Silvereye 1 Case Study – the False Positive

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SUMMARY

The objective of the recent Silvereye 1 exploration well in Bass Basin was to test Paleocene and Cretaceous sandstone reservoirs of the Eastern View Coal Measures (EVCM). The well was designed to test a faulted four-way dip closure and stratigraphic trap interpreted as a sand filled channel. Pre-drill analysis relied on a recent 3D marine seismic survey with well control provided by 2D seismic ties to wells located in adjacent exploration permits.

The pre-drill interpretation of a gas-bearing sandstone-filled channel was based on a brightening of seismic amplitude (a predominantly class 3 AVO anomaly) associated with the channel feature. The AVO behaviour was consistent with the response at the same gas-bearing stratigraphic level in the nearby White Ibis 1 well, hence the presence of hydrocarbons (gas) was considered likely.

The well intersected the predicted stratigraphy but failed to encounter hydrocarbons at any of the reservoir intervals. A channel sand was intersected within a thick claystone interval at the pre-drill proposed stratigraphic trap. The claystone is characterised by low-velocity and high density, while the sandstone has slightly higher porosity than sand typically encountered in this section. It was the contrasting characteristics of these lithologies that determined the class 3 AVO response and the mis-interpretation of the anomaly. We show that a close examination of the rock physics trends of reservoir and non-reservoir rocks in surrounding wells could have allowed this scenario to be recognised pre-drill.

Failure to recognise all possible lithological characteristics in the pre-drill AVO model meant that not all outcomes were analysed, and hence were not included in the risking of the prospect . The post drill evaluation has recognised that rock physics studies are an important tool for recognising all possible scenarios to aid in prospect evaluation.

Had a more comprehensive rock physics evaluation been conducted, the actual outcome would likely have been recognised as one of several possibilities, but would not necessarily have prevented drilling of the well.

Keywords: Bass Basin, channel, AVO, rock physics

INTRODUCTION

The primary targets of the Silvereye 1 well were the sandstone reservoirs of the Eastern View Coal Measures (EVCM) within a faulted four-way dip closure and an interpreted stratigraphic trap defined by a high amplitude response on 3D seismic (Figure 1).

Silvereye 1 is located in exploration permit T/44P on the flanks of the Bass Basin which contains a proven working petroleum system (Figure 2). The nearest well, White Ibis 1, located 18 km SE of Silvereye 1, intersected sub-commercial hydrocarbon pools in 3 reservoir intervals. The recent Trefoil gas discovery is approximately 27kms away and intersected over 20 hydrocarbon bearing reservoirs. The Yolla gas field is the nearest production facility with oil and gas present within reservoirs at the Top EVCM and within the intra EVCM Eocene and Paleocene sandstones. All these wells contain gas in the same stratigraphic interval that was the primary target of Silvereye 1.

The top of the primary target sands within the lower *L. balmei* at Silvereye 1 are mapped as the intra-Paleocene marker and is the age equivalent to the Yolla Field top 2973 gas-bearing sand. Most significantly this horizon is also mapped as equivalent to the uppermost gas reservoir in White Ibis-1, which has a similar AVO response and is overlain by competent sealing lithologies (Figure 3).

Regional Setting

The Bass Basin is located offshore in south-eastern Australia between Victoria and Tasmania. It is one of a series of sedimentary basins that formed in response to rifting during the Late Jurassic to Early Cretaceous between Australia and Antarctica (Williamson et al., 1987) and represents a failed arm of the Southern Margin Rift System. Due to its regional tectonic setting between two major rift systems, the Bass Basin was affected by multiple episodes of upper crustal extension and compression, driven by both inter- and intra-plate stresses. Structural development was further influenced post breakup along the central Southern Margin by the prolonged fragmentation and clearance of Antarctica along western Tasmania. The Bass Basin covers approximately 65000 km^2 and water depths range from 30 to 90 m.

The rifting created a series of northwest-southeast oriented grabens offset by associated east-west wrench movement. The Pelican, Yolla and Cormorant Troughs comprise the major depocentres in the western Bass Basin. These depocentres are fault-bounded half-grabens that progressively developed via growth faulting during the active rifting and thermal subsidence phases of basin evolution. The dominant structural trend in the basin is northwest-southeast, highlighted by the orientation of the major faults and troughs that produce interlinked half-grabens.

Stratigraphy

The primary objectives of Silvereye 1 were to test reservoir intervals of the Late Cretaceous to Paleocene lower EVCM (Hansen, 2010). This interval has been intersected in numerous wells in the basin. It is a sequence of late lowstand sediments grading through a transgressive systems tract, capped by high-stand sediments. Environments are gradational both laterally and temporally from alluvial through fluvio-deltaic and nearshore to deeper restricted lacustrine. Primary sediment input to the basin was from the southeast with minor localised input also deposited transversely from the flanks of the troughs. The gas-bearing reservoir intervals intersected in White Ibis 1 are interpreted to be deposited in a fluvial channel system. The age-equivalent sediments in the Silvereye 1 well are interpreted to have been deposited in a similar depositional environment.

Seal is provided by the vertical sealing capacity of multiple intra-formational seals within the Paleocene lower *L. balmei* and the Late Cretaceous *F. longus* SP zones of the EVCM which has been demonstrated by the stacked gas accumulations at Trefoil and White Ibis gas discoveries, the producing Yolla Gas Field. The main top seal which overlies the intra-Paleocene seismic marker is seen in all the wells drilled in the adjacent exploration permit.

PRE-DRILL ANALYSIS

Pre-drill analysis of the prospect utilised the recently acquired Silvereye 3D marine seismic survey with well control provided from adjacent exploration permits. Regional 2D seismic surveys were interpreted as part of the project and established correlation to nearby wells White Ibis 1 and Bass 3. Selected lines from various vintages were reprocessed to improve the seismic tie, obtain amplitude balanced correlation, and enhance the confidence of the seismic interpretation.

From this work the Silvereye prospect was mapped as a faulted anticlinal closure over a basement high. A stratigraphic component to the prospect (interpreted as a potential channel) was identified over the feature from seismic amplitude data, (Figure 1). Hence the trap was defined by a combination of the structure and the interpreted stratigraphy. Correlation to White Ibis 1 provided the main control on the expected stratigraphy and was used as an analogue for AVO model studies.

