BRINGING NEW INSIGHTS TO CENTRAL NORTH SEA WITH OBN AND FWI IMAGING

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Summary

Spanning decades of exploration and production in the United Kingdom Continental Shelf, many programs of towed streamer data have shaped our knowledge of the Central North Sea. However, the fundamental lack of illumination and azimuth/offset coverage provided by towed streamer geometries, remains a blocker to resolving the imaging challenges associated with many higher-risk Jurassic and Triassic plays. This means that existing streamer data is rapidly approaching the limit in the value it can add to our understanding of this mature basin.

The Cornerstone ocean bottom node (OBN) program looks at using the well-known benefits of OBN data; full azimuths, long offsets and rich low frequencies, to provide a step change in imaging of this important region of the North Sea. This is achieved through improved model building, in particular the detail unlocked by full waveform inversion using the latest Time Lag cost function (Zhang et al.,2018).

Utilizing TL-FWI on this OBN data aimed at improving the entire section of the velocity model: the complex overburden, intra chalk and sub-chalk layers.

In addition to the added illumination achieved from OBN data, the use of the multiples, further illuminates areas of the subsurface not captured in the primary wavefield.

Bringing new insights to Central North Sea with OBN and FWI imaging

Introduction

Spanning decades of exploration and production in the United Kingdom Continental Shelf, many programs of towed streamer acquisition and processing have shaped our knowledge of the Central North Sea. The latest FWI technologies have been successfully applied in this region to improve the imaging of new and legacy streamer datasets, providing additional insight into the remaining potential of the Central North Sea (CNS). However, the fundamental lack of illumination and azimuth/offset coverage provided by towed streamer geometries, remains a blocker to resolving the imaging challenges associated with many higher-risk Jurassic and Triassic plays and the complex structures associated with Permian salt movement. These fundamental limitations in Towed Streamer acquisition geometries, mean that existing streamer data is rapidly approaching the limit in the value it can add to our understanding of this mature basin.

The Cornerstone ocean bottom node (OBN) program looks at using the well-known benefits of OBN data; full azimuths, long offsets, rich low frequencies, to provide a step change in imaging and further advancing our understanding of this important region of the North Sea. Whilst the full azimuth OBN data increases the nominal fold and illumination, improving signal-to-noise-ratio (S/N) in the deeper structures, this paper concentrates on the benefits the OBN data brings to the imaging through improved model building, in particular the detail unlocked by full waveform inversion using the latest Time Lag cost function (Zhang et al.,2018).

Acquisition Overview

The Cornerstone OBN 2020 survey acquired long-offset, full-azimuth data covering approximately 1650km^2, making it the largest OBN program in the Central North Sea (Figure1). The water depth is varying between 85m to 104m.

The four-component data were acquired employing a 50m x50m shot carpet, resulting in trace density in excess of nine million traces per square-kilometer.

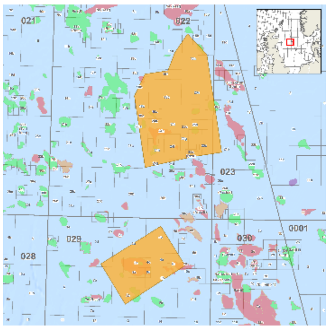

***Figure 1** Acquisition Area*

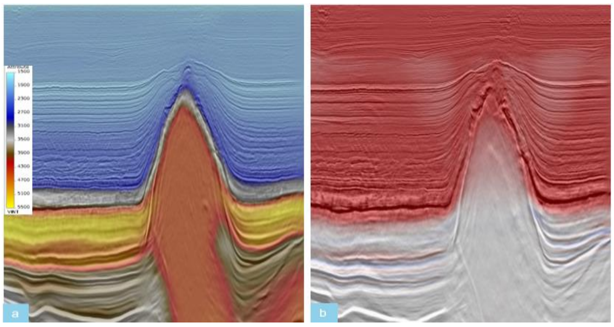

***Figure 2** a) Typical velocity profile over the CNS with the presence of fast and thick Chalk (Vp ~5000m/s) b) Diving wave illumination; limited penetration below the chalk section is observed.*

