Maximizing resolution from HD3D seismic over the Greater Endurance CO2 store area, Southern North Sea, UK

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Summary

High-density 3D seismic data over the Greater Endurance CO2 area have been processed by deploying a processing sequence to maximize resolution, including migration algorithms using primary reflections or multiples. Although near-offset sampling is dense with the new 3D survey, imaging with multiples provides further uplifts and complimentary information as the illumination and raypath diversity are increased when each receiver is used as a virtual source. The final data are compared with legacy 3D volumes and 2D site survey data, demonstrating the significant value the new data adds to initial shallow geology screening exercises and improving store characterisation.

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Introduction

High-density 3D (HD3D) seismic data is critical for site characterisation and risk assessment of CO_2 storage sites. Whereas legacy 3D datasets typically have been conducted for deeper imaging targets, survey design criteria for carbon capture and storage (CCS) can be different with the objective to image shallower targets and the overburden. In 2022, a novel HD3D survey was conducted over the Greater Endurance CO_2 store area in the Southern North Sea on behalf of the Northern Endurance Partnership (NEP). One of the main challenges of the project was to deliver accurate imaging of the geological formations above the Bunter Sandstone storage formation at around 1000 m depth, and uniform coverage in the 30-60 m offset range was required (Widmaier *et al*., 2023). The 3D survey was therefore acquired using a 9 x 50 m x 3000 m streamer spread and a wide-tow quad-source configuration (total source spread of 187.5 m) with the sources placed over the front end of the streamers, resulting in high near-offset coverage both in crossline and inline direction whilst maintaining survey efficiency (Cooper, 2022). The first processing of the 2022 HD3D survey was completed in 2023 following a conventional full integrity processing sequence, with final data meeting project objectives, showing significant uplift in resolution and imaging compared to legacy data sets, which allowed for better characterisation of the overburden and storage formations (Tarasewicz *et al*., 2024).

In 2024, a subset of data over the BC39 prospective store (Figure 1) was re-processed to investigate if shallow imaging could be further improved by deploying a high-resolution (HR) processing sequence defined to maximize resolution, including migration algorithms using primary reflections or multiples. The final primary imaging results show significantly improved shallow resolution compared to legacy data sets. Although near-offset coverage is high with the new 3D survey, imaging with multiples provides further uplifts and complimentary information as the illumination and raypath diversity are increased when each receiver is used as a virtual source. The final high-resolution data was compared with 2D site survey data acquired in 2024, and ties well in terms of resolution and reflectivity of key events.

