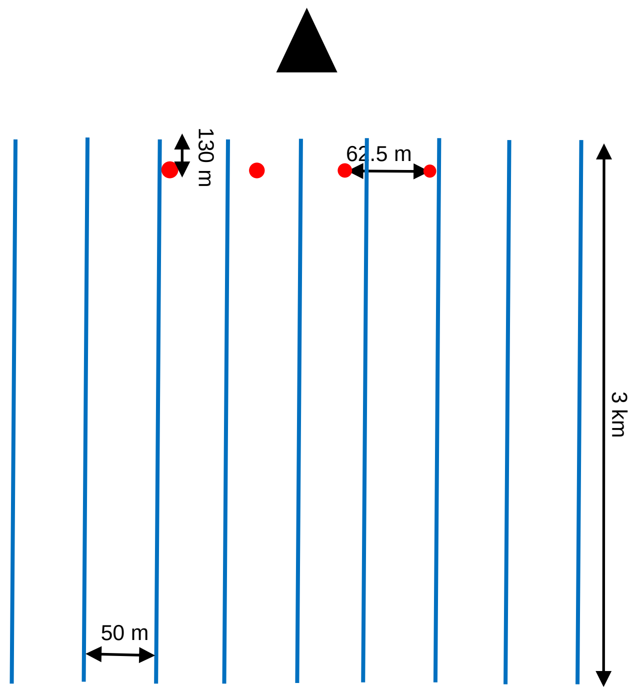
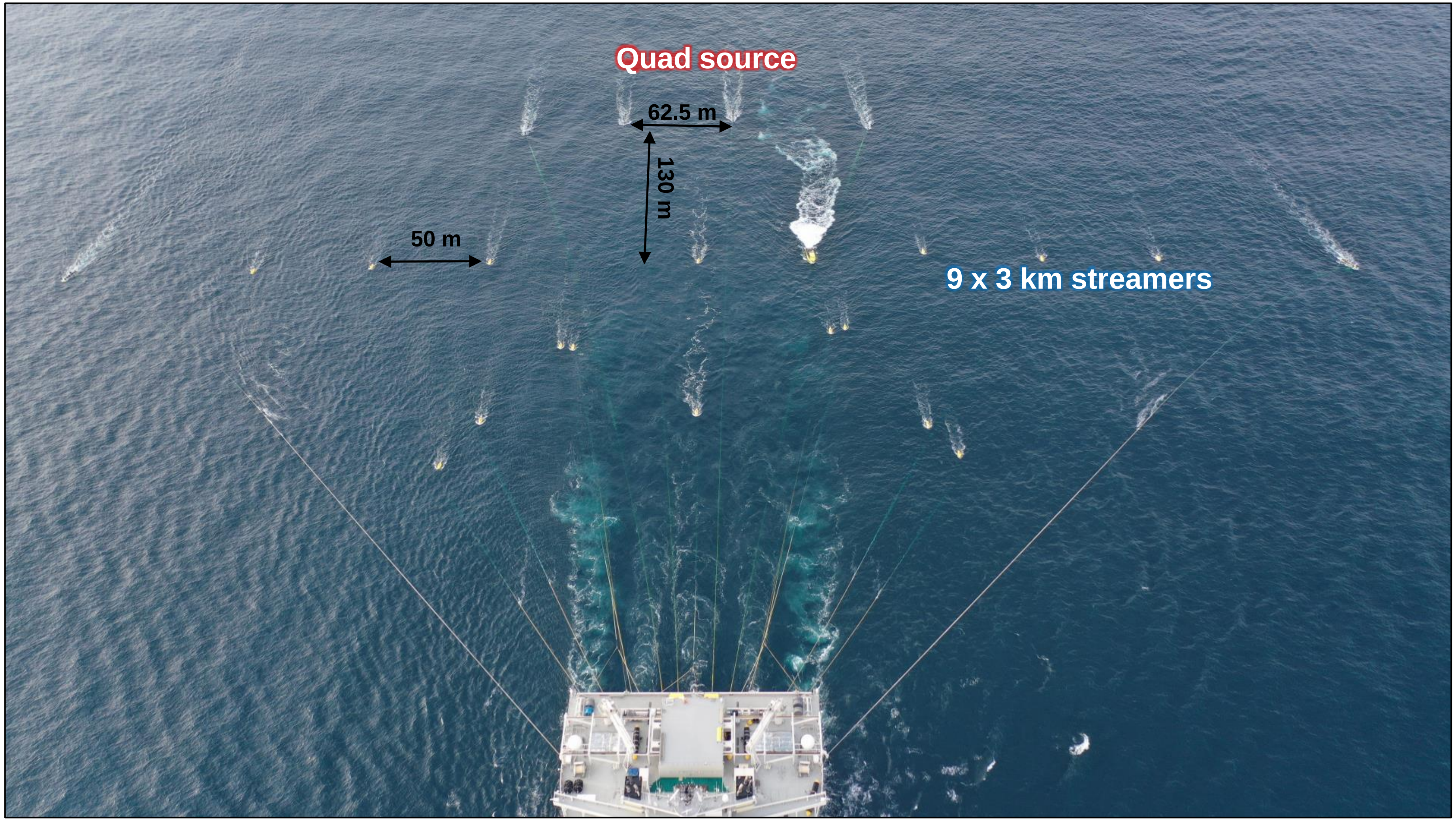
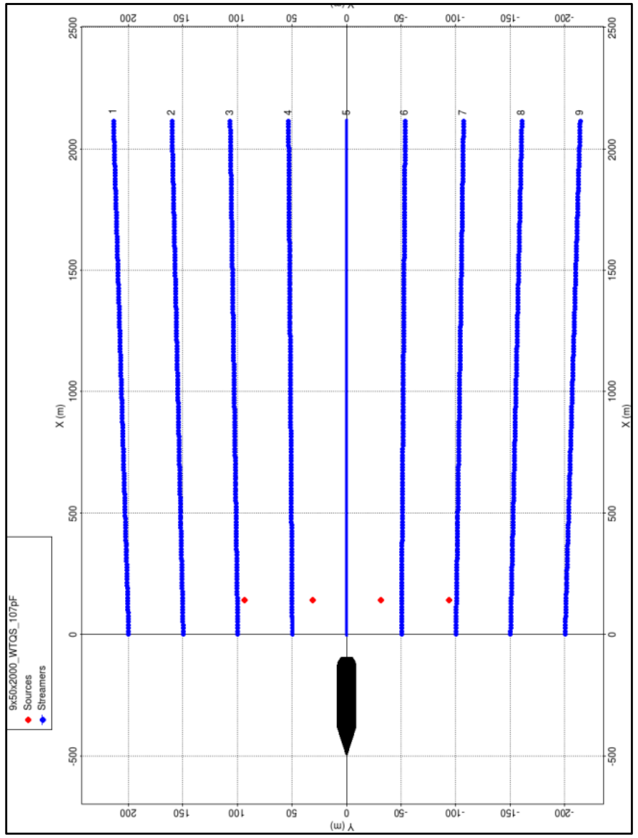