Migration Pathways

The Cretaceous has been ranked as having good to very good source rocks, with the Maastrichtian interpreted to have good to excellent oil potential and gas potential, (Boreham et al., 2003). The Paleocene and Eocene source rocks in the basin also have the potential to expel hydrocarbons. All of the gas bearing sands discovered in the Paleocene and Cretaceous sands to date have generally been very interbedded. These sands together with linking faults are presumed to be the main conduits for hydrocarbon migration.

The intra-Paleocene marker regional depth structure map (Figure 2) was utilised to determine potential migration routes to the mapped prospects and leads within exploration permit T/44P. The Silvereye prospect was determined to be optimally located to receive hydrocarbon charge assuming the presence of a mature Cretaceous source facies.

AVO Analysis

Migrated, NMO corrected gathers from the 3D seismic volume were conditioned to remove noise and flatten events in the target interval in order to undertake AVO analysis on the prospect. Intercept and Gradient volumes were produced, calculated for incidence angles up to 36 degrees.

Analysis of the Gathers & AVO volumes revealed a class 3 AVO anomaly coincident with the inferred channel mapped over the prospect area (Figure 1 & 4). Using the Rutherford and Williams classification scheme (Rutherford & Williams 1989), a Class 3 reflection event exhibits a negative reflection coefficient at normal incidence (ie P-Impedance decreasing across boundary), becoming more negative with increasing incidence angle. This produces the well-known 'bright spot' associated with Low-Impedance, Low-Poisson's ratio Gas sands.

Comparison with Existing Wells

The Class 3 AVO behaviour observed over the Silvereye Prospect was known to be consistent with the AVO behaviour observed in seismic over existing wells which intersected gas-bearing sandstones, as well as forward models computed using the logs from these same wells. Specifically the Trefoil field and the nearby White Ibis 1 well are known to contain gas-bearing sandstones which produce a Class 3 AVO response on seismic data due to their low P-Impedance and Vp/Vs ratio relative to their encasing shale.

Forward modelling was conducted on the White Ibis 1 well in order to compare the expected AVO response with that observed over the prospect. This well was considered the most relevant candidate for modelling due to its proximity to the prospect, similar interpreted stratigraphy, and the existence of a recorded shear wave log in this well. Models were created for the insitu gas-bearing case, as well as a brine case using logs created via the Gassmann equations (Smith et al 2003).

The modelled seismic response from the top of the gas-bearing interval in White Ibis 1 was found to be similar to that observed over the Silvereye prospect, with a negative normal incidence amplitude, becoming more negative with offset (Class 3). The brine case exhibited a less negative normal incidence amplitude, and a near-zero gradient. It was therefore determined that a non-hydrocarbon bearing sand would not produce a bright seismic event or anomalous AVO gradient.

The responses for both cases are shown in Figure 5 using average elastic parameters of the seal and reservoir units for input to the Zoepprtiz equations for P-wave reflectivity versus angle of incidence. Similar results were obtained when the complete White Ibis well logs were convolved with a suitable wavelet. Further modelling of the White Ibis logs incorporating changes in sand porosity, and zero-reservoir scenarios also failed to produce a reflection event with similar AVO properties to that observed over the prospect.

Given the magnitude of the AVO response associated with the channel mapped over the prospect and it's similarity to the modelled gas case in White Ibis 1, combined with prior knowledge of AVO behaviour associated with gas bearing sandstones in other wells, the AVO study concluded that the most likely channel-fill was a sand with anomalously low P-Impedance and Vp/Vs ratio due to the presence of hydrocarbons. Key risks to this interpretation that were discussed pre-drill, were the possibility of low-saturation (sub economic) 'Fizz Gas', and an incomplete explanation for the absence of a down-dip amplitude shut-off. Also considered a key risk was the calibration of the magnitude of the observed AVO response, due to the absence of well data within the 3D seismic volume. It is fair to say in hindsight that the similarity of the AVO response to that of a nearby gas field somewhat blinkered the evaluation from investigating these risks in more detail.

DRILLING RESULTS

The Silvereye 1 well intersected the stratigraphy as predicted but failed to encounter hydrocarbons at any of the reservoir intervals. The well did intersect a 20.2m thick channel sand encased within a thick claystone interval.

The claystone composition is mainly kaolinite and is described as brownish grey, firm to rarely moderately hard, non calcareous, highly argillaceous, with minor black carbonaceous flecks, trace carbonaceous laminae, minor mica, trace to locally common disseminated pyrite (Phillips, 2011).

The channel sand is blocky dominantly loose quartz, very fine to very coarse, poorly to moderately sorted, dominantly angular to subangular, with rare pyrite, rare mica, trace shell fragments, trace coal. The calculated average porosity is calculated to be ~28% (Hall, 2011). The boundary of the sand unit is represented by sharp changes on gamma-ray, resistivity, and density logs. Acoustically, the contrast between the sand and encasing shale is dominated by the density with values decreasing from 2.51g/cm^3 in the shale to 2.177g/cm^3 in the sand. The properties of the sonic logs (compressional and shear) for this interval are not diagnostic of a good quality sand but comparable with surrounding wells see Figure 6.

The claystone interval has been recognised in a number of nearby wells and provides a good regional marker for the western Bass Basin. The thick underlying claystone is interpreted as a regional seal for the intra-Paleocene marker. The channel sand correlates to a thin silty interval in White Ibis-1 and Trefoil-1 and is of a younger age (upper L. balmei) to the youngest White Ibis 1 hydrocarbon sand (lower L. balmei).

POST DRILL ANALYSIS

Due to the absence of hydrocarbons in the target sand, post-drill AVO analysis was undertaken to determine the cause of the bright AVO Class 3 seismic event associated with the channel sand top and base horizons.

The elastic properties of the reservoir and non-reservoir lithologies in Silvereye 1, White Ibis 1 and Bass 3 were picked from the well logs. Several discreet rock-physics trends were identified. All sandstones were assigned to a single rock-physics trend, whereas non-reservoirs were differentiated into two lithologies. One comprising a Low Vp, High Density claystone with relatively high Vp/Vs ratio and slightly higher P-Impedance compared to sands, and the other a siltstone lithology (typically interbedded with the reservoir sands), being much higher in Vp and P-Impedance and with much smaller Vp/Vs contrast relative to sands, (Figure 7). The top reservoir seismic event in both the White Ibis and Silvereye wells is the result of a claystone/sand interface, and due to the properties described above, this interface can be expected to exhibit a decrease in both P-impedance and Vp/Vs ratio regardless of sandstone pore fluid (ie HC or Brine).

