Next Generation Land Processing Gives Confidence in Old Basin

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SUMMARY

Noise is often the dominant problem with land seismic data and very few new processing techniques have been developed in the last 5 years or so to address this. Acquisition advancements have been made with deployments of more receivers and compressed sensing technology, but data quality is still limited by shallow subsurface noise, particularly scattering. We show here how recent new algorithms that have shown huge improvements in data quality in other parts of the world have been used to build confidence in vintage data from the Beetaloo Sub-basin.

Some 2,000km of multi-vintage 2D data (1989-2012) covering much of the Beetaloo Sub-basin was reprocessed through a modern workflow aimed at reducing the impact of the noise and creating a unified dataset fit for delineating structural geometries and planning future drilling and seismic work in the area.

Key elements of the new workflow discussed here include:

- Wave Equation Refraction Statics;
- Full Waveform Corrections;
- Denoise in various domains – Radon, FK, Cadzow, etc.;

The combination of these technologies has resulted in a huge uplift in data quality and a unified dataset, enabling planning for future activities to be made with greater confidence than was possible using previous, disparate datasets and assist in future development of a highly prospective basin.

Key words: Processing, Noise, Land Seismic, Full Waveform.

INTRODUCTION

Noise, in all forms, but particularly distortion of signal in the shallow subsurface, is usually the dominant problem with land seismic data and very little has changed with regards to typical land processing workflows in the recent past. Indeed, near-surface geological variability is the number one reason for the huge differences in imaging quality between typical land and marine seismic data (Stork, C., 2020). Acquisition advancements have been made in recent years with deployments of more receivers and compressed sensing technology – though more work can be done in optimising survey designs to take noise into account - but data quality is still limited by shallow subsurface noise, particularly scattering. New processing algorithms, which can utilise sparsity to handle aliased noise, have been developed and improve noise removal or handling, particularly scattering (Stork, C., 2021(a)). Application of these techniques to vintage datasets have often resulted in vast data quality improvements to 2D data from the Beetaloo Sub-basin….

The Beetaloo is a sub-basin of the McArthur Basin located onshore in the Northern Territory, Australia approximately 500km south-east of Darwin. It lies between Katherine, 100 km to the north, and Tennant Creek, 250 km to the south and covers approximately 28,000 km^2. It is thought to potentially contain over 500Tcf of gas – comparable to the Marcellus Basin in the US – but there have been no developments sanctioned to date. Origin Energy farmed into three Falcon Oil & Gas permits in 2014 and increased their share in both 2017 and 2020. A recent divestment to Tamboran Resources was announced in September 2022.

Over 4000 line km of mixed vintage 2D seismic have been acquired as part of different acquisition surveys in the Beetaloo Sub-basin, the majority by Hess Australia in 2011/12. Land Seismic Noise Specialists (LSNS) were asked to reprocess just over 2,000 km to better delineate the structural geometry of the basin and correlations between well penetrations to provide a more robust planning tool for future well locations and potential future seismic acquisition. A map showing the seismic data, coloured by vintage, is shown in Figure 1 below.