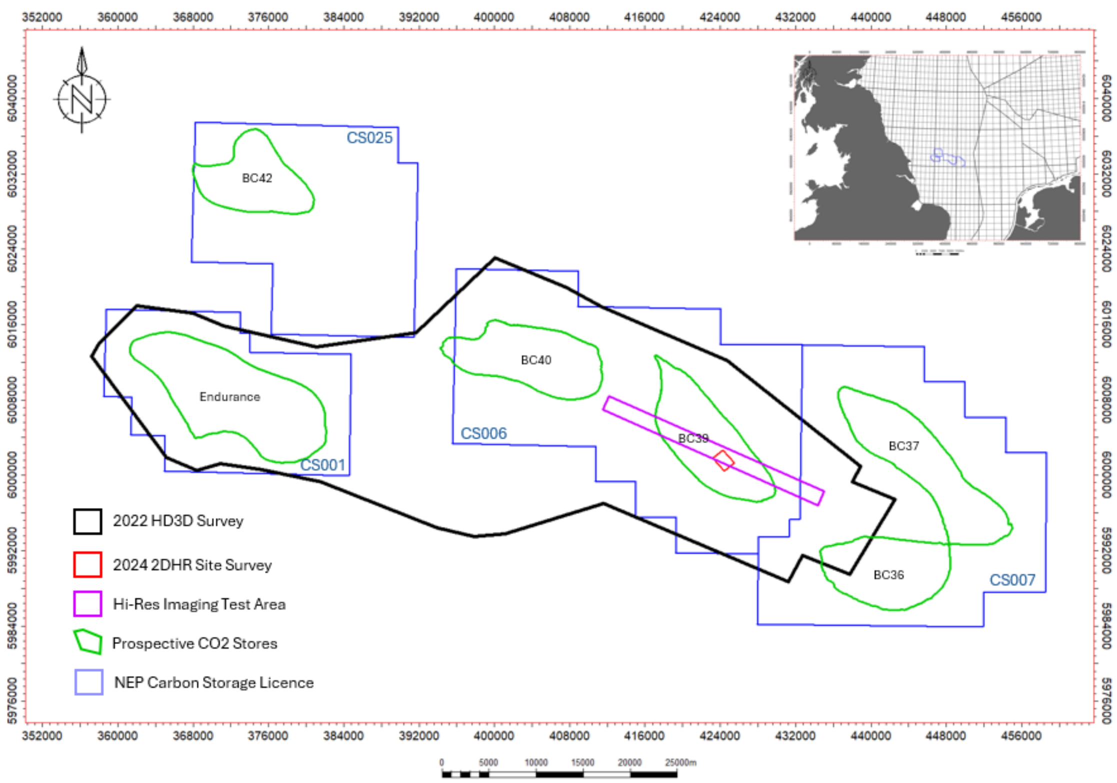

Figure 1 *Map of the Greater Endurance Store area with the test area outlined by the dark blue polygon*

Data processing

Overburden characterisation is a key component to assessing containment risk within prospective CO_2 stores within the Greater Endurance Area. The overburden above the BC39 prospective store was identified as being complex due to the presence of a highly faulted chalk sequence, pronounced shallow unconformity and shallow channels. This complexity had led to imaging issues within the overburden and improved shallow imaging was identified as a key step toward improving store characterisation.

A 50 km^2 subset of the 2022 survey was processed from field data at the recorded temporal sampling of 2 ms. The processing sequence was designed to be light compared to standard 3D marine processing sequences, while focusing on key steps to maximize resolution. This allowed for shorter turnaround to quickly assess the potential increased resolution of the shallow image. The data were processed following two routes, one for imaging using primary reflections and one for imaging with multiples. Both routes used the velocity model from the full integrity processing from the 2022 acquisition for migration.

The first route of data processing was defined for imaging with primary reflections. Pre-processing comprised of 3D wavefield separation (Day *et al.,* 2014), 3D source deghosting and designature, compensating for receiver and source ghosts and source signature effects to enhance the bandwidth of the seismic data. Wavefield extrapolation multiple modelling (Pica *et al*., 2005) and multi-domain multi-scale adaptive subtraction (Perrier *et al*., 2017) was applied to attenuate multiples off the shallow water bottom. Prior to anisotropic Kirchoff Pre-Stack Depth Migration (KPSDM), the data were binned and regularized on a 6.25 m x 6.25 m grid with 25 m offset class spacing to maximize resolution and signal-to-noise in the shallow section.

The second route employed Separated Wavefield Imaging (SWIM) (Whitmore *et al*., 2010). While conventional imaging relies on primary reflections between sources and receivers, SWIM uses the recorded down-going wavefield at each receiver as virtual sources. Even if data were acquired such that the high near-offset sampling provides high quality near surfaces images, using multiple reflections effectively increase the sampling and illumination, and can therefore provide additional information and resolution.

After migration and stacking, the SWIM and KPSDM volumes were merged at a two-way travel-time of 250 ms to produce a single volume. The two routes provide complementary images, and the crossover point between the SWIM and the KPSDM depends on geology and acquisition geometry. Therefore, a more sophisticated merge approach in the pre-stack domain should be applied to fill in any missing near angle information in the KPSDM data (Oukili *et al*., 2019) to retain as many details as possible. A separate KPSDM volume was also produced as reference. The two volumes will be referred to as high-resolution (HR) KPSDM and SWIM-KPSDM merge.

Results and Discussion

Before the 2022 acquisition, the legacy 3D dataset was from the Greater Ravenspurn acquisition in 2013, processed in 2014. The data (Figure 2a) is of poor resolution in the shallow. This is due to the acquisition setup, with limited near-offsets, and a processing sequence that would be considered out-dated today. In contrast, the full integrity final stack from the 2022 acquisition (Figure 2b) shows dramatically improved resolution and spectral bandwidth. Imaging of the shallow is further improved in the HR KPSDM (Figure 2c) and HR SWIM-KPSDM merge (Figure 2d), in particular the interpretability and continuity of the shallow unconformity and channels is clearly improved. The resolution of the two HR volumes is comparable due to the rich near-offset sampling, however imaging with multiples still shows smaller scale details and reduced footprint, in particular visible on the crossline section. On the other hand, crosstalk is clearly visible on the SWIM, which is due to interference of primaries and interference of higher-order multiples.

