

Dude, where's my AVO? A case study from the Browse Basin, North West Shelf, Australia

Said Amiribesheli*

Discover Geoscience Pty Ltd
West Perth, WA 6005

s.besheli@discovergeoscience.com

Jordan McGlew

Discover Geoscience Pty Ltd
West Perth, WA 6005

j.mcglew@discovergeoscience.com

Joshua Thorp

Searcher Seismic Pty Ltd
West Perth, WA 6005

j.thorp@searcherseismic.com

SUMMARY

The Braveheart-1/ST1 well (2009) was drilled on a pronounced Class III AVO anomaly identified on the Braveheart 2D and Braveheart infill 2D seismic data in the Browse Basin, Australia. The well was dry with no indication of hydrocarbons. During a post-drilling analysis of the well, the seismic synthetics generated displayed no Class III AVO anomaly at the well location. The failure of seismic to predict a correct AVO response at the well raised major questions around the legitimacy of AVO and Quantitative Interpretation (QI) approach for prospect generation and maturation in the Browse Basin.

In 2011, Searcher Seismic acquired the long offset (8km) Vampire 2D seismic survey in the Browse Basin that tied 60 wells (including Braveheart-1/ST1). The assessment of the Vampire PSDM (2018) data at Braveheart-1/ST1 reveals that the Class III AVO anomaly is absent. Looking back at the well result it is likely that the generated Class III AVO in the vintage 2D data was caused by insufficient acquisition parameters and an inappropriate processing workflow.

This paper demonstrates how the acquisition of long streamer seismic, with appropriate processing could help to avoid misidentification of false AVO anomalies and also help identify true AVO anomalies, which have been masked by unsuitable acquisition and processing workflows. This paper could help support a more successful drilling program.

The Vampire long streamer 2D PSDM seismic data with preserved amplitude, provides great opportunities for the geoscientist to reassess the exploration potential in the Browse Basin. Using this dataset with 60 well ties also offers profound opportunities to run a 3-term AVO Inversion for reservoir characterisation and field development planning of the main fields in the Browse Basin.

Key words: *M. australis* sand, Vampire 2D, PSDM processing, AVO inversion, prospect generation.

INTRODUCTION

The Browse Basin covers an area of approximately 140,000km² offshore Western Australia and is filled with 15km of sediments from the Palaeozoic to Recent (Blevin et al., 1997; Struckmeyer et al., 1998). There are four sub-basins within the Browse Basin; the Caswell, Barcoo, Scott and Seringapatam sub-basins (Hocking et al., 1994; Struckmeyer et al., 1998) (Figure 1).

The Browse Basin is a prolific hydrocarbon province hosting major oil, gas and condensate accumulations (Barber, 2013) (Figure 1). More than 200 wells have been drilled in the basin with over 20 hydrocarbon discoveries. Most of the discoveries occur in the Jurassic and Cretaceous (Brincat et al., 2003).

TECTONO- STRATIGRAPHIC FRAMEWORK OF THE BROWSE BASIN

The Browse Basin was initiated during the creation of the Westralian Super-basin in the late Palaeozoic creating the main northeast to southwest structure (Blevin et al., 1998; Lawrence et al., 2014). During the Late Triassic there was a period of compression, inversion and uplift (Struckmeyer et al., 1998; Lawrence et al., 2014) during which sediments from the Early Triassic were eroded and transported into the Caswell Sub-basin.

Extension in the Early to Middle Jurassic continued the north-easterly structural trend with Plover Formation fluvio-deltaics being deposited (Barber, 2013). The extension continued into the Middle Jurassic with Argo-land completely separating with a subsequent period of rifting during the Callovian to Oxfordian (Symonds et al., 1994; Blevin et al., 1997). A drowning event in the Late Oxfordian to Kimmeridgian deposited organic-rich claystones, known as the Lower Vulcan Formation (RPS Energy, 2008). The Brewster Formation was deposited into the basin from the eastern margin as submarine fans in the Late Jurassic to Early Cretaceous.

During the Early Cretaceous, thermal subsidence continued (RPS Energy, 2008) which overtook the rate of sediment supply in the Valanginian causing a marine transgression and an increase in argillaceous sediment input (Radlinski et al., 2004). The Echuca Shoals, the primary target for Braveheart-1/ST1, was deposited as a post-rift sequence (Figure 2). This is dominated by claystones with occasional pulses of sand deposited as submarine fans (Barber, 2013) during short phases of regression in a mainly transgressive period (Blevin et al., 1997).

