ReGenerating the Gippsland Basin

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New subsurface imaging algorithms have created a step-change in imaging quality over recent years, to the extent that even relatively recent data benefits from reprocessing. Developments in tomography and Full-Waveform Inversion (FWI) have revolutionised velocity model building, while migration algorithms have also undergone evolution, so that least-squares algorithms have been extended to Reverse Time Migration (RTM) and can incorporate Q compensation. Deghosting and bandwidth extension deliver sharper wavelets while outstanding improvements have also been made in noise and multiple attenuation. These many improvements mean that there is a vast array of existing seismic data that can benefit from reprocessing.

The Gippsland Basin in South-Eastern Australia has been producing hydrocarbons since the early 1960's when several giant oil and gas fields were discovered. It can therefore be considered to be a mature area, where production rates have been declining for the last twenty years and, with diminishing reserves, new reservoirs are being sought to meet the energy supply needs in this region. In many ways, this area is underexplored as the major fields were discovered on a coarse grid of 2D seismic, and there has been limited seismic coverage since (Mudge 2018). There are still extensive areas where no 3D surveys have been acquired and where such surveys do exist they have an average age of 15 years. The most recent significant seismic reprocessing program was performed by CGG during 2009-2014, using the most up-to-date tools available at the time. However, with the recent surge in the development of broadband imaging technology, new bandwidth-enhancing techniques can be applied to older data to significantly improve the image quality.