The observed AVO anomaly, wrongly interpreted as being hydrocarbon related at Silvereye 1, appears to be the result of variations in elastic properties in both the sands and clays, such that the P-Impedance contrast and Vp/Vs ratio contrast greater than that modelled using mean values from White Ibis 1 (Figure 8 and 9). Figure 9 shows the expected magnitude of the P-Impedance and Vp/Vs ratio contrast across a Clay/Sand interface for the White Ibis 1 brine logs, assigned to a normal distribution using the uncertainty in Vp,Vs and Density derived from the rock-physics trend. Both the claystones and sandstones intersected in Silvereye 1 had properties within the uncertainty range of the same lithologies interpreted from nearby wells, and the magnitude of the Mean P-Impedance and Vp/Vs ratio contrast falls within the expected distribution predicted from White Ibis 1 (approximately -0.7 and -0.9 standard deviations from the mean for P-Impedance and Vp/Vs ratio respectively).

The increase in the Vp/Vs ratio contrast between clays and sands at Silvereye 1 (relative to the expected modelled values) is not as great in magnitude as what is observed for Gas-bearing sands in White Ibis 1 (Figure 9), however it is sufficient to result in a negative P-reflectivity Gradient, producing a Class 3 AVO response (Figure 8 bottom). Although the White Ibis Gas model has a slightly more negative Intercept and Gradient than the Silvereye in situ model, the difference is small relative to the noise in the seismic data and uncertainty in calibration due to the absence of wells within the 3D seismic volume.

As mentioned previously, the Silvereye 1 channel sand was found to be younger than interpreted pre-drill, resulting in the Intra-paleocene marker coincident with this event being shifted one seismic cycle deeper in the section. As indicated in Figure 6, the sand now correlates to younger sand intersected in White-Ibis 1. This sand is seismically thin (≈ 5m), and also thin relative to the 20.2m sand intersected in Silvereye 1, and is interpreted as being brine-saturated in White Ibis 1. Using the elastic properties of this sand as input to a revised White Ibis brine model, the sand was found to be lower in both P-Impedance and Vp/Vs ratio than the White Ibis brine sand used in pre-drill modelling.

Figure 9 shows the magnitude of the difference in P-Impedance and Vp/Vs ratio relative to the expected uncertainty in the pre-drill Brine sand mode. Also shown is the P-reflectivity resulting from a Clay/Sand interface using this younger sand and leaving the clay parameters unchanged. The P-reflectivity is very similar to the clay/sand interface at the top Silvereye channel sand, and presumably this sand would produce a similar AVO anomaly to that observed at Silvereye if it had been thick enough to be imaged by the existing seismic surveys.

The difference in elastic parameters between the Brine sand used in pre-drill AVO modelling, and those of the younger sand used in the post-drill model may be the result of subtle changes in lithology, however it is likely that a greater source of error lies in the Gassmann fluid substitution used to model a Brine saturated sand from the Gas bearing sands in White Ibis 1. Given that the younger sand used in the post-drill model was Brine saturated already and requires no corrections, it is assumed that these parameters are more reliable, and the similarity of the post-drill model to the Silvereye 1 validates this assumption. It is therefore considered preferable to derive reservoir parameters from Brine-saturated well logs where possible, to eliminate the possibility of error in even the most carefully performed fluid substitution.

Despite the correlation error and possible error in fluid substitution, the correct lithology types were input into the pre-drill model, and the actual elastic properties of the Clay/Sandstone interface intersected in the Silvereye well fall within the uncertainty range of the pre-drill parameters. Therefore, if a Rock Physics Template had been developed pre-drill to quantify this uncertainty, it should have been possible to construct both plausible hydrocarbon & non-hydrocarbon models that reproduce the observed AVO anomaly, using elastic parameters for seal & reservoir within the expected uncertainty range of the mean values.

CONCLUSIONS

Prospect evaluation is most complete when all data is taken into account and all reasonable models have been tested against those data. However in our experience, models supporting the favoured outcome are often given more prominence than alternative outcomes. This work has shown that had a more holistic approach to the prospect evaluation been undertaken then perhaps a more conservative view of the prospect chance of success would have been adopted. In particular all aspects of the geological model should be considered, avoiding the pitfall of allowing one particular model to dominate the risking of alternatives.

The AVO anomaly coincident with the top and base of the Silvereye channel sand was found to be the result of larger than anticipated Impedance and Vp/Vs ratio contrast between reservoir and non-reservoir lithologies, sufficient to produce a negative, brightening seismic event similar in expression to a gas-bearing sandstone modelled from the most adjacent well.

Post-drill analysis included the development of a rock physics model incorporating data from several nearby wells, with the Silvereye data being included to determine if the intersected lithologies were anomalous. This revealed that the local reservoir/non-reservoir elastic properties encountered at Silvereye-1 were within the expected range of uncertainty derived from pre-existing wells, but that this full range of uncertainty was not factored into pre-drill modelling.

Furthermore, the channel sand intersected in Silvereye 1, which exhibited the AVO anomaly, is of a younger age than originally interpreted, resulting in a change in the correlation to the White Ibis 1 well at the Intra-Paleocene level. Revised AVO modelling was conducted using the elastic parameters of thin brine-saturated sandstone in White Ibis 1 found to be the approximate age equivalent of the Silvereye channel. This revised brine-saturated model produced an AVO response similar to the Silvereye channel sand. This result highlights the importance of accurate seismic correlation to wells, and in this case also suggests that it is preferable to derive reservoir parameters from well logs over brine saturated sands rather than relying on the accuracy of Gassmann fluid substitution to recover brine parameters from hydrocarbon bearing sands.

If this work had been undertaken prior to drilling it would have been possible to quantify uncertainty in the reservoir and non-reservoir elastic parameters, and construct plausible forward models for both hydrocarbon and non-hydrocarbon scenarios to explain the AVO anomaly observed in the 3D seismic data. This in itself may not have affected the final drilling decision since a Gas bearing channel sand would have remained a valid model however it certainly would have had a bearing on the outcome of the risking process.