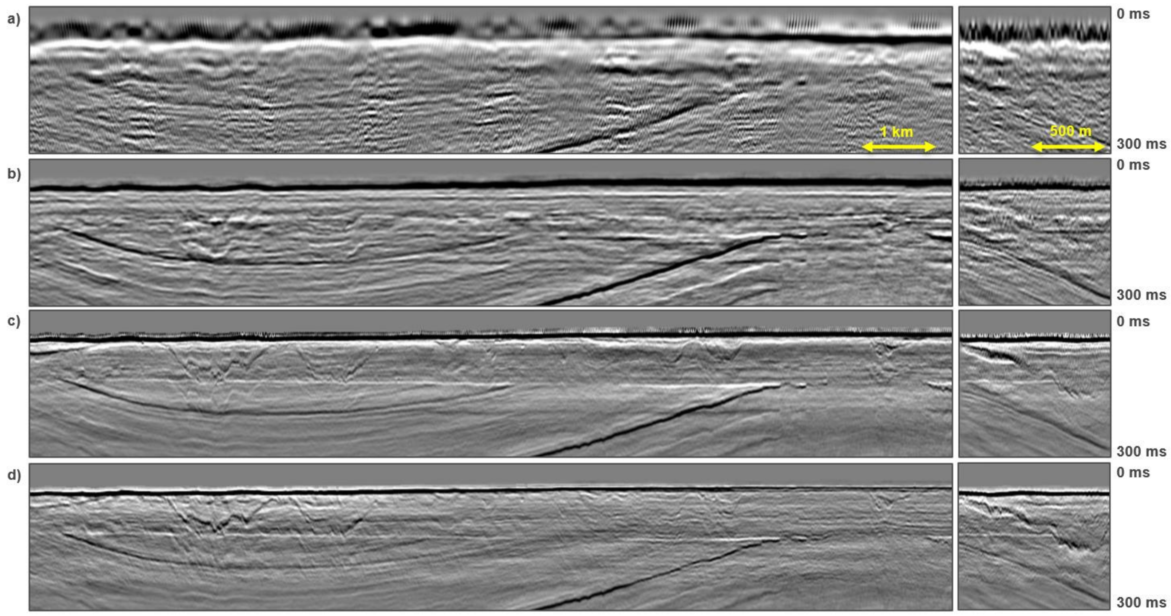

Figure 2 *Seismic sections (inline, left and crossline, right) of a) KPSTM from 2013 Greater Ravenspurn acquisition, b) final stack from full integrity processing from 2022 acquisition, c) HR KPSDM from 2022 acquisition, d) HR SWIM-KPSDM merge from 2022 acquisition (bottom).*

Further value from the high-resolution data is illustrated with the ability to extract volumetric attributes in the very near surface. Figure 3 shows a time slice of the HR KPSDM and full integrity volumes in an area around the proposed appraisal well location 10ms below the sea floor, comparing imaging of shallow channel features. Imaging of all channels are enhanced within the HR volume, with additional channels visible close to the planned well location. These additional channels could not be identified in a geohazard screening exercise conducted using the full integrity data, and significant value is added by the high-resolution data to initial shallow geology screening exercises.

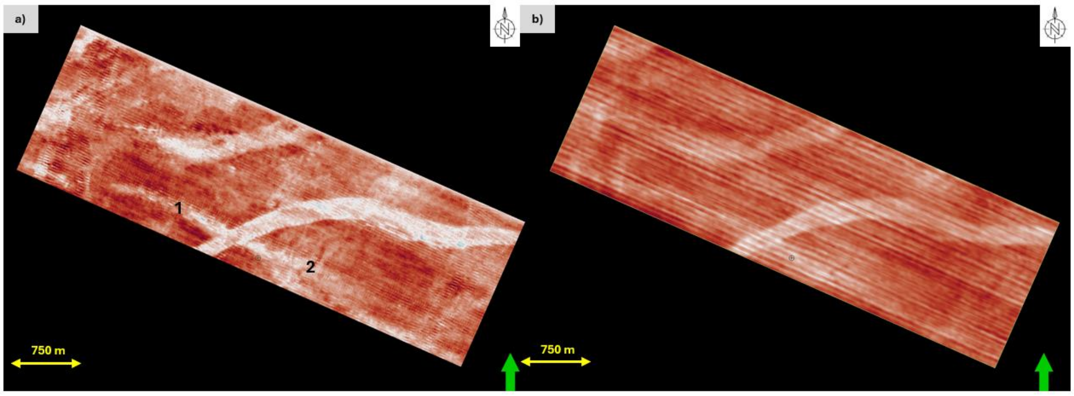

Figure 3 *a) Time slice at 68 ms from a) HR KPSDM volume, b) Full integrity volume from 2022 acquisition. Note the general improvement in shallow channel definition within the HR KPSDM and the imaging of E-W channel 1 and SW-NE channel 2 close to the proposed appraisal well location.*

