Reservoir Imaging Using Seismic Attributes, Pattani Basin, Thailand

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Abstract

In the Pattani Basin, Gulf of Thailand, the sand reservoirs of Sand A and Sand B are studied by using seismic attributes to image the reservoir. The reservoirs are Late Miocene age and comprise of moderate to high porosity and permeability sandstones with enclosing mudstone. Seismic attributes are useful for interpreting and presenting as much reservoir detail as possible. The attributes were created by using full stack and partial stack of 3D seismic processing data, well log data and geo-steering data. The first part of the study was aimed to improve seismic quality for understanding sand body distribution. The geological data from well drilling, especially from the results of geo-steering, was compared to seismic attributes to define the distribution of thin sand reservoir in Sand A and Sand B. The Middle-Tertiary Unconform-ity (MTU) that occurs below the reservoir was also mapped using seismic attributes. The seismic attributes include structural orientation filtering, similarity series, geometry attributes, and instantaneous attributes. The attributes were used to improve and identify reservoir distribution images. The result of using seismic attributes for reflector continuity enhancement, structural smoothing or structural orientation filtered is the best for recognizing the discontinuity reflector for unconformity identification. Similarity attribute is used for checking the quality of processing and acquisition before combining with other seismic attributes. The smooth dip of maximum similarity is an interesting attribute for identifying the unconformity of the MTU on the boundary of the basement high. The best sand reservoir identification attribute is the relative acoustic impedance attribute volume that was used with well log data for proving the sand distribution and imaging sand-predictive maps. Multiattribute and composite attributes that are generated from two different seismic attributes can image reservoir distribution within sedimentary basin and depositional features in one image.

Keywords: Reservoir imaging, Seismic attributes, Relative acoustic impedance, Multiattribute, Composite attribute, Pattani basin

1. Introduction

In the Gulf of Thailand, the Tertiary age Pattani Basin is the most productive hydrocarbon bearing basin in Thailand. The target main reservoirs in this study area are the sand A, B that are deposited above the Middle-Tertiary Unconformity (MTU).

1.1 Objectives

The aim of this research is to achieve reservoir imaging by generating seismic attributes for identifying the unconformity and the overlying reservoirs by improving seismic quality for understanding sand body distribution based on geo-steering and controlled wells data and comparing between a new analog of seismic attributes used to identify the Mid-Tertiary Unconformity and specifically to define distribution of thin sand reservoirs.

1.2 General Geology

The Pattani Basin is the deepest and the longest of rift basins in Thailand (Figure 1). This basin is divided into three parts by location including; northern, central and southern parts. (Morley & Racey, 2011). The basin is the result from the tectonic collision of Indian plate with the Eurasian Plate that generated rifting in east-west direction from north-south compression to form the Pattani Basin. The South Pattani basin is a half-graben rift basin that opened in the Cenozoic following the Indian-Eurasian collision.

The regional stratigraphic succession contains a series of Tertiary sediments overlying a pre-Tertiary basement (Figure 2). In this study area, the reservoirs are believed to be Early Miocene and/or Late Oligocene ages and dominantly comprise of moderate to high porosity and high permeability sandstones, enclosed with mudstones. This prospect is called the Lower Reservoir section that is dominated by thicker mudstone interval containing thinly bedded sandstones and siltstones. Lacustrine and/or fluvial environments are the interpreted depositional environments of the reservoirs.

1.3 Seismic Attributes

A seismic attribute is any measure of seismic data that helps the interpreter to visually enhance and quantify features of interpretation interest. Seismic attributes are a powerful aid to seismic interpretation (Chopra and Marfurt, 2007). This study will use geometrical attributes and instantaneous attributes. The instantaneous attributes such as instantaneous phase with the geometrical attributes including curvature, similarity, dip of maximum similarity, instantaneous lateral continuity and shale indicator were used for identifying the unconformity. The attributes used for identifying sand reservoir were instantaneous attributes that consist of sweetness, trace envelope, instantaneous frequency. Relative acoustic impedance was also used in this study.

1.4 Data Availability

The study is based on 3D seismic cube of Prestack depth migration (PSDM) with area coverage of 62 km^2. The research area lies on the southern Pattani Basin. Record length is 3.6 seconds, while sample interval is 0.002 seconds with frequency range from 1-140 Hz. Polarity is reverse polarity. There is wireline data from 17 wells with time-depth log and conventional logs that consist of deviated and horizontal or geosteering wells (Figure 3).

1.5 Methodology

The well log data from 17 wells and full-partial stacks seismic data were used in this study.

Well log data was used for well tie to seismic and top of sand formation used with rock physic analysis from wells. From 3D stack seismic, it was used to study seismic attributes for identifying unconformity and sand reservoirs. Then, choosing the optimum attribute from the results a combining of attributes produce composite attributes and multiattributes.

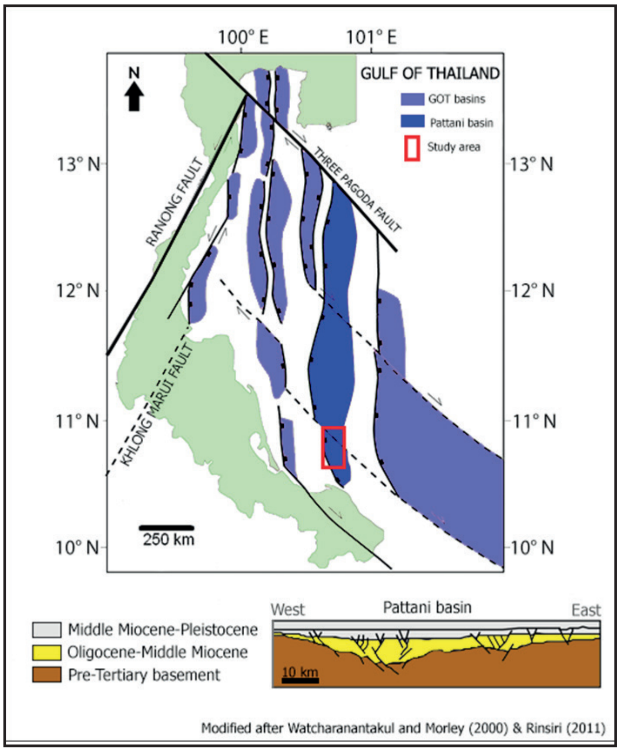

Figure 1 Illustration of regional tectonic map of Gulf of Thailand with cross-section of Pattani basin shows the location of study area in red box. The structural pattern is the result from tectonic collision of Indian plate with the Eurasian Plate that has generated Pattani basin rifting.

