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Hydrocarbon Prospecting in Deepwater Trinidad Using AVO and Spectral Decomposition

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Abstract

Amplitude versus offset (AVO) and spectral decomposition (SD) techniques were used for direct hydrocarbon identification (DHI) in the Plio-pleistocene section in Deep Water Trinidad & Tobago to help to quantify better the risk during hydrocarbon prospecting. In order to understand and predict the seismic response for different fluid types and lithologies, AVO and SD modeling based on existing well log information close to the study area were performed. The controlled synthetic models simulated the seismic response for wet sands, commercially saturated gas sands, and partially saturated gas sands, as well as variations due to lithology. After modeling and validation of the technique with real pre-stack and post-stack seismic data on calibration well locations, seismic analysis supported with AVO and SD technologies was performed to evaluate prospects located in Deep Water in Trinidad & Tobago. Very subtle differences in the AVO and SD responses were the only way to discriminate between hydrocarbon and lithology. Very subtle variations during AVO and SD analysis suggest that the lithology factor can produce false DHI in the area. SD also showed the potential of helping separate fully saturated gas sands from partially saturated gas sands.

Introduction

The use of amplitude versus offset (AVO) and spectral decomposition (SD) techniques for direct hydrocarbon identification (DHI) in the Plio-pleistocene section in Deep Water Trinidad & Tobago can help to quantify better the risk during hydrocarbon prospecting. These seismic technologies require the use of pre-stack and post-stack seismic data that has been processed for preserving relative amplitude and frequency spectrum. In order to understand and predict the seismic response for different fluid types and lithologies, AVO and SD modeling based on existing well log information close to the study area was performed. The controlled synthetic models simulated the seismic response for wet sands, commercially saturated gas sands, and partially saturated gas sands, as well as variations due to lithology. The fluid substitution was performed using Gassman's equation after proper petrophysical analysis and invasion/dispersion corrections were done on the well data.

Petrophysics and Fluid Replacement

Invasion and dispersion corrections were applied to the well log data previous to fluid replacement. Fluid replacement was performed using Gassman's equation to simulate the fluid and saturation effect on the well log response on the P-Wave Velocity, Density and S-Wave Velocity due to the presence of brine, partially saturated and full gas sand cases. The resultant fluid replacement log responses are shown in figure 1. Figure 2 shows a sketch of the expected response for P-Wave Velocity, Density, S-Wave Velocity, Poisson Ratio and Acoustic Impedance for the same fluid cases.

The differences in the petrophysical properties between wet sands, commercially saturated gas sands and partially saturated gas sands (non-commercial) indicated that it is possible to separate them under ideal circumstances.

