Seismic Characteristics of the Overpressure Area in Southern Pattani Basin, Gulf of Thailand

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Abstract

An overpressure zone is a zone where the formation pressure is higher than hydrostatic pressure. Moragot and Pailin fields in Southern Pattani Basin, Gulf of Thailand, have pore pressures that represent a drilling hazard. In an undrilled location, seismic data is the main information available for pre-drilled prediction of overpressures. Therefore, the seismic velocity data from the stacking velocity cube is an important key to investigate overpressure by converting the stacking velocity to the interval velocity using Dix's equation. The overpressure area shows slower interval velocity when compared to normal pressure areas. These slower interval velocities were visualized by two methods: isochronal velocity mapping and overpressure volume generation. The interval velocities were mapped to generate the isochronal velocity mappings in 250 m/s intervals starting from 2,950 to 4,200 m/s. The thicker time intervals, representing an area of slower interval velocities, correspond to overpressure areas. This model has an 88% correlation with RFT data. The main uncertainty is below 2,600 mTVDSS due to mapping resolution. The second method developed is to produce an overpressure volume which is a residual velocity anomaly volume. This model is made by subtracting the seismic velocity volume from the created normal pressured velocity volume. This resulting overpressure volume is consistent in indicated overpressure zones. The seismic velocity was further studied to estimate overpressure degree using the Eaton's method. The result was not conclusive and may need further study using a higher resolution velocity volume. The outcomes from this study can used to identify overpressure by using seismic velocity in the pre-drill phase.

Key words: Overpressure, Stacking velocity, Seismic velocity, Slower interval velocity, Pattani Basin

1. Introduction

In the Pattani Basin, Gulf of Thailand, the main hydrocarbon accumulation areas also have encountered overpressure. Overpressure is an abnormal pressure that exceeds hydrostatic pressure at a specific depth. It is an unexpected zone that can cause drilling issues such as a well kick, loss of circulation and well hole caving. This can be due to a pre-drill inappropriate estimation in formation pressure. Basically, in an exploration phase, the seismic data is the main available information, and usually forms the primary pore pressure prediction. Therefore, the main objective of this study is to identify seismic characteristics related to overpressure in Moragot and Pailin fields for pre-drilled prediction. The seismic velocity is the main information used in this study. The results can reduce uncertainties from encountering unexpected overpressure zones.

2. General geology of the study area

The Pattani basin is an extensional basin which is a result of Indian-Eurasian collision during Early Tertiary. The normal fault sets both west and east-dipping faults are developed. Morley and Racey (2011) suggest for the Tertiary stratigraphy in Pattani Basin that the basin has high sedimentation rate, which deposited more than 6,000 meters of sediments since Miocene.

It is comprised of both non-marine and marginal marine silici-clastic sediments. The lithostratigraphy of Pattani Basin is divided into 6 sequences. The section of interest starts from 1,500 to 2,500 ms or 1,400 to 3,500 mTVDSS and covers middle of Sequence 4 to middle of Sequence 2 (Middle Miocene to Early Miocene). Sequence 4 is fluvio-deltaic depositional environment. It contains sand, shale and a few coals. Sequence 3 is a high impermeable sediment accumulation from marginal marine sediments. This unit is the primary hydrocarbon-producing zone due to it containing high source rock packages. Sequence 2 depositional environment is fluvial, lower delta plain and intertidal. The combinations of fault trap and top seal from thick shale interval in Sequence 3 have resulted in hydrocarbon accumulation starting from top Sequence 3 to well TD and also related to overpressure interval. The overpressure degree distribution tends to decreasing from NW to SE direction and it corresponds to stratigraphic change in this area.

2. Methodology

The methodology mainly focuses on seismic velocity to identify area of overpressure for pre-drilled locations evaluation. Well log data including density, sonic and RFT data from total 8 wells are used to investigate overpressure characteristic as compared to normal pressure. This information is tied to seismic data at the well location, and then the changing seismic characteristic due to overpressure was investigated.

3. Results and Interpretations

3.1 Overpressure investigation from well log data

Total 8 studied wells, pore pressure data collected in the sand using wireline repeat formation tests (RFT) were used to classify overpressure and normal pressure wells. Well-08 was only one well that defined as normal pressure well which pore pressure lower than 8.5 ppg (pound per gallon in equivalent mud weight). Sonic and density log were used to compare between overpressure and normal pressure wells as shown in Figure 2.