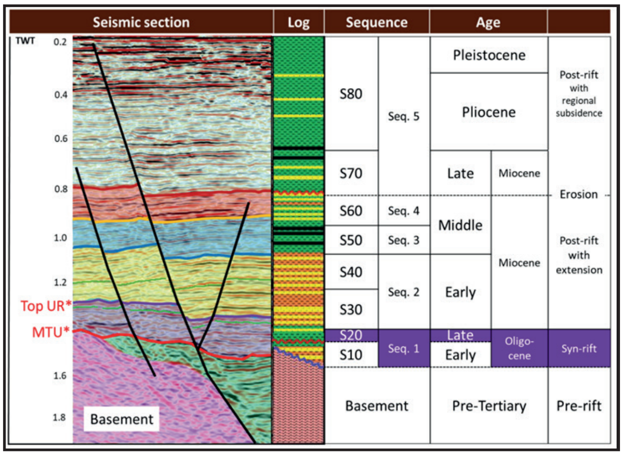

Figure 2 Illustration of stratigraphic column contains the number of sequence with the age occurring and tectonic events comparing with seismic section from study area, the interested zone is located at S20, sequence 1 in Late Oligocene syn-rift deposition as highlighted in purple. It is divided by the top of Middle Tertiary Unconformity (MTU) (red line) and Top of upper reservoir (Top UR) (Purple line).

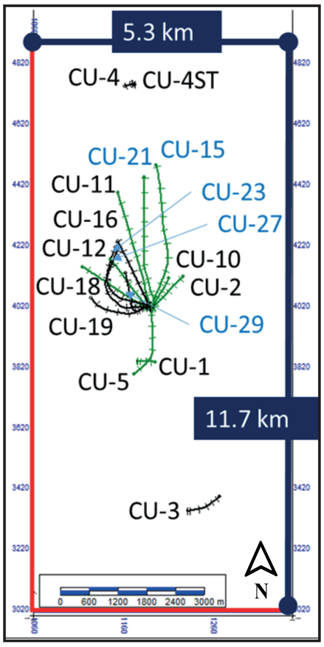

Figure 3 Well distribution and location in study area and aerial size measurement. 12 deviated wells are specified by black color letter. 5 geosteering well are specified by blue color letter.

2. Results

2.1 Seismic attributes for reflector continuity enhancement

Structural smoothed volume, which removed the incoherent data, can better show the discontinuity reflector on basement high and sharpen the fault images. So, the structural smooth volume was selected to test in other coherency attributes for unconformity detection and in unconformity identification (Figure 4).

Similarity attribute is the attribute for checking the quality of processing and acquisition before using it in the other attribute. This attribute in full-stack volume can image some small faults better than the similarity attribute in partial stack volumes by using parameter from Table 1. Moreover, it was tested to produce the optimum volume by using different parameters. (Figure 5).

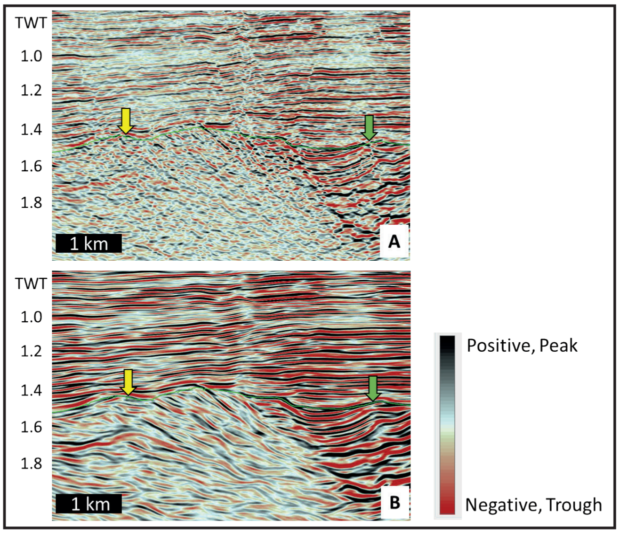

Figure 4 Seismic section along crossline 3850 A) Original of Full-stack seismic volume B) seismic volume after Structural orientation filtered (SOF) Arrows point down to Middle-Tertiary Unconformity (MTU) dividing between; yellows arrows point the contact between sand reservoir and basement high, green arrows point the contact between sand reservoir and another lower sand (S10).

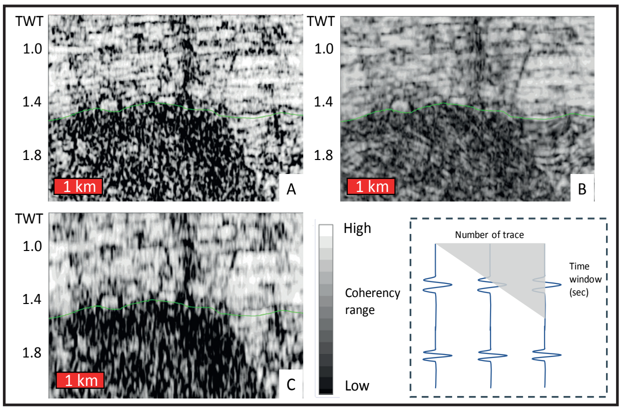

Figure 5 The result by adjusting parameter with the same bandpass when it runs in seismic attribute A) Similarity attribute result by using parameter from Table 1 B) Similarity attribute result with adjusting dip scan parameter, which are number of trace (3), max dip (0.032 sec/trace), and dip scan increment (0.004 sec/trace) C) Similarity attribute result with adjusting time window from similarity (0.008 sec). Image from A can shows a greater resolution than others.

