Prediction of Reservoir Sands by Using Rock Physics and Simultaneous Inversion: Case Study from the Pattani Basin, Gulf of Thailand

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Abstract

The study area is located at the southeastern edge of the Pattani Basin within the Gulf of Thailand. The reservoirs in this area are sands associated with fluvial systems and sands show rapid lateral and vertical changes. The study area is composed of two zones separated by regional fault. The western part is gas prone area and the eastern part is oil prone. This report presents workflow to predict sand distribution and to identify hydrocarbon reservoirs by using rock physics analysis and simultaneous inversion.

AVO modeling indicates that Class III and Class IV sands are dominant in the area. AVO analysis can discriminate gas and water-wet zones. However, it is not possible to differentiate low saturation and high saturation gas zones. Density is the most sensitive rock physics parameter for lithology identification. Combination of density and Vp/Vs can differentiate reservoir fluids within narrow depth range by establishing accurate cutoff based on rock physics analyses. Inverted density volume computed through pre-stack simultaneous inversion provides reasonable prediction for sand distribution in the area. Horizon slices of Vp/Vs can identify hydrocarbon zones within narrow depth range if appropriate cutoff is applied.

Low Vp/Vs and low-density anomalies within the high structure may be considered potential target for future exploration

Keywords: Pattani basin, Rock physics, Simultaneous Inversion, Sand distribution

1. Introduction

The rift basins in the Gulf of Thailand are major hydrocarbon producing areas of Thailand (Morey and Racey, 2005). The reservoirs in these basins are sands associated with fluvial systems, which are highly compartmentalized.

The rapid lateral stratigraphic changes due to fluvial depositional systems are primary factors causing this compartmentalization. Moreover, it is also required to differentiate different reservoir fluids. Most of the wells until now have been drilled on structures and it is common to find different lithological facies and reservoir fluids. Therefore, it is important to delineate sand bodies and hydrocarbon zones for field development programs.

I applied rock physics analysis and simultaneous inversion techniques to map reservoir sands and to detect hydrocarbon zones two fields of the Pattani basin within the Gulf of Thailand. The western fields and eastern are separated by a regional fault (Figure 1 and Figure 2) According to exploration well's data the area west of regional fault is gas prone and area east of the fault is oil prone. Therefore, it is critical to determine zones of oil and gas for further field development programs. Key objectives of my study are

1. Conduct rock physics analysis to determine lithology and fluid sensitive rock physics parameter.
2. Perform AVO analysis to identify different classes of reservoir sands and to evaluate AVO analysis for hydrocarbon detection in the area.
3. Conduct seismic inversion to map fluvial sands in the area.

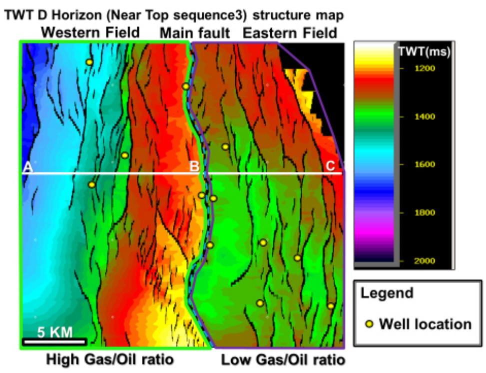

Figure 1 the regional time structure map(Top sequenc3) of this study area show the main fault is separate the study area to be eastern field and western field. ABC line show cross section in Figure 2.

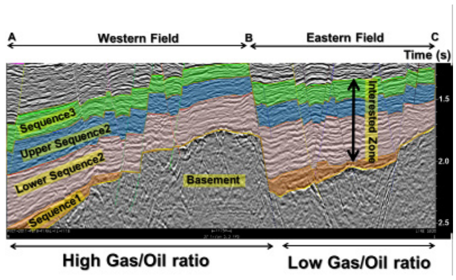

Figure 2 the regional seismic section along study are show the interested zone. The western field is gas porn area and the eastern field is oil prone area.