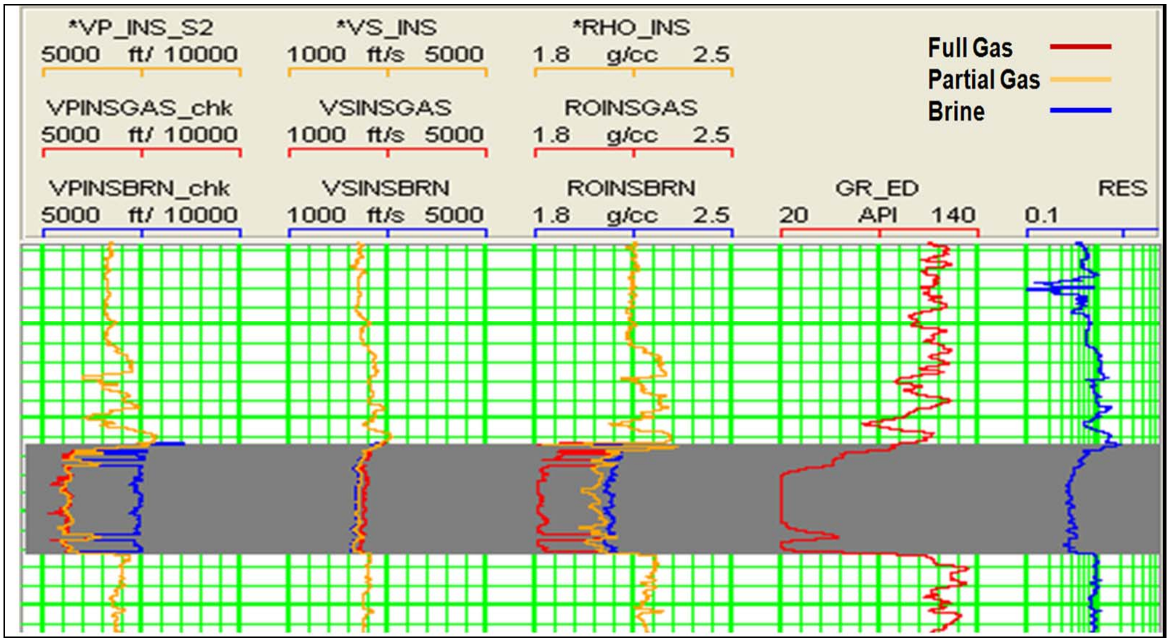

Figure 1: Fluid replacement results. The effect of the fluid type and saturation changes the well log response. Track 1 shows Vp or P-wave velocity, track 2 is Rhob or density and track 3 is Vs or S-wave velocity. In the first 3 tracks: Red, orange and blue colors represent log response for full gas, partial gas sand and wet sand. The GR is displayed in track 4 and the in situ resistivity in track 5. Notice that the in situ case is equivalent to the partial gas saturation case.

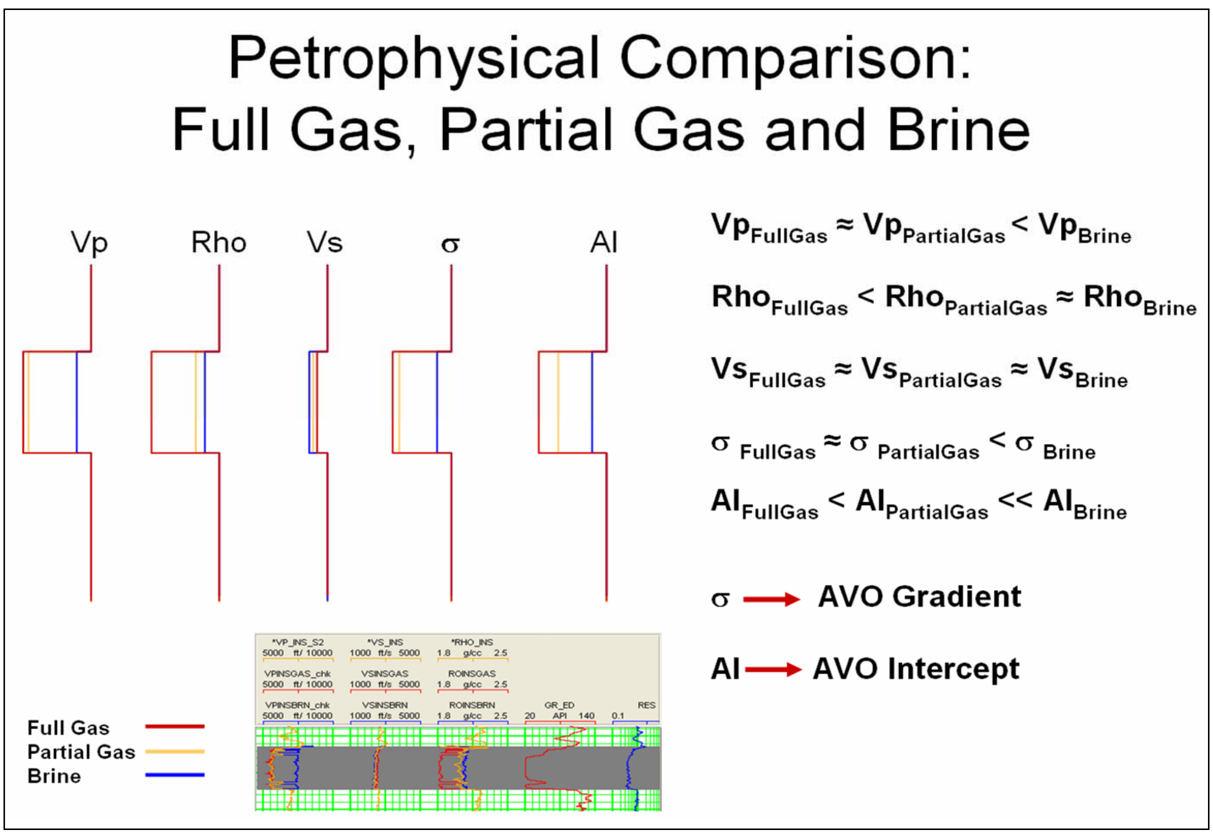

Figure 2: Sketch showing petrophysical properties for sand filled with different fluid types. Vp = P-wave velocity, Rhob is density, Vs is S-wave velocity, next track is Poisson's ratio and AI is impedance. Red, orange and blue colors represent log response for full gas, partial gas sand and wet sand. The bottom part is an insertion of figure 1 that shows the data used to generate the sketch.

