Rock physics analysis: a tool for lithology and fluid prediction in the Gulf of Thailand

Mirza Naseer Ahmad
Petroleum Geoscience Program
Chulalongkorn University,
Bangkok ,Thailand
naseerrb3@yahoo.com

Philip Rowell
Petroleum Geoscience Program
Chulalongkorn University,
Bangkok, Thailand

SUMMARY

The Tertiary rift basins of the Gulf of Thailand are major hydrocarbon producing areas. The reservoirs in these basins are mostly fluvial sands of Miocene and Oligocene age. Gas is found mostly in central basins whereas there are more oil discoveries in western marginal basins. The main objective of this study is to understand the vertical and spatial trends of different rock physics parameters which can be used to differentiate lithology and fluids in these basins. Cross-plot and fluid substitution analysis were performed to determine lithology and/or fluid sensitive rock properties. Cross-plot analysis shows that sands have low P-velocity and density at shallow depths as compared to shale but the contrast of P-velocity between sand and shale decreases significantly at deeper levels. However, density shows significant contrast between sand and shale throughout the zone of interest and is therefore a more useful lithology discriminator. Density can also distinguish highly gas-saturated sands (80%) from water-wet sands throughout the zone of interest. On the other hand, oil-bearing sands cannot be so easily discriminated from water-wet sands. In comparison Vp/Vs can only successfully resolve high porosity sands (>16%) and gas sands when used in combination with P impedance. This regional rock physics study indicates that appropriate inversion techniques for lithology and fluid prediction studies need to be considered carefully. Post stack P-impedance volumes generated by inversion are very useful at shallower levels down to 1900 to 2000 metres but at deeper levels, density volumes generated by pre-stack simultaneous inversion are more appropriate.

Key words: Gulf of Thailand, Seismic Inversion, Rock physics.

INTRODUCTION

The Gulf of Thailand consists of a series of Tertiary age north-south trending extensional basins. The reservoirs in these basins are fluvial channels and overbank sands which are highly compartmentalized. One of the factors in this compartmentalization is the rapid lateral stratigraphic changes inherent to the fluvial depositional systems and imaging these sand bodies is critical for resource evaluation in both exploration and development programs. The objective of the present study is to understand the vertical and spatial trends of different rock properties within different basins of the Gulf of Thailand which can differentiate fluid type and lithology. As a starting point two basins were selected, an oil producing western margin basin and a gas producing central basin. Cross-plot and fluid substitution analysis were performed using data from 12 wells in these two basins to determine lithology and fluid sensitive rock properties at different reservoir levels. The results will help to select the appropriate inversion technique to use to identify different pore fluids and lithologies at the various reservoir levels within the Gulf of Thailand.

GEOLOGICAL BACKGROUND

The Gulf of Thailand is composed of rift basins with a half-graben dominant rifting style. Basins in the area can be divided into two parts by the north-south trending Ko Kra ridge (Figure 1). This ridge separates larger and deeper basins to the east from narrower and more elongate basins in the west. The basins in the west are predominantly oil prone while the basins to the east are more gas prone. The main reservoirs in the Gulf of Thailand are Lower to Middle Miocene and Late Oligocene fluvial channel and overbank sandstones.

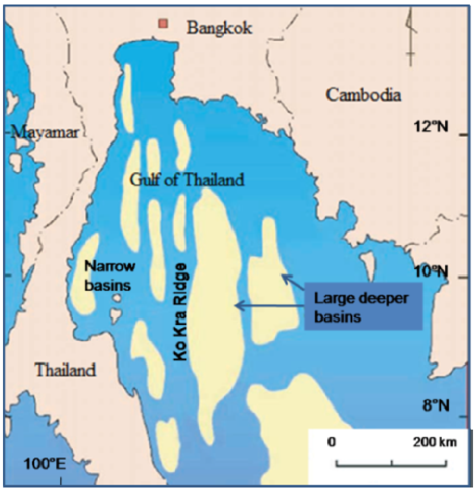

Figure 1. Basins in the Gulf of Thailand. Basins west of Ko Kra Ridge are deeper while basins east of the ridge are narrower.