2.2 Seismic attribute for unconformity identification

Smoothed dip of max similarity low pass filters the dip of their maximum similarity value to evaluate the averages over longer windows.

The result of using different attributes revealed that the smoothed dip of maximum similarity in Figure 6C has the best result. This attribute was able to illustrate the unconformity of MTU with the basement hight at the center of study area. The extent of the unconformity in the center of area was highlighted by the hight value.

Table 1 Seismic attribute parameter that are used for attributes in this study

Bandpass	
Low Cut Frequency	8 Hz
Low Cut Slope	12 db/octave
High Cut Frequency	55 Hz
High Cut Slope	24 db/octave
Dip Scan	
Number of Traces	3
Max Dip	0.016 sec/trace
Dip Scan Increment	0.002 sec/trace
Similarity	
Time Window	0.04 sec
Variance	
Time Window	0.12 sec

Instantaneous phase attribute is the only one instantaneous attribute that can be used for identifying unconformity. It is computed by a function for giving the results of phase in each reflector. By using the change of phase of seismic, it can show varies zones of phase, especially, at basement high anomalous zones.

2.3 Seismic attribute for sand reservoir identification

Relative acoustic impedance attribute at sand horizons is the recommended attribute by combining with RMS amplitude extraction or volume attribute method within the interested window along horizon. The relative acoustic impedance is showing the contrasting of any acoustic impedance (AI) in interested interval, a positive value indicated a positive contrast of AI and a negative value referred to a negative contrast. It can be used to predict each of the sand bodies distribution. Comparing between Sand A and Sand B, the value of relative acoustic impedance attribute in Sand A is higher than Sand B. By adjusting dip scan parameters including number

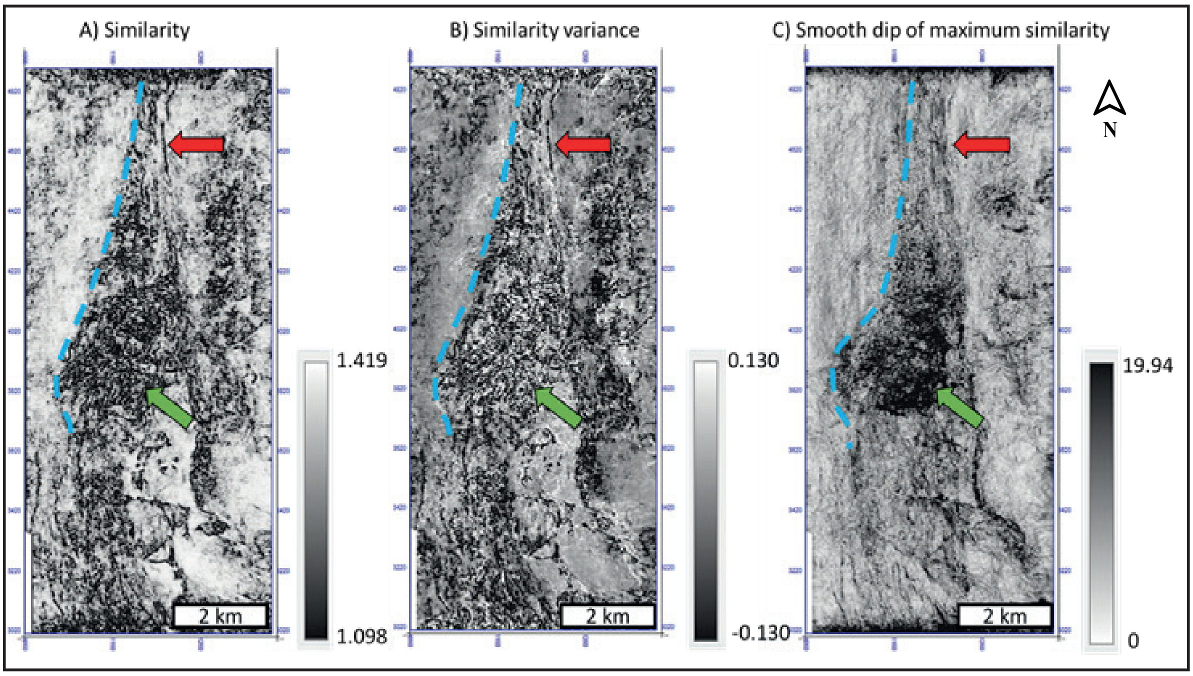

Figure 6 The seismic attributes on time-slice 1.46 sec.; A) Similarity attribute B) Similarity variance C) Smooth dip of maximum similarity. Green arrows are pointed to basement high, only smooth dip of maximum similarity attribute can show the different values from anomaly from fault, high value from this attribute stand for high dip. Red arrows are pointed to evidences of main fault, excepting smooth dip of maximum similarity which cannot show fault clearly. Blue dash lines are indicated to predictive boundary of unconformity or pinch-out boundary between sediment against the basement high.

of trace, max dip, and dip scan increment, the results showed that it affected the image of the seismic attribute. From Figure 7, the parameters are 3, 0.016 sec/trace, 0.002 sec/trace, for number of trace, max dip, and dip scan increment respectively. While in Figure 8 has input parameters in higher values, the parameters are 9, 0.032 sec/trace, 0.004 sec/trace, for number of trace, max dip, and dip scan increment respectively. By this method, the resolution for scanning will decrease. It can be recognized that Sand B in Figure 7 is more continuous than Sand B in Figure 8. So, if dip scan parameters are adjusted to higher values, the sand bodies will be more continuous. The horizon attribute slice in Sand A and Sand B shows different sand bodies. Sand A is clearly distributed from north to south, at the center, the positive values show the most contrast of acoustic impedance. Sand B is also distributed along a north to south direction, but the connectivity is abruptly changed at the center of area (Figure 9).

