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DETECTION OF RESERVOIR SANDS USING SEISMIC ATTRIBUTES AND SPECTRAL DECOMPOSITION IN THE SOUTHEAST OF PATTANI BASIN, GULF OF THAILAND

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Abstract

Pattani basin is a structurally complex extensional basin of the Gulf of Thailand. The reservoirs are highly compart-mentalized sand by the rapid lateral and horizontal stratigraphic changes due to fluvial depositional systems (Lower to Middle Miocene) and a series of normal faults. The reservoirs in the study area are thin and limited in lateral extent which makes it difficult to predict reservoir distribution, orientation and thickness based on conventional seismic volume. Advanced geophysical techniques were applied to improve the reservoir imaging and prediction. RMS and coherence attributes successfully detected the channel-like features by using twenty-milliseconds (20ms) window horizon slicing along the reservoir interval. Far angle stacked volume delivers different imaging of reservoir distribution for more lateral extension. From rock physic analysis, acoustic P-impedance and near angle elastic impedance can discriminate sand and shale in unit 2 and 4. The far angle elastic impedance can help discriminate sands in unit 2, 3 and 4. High amplitudes on the root-mean square (RMS) amplitude attribute correspond to sands at well locations from blind test wells. Coherence provides higher resolution for detecting channel edges. The channel width varies from 150 to 950 meters and N-S to NW-SE orientation. Spectral decomposition shows a good response tuning at 36 Hz of 20 meters thick sand while higher frequencies show bright amplitudes for relatively thinner sand. This study suggests that the RMS and coherence can be used to detect reservoir distribution and spectral decomposi-tion can predict thickness.

Keywords: Porosity trend, Sandstone reservoir, Southern Pattani Basin, Cementation

1. Introduction

The southeastern part of Pattani basin is a structurally complex extensional basin of the Gulf of Thailand. The reservoirs are sands associated with fluvial and deltaic systems which are highly compartmentalized by the rapid lateral and horizontal stratigraphic changes due to fluvial depositional systems. The series of normal faults are another factor causing this compartmentalization. The reservoirs are thin (2 – 20 m.) and limited in lateral extent (less than 1 km.). It is difficult to predict distribution, orientation and reservoir thickness based on conventional 3D full stacked seismic data where the reservoirs are below the tuning thickness.

Prediction of reservoir sands by using rock physics and simultaneous inversion was previously studied in the same study area by Visadsri (2013). Combination of density and Vp/Vs can differentiate reservoir fluids within narrow depth range by establishing accurate cutoffs based on rock physics analyses.

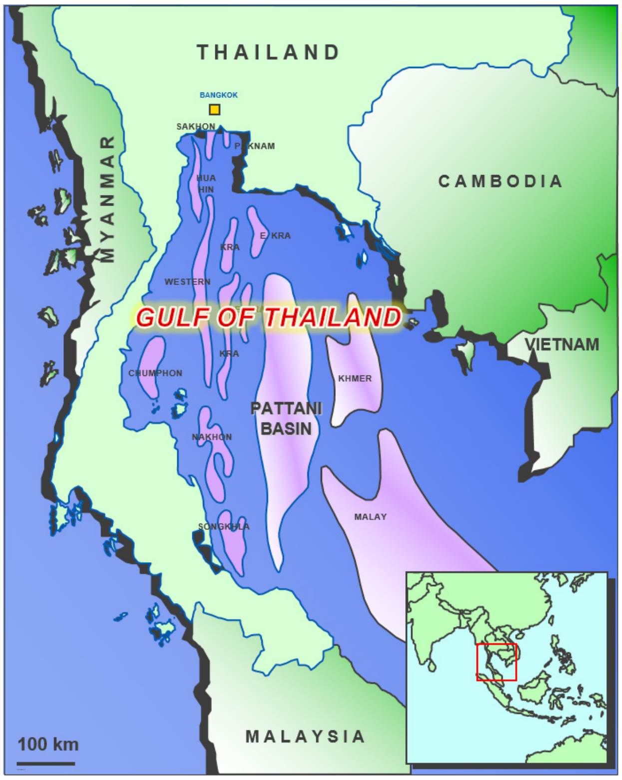

Figure 1. The study area is located in the southeastern part of the Pattani basin, Gulf of Thailand.

Inverted density volume computed through pre-stack simultaneous inversion can provide a reasonable prediction for sand distribution at well locations and shallow sections.

This research aimed to study in more detail the reservoir characterization by utilizing well logs and seismic data to define geometry and distribution of reservoir sands in the southeastern part of the Pattani basin. The key objectives of this study are:

1) Define reservoir distribution, orientation and size of sand body by using seismic attributes

2) Study the response of different frequency of spectral decomposition as a function of different thickness of reservoirs

The study area is located in the southeastern part of the Pattani basin (Figure 1).

2. Rock Physics Analysis

The cross plots of rock physics versus depth from well data is shown in figure 2. The combination of these parameters is used to observe the lithology relationship. The yellow line is the sand trend while the green line is the shale trend. A gamma ray cut off of 80 API unit was used for quick look interpretation for shale volume.

Figure 2A-C shows the cross plots of density, P-wave, and S-wave velocity versus depth. The density of sand is lower than shale for all units and increases with depth. The contrast of P-wave and S-wave velocity cannot discriminate sand and shale from shallow section to deep section. The P-wave of shale is the same as sand at unit 3 and 4 and higher than sand at unit 2. The S-wave of sand is much higher than shale for all units.

These parameters from the cross plots increase with depth following the compactional trend from density and velocity. The cross plots of acoustic P-impedance and near angle elastic impedance can discriminate sand and shale in unit 2 and 4. The low contrast in P-impedance in unit 3 cannot discriminate sand and shale. The far angle elastic impedance can help discriminate sand and shale in unit 2, 3 and 4 as shown as figure 2D-F.

