Tu_R01_08

Revealing Pre-Carbonate Reservoirs Using Advanced Modelling and Imaging Methods

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Summary

Through recent years, several new technologies have been introduced while various standard processing workflows have been further improved to obtain more valuable results in seismic processing. This has made reprocessing work a feasible route to discover the potential of marginal field in deeper, pre-carbonates zones using existing acquired data. In this paper, we exhibit how complex carbonate layers and pre-carbonate reservoir were revealed from narrow azimuth and limited offset dataset. It has been achieved through the application of effective broadband pre-processing methods, comprehensive velocity model building and advance imaging technique.

Introduction

Seismic data from Offshore Sarawak is faced with three main challenges: Shallow Water Multiples, Gas Clouds and Pre-Carbonate Imaging. Pre-Carbonate Imaging is essential to reveal and de-risk the reservoirs lying just underneath in a highly faulted and fractured regime. The carbonate platforms and pinnacles act as a mirror, reflecting most of the seismic signal and producing a lot of internal multiples. This survey is over such a complex carbonate field where a 3D marine seismic data was acquired in 1999, with six conventional streamers and a maximum offset of only 4000m. This dataset was reprocessed in 2012 but the limitations of time processing and imaging are apparent. The data suffered from amplitude loss due to absorption by gas bodies and carbonate layers, causing poor reflector continuity especially at the target zone. Remnant noise and multiples beneath the carbonate layer mask the deeper fault systems (Tingay et al., 2009). It was obvious that the problem could not be resolved using conventional multiple modelling or imaging methods, so latest advanced imaging technologies were implemented which successfully unmasked the reservoir.

Methodology

During the pre-processing, a broadband processing flow including source and receiver deghosting was applied, which helped to broaden the bandwidth and to improve the signal-to-noise ratio. In addition, 3D Inverse Scattering Series based Interbed Multiples Attenuation (3D-ISS-IMA) (Wang et.al. 2014) was applied to attenuate interbed multiples beneath the carbonates layer (Figure 1). The combination of these two processes produced sharper and clearer events that allow for easier interpretation.

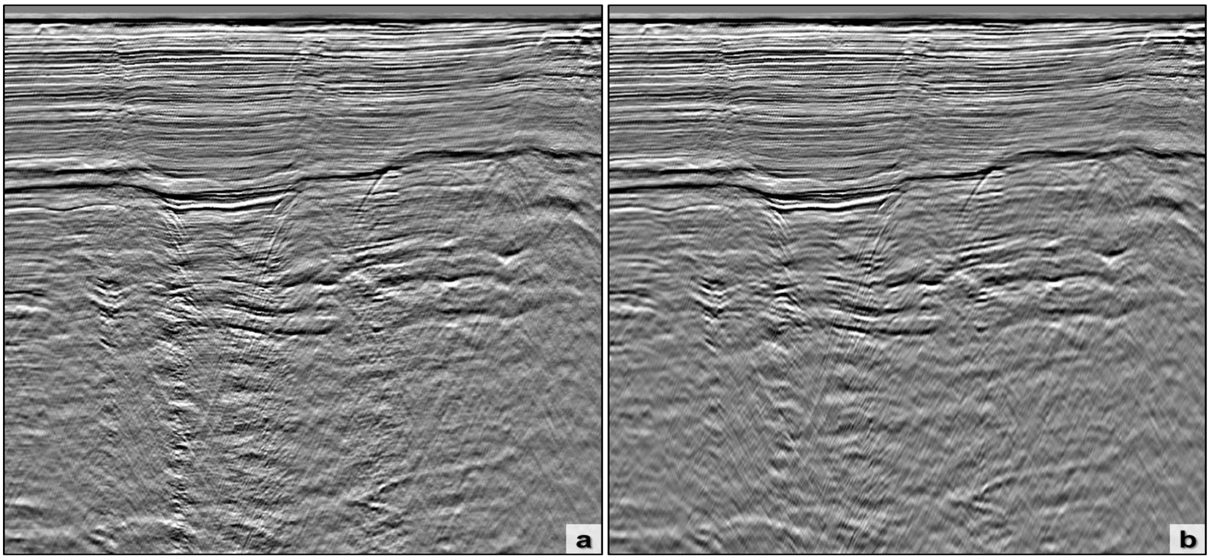

***Figure 1** Near Offset Stacks: **a.** before, and **b.** after 3D-ISS-IMA application. Strong interbed reverberations have been successfully attenuated to clean up the pre-carbonate layer.*