AVO and Spectral Modeling

The fluid replacement results were used to generate synthetic seismic models. Analysis of the results indicated that hydrocarbon identification was possible and the typical AVO and SD response for hydrocarbons for sands close or above tuning was class III and class IV.

Figure 3 shows the AVO and SD synthetic seismic models for brine, partially saturated gas and full gas sand cases. The offset gathers (Gathers) were calculated using Zoeppritz's equation. Angle stacks (Stacks) from 0 degree to 30 degrees were calculated for each synthetic model. SD was performed on the stack sections using exponential pursuit decomposition (EPD) a variation of matching pursuit technique (Castagna, 2006).

In figure 3 the amplitude extraction over the synthetic gathers shows the potential to differentiate hydrocarbon from brine using AVO. Very distinctive intercept and gradient amplitudes separate the brine case from the hydrocarbon cases. The separation between the partial gas case and the full gas case is relatively small in the conventional stack and gathers analysis.

The spectral decomposition results observed in the synthetic frequency gathers confirms also that it is easy to separate brine from hydrocarbon and that there is important overlap between the spectral response of the partial gas and full gas cases; however the synthetic models in figure 3 show a significant difference in the high frequency part of the spectrum for the partial gas and the full gas cases. The bandwidth of the full gas case is wider when compared to the bandwidth of the partial gas case. It is also observed that the high frequencies are boosted in the full gas case. It is important to clarify that the thickness of the reservoir is the same for the synthetic models and the only variable changing is the water/gas saturation. Even the velocity of the partial gas and the full gas are similar, reducing the time/depth conversion difference between the full and partial gas cases.

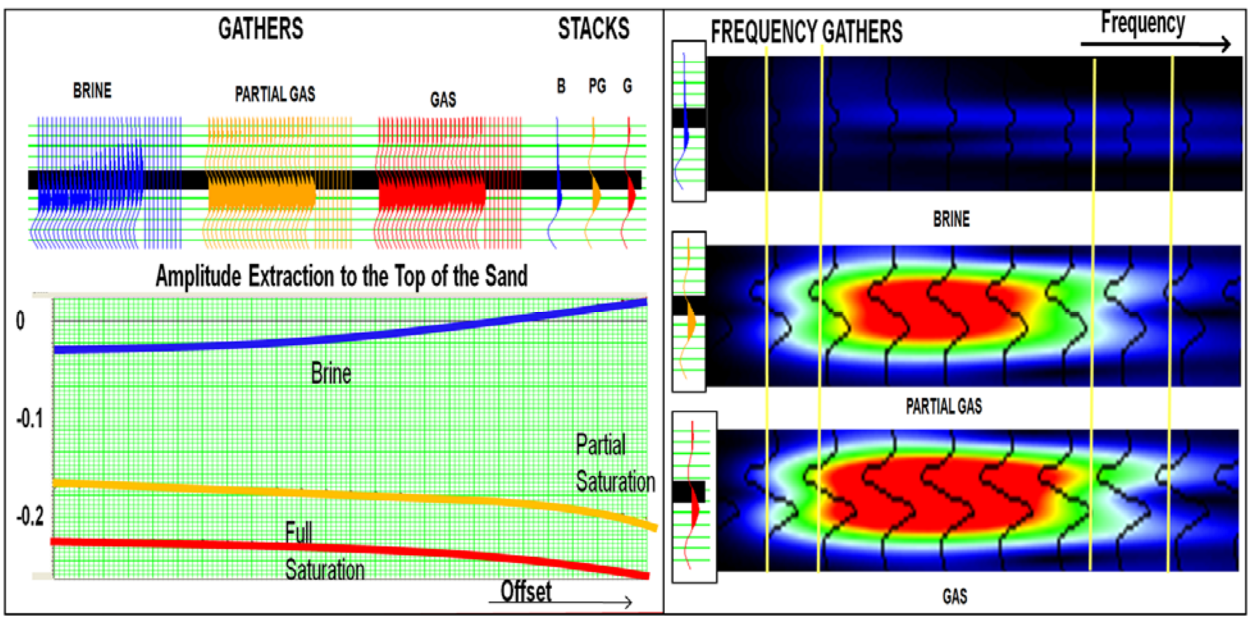

Figure 3: AVO and Spectral Modeling: to Simulate Effect of Different Fluid Types and Saturation Seismic. Gathers show AVO response for sand filled with different fluid types. Stacks show amplitude response for sand filled with different fluid types. Amplitude extraction on the top of the sand is shown. Spectral Gathers show the spectral decomposition results for the stacks for the different fluid types. The overlayed trace in the frequency gather represents the actual stack trace repeated. Red, orange and blue colors represent the response for full gas, partial gas sand and wet sand.

