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Reviving a Mature Basin through High-End Imaging Technology

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Summary

This paper highlights compelling imaging improvements achieved through modern high-end reprocessing in the Gippsland Basin. The area of study, largely represented by the Bass Canyon, has strong exploration potential as well as high risks. The major challenges in this region are related to geologic complexity and seismic imaging limitations, i.e.: a) extensive velocity anomalies leading to velocity uncertainties and false structural closures that increase drilling risk; b) strong noise interference and limited imaging clarity that affects AVO analysis. By integrating the modern techniques of 3D deghosting, full waveform inversion (FWI) and least-square Q pre-stack depth migration (LSQPSDM), the newly reprocessed data yields a substantial amount of added value over legacy datasets, resulting in an improved understanding of the subsurface geology and clearer prospect mapping. This reprocessing approach demonstrates, even in basins that are considered mature, that new ideas and technology can change long-held perceptions and rejuvenate exploration interest.

Introduction

The Gippsland Basin, situated in southeastern Australia, is where several giant oil and gas fields were discovered in the 1960s. Most of the major fields are reservoirs of high quality, multi-darcy sandstones, namely of the top Latrobe (TOL). To date, the Gippsland Basin may be considered as being mature given that production rates have been declining since the late 1990s. With diminishing reserves in the existing oil and gas fields, new reservoirs are being urgently sought to meet the energy needs of southeast Australia. As a result, the exploration focus is moving to higher-risk areas such as the continental basin margin, e.g Bass Canyon (indicated by the red box in Figure 1).

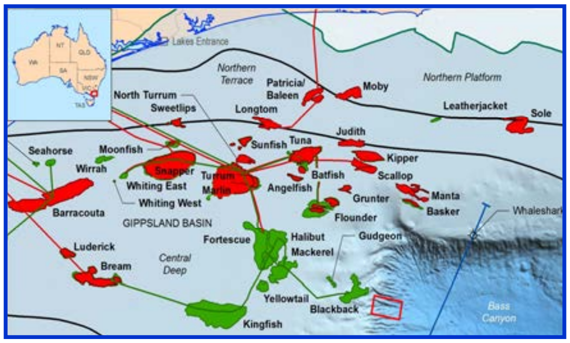

Figure 1. *Gippsland location map*

Geologically, the Gippsland Basin has rich source rocks that have the potential to generate huge hydrocarbon volumes that can be trapped both within the fluvial-deltaic/slope-fan sands of the intra-Latrobe and in the deeper Golden Beach sands. Unfortunately, both targets can be challenging due to the imaging difficulties. High resolution velocity modeling and imaging is essential to stabilize AVO inversion and to improve the understanding of the remaining prospects.

In this paper, we demonstrate the value of reprocessing the legacy narrow-azimuth Tuskfish 3D survey (2003 acquired). Focusing on the Bass Canyon area, an advanced workflow including 3D deghosting, full waveform inversion (FWI), and least-square Q pre-stack migration (LSQPSDM) has been integrated to target the mentioned velocity model building and seismic imaging challenges.

Hybrid FWI and Tomography Velocity Model Building Flow

Where a complex shallow overburden exists, full waveform inversion (FWI) has been proven to be effective in reducing depth uncertainty and in generating high-resolution and high-fidelity velocity models (Lambare at al., 2015). However, when applied to traditional narrow azimuth data (NAZ), its application is often limited by the maximum offset recorded, the poor signal-to-noise ratio at the low frequency end (Dellinger ae al., 2017) and the important but disregarded cross-talk between velocity and anisotropy. To tackle these challenges, a hybrid FWI and tomography velocity model building flow was applied to our case study: we interleaved FWI, focusing on resolving the velocity contrast from the shallow high velocity channels (Figure 2b), with the tomography update, focusing on the low frequency background trend and anisotropic parameters update.

The starting model for FWI is from the legacy 2012 PSDM reprocessing, which gives overall flat CIG gathers (Figure 2d) and a good low frequency trend. However, it clearly shows the limitation of the tomography approach: the velocity model lacks the lateral resolution to model the high velocity channels, thus leaving non-geological undulations in the deeper images as highlighted in Figure 2a. To make FWI work for this vintage dataset (source depth 8m, receiver depth 9m), special care was taken to precondition the input data at the low frequency end: dipole sparse tau-p inversion was applied to attenuate the low-frequency/high-dip noise (Yu et al., 2015). Since nearfield hydrophone (NHF) data was not recorded in this survey, the wavelet used for FWI was obtained from the far field signature. Different debubble operators have to be applied to the far field signature and the field data to overcome the issue of poor bubble modeling. Although data with reasonable signal-to-noise can be seen from 2~4Hz after the preconditioning, FWI starting from 6Hz generated a more stable update. To mitigate the potential cycle skipping issues, dynamic warping FWI (DFWI) (Wang et al., 2016) was applied. The velocity contrast from the high velocity channels has been captured by the 12Hz FWI update. The perturbation is not huge (less than 10% or max 400m/s), however, it effectively removes the complex distortion/imprint of the overburden on the image as highlighted in Figure 2b. The wobles in the CIG events are removed and the focusing is greatly improved as shown in Figure 2e.

