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Interpreting the Past, Discovering the Future

Advanced reprocessing and imaging: enhancing legacy surveys

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SUMMARY

This work demonstrates how fully utilizing a modern reprocessing and depth imaging sequence significantly enhances seismic data quality, thereby extracting additional value from older seismic datasets. Using an example from the northern Browse basin, a case study is presented in which the combination of broadband processing, advanced demultiple techniques and anisotropic earth model building produce significant uplift in the imaging results from what is a historically challenging basin for successful seismic data.

The reprocessing sequence was undertaken in two phases. The first phase focused on lowering the noise levels and extending the useful bandwidth of the conventionally acquired seismic data using deghosting techniques. This was combined with 2D and 3D surface demultiple techniques to produce a dataset with low noise levels and a broad signal spectrum for migration. These data were subsequently input to the second phase of the reprocessing which focused on deriving a detailed and accurate earth model. Further anisotropy analysis and well calibration routines were performed to calibrate the earth model to the well data.

The final imaging was performed using TTI Kirchhoff prestack depth migration and comparisons were made to the previous time domain imaging results undertaken in 2010.

Key words: broadband, demultiple, velocity modelling, tomography, anisotropy

INTRODUCTION

Reprocessing of 3D seismic data has improved significantly over the last five years. With the advances in broadband seismic acquisition systems, similar advances in processing and imaging technologies are required. The result of this is that reprocessing of vintage data has also significantly improved, especially in areas that historically were considered challenging.

The northern Browse Basin on Australia's North West Shelf is one such challenging area for performing seismic data processing and imaging projects. The shallow water area is covered by over 1 km of Tertiary carbonates that strongly attenuate the seismic energy with depth, increases unwanted noise and creates an abundance of multiple energy that is very difficult to remove.

In 2015, reprocessing and imaging was performed on the Cartier MC3D survey, located in the northern Browse Basin. The survey was acquired and first processed during 2010 and encompassed an area of 2850 km^2 to the east of Cartier Island on the Ashmore Platform, shown in Figure 1.

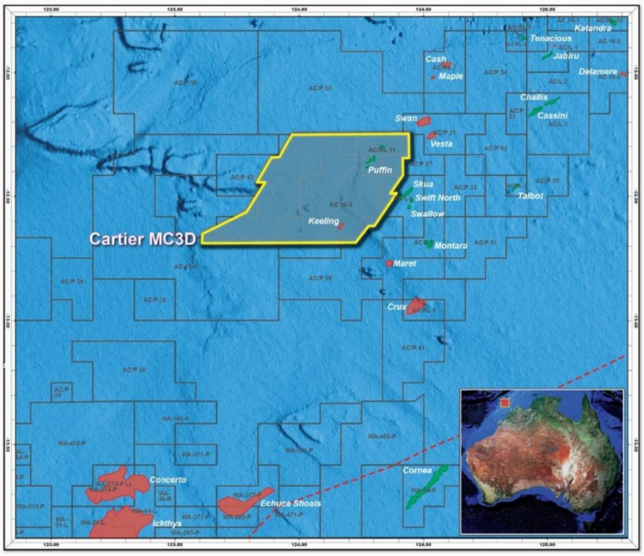

Figure 1: Cartier MC3D location, Browse basin

The survey area contains the Puffin oil field, Great Awk-1 oil discovery and Woodbine-1 gas discovery. This is a proven hydrocarbon province with multiple play concepts and trapping mechanisms, with a number of additional discoveries and producing fields in the surrounding area. However there are also dry wells in the region and industry understanding, especially away from the wells and using existing seismic data, is still limited. Seismic data improvements in this area have a strong probability to identify new leads and enhance existing oil and gas prospects.

The survey was located in water depths between 35 and 230 m, with Cretaceous, Jurassic and Triassic zones of interest located at depths between 3 and 6 km. Water bottom multiples were prevalent throughout the survey area, significantly disrupting the imaging of the Cretaceous Puffin formation and the deeper zones of interest. Minimising the impact of the multiples while enhancing the primary energy was a key objective of the pre-migration data processing.

The seabed contained a north-south trending canyon and also a reef structure towards the centre of the survey. The overburden section consisted of mostly low dip layered units with significant vertical velocity variations indicated on the well logs down to the

Cretaceous level. Below this, the Cartier survey was characterised by tilted horsts and steeply dipping structures throughout the Jurassic and Triassic section, with highly faulted Permian reef structures around 6 km depth. The distinct velocity and anisotropy characteristics of all these features needed to be addressed in order to derive an accurate Earth model for the optimum imaging result.