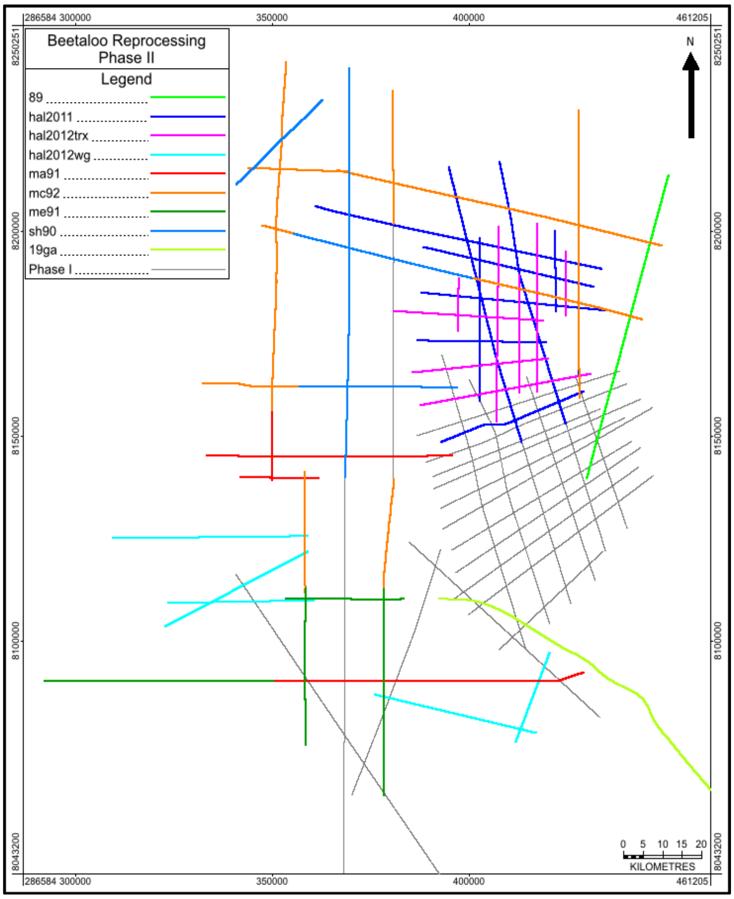

Figure 1. Map showing lines processed during the project, coloured by vintage. Lines shown in grey were processed during a previous phase of work.

The main zones of interest were the Kyalla and Velkerri formations, generally found down to about 3.5km depth (1.8 sec TWT). The goals of the processing were to improve event continuity and vertical resolution, increase signal to noise ratio, image faults and resolve the ‘bumpy’ nature of the data due to pull-up and push-down. It was our professional opinion that 90% of the imaging problems result from the top 500m of the subsurface, which includes lateritic surficial sediments, volcanics and karsted-limestones.

LSNS proposed to use some proprietary processing technology in this work, including Wave Equation Refraction Statics and Full Waveform Correction, specifically aimed at improving the shallow section in order to improve the imaging deeper down. Further noise removal was carried out using more common methods, including Cadzow filtering.

Wave Equation Refraction Statics

Wave Equation Refraction Statics (WERS) is a process by which the “early arrival” energy is examined to compute static corrections and similar surface corrections. The “early arrival” energy includes the first breaks and the energy just after the first breaks and is often larger amplitude and cleaner than the precise first breaks. WERS analyses the early arrival energy with other traces to determine stable static corrections.

WERS uses the first break package to apply both statics (computed in addition to the previous delay-time refraction statics) and phase corrections to shots, receivers, and frequency bands to correct for near-surface distortions. All corrections are calculated and applied on azimuth bins (in the case of 2D data, this represents only 2-directions determined by which side of the source any receiver is on).

Full Waveform Correction

Land Seismic Noise Specialists’ proprietary Full Waveform Correction (FWC) is a surface consistent correction utilizing FWI technology that partially undoes the scattering distortion from the near surface. This process utilizes the reflections within the data, as opposed to the WERS process that utilizes the early arrival energy.

SEISMIC PROCESSING RESULTS

Aside from the LSNS proprietary processing technology, a modern Pre-stack Time Migration processing flow was applied to all vintages within the dataset. The key features of this flow are given below, highlighting the innovative technology.

- Geometry and refraction statics application
- Q-compensation and whole-data whitening
- **LSNS' proprietary Wave Equation Refraction Statics**
- Conventional residual statics
- Pre-migration denoise
- TFD (Time-Frequency Domain Denoise)
- Dip Filtering (Including FK-Filtering and Dip Attenuation Filtering)
- **LSNS' proprietary Full Waveform Correction**
- Velocity updates (hand-picked) during the process
- Kirchhoff Offset PSTM
- Linear Radon Filtering
- Time-variant trim statics
- Stacking
- Cadzow filter
- Project-wide correlation-based tie-adjustments to lines

An example of shots before and after WERS is show in Figure 2. It is clear to see the reduction in jitter after WERS and better alignment of early arrival energy. This would be expected to manifest in better alignment of reflections too.