The sonic and density value corresponding to pure shale were used to do a crossplot with depth. In the normal pressure well (Well-08), the sonic with depth crossplot shows that the regression curve increases with depth. After comparing to overpressure wells, the regression trends of the other 7 overpressure wells have significantly higher interval transit time (slower interval velocity) in the overpressure zone. The results are similarly in density and depth crossplot. In the overpressure interval, the density is lower than in the normal pressure section.

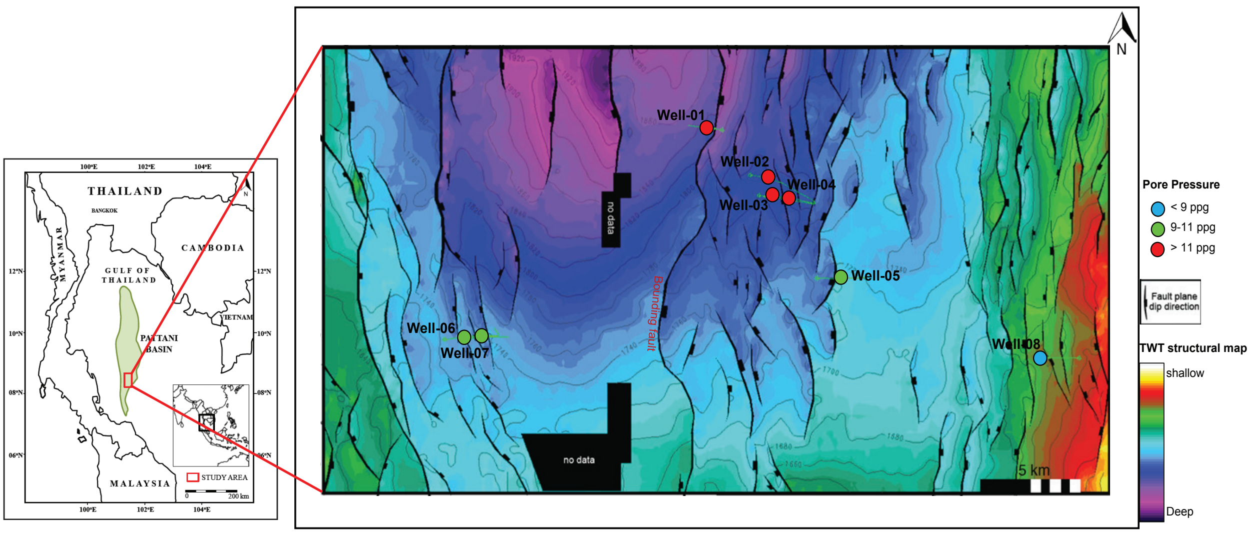


Figure 1. Study area is located in the southern Pattani Basin, Gulf of Thailand. It consists of two fields namely as Moragot and Pailin. Total 8 studied wells show location on time structural map at near Top of Sequence 3. The overpressure degree observes in wells tend to decrease from basin center to basin flank.