METHODS

Different rock physics techniques were applied to determine the rock properties which can effectively discriminate between lithologies and pore fluids in the prospective reservoir intervals. Moreover, this lithology and fluid sensitivity analysis would be useful in the selection of appropriate inversion methods in the study area. We applied cross-plot analysis and Biot-Gassmann fluid substitution to determine lithology and fluid sensitive rock properties. Cross-plots of acoustic impedance, Vp/Vs and density with respect to shale volume and water saturation were analysed using well log data from twelve wells. These cross-plots were also analysed at different depth intervals to check the depth sensitivity of various rock properties. Cross-plot analysis was also performed at seismic scale after re-sampling and filtering out the high frequencies in the log data to check the feasibility for prediction of different lithologies and pore fluids using seismic. We also performed fluid substitution for different percentages of gas and oil saturation at different levels to observe the variation in rock physics parameters.

RESULTS

Sands have relatively lower P-wave velocity and density compared to shales in the study area (Figure 2a). However the contrast of P-wave velocity for different lithologies is more significant at shallower depths than at greater depths (Figure 2b). This reduction in contrast with depth is also observed in acoustic impedance which is a product of P-wave velocity and density (Figure 2b). On the other hand, density shows significant lithology contrast throughout the zone of interest. A cross-plot of P-impedance vs. shale volume indicates that P-impedance varies with both depth and lithology (Figure 3). Clean sands have relatively lower P-impedance as compared to shales and silty sands, and P-impedance in general increases with depth. P-impedance increases as the percentage of shale content increases to 60-70 % after which P-impedance starts decreasing. This decrease in P-impedance is due to a decrease in P-velocity for high percentages of shale content. This decrease in velocity beyond 60% shale content is attributed to transition from grain-supported sediment to clay-supported sediment at and beyond the 60% shale content level (Avseth, et al, 2005). Cross-plots of P-impedance and shale volume for different depth intervals show clean sands have distinguishable P-impedance at shallow depth intervals whereas at deeper levels sands and shales are less distinguishable from each other (Figures 4a and b). The shallow cross-plot (Figure 4a) also shows that gas sands have distinctly lower P-impedance as compared to water-wet sands at these depths. The higher the percentage of gas saturation the lower is the observed P-impedance. In the deeper section this P-impedance contrast between gas-sands and water-wet sands is less prominent (Figure 4b). The cross-plots of well log data in the oil producing western basins show similar trends, but in contrast the P-impedance cannot discriminate oil bearing zones at any levels. As P-impedance can only discriminate lithologies down to certain depths in the study area, post-stack seismic inversion techniques which solve only for P-impedance will only be effective for lithology discrimination in shallow zones, down to 1900~2000m.