9 streamer solution

Key design benefits:
- ~ 2 x efficiency of 4 streamer solution
- Both positive and negative very near offsets
- Natural 6.25 m bin size in XL
- Additional far offsets up to 3 km
- Geostreamer

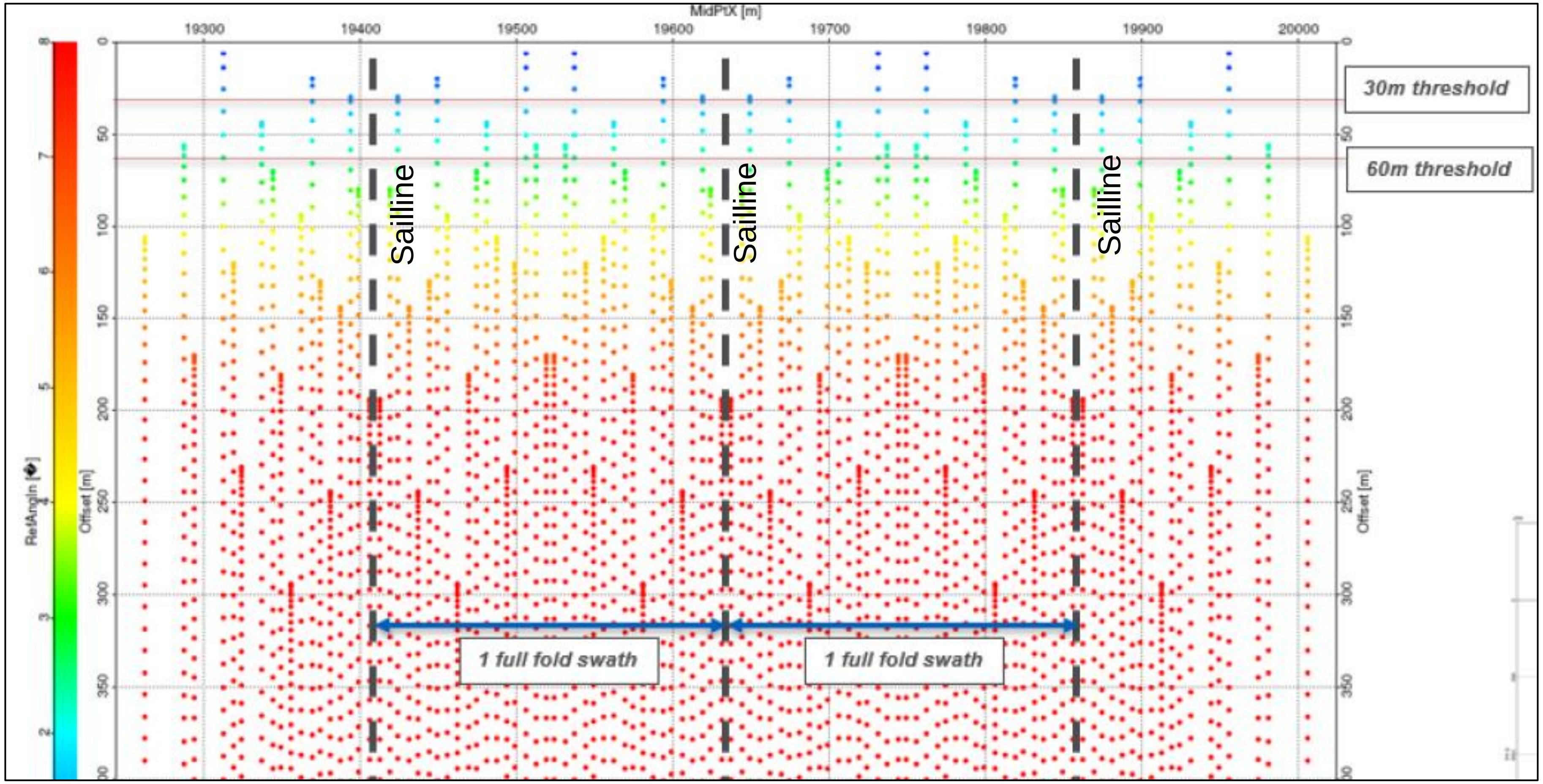
NEP CCS Final Configuration - In the field



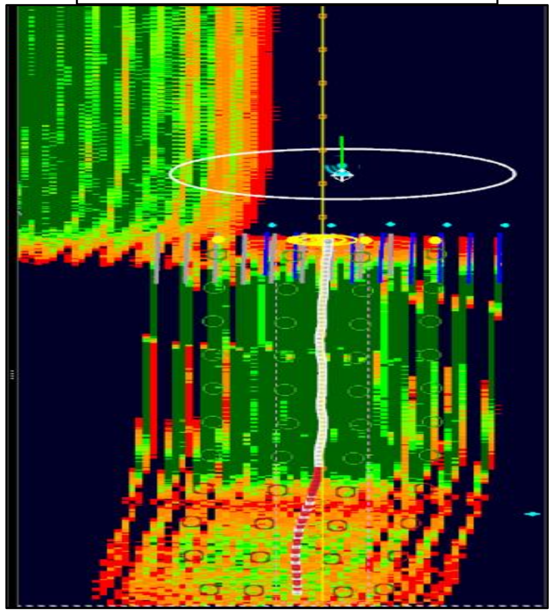


NEP CCS Final Configuration - Near Offsets

- The configuration involved overlapping coverage between saillines to fulfil the near offset requirement and achieve even fold