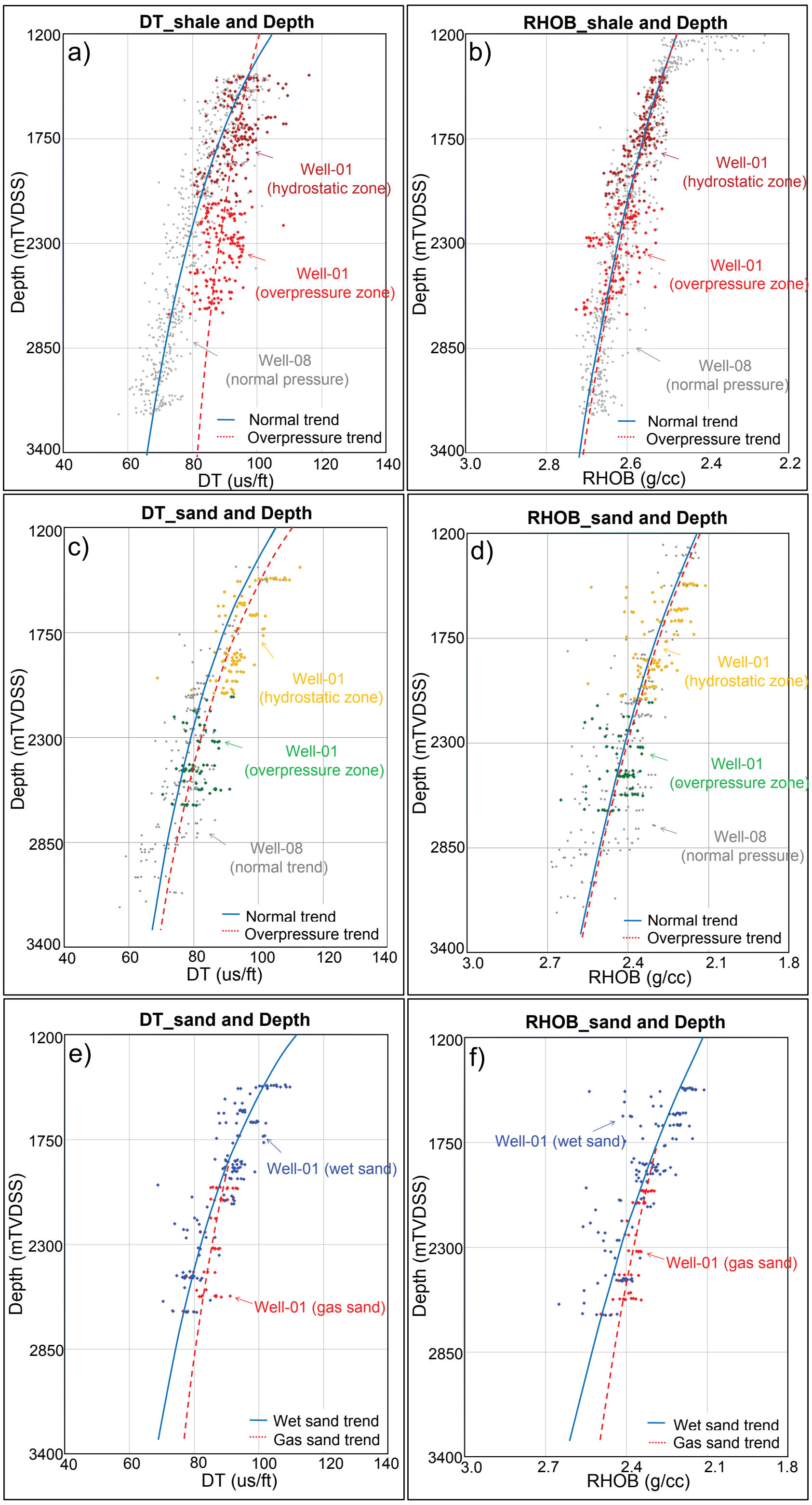


Figure 2. The crossplot of sonic and density logs with depth comparing between overpressure well (Well-01) and normal pressure well (Well-08): a) Sonic interval transit time of shale points with depth show significant higher interval transit time in the overpressure zone. b) Density of shale points with depth show slightly lower density in the overpressure zone. c) and d) Sonic and density of sand point crossplot with depth, the overpressure well trend show slightly higher interval transit time and lower bulk density when compare to normal pressure well. e) and f) Gas sands show higher interval transit time and lower density than wet sands.

The sonic and density value of sand in overpressure wells have a strikingly similar trend with normal pressure well but they tend to have lower velocity and bulk density. In term of different fluid type in pore spaces, gas sands show lower velocity and density than wet sand.

The overpressure characteristics are slower interval velocity and lower bulk density when compare to normal pressure interval. However, the shale sections are more correlated to overpressure interval than sand section particularly in significant slower velocity in overpressure zone.

3.2 Well tie to seismic data

Both sonic and density log were used to generate synthetic seismograms to tie the information from well to seismic. The synthetic seismograms show good correlation ranging between 50% to 70% with the seismic section along wells. The well velocity derived from time-depth conversion show different velocity trend that correspond to the observed maximum overpressure in wells. The normal pressure well show fastest velocity trend while overpressure wells show slower velocity depending on the magnitude of the formation pressure. This supports the fact that overpressure zones can be detected as slower velocity zone and should be detected in the seismic velocity volume.