REPROCESSING

At the time the Cartier MC3D survey was acquired and originally processed there was limited routine use of processing techniques to remove the effects of the additional source- and receiver-side surface reflections (known as ghosts). Consequently the resulting data was somewhat band-limited by the acquisition parameters of source and receiver depths. Subsequent advances in data acquisition can now provide data free from a receiver-side ghost. However technology can now minimise the impact of the ghosts (i.e. deghosting) allowing a broadening of the signal amplitude spectrum that provides a compact wavelet ideally suited for high resolution processing and inversion.

The Cartier survey was acquired with a 10 x 6000 m at 100 m separated spread of conventional recording streamers towed at 7 m and dual airgun source arrays towed at 6 m. Prior to deghosting an extensive noise attenuation processing flow was applied that specifically addressed the low frequency coherent and random noise content that was typically of a similar strength to the underlying signal. The main wavelet processing stage contained a series of 1D and 2D deterministic processes that provided attenuation of the bubble pulse energy, source- and receiver-side deghosting using the recorded depth information and finally shaping to a zero phase wavelet. Removing the ghosting effects from the source wavelet typically leaves an amplitude spectrum that is heavily biased to the low frequencies. Further spectral shaping was therefore performed to an interpreter-preferred target spectrum to provide a more compact wavelet.

The shallow water depths over the survey area produced strong short period complex surface multiples that were addressed using a combination of a 2D deterministic approach, to specifically target water layer multiples, followed by 3D SRME to attenuate remaining long period surface multiples. An initial pass of velocity analysis was performed after first applying temporary static corrections to compensate for the near surface effects of seabed reef and channel features. These velocities were used to temporarily flatten the CMP gathers prior to a mild pass of high resolution radon demultiple. This robust pre-imaging demultiple approach provided a low-noise input to the imaging that was further complemented by final residual multiple attenuation applied post-imaging.

The broadband nature of the reprocessing created a dataset ideally suited for measuring residual moveout (RMO) and creating an accurate depth velocity model. The low noise levels and extended bandwidth of the data enhanced the definition and continuity of the primary events on depth migrated CIP (common image point) gathers, particularly below the Cretaceous unit at approximately 3 km depth. With more clearly defined events on CIP gathers, consistent and accurate RMO picks for tomography were made.

VELOCTY MODELLING

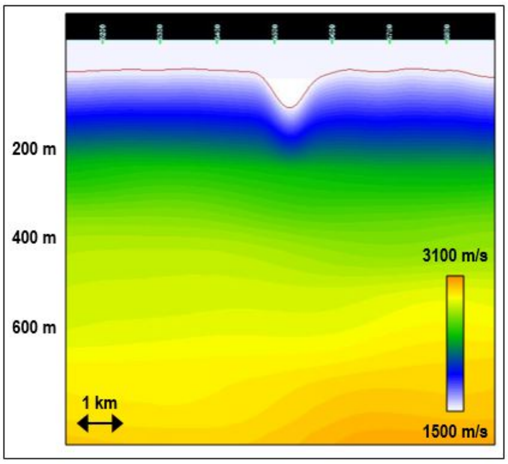

Figure 2: Estimated velocity model beneath the seabed canyon, with the seabed position illustrated by the red line

An initial isotropic velocity model was built based on pre-migration interpreted velocities in the time domain, converted to depth interval velocity and smoothed along geological constraints. A near surface model was added to this, which incorporated an estimated velocity compaction trend associated with the seabed canyon as well as a constant velocity interpreted geobody for the reef.

The presence of canyons and other rugose seabed features can cause amplitude and structural distortions after performing depth migration if the initial earth model is too simple. By incorporating a detailed velocity correction for these features from the beginning of the earth modelling, imaging distortions are minimised which can otherwise adversely affect the tomography results when solving for deeper long-scale velocity trends. An example near surface velocity compaction trend in the vicinity of the seabed canyon is shown in Figure 2.

Initial TTI anisotropy parameters for the model were estimated using the calibrated sonic logs and key formation markers from the available well data and propagated for the entire area using horizon-guided interpolation techniques.

