MAPPING OF RESERVOIR SANDS USING SEISMIC ATTRIBUTES AND POST STACK SEISMIC INVERSION IN NAM CON SON BASIN OFFSHORE VIETNAM

Huong Ngoc Dao*

Petroleum Geoscience Program, Department of Geology, Faculty of Science,
Chulalongkorn University, Bangkok 10330, Thailand
*Corresponding author email: ngochuong202@gmail.com

Abstract

The study area lies within the Nam Con Son Basin located in East Sea offshore Vietnam. The reservoirs in the study area are Middle Miocene clastics of deep marine origin. The reservoirs are heterogeneously distributed and distribution of the reservoirs is further complicated due to complex extensional fault system. Therefore mapping of these reservoirs is difficult based on seismic data. The purpose of this study is to apply rock physic analysis, seismic attributes and post-stack seismic inversion to map sand geometries and hydrocarbon zones. According to rock physics analysis, P-impedance of shale is less than the sand, and the presence of gas within sand reduces the P-impedance. Therefore P-impedance of gas sands and wet sands is different. However, P-impedance of shale and gas sand may partially overlap within the larger interval. Hence, by the analyze P-impedance within the narrow zone of the reservoir we may successfully map the gas sands and differentiate gas sands and wet sands. The extracted P-impedance horizon slice along inverted P-impedance volume successfully mapped the gas sand distribution. RMS attribute shows high amplitude along gas saturation zone. Low-frequency amplitude anomalies obtained from spectral decomposition indicates high value at well with high gas percentage, whereas at the well with a low proportion of gas, it does not show high amplitude. Thus, the combination of spectral decomposition and seismic inversion may successfully map hydrocarbon distribution. The fault blocks which are close to the high structure has relatively more sand. The proposed workflow for mapping sand and gas sand can be used for the further well drilling programs.

Keywords: Gas sand, P-impedance, post-stack seismic inversion, spectral decomposition low frequency

1. Introduction

The study area is located in Nam Con Son Basin in the Southeast of Vietnam (Figure 1).The main reservoirs in this basin are Miocene clastics, ranging from continental deltas to deep marine turbidites, and high-quality Miocene carbonates (Liem, 2013).The present study is focused on turbidite sandstones which have complex architectures and geometries. The distribution of these sands is further complicated due to the extensional fault system. The prediction of these reservoirs and hydrocarbon bearing sands is difficult to assess based on conventional seismic data. Therefore, it is critical to propose a workflow for the prediction of sand geometries and hydrocarbon zones. In this study, I analyzed 3D seismic data and applied rock physics analysis, seismic attributes (RMS & spectral decomposition) and post-stack seismic inversion for the prediction of lithologies and hydrocarbon zones. Incoherence attribute was applied to improvethe imaging of the fault systems within the area.

2. Methodology

Rock physics analysis

Rock physics analysis aims to determine

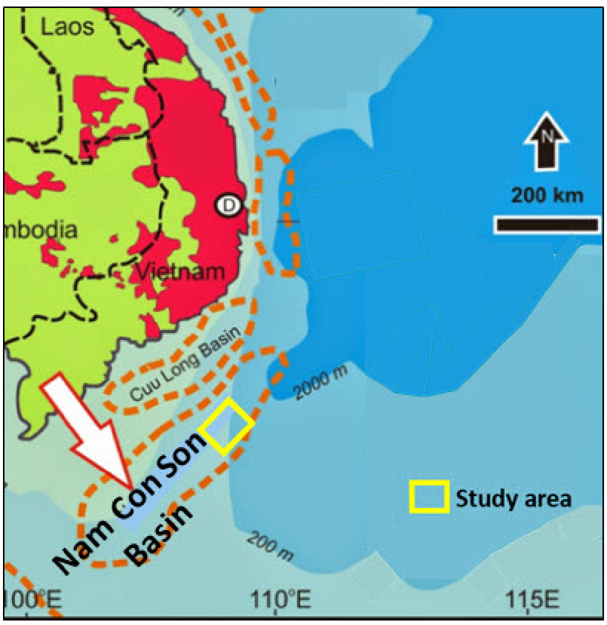

Figure 1. Location of the study area in offshore Vietnam.

the rock properties. Cross plot of acoustic impedance density and velocity were plotted with respect to shale volume and water saturation to determine the rock physics parameters that best distinguish lithology or fluids. These cross-plots were also analyzed as a function of depth to check the depth dependence of rock physical parameters. The well logs were up-scaled to the seismic data before carry out the inversion process to provide an initial input seismic model for the inversion process, and to compare inversion result with logs at the same vertical resolution. The sand reservoir is defined by using shale volume cut-off is 40% whereas the cut-off of water saturation is less than 40%.