3.3 Overpressure investigation from seismic velocity

The continuous RMS velocity cube was obtained from seismic processing. This volume was converted to interval velocity using Dix's equation.

The seismic interval velocities were extracted along the wells to compare to well log measured interval velocities. The seismic velocities in overpressure wells show slower seismic interval velocity corresponding to overpressure zone as shown in Figure 3. This abnormal phenomenal illustrates that the seismic velocity can be detect overpressure similar to the well information. There are two methods using to recognize these slower interval velocities: Isochronal velocity mapping and Overpressure volume generation.

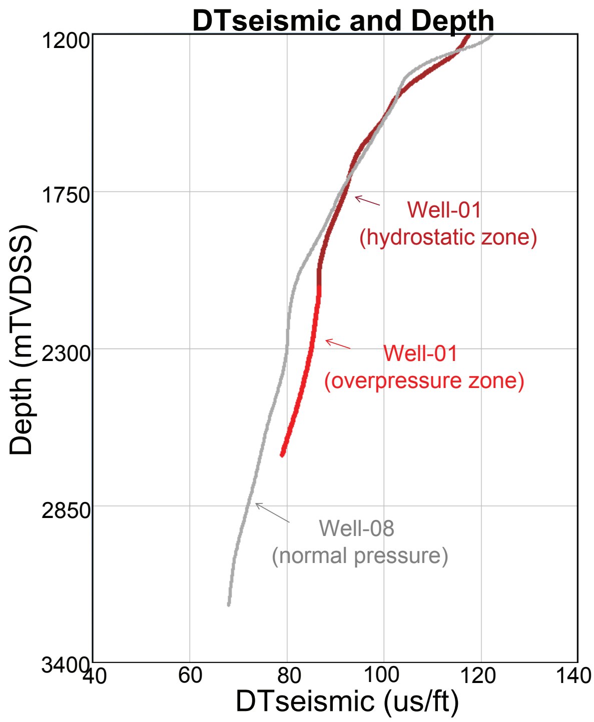


Figure 3. Seismic velocity comparison between Well-08 (normal pressure) and Well-01 (Overpressure) shows higher interval transit time (slower velocity) within overpressure zone similar to sonic log characteristic.

3.3.1 Isochronal velocity mapping

The well section along the seismic interval velocity volume shows an overall increasing interval velocity with depth. However, there are obvious variations of time thickness at the same velocity interval. The interval in the overpressure well is thicker due to slower velocity than in the normal pressure well.

Isochronal velocities are mapped using a 250 m/s velocity incremental starting from 2,950 to 4,200 m/s. These isochronal time thickness maps are shown in Figure 4. The shallower section within the hydrostatic pressure interval (2,950 to 3,200 m/s) show constant time thickness that corresponds to similar velocity in this interval. There are more variations in some areas within the transition zone before getting into the overpressure interval (3,450 to 4,200 m/s). This model correlates up to 88% match to the RFT data in all 8 wells. The thicker intervals show pressure higher than 8.5 ppg (overpressure) starting at isochronal velocity between 3,450 to 3,700 m/s. Below 2,600 mTVDSS or particularly between 3,700 m/s to 4,200 m/s, there are some uncertainties in the isochronal maps where the well pressure data show overpressure but the observed time interval was thinner than the hydrostatic well location. This uncertainty might be depended on the resolution for velocity mapping to represent the overpressure zone. Therefore, the isochronal velocity in the shallower section can be used to indicate expected top overpressure area.

3.3.2 Overpressure volume

The interval with slower velocity is defined as the overpressure zone. The overpressure volume which is a residual velocity anomaly volume was generated by subtracting measured interval velocity volume from the normal velocity volume.

The normal velocity volume was generated by simplifying the velocity trend in normal pressure location into a linear relationship. The equations used to define a linear relationship were equation (1) for depth and equation (2) for time.

$$V = V_o + k\,(Z - Zml) \qquad (1)$$

$$V = V_o \times 10k\,(t - tml) \qquad (2)$$

The intercept (V_o) is the velocity at mud line while the gradient (k) is the one-way depth gradient of velocity and its unit is in second^{-1}. This gradient comes from best-fit line in depth with seismic velocity along Well-08's location. There are two different gradients identified. The section from the mud line to the top of Sequence 3 has a gradient of 1.01 second^{-1}. The section from the Top of Sequence 3 down to 2,700 ms (base of interested window), the gradient changes to 0.65 second^{-1}. These gradients can refer to normal compaction gradient in normal compaction condition. This volume is assumed as a volume without overpressure.

