Application of high-end seismic imaging technologies for field development in NWS Australia

Min Lee Chua 1  
Kai Zhao 1  
Wai King Yong 1  
Xiang Li 1

1 CGG, 1 Ord St, West Perth

SUMMARY

The North West Shelf, situated in the north-west of Western Australia, is a world-renowned offshore hydrocarbon province with investments of more than A$200 billion to date. However, the quality of the legacy seismic often suffers from severe residual multiple, limited bandwidth and poor S/N ratio within the reservoir level. This is mainly due to the existence of a complex shallow overburden with a strong water bottom, tertiary carbonates and channel systems.

With the recent advancement in seismic imaging technologies, it is now feasible to mitigate these challenges through high-end reprocessing. In this paper we will demonstrate how a tailored processing flow was applied on a development project on the North West Shelf. The key technologies that we will review here are (1) de-multiple workflow with 3D curvelet domain subtraction, (2) hybrid Tomo-FWI velocity model building, and (3) Least-Squares Q Pre-SDM (LS Q-PSDM). The application of these high-end technologies significantly improved the quality of the final imaging, which helps with reducing uncertainties and minimizing risk in the field development.

Key words: Shallow water de-multiple, 3D curvelet subtraction, deghosting, hybrid Tomo-FWI, Least-squares Q migration, NW Shelf Australia

INTRODUCTION

The area of interest described in this paper is in Browse Basin, NWS Australia with water depth ranging from 200m to 300m. The area was covered by two vintage seismic surveys with perpendicular shooting directions and wide-tow streamer settings.

A quick look into the data before de-multiple shows that the dominant energy recorded is short period multiples, including both water layer related multiples and a shallow carbonate related surface multiple (Figure 1). The fact that the multiple energy is much stronger than the underlying primaries, combined with both having a similar dip, makes the de-multiple process particularly challenging. The key to success here is to separate different orders of short period multiples in the modelling and then apply subtraction in a domain with better sparsity. In the paper, we will discuss how a combination of MWD (Wang, 2014) and iterative SRME (Vershuur, 1997) achieved accurate multiple modelling, and how a simultaneous subtraction in 3D curvelet domain (Wu et al., 2014) achieved the optimized de-multiple result as shown in Figure 2.

Figure 1. Seismic data in different domains before de-multiple. Note the surface multiples are a magnitude stronger than the primaries.

Figure 2. Seismic data in different domains after de-multiple.
Finally we look at whether the S/N ratio and resolution can be further enhanced by least-squares Q migration, in which absorption is incorporated into the Kirchhoff modelling operator and inversion is approximated by Hessian filtering.

**DEMULTIPLE**

Conventionally, the de-multiple workflow in shallow water is applied in sequential order: first attenuation of the short period water layer related multiple then attenuation of the long period surface multiple. However, this approach normally leaves strong residual multiples in NWS data because of two fundamental limitations: firstly it fails to model the multiples with a water layer bounce in the middle between two primary bounces; secondly it fails to mitigate the strong cross-talk between surface multiples of different orders. To better separate these multiples, we come up with an optimized de-multiple workflow for the shallow water NWS data as shown in Figure 3. We generated the water bottom related multiple model using 3D MWD (Wang, 2014) through modelling the Green’s function of the water-bottom primary reflections. We then convolved it with recorded data to predict the water-layer related multiples. Next we applied an iterative 3D SRME scheme to reduce the cross-talk in surface multiple prediction: the first pass of SRME predicts the multiple model by convolving recorded data with itself (D*D), then Radon de-multiple was applied on the 1st pass subtraction result to form the primary model P', and finally this primary model was convolved with the recorded data (D*P') in the 2nd pass SRME.

By providing both the 3D MWD and 3D iterative SRME models to the adaptive subtraction process, this simultaneous subtraction provides an improved de-multiple result over the conventional sequential de-multiple flow as shown in Figure 4.

**Figure 3. Optimized de-multiple workflow**

Furthermore the simultaneous adaptive subtraction is done in the 3D curvelet domain: the sailline data (shot/channel/time) is transformed to curvelet domain with six dimensions (dip/azimuth/frequency domain and k1/k2/k3 in the spatiotemporal domain) as described by the formula below:

$$C(j, k, l) = \int_{R^3} D(t, \tilde{x}) \varphi_{j,k,l}(t, \tilde{x}) dt d\tilde{x}$$

3D Curvelet transformation provides a natural representation of seismic events and ultra-sparsity (Wu et al., 2014). Compared to the conventional least-squares approach, the 3D curvelet subtraction provided better balance between multiple attenuation and primary protection. The effectiveness of this whole workflow is clearly demonstrated in Figure 2: a clear faulting block and high signal-to-noise ratio is achieved after the full de-multiple workflow is applied.