Velocity Model Building and Imaging: Time Lag FWI

Traditional approaches to velocity model building in the North Sea have relied heavily on ray-based tomography. In recent years said model building has evolved to utilize full waveform inversion (FWI) to update the overburden, but was unable to update the chalk and deeper model due to lack of diving-wave penetration (Figure2). Below the penetration depth of the diving waves, it is necessary to include reflections in the FWI. However, reflection FWI can be very challenging especially in areas of large impedance contrasts, leading to amplitude and travel time mismatch/cycle skipping between modelled and recorded seismic.

To address this, Time-lag FWI (TL-FWI) was developed (Zhang et al., 2018) which has been proven as a reliable tool in updating high contrast velocity medium. This algorithm uses a cost function aimed at mitigating cycle skipping and amplitude discrepancies between synthetic data and the recorded seismic data, using a kinematic only cost function. A cross-correlation coefficient based weighting is used to promote more reliable travel time measurements in the inversion.

TL-FWI has been applied with some success to Towed Streamer datasets in this region of the CNS (Fallon et al., 2020). However, even with an accurate starting model, faced with the fundamental limits of illumination in offset and azimuth and lack of S/N at ultra-low frequencies, TL-FWI would have a limited impact on the model update.
The toughest challenges of the complex salt diapirism and sub Base Cretaceous Unconformity (BCU) set a technical challenge unlikely to be solved by the geometrical constraints of towed streamer data, requiring a step change in acquisition through OBN for fully exploiting the benefits of FWI. Surveys in the Gulf of Mexico have led the way in demonstrating that the right OBN data combined with the power of algorithms such as TL-FWI, can unlock the details of complex deep structure and intricate salt geometries.
Utilizing TL-FWI on the cornerstone OBN data aimed at improving the entire section of the velocity model: the complex overburden, intra chalk and sub-chalk layers. The starting velocity model for TL-FWI was the 2020 regional velocity model derived using dual azimuth (E-W and N-S) towed streamer data. TL-FWI has added detail in the chalk layers, with the model conforming to seismic impedance contrasts in the Jurassic section, driven purely by the data. Imaging with the TL-FWI model further improves the focusing in the Chalk and sub-BCU image.

Figure 3 shows a typical velocity section co-rendered with the imaging results after TL-FWI, compared back to the latest Towed Streamer data. As expected, the results also exhibit significant improvements in imaging brought by the improved S/N and illumination provided by the OBN data.

