Potential of FWI Imaging for Shallow Turbidite Shadow Zone : A Case Study

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Summary

Building a high-quality seismic image depends on many factors related to acquisition parameters, pre-processing technologies, accuracy of the velocity and anisotropy models, etc. Full Waveform Inversion (FWI) has lately been used extensively to find a velocity model, especially for geologically complex areas.

We present a case study from offshore Liberia, where slope gradient and clusters of gas vents create collapse structures over several kilometres, letting muddy slumps and mass transport complexes (MTCs) above seal level collapse into 100s of meters thick infill debris. These chaotic geobodies scatter seismic energy, creating a significant challenge for traditional imaging algorithms to image seismic events below them. The Liberia Basin observed technical successes of wells drilled from 2009-2011, therefore the petroleum system is proven, which encourages future exploration. However, features of interest and petroleum prospectivity are still widely underexplored.

TGS acquired and processed several sets of seismic data to evaluate the hydrocarbon prospectivity of the basin. Current processing using Dynamic-Matching FWI (DM FWI) provides a superior quality image to help understand the potential of the basin in terms of structural evolution and possible hydrocarbon system. Figure 1 shows an overall picture of location of the project area.

Using traditional imaging algorithms, the shallow turbiditic setting generates a shadow zone that suffers from signal absorption and scattering. DM FWI has been applied to produce FWI imaging which show improved image resolution with increased S/N, better illumination, and improved amplitude consistency.