Improved spatial resolution can also be observed in the perturbation display (Figure 2c as vertical sessions and Figure 2f as depth slice at 1800m).

Following the 12Hz FWI, further tomography updates and mis-tie analysis were conducted to update the Delta/Epsilon field. It was noted that it was much easier to derive a geological consistent anisotropic model once the imprint from the overburden had been removed. With the updated Delta/Epsilon field, the second iteration of FWI (15Hz) was applied to further improve the resolution of the model. The model was then finalized after several more iterations of tomography updates following the 15Hz FWI. Figure 3 shows the traverse line through the key wells: Figure 3a is the legacy velocity overlaid on legacy PSDM volume and Figure 3b is the new hybrid FWI/TOMO model overlaid on the reprocessed LSQPSDM volume. The structure is more geologically consistent and the key mis-tie at the top of the Latrobe (TOL) horizon has been improved from over 100m at the Dory well to less than 10m overall. This provides the crucial assurance necessary for the closure interpretation.

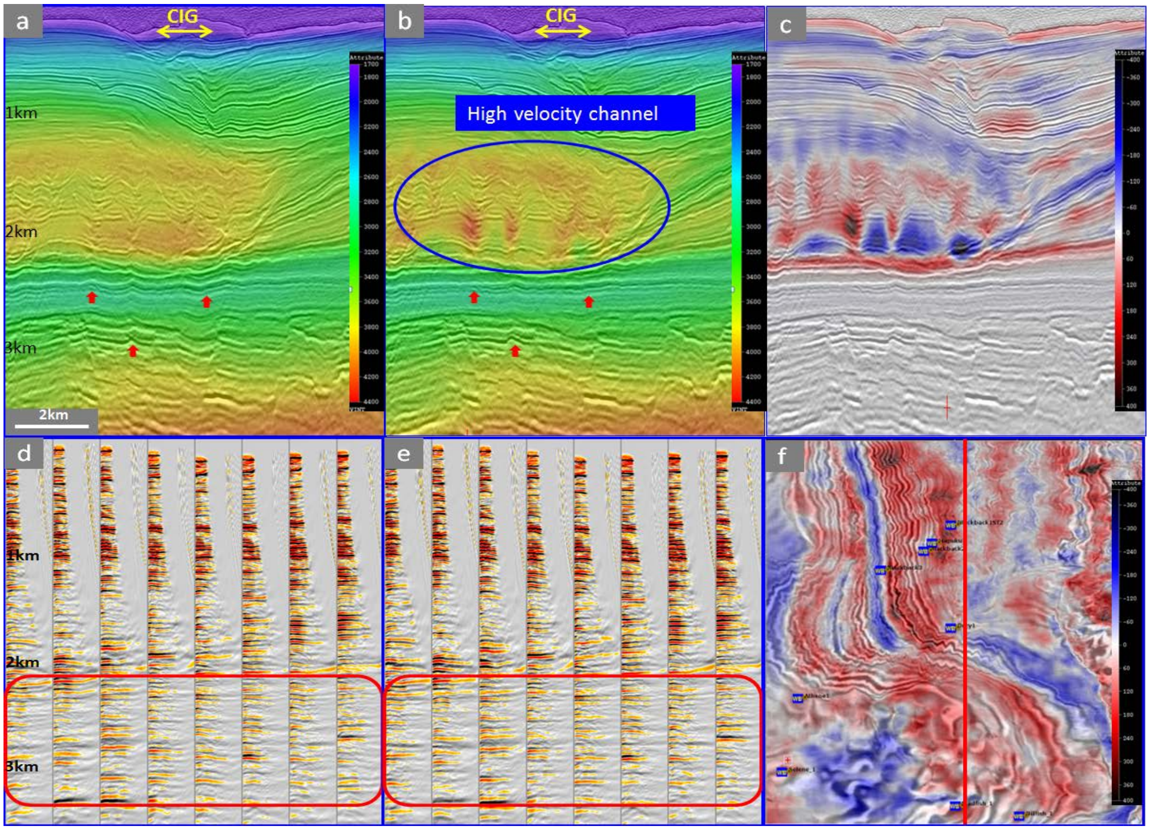

Figure 2. *Kirchhoff PSDM seismic-crossline session. (a) overlaid with legacy model (b) overlaid with 12Hz FWI model; corresponding CIGs. (d) with legacy model and (e) with 12Hz FWI model; 12 Hz FWI perturbation overlaid on seismic; (c) vertical session and (f) depth slice at 1800m.*