Seismic attributes analysis

The RMS attribute proves particularly useful when values run through the positive and negative domain like in sinusoids or seismic traces. Hence it emphasizes the variations in acoustic impedance over a selected sample interval. The time window for RMS attribute map computation was selected depending upon the thickness of sands. Spectral decomposition of seismic data is a mathematical tool for transforming seismic data from time domain to frequency domain. Low-frequency zone, associated with the presence of hydrocarbon, provide useful information for reservoir characterization (Castagna, 2003).The data was spectrally decomposed from 11 Hz to 32 Hz at an interval of 2 Hz. The objective of spectral decomposition is to check the response of gas sands at iso-frequency sections for hydrocarbon prediction.

Seismic post-stack inversion

Seismic inversion is a technique that has been used to transform seismic data into acoustic impedance, which is then used to make predictions about lithology and fluid distribution (Dubey, 2012). In the first phase, the initial background model was created by using impedance logs of wells. In the second phase P-impedance volume was computed using initial low-frequency model, known wavelet, and full stack seismic data.As seismic data is band limited, it is devoid of low frequencies. The low frequency was added by using initial low-frequency model. In this study, the wavelet was extracted for the zones of interest using available well and seismic data. The final inversion result, therefore, relies on the seismic data as well as on the additional information of the well data.

3. Results and interpretations

Rock physics analysis

Based on the cross plot of GR and the acoustic impedance of the complete well it is inferred that the acoustic impedance is depth dependent. Acoustic impedance is relatively high at a deeper level. Because of this depth dependency, different lithologies may have the same acoustic impedance within the larger interval. However, acoustic impedance and GR has an inverse linear relationship within the narrow intervals of 100m (Figure 2). The presence of gas reduces the acoustic impedance of the sands. Therefore acoustic impedance can be used in narrow intervals to predict hydrocarbon distribution within the study area.

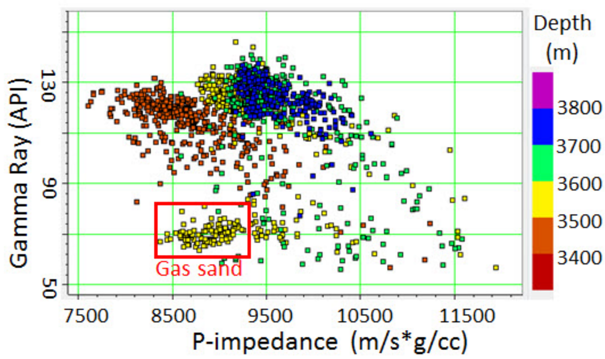

Figure 2. Cross plot of P-impedance and Gamma Ray colored by depth for well HDN-3X (B): In each 100m depth interval P-impedance increases from shale to sand. Gas sands shows low P-impedance.

Vertical section of different logs for depth interval 3550 - 3650m consisted of gas sands is shown in Figure 3. Within the gas sand interval, the P-impedance of gas sands is in the range of8500-9200 (m/s*g/cc) while the P-impedance of low gas saturation sands ranges from 9200-10000 (m/s*g/cc) (Figure 4). The acoustic impedance f wet sand is significantly higher than shale.However due to the presence of a low percentage of hydrocarbons in sand, the acoustic impedance of reservoir sands reduces and becomes similar to that of shale and less than that of wet sand. The density of sand is less than shale, but there are some points, which show high density and low gamma ray, these may be due to the presence of carbonate cement in sands (Figure 5). On the vertical logs section, these points show low GR, high density and high P-wave velocity. The density of gas sand decreases to 2.3-2.4 (g/cc) which is less than wet sand and shale

