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USE OF SPECTRAL DECOMPOSITION AND OTHER SEISMIC ATTRIBUTES TO PREDICT SAND DISTRIBUTION IN SOUTHERN PATTANI BASIN, THAILAND

Amalia Kusuma Dewi

Petroleum Geoscience Program, Department Geology, Faculty of Science,
Chulalongkorn University, Bangkok 10330, Thailand
Corresponding author email: amaliadw99@gmail.com

Abstract

The study area has reservoirs that are thickening and thinning along pay zones and restricted in lateral distribution. Therefore it is necessary to have a better understanding of the distribution of sand to optimize the hydrocarbon recovery in this area. The objective of this study is to predict the sand distribution by using spectral decomposition and other seismic attributes such as Structurally-Oriented Filtering (SOF) and Similarity to have a better prediction of the hydrocarbon zones. Spectral decomposition techniques typically generate a continuous volume of instantaneous spectral attributes from broadband seismic data, to provide useful information for reservoir characterization and direct hydrocarbon detection (Partyka et al., 1999; Castagna et al., 2003; Liu and Marfuit, 2007). The filters in a filter bank for spectral decomposition are usually Gabor (a linear scale) or Morlet (an octave scale) wavelets, which have the property of minimum uncertainty. The property of the octave scale is to have the higher central frequency with a higher bandwidth. The linear scale has every central frequency with the same bandwidth. By using multiple frequency bands and comparing the result between octave and linear scale there may be additional insights about the thickness of the sand. Based on the amplitude characteristics of both sands, the results showed that the octave scale can be used to identify the sand distribution, but in order to identify the thickness of the sand and also distinguished between the two thin sands, the linear scale is the best method. Horizon slices, extracted from high-frequency volumes of the spectral decomposition show the spatial distribution of hydrocarbon which matches with existing well data. Hence, this technique is useful for identifying the sand distribution, sand thicknesses and hydrocarbon occurrence.

Keywords: Spectral Decomposition, Thin sand, Geosteering, thickening and thinning.

1. Introduction

The Pattani Basin of the Gulf of Thailand is one of the major hydrocarbon producing areas in Thailand. This hydrocarbon play is mature, thus sufficient to generate oil and gas. This study will focus on the southern part of the Pattani Basin (Figure 1), which is an oil discovery from Miocene stacked fluvial sandstones deposited on a North-South trending faulted basement high. The Miocene-age clastic reservoirs can be generally characterized as small-compartmentalized fluvial reservoirs (5-60 feet in thickness).

The reservoir sands are composed of multiple channel sands that have locally complex vertical and areal stacking patterns. These reservoirs are sometimes thin, quite marginal to develop and have restricted lateral distribution, thus there is a need to have a better understanding of sand distribution to optimize the hydrocarbon recovery in this area. This area requires a high evaluation of geological and stratigraphic features in its development efforts.

Previous drilling in the Pattani area only relied on structural traps and strong seismic anomalies. The CU-10D well is the first well to be drilled on the west side of a fault shadow disturbance on seismic data that occurs in the CU-2 area, and confirm oil reservoir presence. One of the objectives in this study is to identify sand distribution, especially on sand A and B. As oil discoveries become more complicated, developing oil fields such as CU field require more accurate and effective techniques.

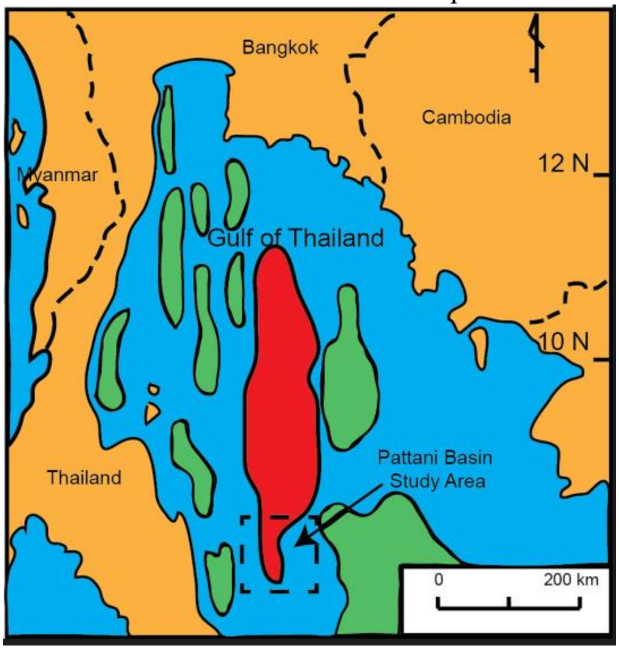

Figure 1. The study area is located in the southern of Pattani Basin, Thailand.

One of the technique that is often used to help analyze and interpret the subsurface geological feature is by using seismic attributes, such as Spectral Decomposition. Spectral decomposition has been used for a variety of applications including layer thickness determination (Partyka et al, 1999). In this research, I studied the spectral response of spectral decomposition in identifying the thickness of the sand and comparing it to the results of the drilling technique of geosteering inversion. When geosteering through a reservoir, the high resolution impedances calculated by the colored inversion ensure that the well is drilled through ideal reservoir. The aim of this study is to reduce the uncertainty of sand presence, predicting the thickness of the sand and optimize the hydrocarbon recovery in this area.

2. Methodology

2.1 Well to Seismic Tie

Well tie to seismic is a method used to match well log information with seismic character. In this study the CU-1D well was used as a checkshot data base. This well is located in the center of the area. A synthetic seismogram was generated from the sonic and density logs. The correlation between the synthetic seismogram and seismic reflectors forms a good match with reflectors (Figure 2).

The top marker of sand A and B are used as a guideline to interpret sand A and B along the seismic inline and crossline directions. Not all wells penetrate both layers of sand A and B. Some horizontal wells are drilled to optimize only one of the sand layers (Table 1).