The residual volume, termed the overpressure volume, is created by subtracting the expected normal volume with the seismic interval velocity volume as shown in Figure 5.a. This volume is used to identify slower velocity areas. The change in color represents the deviation of velocity which is slower than the normal velocity trend. Top of these anomalies are observed close to top of Sequence 3. The cross section along the studied wells shows consistent results with RFT data. These brighter colors (light blue to red) are related to pressure higher than 8.5 ppg. The examples from well section are shown in Figure 5.b.

Thus, this model can be used for preliminary investigation and identification of any possible expected overpressure areas for new well locations.

3.4 Pore pressure prediction from seismic velocity

Overpressure zones can be detected as slower interval velocity zones in the seismic velocity volume. Consequently, the seismic velocity volume can be used to estimate the magnitude of overpressure. This pre-drilled data can be used to design mud weight program to cover formation pressure.

The seismic interval velocities were compared to the interval velocity derived from wells. The results show that the seismic velocity is 10% faster on the average. Therefore, all seismic velocities were adjusted by subtracting 10% from the seismic velocity to match the velocities from the wells before doing pressure prediction. The adjusted seismic velocities show similar velocities of the shale trends. Thus, these seismic velocities are assumed that they are measured shale velocity.

The pore pressure concept as defined in equation (3) is the difference between overburden stress and effective stress. PP is pore pressure or fluid stress. OBG is overburden stress or total stress during burial history and σ is effective stress.