Extracted data in one horizon may not represent the distribution of sand body, so the volume attribute in Figure 10 will be used for displaying a larger interval by using vatRMS function or root mean square (RMS) that is the function for computing. The time interval for calculating in vatRMS can be assumed from well data by generating the new horizons from phantom horizon or using an interval function.

For rock physic analysis (Figure 11), the result can be concluded that Sand A is divided into three sand layers by thin shale that are potential oil sand reservoirs. Sand B is above Sand A and has a thickness of 9 m. (30 ft). Sand B is thinner than the total thickness of Sand A that is about 21-28 m. (70-90 ft).

By using the data from CU-12D in density with depth (TVDSS) and volume of clay (Vcl) cross-plot (Figure 12), it can be shown that the anomaly of lower density and low volume of clay in chart are referred exactly to zone of oil sand in well log. So, we can use the properties of low density of sand to determine sand distribution on seismic attribute. It is the reason that relative acoustic attribute can be used in this situation. Because, there is a lack of sonic log data in these wells, it cannot be summarized with P-impedance in this case.

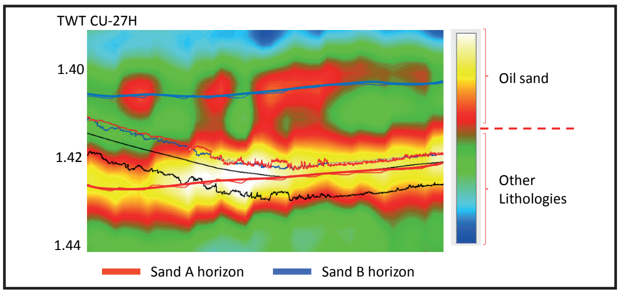

Figure 7 Seismic section along horizontal well of CU-27H in Relative acoustic impedance by using dip scan parameters, which are 3, 0.016 sec/trace, 0.002 sec/trace, for number of trace, max dip, and dip scan increment respectively.

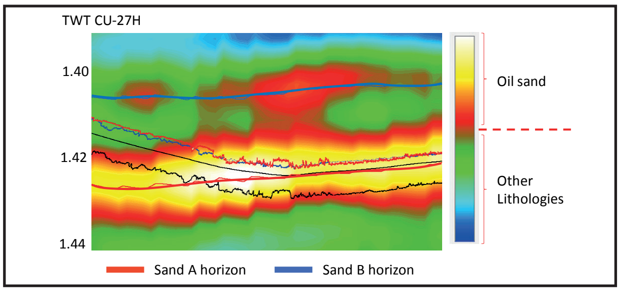

Figure 8 Seismic section along horizontal well of CU-27H in Relative acoustic impedance by using dip scan parameters, which are 9, 0.032 sec/trace, 0.004 sec/trace, for number of trace, max dip, and dip scan increment respectively. Sand B's high value of connectivity is greater than Figure 7 that is used lower value parameter.

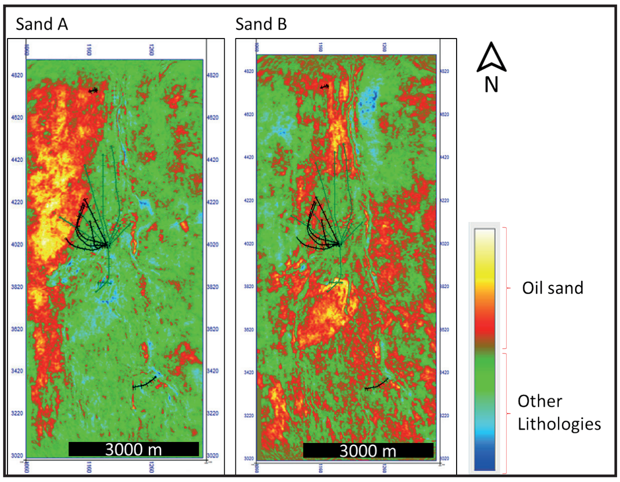

Figure 9 Horizon attribute slice of Sand A and Sand B by Relative acoustic impedance using the same interval value. Positive values in red color are predicted to indicate the hydrocarbon zone within sand reservoir, green to blue values could be other lithologies. It can be recognized that each of the sands has different distribution.

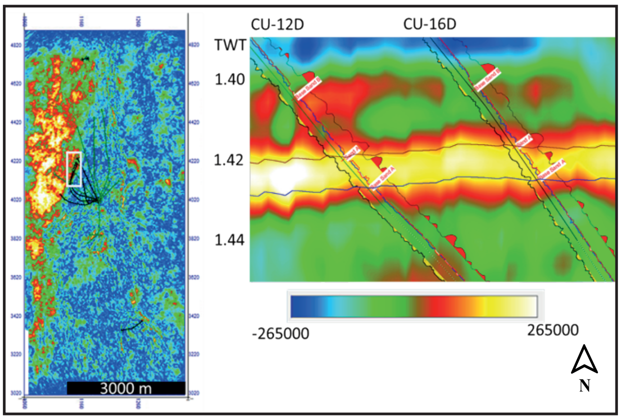

Figure 10 Volume attribute of vatRMS function of Relative acoustic impedance attribute with well correlating from deviated well of CU-12D and CU-16D. White box is located to seismic section that showed well correlation between CU-12D and CU-16D. Blue and brown lines are also phantom horizons that are used for calculating in RMS volume attribute functions. The result is shown on the map, where the positive value distribution refers to hydrocarbon zones in sand reservoir. It is also compatible to results with well correlations.