The log response shows that sand B is characterized by a single layer of sand with a thickness varying from 14 feet to 40 feet, while sand A is thinner and consists of more than one layer of sand with variations in thickness from 5 feet to 20 feet (Figure 3). Summary of log responses of each wells shows that sand B is not well developed in CU-2D and 10D.

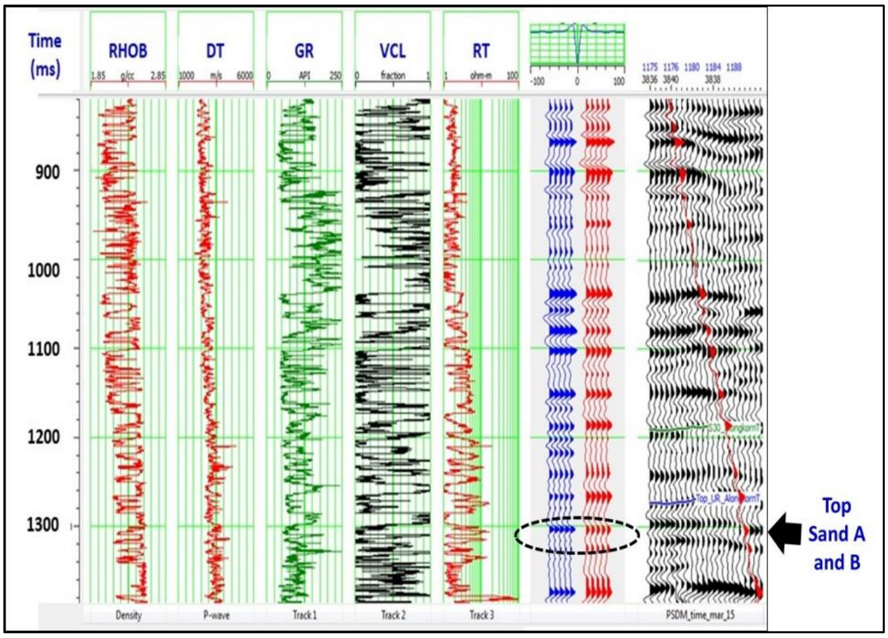

Figure 2. The synthetic seismogram of CU-1D. Top sand A and B is below Top UR. The synthetics were generated by using extracted wavelets from the well.

No	Well name	Type	Sand A	Sand B	Remarks
1	CU-1L	Deviated	N	Y	Poor pay count, converted to water injector
2	CU-1D	Deviated	Y	Y	
3	CU-2D	Deviated	N	N	Sand A dan B was not well developed
4	CU-10D	Deviated	N	N	No strong seismic anomaly exists on Sand B. Sand A and B was not well developed
5	CU-11D	Deviated	Y	Y	
6	CU-12D	Deviated	Y	Y	
7	CU-15H	Horizontal	N	Y	Objective Sand B
8	CU-16D	Deviated	Y	Y	
9	CU-18D	Deviated	Y	Y	
10	CU-19D	Deviated	Y	Y	
11	CU-21H	Horizontal	N	Y	Objective Sand B
12	CU-23H	Horizontal	N	Y	Objective Sand B
13	CU-27H	Horizontal	Y	Y	Objective Sand A
14	CU-29H	Horizontal	N	Y	Objective Sand B

Table 1. List of wells that encountered sand A and B. The main wells in this study are the horizontal wells, which is CU-15H, 21H, 23H, 27H and CU-29H.

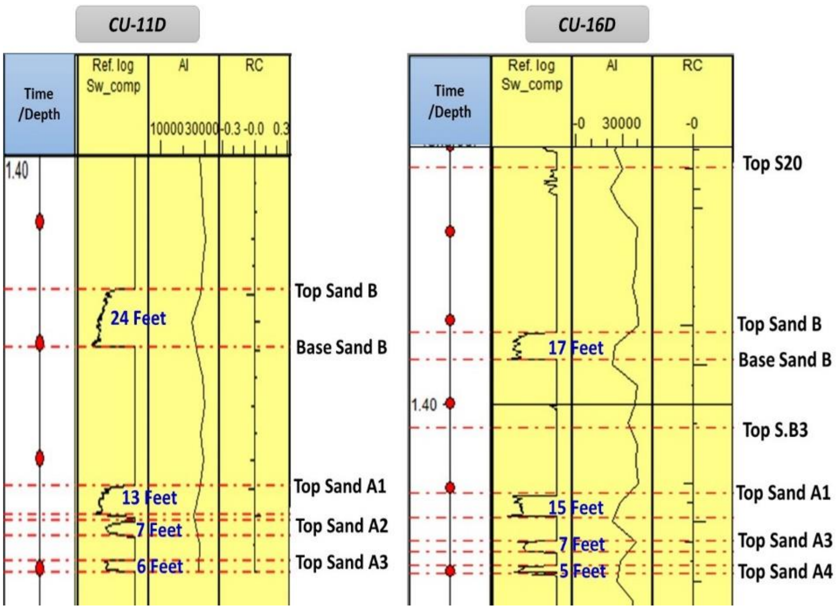

Figure 3. Well Logs showing characteristics of sand A and B in CU Field. Majority of sand B is thicker than sand A, but sand A consists of more than one layer of sand.

2.2 Horizon Interpretation

There are two horizons interpreted in this study, horizon of sand A and B. According to the well tie in seismic, due to the seismic resolution amplitude reflection on Sand A and B, sometimes the seismic image of the sands are separated and sometimes joined into one strong amplitude (Figure 4). Sand A and B are seen as a peak (black) overlying a trough (red). The horizon of sand B is easier to pick than the horizon of sand A, since no wells encounters sand A on the south and east part of the study area.

2.3 Time and Depth Structure

This study area has NW-SE and N-S main fault trends with some potential fault shadow distortion in the northern part of the area. The trap in this field is a structural trap, which is dominated by a three-way dip closure located within the up-thrown footwall of an eastward dipping normal fault zone. There is also a stratigraphic trap component as the sand was found overlapping and pinching out in an east direction over the Middle Tertiary Unconformity (MTU) Unit. This study will focus on the western part of the region, which is a well proven and high structure area. The highlighted area (blue circle) in Figure 5 is the area with minor faulting and most of the wells are located this area.