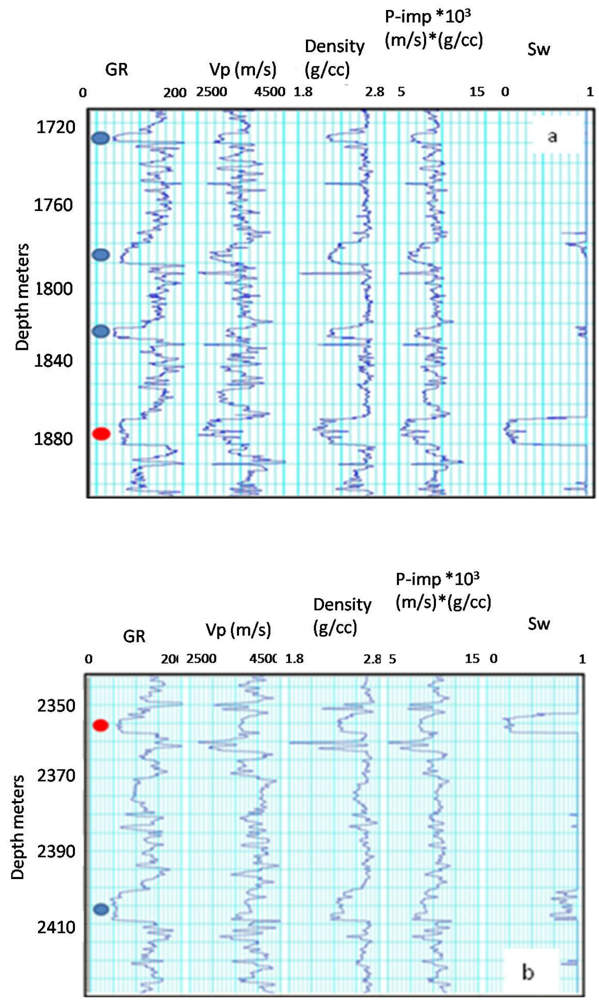

Figure 2. (a) Logs (density, GR and DT) and computed P-impedance and Sw logs for a shallow depth interval. These logs indicate significant P-wave velocity & density contrast between sand & shale. (b) Same log set for a relatively deeper depth interval. P-wave velocity contrast between sand & shale decreases but there is still significant density contrast. Red marked circles are gas sands while blue circles are water wet sands.

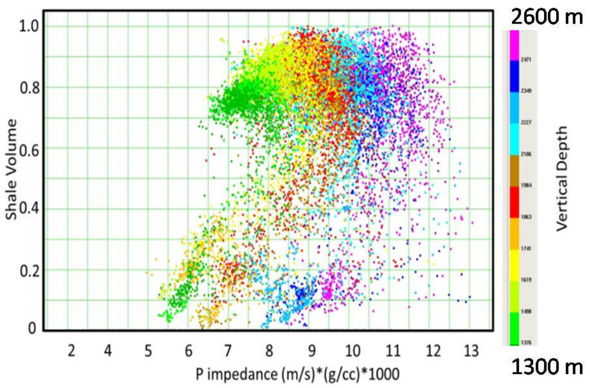

Figure 3. Cross-plot of P-impedance versus Shale Volume colour-coded by vertical depth. P-impedance increases with depth for all lithologies.

In the deeper section post-stack inversion will have only limited capability of lithology discrimination. A cross - plot of P-impedance vs. Vp/Vs from wells in the central basin (Figure 5) over a depth interval of 1500-2300m shows that high porosity sands (> 16%) can be discriminated from shales with minor overlaps by using a combination of P-impedance and Vp/Vs, whereas low porosity sands cannot be discriminated as easily. The high porosity gas sands highlighted have low Vp/Vs but these sands are situated at shallow depth intervals and are the same sands which are discriminated from shale based on P-impedance contrast. This cross-plot shows that P-impedance along with Vp/Vs is suitable for high porosity sand discrimination at all depths but can only discriminate fluid effect in the shallower section. This effect can also be seen by comparing Figures 4a and b. In contrast the cross-plots of oil producing wells within a western basin indicate that it is difficult to differentiate oil from water at any level using P-impedance and Vp/Vs in combination (Figure 6).