Least Square Q-Kirchhoff Migration (LSQPSDM)

Other difficulties in this region consist of the limited bandwidth, distorted phase/amplitude, strong noise interference, poor subsurface illumination and the expected attenuation by anelastic absorption and elastic scattering (Q factor). Despite the application of 3D joint deghosting and designature (Wang et al., 2015), which ensure both amplitude and phase fidelity during bandwidth broadening, standard Kirchhoff PSDM is unable to fully recover the amplitude and resolution. This persists even when using the high resolution model from Hybrid FWI and tomography. Recently, with increased computing power, least-squares migration (LSM) has re-emerged in the imaging industry to overcome some of these shortcomings. Similar to Wu et al. (2017), we incorporated Q into least squares migration (LSQPSDM) to simultaneously achieve better illumination and Q compensation (Wang et al., 2017). The results are shown in Figure 4 as compared with conventional QPSDM results. Noticeable over-boosted noise can be seen in conventional QPSDM. In contrast, LSQPSDM provides sharper fault imaging (pointed by blue arrows), reduced migration artifacts and higher signal-to-noise ratio in the deeper section which is vital to the source rock mapping and Golden Beach prospect depiction (pointed by green arrows). Better focusing and continuity can also be observed in CIGs (pointed by yellow arrows) to stabilize future AVO work.

Final Results

It is important to mention that a reservoir orientated processing strategy was complied with to ensure processing parameters chosen in the pre-migration domain were appropriate in the final imaging domain. For each key stage, 3D PSDM was conducted and then AVO and other attributes, e.g. near to far stack correlation, wavelet consistency, RMS map, etc., were analyzed to maximize the value of the processing techniques and to ensure the preservation of true amplitude responses. These efforts confirmed the confidence in AVO responses and added value to the reprocessed data over legacy datasets as shown by the comparisons in Figure 3. Crucial uplifts observed in the newly reprocessed data are: 1) a more geologically plausible velocity model resulting in better mis-tie of top Latrobe; 2) better suppression of multiples and coherent noise, events are more continuous and focused; 3) higher resolution imaging, particularly top/intra- Latrobe, at depth; 4) sharper fault delineation; and 5) reliable AVO inversion. Figure 5 shows the inversion result of relative Vp/Vs ratio as an indicator of the existence of a gas sand. In contrast to the legacy data, the Dory field can be clearly delineated in the new data. Moreover, a Golden Beach prospect is now clearly observed (marked by the blue circle). The inverted Vp/Vs result at the Dory well location is then correlated to well data at the reservoir level, the correlation coefficient is also greatly improved from 48% to 74% indicating the higher confidence in mapping the remaining prospects.

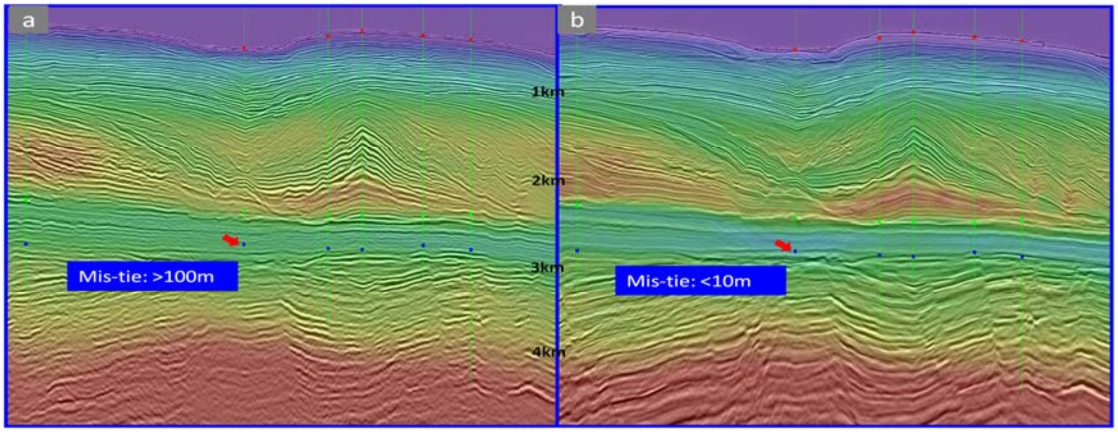

Figure 3. *Traverse line passing through key wells. (a) legacy PSDM (with post-migration Q) overlaid with legacy velocity model and (b) reprocessed LSQPSDM overlaid with final FWI velocity model.*