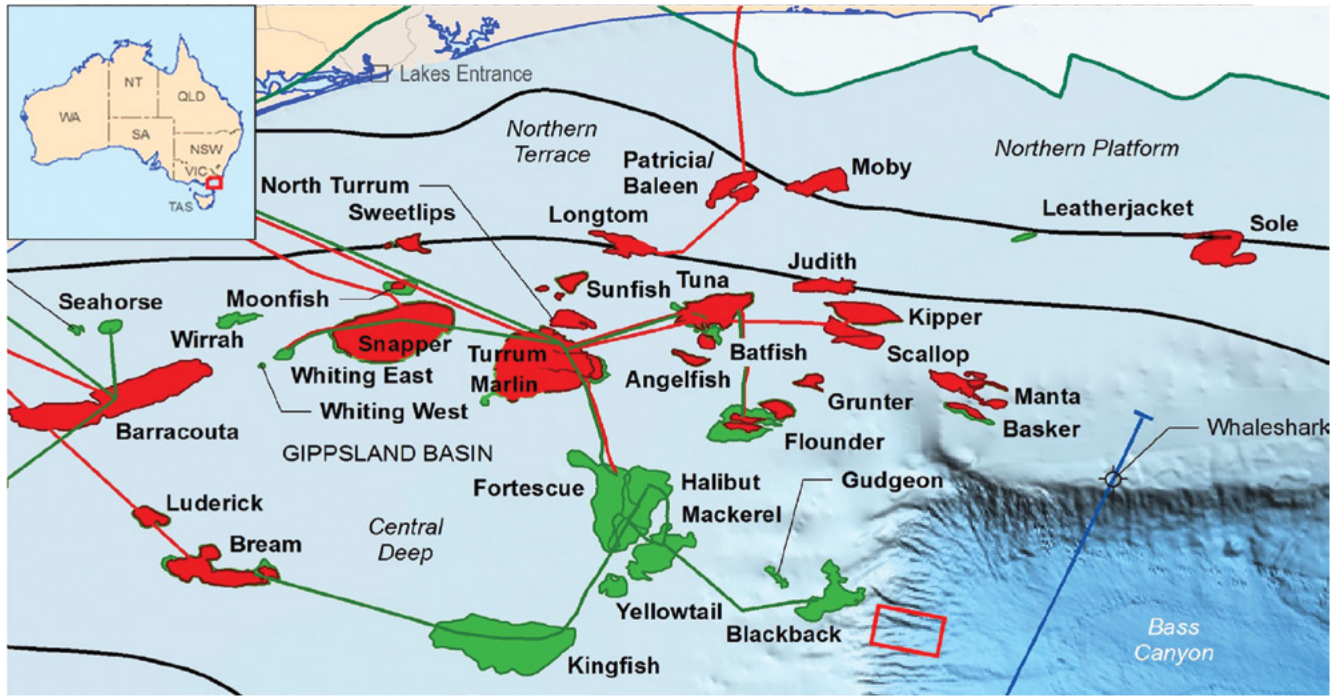

Figure 1: *The Gippsland Basin, with initial test area outlined in red.*

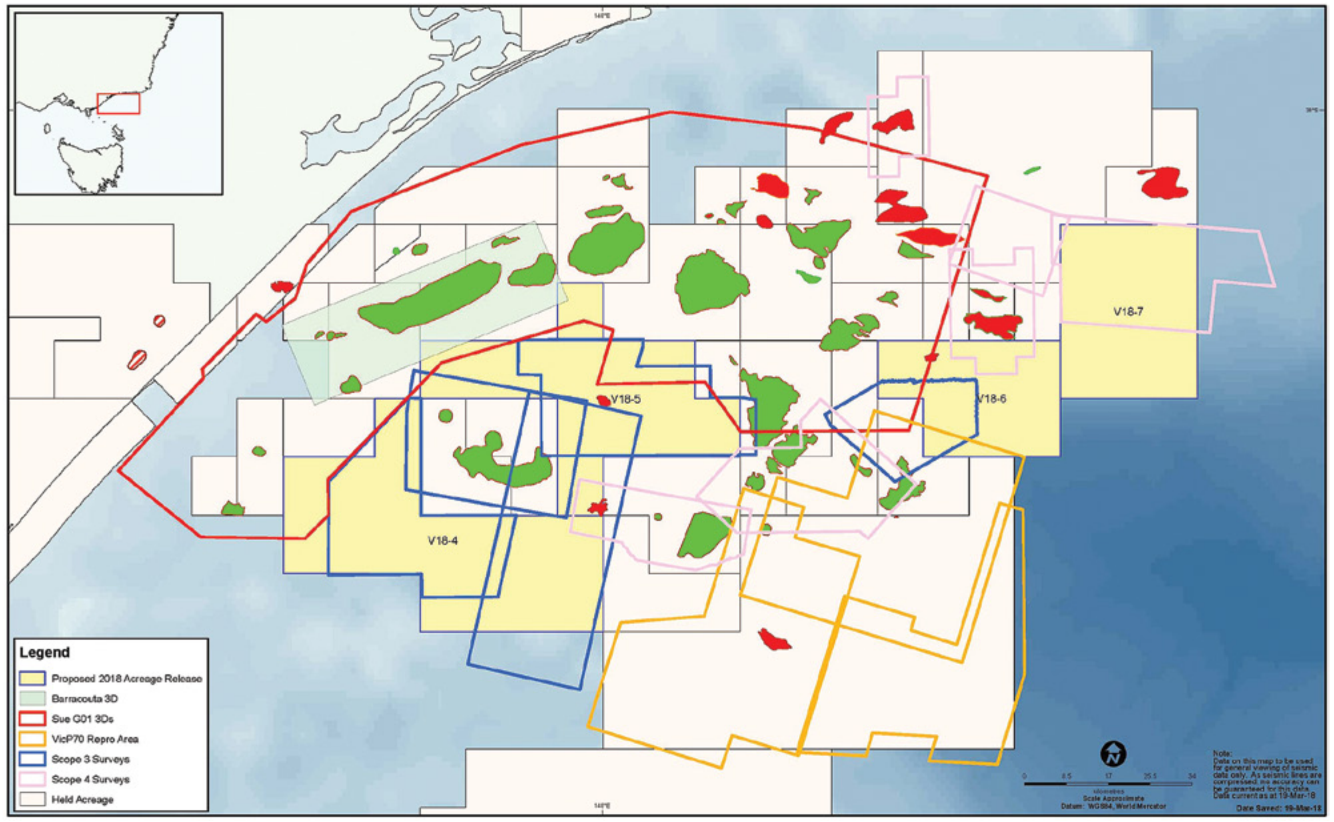

Figure 2: *Map showing the different scopes of the Gippsland ReGeneration project.*

Unlike other mature basins, there have been no leaps in production due to the application of 3D seismic, broadband technology or deepwater exploration, largely because there was little interest in seismic after the major fields had been discovered. CGG believes that this means that there is considerable scope for more discoveries to be made by reprocessing existing data sets with the latest high-end technologies, and that there is potential for a huge uplift in imaging quality, especially in the areas previously found to be challenging. Reprocessing the existing data can also provide insight into improvements in acquisition parameters that could be made for any new surveys.

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 suffer from imaging challenges due to extensive velocity anomalies, which may lead to false structural closures, and strong noise interference, which can limit imaging clarity and affect amplitude-versus-offset (AVO) analysis. High-resolution velocity modeling and imaging, using techniques such as