**Figure 4. Near channel comparison of input (A), after sequential MWD + SRME 2 subtraction flow (B) and after optimized simultaneous MWD + SRME 2 subtraction flow (C). Bottom panel is the autocorrelation.**

**Hybrid FWI and Tomography Velocity Model Building Flow**

The geology of NWS Australia can be described as sedimentary in general but with shallow carbonate build-up and occasional karst formations. This creates a strong velocity contrast and can thus impact the imaging beneath it unresolved. Full waveform inversion (FWI) has been proven to be effective in generating high-resolution and high-fidelity velocity models (Lambare et al., 2015), however, its application in this case is constrained by limited penetration of diving waves (strong velocity inversion beneath the shallow carbonate layer) and poor signal-to-noise ratio at the low frequency end. To tackle these challenges, a hybrid FWI and tomography velocity model building flow was applied in our case study. This methodology interleaves the tomography update and FWI update in the velocity model building: a tomography update to focus on the low frequency background trend and anisotropic parameters update, and FWI to focus on resolving the velocity contrast from the shallow high velocity channels (Dickinson et al., 2017). To improve the penetration of FWI, we use both refraction and reflection...
energy in the inversion. The hybrid FWI-Tomography VMB flow successfully resolves the strong velocity contrast in the carbonate layer. The final velocity not only fits the geology but also has a good correlation with the well sonic data (Figure 5). More importantly, the un-geological imprint in the image is removed resulting in much clearer geological structures at the reservoir level (Figure 6).

**Figure 5.** High resolution velocity model after hybrid Tomo-FWI VMB flow (left) and its comparison with well sonic data (right)

**Figure 6.** PSDM stack overlaid with initial velocity (left) vs final velocity (right).

### Least Square Q-Kirchhoff Migration (LSQM)

The broadband survey and processing provided broad bandwidth and high resolution for the shallow events, however, the high frequency components decay rapidly with depth which leads to low frequency components dominating the amplitude spectrum for the deep section, thus causing a deterioration of visual resolution in the target layer. QPSDM is generally preferred over a conventional post migration Q compensation process to compensate for the absorption effect. However, QPSDM is prone to over boosting migration swings and high frequency noise although it better handles the 3D absorption effect along the ray path. The best approach is least square Q-Kirchhoff migration (LSQ-PSDM). Similar to Wu et al. (2017), we incorporated Q into least squares migration (LSQ-PSDM) to simultaneously achieve better illumination and Q compensation (Wang et al., 2017). The results are shown in Figure 7 as compared with QPSDM results. The benefits of LSQ-PSDM can be observed in three key aspects: firstly, by compensating the illumination of dipping reflectors, LSQ-PSDM provides sharper fault imaging; secondly, by inversion of the migration operator, migration swings are suppressed; lastly, the sparsity from the Hessian operator helps to suppress the high-frequency random noise and thus provides higher signal-to-noise ratio. From the comparison, it shows that AVO character is preserved by LSQ-PSDM with better consistency achieved between near stack and far stack (Figure 9). In the coherency cube, we can observe a much clearer faulting system from LSQ-PSDM result (Figure 8).

The final image was compared with the legacy image in Figure 10. The application of these high-end technologies significantly improved the quality of the final imaging: residual multiples have been mostly removed, fault imaging is much clearer, and resolution and signal-to-noise ratio is much higher in the reservoir level. All these have helped in reducing uncertainty and minimizing risk in the field development.

**Figure 7.** Near offset (A and B), full stack (C and D) and timeslice comparison (E and F) of Q-PSDM and LSQ-PSDM.

**Figure 8.** Coherency volume timeslice generated from Q-PSDM (top) and LSQ-PSDM (bottom) full stacks.
CONCLUSIONS

Seismic data from North West Shelf has been facing a lot of challenges for a long time, namely severe residual multiples, limited bandwidth and poor S/N ratio at the reservoir level. High end seismic imaging technologies are needed to better solve these geophysical problems. In this paper, we have demonstrated that data that was imaged recently can be significantly improved when we take a methodical approach towards understanding each fundamental challenge and by applying the most appropriate and best technology available. We believe those technologies can provide an effective solution to NWS data with similar issues thus significantly enhancing interpretation and de-risking for field development.

ACKNOWLEDGEMENTS

We thank Shell Australia and CGG for permission to publish this work. We thank CGG R&D team for their technical support and advice.

REFERENCES