2. Methods

Rock physics

Cross-plots of P-velocity, S-velocity, Density, P impedance, S-impedance, Lambda rho, and Mu rho with respect to V-Shale and color coded by water saturation from six- good data quality wells was used to determine the physical parameters that may distinguish sand from shale and hydrocarbon sands from water-wet sands. Cross plots were also analyzed for depth intervals of 500 m and in each stratigraphic sequence.

AVO modeling

AVO modeling was done within two different clean sands in the shallow part. Fluid substitution by using Gassmann's equation (Gassmann, 1951) was done for both gas and oil cases. I created five sets of log curves for gas and oil at the interval of 20%.Angle synthetics were created by using Zoeppritz algorithm (Zoeppritz, 1919) from 5-55 degree for different curves computed through fluid substitution. The input of angle synthetics in every cases was analyzed by AVO gradient analysis by using three Term Aki-Richards (Aki, 1980) intercept/gradient/ curvature approach. Amplitude versus offset cross plot and gradient versus intercept cross plot were generated to define the class of AVO sand and fluid effect in each fluid content cases.

Inversion

Well to seismic ties were established for five wells to use them for inversion process. I performed two types of wavelet estimation that are Statistical wavelet estimation and Extracted wavelets along wells from three angle stacks. Low frequency Models for P-impedance and density was created by using five wells (A-07, A-10, A-11, B-03, and B-05) and four key horizons. Pre-stack simultaneous inversion was executed for P-impedance, S-impedance and density. I performed QC of inversion output volumes by comparing original log and inverted rock physics parameters at well locations. Comparison of logs and inverted rock physics parameters was performed at wells, which were not used for the inversion process. Comparison of GR log and water saturation curve was also performed with respect to different rock physics parameters.

3. Results

Rock physics

There are 3 main results in rock physic. Firstly, the P-impedance cannot discriminate clean sand (V-shale > 30%) from shale in some interval(Figure 3) while the density can discriminated sand from shale in all depth intervals(Figure 4). Moreover, Vp/Vs ratio is possible to discriminate very clean sand from shale in some interval. And

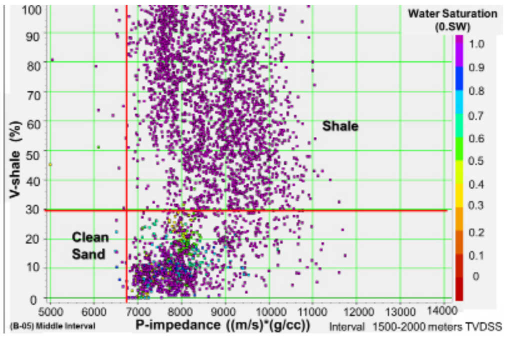

Figure 3 Cross-plot of P-impedance and V-shale of well B-05 color coded by water saturation. This cross-plot is from 1500 to 2000 meters TVDSS (Middle level).I show cleans sand data located in the same zone of shale data base on P-impedance.

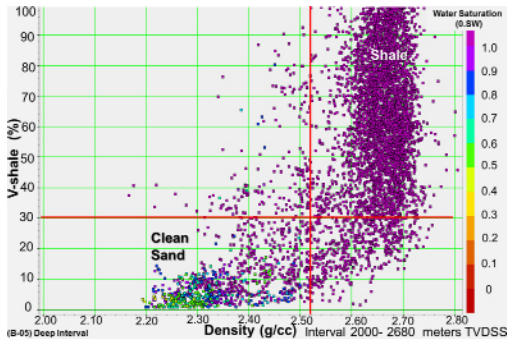

Figure 4 Cross-plot of Density and V-shale of well B-05 color coded by water saturation. This cross-plot is from 2000 to 2680 meters TVDSS (deep level).It show cleans sand zone located separately from shale zone base on density.

it possible to discriminated hydrocarbon in some interval partially in some interval also (Figure 5). The validation of lithology discrimination by density was show in the good relationship between sand zone in cross plot and low gamma ray zone in log (Figure 6).