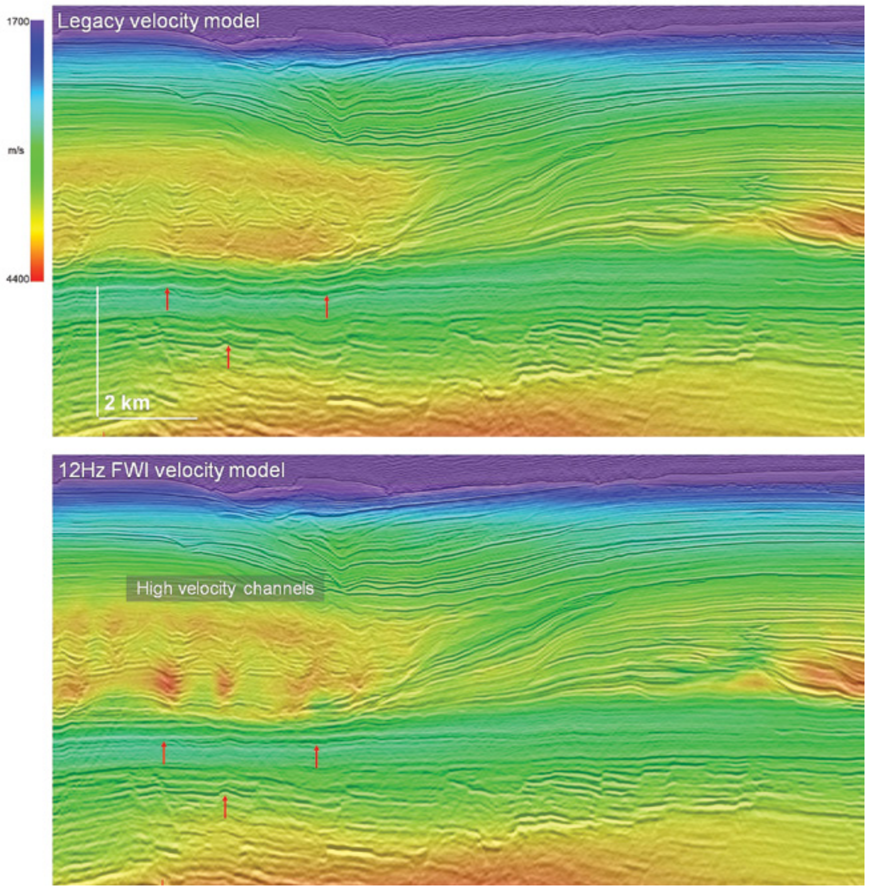

Figure 3: *Kirchhoff PSDM seismic crossline overlaid with legacy velocity model (top) and 12Hz FWI model (bottom).*

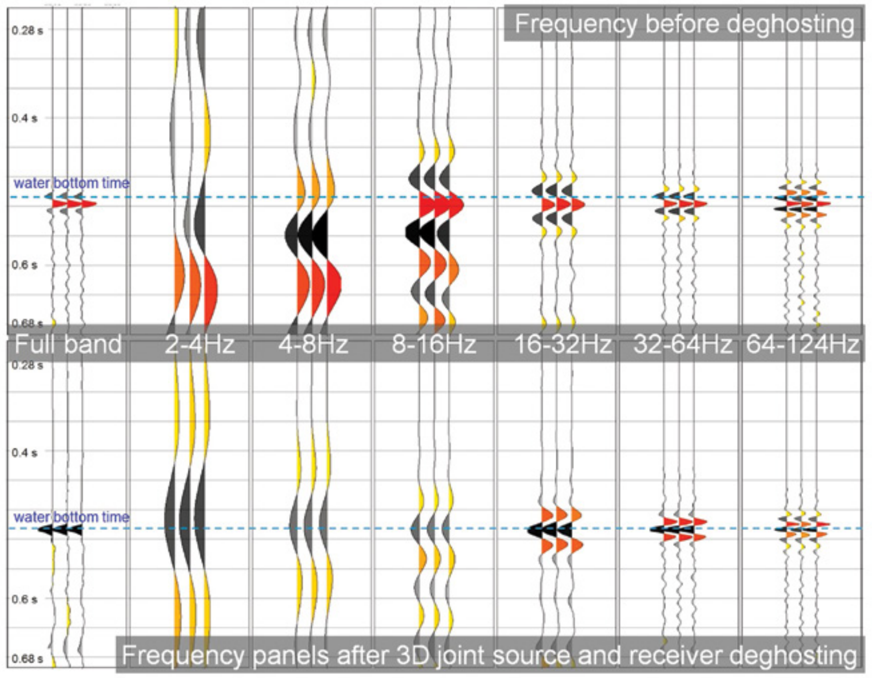

Figure 4: *Frequency panels before and after 3D joint source and receiver deghosting.*

modern 3D deghosting, full-waveform inversion (FWI) and least-squares Q pre-stack depth migration (LSQPSDM), are essential to stabilize AVO inversion and to improve the understanding of the remaining prospects and the subsurface geology for clearer prospect mapping.

The CGG Gippsland ReGeneration project started in late 2016 with the analysis and reprocessing of a small test area over block Vic/P70 in the Bass Canyon area, which resulted in a fully-funded pilot area of 450 sq km being reprocessed as a final proof of concept (see Figure 1). The pilot area was over the shelf break, an area that has historically proved challenging to image, and where acreage has been taken up and relinquished many times. Acquisition, processing, reprocessing and test drilling campaigns have been performed here with little success and mis-ties of seismic-to-well markers of over 180 m have been observed with little correlation of the subsurface geology to the seismic imaging.

Following the success of this pilot project, CGG initiated the reprocessing of additional data sets, starting with the Vic/P70 and Western Northern Margins Project. More data has since been added to extend the product (see Figure 2), and further surveys are being incorporated in additional scoped phases until eventually all 3D surveys in the area (approximately 13,000 sq km) will have been reprocessed. This reprocessing and improved imaging is revealing new potential deep-reservoir targets and extensively improving understanding of the basin.