3. Root Mean Square (RMS) Analysis

Amplitude maps were generated by using RMS amplitude attribute along the interpreted horizons to map the sand distributions. Twenty-milliseconds window interval along an interested interval (unit 2 to unit 4) was selected along each

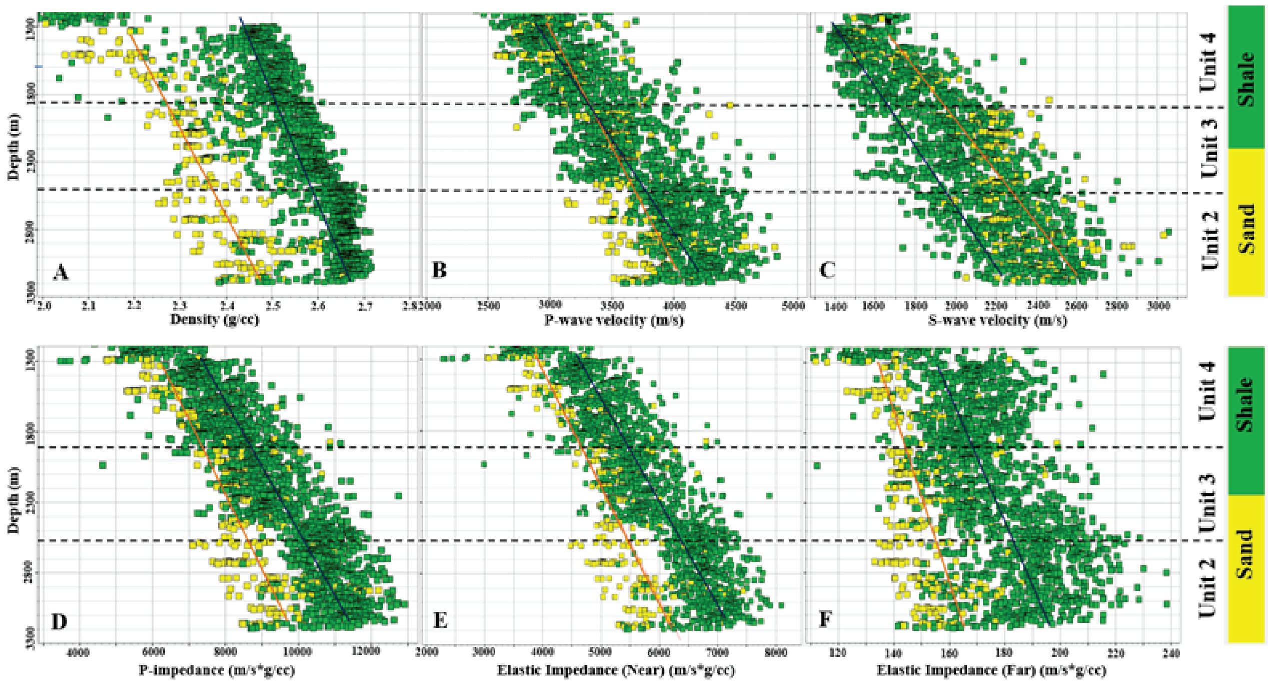

Figure 2. is well log cross plots showing A = Density, B = P-wave, C = S-wave, D = P-impedance, E = Near angle elastic impedance, F = Far angle elastic impedance versus depth colored by gamma ray for sand and shale.

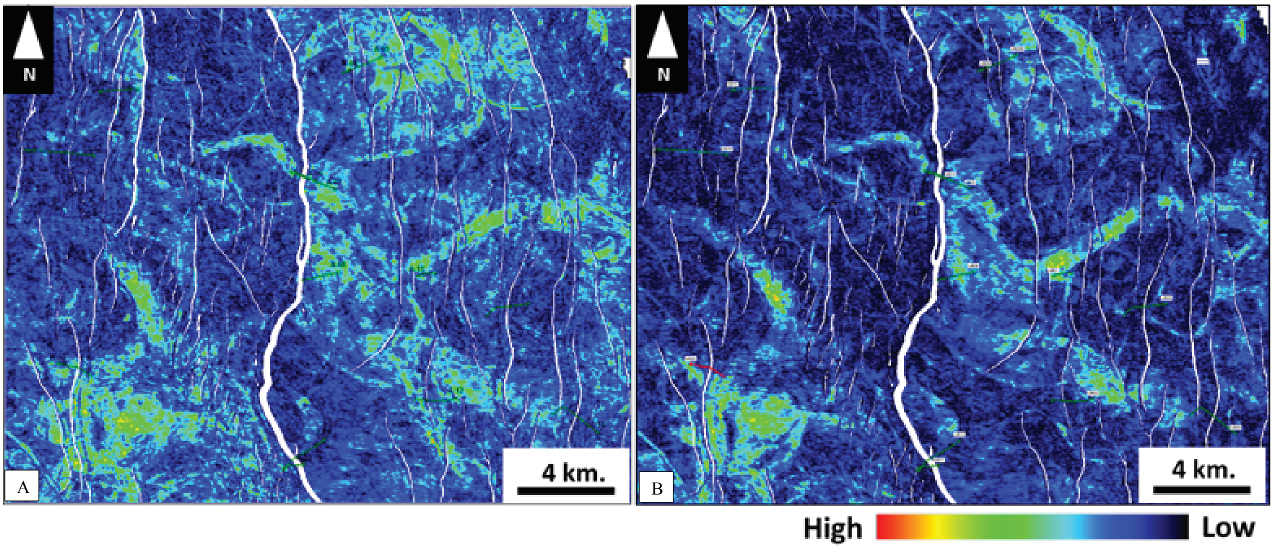

Figure 3. The RMS attribute maps above D horizon 40 ms (60 m) with 20 ms interval on full angle stacked volume shows a landscape of geological meaningful patterns or channel-like features. The channel-like features are more extensive and lateral in far stacked volume (3A) and can be discriminated from the multi channels compared with full angle stacked volume (3B).

horizon that covered the thickness of the sands encountered at wells and reflective events of increasing and decreasing impedance. The twenty-milliseconds window was subtracted above and below the key markers by using the Phantom horizon method. The RMS attribute was then calculated along the selected 20 ms interval.