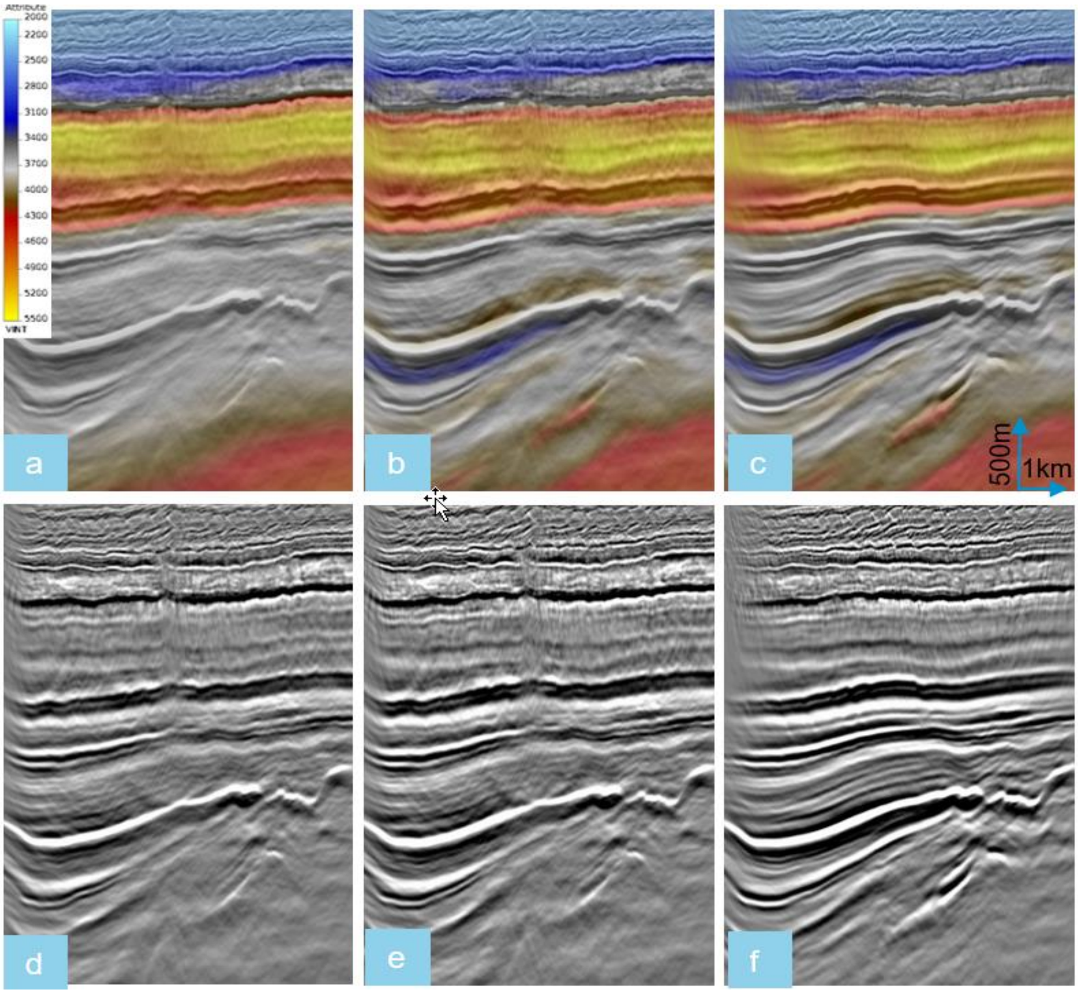

Figure 3 *: a) and d) Towed streamer RTM image with 2020 towed streamer model, b) and e) Towed streamer RTM image with TL-FWI model , c) and f) OBN RTM image with TL-FWI model*

On figure 4, looking into the depth slices; TL-FWI has resolved details for the complex structures within the sub-chalk layers.

