Unveiling the Seismic Image Beneath Volcanics in the Bass Basin

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SUMMARY

Volcanic and intrusive igneous rocks are common throughout the offshore Bass Basin, Southeast Australia, due to multiple episodes of magmatism. These igneous bodies have complex internal structures that cause distorted seismic images and poor illumination beneath them. This paper demonstrates an application of Time-Lag Full Wave-form Inversion (TLFWI), and an integrated de-multiple workflow to greatly improve the seismic image beneath volcanic bodies. Least-Squares Q Migration (LS-QPSDM) was applied on the improved pre-processed data and velocity model to achieve: 1) well-defined volcanic bodies that enable the unveiling of the underlying events and hence make it more suitable for interpretation; 2) a good synthetic well-tie and overall small depth mis-ties; and 3) a seismic volume with improved fidelity for attribute inversion.

The uplift in imaging allowed confident mapping of a previously unidentified upthrown fault-bound closure that could lead to further development of the Yolla field, which is important to meet the rising demand for natural gas on the East Coast of Australia.

Key words: Volcanic, FWI, De-multiple, Bass Basin

INTRODUCTION

The Bass Basin, located offshore between the southern tip of Victoria and the northern margin of Tasmania, lies in the shallow water of Bass Strait. Oil companies currently extract natural gas and transport it to an onshore processing plant in Victoria. It is then used to feed an increasingly large East Coast Australia gas market. Volcanic and intrusive igneous rocks are particularly common in the basin due to lithospheric stretching. The buried volcanic sequences and intrusive bodies that were formed from the cooled magma are frequently encountered during petroleum exploration and production (Holford et al., 2017; Watson et al., 2019). In a shallow water environment they lead to complex multiples. Moreover, the shallow volcanic sequences reduce the penetration of sound wave energy and introduce challenges for accurate velocity model building and seismic migration. Thus, the quality of seismic imaging usually deteriorates severely beneath these bodies due to residual multiples and an inaccurate velocity model.

In this paper, we discuss the reprocessing of the Yolla 3D marine seismic survey, acquired by MV Western Atlas in 1994. The survey area has a water depth of 80m and is located 147km offshore of southern Victoria (Figure 1). The survey configuration was flip-flop, 3-streamer narrow azimuth (NAZ) with 3km cable length and minimum inline near offset of 143m. The legacy seismic image is of poor quality under the shallow volcanic bodies due to strong residual multiples and distorted imaging, hence it is difficult to interpret at the reservoir level. To improve the seismic imaging quality, two main technologies were employed: 1) Advanced de-multiple flow to attenuate both surface-related and inter-bed multiples; and 2) Integrated velocity model building with Time-lag Full Waveform Inversion (TLFWI).

ADVANCED DE-MULTIPLE FLOW

A comprehensive de-multiple flow was designed to improve the multiple attenuation. As shown in Figure 2, the flow includes water-layer, surface-related and inter-bed multiple modelling and subtraction in the 3D Curvelet domain.

In general, effective water-layer-related multiple attenuation is very challenging for shallow water. In our case the challenge was increased further by the strong multiples generated by the spatially variant, shallow volcanic sequences. Different techniques were tested to overcome these issues. Wave equation-based water-layer de-multiple (MWD) has proven to be an effective tool to facilitate water-bottom-related multiple attenuation (Wang et al., 2011). However, as MWD is unable to model the multiples generated by near-seabed reflectors, a data-driven modelling method like shallow-water de-multiple (SWD) (Yang et al., 2013) can also be applied to provide more complete multiple models. In this study, the MWD and SWD models were utilized simultaneously to optimize the final subtraction of water-layer-related multiples.

Strong velocity contrasts are present in the Bass Basin sedimentary sequence. These reflectors generate strong long-wavelength surface-related multiples. The tuning and crosstalk between different orders of multiples increase the amplitude inaccuracy of the predicted multiple models, which negatively impacts the subtraction. In addition, the dips of the weak primary signal and multiples are difficult to discriminate in the channel domain. Together, these issues result in either primary damage or residual multiples after subtraction. In our work, recursive SRME modelling was conducted to correct the amplitude prediction. Similar to what Chua et al. (2019) suggest, we extended the crossline dimension for subtraction to preserve weak primaries by increasing the sparseness of the dip separation in the crossline direction.