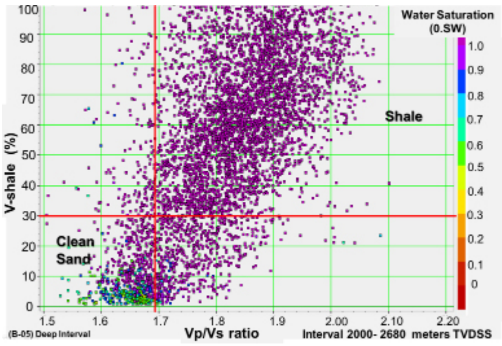

Figure 5 Cross-plot of Vp/Vs ratio and V-shale of well B-05 color coded by water saturation. This cross-plot is from 2000 to 2680 meters TVDSS (deep level).It show very cleans sand zone located separately from shale zone base on Vp/Vs ratio. Moreover, the low water saturation zone is located separately from high water saturation zone partially.

AVO modeling

The sample of shallow big clean sand show was testing in AVO model.

There are Class3 and Class4 sand were identified in the area base on amplitude versus offset cross plot. Moreover, 100% gas saturated sands and 100 % brine saturated sands can be discriminated based on AVO. (Figure 7)

While, Fluid substitution results show that 20 % gas saturated sands and 100% gas saturated sands are plotted close to each other. This means that economical and non-economical gas sands have similar AVO response (Figure 8). In the oil case is show the similar result also.

Density and Vp/Vs volume was generated. And There was analyzed the quality by using the cross correlation and blindest.

The good result of comparison between original log data and inverted

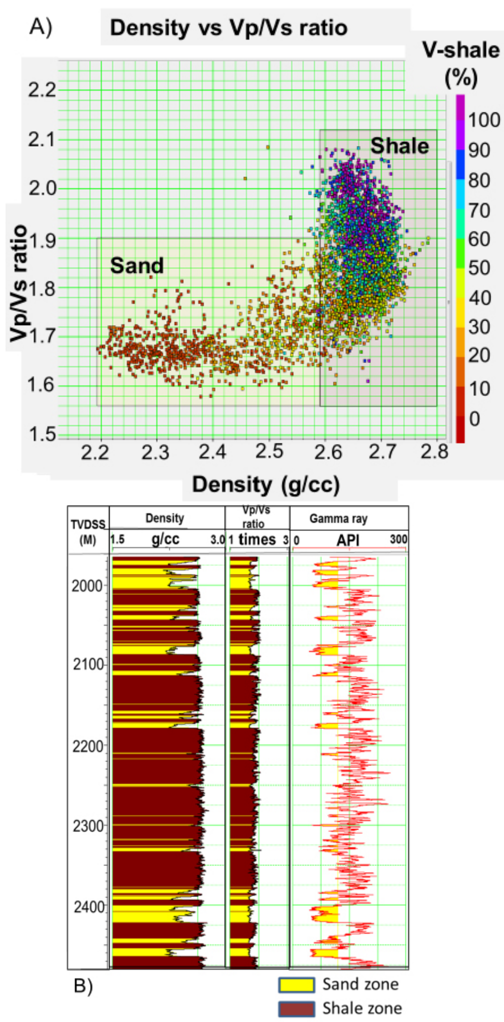

Figure 6 (A)Cross plot of Density and Vp/Vs color coded by V-shale in well B-05 from 2000-2500 m (TVDSS). (B) Lithologies are marked based on zone of cross plot. It show good correspond of sand and shale zone with low gama and high gamma respectively.

log data that density and Vp/Vs volume are 78.3% and 0.585% cross correlation co-efficeincence respectively(Figure 9). The wells are not using in the inversion process, were testing in blind test. It show the good result that the original density log correlated with the low-density zone in the density section (Figure 10A). Moreover, it shows the

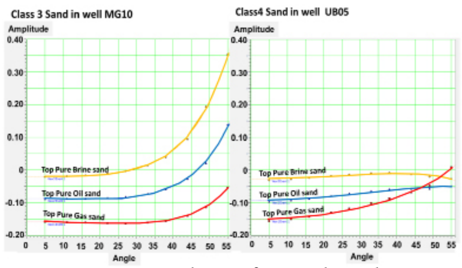

Figure 7 cross plot of amplitude versus angle, (Left) It shows this sand is the class3 sand due to top pure gas show negative interception and negative gradient. (Right) It shows this sand is the class4 sand due to top pure gas show negative interception and positive gradient (Castagna, 1988 and Avseth P, 2005).