The calculated RMS attributes can outline geological meaningful patterns or channel-like features on seismic found in reservoir interval from unit 2, 3 and 4. The RMS were run in full angle seismic volume and far angle seismic volume to determine whether there was any geologically meaningful pattern of sand distribution. The cross plot from rock physics analysis represents the far angle elastic impedance that can discriminate sand and shale in unit 2 to 4. However, the original full angle stack and P-impedance cannot discriminate sand from angle stacked volume provides different imaging. In contrast, the near angle stacked and mid angle stacked volume provides the same result as full angle stacked volume. The full angle stacked volume and far angle stacked volume have been

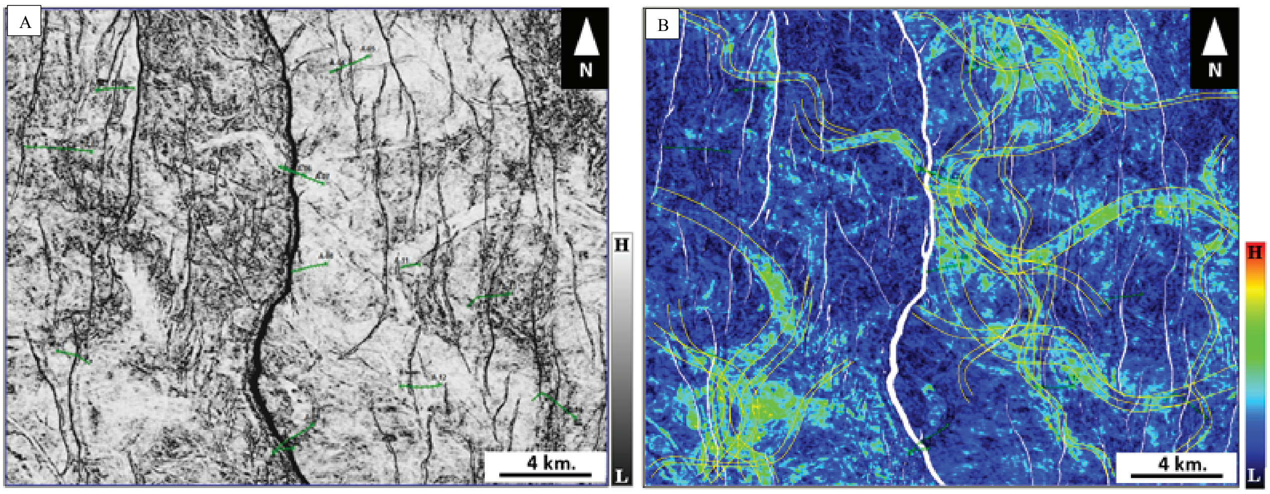

Figure 4. Coherence horizon slice above D horizon 40 ms (60 m) with 20 ms interval shows the darker sinuous features in the background of black and white color (9A). The coherence attribute can help mapping the channel together with the RMS attribute provides higher accuracy of mapping the sand distribution and orientation that align with the RMS attribute.

chosen as representative of these volume for RMS attribute analysis.

The RMS attribute maps above D horizon 40 ms (60 m) with 20 ms interval on full angle stacked volume shows a landscape of geological meaningful patterns interpreted as channel-like features as shown in figure 3. The channel-like features have been mapped along the RMS attribute map. The high amplitude distribution indicates meander channel shapes with high and low sinuosity generally trending in a Northwest to Southeast direction. The patterns show the stacking of many single channels of a channel belt through this interval.

The result of RMS amplitude from the far stacked volume provides different imaging of the same interval as the full angle stacked volume. The channel-like features are more extensive and lateral in extent in far stacked volume and can be discriminated from the stacked-channels obtained with the full angle stacked volume. Single channels can be identified from the stacked high amplitude or channel belt for some channels in full angle stacked volume and far stacked volume.

The RMS amplitude successfully identified channel-like features in full angle stacked and far angle volume by using the 20 ms (30 m) window RMS map. High amplitudes on the RMS correspond to sands as confirmed at well locations where blind test wells have penetrated that the high amplitude area. Also, the synthetic seismogram confirmed the high amplitude and troughs on seismic indicate sands. The RMS attribute is limited at the depth of 2,200 meters where the responses of the seismic cannot display the reservoir distribution.

4. Coherence Analysis

Coherence volumes were generated over the full angle stacked volume and far angle volume. White color has the highest coherence in the seismic volume while black color is showing the lowest coherence (Figure 5).

Coherence time slice shows the darker sinuous features in the background of black and white color. The sinuous features are parallel to each other and filled by high coherency in the middle of those events as shown in figure 9A. The sinuous features can be interpreted as single channels. The edges of the channels are the incoherence event that can be the shale event and the channel is filled with sand. The incoherence feature with single lineament can be interpreted as faults. The series of faults passed through the channels but the channels are still consistent across faults.

The coherence slice at 40 ms (60 m) above D horizon on full angle stacked volume shows the landscape of channel-like features in figure 9B. The channel-like features can be mapped as channel edge from the incoherence along the coherence time slice (Figure 4). The coherence attribute can help mapping the channel when combined with the RMS attribute to provide a higher accuracy of mapping the sand distribution. The channel-like feature with high and low sinuosity generally trend in a Northwest to Southeast direction.