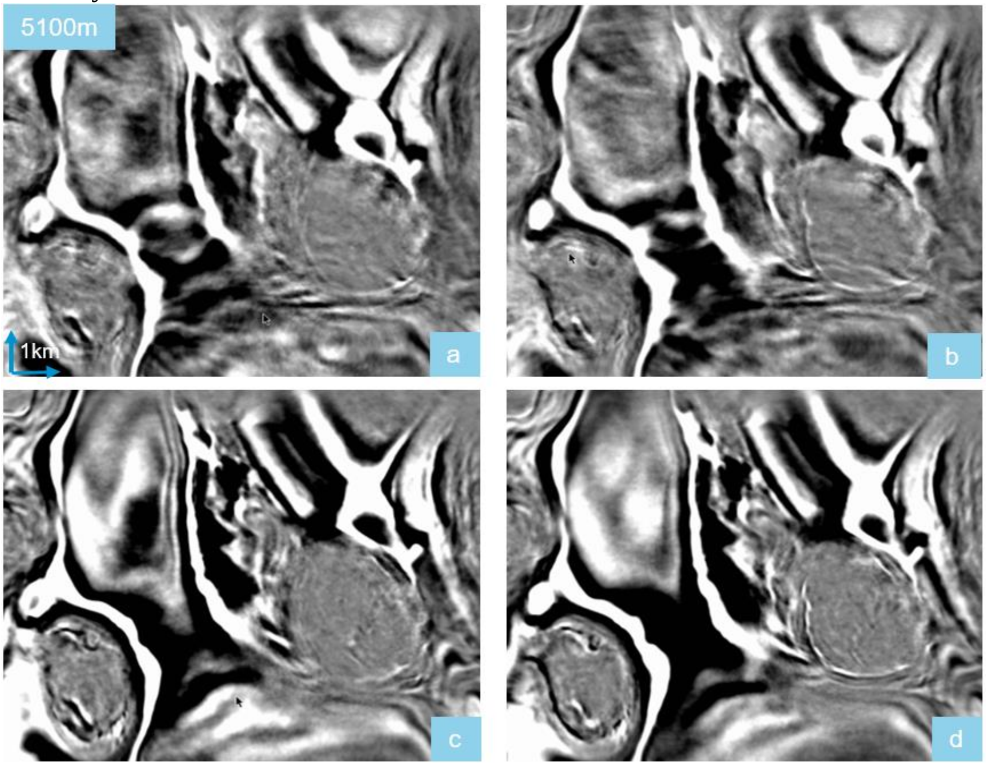

***Figure 4**: a) and b) Towed Streamer RTM image with 2020 TS model and TL-FWI model respectively c) and d) OBN RTM image with 2020 TS model and TL-FWI model respectively*

Figure 5 shows a representation of the shallow velocities. TL-FWI is improving the resolution and capturing the shallow low velocities anomalies with a high level of detail which are potentially related to gas trapped within the complex faulting system above the salt diapir structure and represent significant drilling hazards. Similarly, the updated model is capturing the diagonal low velocity features for the regional trend of the glacier channels. If not captured in the model these anomalies would imprint on the underlying seismic leading to structural distortion. We also observe a high level of detail in the upside events around the salt diapir.

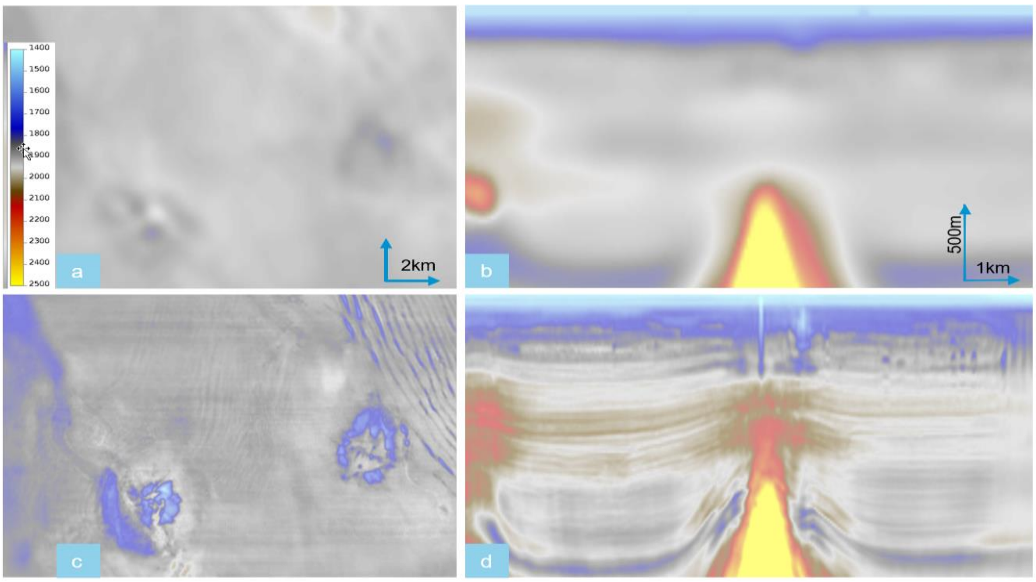

***Figure 5:** Shallow TL-FWI update example: a) depth slice at 370m b) cross-section for 2020 Towed Streamer model c) and d) model updated by TL-FWI*

TL-FWI utilizes the full wavefield: diving waves, reflections and multiples. In addition to the added illumination achieved from OBN data, the use of the multiples further illuminates areas of the subsurface not captured in the primary wavefield. Nowhere is this better demonstrated than the shallow section. The receiver spacing in OBN data typically leads to poor imaging in the very shallow section. Unlike deeper water areas, in the shallower water of the North Sea, the downgoing mirror image (Grion et al., 2007) does not add significant illumination to the shallow image.