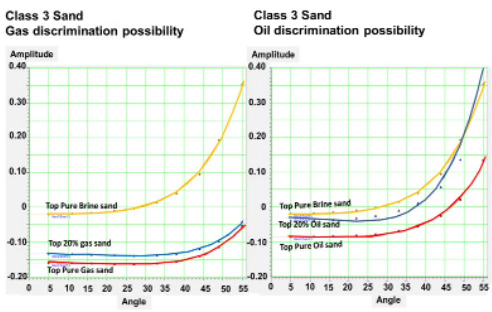

Figure 8 cross plot of amplitude versus angle in class 3 sand. (Left), It shows the top pure gas and 20% gas response similarly.(Right) Top pure oil, pure brine and 20% oil are similar response.

good relationship of low V-shale and low-density zone (Figure 10B). Both analysis shows that the inverted volumes is reasonable acceptable.

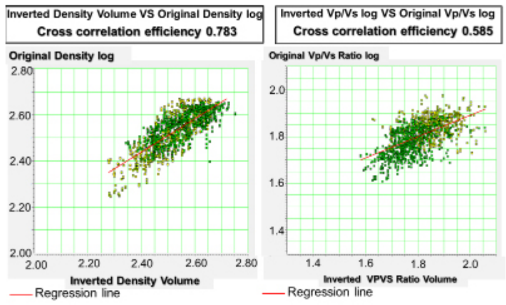

Figure 9 The cross plot between inverted density volume and original log data. (A) Density inverted volume show good correlation. (B) Vp/Vs ratio inverted volume show moderate correlation.

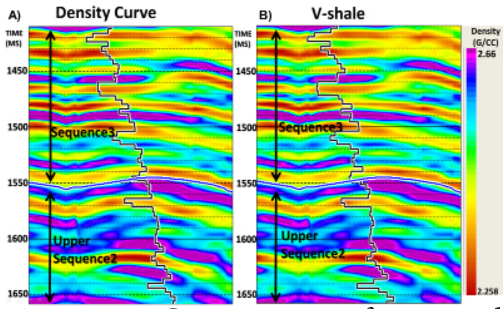

Figure 10 Comparison of inverted density section and density log in the upper part of well B-01. (A) log displayed in curve form. (B) displayed log is v-shale.

4. Discussion

Sand distribution

According to rock physics, the density cutoff for density discrimination for clean sand is 2.52 g/cc (Figure 11, Right).The Figure 11 displays the density horizons slice of O horizon+76ms within the lower sequence2 interval (lower Miocene). No large channel belt can be seen on this horizon slice, but we can observe three major sand distributions. In the northeastern side of western field, large clean sand body is located, while in the southern part we can only see small patch of sand. Moreover, on the enlarge view we can see relatively narrow channel belt (Figure 12). These channel belts are N-S trending.

Hydrocarbon distribution

Rock physics shows that reservoir fluids can be discriminated within narrow zone (depth and sequence basis).

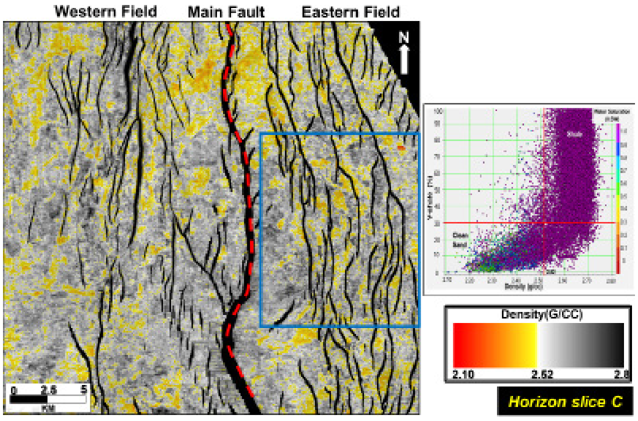

Figure 11 Density horizon slice with in lower sequence2 (extracted from O horizon + 72 ms) as shown. Cross plot within lower sequence 2 data shown on right side of the figure. It show density cutoff for clean sand at this level is 2.52 g/cc that applied to color bar of horizon slice. The blue box show the enlarge picture in Figure12A.