While improved signal processing is a benefit in this work, the model building was the main focus of this reprocessing. Many different technologies and their combinations were evaluated to improve the depth velocity model. The final model building workflow consisted of Diving Wave Tomography (DWT), High-Frequency Full Waveform Inversion (HF-FWI), High Definition Reflection Tomography (TomoHD), Dip Constrained Tomography (DCT) and Scanning Tomography. A Total-Q-Tomography flow was applied to create a Q model.

Since the data previously had only gone through time processing, the initial velocity model was derived from PSTM velocities. DWT provided a more accurate shallow velocity by using first break picks to invert for velocity. The DWT model was merged with the initial velocity model and then calibrated to existing wells to create an initial VTI model.

Although diving waves do not illuminate the target depths, the aim for FWI was to obtain a high resolution velocity field that captures shallow gas bodies and helps to heal time sagging that affects the deeper image (Ratcliffe et al., 2014). Dynamic Warping FWI (Wang et al., 2016) was run using diving waves in a frequency marching manner from 4 Hz to 12 Hz. This was followed by HF-FWI to 24 Hz by also incorporating reflections (Kumar et al., 2014).

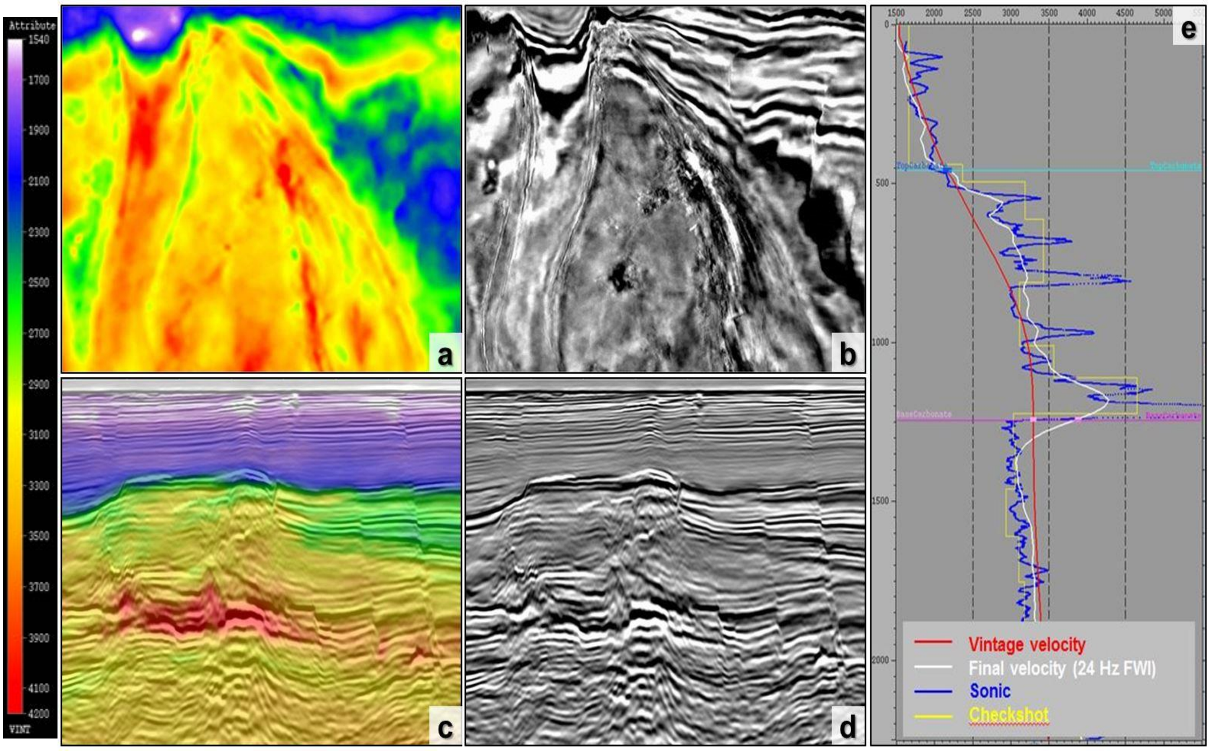

***Figure 2 a.** Depth slice of velocity model within carbonate layer. **b.** Depth slice of Q-TTI-RTM stack. **c.** Inline slice of velocity model. **d.** Inline slice of Q-TTI-RTM stack. **e.** Velocity profile at well location. 24 Hz HF-FWI gives high-resolution velocity conforming to geology which was used for Q-TTI-RTM.*

Five iterations of TomoHD were used to update the carbonate and pre-carbonate layers. DCT incorporated RMO picks and dip information together in the tomographic engine to produce flat gathers and geologically plausible structure. Scanning tomography (Gong et.al. 2018) on the other hand helped in getting more accurate velocities inside the carbonate platforms - which consist of variable facies, from clastics with carbonates stringers and ramping to buried reef pinnacles and also karst. Migrating with different velocity percentages enabled better RMO and structural picking. These were fed into Scanning Tomography inversion to improve the velocity model. A Tilted Transverse Isotropy (TTI anisotropy) model was then created (Figure 2) to honour TTI effects in the pre-carbonate layer.

A Total-Q model was generated via three iterations of Q-tomographic updates. Anomalous Q model estimation was done using the “FWI guided Q tomography” approach (Zhou et.al. 2013). This was then combined with a background Q model, built using two iterations of Frequency Shift Q-tomography (Xin et al., 2014), to result in a Total-Q model. The final Q model (Figure 3) was seen to improve amplitude and phase distortion underneath high absorption zones such as shallow gas bodies present above and at the top of the carbonate platform, and the carbonate reefs.

Q-TTI-Kirchhoff Depth Migration (Q-PSDM) and Q-TTI-Reverse Time Migration (Q-TTI-RTM) were both run (Figure 4), first to satisfy the need of resolution in post-carbonate layers and second to handle complex wave pathing in the complicated fault system within reservoir zones (pre-carbonates) up to the carbonate platform. The 24 Hz HF-FWI velocity model, along with the Total-Q model, was used to run Q-TTI-RTM (Xie et.al. 2015) and output RTM angle gathers which were cleaner (Figure 5) and resulted in a stack image that is simpler and easier to interpret compared to Kirchhoff. This not only helps to achieve a more confident structural interpretation but the RTM angle gathers also produce more stable and cleaner angle stacks which are crucial in AVA/AVO studies.