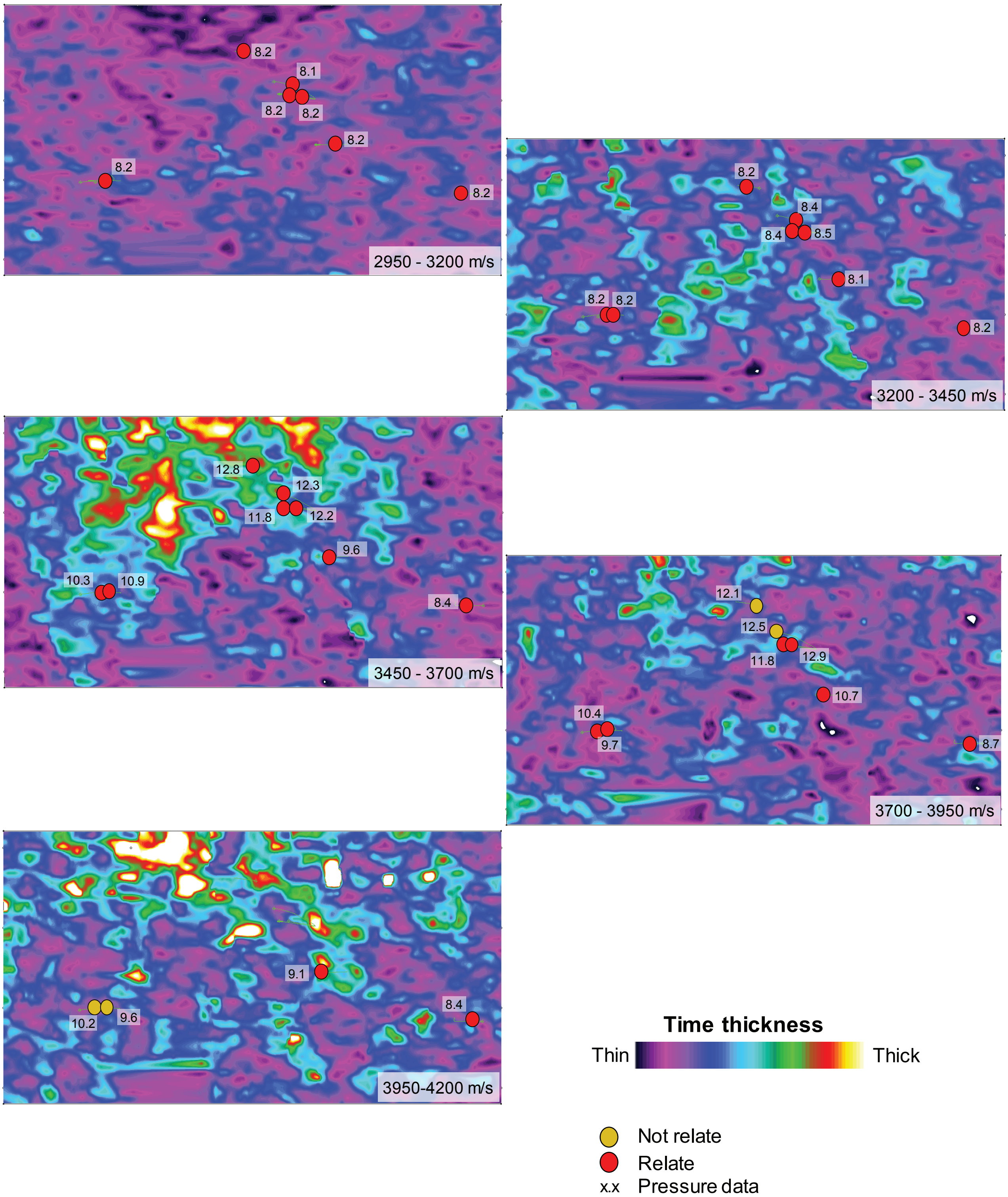
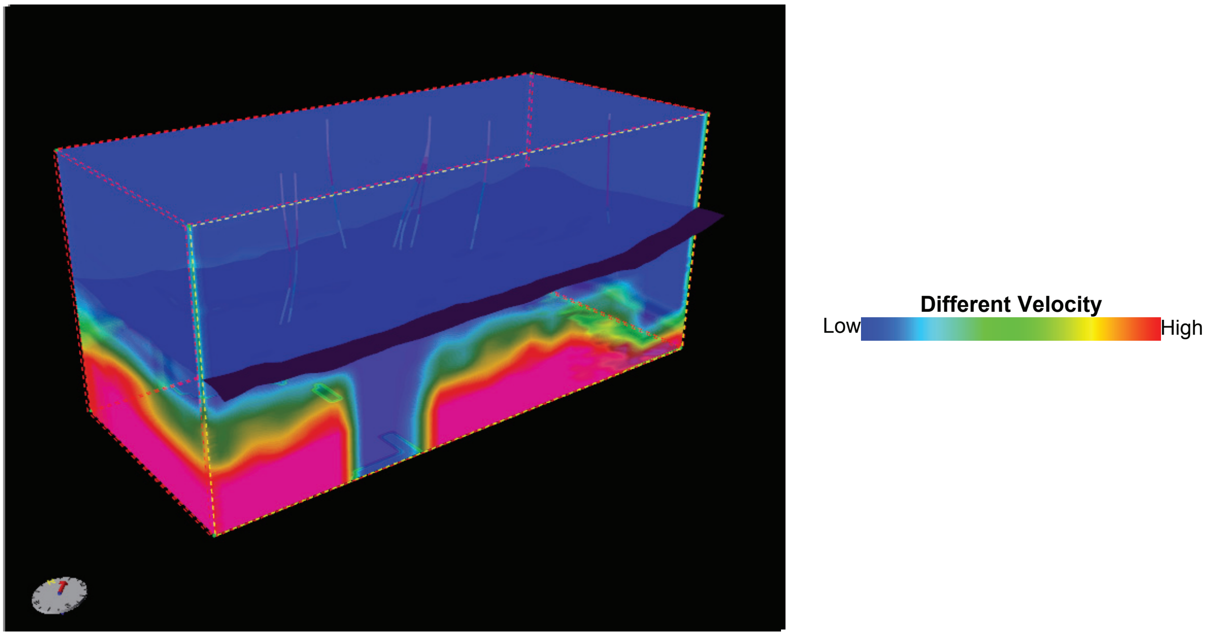


Figure 4. Isochronal maps of velocity in every 250 m/s show variation of time thickness. The thicker sections correspond to higher pressure data over 8.5 ppg. The isochronal velocity maps between 3,700 to 4,200 m/s show uncertainties that higher pressure is thinner interval as yellow circle location.