Figure 13 shows cross-plot of density and Vp/Vs. This figure illustrates that based on Vp/Vs ratio reservoir fluids can be differentiated. Gas has Vp/Vs less than 1.67 and Vp/Vs for oil is ranging from 1.67-1.76. These computed ratios are only valid for small interval in the range of 1700-1900 m (narrow zone in lower sequence2). For other depth intervals, we need to determine separate ranges, as Vp/Vs is variable with depth. Cutoff values of Vp/Vs were applied on O+176 ms horizon slice.

This horizon slice is located within narrow zone in lower sequence2 (1700-1900m at A-11). The horizon slice after applying cutoff for gas and oil shows that low Vp/Vs values (in the range of gas) are distributed within the western

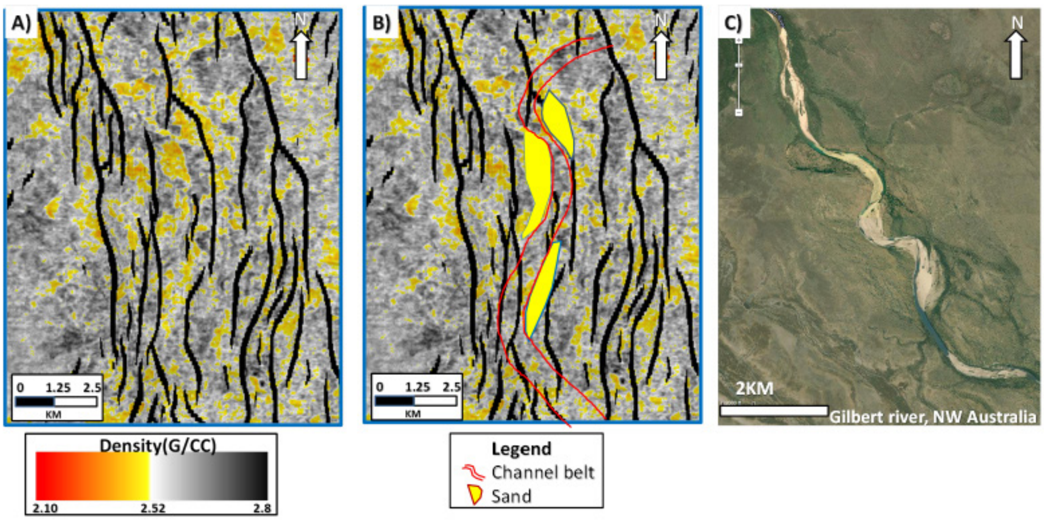

Figure 12 (A) This zoom picture of marked blue box base on Figure 92 (B) Interpretation of the low density value (C) Recent point bars in North west Australia as analog.