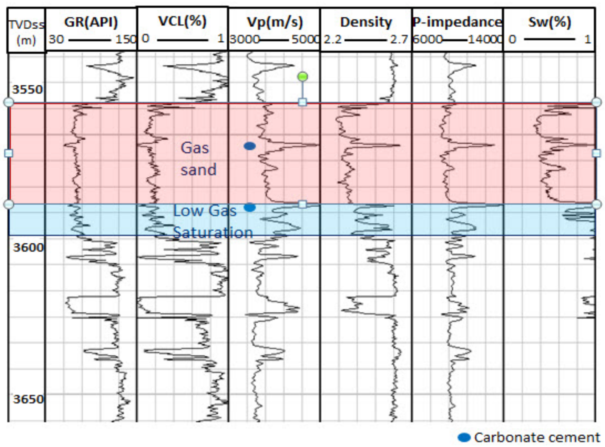

Figure 3. Well logs data comprising gamma ray (GR), shale volume (Vsh), P-wave (Vp), density, computed acoustic impedance and water saturation for depth interval 3550-3650m at well HDN-3X.

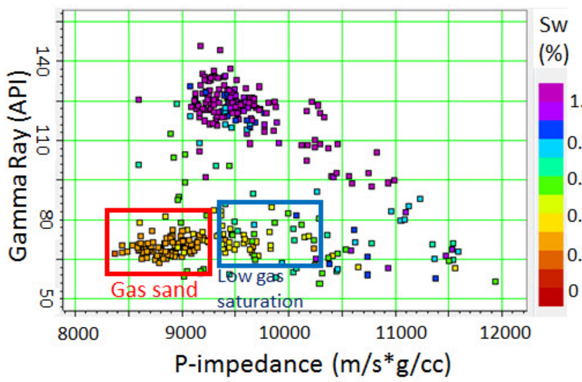

Figure 4. Cross plot of P-impedance and Gamma Ray colored by shale volume in depth interval 3550-3650m.

Seismic attributes analysis

RMS attribute was calculated for determining sand reservoir distribution by using 22ms time window that is equivalent to 45m thickness of reservoir interval (Figure 6). On the RMS attribute map, observed high amplitude corresponds to gas sand at the well locations. Therefore, the high amplitude in this area represents gas sand distribution (Figure 14). The high values were observed mostly near both the drilled wells within the structural closure.

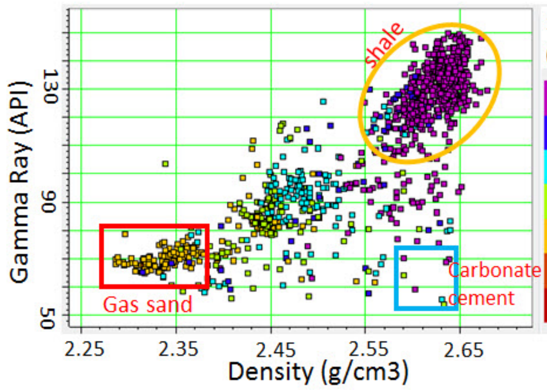

Figure 5. Cross plot of Gamma Ray and Density colored by shale volume (A) and colored by water saturation (B) in depth interval 3550-3650m.

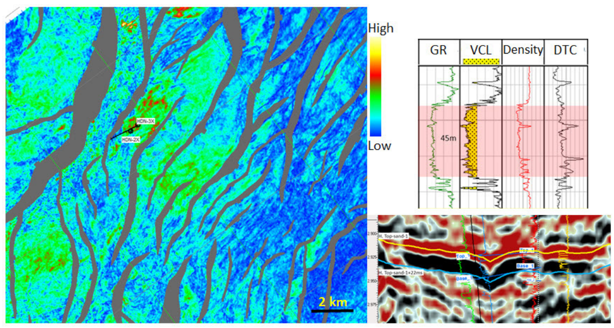

Figure 6. The RMS amplitude map of Horizontop-sand1. The well logs show the RMS window range (red zone) covered in well HDN-3X and the seismic section along well bores.

Different low frequencies were tried to observe the gas response of the reservoir. At 19Hz the gas sands indicated brighter amplitude (Figure 7). The low frequency map can also be used for the prediction of gas sand. The high amplitude matched with gas sand at the well location. The well HDN-3X is within the high amplitude, and this well has gas at this level. Whereas well HDN-2X is plotted within the low amplitude and it is reported only low gas saturation. Hence, low-frequency spectral decomposition anomalies can provide useful information for identification of gas zones.