The Aptian was a time of regression and tectonic stability with passive thermal subsidence occurring during which clastic sediments were deposited. In the Cenozoic, tectonic stability was interrupted by the collision of Australia and Asia, this resulted in compressional uplift along the NWS margin (Longley et al., 2002; Lawrence et al., 2014).

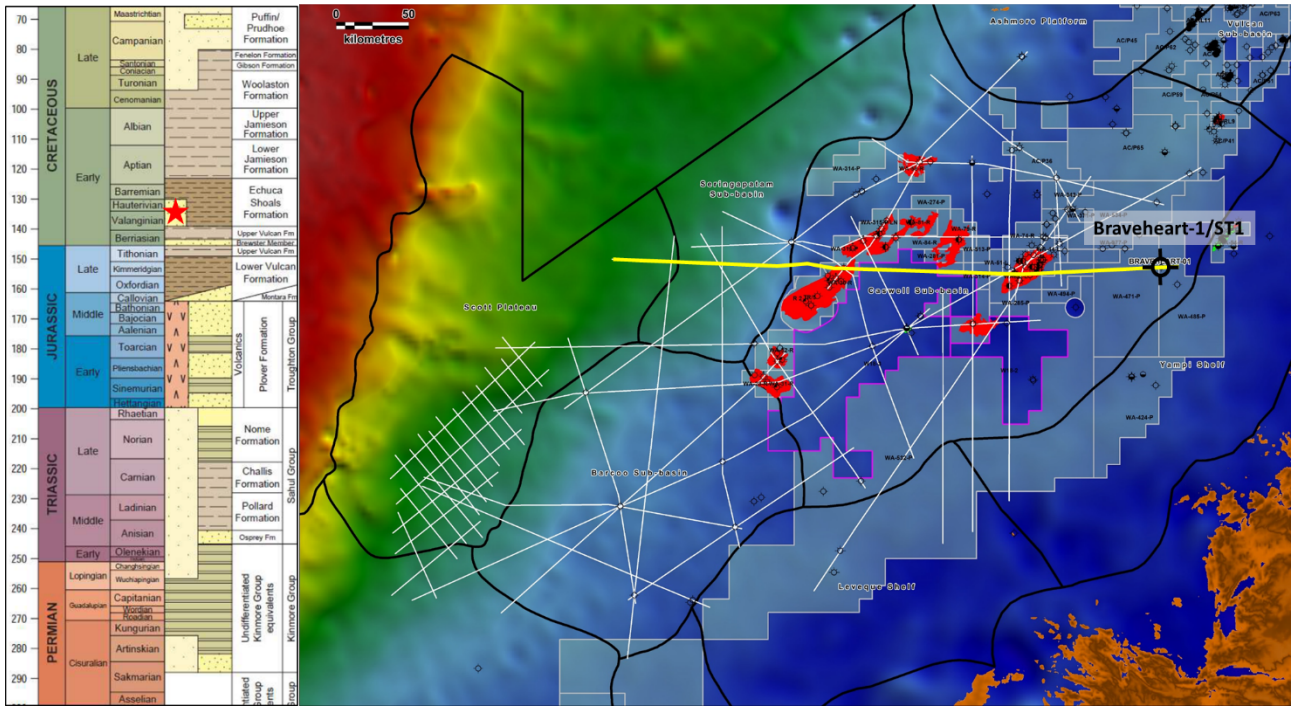


Figure 1. The Vampire 2D Seismic Survey is shown in white in the Browse Basin with the yellow line indicating the Vampire 2D line displayed in figures throughout the paper. The black outlines depict the structural elements (from Department of Mines, Industry Regulation and Safety, Western Australia) overlaying the Bouguer Corrected Gravity (Bureau Gravimétrique International, WGM2012 Model). Generalised stratigraphy of the Browse Basin is modified after Geoscience Australia with the red star indicating the location of the *M. australis* sands.

