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Improving pre-salt imaging offshore Angola using narrow-azimuth towed-streamer seismic data

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Abstract Summary

The ideal seismic data for pre-salt exploration in the Kwanza basin offshore Angola would be long-offset, full-azimuth data, such as that provided by ocean-bottom node acquisition. There exists, however, an extensive library of narrow-azimuth towed streamer seismic. Here we show how this legacy data can be significantly improved using the latest processing and imaging techniques to support renewed interest in exploration in this basin with significant unresolved hydrocarbon potential. In particular we show how elastic full-waveform inversion is changing our approach to earth model building in the area, enabling efficient reprocessing over large areas.

Introduction

The Kwanza basin presents several challenges to seismic imaging, with a complex overburden characterized by strong velocity contrasts associated with salt bodies and carbonate buildups. It is well known that the ideal seismic data in such a complex environment would have full-azimuth illumination, long offsets for diving-wave penetration, and be rich in low frequencies. Such data is typically provided by ocean-bottom node seismic. The majority of data acquired to date in the Kwanza basin, however, is limited-offset, narrow-azimuth towed-streamer seismic, which with the heritage data processing and imaging workflows currently applied presents a number of unresolved challenges for pre-salt interpretation and reservoir characterization. In this paper we demonstrate how the latest seismic data processing and imaging technologies overcome some of the challenges of heritage seismic data to provide a cost-effective way to reduce exploration risk across the basin. We illustrate this with two reprocessing case studies, one from block 20/11 where the salt is moderately complex and one from block 35 where the overburden is significantly more complex.

Method

Significant improvements in signal processing have been made in recent years, including new technologies in noise attenuation, deghosting and multiple attenuation. These enable us to recover broadband data with improved signal-to-noise at both low and high frequencies. While improved signal processing is important, it is the estimation of an accurate and well-resolved velocity model which is critical to achieving reliable pre-salt imaging.

Full-waveform inversion (FWI) has emerged in recent years as a powerful method for building high-resolution subsurface models by leveraging the complete information content of seismic wavefields, and can add value to both new and heritage seismic data. The combination of a complex overburden with strong velocity contrasts combined with little recorded diving-wave energy requires an integrated approach to model building and an FWI algorithm designed to work in such environments. The algorithm must have advanced physics to accurately simulate the complex wavefield propagation in the area, it should use both reflections and refractions and have a robust objective function to mitigate potential cycle skipping.

In 2022 reprocessing of heritage data over the Golfinho field was carried out to support field development planning. The input data consisted of three single-component narrow-azimuth streamer datasets with maximum offsets from 4,800 to 8,000 m and varying source and receiver depths (Matta et al 2023). The heritage data had significant distortions in the pre-salt associated with inaccuracies in the existing velocity model. After broadband signal processing, a new anisotropic TTI velocity model was built using a combination of CIP tomography (including the use of reverse time migration (RTM) gathers for pre-salt updates), along with acoustic enhanced template matching (ETM) FWI (Cheng et al 2023), and born-based reflection FWI (Vigh et al 2016). The combination of techniques used in a top-down approach overcame the limitations of the input data to provide a significant uplift in data quality and pre-salt interpretability.

While acoustic FWI enabled significant image improvements at Golfinho, we know that in complex environments like offshore Angola, elastic effects are significant, especially as the salt becomes shallower and more complex. The recent introduction of efficient elastic FWI (Vigh et al, 2022) allows us to address these effects in a cost-effective manner. We selected a test area with more complex salt in block 35 to evaluate the potential of elastic FWI in the most complex areas, even with limited offset input data. Figure 1 shows an initial elastic FWI test providing improved data fit, increased focusing and interpretability of the top salt and simplifying the base salt reflector.