This case study highlights the importance of understanding the elastic properties of all lithologies known from prior drilling, how these properties vary with depth and location, and the range of uncertainty expected. Once these parameters are derived it is possible to consider a wide range of plausible geologic interfaces, and determine the expected seismic expression of each. The main goal of this process should be to determine if there exists a plausible non-hydrocarbon model to explain a given seismic anomaly, rather than simply seeking to confirm a hydrocarbon-related model. This approach becomes even more applicable in the absence of structural conformance or other direct hydrocarbon indicators, as was the case in this instance.

ACKNOWLEDGMENTS

The authors thank the T/44P joint venture for permission to publish this paper, and Origin Energy staff for assistance in editing the manuscript with special thanks to Randall Taylor and Deidre Brooks.

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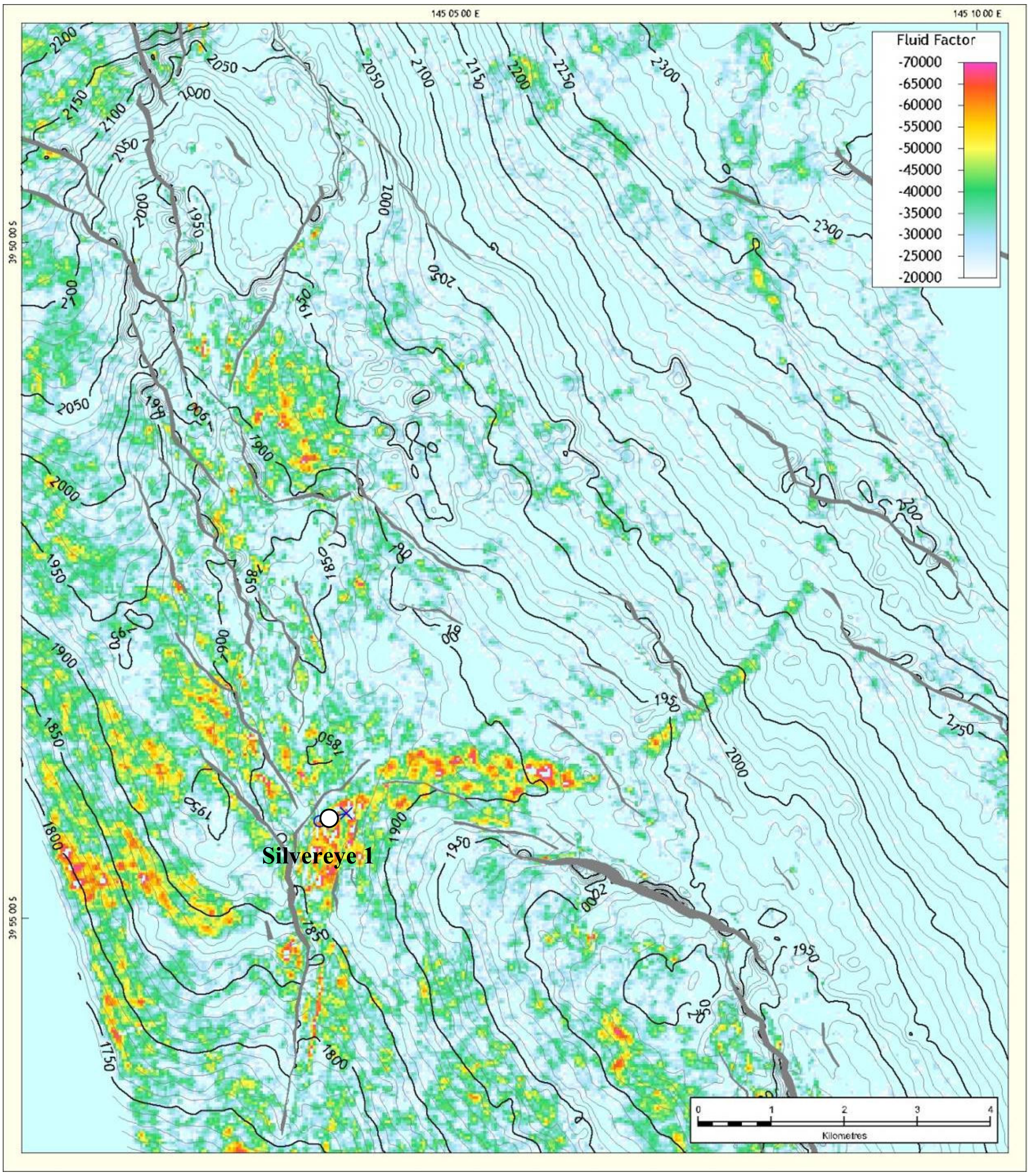