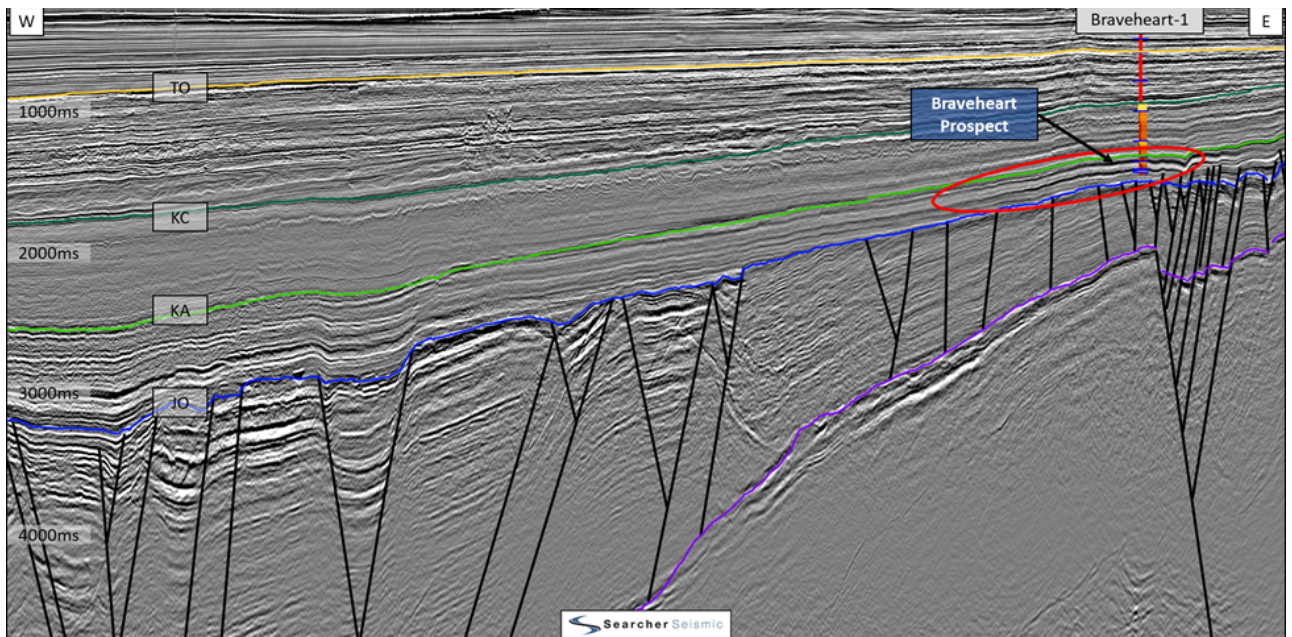


Figure 2. The Vampire 2D PSDM Full Stack seismic line (courtesy of Searcher Seismic) tied to the Braveheart-1 well. The red polygon indicates the strong amplitude anomaly the well was drilled on. The prospect was situated up-dip on the Prudhoe Terrace with the Caswell Sub-basin depocenter to the west of Braveheart-1. Location highlighted in Figure 1.

BRAVEHEART-1/ST1 WELL RESULT

The Braveheart prospect has been identified as a structural-stratigraphic trap with a strong Class III AVO anomaly (Figure 3). The *M. australis* sand, the primary target, has been described as an Early Barremian to Late Hauterivian fan play in the Echuca Shoals Formation (Exoil, 2010). As the *M. australis* sand is deposited in the post rift thermal subsidence phase, structure is not the main trapping mechanism for this prospect,

although there is a possibility of limited fault movement. The prospect is situated in the shallow marine transgressive system tract, providing a favourable setting for a stratigraphic trap. Due to the domination of claystone within the Echuca Shoals Formation, top, base and lateral intra-formational seals can be provided. The Plover Formation (oil and gas prone), Vulcan Formation (oil prone) and Echuca Shoals Formation (oil prone) were the potential source for the prospect (Exoil, 2010). Oil discoveries in the nearby Cornea field was evidence of charge

migration across the Prudhoe Terrace, through the Braveheart prospect and onto the Yampi Shelf. Additionally, the prospect was overwhelmingly supported by the presence of strong Class III AVO anomaly. The AVO anomaly was interpreted to be a direct hydrocarbon indicator (DHI). The Braveheart-1/ST1 penetrated a gross interval of 30 m of Lower M. *australis* sandstone. The sandstone was reported to be of good quality with an average 28% porosity. While there was some evidence of residual hydrocarbons at the top of the reservoir interval, most of the cleaner sands were water-filled.