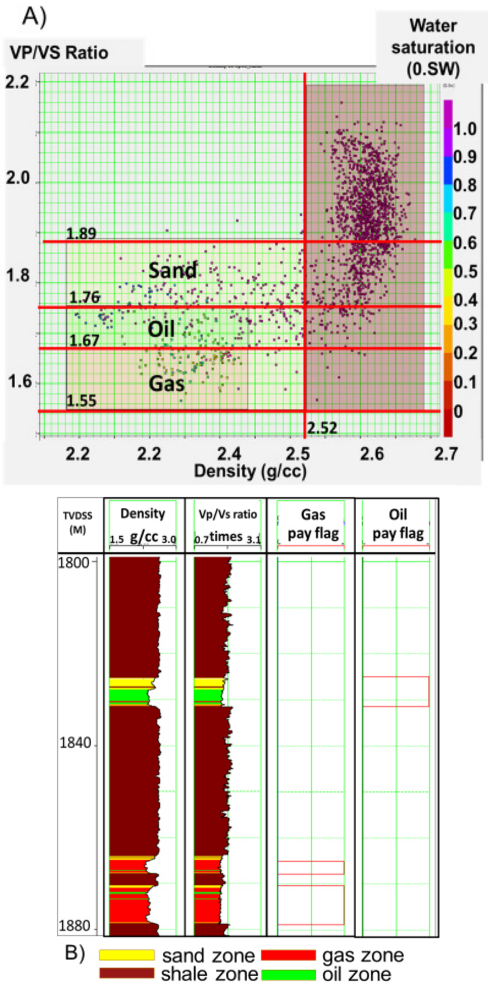

Figure 13 (A) Cross plot of Density and Vp/Vs color coded by water saturation in well A-11 from 1700-1900 m (TVDSS). (B) Fluids and Lithologies are marked based on zone of cross plot. It show good correspond of oil zone and gas zone with oil pay flag and gas pay flag respectively.

part of the area (Figure 14).
While in the eastern part of the area most of the low Vp/Vs values are in the range of oil. This predicted distribution of Vp/Vs is in comparison with data from exploration wells. Most exploration wells show gas in the western part and oil in the eastern part at this stratigraphic level (Figure 14).

Figure 15A shows the log data of one representative well in the gas prone area. Log data shows gas presence in low saturation. Figure 15B shows one representative well from oil prone area and this well is located on low Vp/Vs value (in the range of oil). Log data shows 50% of oil within this interval. Therefore, low anomalies of Vp/Vs may provide useful information for the prediction of hydrocarbons in the narrow zone.

However, care must be taken to establish cutoffs for different reservoir fluids at different depth levels. According to AVO modeling, it is not possible to differentiate between low percentage and high percentage of hydrocarbons as both are producing same response. We can discriminate water-wet sands and hydrocarbon saturated sands, but

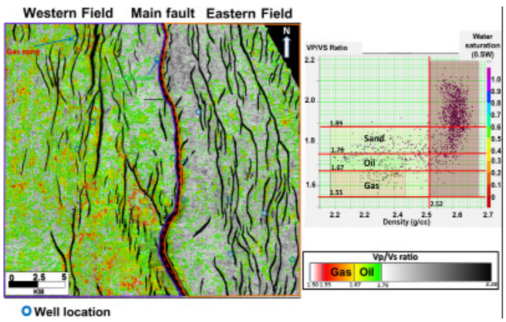

Figure 14 Vp/Vs ratio horizon slice extracted from O horizon + 176 ms shows possible hydrocarbon distribution along study area. Rock physics study shows the Vp/Vs cutoff of gas and oil are 1.55-1.67 and1.67-1.76 respectively. Gas zone (red color) and oil zone (green color) are proved by well data in Figure 15A, Figure 15B respectively.

cannot discriminate low and high hydrocarbon saturated zones. This makes impossible to differentiate economical and uneconomical hydrocarbon satu-

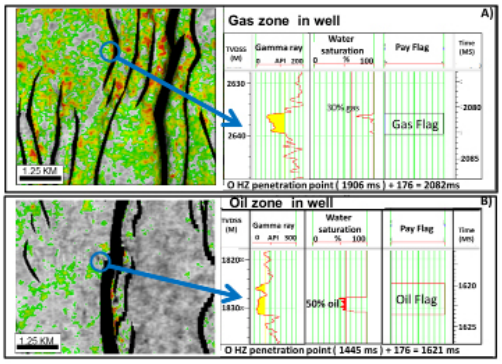

Figure 15 The zoomed picture of Vp/Vs horizon slice from Figure 14 at well on gas zone and oil zone. (A) It show the low Vp/Vs corresponds with gas flag. (B)And the high Vp/Vs ratio corresponds with oil flag.

rated zones in the area by this method.

Analysis of density and Vp/Vs anomalies over high structure

In the previous sections, it has been proved that density can successfully predict sands and Vp/Vs up to some extent can be useful to differentiate fluids. Here I am presenting analysis of anomalies over high structure

Gas sand on closure case show in A-16. It is an example of a well with gas (Figure 16). This well was drilled along fault within the closure structure. Density horizon slice shows low anomaly at well location (Figure 16 C) and Vp/Vs ratio is also low at this level (Figure 16 D).Wet sand on closure case show in B-03.it is an example of a well drilled along a fault within the closure structure (Figure 17A). This well has water-wet sand at this level. Density horizon slice shows low anomaly at well location (Figure 17C), while Vp/Vs is high (Figure 17D).