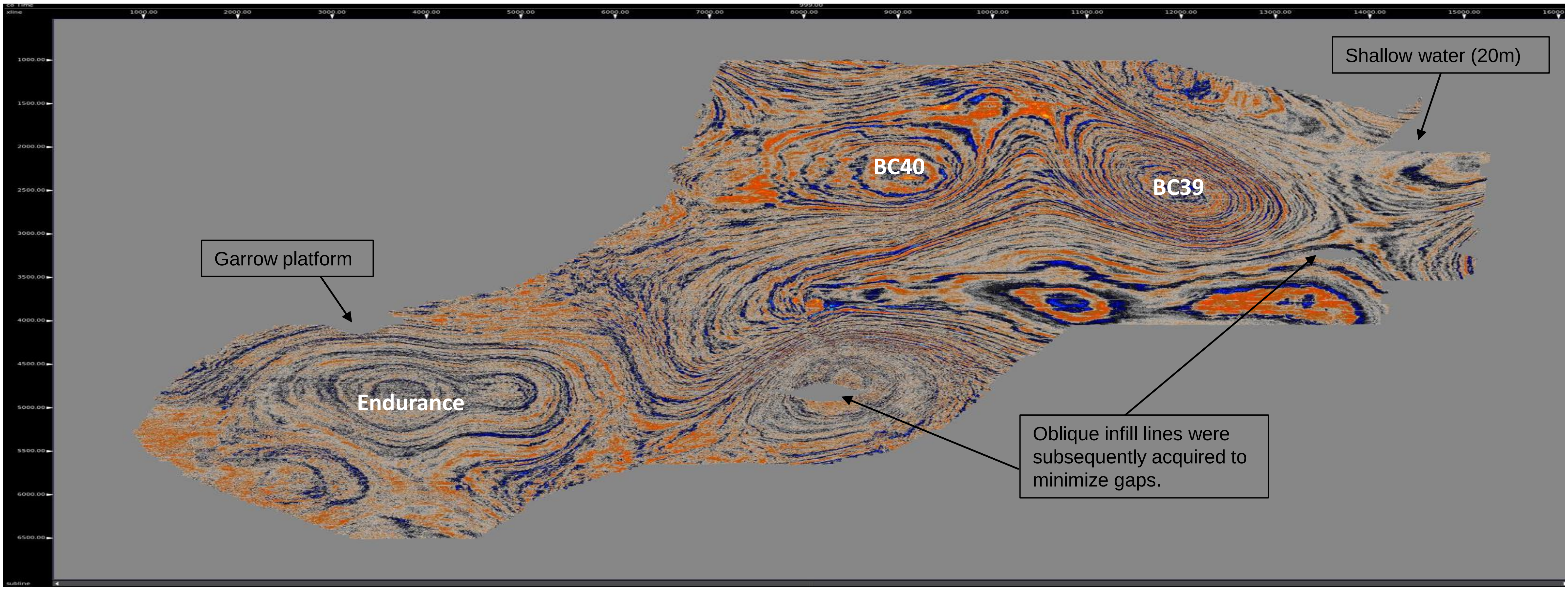


Screenshot from Nav desk showing inter-leaved coverage

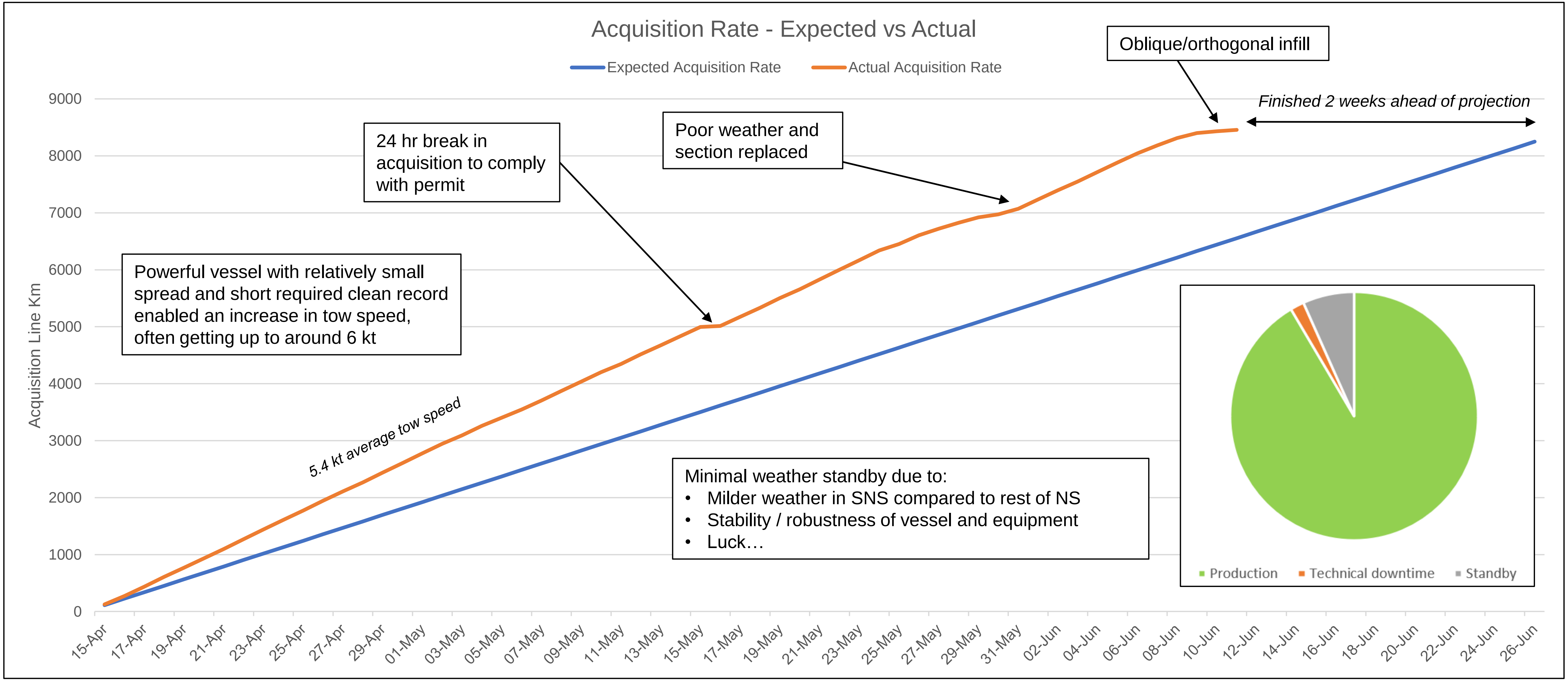


NEP CCS Acquisition Results: Time-slice @ 1 second

- The QC time slices from the vessel showed relatively minimal acquisition footprint at the reservoir level



