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Unveiling Subsurface Complexity: High-Resolution Model Building from a Central Luconia, Sarawak Case Study

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Summary

The Central Luconia Province, situated within the Sarawak Basin of East Malaysia, stands as a significant hydrocarbon-producing field. While exploration efforts have yielded success, challenges persist, primarily stemming from the shallow-water environment and uncertainties of surrounding seismic reservoir definition.

To address these challenges, the Sarawak 3D multiclient program was initiated in 2020. The program focused on the hydrocarbon-proven West Luconia area, characterized by Tertiary clastic and carbonate targets. The program aimed to overcome obstacles associated with complex faulting, folding, and shallow gas accumulations. These geological complexities present hurdles for seismic imaging, thereby increasing risks in reservoir characterization.

The geophysical earth model building methodologies employed leveraged a combination of full-waveform inversion, common-image-point tomography, and Q tomography workflows. The objective in integrating these techniques is to construct detailed velocity and Q property. These models not only enhance seismic imaging but also enable the definition of overburden heterogeneity and reveal hidden structures concealed by gas bodies.

Our approach represents a novel and comprehensive strategy to tackle the geological and geophysical challenges inherent in the Central Luconia Province. Through advanced workflow, we have optimized production efforts which have benefited in unveiling the region's hydrocarbon potential.

Introduction

The Sarawak multiclient Polygon 1B survey is located at the Luconia Basin, offshore Sarawak. This area mainly consists of a shallow-water area, with water depth ranging from 20 to 80 m. The presence of gas-charged sediments, shallow gas pockets, and complex basin structures have resulted in seismic imaging challenges such as gas chimneys, velocity anomalies, and seismic attenuation. Existing imaging of the legacy seismic data have hindered exploration and development due to limitations of the previous earth model building (EMB) and imaging.

The sedimentary system has a strong impact on the images of overburden sediments; in this area, earth modelling is extremely complex because of rapid velocity changes laterally and vertically. For example, the slow velocity anomalies are associated with presence of shallow gas and fault blocks in recent time migration images (Figure 1).

A tailored comprehensive model building workflow was thus designed to address the geophysical challenges by utilizing a combination of full-waveform inversion (FWI) (Vigh et al., 2016), common-image-point (CIP) tomography (Woodward et al., 2008) and Q tomography (Cavalca et al., 2011).

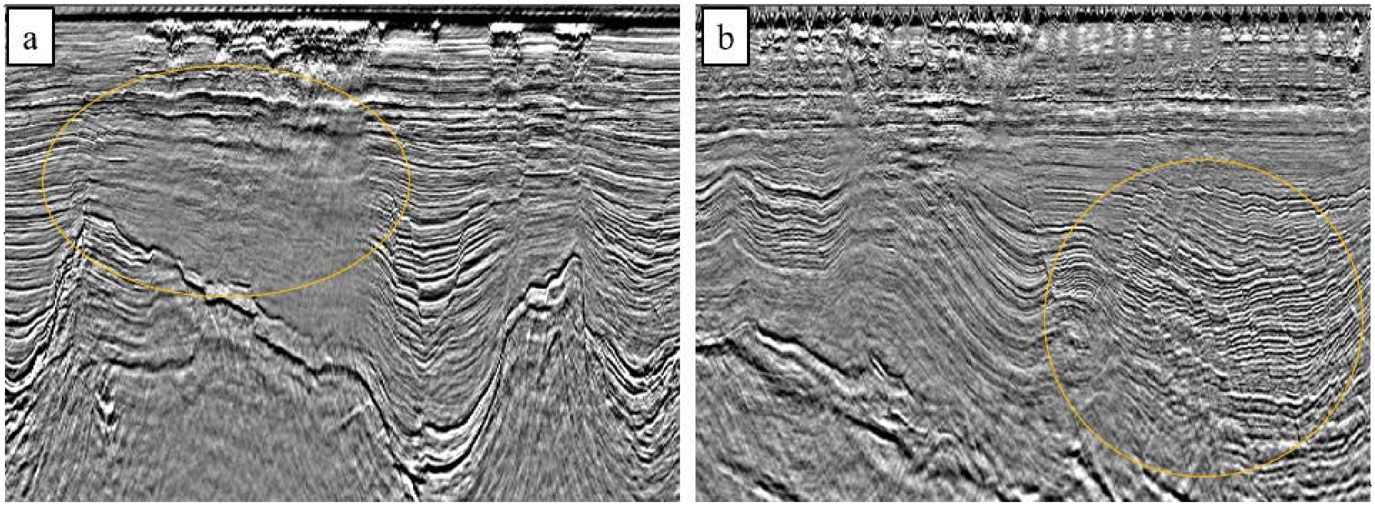

*__Figure 1__ Anisotropic Kirchhoff time migration images of 3D streamer seismic data (in two-way time, TWT) over the shallow gas body in inline (a)
and crossline (b) showing amplitude loss and complex fault compartments.*

Current seismic processing and imaging aim to resolve the overburden structure, recover the amplitude loss, and improve overall image.