The result of coherence from the far stacked volume provides different images of the same interval as full angle stacked volume. The channel-like features are more extensive and lateral in extent in some area of the far stacked volume compared with full angle stacked volume.

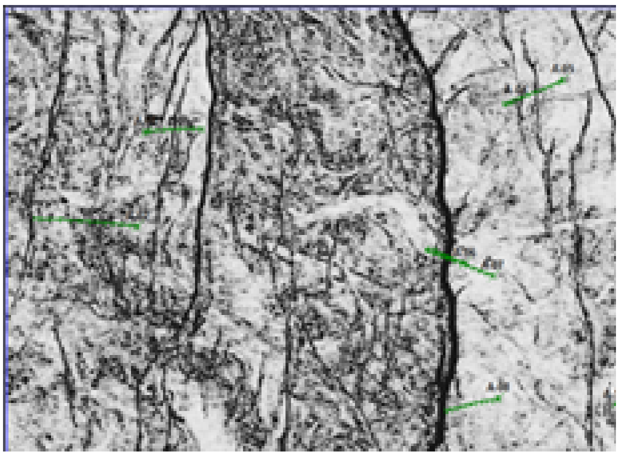

Figure 5. Coherence horizon slice above D horizon 40 ms (60 m) with 20 ms interval shows the darker sinuous features of low coherence.

5. Spectral Decomposition (SD)

Spectral decomposition was computed using SD Trace Sub-band outputs from normal traces containing frequencies or frequency/wavenumber bands. The selected band limited range of iso-frequency volumes were processed from 10 to 80 Hz at the interval of 5 Hz. resulting in 17 bandings of individual iso-frequency range volumes. Banding based on Linear Scale simply divides the range of frequencies into the number of bands selected linearly. Reservoir thickness determinations identified by spectral decomposition are based on the tuning effects at different frequencies that exhibit an acoustic impedance contrast (Taner, et al., 1979). The maximum amplitude occurs at tuning thickness which is a function of frequency/wavenumber and bed thickness (Puryear and Castagna, 2008).

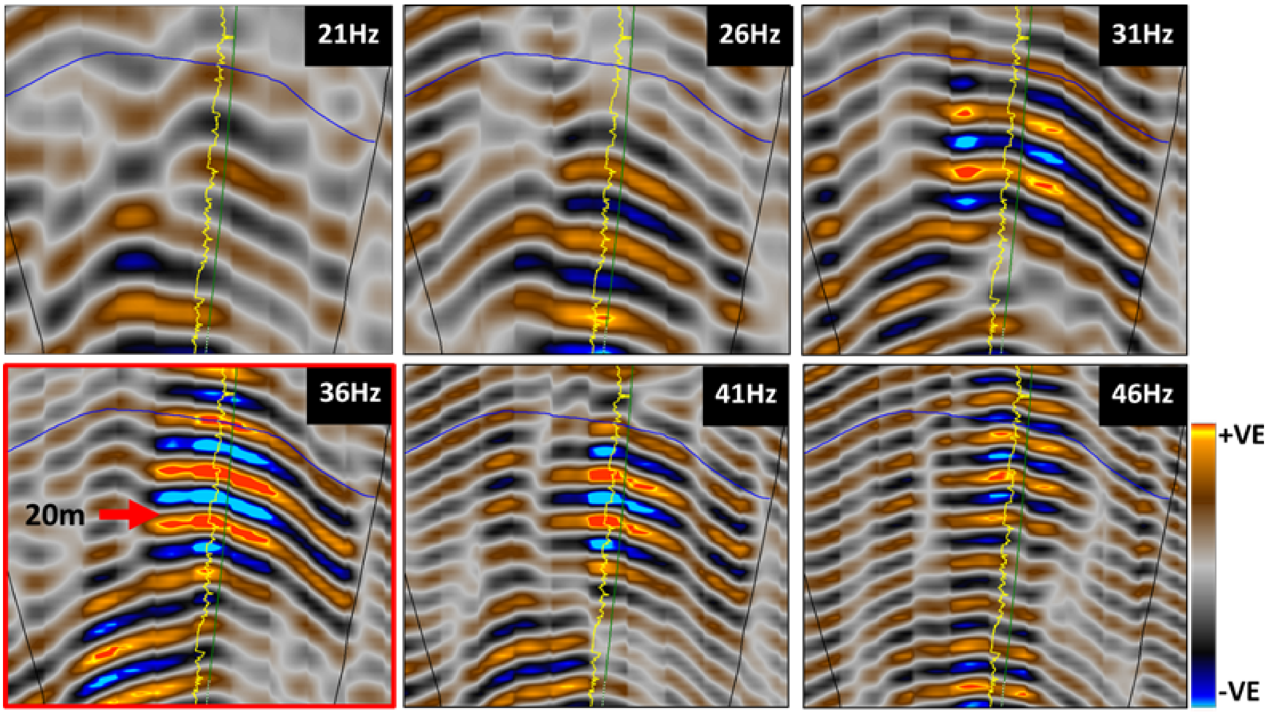

Figure 6. The location of maximum amplitude is changing the frequency with various reservoir thickness. At 36Hz the primary amplitude event displays its highest amplitude. A logical conclusion is that the seismic is responding to a 20 meters thick sand that relates to 36 Hz.