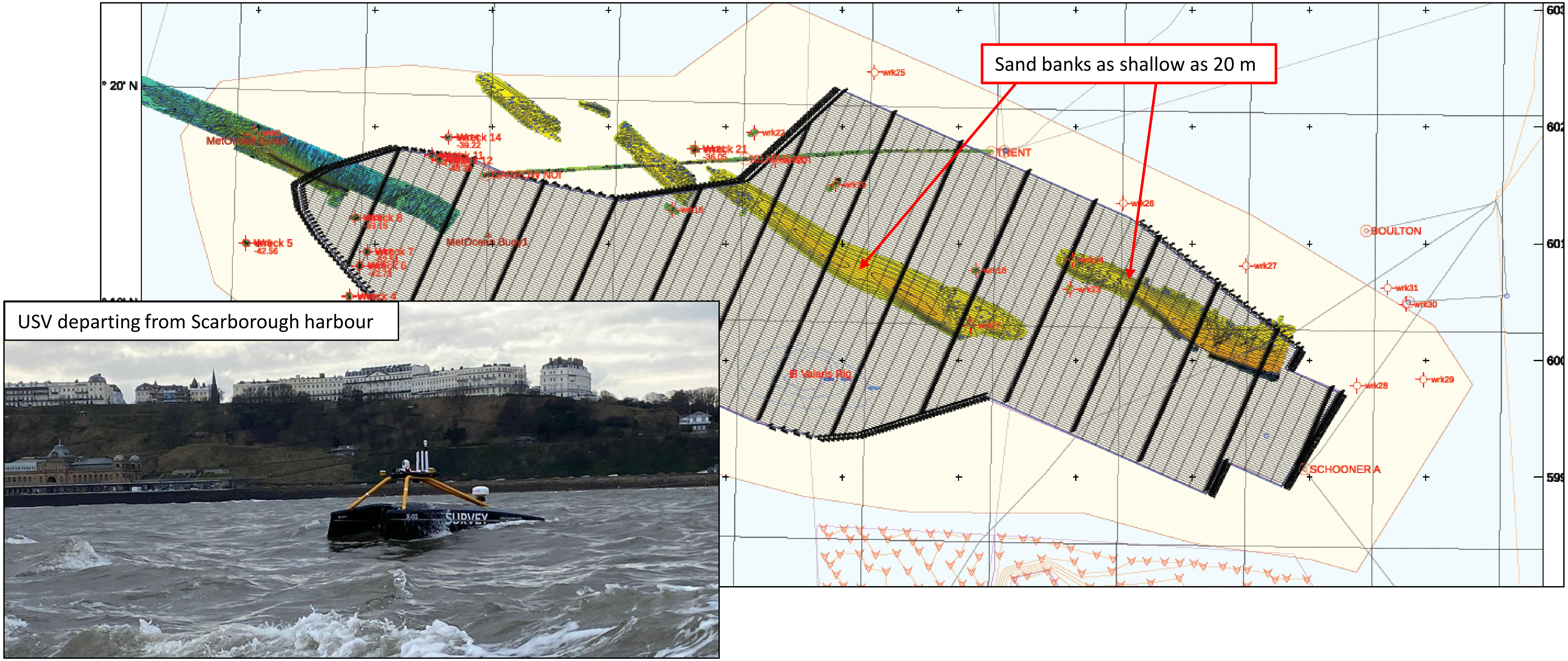
NEP CCS Operational Efficiency



NEP CCS Operational Learning – Shallow Water

Shallow water and shipwrecks present snagging hazards for towed-equipment – transferable to other CCS projects in shallow setting / close to shore

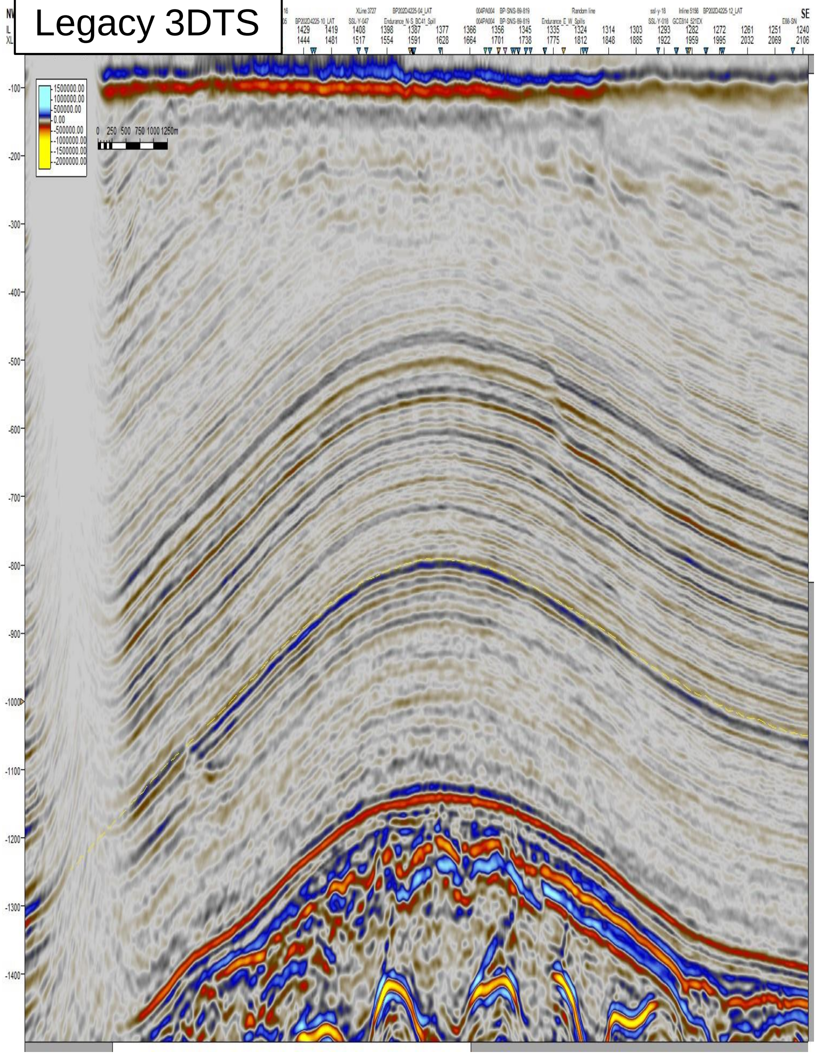
Uncrewed surface vessels (USVs) were utilized both before and during the survey to de-risk areas of shallow water