Figure 6 is showing a comparison of the conventional OBN RTM image, with the 'FWI image'. The 'FWI image' (also referred to as TL-FWI imaging) is an estimation of reflectivity directly derived from TL-FWI (Zhang et al., 2020).

In addition to the improved imaging, we observe the impact of the extra illumination of the multiples, which help in healing the acquisition footprint, filling in the acquisition holes and extending the image to a broader area. Since FWI by nature is a least-squares fitting process of the full wavefield, we also benefit from improved signal to noise and balanced illumination akin to a Least Squares migration.

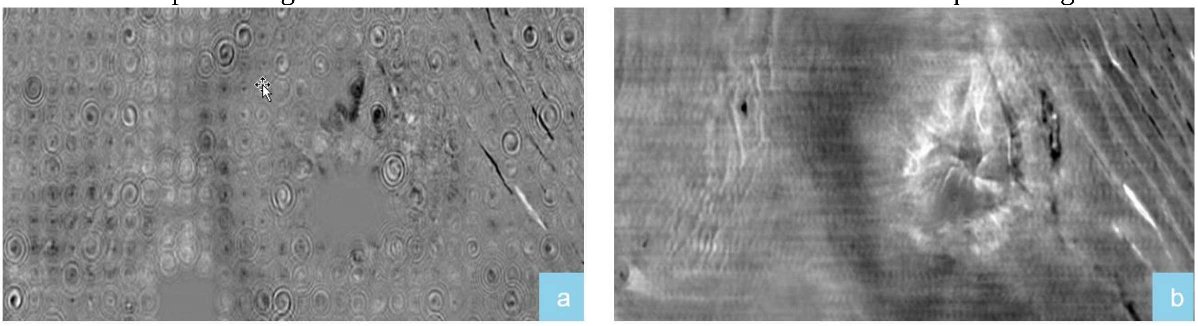

***Figure 6**: Depth slice at 360m a) OBN RTM Image b) TL-FWI Imaging*

Conclusions

The Cornerstone OBN 2020 survey combines the benefits of OBN data; rich low frequencies, long offset data and full azimuths illumination, with the latest TL-FWI algorithm to provide a step change in imaging of the Central North Sea.

We see significant benefit in S/N arising from the added fold and illumination from the OBN data.

Focussing is further improved by detail in the velocity added by TL-FWI in the deep section, also through removing distortions imprinted upon the deep by velocity anomalies in the shallow section.

TL-FWI is unlocking unparalleled detail, resolving the shallow channels and complex faulting system around complex salt diapir, detail not seen previously.

This has led to the production of a TL-FWI image that outperforms the seismic image from the OBN data and recent streamer datasets.

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References

Fallon,P., Hall,F., Cattini,G., Holman,A., and Hollingworth,S., [2020] Exploiting the Full Wavefield to Overcome Limitations of Ray Based Tomography in the Central North Sea , EAGE, Conference Proceedings.

Grion,S., Exley,R.,Manin,M.,Miao,X., [2007] Mirror imaging of OBS data, first break volume 25, Nov.

Shen, X., Ahmed, I., Brenders, A., Dellinger, J., Etgen, J., and Michell, S. [2017] Salt model building at Atlantis with full-waveform inversion.SEG Technical Program Expanded Abstracts 2017,1507-1511.

Tarantola, A. [1984] Inversion of seismic reflection data in the acoustic approximation. Geophysics, 49(8), 1259-1266.

Zhang, Z., Mei, J., Lin, F., Huang, R., and Wang, P. [2018] Correcting for salt misinterpretation with full-waveform inversion. SEG Technical Program Expanded Abstracts 2018, 1143-1147.

Zhang, Z., Wu, Z., Wei, Z., Mei, J., Huang, R., and Wang, P. [2020] FWI Imaging: Full-wavefield imaging through full-waveform inversion.SEG Technical Program Expanded Abstracts 2020