Analysis of the differences observed in the synthetic AVO and SD seismic modeling for wet sands, commercially saturated gas sands and partially saturated gas sands (non-commercial) indicated that it is possible to separate them under ideal circumstances.

Validation in Area with Well Control

After modeling, validation of the techniques with real pre-stack and post-stack seismic data on calibration well locations was performed.

Previously drilled amplitude anomalies were verified with AVO and SD using the criteria learned during the modeling. It was concluded that some of the anomalies had the right AVO and SD response for hydrocarbon but others had misleading AVO and SD responses that are more typical to lithologycal variation than to fluid effect.

During the reevaluation of the previously drilled prospects it was found that not all of the post stack amplitude anomalies drilled had commercial hydrocarbon and several of them had amplitudes related to lithology. Very subtle differences in the AVO and SD responses were the only way to discriminate between hydrocarbon and lithology, which make the AVO and SD analysis more complex and the inclusion of other criteria as pressure information and geological knowledge may be required to discriminate between “good” hydrocarbon anomalies and the “bad” ones.

Figure 4 shows the AVO and SD analysis in two anomalies drilled by one of the calibration wells. AVO response in both cases indicated the presence of hydrocarbon; however the spectral response for the fully saturated gas sand (sand A) is distinctive to the partially saturated sand (sand B). The amplitude spectrum in the full gas case is wider and the high frequencies are boosted while the partially saturated gas sand shows bright spectral amplitude but the width of the amplitude spectrum is comparable to the bandwidth of the background. The distinctive boosted high frequency pattern for the fully saturated gas sand has also been observed in other basins, including Gulf of Mexico, however at this point it is only a generalized observation and in the literature a detailed explanation of the phenomenon has not been reported. The phenomenon occurs right at the reflection associated with hydrocarbon and it is very different to the well documented attenuation phenomenon typically observed below gas reservoirs. The phenomenon observed is opposite to attenuation since the gas produces a boost of the high frequencies instead of a decrease of the high frequencies (attenuation below a gas sand).