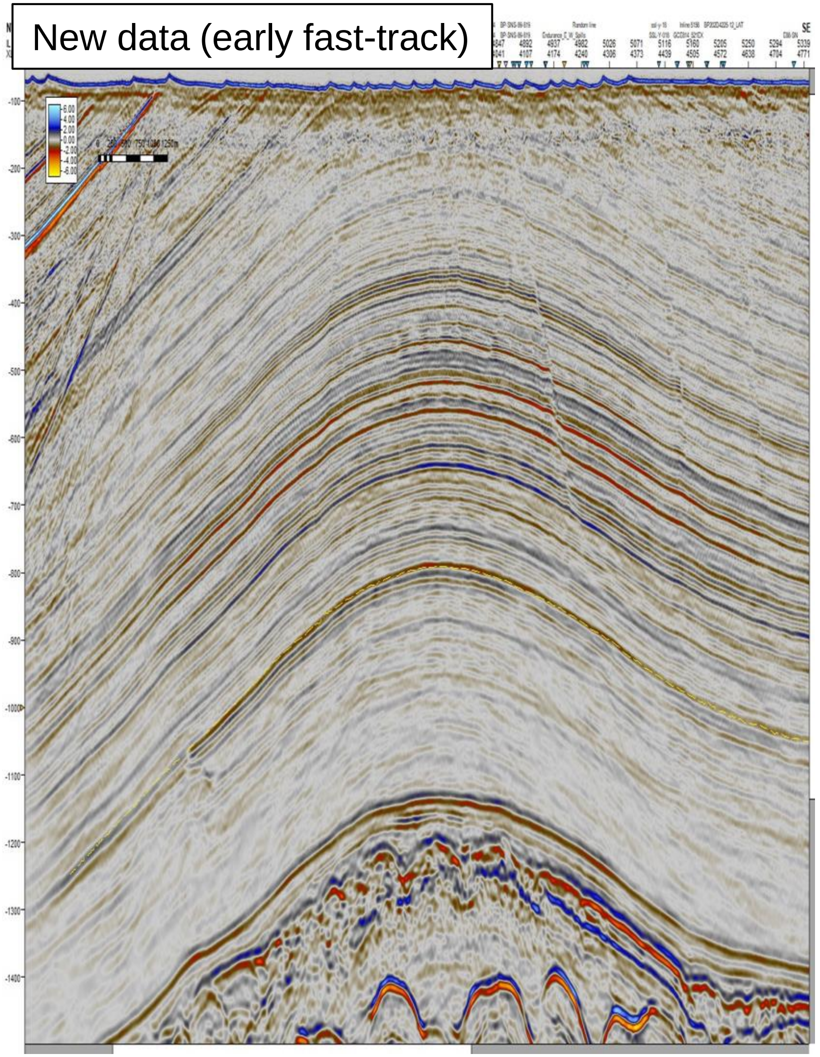
USV departing from Scarborough harbour

Legacy 3DTS vs New data vs 2DHR

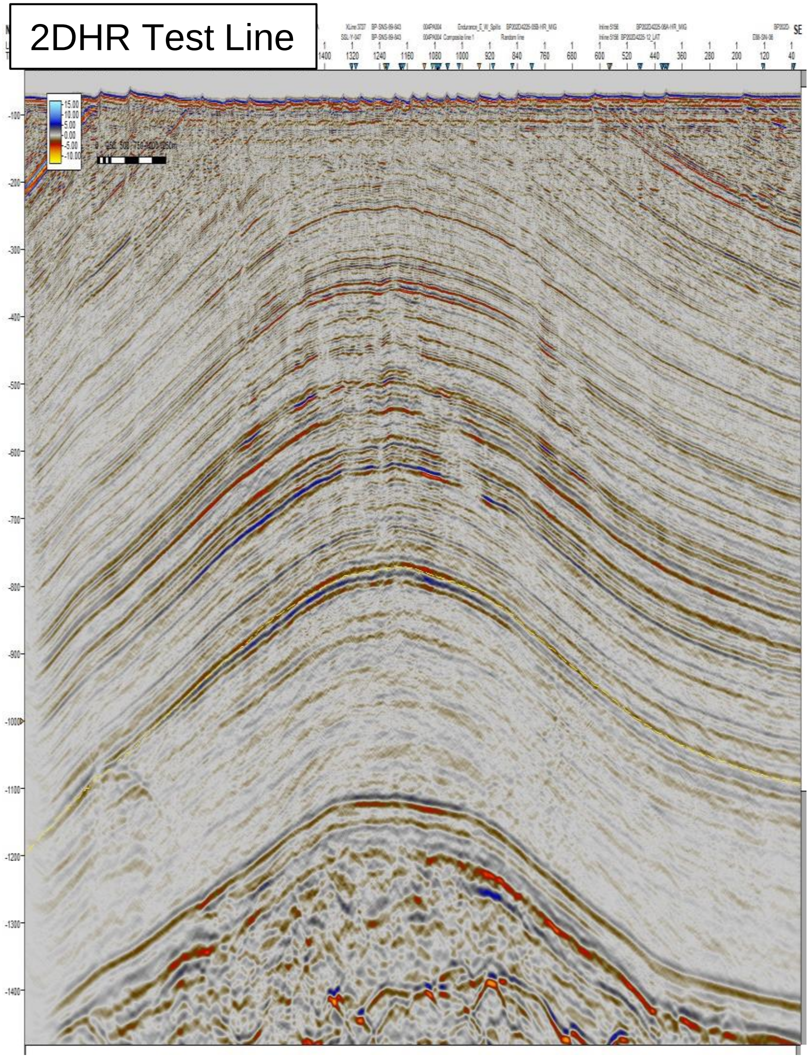
Legacy 3DTS



New data (early fast-track)