Figure 1. Intra-Paleocene Horizon depth structure and Fluid Factor amplitude map

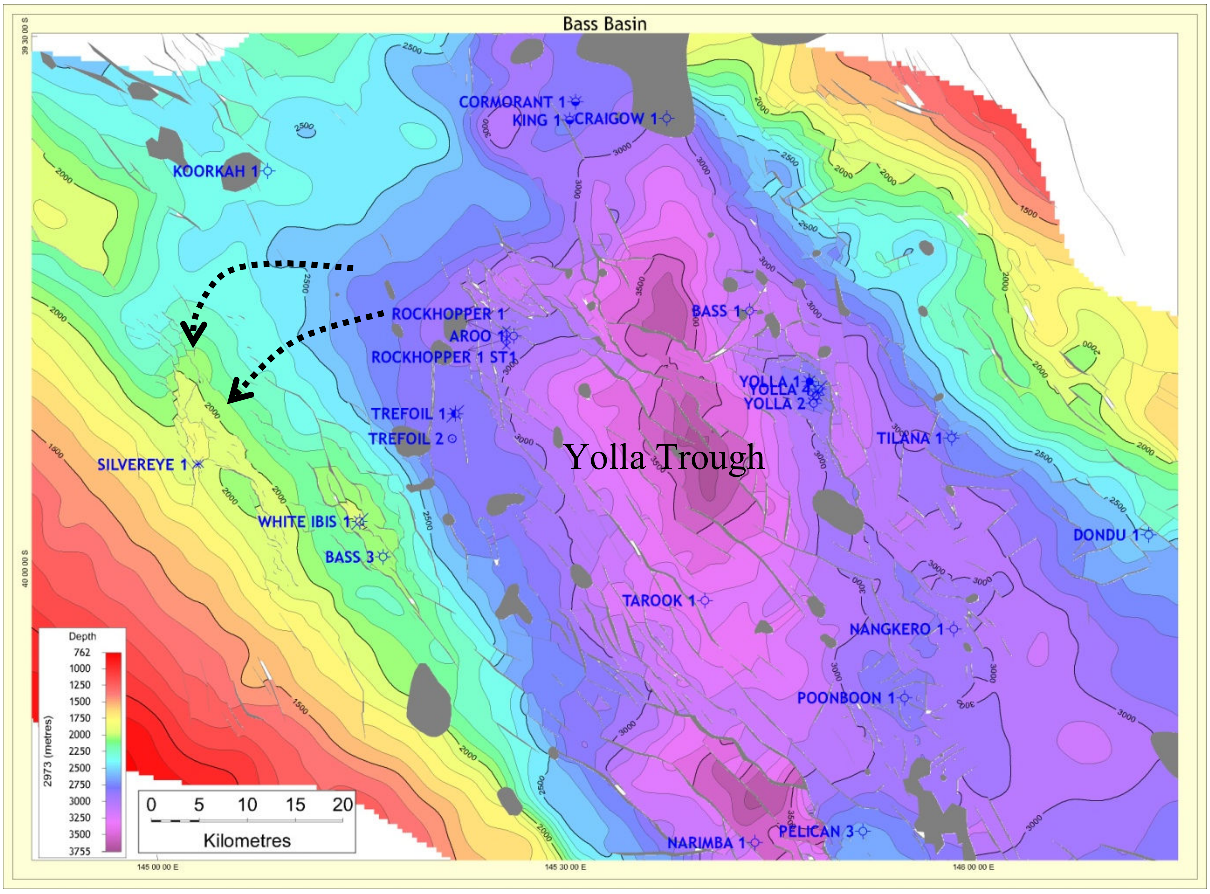

Figure 2. Intra-Paleocene horizon Regional Depth Structure Map showing migration pathways into the Silvereye Structure