High-resolution velocity model building

The multistage EMB workflow consisted of initial model building, FWI, and CIP tomography. The accuracy of the initial velocity model is pivotal for FWI to converge effectively while maintaining computational efficiency. In the initial stage, a challenge was that only a fast-track onboard-picked velocity model was available. To overcome this hurdle, FWI with a travel-time objective function was employed, as suggested by Jiao et al. (2015), to mitigate the cycle-skipping issue inherent in traditional FWI caused by inaccuracies in the initial velocity model. The lowest usable frequency in the data (peak 4 Hz) was used for the first frequency band of FWI to further reduce the risk of cycle skipping. Two frequency bands of Q-FWI up to peak frequency of 8 Hz were applied and achieved sufficient resolution to capture the overburden anomalies. The Q model was updated based on an empirical relationship with compressional velocity to provide a lower Q value in the shallow subsurface, especially at the shallow gas body. Multiple passes of FWI up to 24 Hz were used to capture overburden anomalies, combined with multiple iterations of CIP tomography. The Q model was subsequently refined and updated utilizing Q tomography, primarily aimed at capturing and refining Q anomalies within the shallow gas body and achieving a layered Q model with structural variability. For the deeper sections, a velocity scanning approach was employed, focusing on updating velocities beneath the basement while adhering to horizon constraints. Throughout the model building stages, validation was achieved through the consistent utilization of Kirchhoff pre-stack depth migration (KDM) and forward modelling.

Results

The results demonstrated that the novel workflow effectively identified changes in velocity caused by shallow gas pockets and geological complexities in the area. The final velocity model accurately represents the shallow anomalies and layered sediments, providing a detailed understanding of the subsurface structures (Figure 2).