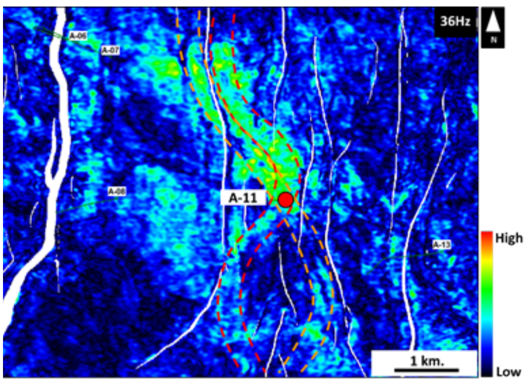

Figure 7. The RMS horizon slice from spectral decomposition, the tuning of 20 meters thick sand at 36 Hz. shows the distribution of high amplitude at the well location (Red circle). The area is 0.32 sq.km.

The maximum amplitude can be observed while changing the frequency volumes which is influenced by reservoir thickness (figure 6). It has been observed that different thicknesses show the highest amplitude due to the tuning effect at different frequencies of Well A-11. Figure 5 shows that the thicker sand bed (~20m.) is associated with high amplitude at 36 Hz, while in the same well thinner beds do not highlight any high amplitude at 36 Hz. The thin sand zone (10 m.) shows high amplitude at higher frequency of 46 Hz. The RMS horizon slice (Figure 7) –from spectral decomposition shows the tuning of a 20 meters thick sand. The distribution of the high amplitude at the well location confirms the amplitude anomaly is the 20m sand. This has an area of 0.32 sq.km.

6. Comparison of Sand Mapping with Blind Test Wells

The comparison of the well log data and the RMS on full angle stacked, far angle stacked and coherence volume was performed with the drilled wells. The high amplitude on the RMS attribute maps on full angle stack and far angle stacked shows the conformable results with the blind test wells in unit 2, unit 3 and unit 4.

Figure 8 shows the result of the RMS attribute on full angle stacked volume with blind test wells in unit 4 where the high amplitude passed through to well locations. The high RMS amplitude corresponded to the low gamma ray log of the blind test wells. Four wells show reasonable match with high amplitude on the RMS map. Also, the response from well log to coherence is moderate to high coherence. The moderate to high coherence within the channel can be interpreted as sand – filled channel as shown by the low gamma ray value from the well log data. Some wells show high gamma ray with a low amplitude on the RMS map but image channel-like features on the seismic. High gamma ray can be interpreted as mud filled channel.

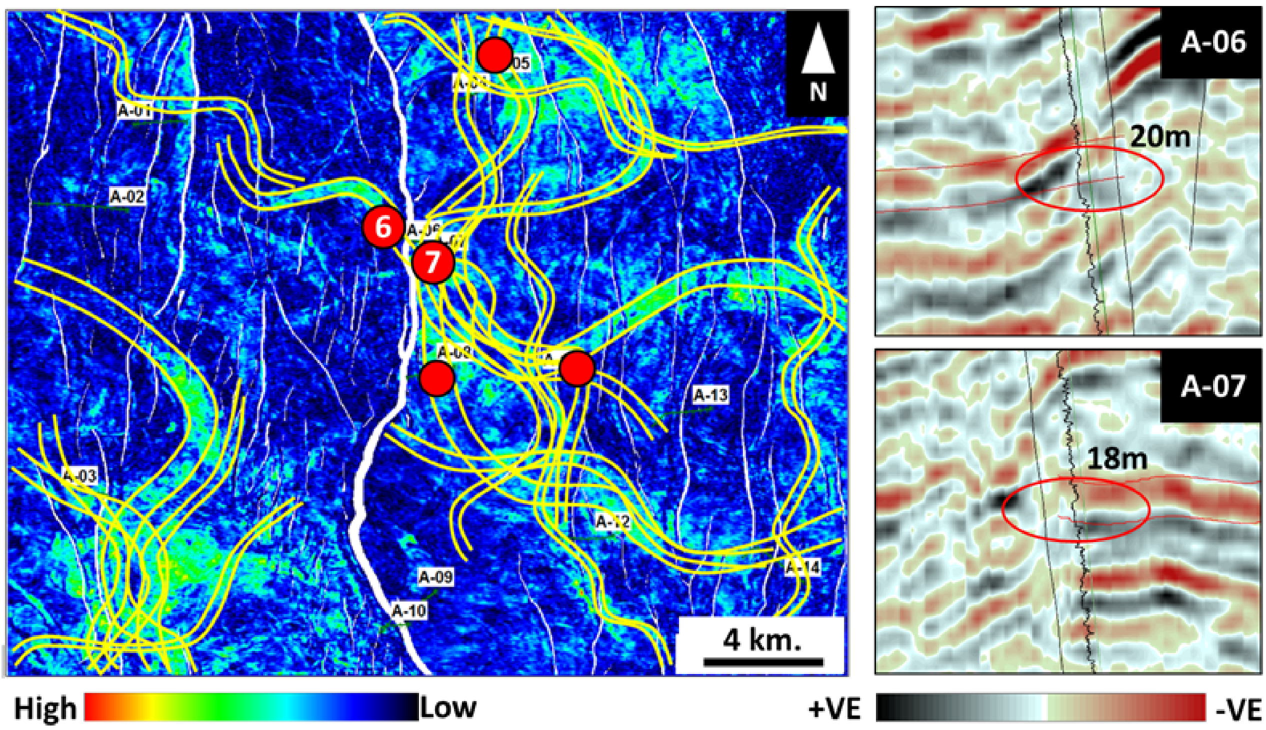

Figure 8. The result of the RMS attribute on full angle stacked volume with blind test wells above D horizon 40 ms with 20 ms interval in unit 4 where the high amplitude passed through to well locations. The high RMS amplitude corresponded to the low gamma ray log of the blind test wells and can be interpreted as sand.