Additionally, inter-bed multiples were also obvious in the data due to a series of strong subsurface impedance contrasts between the sedimentary sequences and the volcanics and intrusive bodies. The true-azimuth 3D inverse scattering series method (ISS) can predict internal multiples produced from all possible generators simultaneously, without requiring any subsurface information (Wang et al., 2014). We applied 3D ISS and successfully attenuated the internal multiples on the Yolla data, using 3D Curvelet domain subtraction to obtain better subtraction with less primary leakage.

The legacy and re-processed seismic results were compared with the available well synthetic in Figure 3. The reservoir in the legacy image (a), highlighted by the green arrows, was contaminated by severe residual multiples beneath the shallow volcanics, thus, the result does not match the well synthetic and the cross-correlation is poor. With the advanced de-multiple flow, the residual multiples are greatly attenuated in the new seismic section (b). The signal-to-noise ratio (S/N) around the reservoir level is now improved and the events match well with the synthetic data.

VELOCITY MODEL BUILDING WITH TIME-LAG FULL WAVEFORM INVERSION

The presence of a volcanic sequence and intrusive igneous rocks in the area not only generates strong multiples but also constructs complex ray-paths. These cause unreliable move-out picking and inhibits tomography from producing meaningful velocity updates from shallow to deep. Conventional application of full-waveform inversion (FWI) on this dataset is also limited due to the low S/N at low frequencies. We can see from Figure 4a that the legacy velocity model lacks resolution and the volcanic and intrusive igneous rocks in the area are not properly defined. Furthermore, the legacy seismic images are distorted and suffer from poor illumination from the shallow section to the reservoir level.

Zhao et al. (2018) and Li et al. (2021) show that a hybrid velocity model building flow of iterative Time-lag FWI (Zhang et al., 2018) and tomography updates are effective for the model update in areas with complex shallow anomalies. TLFWI, which uses a traveltime-based cost function, has the potential to mitigate cycle-skipping and downplay the impact of amplitude-discrepancy, leading to more reliable updates than conventional FWI. In our case, 8Hz Time-lag FWI including both diving wave and reflection energy was used for the low-wavenumber update, and tomography and well mis-tie analysis were then employed to utilize the kinematic update from gather curvatures to update the anisotropic fields. Finally, another round of 30Hz Time-lag FWI was added to achieve a high-resolution model, which improved the details for the complex velocity areas.

The final velocity model (Figure 4b) generated by the hybrid model building flow has successfully inverted the contour and velocity of the volcanic sequences and intrusive igneous rocks (green arrow in Figure 4b). This model follows the geological structure well and reduces the distortion and swings beneath. The strata and fault are also properly imaged with the new model. Well sonic QC (Figure 5) shows good matching between the new velocity and the well sonic log.

FINAL RESULT ANALYSIS

Least-Squares Q Migration was applied on top of the improved pre-processed data and velocity model, further improving the image quality. Migration swings (Figure 6a), caused by residual multiples and an inaccurate velocity model were much reduced with the new workflow. This is clearly visible in the new LS-QPSDM full stack (Figure 6b). The reservoir (green arrow in Figure 6b), intrusive volcanic event in the target zone (white circle) and the basement (dark arrow) in the deeper part were properly recovered with the removal of overlying multiples. The fault (yellow arrow), which is sensitive to the accuracy of the velocity model, is now correctly imaged and positioned. New interpretation and well analysis confirmed a good match of seismic and well markers across the section and particularly at the reservoir level. All these factors contributed to a good synthetic well-tie (Figure 3b) and produced a seismic volume with higher fidelity for attribute inversion.