2.4 Spectral Decomposition

Spectral decomposition of spectral data was described by Partyka et al. (1999). Over the last decade, spectral decomposition has become a well-established tool that helps in the analysis of subtle stratigraphic plays and fractured reservoirs.

Spectral decomposition (SD) is a way of viewing discrete elements of the data by looking at a band limited section of the frequency spectrum that can give a greater insight into the information contained within the data.

SD converts seismic data to the frequency domain by using Discrete Fourier Transform (DFT) or Maximum Entropy Method (MEM). The input to spectral decomposition is a seismic volume and the output to be several volumes, each one representing a different frequency band (Figure 6).

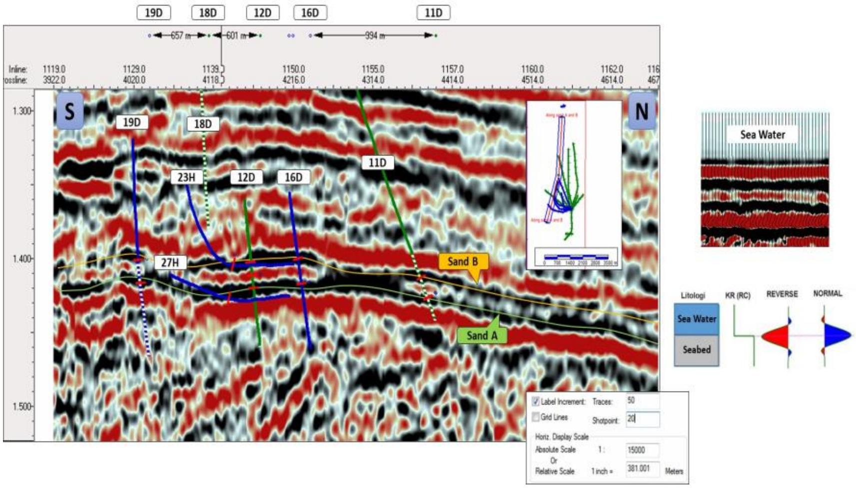

Figure 4. Seismic response in Sand A and B based on the wells. The sand A and B are displayed as a peak (black). Seismic data was processed to zero phase negative standard polarity.

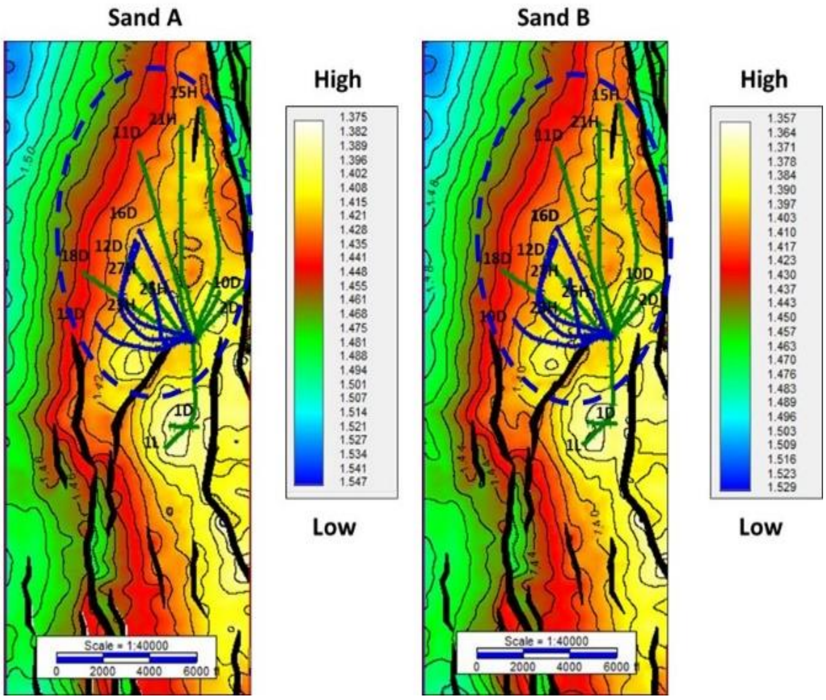

Figure 5. Time Structure Maps of Sand A and B, with map scale in feet. All the well displayed are in the high structure and the geosteering wells are horizontal wells with symbol H.

Spectral decomposition is run in order to analyze different frequencies of the seismic volume to observe the different bands and to examine each band volume. The frequency cubes that result from the SD process can potentially be used to map variations in bed thickness, geologic discontinuities and differentiation of fluids in the reservoir.

Spectral Decomposition in IHS Kingdom Suite Software is broken down into the Envelope Sub-Band and Trace Sub-Band. SD Envelope Sub-Band is the amplitude envelope of the frequency bands that show a better image for amplitude anomalies at different frequencies, while SD Trace Sub-Band shows traces at different frequency bands.

The filters in a filter bank for spectral decomposition are usually Gabor or Morlet wavelets, which have the property of minimum uncertainty. Gabor and Morlet wavelets are essentially the same: both are formed as the product of a Gaussian window with a complex sinusoid (Barnes, 2016). Figure 7 shows the distinction between them is how they behave in a filter bank. Gabor wavelets all have the same length, envelope, bandwidth, and spectral shape, while Morlet wavelets, all have the same form derived by stretching or squeezing a basis wavelet, or “mother wavelet” (Barnes, 2016).

Morlet wavelets provide sharper images at higher frequencies because they are shorter, and they provide more reliable images at low frequencies because they are longer. These properties offer a distinct advantage in the analysis of thin beds over a wide range of thicknesses. Gabor wavelets have trouble with thick or thin features because they have fixed length.