Five iterations of multi-scale CIP tomography were used to update the model. Each tomography iteration used multi-parameter (also referred to as non-parametric) RMO picking. This type of picking has been used since the inception of 3D CIP tomography (Woodward et al, 1998). This picking method is particularly important in the presence of short scale lateral velocity variations, such as those observed in the Browse basin that are associated with overburden features and extensive faulting. Multi parameter picks correctly identify and record the depth of the automatically picked events for every trace, instead of estimating an average RMO across the CIP gather. This method allows linear and non-hyperbolic moveout to be accurately picked and used in the travel time tomography process to achieve higher resolution models.

Within the tomography, directional smoothing consistent with the geologic dip direction of the seismic data (Clapp et al, 2004, Bakulin et al 2010, Zdraveva et al, 2013 and Fell et al, 2013) was used for each model update, instead of a conventional rectilinear smoothing approach (Woodward et al, 1998). The dip information was derived by estimating the 3D geologic dip and azimuth from an intermediate depth migrated stack. The use of implicit (soft) geological constraints imposed by these steering filters in multi-scale tomographic iterations resulted in geologically consistent and structurally constrained model updates.

The anisotropy parameters were refined throughout the velocity updating, including the application of a residual well velocity correction. Several of the wells across the Cartier survey exhibited significant vertical velocity contrasts, related to specific Tertiary and Cretaceous intervals. These contrasts were reduced but still observed in the model after three updates, due to the limited moveout difference exhibited by the events in these intervals.

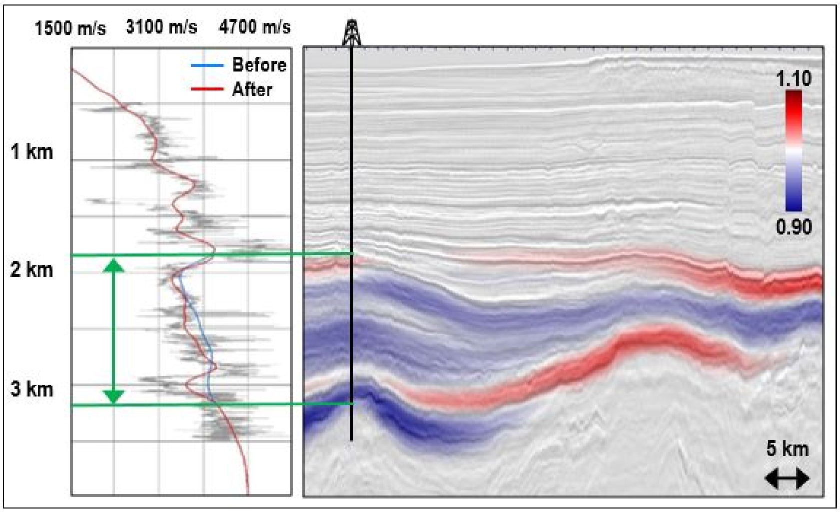

Figure 3 Residual well velocity correction shown at a well location (left) and as a 3D scalar model (right)

To account for these contrasts more accurately, a well tying model was derived which applied a residual 3D layer constrained scalar to the velocity model, restricted to the specific layers as shown in Figure 3. This correction, while having minimal impact on the gather moveout, improved the mistie to key formation markers in depth as well as matching the well velocity trends.

A further anisotropy parameter update was applied to the model prior to the final velocity model update. The delta field was adjusted to minimise the remaining mistie to the key depth markers, with the changes implemented via layer extrapolation constraints. This final correction included the introduction of a negative delta over several Tertiary intervals, a practical approach taken in order to increase the depth of the seismic data to tie some of the Tertiary well markers.

IMAGING

The velocity and Kirchhoff pre-stack depth migrated stack displays shown in Figure 4 demonstrate how the derived final velocity conforms to the geologic structure while resolving lateral details throughout the section. In the overburden, successive high resolution tomography updates combined with the residual well velocity correction have resolved both vertical and horizontal details in the model.

Below 3 km depth, the final velocity shows a strong conformance to the complex faulted structures of the Jurassic and Triassic sections. By making detailed and careful multi-parameter RMO picks, many of the velocity contrasts across faults in the Triassic can be picked accurately and resolved in the tomography. Used in conjunction with the steering filter tomography, these fault-constrained velocities also conform to the dip of the events, resulting in a high resolution, geologically plausible velocity model.

