Learnings from elastic FWI with OBC and DAZ streamer data over the Mariner Field, East of Shetland

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Introduction

The Mariner Field is located on the East Shetland Platform in Block 9/11a of the UK North Sea and contains significant remaining reservoir potential. The field comprises two key Paleocene reservoirs: the deeper Maureen Formation and the more transparent, shallower Heimdal Sandstone, which exhibits a weak P-wave impedance contrast. Imaging of both prospects is challenged by significant overburden complexity, including shallow and deeper channel systems as well as sand injectites. As a result, a detailed and accurate imaging model is critical for field development and prospect delineation.

To address this, elastic Full Waveform Inversion (FWI) was applied in parallel to two distinct datasets: a larger dual-azimuth (DAZ) multi-component streamer dataset acquired in 2012, and a smaller but overlapping ocean-bottom cable (OBC) dataset from 2008. The streamer dataset provided offsets up to 3.5 km, while the OBC dataset offered azimuthally rich illumination with offsets extending to 12 km. Both inversions were carried out up to 40 Hz to capture strong model heterogeneities.

In this case study, we analyze the two parallel inversion results and assess the imaging uplift relative to vintage results from 2020, where acoustic FWI was applied to the streamer data and the OBC model was further refined using reflection tomography.

Methodology

The vintage processing from 2020 indicated strong shear impedance contrasts and elevated Vp/Vs ratios in both the transparent Heimdal sands and the Maureen Formation. Elastic FWI was therefore applied to both datasets to better reproduce the observed elastic effects associated with these impedance contrasts (Liu *et al*., 2024).

The FWI implementation employed a dynamic matching (DM) objective function, which maximizes the local, windowed cross-correlation between observed and synthetic data (Mao *et al*., 2022). This results in a phase-driven inversion that is more robust to cycle skipping and reduces sensitivity to non-coherent noise. Due to computational cost considerations, only frequencies up to 20 Hz were treated elastically. At lower frequencies, event tuning between pressure and converted-wave energy introduces stronger phase and amplitude effects, whereas higher frequencies exhibit improved event separation. This provided the rationale for transitioning to acoustic FWI at higher frequencies.

The initial Vp model was derived from a smoothed version of the vintage velocity model, followed by long-wavelength global tomography and anisotropy calibration. The shear model was constructed using available shear logs to establish Vp/Vs regression relationships for each geological layer, which were subsequently updated throughout the elastic FWI process in response to changes in the Vp model. Reflection tomography was applied to a limited extent between FWI stages, primarily to help decouple velocity and anisotropy effects.

The Maureen Formation overlies crystalline basement, with a significant velocity contrast at approximately 1.5 km depth. This contrast generates strong diving and refracted energy at relatively short offsets. To stabilize the FWI process for both streamer and OBC data, it was critical to accurately represent this contrast

so that synthetic data could reproduce the observed wavefield, enabling reliable reconstruction of the complex velocity model.

Results

Figures 1a and 1b show a comparison between the vintage OBC velocity model and the new DM-FWI model at 40 Hz, with the corresponding Kirchhoff PSDM stack overlaid. The vintage model captures the large shallow channel (annotated by the yellow arrow) but lacks sufficient resolution to adequately resolve and simplify the seismic structure at the Maureen surface (red arrow). In contrast, the DM-FWI result in Figure 1b captures both shallow and deeper geological features (green arrows), while also resolving significant lateral velocity variations within the basement structure below ~1.5 km depth.

As noted in the previous section, correct conditioning of the basement velocities prior to FWI was critical for inversion stability. The vintage OBC model lacked an accurate velocity contrast in the basement, resulting in poor fault imaging and strong multiple artefacts.

Figure 1c shows the OBC data migrated using the streamer-derived DM-FWI model. Despite significant differences in acquisition geometry and the use of two independent inversion workflows, a relatively good convergence of the background velocity trend is observed (Figures 1b and 1c). However, the OBC-based FWI result exhibits significantly higher resolution, capturing smaller-scale features and stronger velocity contrasts throughout the section.