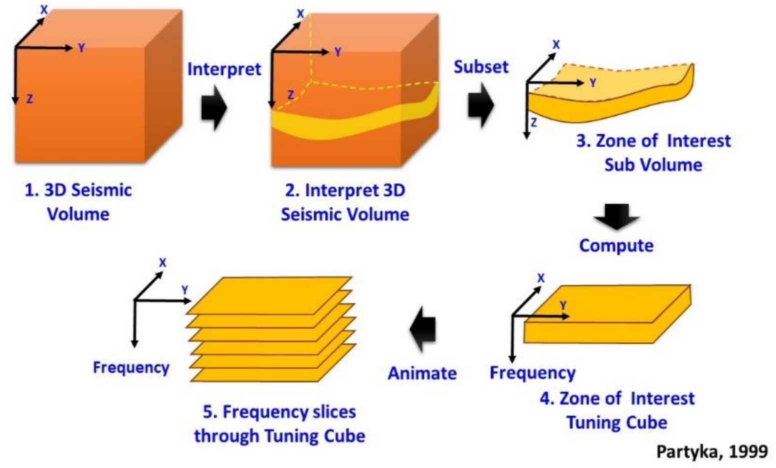

Figure 6. The process of spectral decomposition attributes. Animating through a series of frequencies along an interpreted horizon allows an interpreter to identify where strata are thinning and thickening (Chopra & Marfurt, 2008).

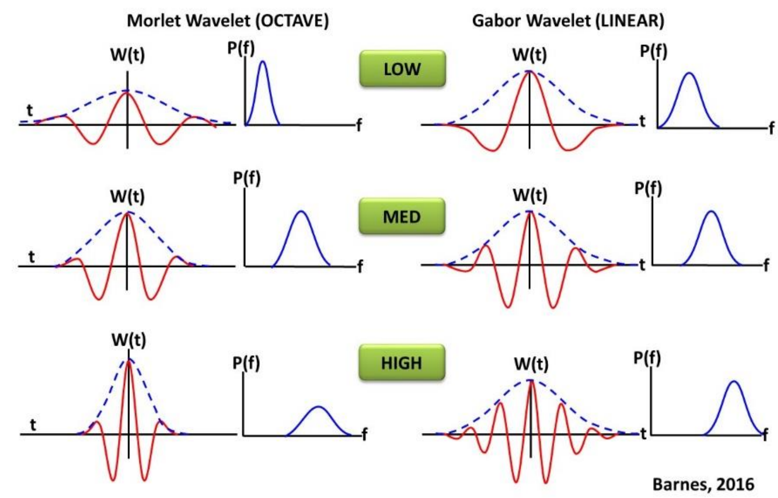

Figure 7. Morlet and Gabor Wavelets and their power spectra. Blue dashed lines are envelopes. (Barnes, 2016).

A wavelet that is longer than a thin bed will likely overlap other reflections that mask the thin bed response. A wavelet that is shorter than the thin bed cannot capture it fully to define its tuning frequency. At low frequencies, Gabor wavelets produce maps that resemble average amplitude. A disadvantage of Morlet wavelets is that a high-frequency map represents less data than a low-frequency map, which complicates comparison. In contrast, a set of frequency maps created with Gabor wavelets all represent the same interval of data because the Gabor wavelets have constant length. In general, Morlet wavelets are preferable in spectral decomposition (Barnes, 2016).

Morlet wavelet is known as an octave scale while Gabor wavelet is known as a linear scale. The octave scale, the higher central frequency will have higher bandwidth while the linear scale, every central frequency has the same bandwidth. For purposes of comparison, both linear and octave scales were used for banding.

The study started by analyzing the influence of layer thickness on a frequency response, especially when the layer is very thin. In this area, the spacing between sand A and B is only 100 feet, and it is necessary to ensure that there is no overlapping reflection on both sands.

By using spectral decomposition attribute, the seismic data can respond for each frequency in different ways (higher frequency, shorter wavelength for detecting thin channel). At a specific frequency band, certain structures are more visible due to tuning thickness. This means that, instead of looking at one volume for a cube of stacked data, interpreters are able to view several of them and see if any single one is better to image a structure or geomorphologic feature (Subrahmanyam and Rao, 2008). This attribute is very useful for solving the problem of thin-bed sand layers. In general, thinner beds will be better displayed with a higher frequency component and thicker beds with a lower frequency.

2.4 Geosteering

Geosteering is a technique for the optimal placement of a wellbore based on the results of real time downhole geological and geophysical logging measurements. The objective is to keep a directional wellbore within a hydrocarbon pay zone defined in terms of its resistivity, density or even biostratigraphy. In the process of drilling a borehole, geosteering is the act of adjusting the borehole position which is inclination and azimuth angles, on-the-fly to reach one or more geological targets. Nowadays, in mature development areas, geosteerings are also used to minimize gas or water breakthrough.

In this study, there are five (5) wells drilled horizontally by using the geosteering technique, which are CU-15H, CU-21H, CU-23H, CU-27H and CU-29H. The target is to drill along the sand B, except the CU-27H well. The CU-21H is the only well that did not have an inversion volume on the report. Inversion volume is the volume generated from the process of transforming the seismic reflection data into a quantitative rock-property such as porosity, permeability or other rock properties of the reservoir. This is to increase the resolution and reliability of the data and to improve estimation of rock properties including porosity and net pay.

Result and Discussion

In this study area, the spectral decomposition method was used to extract the characteristic frequency component to determine the frequency anomalies associated with sand A and B, which are thin layers. The dominant frequency band (Figure 8), between 10 – 60 Hz was considered for slice generation and estimation of tuning frequency. Spectral sub-bands that lie outside or partially outside the frequency spectrum of the original data, will give inaccurate measurements of tuning, especially at the lower end of the frequency spectrum.

Tuning thickness is usually computed as one quarter of the wavelength, the Rayleigh criterion, but this is subjective and depends on the noise level in the data. Wavelength increases with depth in the Earth because velocity increases and frequency decreases. Thus, seismic reflection surveys lose resolution with increasing depth in Earth. At a higher frequency, finer scale layering can be resolved by using 1/4 to 1/8 the dominant wavelength, but at a low frequency, detail is lost.