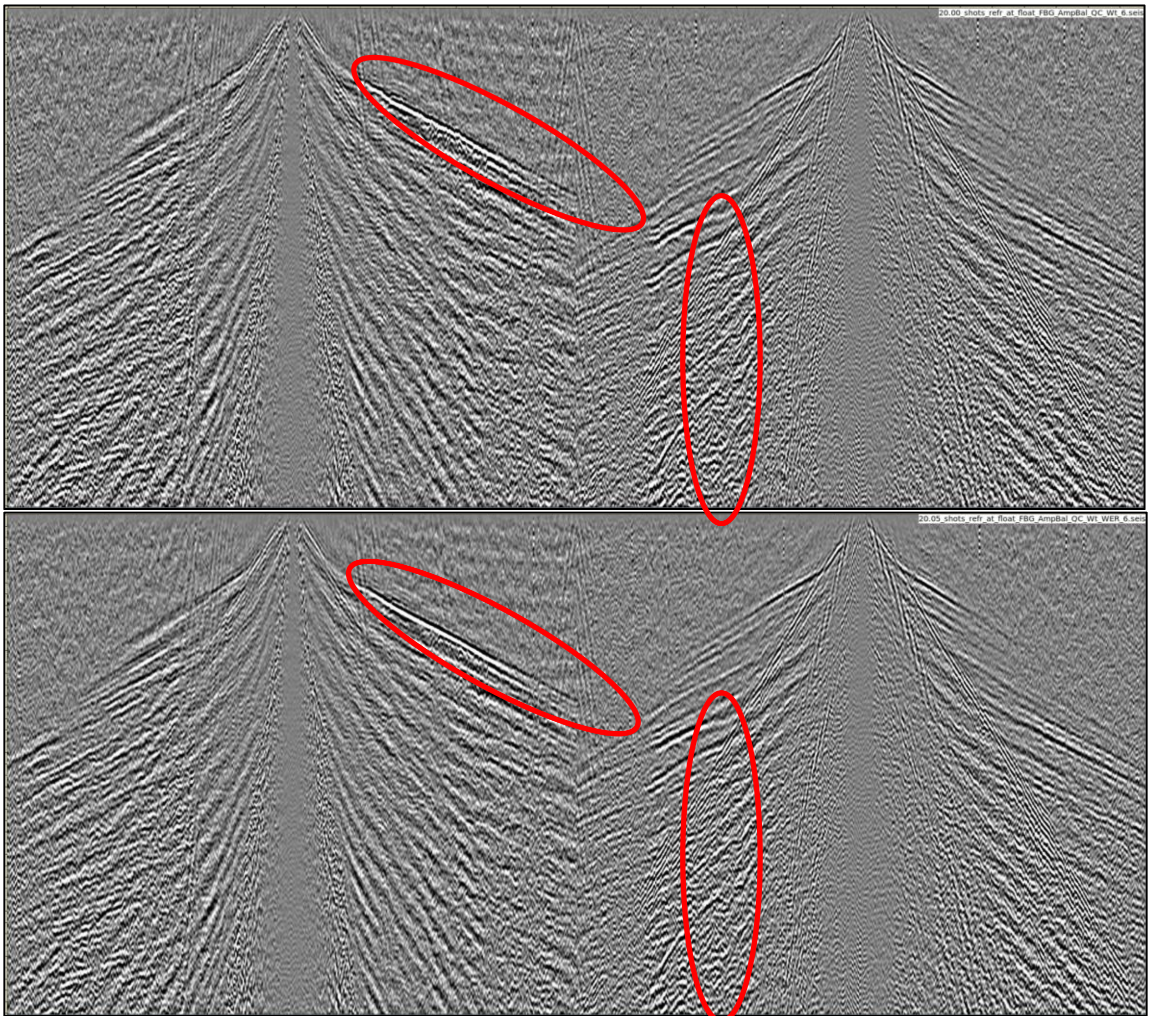

Figure 2. Example from MC92 vintage data showing 2 shots before (top) and after (bottom) Wave Equation Refraction Statics.

Below, in Figure 3, is an example of shots with FWC applied. The general reduction in noise and the improvement in continuity of reflections is clear, both in the shallow and deep sections.