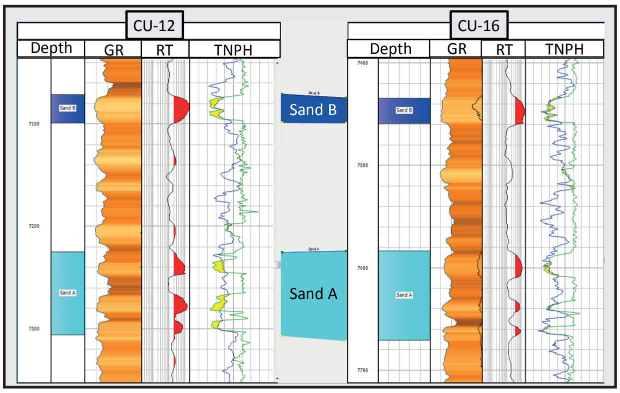

Figure 11 Well Correlation of Sand A and B from well CU-12D and CU-16D. Sand A is showed the package of three sand bodies stacking together, while Sand B displayed a single in thin sand. This is the reason why in relative acoustic impedance Sand A showed thick interval of high value (Figure 10), because, in processing, the function for scanning has grouped value together, while in Sand B, the processing cannot reach to the limit of thickness.

3. Discussion

3.1 Well evaluation with relative acoustic impedance attribute

For understanding the distribution of sand bodies, in this study, it has taken the observation by using seismic attribute of relative acoustic impedance. The horizons of Sand A and Sand B are extracted data in seismic data with wells. It is generated as horizon slices of relative

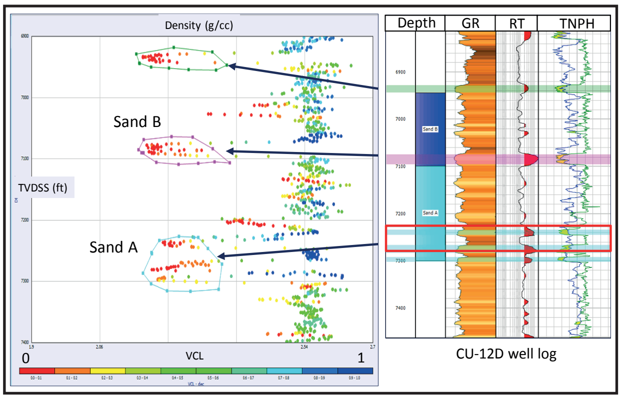

Figure 12 Crossplot of density (g/cc) against with Depth in TVDSS (ft) referring to CU-12D well log show the zone of low density anomaly that is located the hydrocarbon zone.

acoustic impedance in each of sands (Figure 13). Each sand has shown different sand distribution that can be recognized by positive value zone. In study area, wells have penetrated to different sand bodies. Sands have been confirmed in wells and compared to the quality of seismic characters in relative acoustic impedance attribute. The seismic characters are compared between relative acoustic impedance value and top marking from each of wells (Figure 13 and Table 2). The quality of oil sand in seismic attribute character for representing oil bearing sand reservoir on relative acoustic impedance imaging has already been discussed and is a reasonable interpretation in geology by well.

Sand A can be recognized by positive value in relative acoustic impedance volume attribute. Sand A occurs on the western part of study area and is wider at the north. Similar to Sand A, Sand B can be recognized by positive value in this seismic attribute. However, the distribution of Sand B by this attribute is almost at the center of area. North and south parts can show positive value, while the center has some negative values and is not laterally distributed.

Oil Sand shows laterally from well correlation. Some zones have been controlled by fault and distributed on Middle Tertiary Unconformity and basement high. . From information in well logs, especially in CU-16D and CU-18D (Figure 14), have corresponded with this seismic attribute, except CU-2D (Figure 15) and CU-10D that are drilled into eastern part of