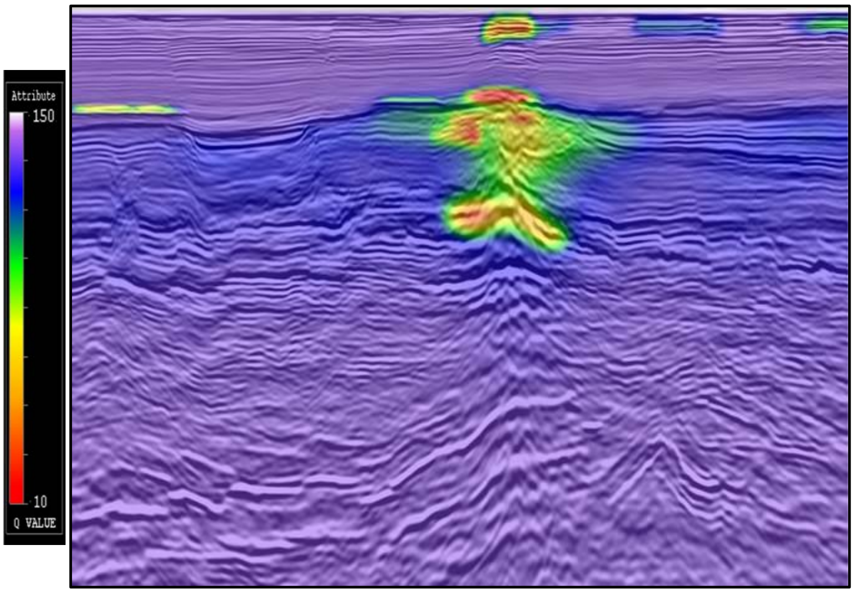

Figure 3 *Multilayer Q bodies captured by Q-tomo. Q-PSDM is able to increase resolution and bandwidth of data and improves amplitude and phase compensation underneath absorption zones.*