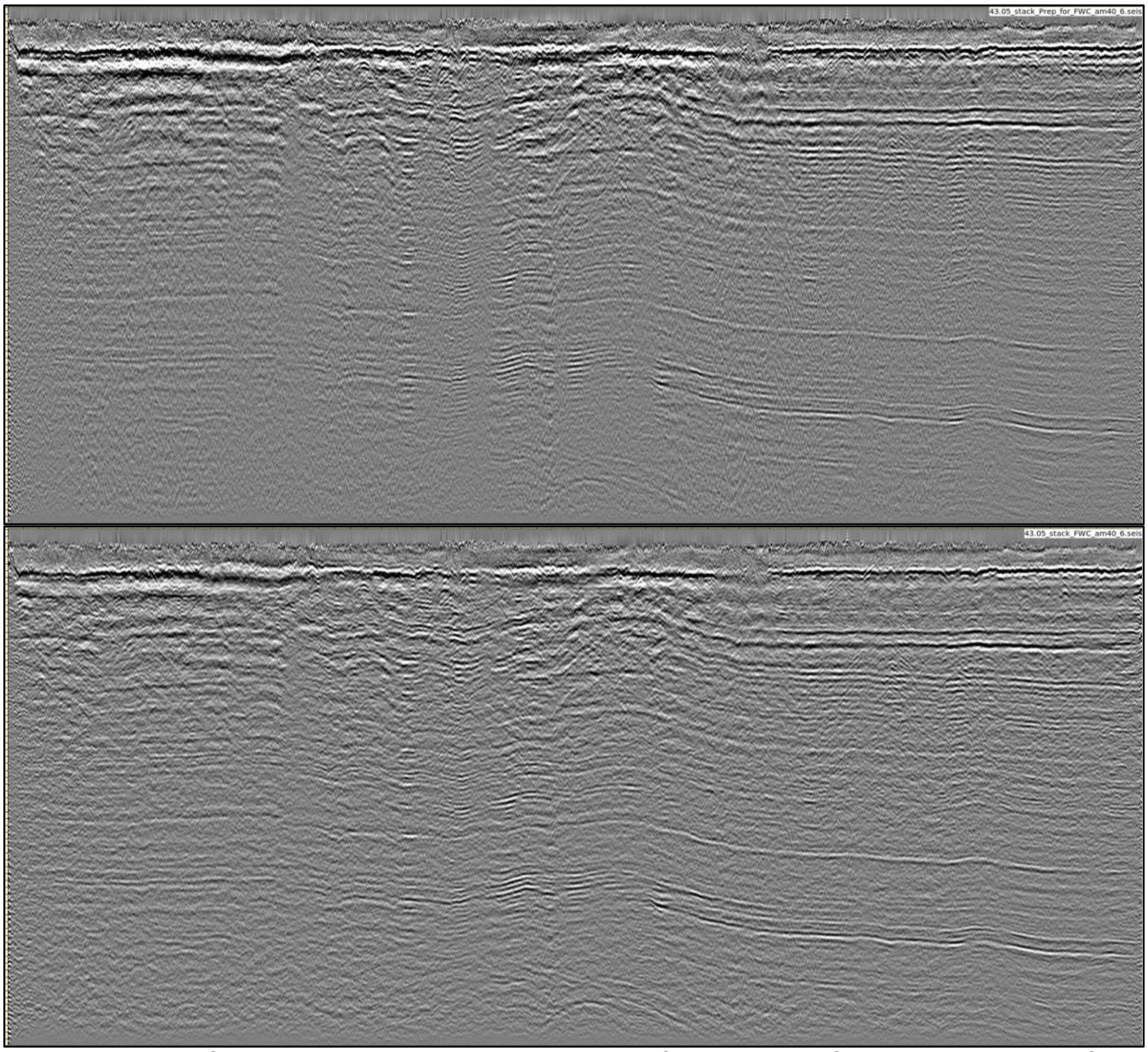

Figure 3. Example from MC92 vintage data showing stack before (top) and after (bottom) Full Waveform Correction.

In order to optimally tie the multiple vintages of data, a proprietary tool was used to compute and apply phase and time shifts to the final stacked lines. These adjustments are computed by determining the tie locations and cross-correlating traces between intersecting lines. Weighting is determined by the peak amplitude of the cross-correlations between lines and is used to provide more weight to good ties (such as from lines that cross at mid-lines and in good data areas) and less weight to poor ties (such as at line-ends or in poor data areas). The weighting and number of intersections for a line form a general matrix that is used to determine the overall optimal adjustment for that line to provide a best-fit tie to all crossing lines.

Examples of the ties before and after this process are shown below in Figure 4. The multi-vintage tie line shows clear improvement in continuity and phase across the joins. This obviously makes any interpretation much easier.