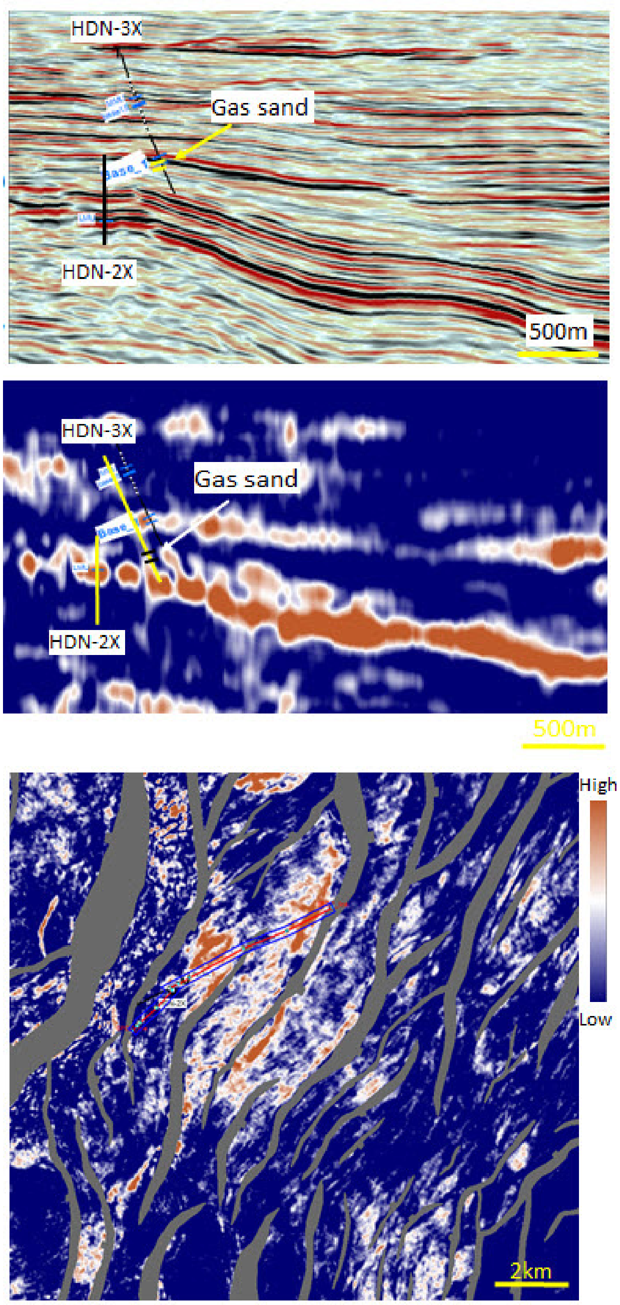

Figure 7. The low- frequency sections are corresponding to the seismic section. A) full stack seismic section B) low- frequency section at19Hz, C) spectral decomposition map of the horizon of top-sand 1 at 19Hz.

Seismic post-stack inversion

The comparison of extracted pseudo logs from P-impedance volume at two well locations shows a reasonable match with original P-impedance logs. The P-impedance correlation values are more than 90% within the target zone (Figure 8).

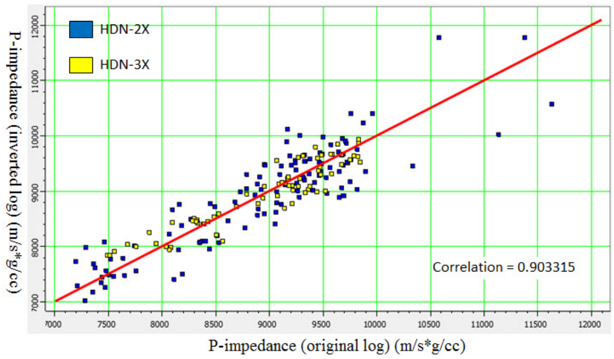

Figure 8. The linear relationship in good correlation in P-impedance of original logs and inverted logs.