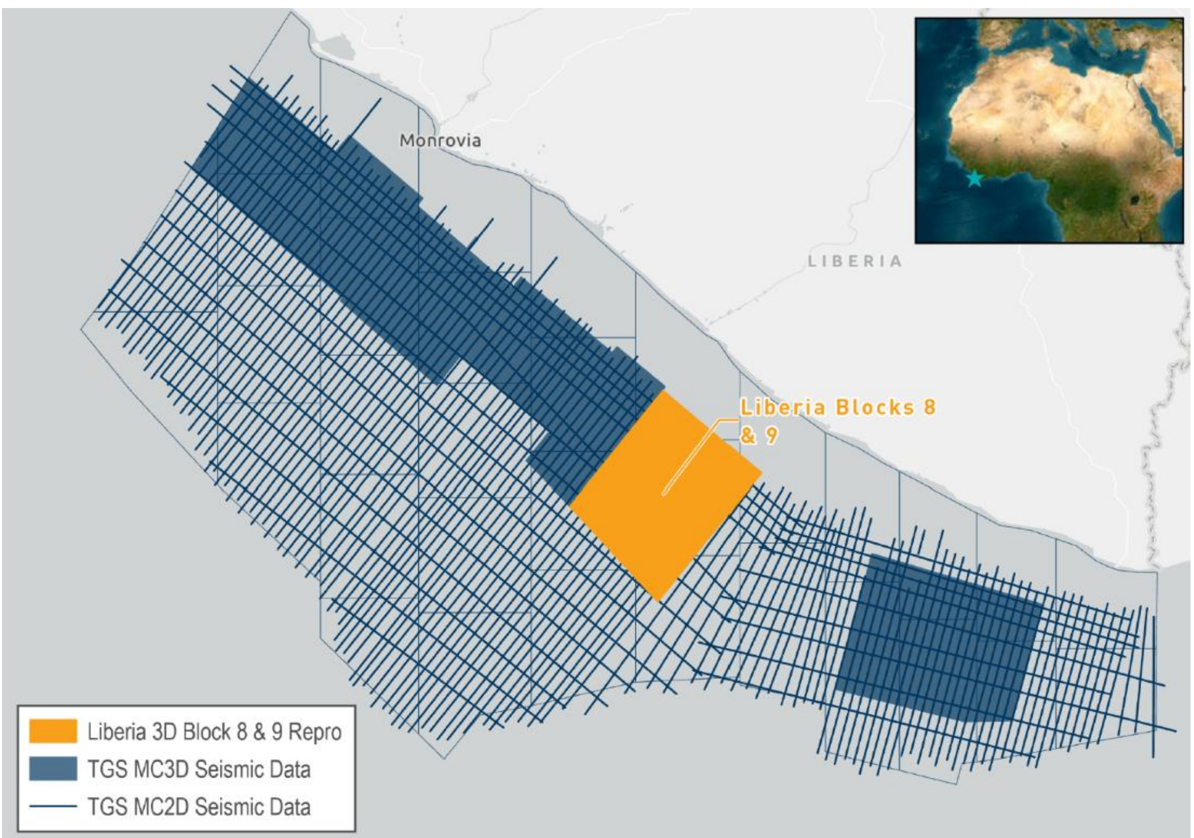


Figure 1: Map of Offshore Liberia project location in orange

Potential of FWI Imaging

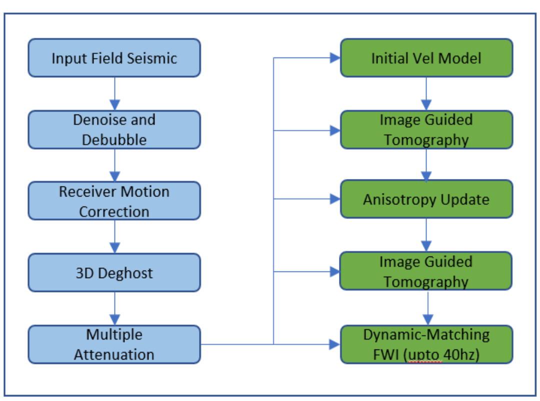
Theory and Method

The main objective of the study in this paper was to improve the image of Mid to Lower Cretaceous events which are the main reservoir sequences in this basin. The image processing was challenged in those zones in the basin due to the wide-ranging high amplitude collapse structures in the shallow sedimentary layers. Traditional imaging techniques struggle in such a setting. DM FWI which utilizes both reflection and refraction data simultaneously, produces a robust velocity model and improves the image resolution. DM FWI is insensitive to cycle skipping and robust to data with low S/N with proven success to produce a structurally conformable update to the velocity model (Mao, et al., 2020, Huang, et al. 2022).

The workflow started with fast-track pre-processing to the input seismic data, including denoise, debubble, deghost and demultiple.

The initial velocity model for FWI was a smooth field after tomographic inversion. The source wavelet used in DM FWI was extracted from the processed seismic data. DM FWI was applied iteratively, beginning with low frequencies at 3Hz, and progressively proceeding to higher frequencies and finally it was performed up to 40Hz across 5 frequency bands. During the inversion, proper QC was performed to ensure the convergence in both data domain and image domain, where data domain QC quantitively measures the mismatch between the forward modelled shot gathers against input shot gathers, while more than one image domain QC methods were utilized including the flatness of common image gathers.

By taking the directional directive along the structure to the FWI velocity model, an FWI Imaging was generated after each band and compared against the corresponding PSDM image.



Results

Due to the high amplitude and high velocity of the shallow collapsed MTCs, post-critical reflections occur at relatively short offsets. Strong heterogeneity causes scattering and energy loss, and mode conversions take place due to a high impedance contrast. Strong attenuation of high frequency energy is also evident due to complex heterogeneous velocity and anisotropy. All these geological complexities result in the conventional imaging to suffer from a lack of illumination and resolution of the events immediately below the chaotic structures, missing the high frequency energy and low S/N. In this scenario, DM FWI produces a detailed high resolution velocity model compared to traditional tomographic inversion.

Starting with the initial velocity model in Figure 2a (inline) and Figure 2b (crossline), DM FWI was applied at different frequency bands with multiple iterations for each frequency band, and the inversion stopped at 40Hz. The corresponding DM FWI results in Figure 2c and Figure 2d show significant updates in both low frequency background velocity and the high frequency contribution that reveal many geological features including internal structures of the MTCs.

An FWI imaging derived from this 40Hz FWI is compared with a corresponding 60Hz Kirchhoff PSDM (Figure 3). The corresponding FWI imaging much better delineates the complex geobody itself and the structures in the shadow zone are significantly improved compared to the corresponding Kirchhoff PSDM stacked image. In these images, events are more coherent and continuous, deeper reflectors are better imaged and images in the shadow zone are recovered. This also demonstrates the advantage of FWI imaging over conventional PSDM with higher resolution, improved continuity in such geologically complex environment. Figure 4 shows one depth slice going through the turbidite shadow zone and demonstrates the ability of the DM FWI to improve the coherency and continuity of the events over conventional imaging.