7. Mapping of Sand

The mapping techniques were integrated for mapping reservoir sand distribution and orientation. Sand mapping was done by using seismic full stacked volume, far angle stack volume and coherency. Possible channel belts can be detected by the combination of those techniques. Reservoir sands are identified as a high amplitude anomaly on RMS attributes. Based on the cross plot from rock physics analysis, the far angle stacked volume provides higher resolution for discriminating sand and shale especially in unit 3. Channel boundaries are identified as a low coherency seismic attribute. The interpreted channels illustrated by horizon slices from RMS reveals a landscape of channels apparently superimposed on each other. This is a result of the different channel being closely spaced in vertical space.

Sand distribution in the three units were mapped along 20 ms window intervals with three seismic volume which are full angle stacked volume, far angle stack volume and coherency. The 20 ms window was subtracted above and below the key markers by using the Phantom horizon method and calculating the RMS along the selected horizons that covered the reservoir interval. The combination of interpretations from 3 seismic volumes became the final interpretation for sand mapping in this study area and is displayed as a horizon slice. Channel orientation and channel width have been measured on the interpreted channels on the horizon slices and summarized for each unit (figure 12).

Unit 2

The channel features provide a good response for RMS on full angle stacked volume and coherence volume. This unit is below the K marker to below the O marker. Seismic below the O marker have a poor response to the RMS attribute and coherence. The far angle volume has better imaging for the shallow section of unit 2 but a poor response in the deeper section at around 1.8 seconds or 2,200meters. The reservoir sand boundaries are difficult to identify on full angle stacked compared with unit 3 and 4. Channels are orientated dominantly in the Northwest – Southeast directions with moderate sinuosity (Figure 9). The general range of channel orientation are from North – South to Northwest – Southeast direction (Figure 15B). The channel width in this unit ranges from 150 to 850 meters. The dominant channel width ranges from 150 meters to 650 meters.

Unit 3

The channels were well defined on the RMS attribute on far angle stacked volume and coherence volume. The RMS on far angle volume was mapped as single channels due to the evidences of the meandering channels superimposed or stacked to each other. On the contrary, the RMS on full angle stacked volume reveals the channel belts of the larger high amplitude channel-like features (Figure 10). The cross plots of far angle impedance versus depth also shows the separation between sand and shale in the unit 3 zone to support the evidence. The mapped channels in unit 3 are orientated dominantly in the North-South direction and Northwest – Southeast direction and have a high sinuosity. The channel width was observed as 150 to 850 meters. The dominant channel width ranges from 450 meters to 650 meters.

Unit 4

The channels in unit 4 were well defined both on the RMS of full angle stacked and far angle stacked volume (Figure 11). The coherence volume also defines the channel edge as well. The one single channel patterns were mapped on the RMS map over the seismic volumes. The result of cross plots shows good separation between sand and shale in unit 4 interval. The orientation of the channels in unit 4 are varied from North – South to Northwest – Southeast direction with moderate to high sinuosity (Figure 17B). Also, the channel widths in unit 4 range from 150 to 950 meters. The 250 to 350 meters wide channels are dominant.

8. Discussions

Different geophysical analyses were applied through the reservoir intervals to map the reservoir sand. This is the appropriate techniques for the seismic data set of the southern part of Pattani basin, Gulf of Thailand. The key findings are summarized below.

1. The seismic attributes that were successfully applied to the study area are the RMS attribute, coherence, and spectral decomposition. Full angle stacked and far angle stacked volumes provide the best response in the seismic attributes. The cross plot from rock physics analysis shows that the far angle stacked volume provides higher resolution for discriminating sand and shale especially in unit 3. These seismic volumes are limited at the depth of 2,200 meters the responsesof the seismic cannot display the reservoir distribution. The seismic resolution decreases with depth as a function of velocity, frequency, and wavelength. The missing intervals

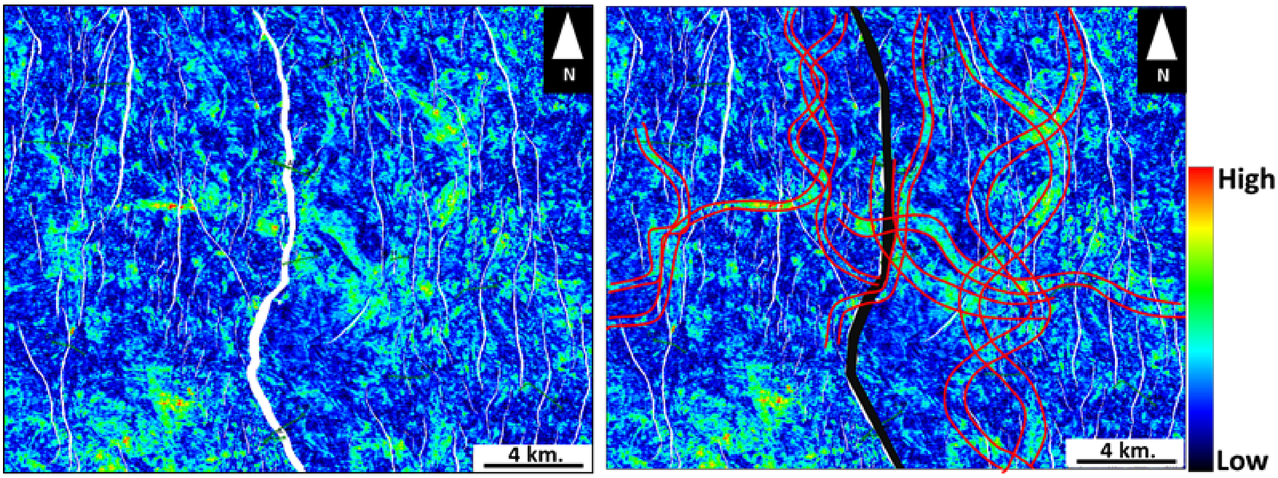

Figure 9. The channel features below K horizon 20 ms (30 m) provide good response for RMS on full angle stacked volume and coherence volume in Unit 2 (9A). The general range of the channel orientation are North – South to North-west – Southeast direction (9B).