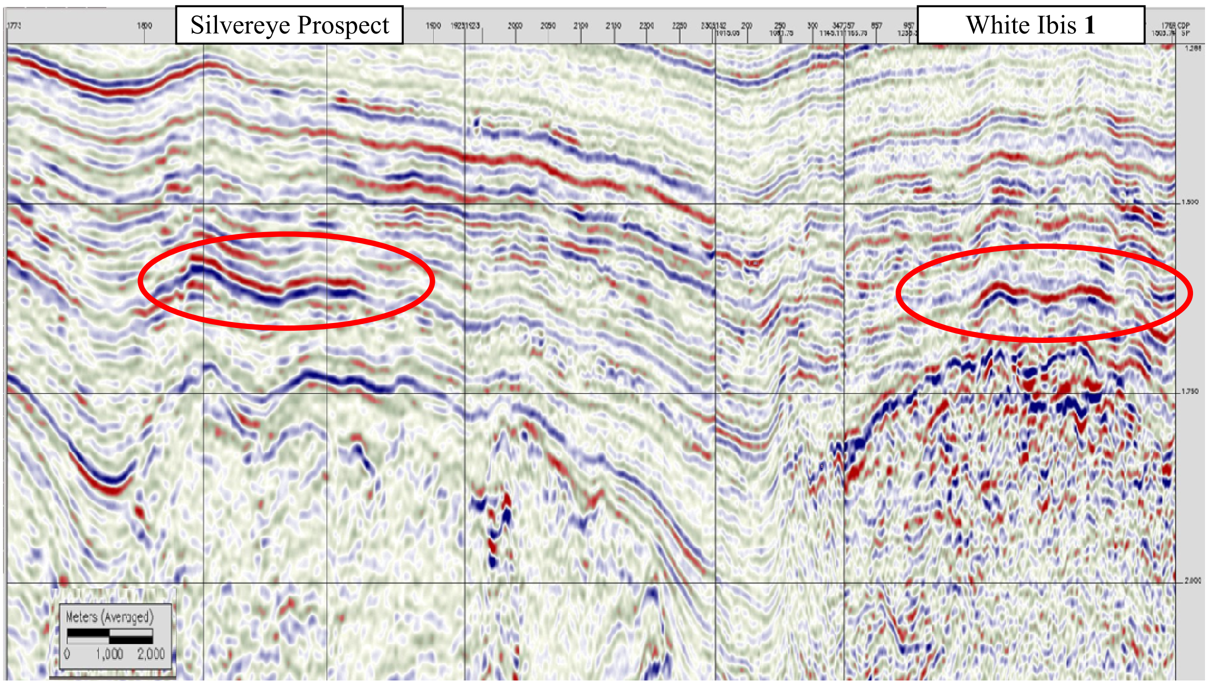

Figure 3. Seismic Traverse Seismic Polarity: Blue = hard, Red = soft

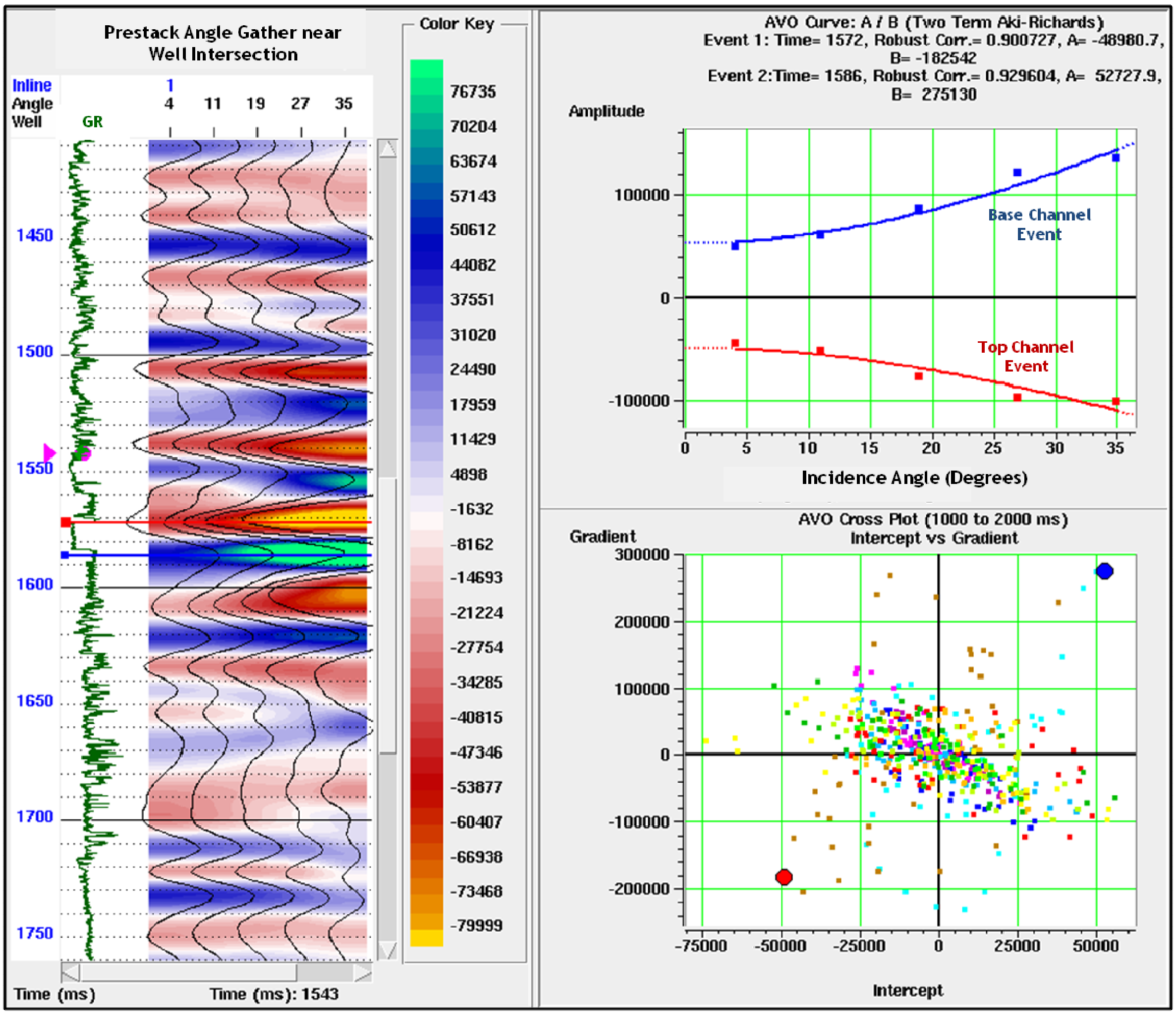

Figure 4. Seismic AVO anomaly, Gradient Analysis from Prestack Angle Gather

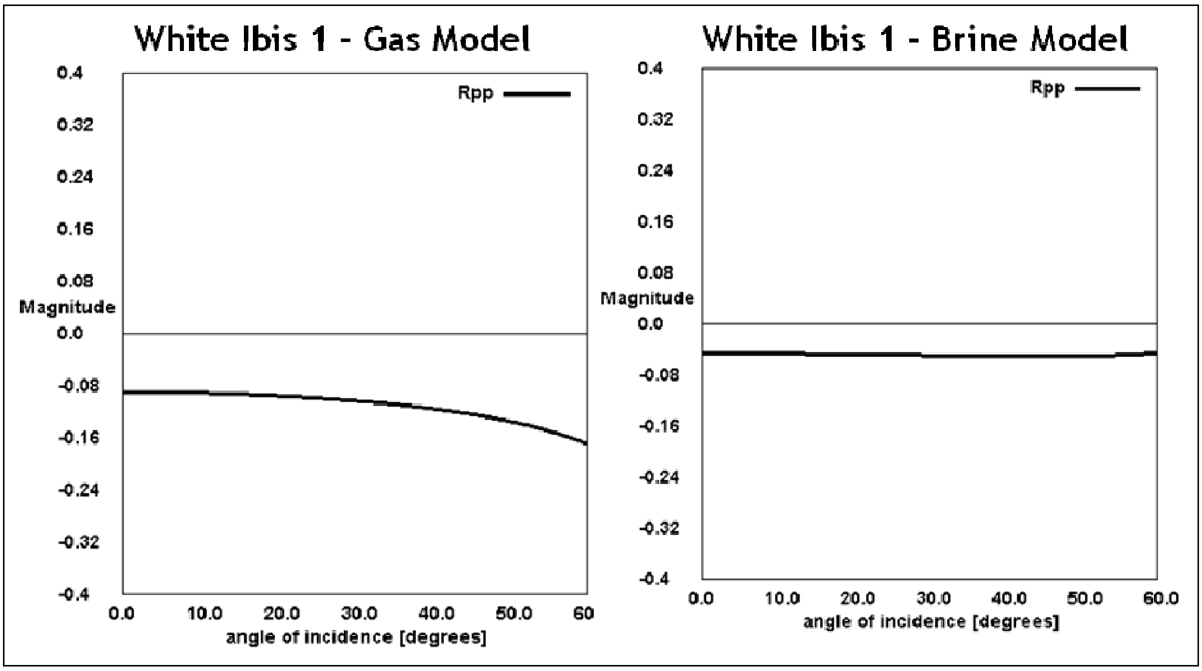

Figure 5. Zoeppritz P-wave reflectivity models summarising expected AVO response for the Top Reservoir at White Ibis–1. Gas Case (recorded logs) and Brine case after Gassmann Fluid Substitution shown.