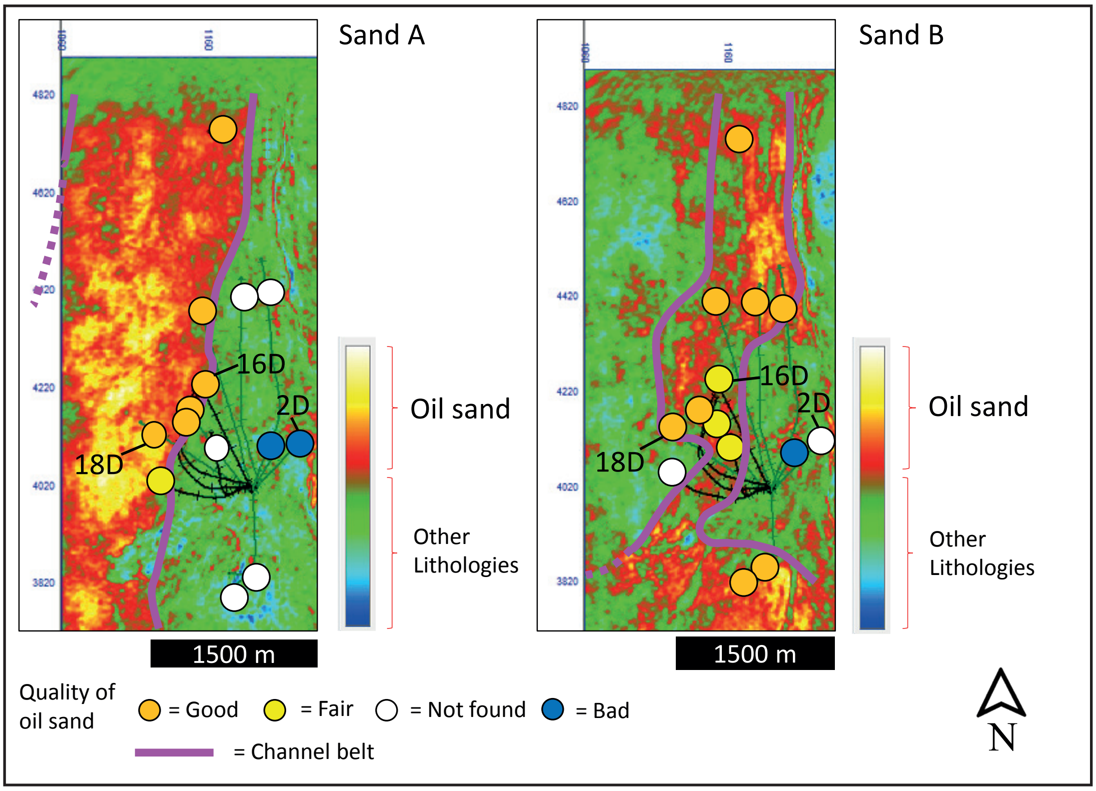

Figure 13 Horizon slices of sands in relative acoustic impedance attribute volumes with well evaluation from top formation show the different in distribution of each sand. Sand A is covered on the western part of study area and it is wider at the north, Sand B is distributed in northern and southern parts, while the center part contained some negative value intervening that is proven by well evaluation. Pink line is stand for predicting channel belt. Well top formation of each well correspond to seismic attribute volume that has ranked by quality of oil sand.

Table 2 The result of observation of wells by evaluating with seismic attribute, well log show the quality of oil sand in attribute character.

Location	Sand A	Sand B	Remark
CU-1D	Not show	Good	
CU-2D	Bad	Not show	
CU-3D	-	-	Not be represented
CU-4D and CU4ST	Good	Good	Merge
CU-5D	Not show	Good	
CU-10D	Bad	Bad	
CU-11D	Good	Good	Stacking
CU-12D	Good	Good	Stacking
CU-16D	Very good	Fair	Stacking
CU-18D	Very good	Good	Stacking
CU-19D	Fair	Not show	
CU-15H	Not show	Good	
CU-21H	Not show	Good	
CU-23H	Good	Good	
CU-27H	Good	Good	
CU-29H	Not show	Fair	

study area. Although it can show a positive value, the sand has not been distributed laterally. It results from the problem of fluid or lithology changing.

For interpretation, the bodies of Sand A refer to an amalgamated channel that is stacking with meandering channel or higher sinuosity channel of Sand B. The Sand A channel's width is more than 1,500 m. that is distributed over study area. While, Sand B channel's width is 1,500 m. with scattering of sand bar.

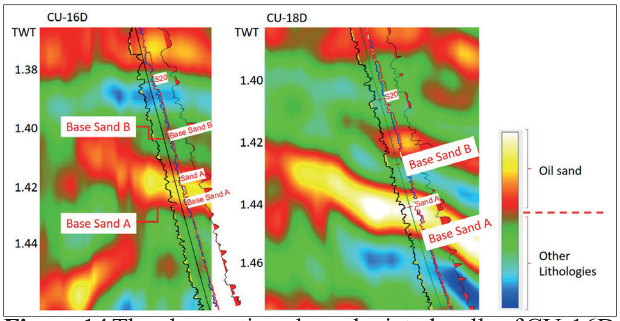

Figure 14 The observation along deviated wells of CU-16D and CU-18D show the different value of relative acoustic impedance between Sand A and Sand B. The location of their well is in Figure 13. From CU-16D, Sand A seismic value is very good as same as the result in CU-18D. Sand B in CU-16D is quite good comparing with CU-18D that show the very good quality.

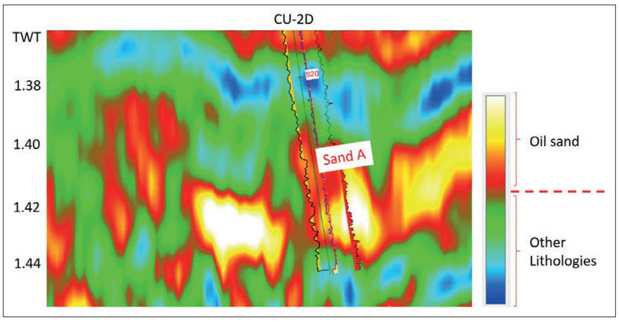

Figure 15 The observation along deviated wells of CU-2D shows positive contrast acoustic impedance in wet sand from Sand A and is not lateral continuity and anomalous thickness. The location of this well is in Figure 13.

3.2 Multiattribute display

This method uses two attributes, which generate the similar model of reservoir. These are the sweetness attribute that involves instantaneous frequency anomalies and the relative acoustic impedance attribute that records zones of positive contrast between reflector of acoustic impedance in seismic. The aims of this method are to combine the data from each attribute and displayed them together on the same horizon to produce better images of reservoir. After overlying and adjusting an opacity of unnecessary values from each of the attributes, multiattribute can verify the distribution of sand and be displayed in reservoir model.

From Sand A horizon (Figure 16), a group of positive values are oil sand distributions at the western end from the basement high. The extremely high positive values from two attributes are only displayed in the middle of interested zone in blue color. This blended attribute is used as a prediction of sand. Where relative acoustic impedance value is not displayed then the high value from sweetness attribute will replace that zone. This combined layer onlaps to Middle Tertiary Unconformity on basement high and is confirmed by time structure map from MTU horizon.

While, from Sand B horizon (Figure 17), the data are scattered from the north to south. However, there are two main areas that have positive value of data distribution. When two attributes are overlaid, the sand prediction values are located at Southern part. It has a positive value where it has proved by well CU-1D and CU-5D. The quality of data of lateral distribution or positive value data decreases at the center of the area around the basement high, however, it has been proven by wells CU-11D, CU-12D and horizontal well CU-23H.