This analysis reveals that sands are in match with low density. Gas

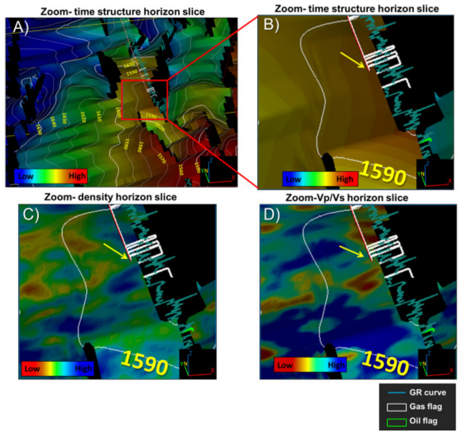

Figure 16 (A) Time structure of K horizon and well location of A-16 is marked on closure structure. (B) Zoomed picture of red box in Figure A. (C) Density horizon slice. (D) Vp/Vs horizon slice. Gamma ray log and gas pay flag are displayed at well location.

zones have low Vp/Vs. On the other hand oil and water, wet sands have Vp/Vs in the same range. According to the comparison of anomalies at high structures, it is evident that very low Vp/Vs anomalies within high structures are

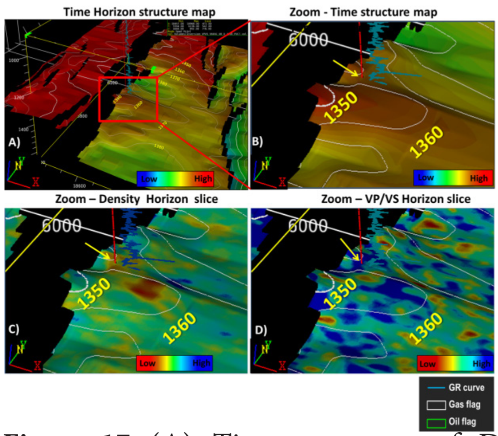

Figure 17 (A) Time structure of D horizon and well location of B-03 is marked on closure structure. (B) Zoomed picture of red box in Figure A. (C) Density horizon slice.
(D) Vp/Vs horizon slice. Gamma ray log is displayed at well location.

promising zones for gas. Whereas, low densities best matched with sands.

5. Conclusions

Rock physics analysis and Prestack simultaneous seismic inversion techniques were applied to map the reservoir sands and to delineate hydrocarbon zones of the Moragot and Ubon area within Pattani Basin of the Gulf of Thailand. The main Findings and conclusions are summarized below:

Rock physics analysis
Density is the most useful rock physics parameter to differentiate sand and shale throughout the zone of interest in the study area. Combination of Density and Vp/Vs can discriminate reservoir fluids within small intervals (< 200 meters) by using previously established cutoffs based on rock physics analysis.

AVO modeling
Class III and class IV sands have identified in the area.
In class III sands, it is possible to differentiate between pure gas, pure oil and pure brine. It is not possible to discriminate low gas saturated zones and high gas saturated zones. Class 1V sands yield same response for gas, oil and brine.

Inversion
Inverted density volume computed through pre-stacked inversion provides reasonable prediction for sands at wells, which were not used for inversion process. We can isolate sand bodies by applying established density cutoffs (based on rock physics) for different levels.

Horizon slices of inverted Vp/Vs volume successfully identified promising zones for hydrocarbon exploration by applying cutoffs of Vp/Vs in narrow intervals.

Low Vp/Vs and low-density anomalies within structure closure may be promising for future exploration work.

Recommendation

Density and Vp/Vs are increasing with depth due to compaction. This phenomenon is masking the effect of hydrocarbon or lithology on rock physics parameters. Prediction of lithology and hydrocarbon can be better if we would be able to remove the effect of depth. Regional trend analysis study is required for different rock physics parameters. Subtraction of this regional trend from inverted volumes may provide better prediction for lithology and hydrocarbon.
Probabilistic analyses by using rock physics and inverted volumes may identify high probability zones for exploration.

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