a)



b)

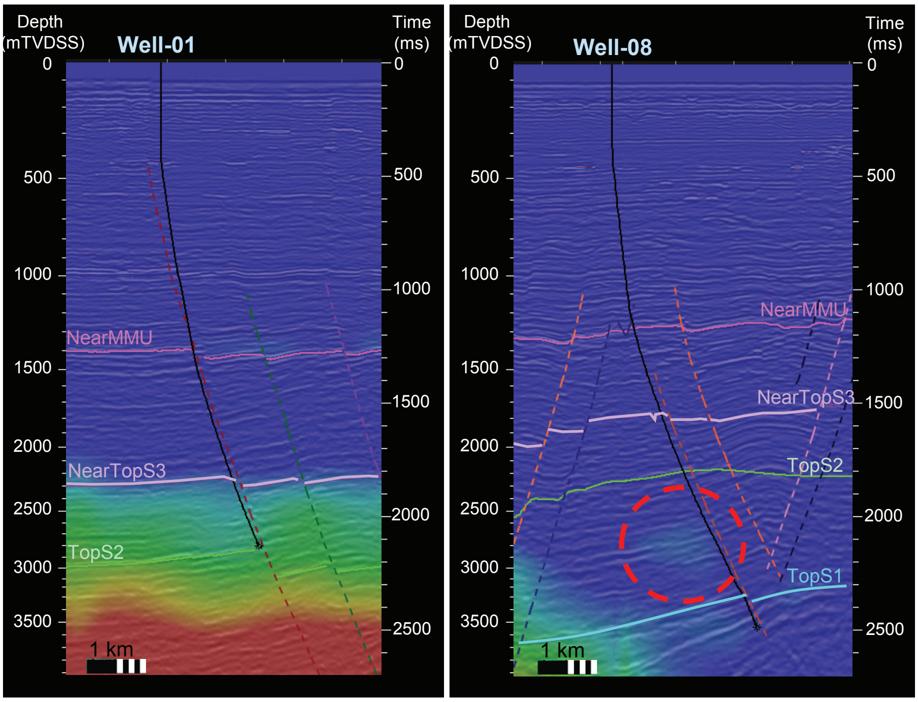


Figure 5. a) Anomaly of slower interval velocity volume generated by subtracting seismic interval velocity volume from the normal velocity volume. b) Cross section along the studied wells. The colors represent the different velocity value between created normal velocity volume and seismic velocity volume. In all overpressure wells, the brighter colors indicate an overpressure interval as an example from Well-01 (10.0-12.8 ppg). Well-08 has one light blue anomaly from 8.7 ppg corresponding to a slightly overpressure (marked in red dashed circle).

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$$PP = OBG - \sigma \quad (3)$$

Eaton (1975) relates seismic velocity to effective stress as in equation (4). The Eaton's method proved to be a successful method in this area based on the two previous studies (Bunyanupong, 2014 and Amonpantang, 2010) which utilized both sonic log and resistivity log for post-drilled pore pressure prediction. In addition, the Eaton's method based on sonic log input was also an effective technique to many fields in Southeast Asia for instance; in the Baram Delta province, Brunei by Tingay et al. (2009) and the Northern Malay Basin, Gulf of Thailand by Limpornpipat et al. (2012). Thus, this method is the most common methodology in pore pressure estimation in sedimentary basins of Southeast Asia. This study attempts to use seismic velocity in order to determine pore pressure by following the same approach.

$$\sigma = (OBG - P_n)(\Delta T_n / \Delta T)^m \quad (4)$$

where Pn is the hydrostatic pressure (assumed at 0.446 psi/ft), ΔT_n is the travel time of normal compaction trend, ΔT is travel time observed from slowness log or seismic velocity, and m is the Eaton's exponent.

The normal compaction trend line is a critical factor that requires sufficient experience and a plethora of applicable information. The deviation from this line will be used to calculate the effective stress as in equation (4). In this study, the normal compaction trend lines are calculated by using the seismic velocity from the Chapman's equation (Chapman, 1983):

$$\Delta T_n = \Delta T_m + (\Delta T_{ml} - \Delta T_m) \times 10^{(c \times DBML)} \quad (5)$$

where ΔT is the travel time at depth, ΔT_m is matrix travel time that in this study applied 55 us/ft, ΔT_{ml} is travel time of mud line, c is exponential decline and DBML is true vertical depth below the mud line.