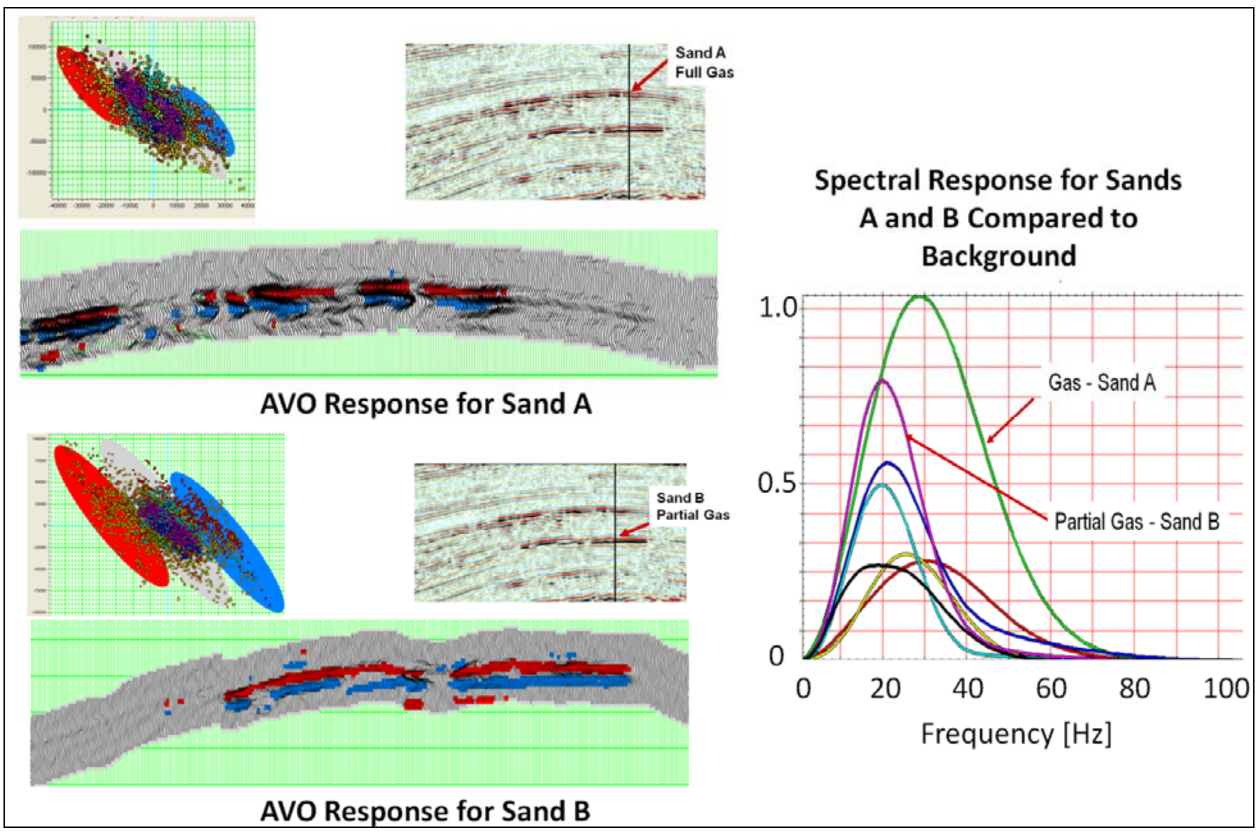

Figure 4: AVO and Spectral Analysis in Calibration Area. AVO crosplotting technique identifies clearly the presence of gas in the area. The spectral response for the fully saturated gas sand (sand A) shows a spectral response different to the response of the partially gas sand (sand B). The spectral response in the full gas case is wider in bandwidth while the spectrum (bandwidth) of the partially saturated gas sand (Sand B) is more comparable to the background.

Detailed analysis of AVO and SD in the calibration area helped to identify wet sands, commercially saturated gas sands and partially saturated gas sands (non-commercial). The same SD pattern response that differentiated the full gas sand from the partial gas sand observed in the modeling was also observed in the two anomalies shown in figure 4. The pattern of higher and wider bandwidth of the frequency response for the full gas sand when compared to the partial gas sand has also been observed in other areas.

Prospect Exploration Risking in Area without Well Control

After good understanding of the petrophysical properties and analysis in a calibrated area, seismic analysis supported with AVO and SD technologies was performed to risk prospects located in Deep Water in Trinidad & Tobago.

Many anomalies related to lithology were observed and discarded using the technique. The risking process gave less risk to the anomalies with similar AVO and SD to the fully saturated gas sand response modeled and validated in the area with wells. Mid risk was assigned to anomalies that only showed good AVO response but with SD response similar to the one observed in the partial saturation case modeled and validated. The higher risk was assigned to anomalies that did have neither positive AVO response nor positive SD response for full saturation gas case modeled and validated.

Figure 5 show a line with a series of amplitude anomalies observed in the conventional seismic. After detailed AVO and SD analysis the main anomalies were ranked based on the AVO and SD signature. The anomalies highlighted in orange are considered as high risk anomalies and in many cases they show a positive AVO response but a poor SD response for hydrocarbon. The anomalies highlighted in green, show less risk than the ones in orange because they not only show a good AVO response but also show good SD for hydrocarbon. Geological criteria are also used while defining the risk of the anomalies.

It was also observed that many AVO and SD anomalies can be produced by lithology and can be interpreted wrongly as DHI.