2D site survey data were acquired in 2024 over the study area for shallow geohazards assessment. The data were acquired with 1 ms sampling interval, 6.25 m shot point interval and 12.5 m receiver interval. Two lines are compared with an inline from the HR SWIM-KPSDM volume in Figure 4a. The resolution is comparable, and the black arrows highlight key events that tie well at the intersections between the 2D and 3D data. Figure 4b shows an arbitrary line of the 3D volume along one of the 2D lines and Figure 4c the corresponding 2D line. Shallow layers and channels can be interpreted on both, although the signal-to-noise levels of the 2D site survey data is higher. In the deeper section misplaced out-of-plane events can be observed on the 2D data, for example where highlighted by yellow arrow.

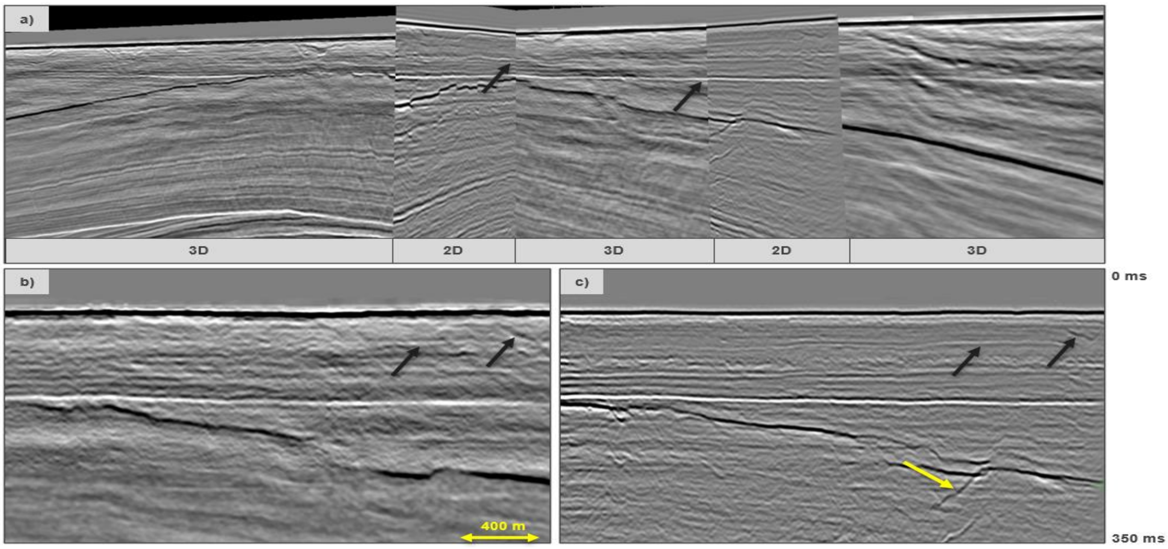

Figure 4 *a) 3D viewer comparison between 2D site survey data and HR SWIM-KPSDM merge from 2022 acquisition, b) HR SWIM-KPSDM merge from 2022 acquisition extracted along 2D site survey data from 2024, c) corresponding 2D site survey data from 2024*

Conclusions

A subset of the 2022 HD3D seismic data from the Greater Endurance Store area has been processed using an HR processing sequence, with improved imaging of the shallow subsurface showing how the processing sequence may be adapted to achieve objectives that are specific to CCS. Imaging with primaries or multiples is comparable because of the rich near-offset sampling of the data, however imaging with multiples still provide uplifts in imaging small-scale features as sampling and illumination is further increased when each receiver is used as a virtual source. Comparisons to 2D site survey data further illustrates the resolution that is achievable from HD3D surveys, and how it can provide value for initial shallow geology screening exercises and optimizing 2D site survey campaigns.

Acknowledgements

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