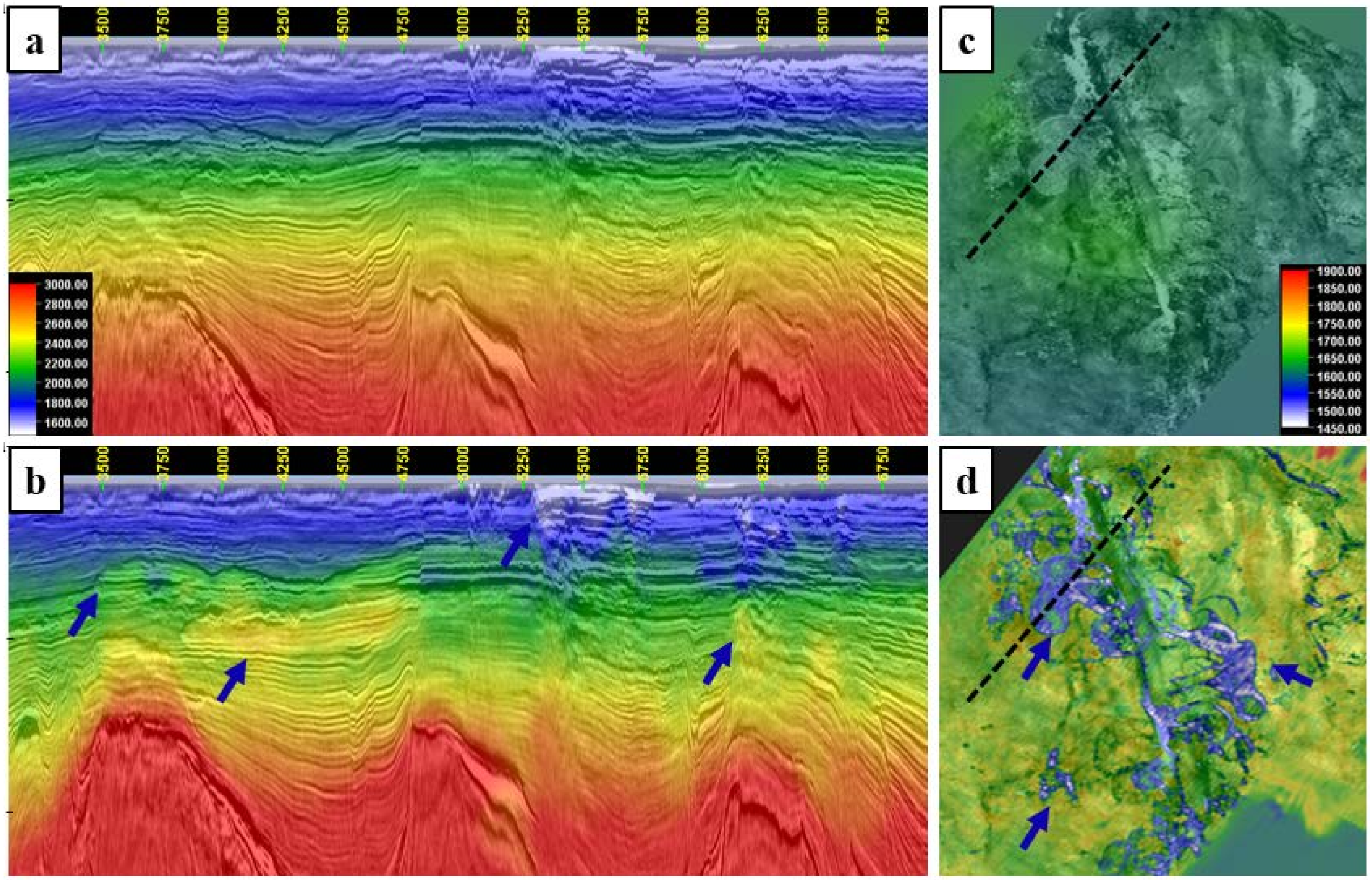

Figure 2 *An in-depth domain comparison between the initial velocity model (a) and the final velocity model (b) and comparison at a depth slice of 100 m between the initial velocity model (c) and the final velocity model (d). The final velocity model showcases high-resolution geological plausibility, enabling the delineation of slow velocity attributed to the abundance of gas bodies and fast velocity associated with carbonate deposits. The inline section (a and b) is demarcated by a dashed line at the depth slice (c and d).*

The final migration was conducted utilizing Q-Kirchhoff pre-stack depth migration (QKDM), integrating the final high-resolution velocity (Figure 3a) and spatial variable Q (Figure 3b) as inputs. The resulting QKDM 2022 image unveils substantial enhancements, particularly within gas body and fault structures, when compared against the 2022 Kirchhoff pre-stack time migration (KTM) images in Figure 4. Notice that sediment layers are unveiled below the gas cloud. The faulting system can be identified and mapped within the mini basin.