2DHR Test Line



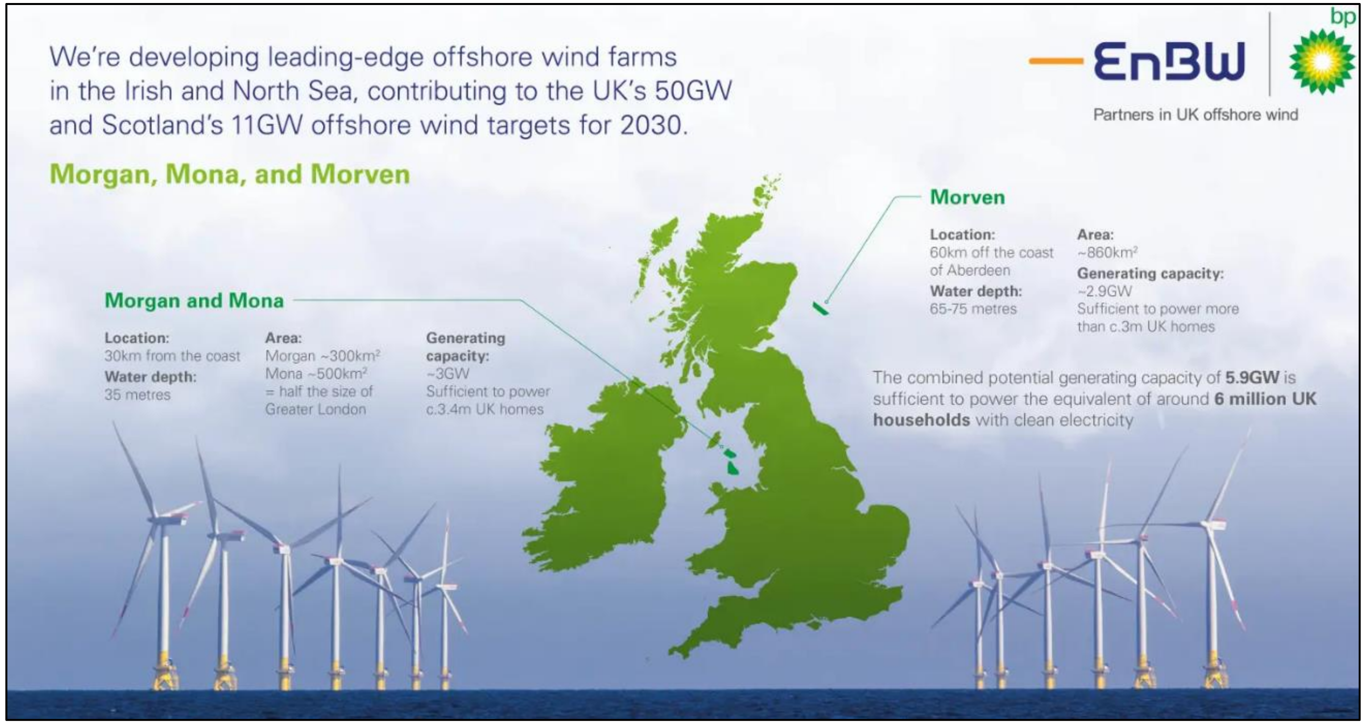
Line is slightly offset from others

NEP CCS Acquisition Related Conclusions / Recommendations

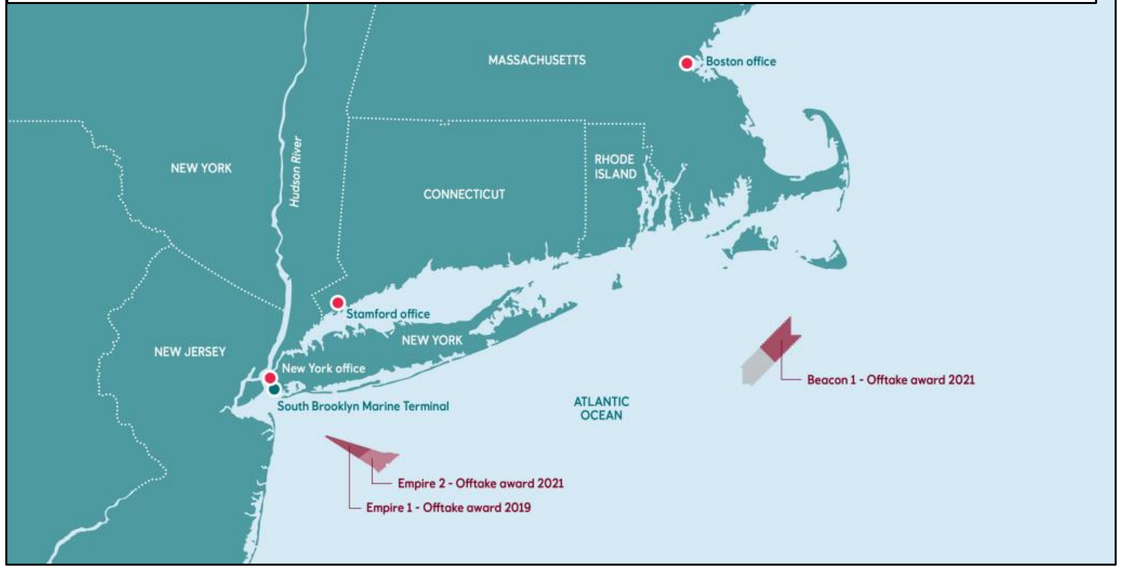
- CCS surveys have their own specific design challenges that need to be carefully evaluated
  - Mostly revolving around imaging shallower targets compared to oil and gas
- These specific challenges require bespoke solutions
  - Standard 3D TS would not have worked for NEP due to lack of near offsets
    - Need 3DHR type data with offsets up to around 2 km
  - Standard 1 or 2 streamer HR set-ups would have been impractical for a survey area of this scale
- Although there were no 'off the shelf' solutions, existing oil and gas technology was adapted successfully for NEP CCS in 2022, utilizing quad-source
  - Acquired a large area (1600 km^2) of high fidelity 3DHR data in an efficient manner (< 2 months)

bp wind – increasing activity

- In addition to CCS, bp is increasingly involved in the offshore wind sector with it's JV partners
- These areas require (ultra) ultra-high resolution data at least in the 2D sense
  - 3D data essential for areas of complex geology and boulders