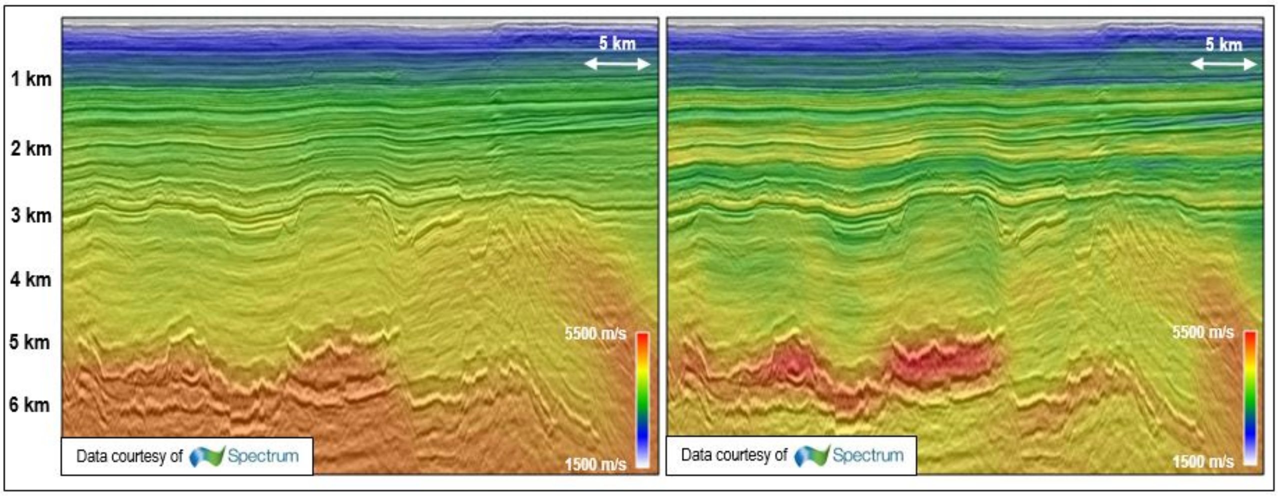

Figure 4: Initial velocity model (left) compared to the final velocity model (right)

Figures 5 and 6 compare examples of the legacy PSTM time stack from 2010 to the PSDM depth stack from the 2015 reprocessing and imaging, stretched to time. This comparison demonstrates the overall imaging impact after applying a modern broadband, advanced demultiple reprocessing sequence in conjunction with detailed, geologically constrained and high resolution depth imaging. Throughout the section, the depth migration section shows more differentiation between the signal and noise, enhancing the interpretability of the section.

The Cretaceous zone imaging between 1.3s and 1.6s two-way-time is clearer with good definition of the basin floor fan sands deposited within the Puffin Formation. The reduction of the wavelet ghosts leaves a laterally extensive soft acoustic event at the top of the sandstone units.

Below 1.6s two-way-time, the imaging impact to the Triassic horsts and tilted fault blocks can be attributed to improved signal to noise, enhanced bandwidth of the low frequencies and careful velocity modelling and imaging. Fault planes are more sharply defined and although the section has not removed all of the remnant multiples, the imaging details are more resolved and the primary signal is now dominant within the PSDM stack.

Below 2.7s two-way-time, the PSDM section shows Permian events are significantly enhanced. The package definition and internal geometries of the carbonates can now be resolved on the PSDM stack and the faulting within the Triassic can now be mapped through the Permian reflectors.