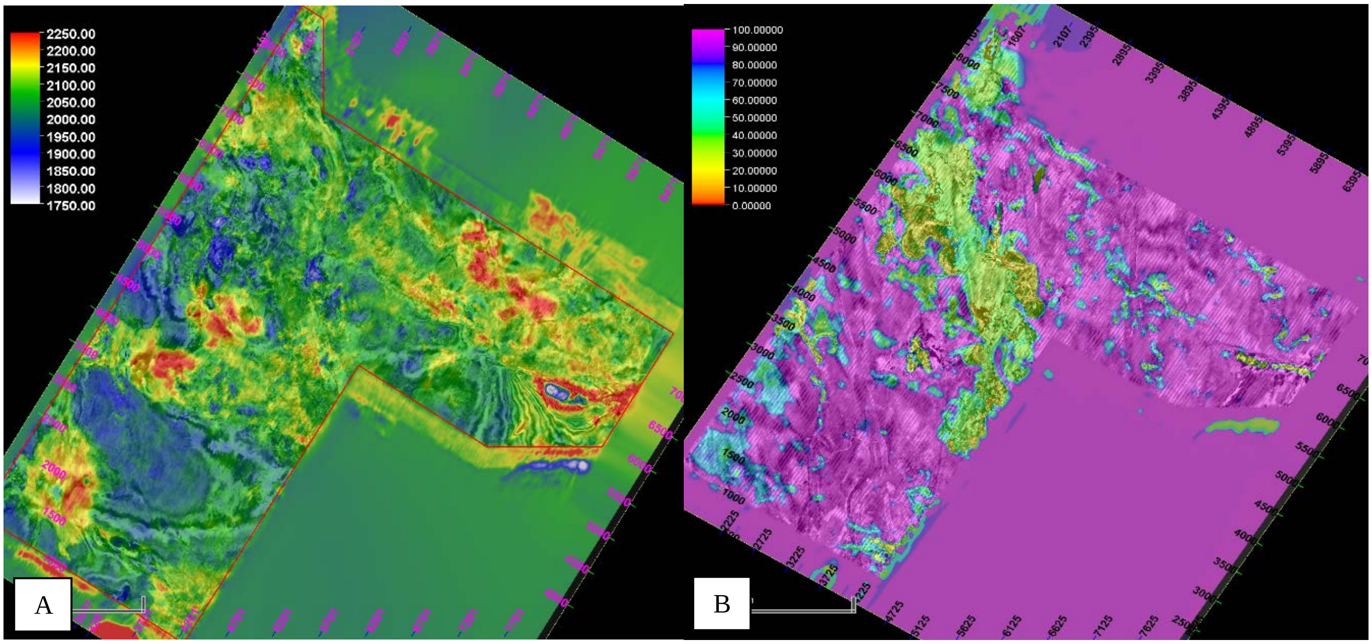

Figure 3 *Depth slices of final velocity model at 400 m (a) and final spatially variable Q model at 200 m depth (b).*

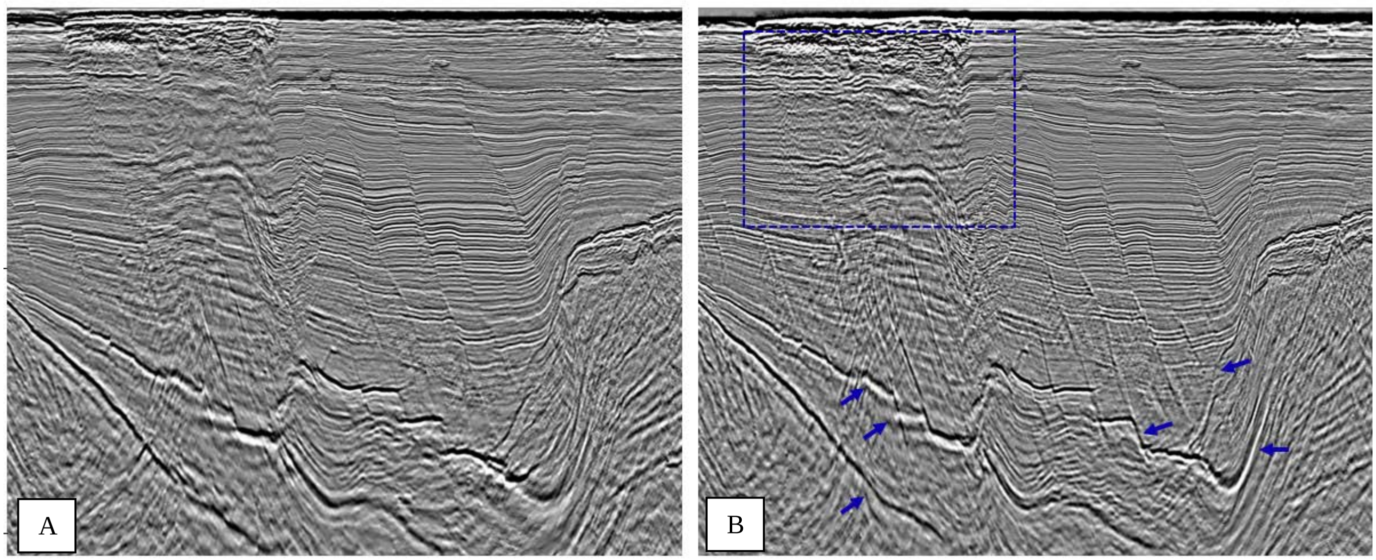

Figure 4 *Seismic section comparison (time domain) at target area between (a) KTM image processed in 2022 and (b) final QKDM image, converted to time domain (TWT) for comparison) processed in 2022. Blue box and arrow show significant improvement beneath the gas cloud and faulting system.*

Conclusions

We have demonstrated the benefits of a tailored workflow to delineate the subsurface that employs a velocity model building methodology, integrating a high-resolution FWI, CIP tomography, and Q tomography. This comprehensive approach precisely delineates the contrast of shallow gas anomalies and shallow carbonate layers. The resulting model and image contribute to de-risking the pre-drill uncertainties of complicated geology within targeted zones, which unlocks substantial exploration potential and producing fields.

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