Conclusions

Shallow high velocity geobodies, such as collapsed slumps and MTCs, challenge conventional tomography-based model building. This study demonstrates that DM FWI can provide a superior alternative to resolve the geobodies and significantly improves the image of the structures below. Compared to conventional tomography, DM FWI inverts both reflection and refraction data simultaneously. FWI compensates for non-uniform illumination and improves amplitude fidelity. FWI-Imaging, which is the equivalent to data domain LSRTM, can therefore, produce better images under geophysical anomalies like these shallow MTCs and chaotic collapse structures.

Potential of FWI Imaging

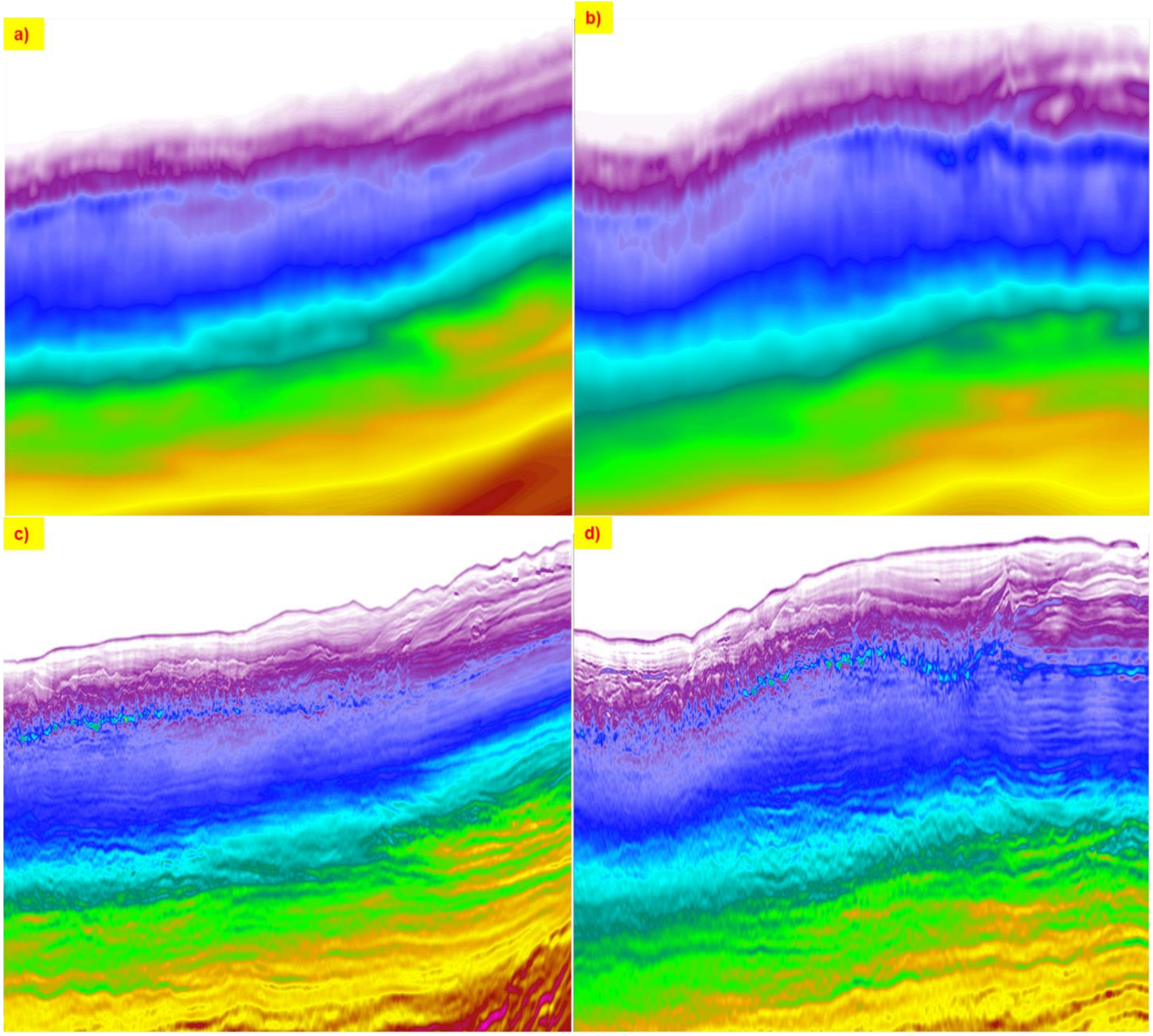


Figure 2: a) & b) Initial velocity model of inline and Crossline; c) & d) 40Hz DM-FWI velocity model of inline & crossline