Empire Wind and Beacon Wind with Equinor (East Coast U.S.)



bp enters South Korea offshore wind market with new Deep Wind Offshore joint venture

15 February 2023

bp and Deep Wind Offshore have formed a joint venture to develop offshore wind opportunities in South Korea. As part of their agreement, bp has acquired a 55% stake in Deep Wind Offshore's early-stage offshore wind portfolio, which includes four projects across the Korean peninsula with a potential generating capacity of up to 6GW.

South Korea is targeting almost 22% of its energy to come from renewable sources by 2030 and is expected to become a leading offshore wind region.

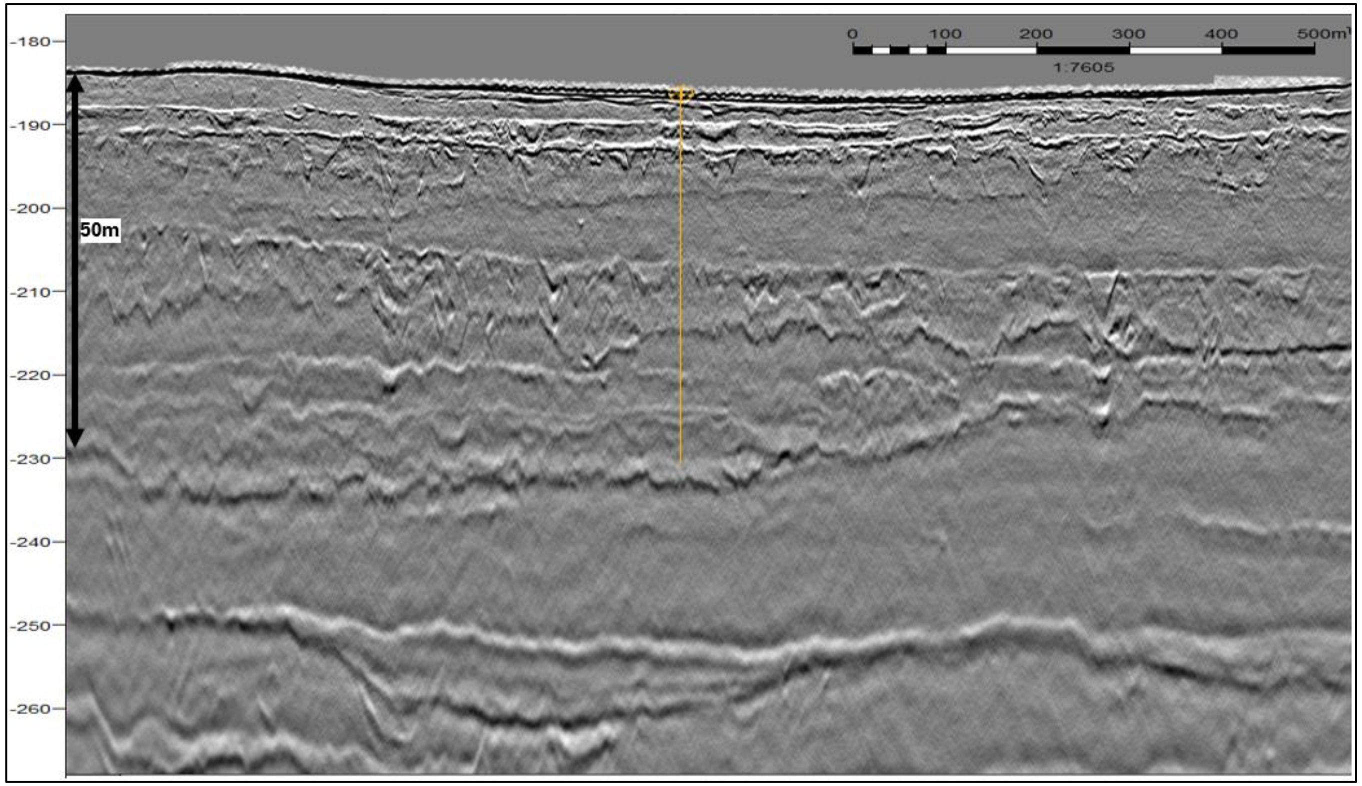
bp wind – new imaging challenges

General Requirements

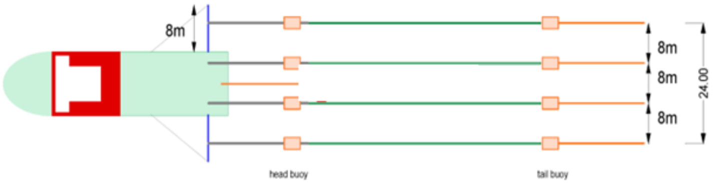
- Obtain images of 100 m below seabed at < 1 m resolution
- Ideally sufficient resolution to image boulders
    - Informing piling/foundation locations
- Specification often referred to as UUHR
- Requires very fast turnaround
- 2D is acquired for screening, followed by 3D micro-siting
- Uncertainty could be reduced by acquiring 3D early

Examples of 3DUHR

- Currently not many published case studies
- bp has previously acquired 3DUHR data at Clair for o&g
    - ~ 6 days to acquire 1 km^2 worth of data
- Windfarm sites are often on the scale of ~ 1000 km^2
- 3D micro-siting may be on the scale of ~ 50-100 km^2