Furthermore, the extended illumination provided by the OBC acquisition enables a more complete velocity update within the basement, which is not fully resolved when using the streamer dataset alone. The features indicated by the green and yellow arrows near the basement (~1.5 km depth) in Figures 1b and 1c illustrate how the improved resolution from the OBC data leads to enhanced structural simplification and focusing. This highlights the importance of longer offsets and broader azimuthal coverage for FWI.

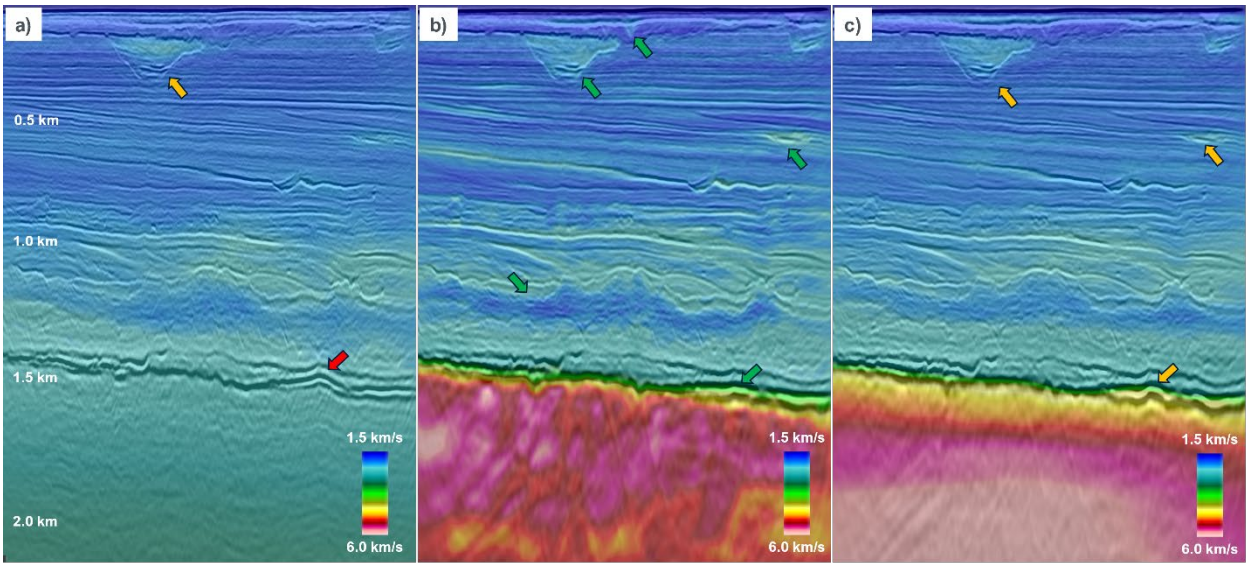


Figure 1: *Vintage FWI model (a) compared to the new DM-FWI results from the OBC data (b) and the streamer data (c). All panels are displayed with the corresponding Kirchhoff PSDM of the OBC data overlaid. The vintage model captures the main shallow channel (yellow arrow) but lacks the resolution to resolve structural undulations near the Maureen Formation and the basement (red arrow). Significant*

improvements in resolution and structural simplification are observed in the OBC-based DM-FWI results (green arrows). The streamer-derived DM-FWI model captures much of the background velocity trend seen in the OBC model but does not fully resolve the same level of detail or structural simplification, particularly within the basement. This is primarily due to the limited offset range of the streamer acquisition.

Figure 2 shows the full extended section of the streamer-derived DM-FWI results overlaid on the Kirchhoff PSDM image from the streamer data. The FWI model clearly resolves both shallow (150–300 m) and deeper channel features (~1000 m), and captures lateral velocity variations beneath the Maureen Formation and into the underlying basement and sedimentary section, as indicated by the yellow arrows.