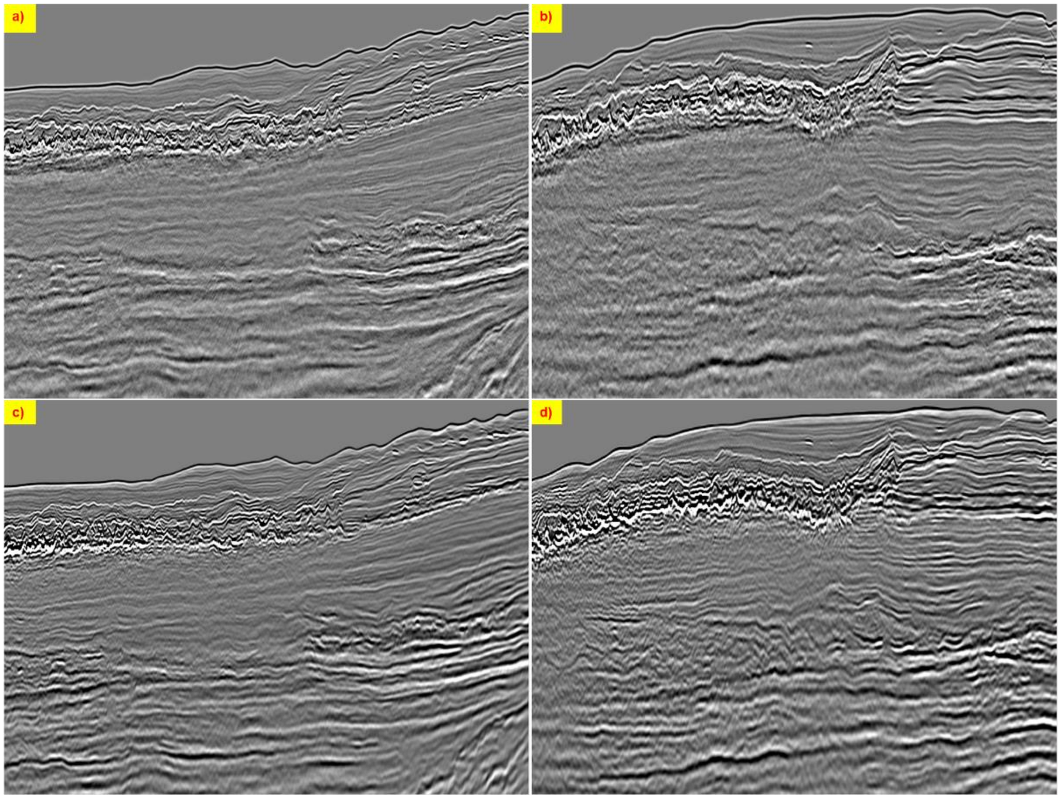


Figure 3: a) & b) conventional Kirchhoff depth migrated image of inline and crossline; c; & d) FWI imaging from 40Hz DM FWI model of inline & crossline

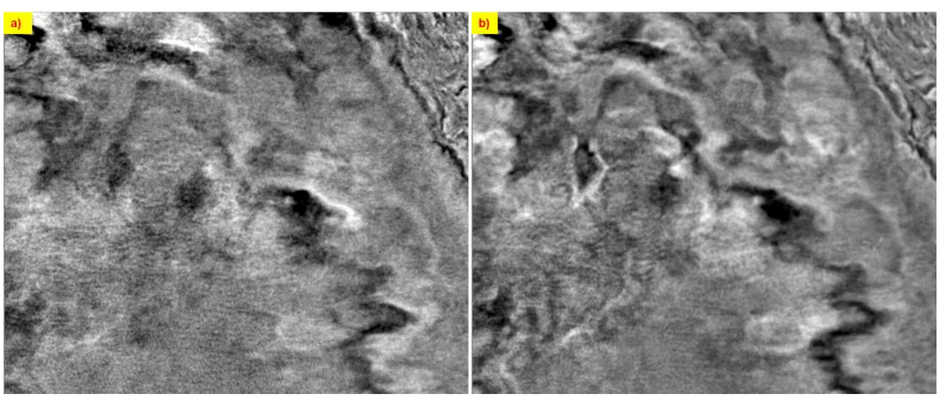


Figure 4: Depth slice of a) Kirchhoff depth migrated image and b) FWI Imaging from 40Hz DM FWI model

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