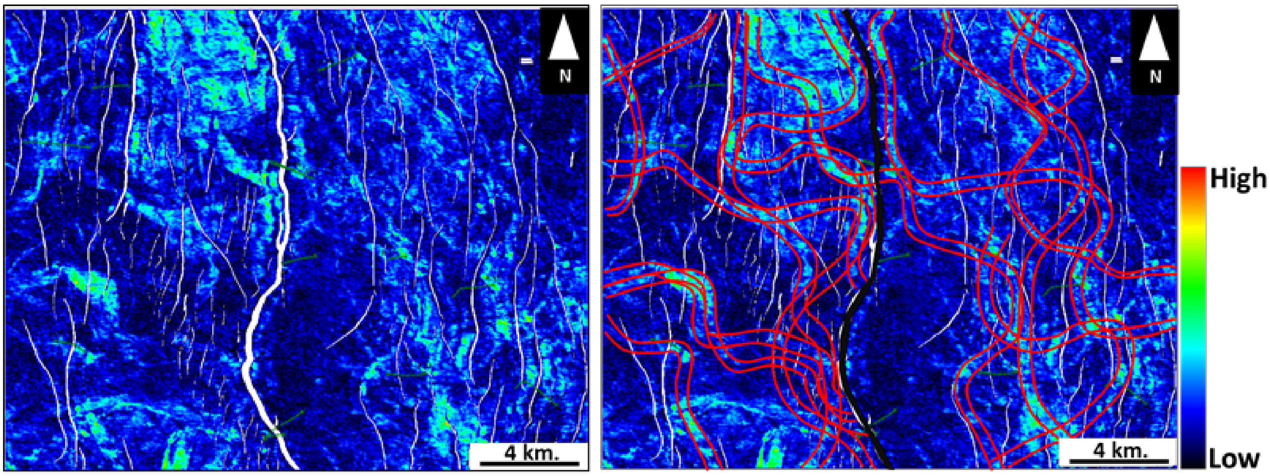

Figure 10. The channels below D horizon 10 ms (15 m) were well defined on the RMS on far angle stacked volume (10A). The mapped channels (10B) in the unit 3 orientated dominate in the North-South direction and Northwest – Southeast direction with high sinuosity.

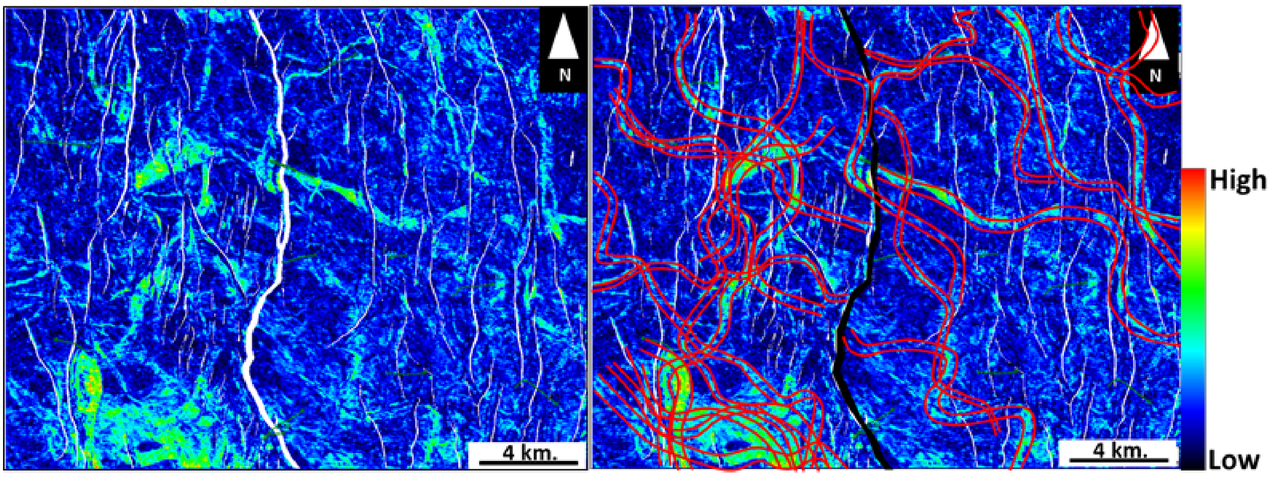

Figure 11. The channels above D horizon 110 ms (160 m) in unit 4 were well defined both on the RMS of full angle stacked and far angle stacked volume (11A). The orientation of the channels in unit 4 are varied from North – South to Northwest – Southeast direction with moderate sinuosity (11B).