Sometimes the quarter-wavelength criterion is too generous, particularly when the reflection coefficient is small and no reflection event is discernable. Sometimes the criterion may be too stringent, particularly when events do exist and their amplitudes can be picked with ease. For example, a shallow feature with a 2000-m/s velocity and 50-Hz dominant frequency potentially can be resolved if it is as thin as 10 m or 33 feet. A thinner feature cannot be resolved. Similarly, for a deep feature with a velocity as high as 5000 m/s and dominant frequency as low as 20 Hz, the thickness must be at least 62 m or 203 feet for it to be resolvable.

The zone of interest chosen for detailed analysis within the seismic volume is 1.3 to 1.55 seconds. The frequency spectrum of the data falls between 0 to 120 Hz (Figure 8) with the dominant frequency range of 10 to 60 Hz and a mode frequency of 30 Hz. The average sonic velocity in this range is 12,000 ft/sec, and if the thickness of the sand is 25 feet or less, then it takes frequencies above 30 Hz to resolve this thickness.

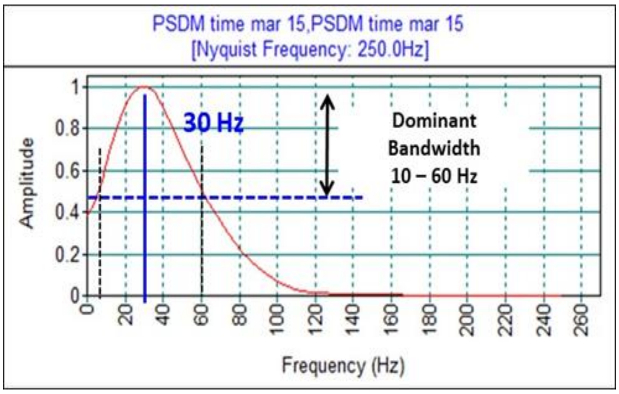

Figure 8. Computed Frequency Spectrum from 1.3 to 1.55 seconds.

The wedge model tuning analysis indicates a tuning thickness two-way travel time of 15 ms. From these results the tuning thickness or vertical resolution of seismic data can be calculated as follows:

¼ Wavelength of Dominant Frequency

Wavelength = Interval Velocity / Dominant Frequency

- 12,000 (Feet/Sec) / 30 Hz = 400

Tuning Thickness = Wavelength / 4 or 400 / 4 = 100 Feet

Tuning Thickness in TWT is 0.015 Sec (Dominant Peak)

Tuning thickness (TWT) / 2 * Interval Velocity = Tuning Thickness

- (0.015/2) * 12,000 = 90 Feet

The study started by analyzing the influence of layer thickness on the frequency response, especially when the layer thickness is less than one-fourth wavelength.

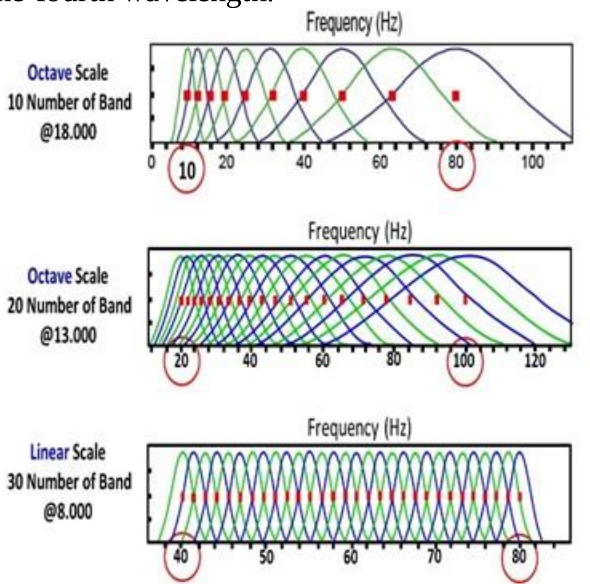

Figure 9. Multiple scaled window used in this study.

Because in this area, the reflected events from top layer to bottom layer overlap and produce a compound signal whose peak frequency depends on thickness. After layer thickness increases beyond one-fourth wavelength, the two events can be separated in two-way travel time.

This study compared three different scaled windows, first is an octave scale from 10 Hz to 80 Hz by using 10 numbers of bands with 18K as a cut off amplitude, the second is an octave scale from 20 Hz to 100 Hz by using 20 numbers of bands with 13K as a cut off amplitude and the last one is a linear scale from 40 Hz to 80 Hz by using 30 numbers of bands with 8K as a cut off amplitude (Figure 9). Every scaled window has a different maximum amplitude used depending on the width of the bandwidth.

Trace sub-band shown in Figure 10 results in the best image to view channels or faults that can help to identify prospects as well as confirm trapping or sealing for a prospect. In a vertical view, envelope sub-band can give the best image to view the thickness of the sand.

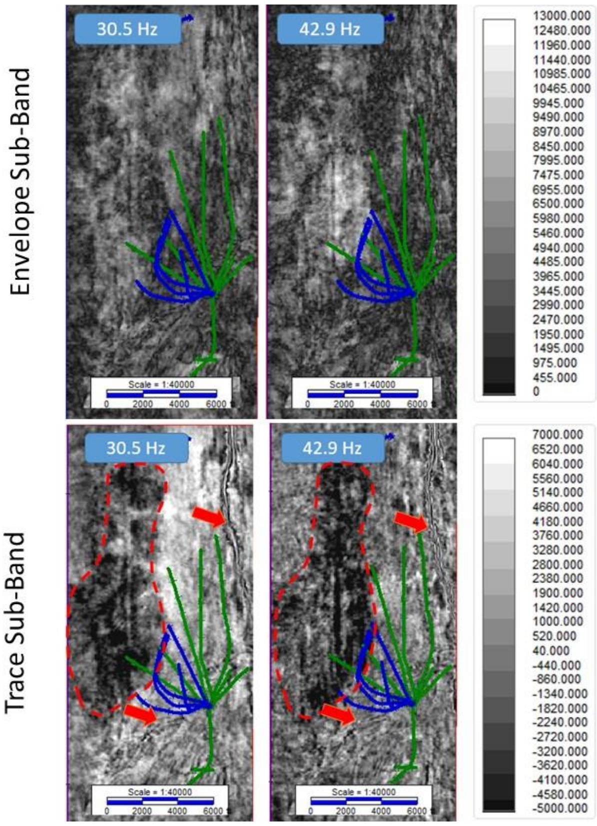

Figure 10. Comparison between Envelope Sub-Band and Trace Sub-Band in Horizon slice with different frequency by using Octave scale with 20 numbers of bands. Trace Sub-Band result in a better view of faults (red arrows) and sand body imaging in a dark color (red dashed). Map scale in feet.