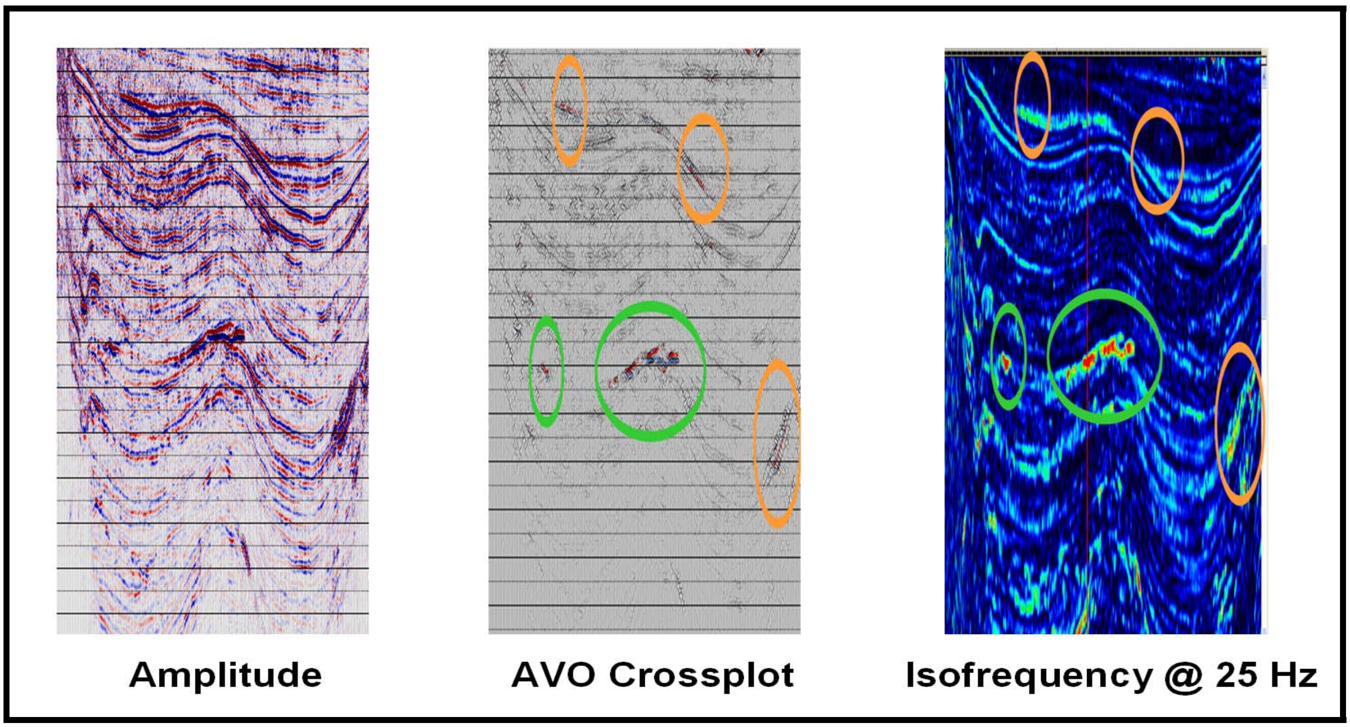

Figure 5: Comparison of conventional seismic amplitudes, AVO crossplot anomalies and isofrequency response at 25 Hz. Several anomalies are observed in the conventional section. Only few anomalies are highlighted in the AVO crossplot section. Integration with SD data helped to risk the anomalies. The anomalies circled in orange are considered anomalies of mid-high risk because the SD response is not the predicted for hydrocarbon. The anomalies highlighted in green were ranked with lower risk because show the expected AVO and spectral signature for hydrocarbon.

AVO and SD analysis in the exploratory area helped to assess the risk of the different anomalies. Anomalies with modeled and validated AVO and SD response for fully saturated gas sand were ranked higher than the anomalies with only AVO. Many anomalies with bright amplitude in the stack section were discarded since they had the wrong AVO response and SD response for hydrocarbon.

Conclusions

A methodology is proposed to evaluate exploratory areas using AVO and SD. Petrophysical analysis, fluid replacement, AVO and SD modeling, validation in area with well control were performed before detailed seismic analysis of the AVO and SD responses was done in the exploratory area. Petrophysical analysis and fluid substitution results demonstrated that very distinctive well logs responses are observed for wet sand, partially saturated gas sand and fully saturated gas sands in the studied area. Petrophysically it was predicted that hydrocarbon identification was possible.

Synthetic AVO and SD models for different fluid types and saturations indicate that fluid prediction is possible with AVO and Spectral Decomposition. The typical AVO response in the study area is expected to be type III and IV. Discrimination of wet sands from gas filled sand was possible with AVO and SD in the calibration area and discrimination of fully saturated gas sand from partially saturated gas sand was possible with SD in the calibration area. In general, the bandwidth of SD response for fully saturated sands is wider than the wet and partially saturated sands; this helped to risk the existing AVO anomalies in a different way.

In the exploratory area, lower risk was assigned to the anomalies with positive AVO and SD responses for hydrocarbon, mid risk was assigned to anomalies with only AVO anomaly and higher risk was assigned to the anomalies with negative AVO and SD response. Geological risk was also included during the evaluation.

Acknowledgments

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