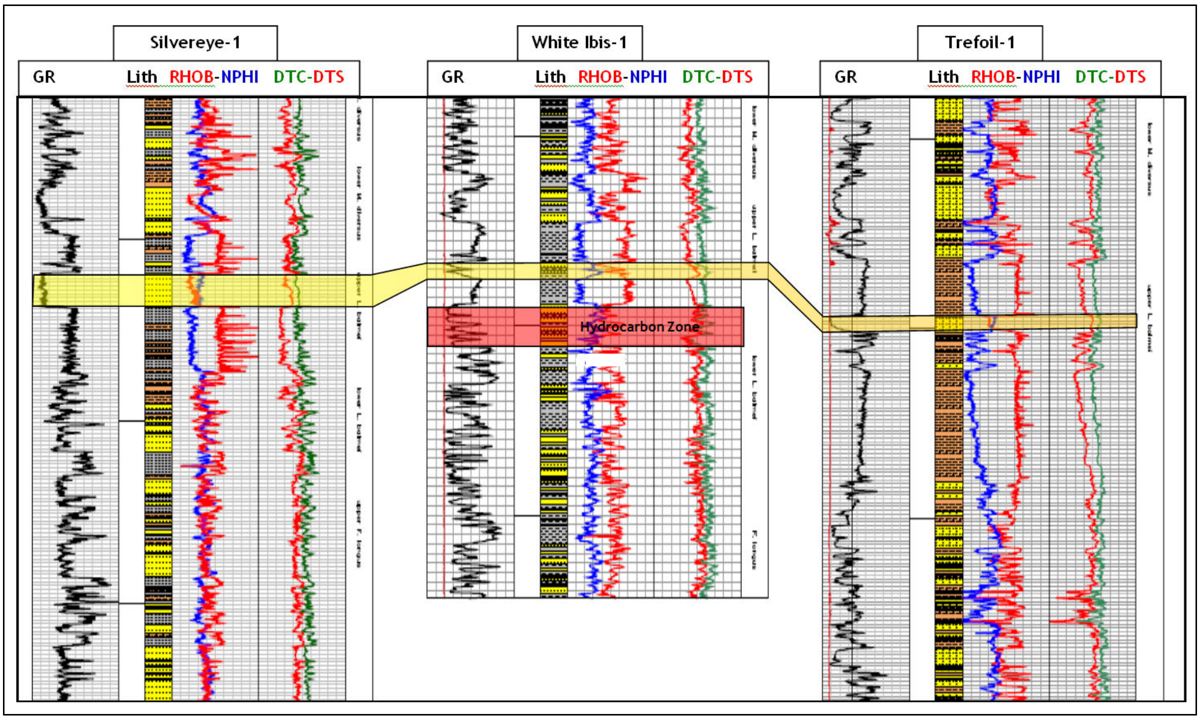

Figure 6. Well Log Correlation

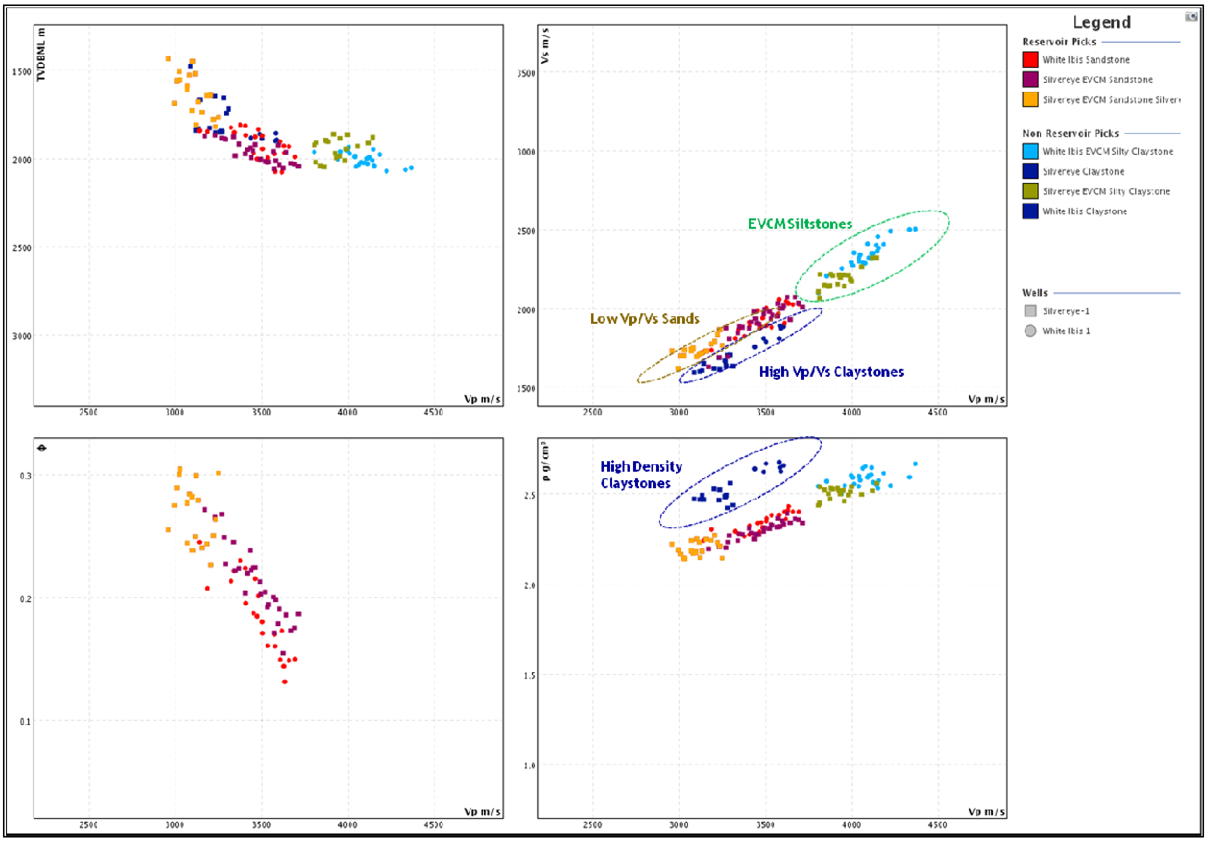

Figure 7: Picking of Rock Physics trends for White Ibis 1 and Silvereye 1. Claystones in both wells exhibit Low Vp, High Density and High Vp/Vs. Local variations in elastic properties have the potential to produce AVO 'false positives' such as that seen at Silvereye-1.