Red-lines from both sand models are represented as a channel belt based on data distribution (Figures 16 and 17). The shape of Sand A's channel belt is easily to identify, because of the distinct edge of the seismic attribute. However, the trending of sand should be distributed out of the area that is marked in dashed line. Sand B's channel belt can be identified by the main part that contained high positive values which are confirmed by well results.

However, the problem from picking the horizons of reservoir and unconformity will affect the seismic attribute results. Adjusting the color value in different seismic attributes should be a check to confirm that the image is geological. The idea of using multiattribute depends on the situation of different area. For example, it can be

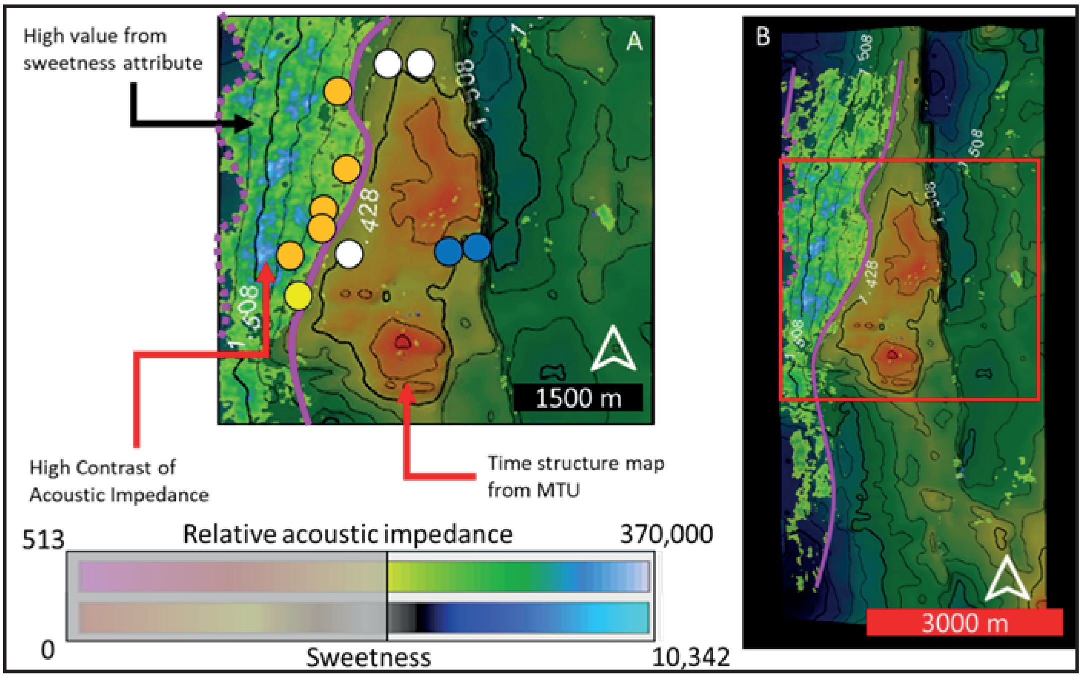

Figure 16 Multiattribute by overlying of sweetness and relative acoustic attributes shows Sand A distribution, the low values are hidden by adjusting opacity, almost half of the seismic values are concealed for showing only high value. A) Map with well evaluation of Sand A enlarging from red box B) Top view of multiattribute with channel belt marking in pink-lines. Circles represented seismic quality ranking see Table 2.

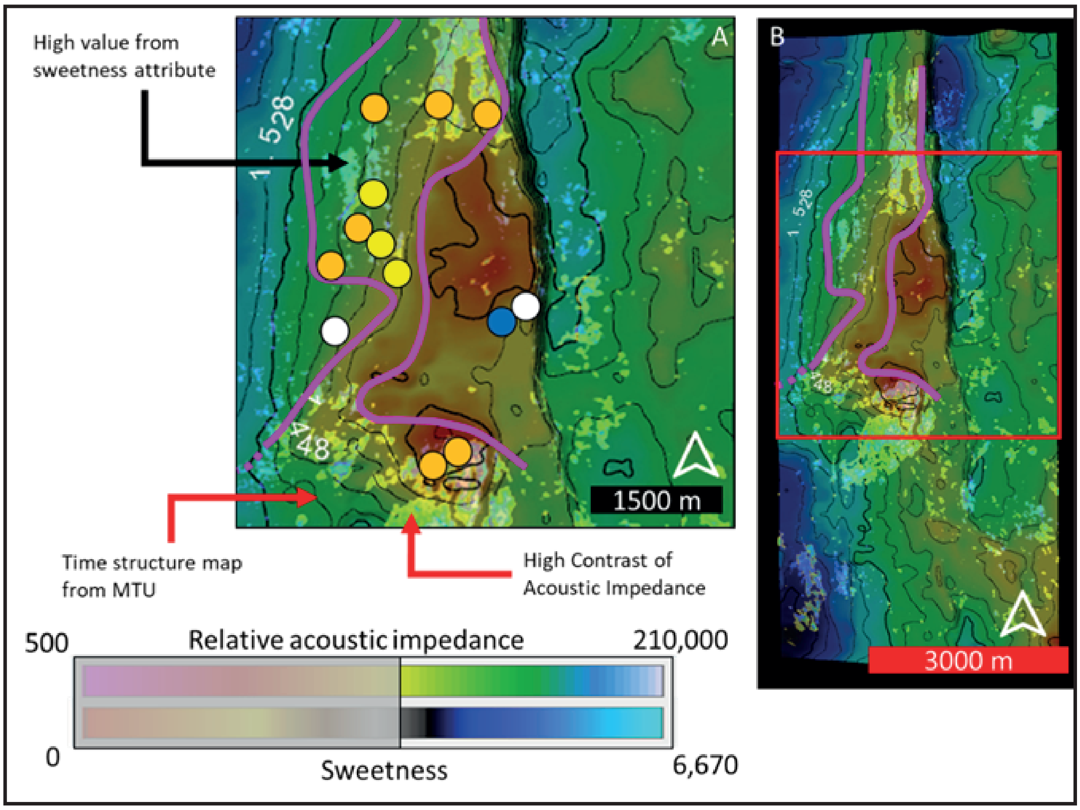

Figure 17 Multiattribute by overlying of sweetness attribute and relative acoustic attributes shows Sand B distribution, the low values are hidden by adjusting opacity, almost half of seismic values are concealed for showing only high value. A) Map with well evaluation by well top marking of Sand B enlarging from red box B) Top view of multiattribute with channel belt marking in pink-lines. Circles are represented seismic quality ranking see Table 2.