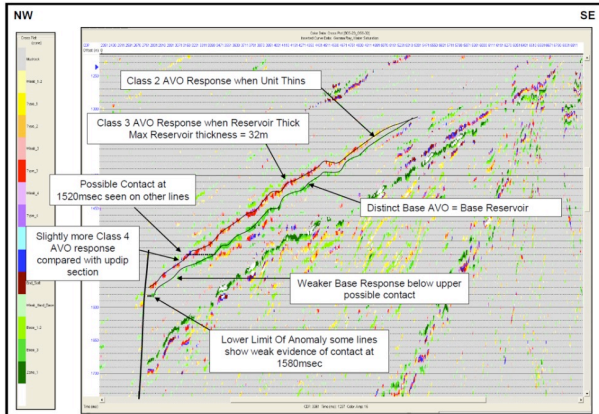


Figure 3. The AVO anomaly the Braveheart-1/ST1 well was targeting on the Braveheart 2D Seismic Survey (RPS Energy, 2008).

BRAVEHEART-1/ST1 WELL TO SEISMIC TIE

Seismic to well tie analysis was performed to compare the seismic response with the synthetics at the Braveheart-1/ST1 well location. Overall, there is a good correlation between seismic and synthetics data (Figure 4). When we compare synthetics at the well with gathers of vintage 2D, we discovered a Class III AVO on the gathers while synthetics seismic exhibits a Class IV AVO. The synthetic seismogram demonstrates Near stack (10 deg) is associated with a strong soft event that is dimming at Mid stack (20 deg) and turning to a trough/zero crossing at Far stack (30 deg). This is a classic Class IV AVO response. This is clearly suggesting the pre-drill observed Class III AVO anomaly on seismic data is not real and cannot be associated with the presence of hydrocarbons. It can therefore be hypothesised that the AVO anomaly observed in the vintage 2D data is caused by poor data acquisition or inappropriate processing. To further analyse this, acquisition of modern high-quality seismic data and appropriate processing was required.

VAMPIRE 2D ACQUISITION AND PROCESSING

Acquisition

Searcher Seismic acquired the Vampire 2D Seismic Survey in 2011 to address the issues and concerns associated with the legacy data in the Browse Basin. An extensive reprocessing campaign of the legacy 2D and 3D open-file datasets revealed that whilst there was significant uplift in the data quality with modern processing technology, several major hurdles remained with the acquisition parameters which could not be resolved with reprocessing. The Vampire 2D data was acquired with 6 m source depth, 25 m shot point interval and 8 km steamer. This acquisition setting ensured that the trace length would image all the play levels and deeper structures within the basin while still providing sufficient fold in the shallow section for velocity

modelling. Modelling of the known geophysical and geological issues in the area indicated that an 8 km steamer would sufficiently image the primary Mesozoic and deeper Palaeozoic targets. Modelling also suggested the 8 km steamer provides enough angle coverage (beyond 50 degrees) for a 3-term AVO inversion techniques at the primary target level.

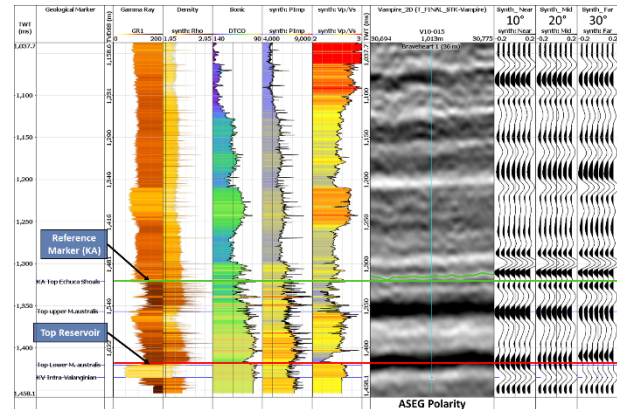


Figure 4. Braveheart-1/ST1 well tie to Vampire 2D PSDM Full Stack seismic data. The red line indicates the Top Lower M. *australis* sands in which the Braveheart-1/ST1 well targeted and the green line indicated the Top Echuca Shoals Formation which is used as a reference marker throughout. The synthetic seismogram demonstrates Near stack (10 deg) is associated with a strong soft event that is dimming at Mid stack (20 deg) and turning to a trough/zero crossing at Far stack (30 deg). This is a classic Class IV AVO response.