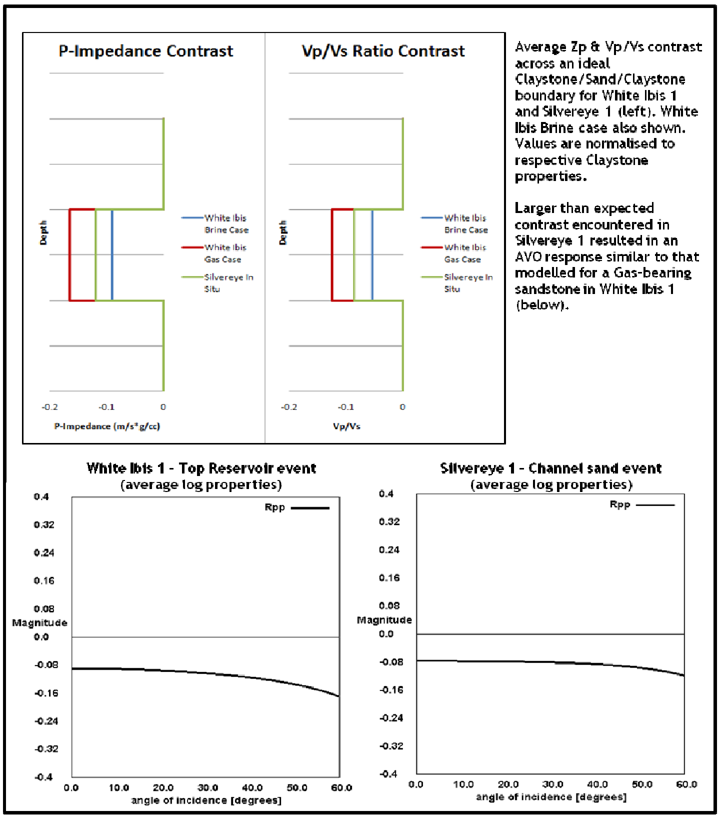

Figure 8. P-Impedance and Vp/Vs contrast for Claystone/Shale interfaces in White Ibis 1 and Silvereye 1 wells. Values are derived from average log properties over the target interval. Zoeppritz-derived P-wave reflectivity is shown for each well.

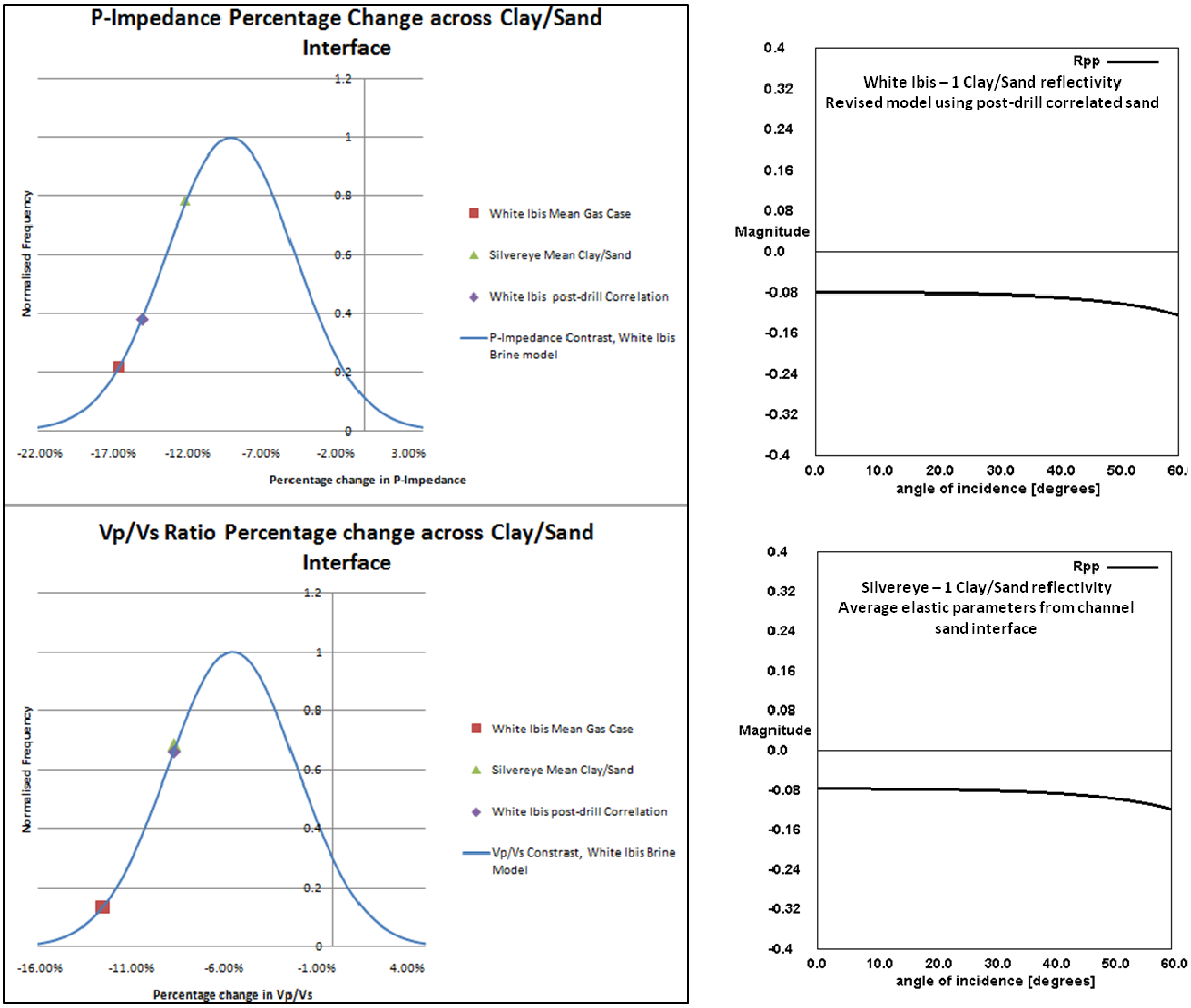

Figure 9. P-Impedance and Vp/Vs contrast shown as the percentage change across a Clay/Sand Interface. The Mean contrast is shown for White Ibis Gas-saturated logs, Silvereye-1 logs, and a revised White Ibis brine model using elastic parameters of the younger sand identified at the level of the post-drill correlation with Silvereye. The points are plotted on a normal distribution curve of expected contrast for the White Ibis-1 pre-drill brine model.