For this study, Eaton' s exponent is assumed to be m = 2 for the sonic velocity (in reference to Amonpantang, 2010), while for the seismic velocity, m = 3 is assumed to get the closest result possible from the RFT data. The result from seismic velocity based pore pressure prediction is not conclusive due to less seismic velocity resolution. The comparison between pore pressure prediction from seismic and sonic velocity is shown in Figure 6.

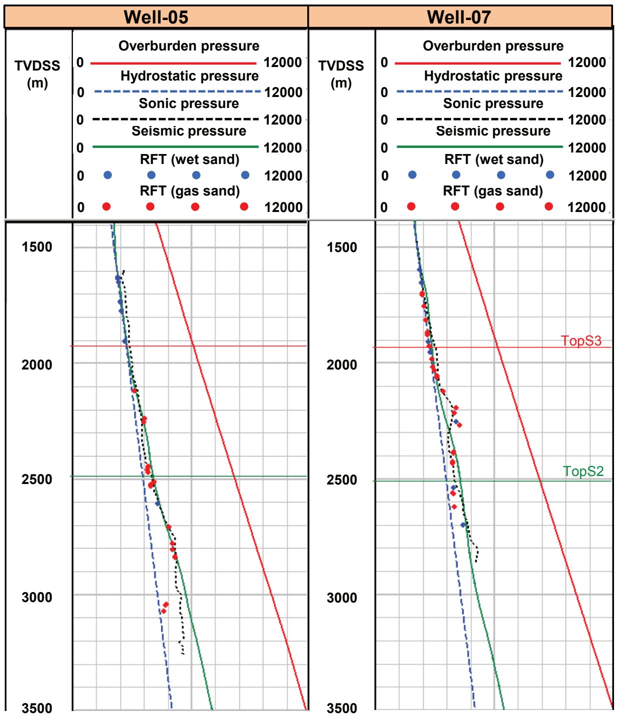

Figure 6. Comparison of estimated pore pressure using sonic velocity (black dashed line) and seismic velocity (green line). Both sonic and seismic velocity in Well-05 can estimate pressure closer to RFT data. Sonic logs data can predict pore pressure better in thinner interval (2,100 to 2,300 mTVDSS) in Well-07.

4. Discussion and Conclusion

The influx of sediment in the Gulf of Thailand reached a high during the Miocene to Recent, particularly the Early to Middle Miocene (Morley and Racey, 2011). Morey and Westaway (2006) suggest that the thick post-rift sediment accumulation is the result from hot crust and high surface processes. Moreover, the structural control and high subsidence rate caused rapid burial of sediments (Morley et al., 2011). The rapid burial rates resulted in shale sections becoming undercompacted as the fluids could not be expelled fast enough. Overpressures are expected following 2 to 3 kilometers of overburden which is starting at top of Sequence 3. Based on the RFT data, not only the gas sands exhibit overpressure, but the wet sands as well possess pressure values of up to 12.5 ppg. In addition, the pore pressure gradients in the studied wells show increasing overpressure that are sub-parallel to the overburden pressure and do not dramatically increase. This indicates and further supports the interpretation that the main mechanism in this area must be related to disequilibrium compaction.

Gas generation associated with kerogen maturation in source rocks is likely to be a minor cause of overpressure (Osborn and Swarbrick, 1997: Tingay et al., 2013). As observed in Sequence 3, there are high organic-rich shales that can be good source rocks (Kamvan, 2013; Morley and Racey, 2011). The characteristic of organic rich shale is high gamma ray, high neutron and low density. The vitrinite reflectance from two exploration wells in this area show 0.5 to 0.9 vitrinite reflectance of the shales below top of Sequence 3 (Bunyanupong, 2014). It indicates that the shales are in the maturation window, and with appropriate pressure and temperature conditions, these organic-rich shales can generate hydrocarbons which can be expelled later into the system and result in higher pressure.

The overpressure areas can be identified pre-drill by using seismic velocity data but the amount of overpressure prediction may need more resolution on seismic velocity.

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