The results of inverted P-impedance volume with original P-impedance logs and GR logs at both well locations. The logs were resampled to seismic scale. In general, there is good agreement between P-impedance logs and the P-impedance derived from the inversion volume in the zone of interest. The depth interval of 3550-3650m consists of gas sand, the P-impedance of gas sand matches with inverted P-impedance of seismic volume (Figure 9). Therefore gas sand thickness can be detected on inverted volume. The lower part of the reservoir has high P-impedance, which shows low gas percentage. In log data, low gas saturation can clearly be observed on the vertical logs. Figure 9 shows thin sand bed of 8m (at time 2950ms) which is below the tuning thickness. Therefore, this may not be predictable by the inverted volume. That is why there is a discrepancy of P-impedance of log data and inverted volume. Similarly in well HDN-2X at some places, P-impedance is not matching with the original log P-impedance, especially within the low gas saturation zone. The P-impedance on inverted volume is low, but the original log shows high values. It may be due to low gas saturation effect on seismic amplitudes

The extracted P-impedance horizon slice along phantom horizon Top-sand 1 + 8ms. This horizon is shifted 8ms downward from interpreted top of gas sand interval. The low value of inverted P-impedance along this horizon

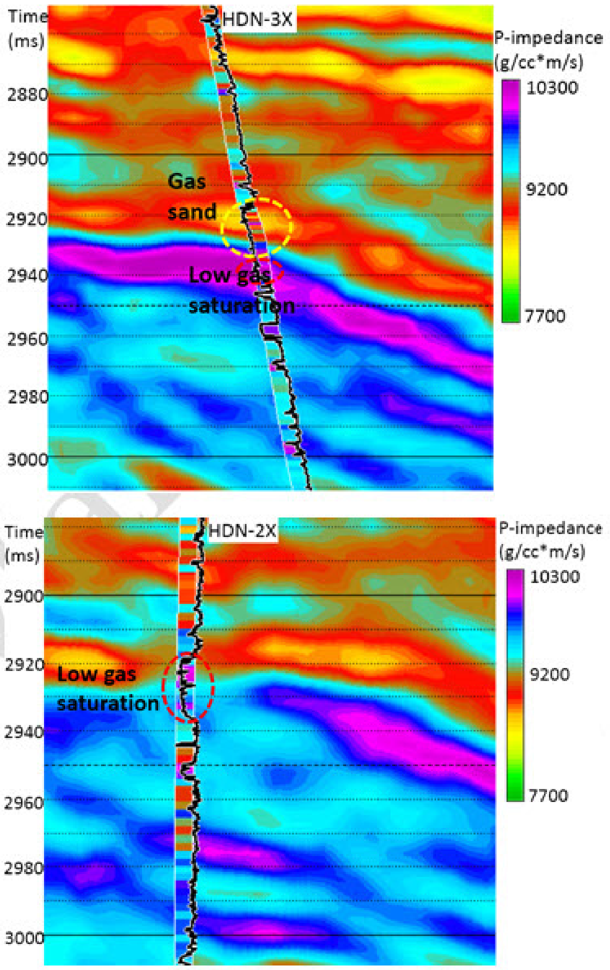

Figure 9. P-impedance generated using model-based inversion at A) well HDN-2X and B) well HDN-3X. The logs curve displayed in cross-section is gamma ray (GR).

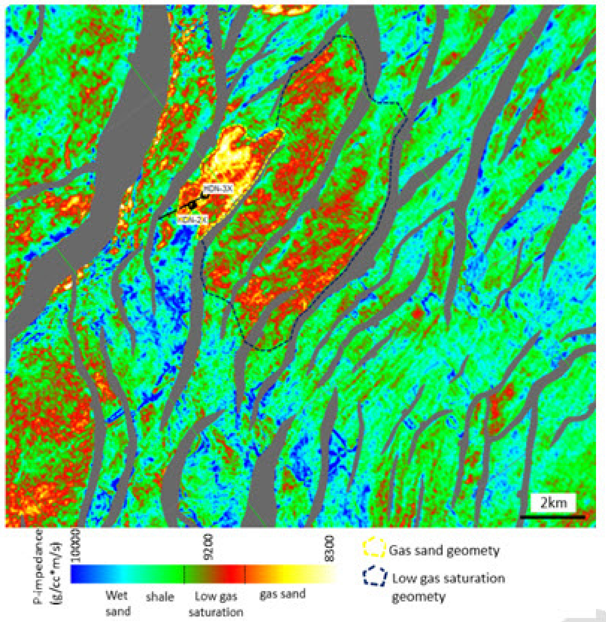

Figure 10. Horizon slice of inverted P-impedance volume extracted at phantom Horizon top-sand 1 + 8ms. Low P-impedance indicates gas sand.

slice represents the gas sand distribution. The gas-saturated zone is bounded by fault blocks and close to the drilled wells. The gas sand and low gas saturation sand geometries were estimated in Figure 10. The low gas saturation is distributed in two fault blocks next to gas saturated fault block.