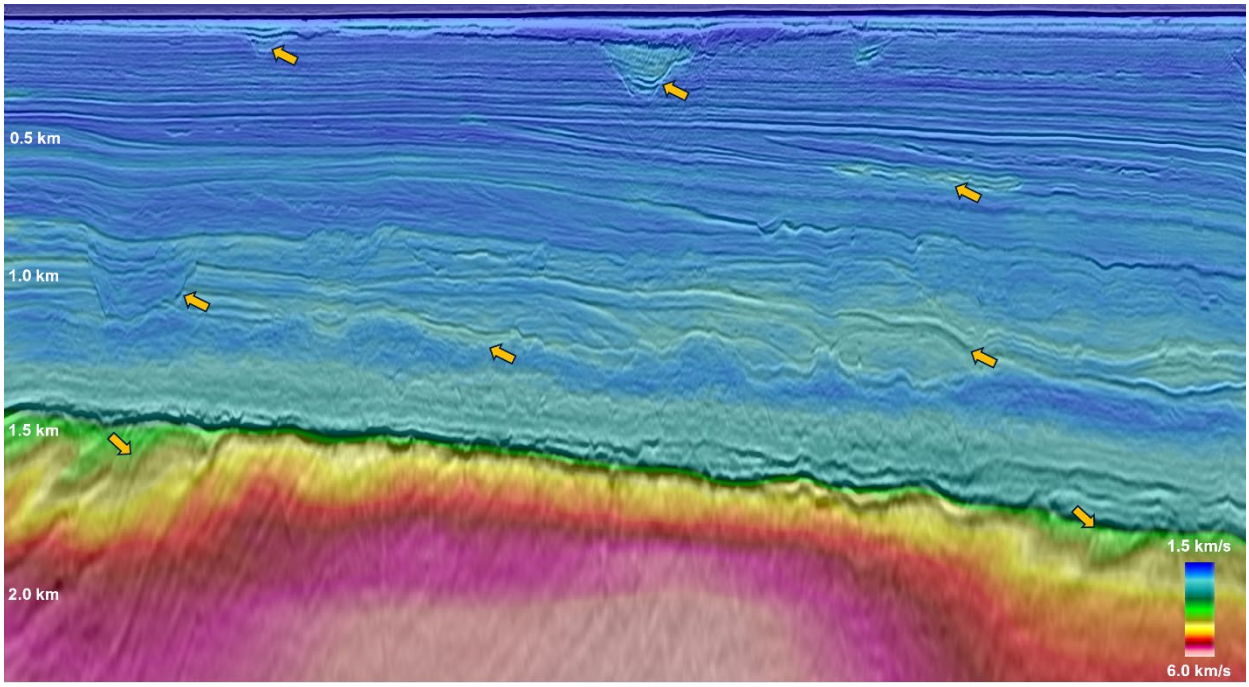


Figure 2: *New 40 Hz DM-FWI model derived from the DAZ streamer dataset, overlaid on the corresponding Kirchhoff PSDM image. Despite offset limitations, the inversion resolves most of the key geological features in the area (annotated by yellow arrows), including shallow and deeper channel systems, sand injectites, and lateral velocity variations beneath the Maureen Formation and into the underlying basement (>1.5 km depth).*

Conclusions

In this case study, we have demonstrated the effectiveness of elastic FWI (with an acoustic transition above 20 Hz) using a dynamic matching objective function to resolve significant geological complexities associated with shallow and deeper channel systems, sand injectites, and deeper basement–sediment velocity variations.

The study utilized both a larger DAZ streamer dataset with limited offsets and a smaller OBC dataset that provided superior illumination, longer offsets, and broader azimuthal coverage. The OBC-based FWI results show a significant improvement in event focusing and structural simplification compared to the

vintage model. The DAZ streamer FWI results captured the background velocity trend but lack the detailed resolution achieved with the OBC data. This highlights the critical importance of acquisition geometry and data quality for successful FWI.

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References

Liu, F., Macesanu, C., Hu, H., Gao, F., Huang, Y., Zhan, G., Sheng, J., He, Y., Calderon, C. and Wang, B. [2024] Enhanced P Wave Imaging Using Elastic Dynamic Matching FWI. *85th EAGE Annual Conference & Exhibition.*

Mao, J., Sheng, J., Huang, Y., Hao, F. and Liu, F. [2020] Multi-channel dynamic matching full-waveform inversion. *In SEG Technical Program Expanded Abstracts 2020 (pp. 666-670). Society of Exploration Geophysicists.*