The imaging challenges in this basin can be divided into two linked geographical areas, driven by the geology and seafloor topography. Firstly, the North Western Platform area has water depths of less than 200m and a characteristically hard seabed, which causes extensive multiple generation and data contamination, with mode conversions and other high levels of coherent energy. This, in combination with shallow high-velocity carbonate channels and highly absorbing and scattering coal reflectors, complicates imaging.

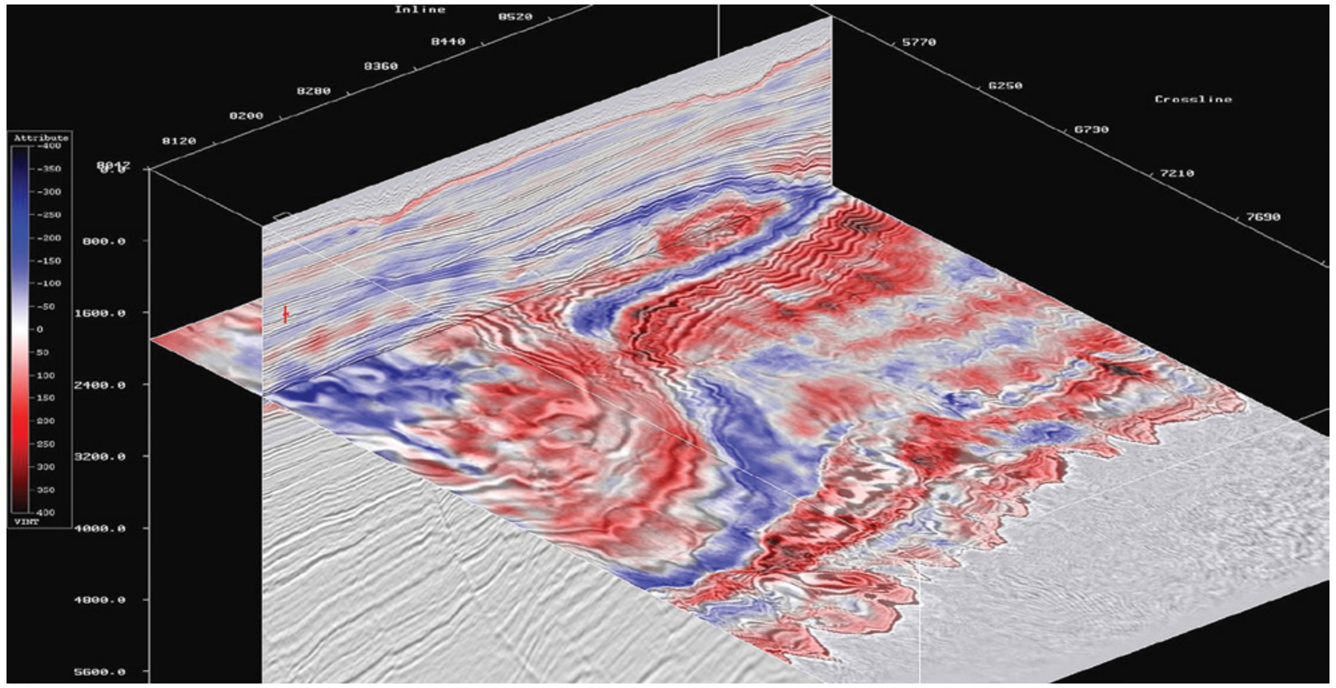

Figure 5: *12Hz FWI velocity perturbation overlaid on seismic, vertical crossline and 1800m depth slice. Maximum perturbation +/- 400 m/s.*