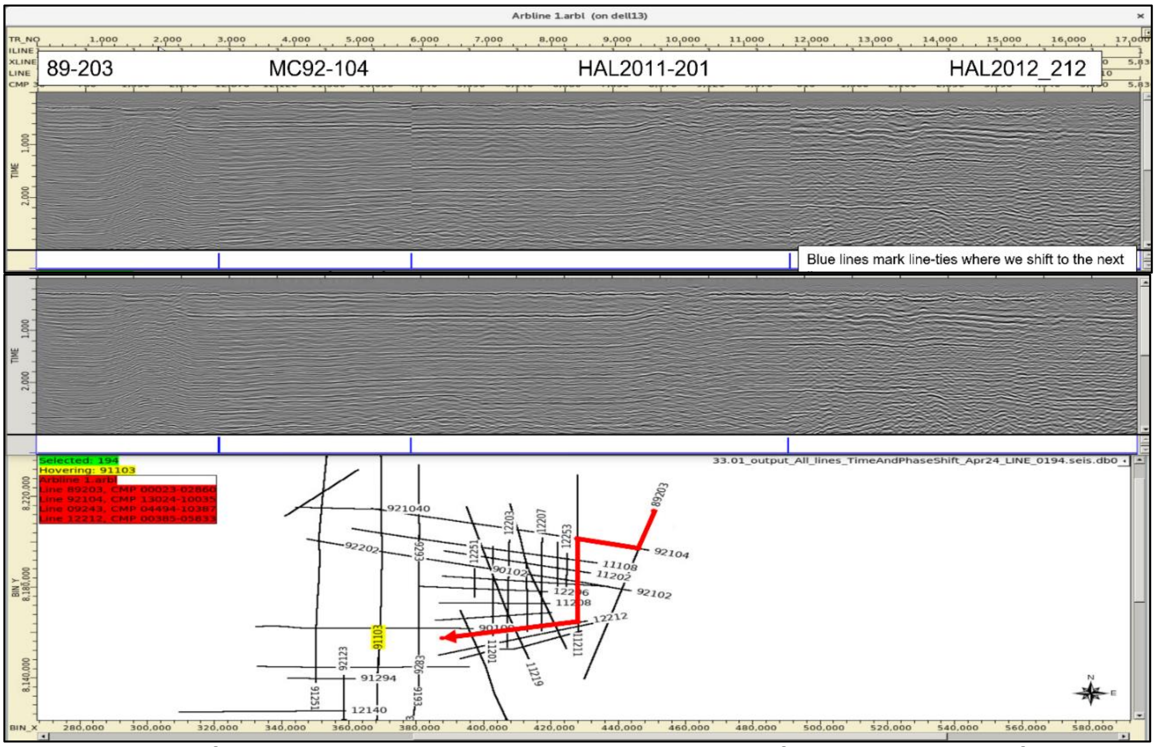

Figure 4. Example from multi-vintage tie-line showing migrated data before (top panel) and after (middle panel) LSNS' proprietary data tie tool. The improvements at intersections are clear. The bottom panel shows the multi-vintage line.

When all this is complemented by other, more traditional, processing techniques, the results speak for themselves. Examples of the full processing results from the previous processing and this modern processing are show below in Figure 5. Although there are clearly differences in scaling in these displays, it can easily be seen that the new processing shows a huge improvement in reflector continuity across the whole line and from top to bottom. Faulting within and below the Kyalla and Velkerri formations are now clear and reflectors are now smooth and easy to map along the line. The shallow geology is now visible.

It is obvious that the new result is much easier to interpret and the continuity of amplitudes in particular, would potentially facilitate future reservoir characterisation workflows.