Processing

The original processing of the Vampire 2D Seismic Survey in 2011 used a Pre-Stack Time Migration (PSTM) workflow that incorporated 4th order Normal Moveout (NMO) velocities at the migration stage. The 4th order NMO velocities provides an approximation to the anisotropy parameter, ETA in PSTM workflows, without having the additional complexity of a second term to analyse. However, this velocity analysis proved to be insufficient for imaging the sections below the highly anisotropic Jamieson Formation shale which is found regionally to be anisotropic in the Browse Basin. The PSTM gathers still had significant moveout at large incident angles at the major play levels and reduced the ability to apply AVO analysis to the dataset. In 2018, Searcher Seismic decided to apply broadband Pre-Stack Depth Migration (PSDM) seismic processing to the Vampire 2D data. Source and receiver broadband deghosting applied via the adaptive deghosting technology, provided a significant uplift in data quality. The PSDM velocity modelling workflow consisted of three anisotropic tomographic updates to the velocity field and a final Kirchhoff PSDM. The velocity modelling workflow also used the wells and interpreted horizons to ensure a consistently tied velocity field throughout the large regional survey. This detailed interpretation and wealth of well information allowed for a high-resolution velocity model that incorporated localised velocity features through the tomographic inversion.

The final processing result offered significantly improved bandwidth throughout the section and improved the stability of the Far and Ultra-Far offset stacks such that they could be used in a 3-term AVO and QI analysis.

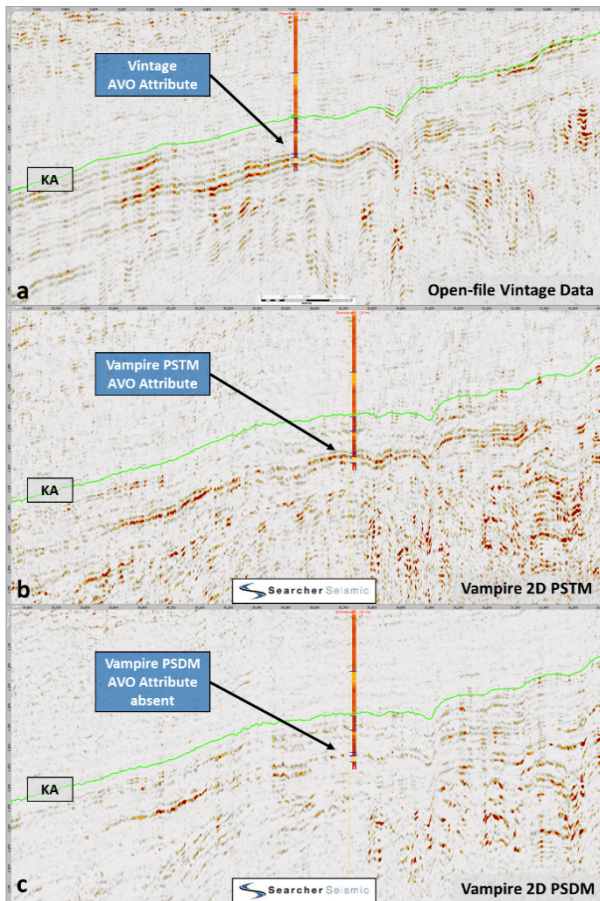


Figure 5. AVO Attributes analysis on the vintage seismic data (a), the Vampire 2D PSTM (b) and the Vampire 2D PSDM (c). The AVO response is most visible in the legacy seismic data. The response lessens in the Vampire 2D PSTM data and almost completely absent at the well location in the Vampire 2D PSDM seismic data.

AVO ANALYSIS

The Braveheart-1/ST1 well was drilled on a convincing AVO anomaly. Figure 3 depicts the pre-drill AVO classification of Vintage 2D data where *M. australis* sand shows a Class III AVO response (RPS Energy, 2008). AVO attribute analysis of vintage data also shows an AVO response at the main target level (Figure 5a). After acquisition of the Vampire 2D data, very similar AVO Attributes were created using PSTM and PSDM data. Analysis of the Vampire PSTM data shows the AVO anomaly at main target level is still present (Figure 5b). However, the assessment of Vampire PSDM data reveals no AVO anomaly at the target level (Figure 5c). It is important to note that from the synthetic seismogram, no AVO response is expected. To further delineate the reason for discrepancy between the PSTM and PSDM AVO responses, an assessment of Vampire gathers was undertaken. On the PSTM gathers (Figure 6a), the energy from post critical angle was stacked into the Far stack creation. The flatness of the gathers on PSTM data also displays the gathers are not flat. On the other hand, PSDM gathers (Figure 6b) illustrates a superior gather flatness and more robust preservation of Far angle amplitudes. It is then concluded that bright Far amplitude response (Class III AVO) observed on the Vintage 2D and PSTM data are caused by inappropriate processing of the Far stacks. The review of the PSDM data reveals that the erroneous high amplitude at Far angles disappear and matches the well synthetics. This means

that the data is not predicting gas where there is none, i.e. giving false Class III anomalies. It also important to note that the strong Near amplitude response observed in both the PSTM and PSDM data most likely is driven by porosity.