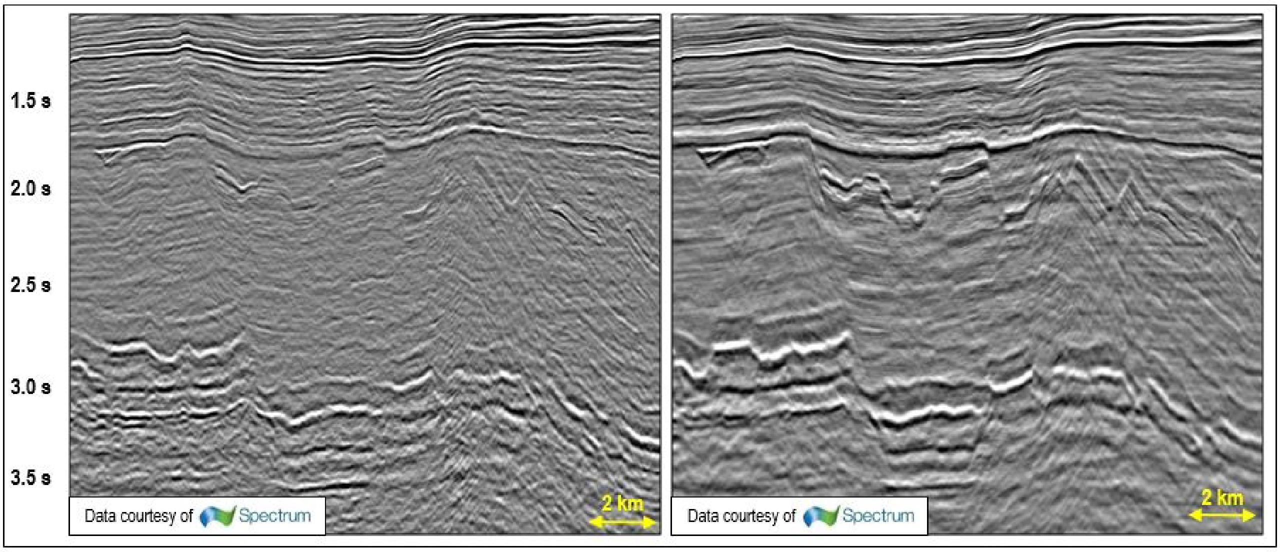

Figure 5: Inline comparison between the legacy PSTM time stack (left) and the PSDM stack stretched to time (right)

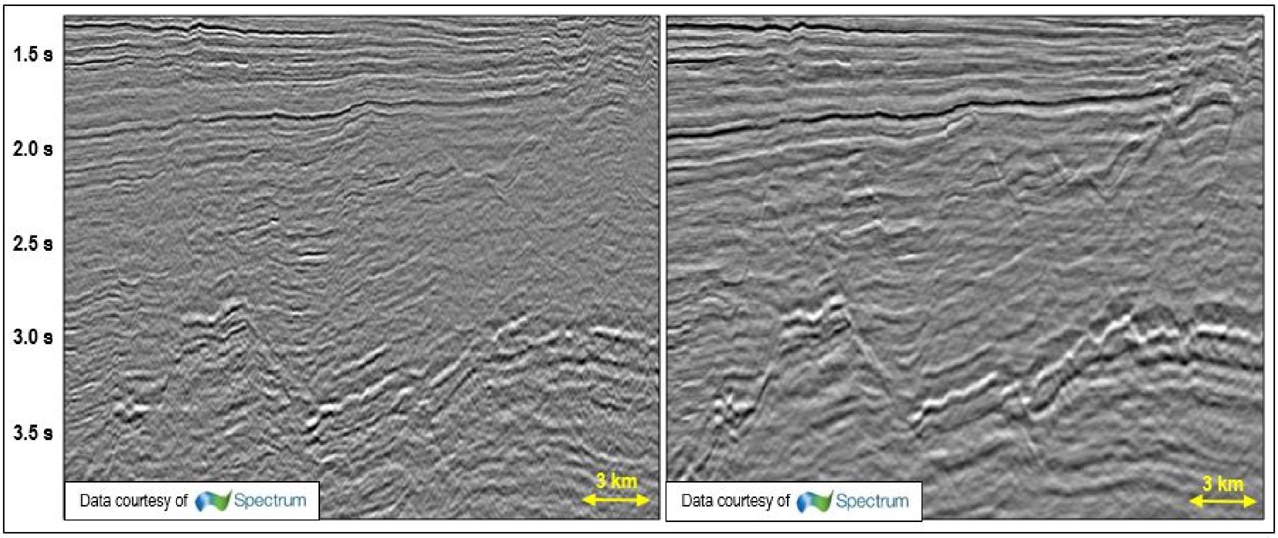

Figure 6: Crossline comparison between the legacy PSTM time stack (left) and the PSDM stack stretched to time (right)

CONCLUSIONS

This case study demonstrates how fully utilizing a modern reprocessing and depth imaging sequence can significantly enhance data quality, extending the value of a legacy acquired seismic dataset. Using a strategic combination of broadband processing, advanced demultiple techniques and anisotropic earth model building produced a significant uplift in the imaging and interpretability of the legacy data.

The improvement in imaging of the Cartier MC3D survey provides a step change in geological understanding of the area. The Puffin Formation sands are now clearly imaged to de-risk fault seal risk and sand-on-sand juxtaposition to ascertain structural volumes. The faulting observed within the Triassic can now be imaged down and into the Permian and will clarify structural models and basin tectonics. Imaging improvements within the Mesozoic offers insights to existing play concepts, illuminates new traps and opens up new plays in the region.

With rapidly improving technological acquisition and processing advances this case study demonstrates the value of reprocessing vintage seismic data as a cost effective exploration strategy in areas of historical imaging challenges.

ACKNOWLEDGMENTS

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