Tectonic control on sedimentation

In general, the process of erosion, transport and sedimentation in the period Middle Miocene in the Nam Con Son basin is mainly controlled by gravity flow, which causes the slumping. According to the core report, the sands may represent a possible small-scale channel infill. The sediment supply for turbidity currents in the study area comes from the high structural platform near wells. The sediment moved down-from high platform area to downthrown sides of the fault due to extensional activity along the fault and erosional phenomenon. The zone of interest located in the syn-rift period, which includes a sequence deposited during active rifting, and thickness changes across the active faults, sediment on the fault footwalls may pass laterally into continuous sequences in the hanging walls. Figure 11 shows the effect of fault system on the lithology distribution.

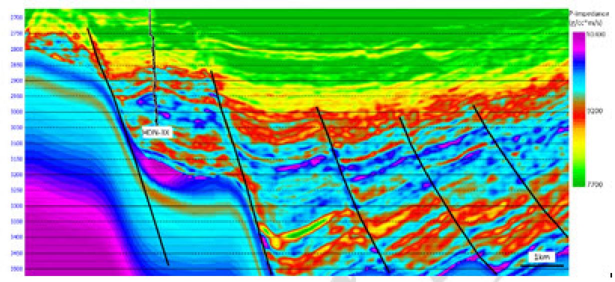

Figure 11: P-impedance cross section shows the effect of extensional fault system on the lithology distribution.

Comparison of seismic attributes and seismic inversion.

The gas sand distributions in the inversion section correspond to bright amplitudes on seismic section (Figure 11A and 11B). The boundary between higher and lower P-impedance in inverted volume matched with the formation top of reservoir sand, which is represented by a trough in seismic section. Amplitude spectra at low-frequency spectral decomposition indicate high amplitudes at gas sands. It shows bright amplitude at well HDN-3X and low amplitudes at well HDN-2X. The well HDN-3X has high gas saturated sands, whereas well HDN-2X has low gas saturation. Therefore, low-frequency spectral decomposition along with P-impedance inversion can be useful for hydrocarbon prediction and may help to reduce the uncertainty for gas sand prediction. RMS attribute map (Figure 6) shows bright amplitudes for gas sands and sands. These bright amplitudes are in the region of low P-impedance. RMS may be useful as a quick tool to observe the distribution of sands and gas sands in the area. However, RMS computation depends on window length that may not be appropriate for the variable thickness of sands. Moreover, it does not quantify the fluids and lithologies based on the well data.

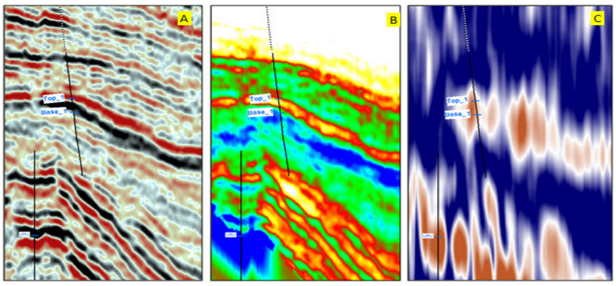

Figure 11. Comparison of full stack seismic data (A) with inverted acoustic impedance section (B) and low frequency (19Hz) spectral decomposition. The marker Top-1 is top of the gas sand, and Base-1 is the base of gas sand.

Recommendations

According to the rock physics analysis, the P-impedance of gas sand and low gas saturation partially overlap with P-impedance of shale in the zone of interest. Therefore the Post-stack seismic inversion have uncertainty in the interpretation of gas sand geometries and distribution.

Cross-plot of Vp/Vs and elastic impedance at 15o angle for both wells revealed that highly gas saturated sands can successfully be isolated (Figure 24). Therefore, simultaneous inversion or AVO analysis may be more appropriate for the prediction of gas sands.