used for representing structure of area with prospect area or displaying gas show with structural trapping or showing an overlapping between two channel stacking.

3.3 Composite attribute

Visualization of two possible attributes is generated by composite displays attribute. The first attribute is using saturated color level and the second attribute using shades of gray or unsaturated colors (Chopra and Marfurt, 2007).

From Figure 18, seismic cube has mapped two 1D color bars by using different seismic attributes. A gray scale in Figure 18A stands for similarity attribute in coherence, while a temperature color bar in Figure 18B is for relative acoustic impedance or impedance attribute. Both of the color bars are created into a new single 1D composite color bar. The output volume of color can be mapped directly to the composite color bar (Figure 18C) in sections.

From composite color bar, the high value of similarity has become transparent and it is replaced by impedance values. Simply stated, the value of impedance is normally greater than coherence value. As a result, the second attribute that is coherence attribute reveals the black and white image, especially, the zone of low similarity (black), while the zone of high similarity (white) is replaced by temperature color from impedance color interval.

By integrating coherence of similarity attribute and relative acoustic impedance volumes, it can identify the distribution of reservoir within the sedimentary basin and can receive information of structural and depositional features in one image (Figure 19).

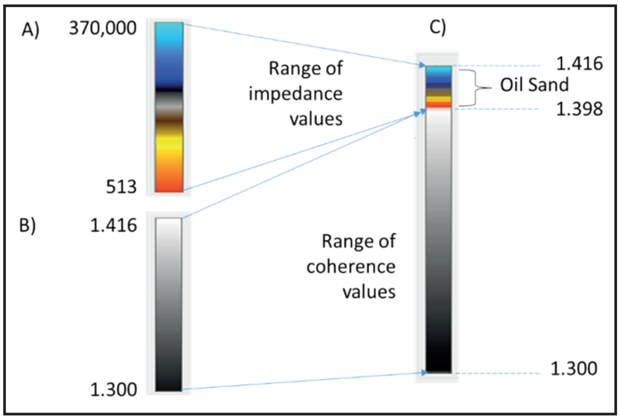

Figure 18 A composite-attribute display of relative acoustic impedance and similarity. A) the color bar of impedance values B) the color bar of coherence from similarity attribute C) the composite-attribute color bar. It can exhibit the zone of reservoir of oil sand that is high positive contrasting of relative acoustic impedance with high similarity.

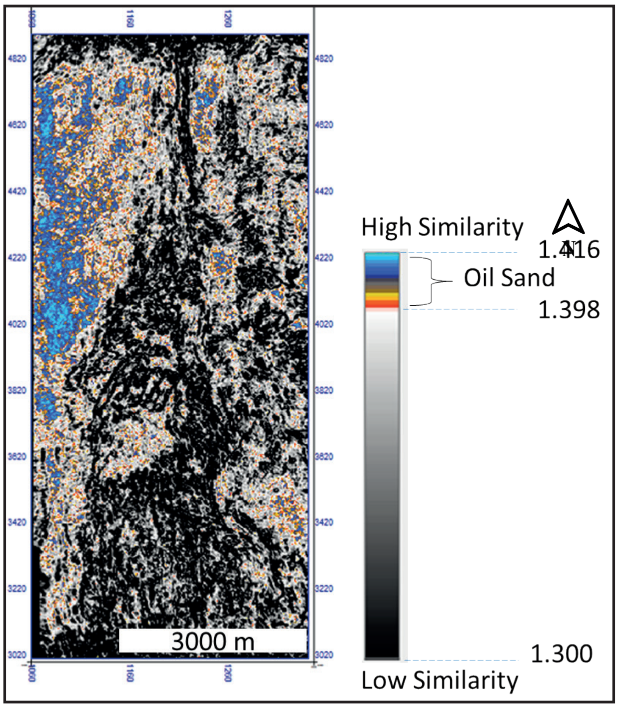

Figure 19 The distribution of Sand A appearing on horizon slices by a composite relative acoustic impedance and similarity volume. The image is the same to single attribute. The negative contrasting value in relative acoustic impedance is not shown, but it replaces low similarity values. So, it can identify the distribution of reservoir and structure and depositional features in one image.

4. Conclusions

The sand reservoir distribution of Sand A, Sand B and unconformity of MTU that occurs below the reservoir in Pattani basin, Gulf of Thailand has been studied in seismic attributes by using full stack and partial stack of 3D seismic volumes, well log data and geo-steering data. Many attributes were used to improve and identify reservoir distribution including;

A) Structural orientation filtered (SOF) is the best attribute for reflector continuity enhancement.

B) The smooth dip of maximum similarity is the best attribute for identify MTU.

C) Relative acoustic impedance attribute is the best technique to identify sand reservoir, because it can differentiate between the two sands.

Relative acoustic impedance attribute volume is recommended to identify sand reservoir, according to well information, the production could be stepped out to the zone of high positive values on the map for new exploration. The combination of attributes forming a multiattributes is one technique for supporting evidence of well locations.

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