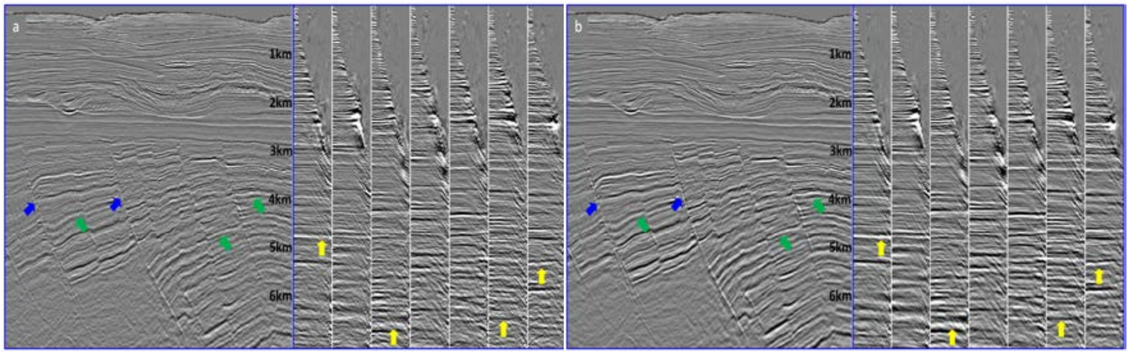

Figure 4. *Full stack and CIGs. (a) with Kirchhoff QPSDM and (b) with Kirchhoff LSQPSDM.*

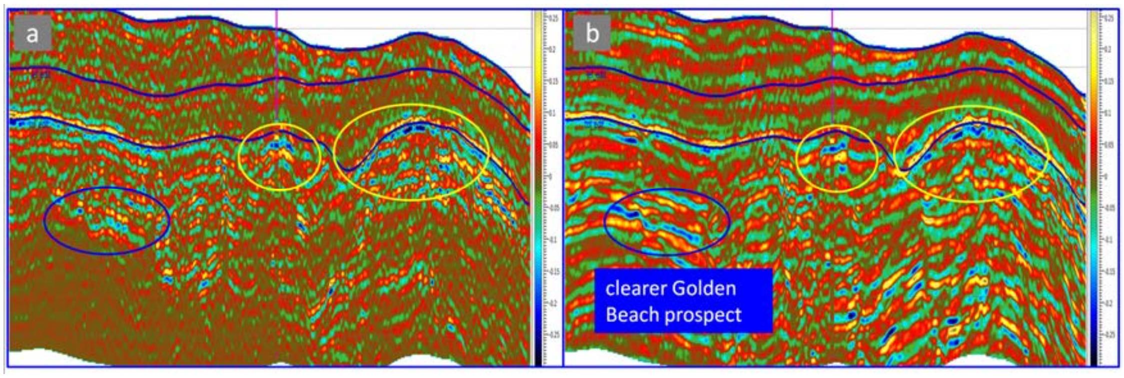

Figure 5. *Inverted Vp/Vs ratio in time (a) from legacy PSDM and (b) from reprocessed LSQPSDM.*

Conclusions and Discussion

The unique challenge associated with the geological complexities of Gippsland Basins has historically impacted the quality of seismic imaging which has been proven to be a significant barrier for reducing exploration risk. The newly processed data shows substantial improvements as compared to the existing legacy data, with improved seismic resolution and fault imaging, a better model with less mis-ties, more reliable AVO inversion for new prospect delineation.The success of the high-end reprocessing proves that even in basins that are considered mature, new ideas and new processing technology can change long-held perceptions, opening up areas for renewed exploration activities.

It is important to emphasize that uncertainties in the derived Q model, as well as the uncertainty of velocity errors, especially for the low frequency trend, will impact the accurate compensation of reflector amplitudes. Nonetheless, by combing varieties of modern processing technologies, the current workflow is a step forward in improving AVO inversion and reducing uncertainties of time depth conversion.

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