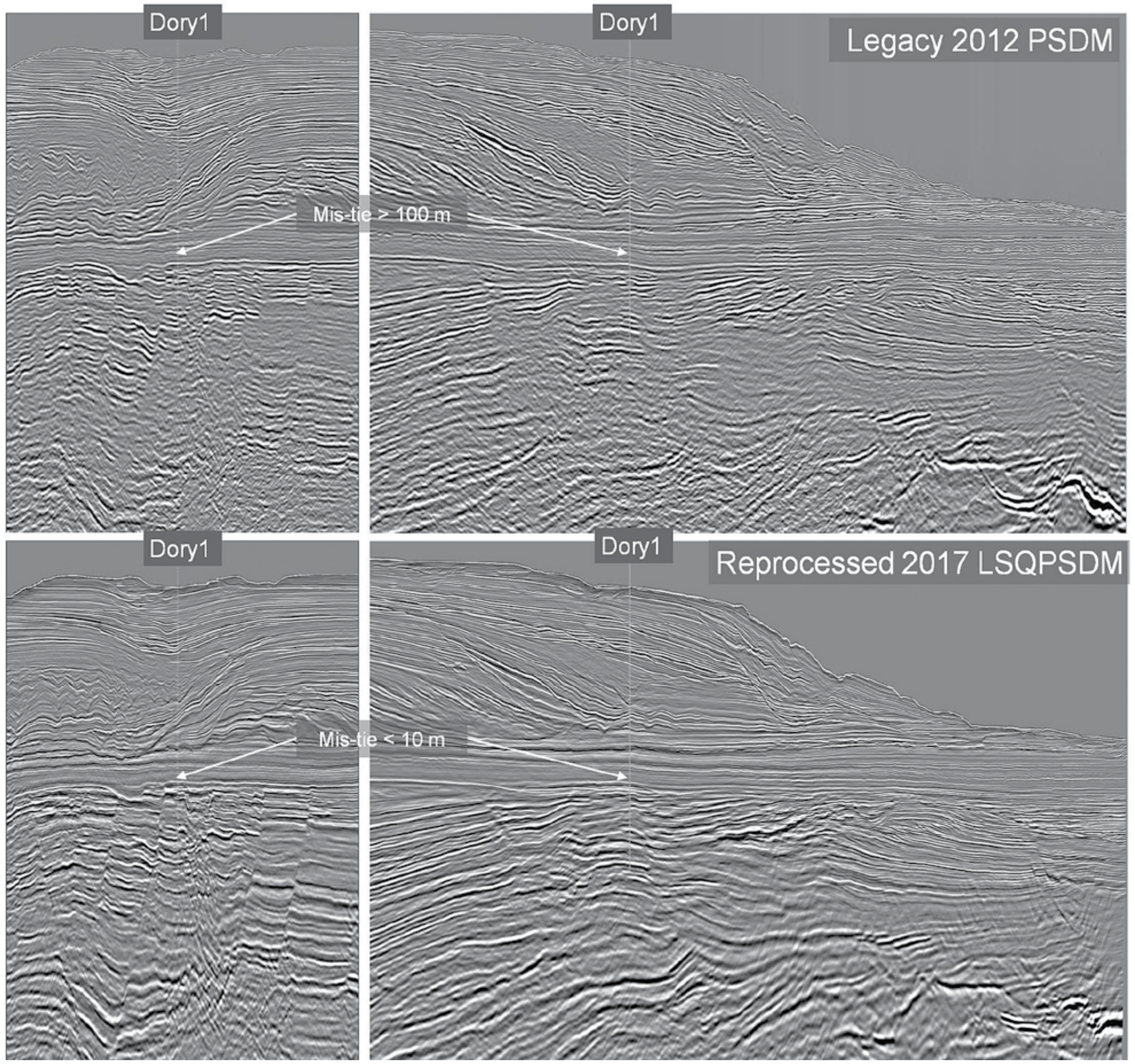

Figure 6: *Inline and crossline through the Dory1 well.*

Previous processing in this area has generally been focused on the most obvious Top Latrobe (principal target horizon) structures.

Further east in the basin, a very rugose seabed shelf-break area, combined with complex velocity variations and high-velocity carbonate channels, creates intense structural imaging challenges and large historical mis-ties between seismic and well data. Complex raypaths have not enabled sufficiently reliable imaging to allow direct hydrocarbon indicator (DHI) techniques, such as AVO studies, to be performed on previous data sets, as remnant multiples contaminated near offsets and residual coherent noise dominated far-offset traces.

Our regeneration of this basin by reprocessing the seismic data is largely dependent on the significant improvements made in velocity model building and imaging algorithms in the last decade. These have been aided by the step-change in resolution, extending the bandwidth to both low and high frequencies, delivered by broadband processing techniques such as joint source and receiver deghosting and designature. Sophisticated noise attenuation combined with advanced demultiple algorithms and workflows clarifies structures and reduces confusion.

FWI is known to be effective in reducing depth uncertainty and in generating high-resolution and high-fidelity velocity models in areas with complex shallow overburdens (Lambare at al., 2015). However, in traditional narrow-azimuth data (NAZ), the limited offsets recorded, the poor signal-to-noise ratio at low frequencies (Dellinger et al., 2017) and the interaction between velocity and anisotropy, often make the application of FWI challenging. In order to overcome these problems, we applied a hybrid FWI and tomography