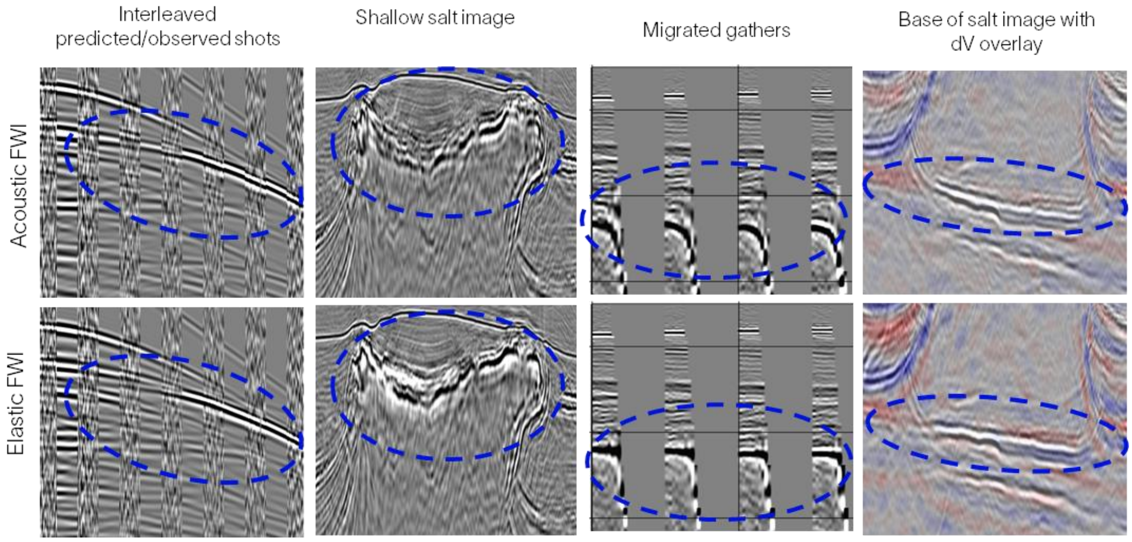

Figure 1: Initial iterations of acoustic FWI from block 35 (top row) and elastic FWI (bottom row) offshore Angola. Especially in areas where salt is shallow acoustic FWI give an incorrect velocity update leading to mismatched shots (column 1) a poorer image of top salt (column 2) and poorly corrected gathers (column 3). Column 4 shows improved simplification and continuity of base salt with elastic FWI.

Results

Figure 2 shows results from block 35 after the application of elastic FWI. The initial model is a smoothed version of the heritage velocity model with the salt in place. Of particular note is the definition of the post-salt carbonates which are critical to improved imaging in the area. The use of elastic FWI here enables an interative workflow where the classical ‘top-down’ approach, including reinterpretation of the salt body is not required, enabling more efficient reprocessing.

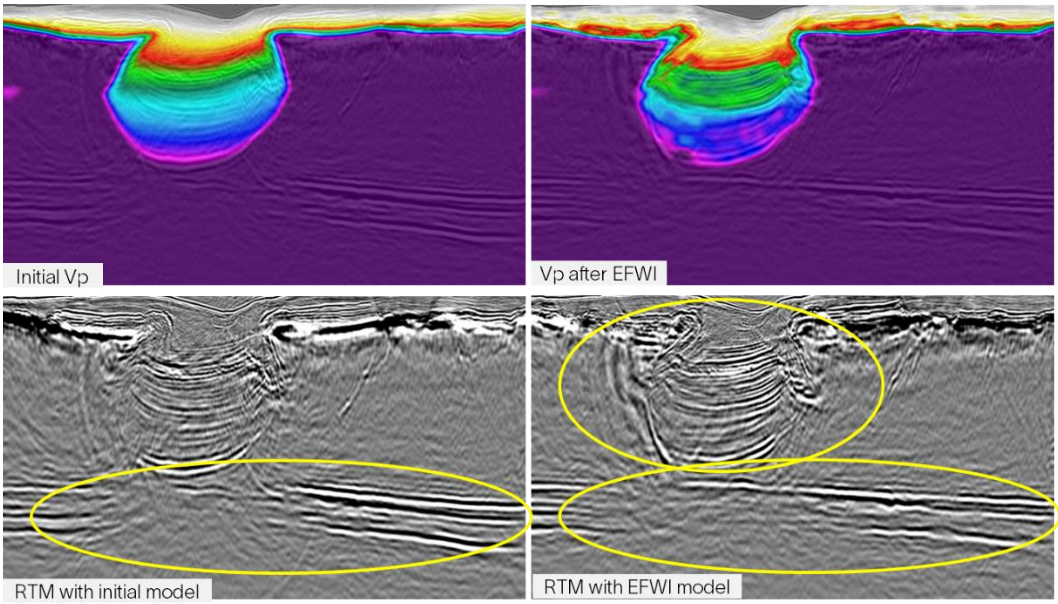

Figure 2: Vp (top row) before (left) and after (right) the lowest frequency band of elastic FWI. Reverse time migration (RTM) migrations with the corresponding models are below. Improvements in imaging the min-basin, base of salt and pre-salt reflectors can be seen.

Conclusions

New processing and imaging technologies, including elastic FWI, provide a step-change in image quality in the Kwanza basin, even using heritage narrow-azimuth towed-streamer data. This approach offers an efficient approach to reducing risk in large-scale pre-salt exploration in the area

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