Introduction

In 2012, PetroSA conducted a 3D towed-streamer seismic acquisition over the Bredasdorp Basin, offshore South Africa. A form of broadband acquisition, two seismic spreads towed at different depths were acquired simultaneously with a dense-over/sparse-under configuration (Kragh et al., 2009). Seven over cables at a depth of 9 m were towed with a crossline separation of 100 m and three under cables, at a depth of 20 m were separated by 233 m (Figure 1). Merging the higher frequencies recorded by the shallow cables with the lower frequencies recorded by the deeper cables allows us to extend the bandwidth of the data for which we have a high signal-to-noise ratio, even in the case of rough sea conditions. The acquisition was followed by a specific broadband processing sequence available at that time. This sequence involved interpolating the sparsely sampled under cable data before combining it with the dense over cable data prior to wavefield separation.

**Figure 1** An illustration of the 2012 over/under acquisition geometry.

Despite the extended bandwidth of the over/under data, an inversion study performed on the 2012 vintage processed data revealed issues related to signal-to-noise ratio, residual multiples, and frequency and amplitude incompatibility for thin reservoir mapping across common image point (CIP) gathers (Figure 2). PetroSA’s internal evaluation recommended a new processing flow to address these challenges and improve prestack elastic inversion for syn rift and/or drift targets accompanied with amplitude variation with offset (AVO) modelling and a rock physics study of the reservoirs.

**Figure 2** Prestack time migration CIP gather extracted at well location. (a) Final 2012 CIP gather. (b) 2012 CIP gather with Radon demultiple. (c) Modelled noise and multiples. (d) Target level after Radon multiple application. (e) AVO angle overlay on CIP gathers. Figure is colour coded with amplitudes for CIP gathers and with angles for AVO.

Since 2012, significant improvements have been made in broadband processing technology, including deghosting and interpolation techniques. We focus on how these new techniques were applied to this heritage acquisition technique to deliver data with a broader useable bandwidth and improved data quality, allowing obtaining new geological insights in the area.
Signal processing workflow

Noise attenuation The original processing utilised a digital group forming (DGF) approach, (Martin et al., 2000), in which the recorded 3.125-m spacing single-sensor traces were processed through initial noise attenuation and signal processing steps to leverage the fine receiver sampling of both signal and noise. The 2019 reprocessing also commenced from single-sensor gathers, but, in this instance, additional tools were used to attenuate strong marine noise generated by crossflow of water across the streamers. Specifically, an improved singular value decomposition technique (Moldoveanu, 2011) and multidomain noise attenuation (Rentsch et al., 2013) were employed. Figure 3 shows the noise reduction enabled by applying the 2019 workflow.

![Figure 3 Under-cable single-sensor gather. (a) Input to DGF. (b) After 2012 DGF. (c) After 2019 improved DGF.](image)

Deghosting An optimal deghosting solution was used in 2012 to perform a de-phase and sum of the data from the streamers at the upper and lower towing depths. In 2019, adaptive deghosting (Rickett et al., 2014) was performed on the upper and lower cables independently, broadening the frequency spectrum by attenuating source and receiver ghost effects and additionally redatuming to mean sea level, thus facilitating the merge of the over and under cable data sets. Adaptive deghosting delivered significant improvements relative to the original deghosting. In addition, including source deghosting further extended the data sets’ bandwidth relative to the legacy data, for which only receiver-side deghosting was applied.

Over/under cable merging The 2012 processing used a compact Fourier interpolation approach (COMFI) (Moore et al., 2008) to interpolate the low-frequency data from the sparse under cables to match the trace locations of the dense over cables. The 2019 reprocessing utilised a 3D sparse time-domain Radon interpolation technique (TDR1) (Schonewille et al., 2014) to regularise and interpolate the sparse under-cable data beyond aliasing in the offset domain. Subsequent to this, in a similar manner to that used in 2012, low-frequency energy (<35 Hz) from the reconstructed under cables was merged with high-frequency energy (>35 Hz) from the dense over cables to obtain a broad frequency spectrum. In this way, we leverage the reduced impact of swell noise as well as a narrowing of the receiver notch at zero frequency resulting from the deep cable tow. The high-frequency component of the shallow tow data is, of course, less subject to the impact of the swell noise. Figure 4 demonstrates the uplift in signal-to-noise ratio and frequency content after merging over/under cables between the legacy and new processing.

Multiple attenuation The 2012 processing utilised a cascaded approach to attenuate water-layer multiples and longer-period free-surface multiples. Firstly, by predicting water-layer multiples using a wavefield extrapolation method and adaptively subtracting the generated model from the input data in the offset domain. A true-azimuth 3D free-surface multiple prediction was then performed on output shot gathers from the previous step to attenuate surface-related multiples. In 2019, an integrated workflow was developed further. Multiples that have reflections in the water layer on the receiver side were predicted using true-azimuth model-based 3D prediction that benefits from the densely constructed gathers, followed by applying wavefield extrapolation methods to predict residual water-
layer multiples. Multidomain frequency-based adaptive subtraction was used to simultaneously subtract multiple models from input data. This was followed by a true-azimuth 3D free-surface multiple prediction workflow after first removing the water-bottom reflection to predict and attenuate the free-surface multiples (Kostov et al., 2015).

Figure 4 Brute stack after dense-over and interpolated sparse-under cable merging. (a) 2012 processing. (b) New processing.

Regularisation and interpolation Reconstructing the multiple attenuated data was achieved using 4D matching-pursuit Fourier interpolation (MPFI) (Schonewille et al., 2013). MPFI has several advantages over COMFI, which was used in the legacy processing, including the ability to interpolate beyond aliasing.

Post-migration processing Residual multiples were attenuated post migration using weighted least-square Radon demultiple. In addition, a residual moveout correction and bandwidth extension were applied. Figure 5 demonstrates the uplift in the final prestack time-migrated images between the legacy and new processing.

Figure 5 Final migrated prestack time migration stack. (a) Legacy 2012 processing. (b) New 2019 processing.

Figure 6 shows the alignment between seismic and acoustic impedance and Vp-Vs performed using prestack AVO inversion QC at the well location. No preconditioning was required before the inversion process, which was not the case for the 2012 processing. This confirms the significant improvement in data quality following the careful reprocessing.

Conclusions

The 2019 workflow has been proven to bring added value to this vintage over/under style acquired data set. The results show a clear improvement in event continuity, clarity, and a reduction in noise and multiple content. A significant broader signal bandwidth was achieved by an improved attenuation of the sea surface ghosts associated with the source and receivers. The use of TDRI to regularise and interpolate the sparse under cables and merge with the dense over cables broadened the bandwidth at the reservoir level. Revising anisotropy, migration and stacking velocities resulted in an improvement in fault imaging and event alignment across the CIP gathers for AVO/AVA analysis. The improvements were attained using both the shallow and deep spreads, rather than the shallow spread only, which demonstrates that legacy acquisition technologies and techniques can have an impact on data quality. The combination of bespoke signal processing with legacy acquisition can deliver the optimum outcome.
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References