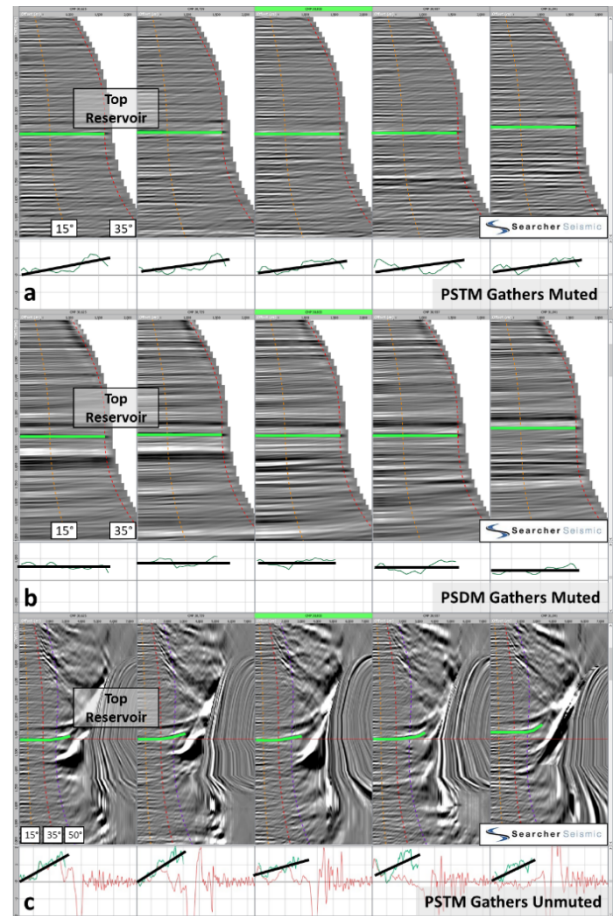


Figure 6. Offset gathers of the Vampire 2D Seismic Survey. Orange = 15 degrees, red = 35 degrees and purple = 50 degrees. (a) The Vampire PSTM gathers muted from 35 degrees show a Class III AVO response where the amplitude increasing from Near to Far offset. (b) The Vampire PSDM gathers muted from 35 degrees are flat and the amplitude response is not increasing with offset. (c) The Vampire PSTM unmuted gathers where data is showing the gathers are not flat and the post-critical angle energy is added to the Far stack angle. It is likely that residual noise and multiples from PSTM processing dim the Near and Mid stacks.

CONCLUSIONS

The Braveheart-1/ST1 well was drilled on a false Class III AVO anomaly identified on the vintage 2D seismic data which resulted in a dry well with no indication of hydrocarbons. Synthetic seismograms generated by well data revealed that there was no Class III AVO anomaly at the well location. With the acquisition of long offset (8km) Vampire 2D data and PSDM processing, we discovered that the false AVO anomaly was the product of inappropriate acquisition and processing. AVO analysis of Vampire PSDM data also demonstrates that a suitable workflow can identify new opportunities where they may have been overlooked due to the paucity of seismic acquisition or insufficient seismic processing workflow. We conclude that the Vampire long streamer 2D PSDM with

preserved AVO, provides a great opportunity for the geoscientist to reassess the exploration potential in the Browse Basin. Using this dataset with 60 well ties also offers profound opportunities to run a 3-term AVO Inversion for reservoir characterisation and field development planning of the main fields in the Browse Basin. Consequently, we have undertaken a QI approach and carried out the a 3-term AVO Inversion study of the Vampire PSDM data. The data was inverted to extract 3 Petro-elastic properties of Acoustic Impedance, V_p/V_s and Density. We believe with these inversion results, the data is suitable to address some of the complex challenges in the Browse Basin, including Brewster Formation (Cretaceous) reservoir quality distribution, reservoir and volcanic discrimination within Plover Formation (Jurassic) and identification of Permian/Triassic Plays.

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