Figures and Tables

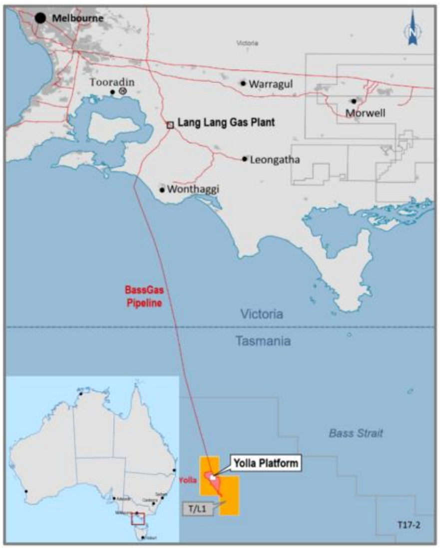

Figure 1. Yolla survey location in Bass Strait

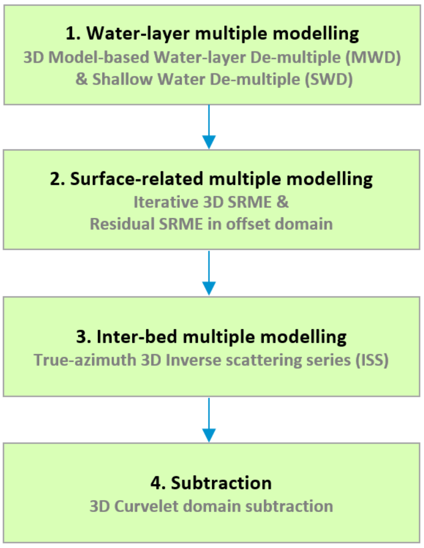

Figure 2. Advanced de-multiple flow

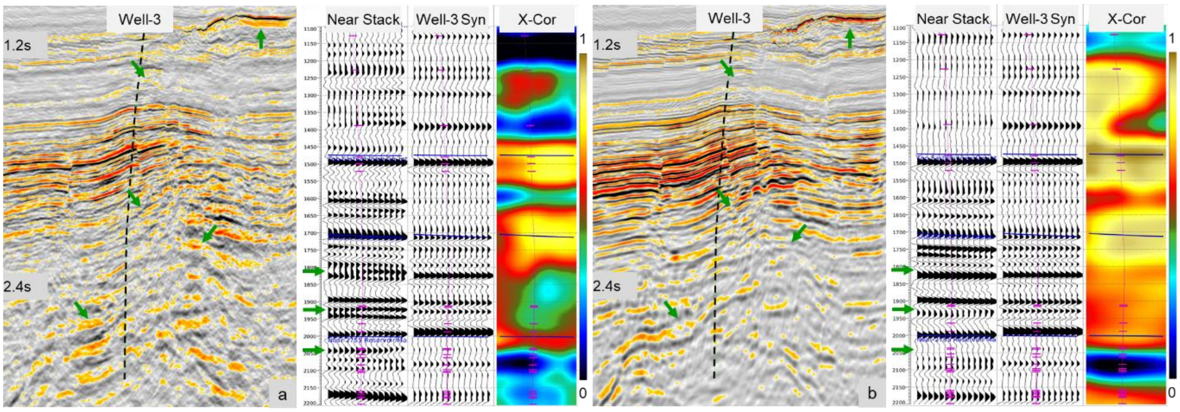

Figure 3. (a) Legacy PSDM and (b) New PSDM stack and their comparison with well synthetic. The residual multiples have been greatly attenuated in the new seismic section. This led to much improved well synthetic data matching. Yellow/red in the cross-correlation column corresponds to a higher cross-correlation.