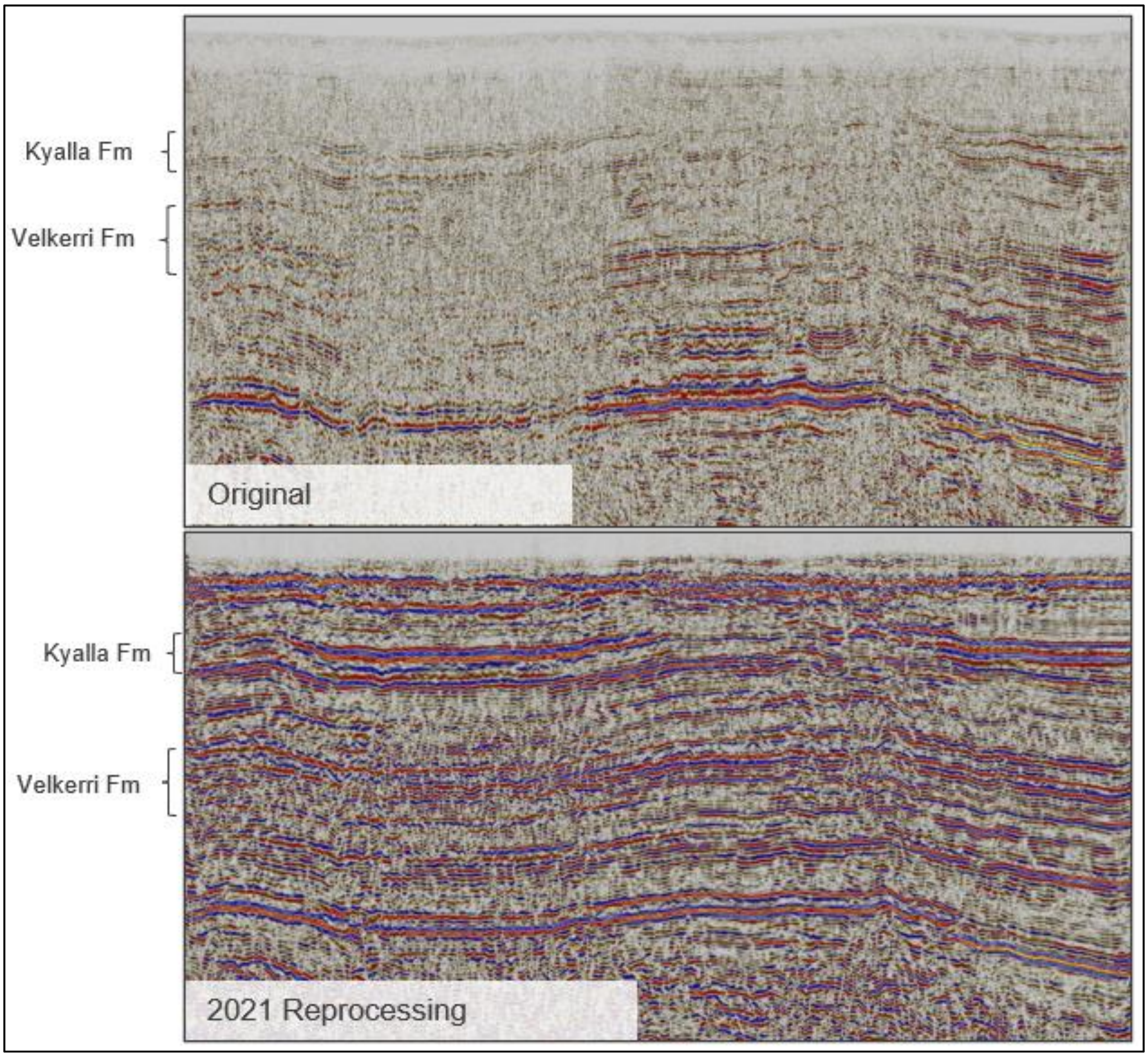

Figure 5. Example of final processed comparison on a 2012 vintage line. The original processing (top panel) shows poor continuity, variable amplitudes, limited signal and 'bumpy' structures. After reprocessing (bottom panel) these issues have largely been removed, resulting in a much-improved product for interpretation.

CONCLUSIONS

The results of this project have provided a robust and consistently imaged dataset suitable for the next phase of regional interpretation and ultimately future well placement. The uplift achieved has provided confidence that future seismic will provide a valuable tool in the de-risking and exploitation of the Beetaloo Basin's unconventional reservoirs in the same way it has in North American shale plays.

Clearly, better understanding of the seismic noise and its' causes is necessary to get the most from the data. Very seldom is seismic noise random, even if it appears so on some data - it is usually a question of sampling the noise adequately. Treating noise as data leads to better outcomes and this can be applied in some form to almost all datasets – new and old – and results in data that can be more confidently used for inversion and reservoir work.

Referring to the original goals of the study, it is clear that in all cases these have been achieved through the adoption of this technology. This has led to much greater confidence in the new interpretation and plans to acquire further data in the area, potentially including a 3D program.

We have demonstrated here that even relatively modern data can benefit greatly from advanced noise handling techniques. Comparable results have been observed from other parts of Australia and around the world, as almost all land data suffers from shallow surface heterogeneity artefacts. Whilst new acquisition can, undoubtedly, offer further improvements in data quality, much modern acquisition focuses on deployment of more receivers and sources, but careful thought should also be given to the placement of the receivers in particular, so further advances can be made. If likely noise is modelled and considered in the design then processing can also be optimised to handle it (Stork, C., 2021(b)).

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