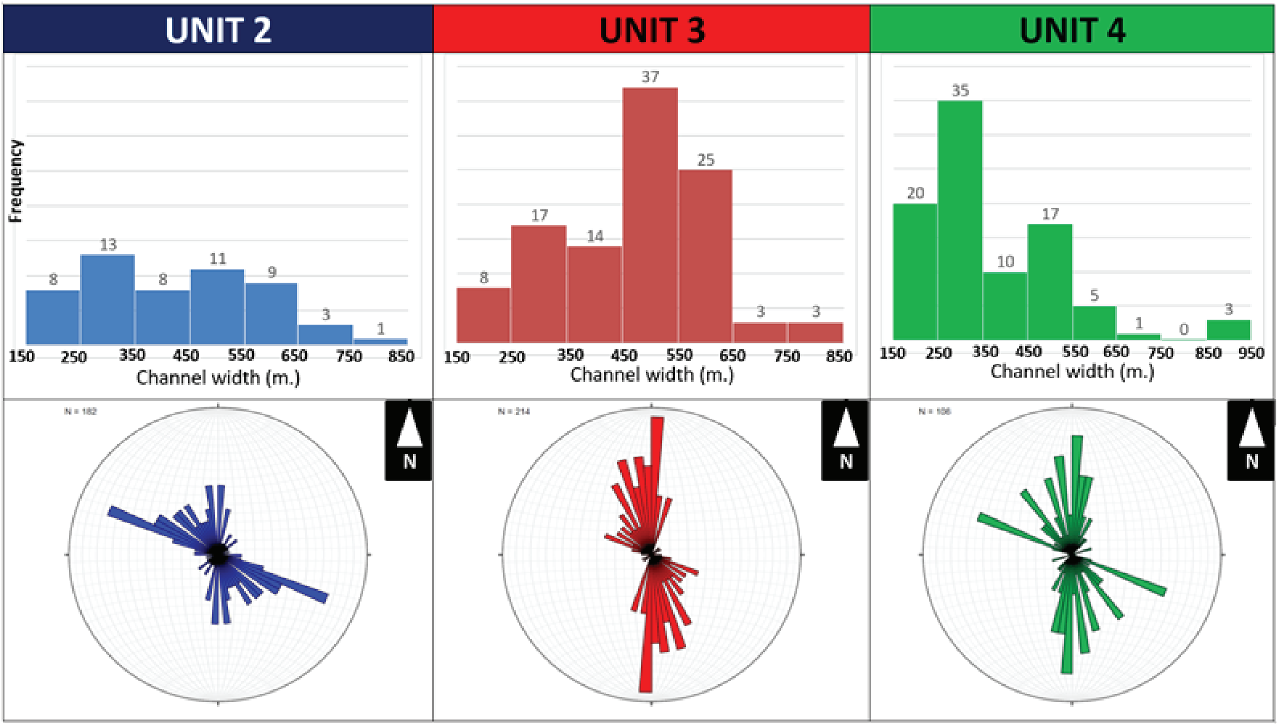

Figure 12. The summary of channel orientation and channel width have been measured on the interpreted channels on the horizon slices in each unit.

below 2,200 meters in unit 2 are due to the poor seismic resolution for imaging the reservoir distribution.

2. Trace envelope, sweetness and edge evidence attributes can also provide the imaging of reservoir distribution as shown in appendix 1. The result from the RMS and coherence provide better reservoir imaging than those attributes especially the channel boundary and high amplitude resolution distribution. Trace envelope, sweetness and edge evidence attributes also help mapping the reservoir distribution in this study area

3. Spectral decomposition responses in amplitude are confirmed as due to the tuning thickness of the sand by comparing the results at well locations. The spectral decomposition in this study was done only on Discrete Fourier Transform (DFT) algorithm and can detect the reservoir thickness at the specific depth ranges from 1,200 to 2,000 meters. The depth below 2,000 meters cannot provide the tuning of the reservoir thickness due to the poor seismic quality below this depth and the sand thickness below 10 meters. For further study, this study area requires more well information of sand distribution and connectivity to improve the spectral decomposition analysis accuracy. Another analysis which can help detecting reservoir thickness could be Continuous Wavelet Transform (CWT) that has different algorithm for spectral decomposition because CWT can help tackling problems involving signal identification and detection of hidden transients that are hard to detect, such as short-lived elements of a signal (Sriburee, 2012).

4. The reservoir distribution and mapping were done by the RMS amplitude map and coherence along the horizon slices subtracted from the seismic markers. The accuracy can be low along fault zone due to the inclination of faults together with the horizons being subtracted vertically across the faults shown as appendix 2. For more accuracy, the horizons need to be adjusted along the fault zone. At the deeper section, the RMS interval should be larger than the shallow section because the wavelength is increases with depth. This study uses the same interval because it covers the peak and trough event at the deep section. The mapping boundary of reservoir distribution is based on the sinuosity or channel-like feature of fluvial environment in the study area on the

RMS maps, while the straight lineations are interpreted as faults. The straight channel can be mis-interpreted using this technique and requires other evidence to confirm the straight channel. The fluid phase identification is difficult to distinguish in this area because of the density of oil and water being similar. For further studies, other techniques need to be tested to determine the fluid phase of the reservoirs.

9. Conclusions

The geophysical attributes were analyzed to detect reservoir sand distribution and orientation in the southern part of Pattani basin, Gulf of Thailand. The conclusions are summarized below.

1. P-impedance (Full angle stacked) and near angle elastic impedance can discriminate sand and shale in unit 2 and 4.

2. Far angle elastic impedance or far angle stacked volume can discriminate sand and shale in the reservoir interval – unit 2, 3 and 4

3. The RMS amplitude maps are useful to detect the reservoir distribution and orientation associated with single channel-like features until the depth of 2,200 meters.

4. The coherence attribute can help defining the channel edges of the reservoir distribution and orientation.

5. Far angle seismic volume provides higher resolution for detection of the reservoir of channel-like feature in the RMS attribute and coherence, especially in unit 3.

6. The response of spectral decomposition is different at different thickness of sands. The frequencies (31-41 Hz) show high amplitudes for thick sands (20m), while higher frequencies show bright amplitudes for relatively thinner sand beds.

7. The amplitude map of spectral decomposition provides the distribution of the tuning thickness at the well location.

8. The blind test wells show reasonable match with the high amplitude of RMS analysis and coherence.

9. The reservoir orientations generally range from Northwest – Southeast to North – South direction with moderate to high sinuosity in unit 2,3 and 4 (Lower to Middle Miocene).

10. The channel width in unit 2,3 and 4 (Lower to Middle Miocene) range from 150 to 950 meters wide and have different dominant channel width in each unit.

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