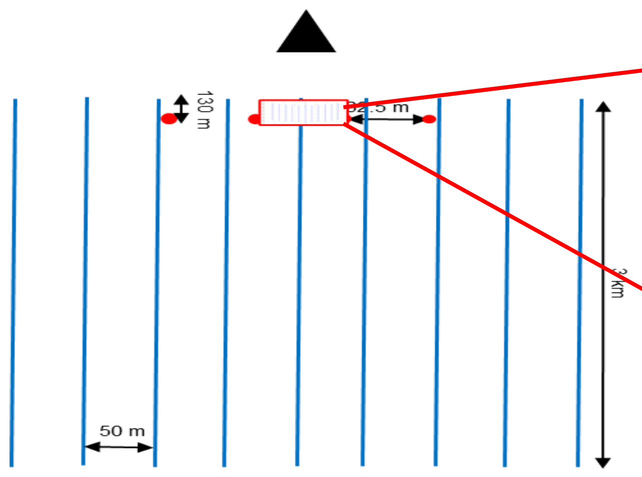


Clair 3D UHR data from Davies & Rietveld, EAGE MAW, 2020

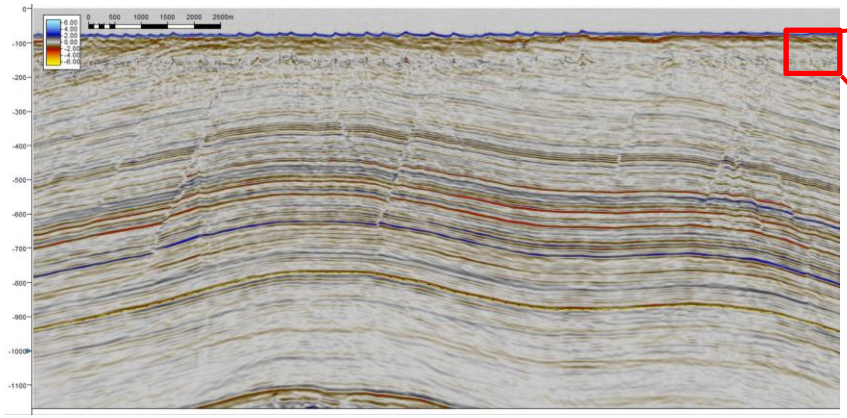


Comparing scales – 3DHR vs 3DUHR

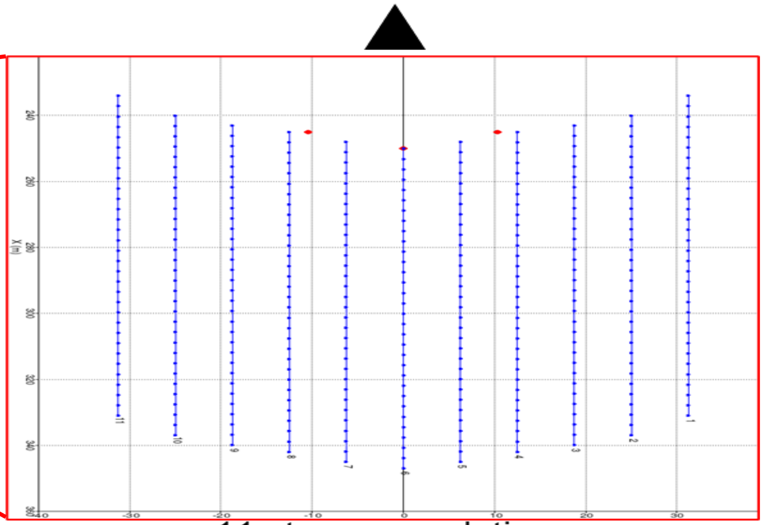
NEP CCS 3DHR



9 streamer solution

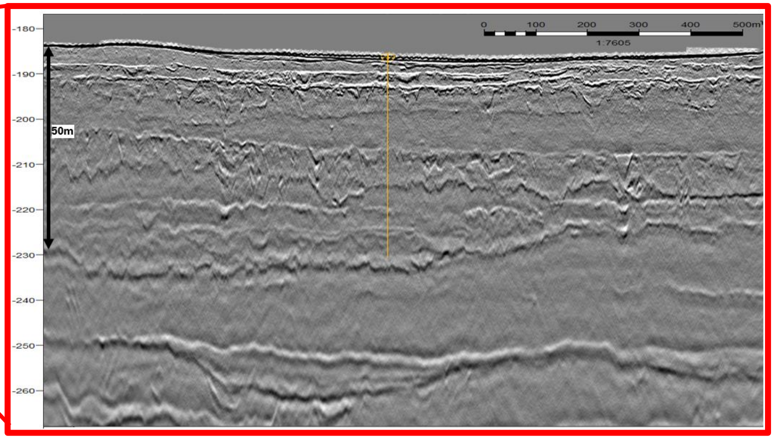


3DUHR Examples



11 streamer solution

Example solution from PGS (Widmaier et al, EAGE 2023)



Clair 3D UHR data. Image from Davies & Rietveld, EAGE MAW, 2020

Current challenges posed to acquisition technology

Windfarm 3DUHR is a relatively immature industry and there are a number of issues that should be progressed.

Current challenge	Impact on cost and/or data quality	Solution in progress?
Equipment is towed shallow to obtain high frequencies resulting in long costly surveys, **sensitive to weather**	High	Yes, UHR deghosting could enable deeper tows but lack of examples
Acquisition solutions not always well tested due to lack of previous wind projects	High	Yes, this will improve with increase in wind projects
Towed configurations often narrow and inefficient relative to the 3D areas required, however, need to maintain positioning accuracy	High	Yes, this will improve with increase in wind projects and testing engineering solutions.
Lack of understanding of acquisition configurations required for specific imaging requirements	High	Yes, this will improve with increase in wind projects
Lack of industry examples in public domain	Moderate	This *should* improve over time (underpins the above)

Wind Acquisition Related Conclusions / Recommendations

- Wind 3DUHR has huge potential value to reduce uncertainty and risk in wind developments
    - Earlier it can be acquired, the better, however, cost appetite is low early on
- A number of challenges still to be fully addressed to improve efficiency and reliability of surveys
- Wider industry sharing of 3DUHR results and contractors building track record will be highly beneficial
    - Competitive industry with both wind operators and contractors competing for space
- Expect there to be a rapid evolution of 3DUHR technology over coming years as new technologies are implemented due to high demand

Acknowledgements

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