An approximate linear trend is observed in the cross-plot of density vs. shale volume. Density increases with increase in shale volume (Figure 7) and there is also a general increase of density of sand and shale with depth as in the case of P-impedance. Despite increase in density of both lithologies with depth sand and shale have different ranges of densities at all levels. A cross-plot of density and shale volume at seismic scale was also analysed, after re-sampling at 4ms and applying high cut frequency filter within the selected zone of interest. This cross-plot also reveals that density can successfully differentiate high gas-saturated sands from wet sands in the depth interval of interest at the seismic scale. Biot-Gassmann fluid substitution for deeper intervals also supports the cross-plot analysis that density is a better indicator of gas-saturated zones as compared to P-velocity (Figure 8). The contrast between 0% and 100 % water saturation is more significant in the density log as compared to the contrast in the P-wave velocity and P-impedance logs in the same interval. A similar analysis using an oil substitution shows that the contrast between oil and water is not significant for P-impedance or density. These cross-plot analyses and fluid substitutions indicate that density is the most appropriate rock property for discrimination of lithology and fluid. This implies that inversion methods that are capable of solving for density would be more suitable for discrimination of lithologies and pore fluids (gas and brine) in the study area. Estimation of the density through seismic inversion has been considered difficult and is dependent on the appropriate angle stacks to get a meaningful result. However some encouraging results have been reported for density estimation where density contrast is the dominant contributor for lithology or fluid discrimination (Behura et al., 2010, Kabir et al., 2006). An estimation of density through simultaneous inversion may be useful in this case if far angle volumes greater than 30 degrees are available.

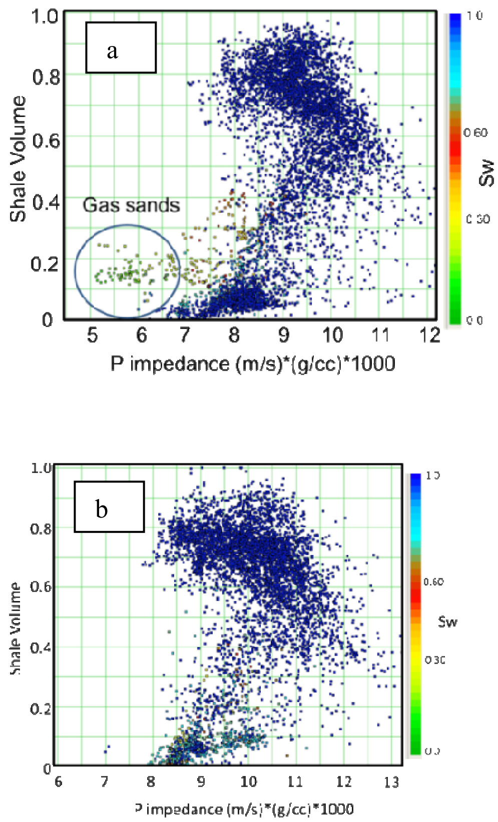

Figure 4 (a) Cross-plot of P-impedance and Shale Volume colour coded by Sw for 1500 to 1800m (b) Same cross-plot for 2100-2300 m.

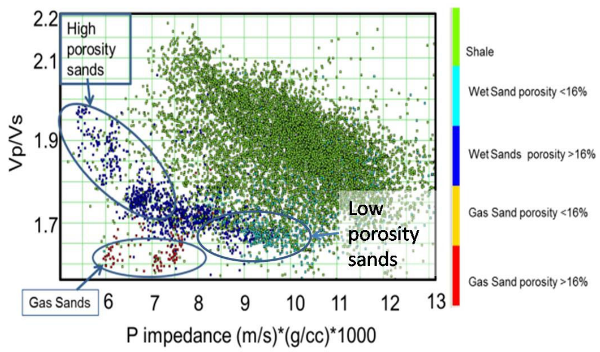

Figure 5. Cross-plot of P-impedance and Vp/Vs colour-coded by interpreted lithology. The depth interval is from 1500 to 2300 m.

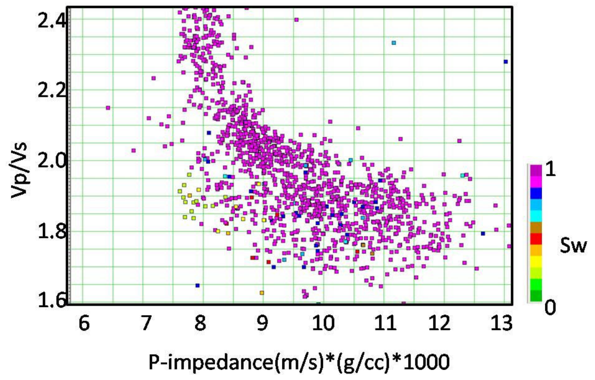

Figure 6. Cross-plot of Vp/Vs and P-impedance from an oil producing well within a Western basin, colour -coded by Sw.