In order to distinguish between envelope methods in high and low frequency, Figures 11a and 11b shows vertical sections through representative envelopes in CU-23H. Highest amplitude shows in a bright color and indicate the frequency closest to tuning for sand A and B.

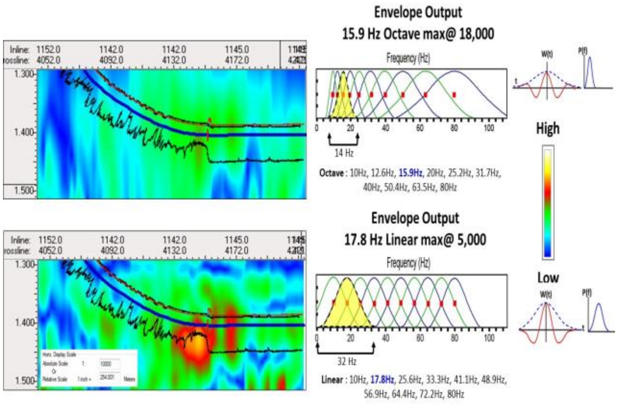

Figure 11a. Envelope Output in low frequency, with 10 numbers of bands in Octave and Linear scale. Between Octave and Linear, the results looks very difference, because Octave has a wider wavelet but narrow bandwidth that may provide a more reliable image because they are longer, while Linear has constant wavelet in a wider bandwidth that might combine thin and thick sands.

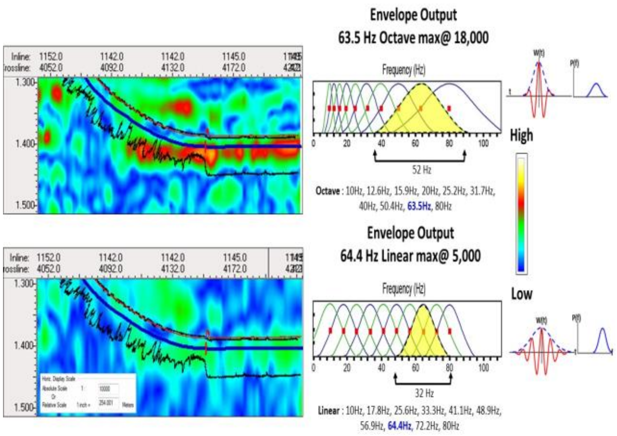

Figure 11b. Envelope Output in high frequency, with 10 numbers of bands in Octave and Linear scale. Octave wavelets provide sharper images at higher frequencies because they are shorter, but it is possible to merge between two thin sands. The linear scale looks smeared, but it has good resolution in small extract window with narrow bandwidth range, this is probably the best method to identify between two thin sand layers.

Figure 12 through 15 shows comparison between geosteering inversions with the multiple scaled windows of spectral decomposition. Refer to CU-23H well on Figure 12, the octave-scale with 10 numbers of bands does not reflect the true thickness of sand A or B due to at low frequencies, the width of the band will merge reflection of both sands.

Sand B in CU-23H well is dominated by a thickness above 20 feet, so at a frequency of 46.9 Hz the SD already represents the same reflection as a geosteering inversion. Whereas, sand A which is dominated by a thickness of less than 20 feet needs higher frequencies to provide the same reflection as geosteering inversion.

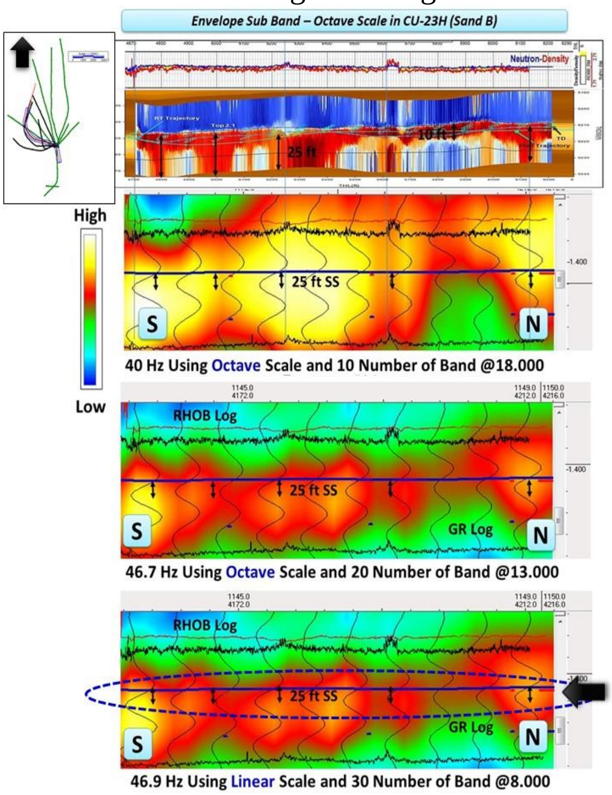

Figure 12. Comparison of CU-23H Horizontal wells. By converting to a linear scale with 30 numbers of bands, the thickness of sand A and B in CU-23H appears to have almost the same thickness pattern, so that there is no visible difference in thickness between sand A and B. Highlighted blue dashed oval shows the best match with the geosteering feature.

By increasing the numbers of bands into 20, the width still merges reflections of the sands. According to the distance between sand A and B which is only 100 feet, an increase in the numbers of bands does not give a significant difference and has not been able to show the actual thickness of each sand.