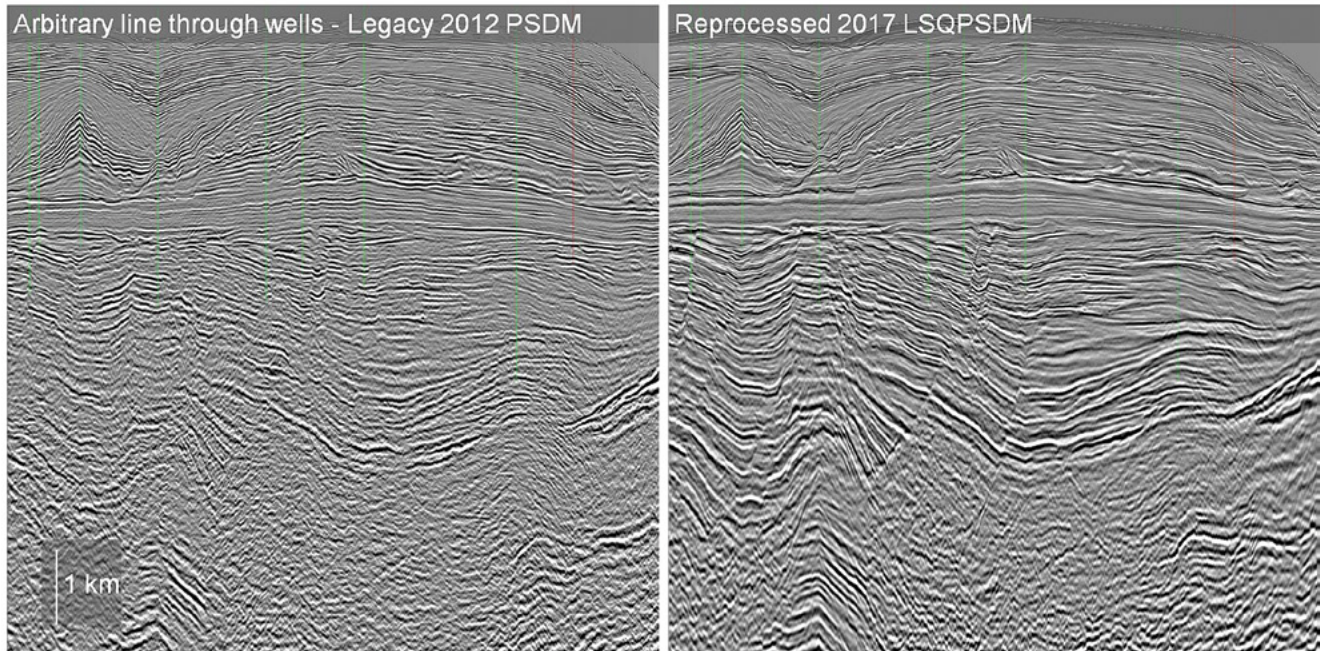

Figure 7: *Comparison for an arbitrary line through the key wells in the region.*