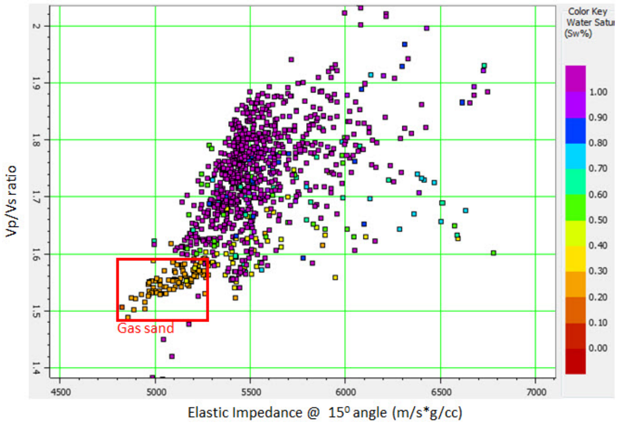

Figure 12. Cross plot of Vp/Vs ratio and Elastic Impedance at150 angle colored by water saturation.

4. Conclusions

Rock physics analysis, seismic attributes, and post-stack inversion were applied to define the distribution of sand reservoirs within the Middle Miocene depositional sequence of the Nam Con Son Basin. The main findings and conclusions are summarized below:

- Acoustic impedance depends on depth and lithology. Sands have higher acoustic impedance than the shale within the narrow depth interval zones of 100 m. The acoustic impedance of sands decreases due to the presence of gas. Hence acoustic impedance volume obtained from post-stack seismic inversion is useful for the identification of promising zones.
- High amplitude values represent the distribution of reservoir sands on the seismic attribute maps (RMS and spectral decomposition). Low-frequency (19 Hz) amplitude anomalies of spectral decomposition delineate high gas saturation zones. Thus low-frequency amplitude anomalies can be used as direct hydrocarbon indicator in the study area.
- Low acoustic impedance values were observed for gas sands on acoustic impedance horizon slices. Acoustic impedance values may not differentiate low gas saturation and shales in high accuracy. However, a high gas saturated sands

can be discriminated on the map from different lithologies and fluids. The acoustic impedance volume is effective for defining the thickness and boundary of the gas sands.
- The combination of acoustic impedance volume and low-frequency amplitude volume can provide value addition for reservoir characterization in the study area.

5. REFERENCES

Ahmad, M. N., 2013. Mapping of fluvial sand systems using rock physics analysis and simultaneous inversion for density: case study from the Gulf of Thailand.

Bouma, A. H., 2002. Geological reservoir characteristics of fine-grained turbidity systems.

Castagna, O., 2003. Instantaneous spectral analysis: Detection of low-frequency shadows associated with hydrocarbons.

Dangprasitthiporn, M., 2015. Lithology prediction using rock physics and acoustic impedance for reservoir distribution in Northern Pattani basin, Gulf of Thailand.M.Sc. Thesis, Chulalongkorn University.

Dubey, A. K., 2012. Reservoir characterization using AVO and seismic inversion techniques.

Gavotti, P. E., 2013. Post-stack inversion of the Hussar low frequency seismic data.

Liem, P. T., 2013. Some comments on the possibility of middle/late miocene-pliocene stratigraphic traps in the centre of nam coson basin.

Priyanto, B., 2012. Lithology prediction using rock physics analysis and seismic inversion within Miocene fluvial reservoir interval in the Songkhla basin, Gulf of Thailand. M.Sc. Thesis, Chulalongkorn University.

Rodriguez, J. M., 2009. Spectral decomposition and inversion: case study of a production area in the cook inlet basin, Alaska, USA.

Rotimi, O. J., Wang, Z., Ako, D.B., 2014. Seismic attribute utilization for structural pattern detection, fault imaging and prospect identification.

Willmore, D., Giao, N., Tin, N.T., Dung, L,V., 1991. Petroleum Geology and Hydrocarbon Potential of Nam Con Son Basin.

Singh, V., 2006. Acoustic to Elastic Impedance –A New Tool for Reservoir Characterization.

Swisi, A., 2009. Post- and Pre-stack attribute analysis and inversion of Blackfoot 3D seismic dataset.

Y, L., 2015. A rock physics model for the characterization of organic rich shale from elastic properties, Petroleum Science.