The sand thickness along the horizontal section in CU-29H well (Figure 13) is only 10 feet and thinner than CU-23H (Figure 12), so it needs a higher frequency to resolve the thickness. The lower frequencies associated with thicker sand will be shown by the red or yellow on spectral decomposition, whereas the higher frequencies associated with the thinner sands will be shown in light green or light blue. Then for sand thickness less than 25 feet, spectral decomposition will not show red or yellow color but only light green or light blue color.

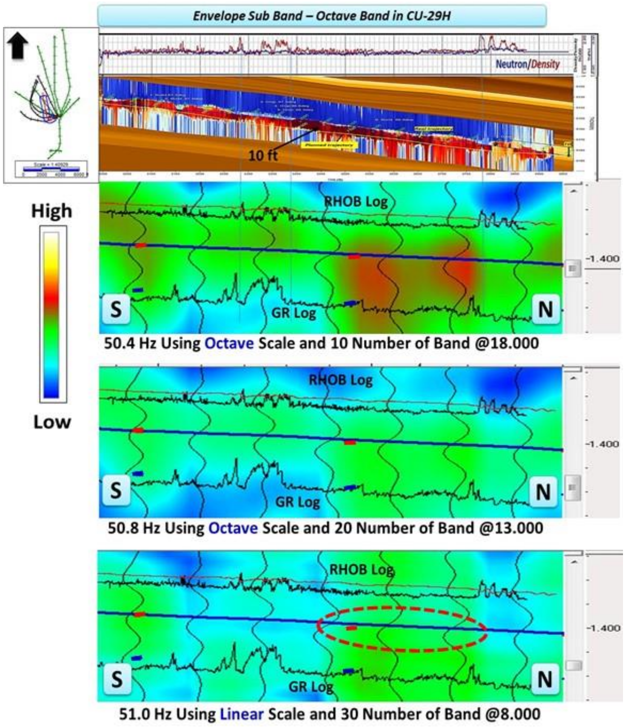

Figure 13. Comparison of CU-29H Horizontal wells. Blue line is a real trajectory of the well, red dotted is the horizon of sand B while the blue dotted is the horizon of sand A. Using an Octave scale of 10 or 20 numbers of bands, the pattern of the thickness looks similar between sand A and B, but using a linear scale with 30 numbers of bands, red circle dashed showed that the sand B is thinner than sand A.

The CU-15H well penetrated the sand at the first horizontal section and then penetrated shale at total depth (TD) (Figure 14). By using higher frequencies to resolve the thickness, the interpreter expects the octave scale with 10 numbers of bands was able to see the boundary when the well penetrates the shale through the TD, but the octave scale with 10 and 20 numbers of bands indicates that the well is visible through the sand instead of shale. With linear scale 30 numbers of bands, it can show similar pattern with geosteering inversion, the shale shows with a dark blue and light blue color. Refer to CU-23H, CU-29H and CU-15H wells, by using a linear scale with 30 numbers of bands is able to distinguish between sand thickness A and B

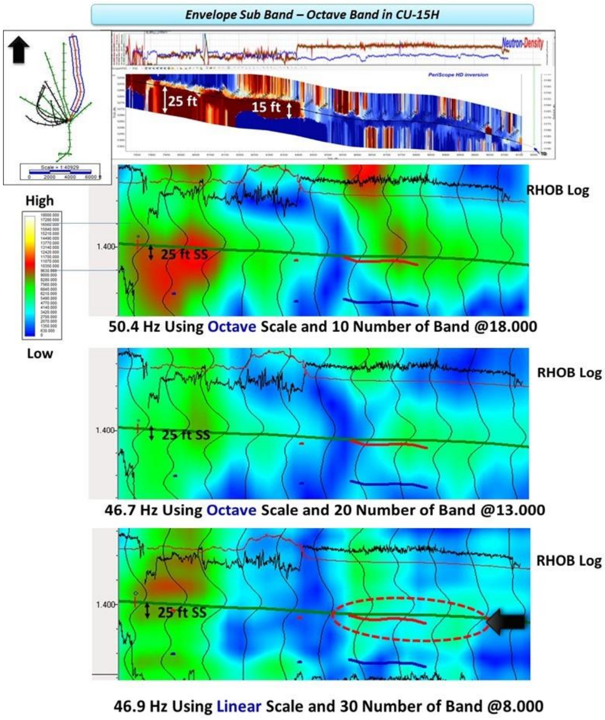

Figure 14. Comparison of CU-15H Horizontal wells. Green line is a real trajectory of the well, red line is the horizon of sand B while the blue line is the horizon of sand A. The lower frequencies associated with thicker sand will be shown by the red or yellow on spectral decomposition, whereas the higher frequencies associated with the thinner sands will be shown in light green or light blue. Refer to the geosteering image, the area in a dotted red circle should be blue or show a darker color.

The CU-27H well is the only geoosteering project that penetrates along sand A (Figure 15). The octave scale with 10 or 20 numbers of bands will merge both of the sands, then the reflection will not shows the real thickness of each sand.

The linear scale with 30 numbers of bands in this well does not show exactly the same pattern as the geosteering inversion, although this scale is better than the use of octave scale.

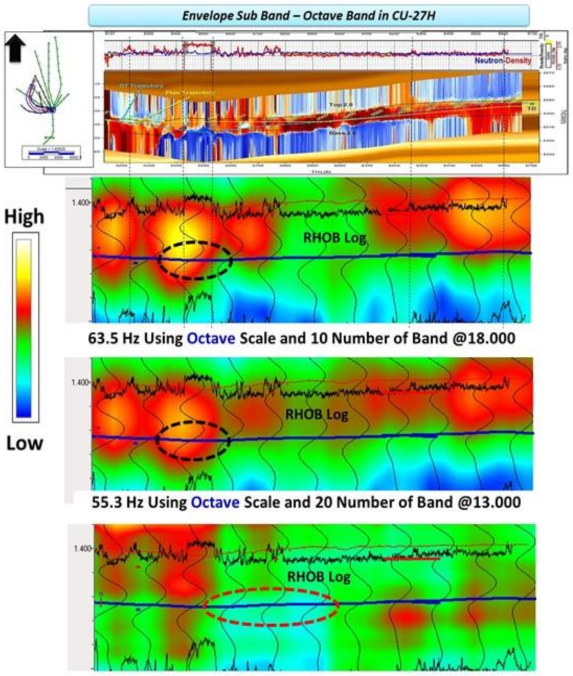

Figure 15. Comparison of CU-27H Horizontal wells. Due to the thin multiple sand layers in sand A, the linear scale with 30 numbers of bands in this well does not show exactly the same pattern as the geosteering inversion. Refer to the geosteering image, the black dashed oval should not show a bright red color because the well did not encounter a thick sand on that area. The closest match is to use a linear scale with 30 band numbers, although the red dashed marks should look greener.