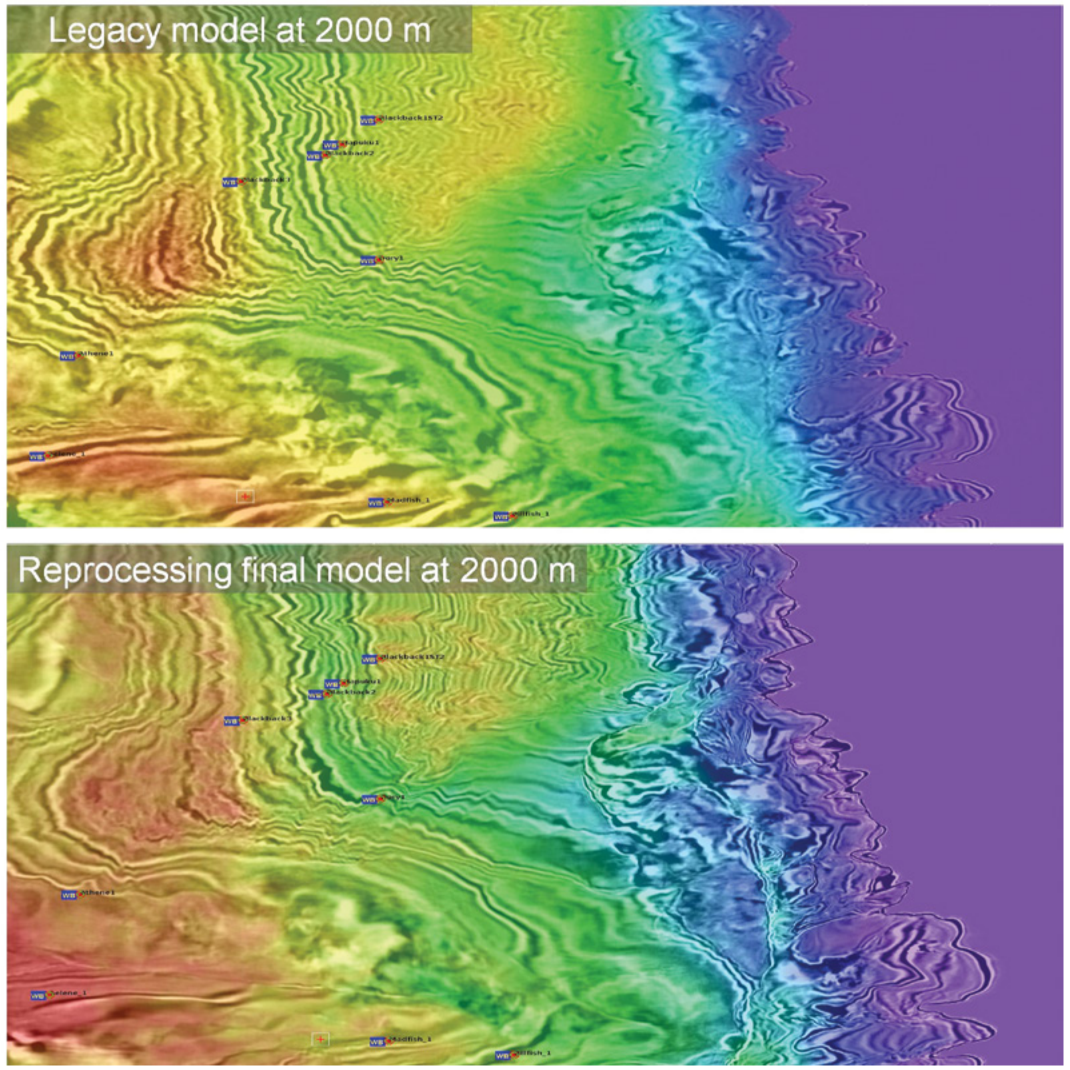

Figure 8: *Comparison of legacy reprocessing velocity models and seismic at 2000m. The new data shows improved resolution and definition, with much better correlation of velocity to structure.*

velocity model-building flow, interleaving FWI, focused on resolving the velocity contrast from the shallow high-velocity channels (Figure 3), with a tomography update, focused on the low-frequency background trend and updating the anisotropic parameters.

The starting model used for FWI was from the legacy 2012 PSDM reprocessing, which delivered reasonably flat common image gathers (CIG), but lacked the lateral resolution to model the high-velocity channels, leaving undulations in the deeper images that did not correspond to the geology (Figure 3). In order to make FWI work for this data set, the input data was carefully preconditioned at low frequencies using dipole sparse tau-p inversion to attenuate the low-frequency/high-dip noise (Yu et al., 2015) while preserving the primary data. As nearfield hydrophone data was not recorded for this survey, the wavelet used for FWI was obtained from the far-field signature. Different debubble operators then had to be applied to the far-field signature and the field data to overcome the poor bubble modeling. Although data with reasonable signal-to-noise ratios can be seen between 2 and 4 Hz after preconditioning, it was found that FWI starting from 6Hz generated a more stable update (Zhao et al. 2018) (Figure 4). To mitigate the potential cycle skipping issues that might have been caused by starting at this frequency, dynamic warping FWI (DFWI) (Wang et al., 2016) was applied. This technique detects the traveltime differences between the predicted and observed data, and uses this to partially warp the observed data to generate a series of data sets connecting the two. A series of conventional FWI's can then be solved to avoid cycle skipping.

The contrast from the high-velocity channels was captured by the 12Hz FWI update. The perturbation is less than 10% (or a maximum of 400 m/s). However, it effectively removes the imprint of the channels on the image, as highlighted in Figure 3. The improved spatial resolution can also be observed in the perturbation displays (Figure 5).

Figure 6 shows the improvement of the reprocessed LSQPSDM using the new velocity model over the legacy PSDM data for a line through the Dory1 well and Figure 7 for an arbitrary line through the key wells. The velocities are now more consistent with the structure (as demonstrated in figure 8) and the mis-tie at the top of the Latrobe horizon at the Dory well is now less than 10m, compared with over 100m previously. This example clearly demonstrates the improvements in imaging delivered by the reprocessing over the legacy data. It shows the improved seismic resolution and fault imaging, thanks to the broader frequency content, with reduced levels of coherent and scattered noise.