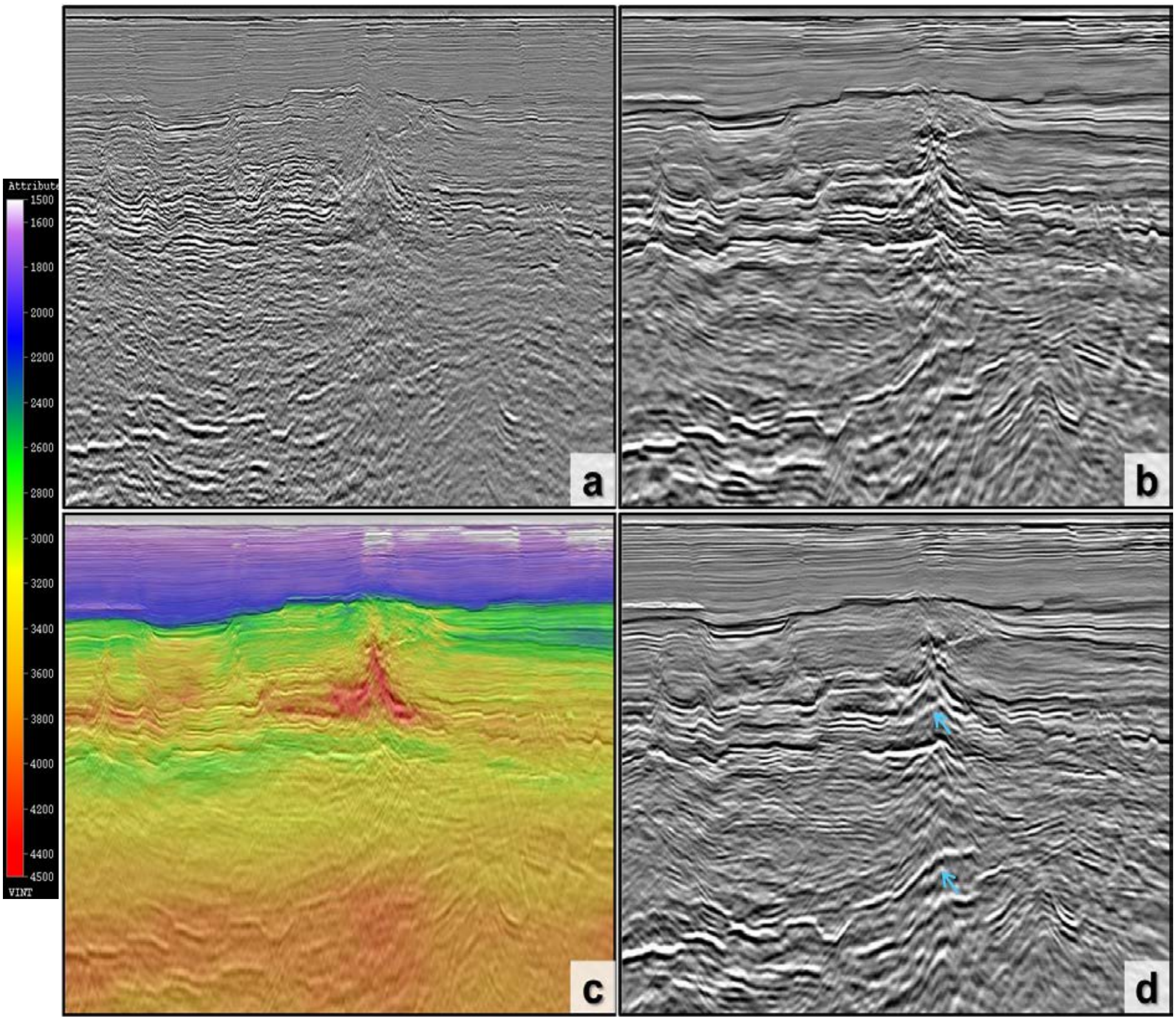

Figure 4 a. *Vintage Kirchhoff PSTM stack.* ***b.*** *Q-TTI-Kirchhoff PSDM stack.* ***c.*** *Final High Definition Velocity Model.* ***d.*** *Q-TTI-RTM stack. Kirchhoff and RTM stacks have higher resolution and better continuity compared to the vintage data. The RTM stack gives a cleaner image of the pre-carbonate reservoir section. The top arrow indicates a buried reef while the bottom arrow indicates older coal horizon which could be the source rock.*

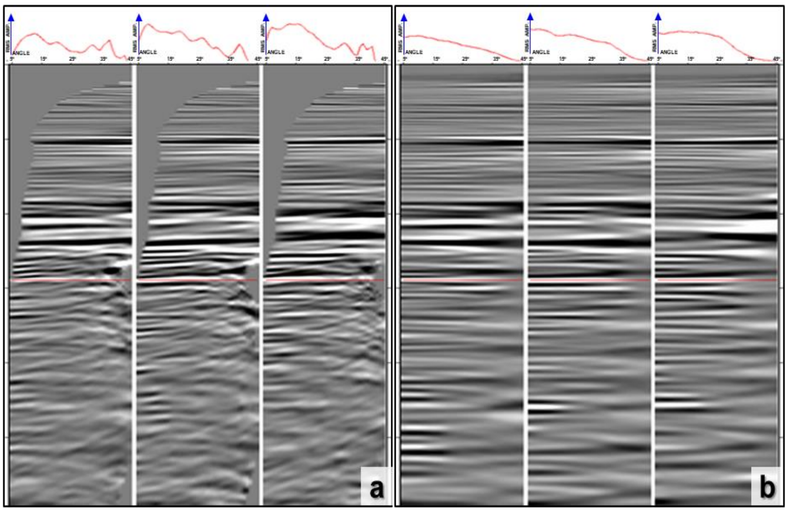

Figure 5 *AVA curve plotted at the level of the thin red line from* ***a.*** *Q-TTI-Kirchhoff, and* ***b.*** *Q-TTI-RTM angle gathers. RTM angle gathers provide cleaner AVA signature at reservoir level (red line).*

Conclusion

In this paper, we have presented how the application of advanced modelling and imaging techniques, including 3D-ISS-IMA, HF-FWI, DCT, Scanning Tomography, Q-tomography and Q-TTI-RTM have helped to resolve challenges in pre-carbonate reservoir imaging. A combination of these techniques has helped to derive a very high-resolution velocity and Q model which can also be used as additional input to interpretation. Production of Q-TTI-RTM angle gathers has pushed even further into creating improved inputs for both structural and quantitative interpretation.

Acknowledgement

The authors thank PETRONAS Carigali Sdn. Bhd., Vestigo Petroleum Sdn Bhd. and CGG for the permission to present these results.

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