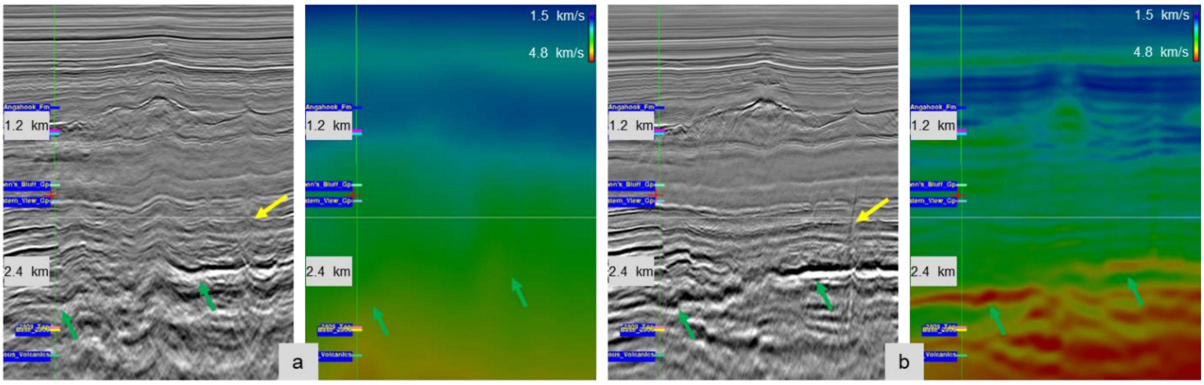

Figure 4. (a) Legacy and (b) New PSDM stack and velocity model. The new final velocity model successfully inverted the contour and velocity of the volcanic sequences and intrusive igneous rocks. This in turn reduced the distortion and swings beneath and enabled proper imaging of the fault.

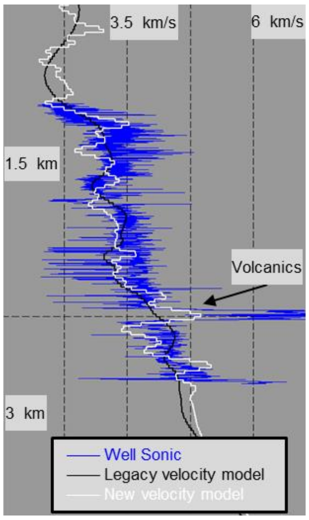

Figure 5. Vintage and New velocity model overlaid on well sonic velocity. The new velocity model better matches the well sonic log.

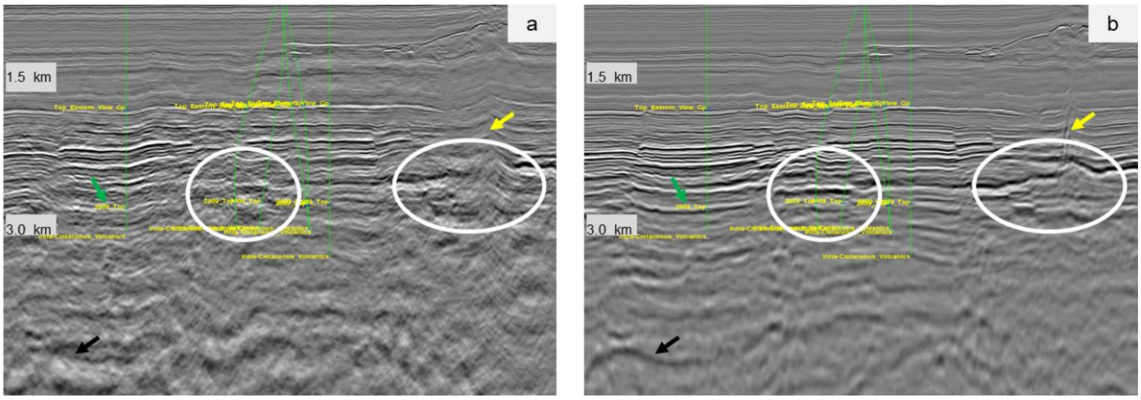

Figure 6. (a) Legacy and (b) final LS-QPSDM stack. Advanced de-multiple, model building and migration flow produced a seismic volume with improved fidelity for attribute inversion.

CONCLUSIONS

The igneous bodies throughout the offshore Bass Basin have very complex internal structures and cause distorted seismic images and poor illumination beneath them. To date, the inadequate seismic image quality has been a significant barrier to reducing exploration risk. With the advancement of high-end processing and imaging technologies, an integrated de-multiple and hybrid velocity model building flow can overcome the existing challenges even with older narrow azimuth short offset streamer data. In our case, the uplift in imaging has allowed confident mapping of a previously unidentified upthrown fault-bound closure that could lead to further development of the Yolla field, which is important to meet the rising demand for natural gas on the East Coast of Australia. Compared with legacy images, the newly reprocessed data not only yield substantial improvements in imaging but also provide further insights into the understanding of the subsurface geology. This work can be extended to adjacent reservoirs in Bass Basin or to other geologically similar shallow water environments.

ACKNOWLEDGMENTS

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