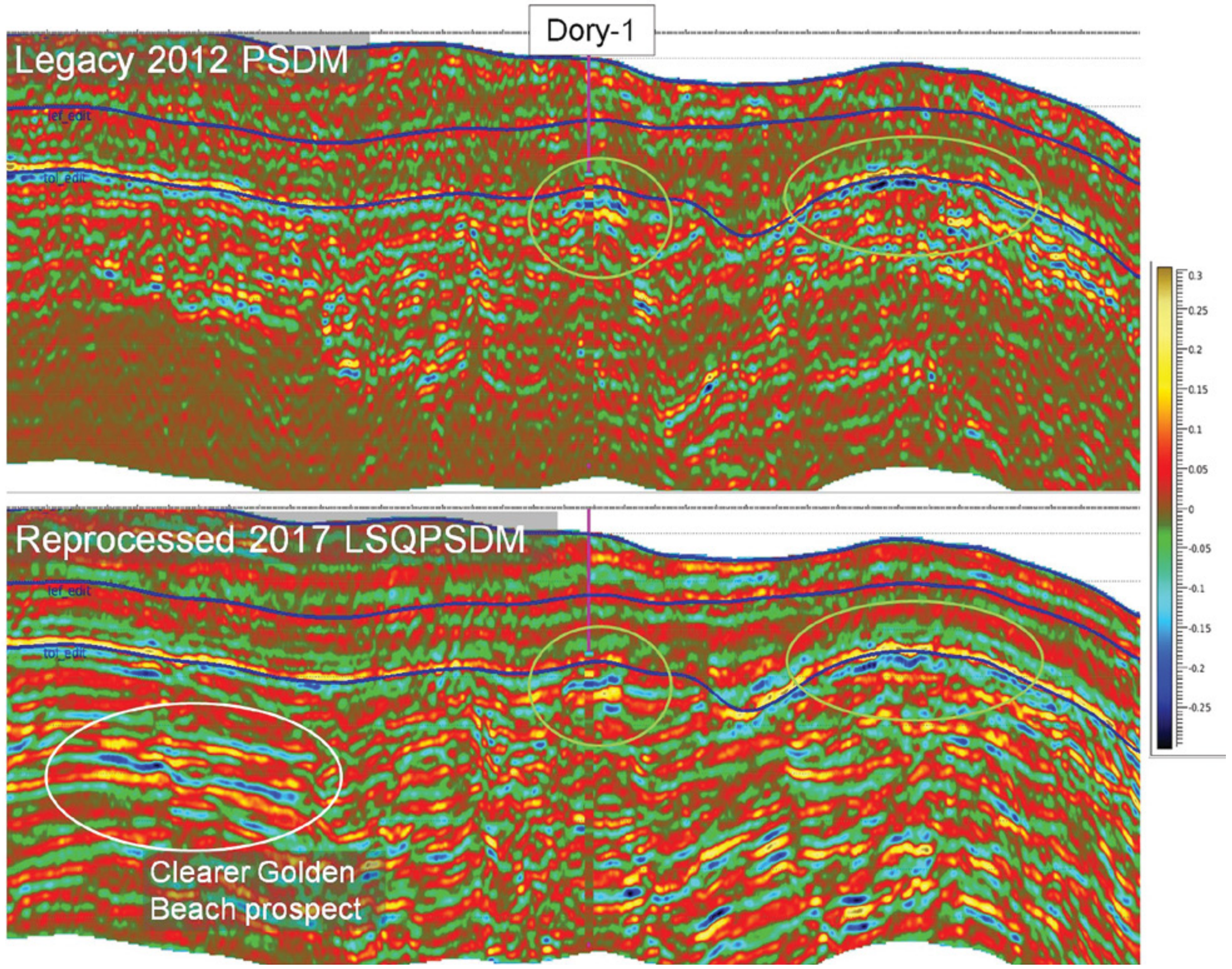

Figure 9: *Comparison of inverted Vp/Vs ratio in time from legacy PSDM and reprocessed LSQPSDM.*

Distortions in the deeper structure are reduced and deeper fault planes are enhanced.

A reservoir–oriented processing workflow was followed with QC at each stage to ensure the preservation of relative amplitudes. This QC included 3D PSDM at every key stage, followed by analysis of AVO and other attributes, such as near- to far-stack correlation, RMS maps, etc. This procedure gives confidence to the AVO analysis of the final data. A comparison of the inversion result of the relative Vp/Vs ratio (Figure 9), which can be an indicator of the existence of gas sands, shows the Dory field to be clearly delineated in the new data. A prospect can also be observed in the Golden Beach formation. The correlation coefficient of the inverted Vp/Vs ratio from the seismic at the Dory well location improved from 48% on the legacy data to 74% on the reprocessed data, giving much greater confidence in mapping the remaining prospects.

The unique challenges associated with the geological complexities of the Gippsland Basin have historically impacted the quality of seismic imaging. The reprocessed data shows substantial improvements when compared to the existing legacy data, with improved seismic resolution and fault imaging, a better model with fewer mis-ties, and more reliable AVO inversion for new prospect delineation. The improved imaging is enabling structural features below the strong coal reflectors on the North Western Platform to be mapped (Mudge 2018). These have not been seen before and may encourage investigation of further production from deeper targets that had hitherto only been suspected. The consistent, high-quality, basin-wide reprocessing effort is delivering enhanced understanding of the petroleum systems in the area, to shed new light on the remaining potential of existing and new plays. This coincides with the Australian government's proposed 2018 offshore petroleum acreage release areas for the Gippsland Basin. Several of these blocks are covered by our reprocessing, which will help to rejuvenate the basin. In addition, there is a projected shortfall in Australia's East Coast gas supplies due to export commitments from LNG plants in other areas of Australia, making increased prospectivity in this mature basin with its existing infrastructure even more welcome.

The success of the high-end reprocessing proves that even in basins that are considered mature, new ideas and new processing technology can open up areas for renewed exploration activity. However, although modern processing techniques have created a step forward in improving the reliability of AVO inversion and reducing the uncertainty of time-depth conversion, there are still limitations due to the use of older-acquisition, narrow-band data. The reprocessing effort and improved images have also delivered insight into the parameters that would be desirable for any new acquisition, both in areas where there is currently no 3D coverage and also where modern acquisition would improve imaging, as there has so far been no broadband acquisition in this area, nor acquisition with offsets longer than 6km. New acquisition could also be combined with existing data to improve illumination by multi-azimuth coverage, and so reduce structural uncertainty. Nevertheless, the Gippsland ReGeneration project is delivering a new framework that will support the revitalizing of hydrocarbon production in this important region, to address the significant projected gap in gas supplies, both by increasing the performance of existing fields and through the discovery and development of new opportunities.

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