The accuracy of thickness of spectral decomposition predictions against geosteering inversion results is 75%. According to the characteristics of sand A and B in amplitude that are sometimes separated and sometimes joined into one strong amplitude (Figure 5), it was decided to use an octave scale with 10 numbers of bands as a horizon map to identify the sand distribution in this field. Based on the horizon map of sand A and B (Figure 16 and 17), good quality sand wells are marked with yellow dots, while poor quality sand wells are marked with light brown dots.

There were 5 of 6 existing development wells proven to have good sand quality even though they were not drilled based on spectral decomposition predictions.

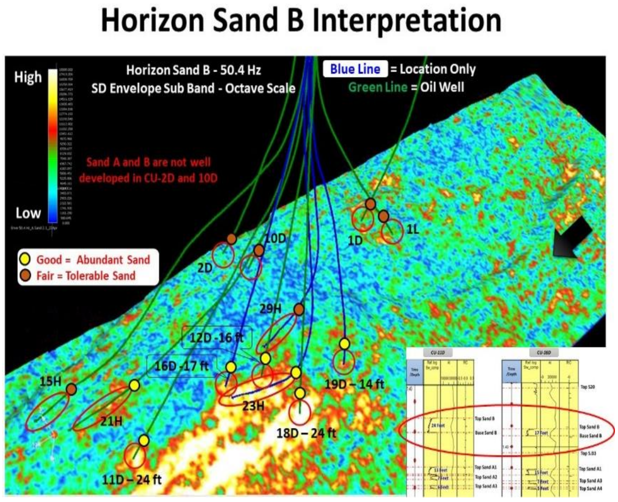

Figure 16. Horizon sand B in 50.4 Hz using Octave scale with 10 Numbers of Bands. Good and fair quality based on the sand content proven by geosteering prediction. The SD attributes is proven to improve the prediction of sand B distribution to 100%.

Figure 17. Horizon sand A at 50.4 Hz using Octave scale with 10 numbers of bands. Due to the characteristics of sand A which consists of more than one layer and is also thinner than sand B, then at a frequency of 50.4 Hz it can only provide 60-70% accuracy because the resolution may overlap other reflections that mask the thin bed response.

Spectral Decomposition can predict well against the presence of sand with good or fair quality sand of geosteering wells. If a new well drilled in the predicted area by using spectral decomposition, it will have a 100% success ratio in finding sand A and B.

Figure 18. Sand B distribution by using Trace Sub-Band with Octave scale and 10 numbers of bands. There is no significant difference in the distribution of sand B between the use of 40 Hz and 50.4 Hz.

Figure 19. Sand A distribution by using Trace Sub-Band with Octave scale and 10 numbers of bands. Due to the thin multiple sand layer in sand A, it is better to use 40 Hz as a predicted sand A distribution, although it needs to be used cautiously due to lower predictability compared to present wells.

There is a need to consider the use of 40 Hz frequency to identify sand A distribution, due to their characteristic of being more than one thin layer sand that cannot be distinguished or becomes a merge of multiple sands, thus the thickness is thicker than sand B (Figure 19). The horizon map of sand A and B shows that the distribution of the sand is mostly concentrated in the North-West part of the field.

Using Trace Sub-Band with an octave scale at 40 Hz and 50.4 Hz of 10 numbers of bands, we can see the overlap between these frequencies to identify the sand distribution in CU field. The maps indicate that sand A and B have similar distribution pattern (Figure 18 and 19).

Conclusion

The objective of this study is to predict the sand distribution by using spectral decomposition and other seismic attributes to have a better prediction of the hydrocarbon zones in the southern part of Pattani Basin, Thailand.
Below are some conclusions from the study:

1. The extraction of spectral decomposition attributes from seismic data can reveal structures that cannot usually be mapped by using conventional amplitude processing.
2. The use of linear scales in spectral decomposition proves a better method for distinguishing between two equally thin layers in a vertical view, whereas the use of octave scale can be used as a prediction of the distribution of sand at the horizon view. To achieve the best results for identifying thicknesses, it is necessary to use the correct band method and the numbers of bands to be able to distinguish exactly between the two thin sands.
3. Based on comparison with the geosteering inversion, it is inferred that the thickening and thinning of the sand can be differentiated by using spectral decomposition attribute with linear scale at higher frequencies 40 – 60 Hz.
4. The octave scale on a spectral decomposition can be used to identify the sand distribution by comparing the characteristic amplitude of both sands,

which is sometimes separated and sometimes joined into one strong amplitude.

5. Sand distribution maps are generally North-South trending on the western part of the CU Field, which agrees with the existing wells.
6. In areas where there is a poor comparison between the geosteering inversion and spectral decomposition the results may be due to scale difference (one-tenth of the seismic scale), inaccurate well positions or an incorrect time-depth relationship.

By using the predicted sand distribution of spectral decomposition, which is located on the northwest side of the field, the risk of not finding hydrocarbons can be reduced. The best maps for sand prediction are horizon maps by using Trace Sub-Band with 10 numbers of bands. These can be used for further step-out development locations and exploration wells. From the sand distribution map, the main trapping mechanism is stratigraphic pinch-out traps in an east direction against the basement.

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