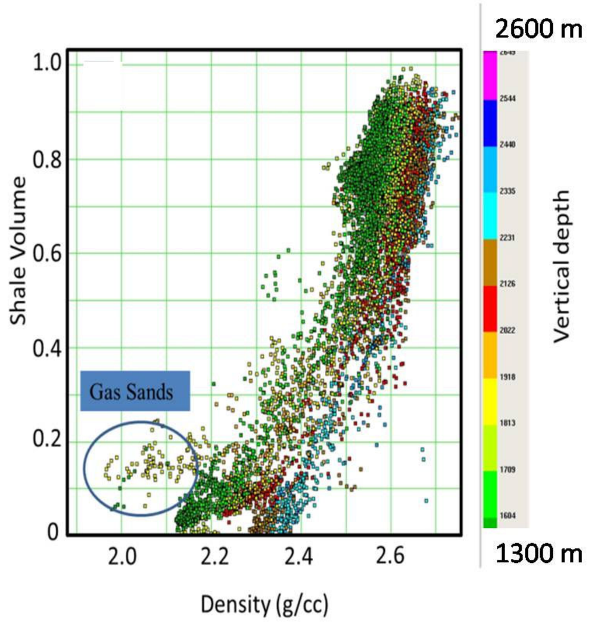

Figure 7. Cross-plot of density and shale volume colour-coded by depth. The circled low densities at relatively shallow depths represent gas sands.

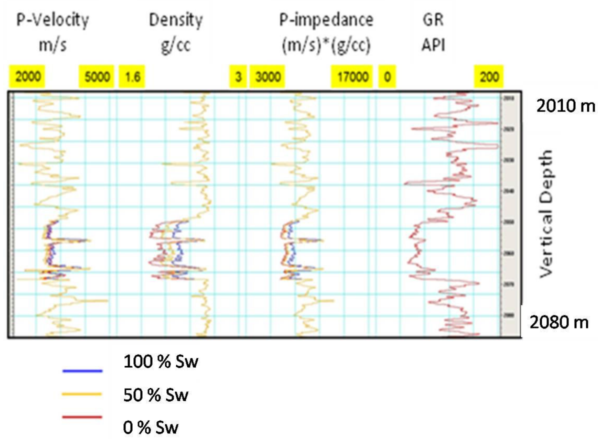

Figure 8. Biot-Gassman fluid substitution (for gas) for 0%, 50% and 100% Sw within the selected zone.

CONCLUSIONS

Rock physics analysis helped to find a relationship between lithology and seismically derived parameters at different reservoir levels in different hydrocarbon producing basins of the Gulf of Thailand. Key findings of the present study are as follows;

- Acoustic impedance can differentiate lithology (sand and shale) and gas sands from wet sands down to approximately 1900 m~ 2000 m but have limited lithology discrimination capability at deeper levels.
- P-impedance and Vp/Vs can differentiate porous sands and gas sands from shales in the shallow section but it is not possible to isolate low porosity sands from shales.
- Density can differentiate between sand and shale throughout the zone of interest. Sands show low density as compared to the shale at all depths.
- Simultaneous inversion for density may provide reasonable lithology and fluid prediction for gas at all levels.

REFERENCES

Avesth, P., Mukerji, T., and Mavko, G., 2005, Quantitative seismic interpretation, Cambridge University Press.

Behura, J., Kabir, N., Crider, R., Jilek, P., and Lake, E., 2010, Density extraction from P-wave AVO inversion: Tuscaloosa Trend example, The leading Edge, 772-777.

Kabir, N., Crider, R. R., Ramkhelawan, R., and Baynes, C., 2006, Can hydrocarbon saturation be estimated using density contrast parameter?; CSEG Recorder, 31-37.