Mapping reservoir geometry and interpretation of depositional environment by integrating seismic attributes with well data, Western basin, Gulf of Thailand

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Abstract

The study of reservoir geometry and depositional environment is necessary for petroleum exploration that will improve the accuracy and add more opportunity for hydrocarbon exploration. The study area is located in Western basin, Gulf of Thailand. The clastic reservoir unit is difficult to detect due to the control by geological structures especially faulting. This research integrates 3D seismic volumes, well log data, horizons interpretation and seismic attributes analysis to identify reservoir geometry and depositional environment. The reservoir unit termed Sand C is the main unit for reservoir detection and depositional environment interpretation which is located above the basement and below Sand B unit. The seismic volume in this study is full-stacked volume that cover 457 km^2 and represent Sand C unit at range 1143-1780 milliseconds. The seismic attribute of a Structural oriented filter was used to interpret the seismic volume because the original volume contains seismic enhanced discontinuities and noise. The well data in study area comprise of 10 wells but only 4 wells which are CU-1, CU-2, CU-8, and CU-9 penetrate through Sand C formation. Each well log represents a conventional log data set for all wells are composed of; neutron log, density log, sonic log, spontaneous potential log, caliper log, gamma-ray log, and resistivity log. The reservoir geometry and depositional environment interpretation used the seismic attributes including RMS amplitude and Sweetness to extract images of reservoir features. The Sand C unit were detected by high amplitude of both RMS amplitude and Sweetness attribute that was controlled by faults in N-S direction and onlap onto the basement. The seismic reflector can identify Sand C unit formed in syn-rifting event which can be observed by wedge shape on reflector. The seismic attribute was evaluated using stratal slices to indicate the reservoir geometry that can identify the depositional environment by the seismic facies combined with the correlation to the well log analysis. The result of seismic interpretation integrating with well log analysis indicates that the Sand C unit was deposited in fluvial environment.

Keywords: Reservoir geometry, Depositional environment, Integrating seismic attributes with well data, Western basin.

1. Introduction

In the Gulf of Thailand, the Tertiary age basins are the most productive hydrocarbon bearing basins in Thailand. The study area is situated in the Western Basin of the Gulf of Thailand about 60 kilometers offshore as shown in Figure 1. The sedimentology section comprises of syn-rift and post-rift sequence and were deposited in a fluvial-coastal system. The medium gravity oil is recovered through strong bottom and edge-aquifer drives. The structural control of this area was comprised of two tilted fault-block traps containing multiple stacked sandstone reservoirs in the Early-Middle Miocene interval. The target reservoirs in this area are T4 and T5 sandstone units that were deposited by post-rift sequence in Middle Miocene age below the Middle-Miocene Unconformity (MMU). This research aims to map potential reservoir units in the syn-rift section by using seismic attributes to identify the characteristics and distribution of the reservoir.

The objectives of this study are to:
1) To identify the reservoir distribution in the syn-rift section by using seismic attributes analysis.
2) To compare different seismic attributes for the ability to be applied for reservoir mapping.
3) To map the Sand C horizon in the syn-rift section and discuss problems with identification of depositional environment and channel mapping.

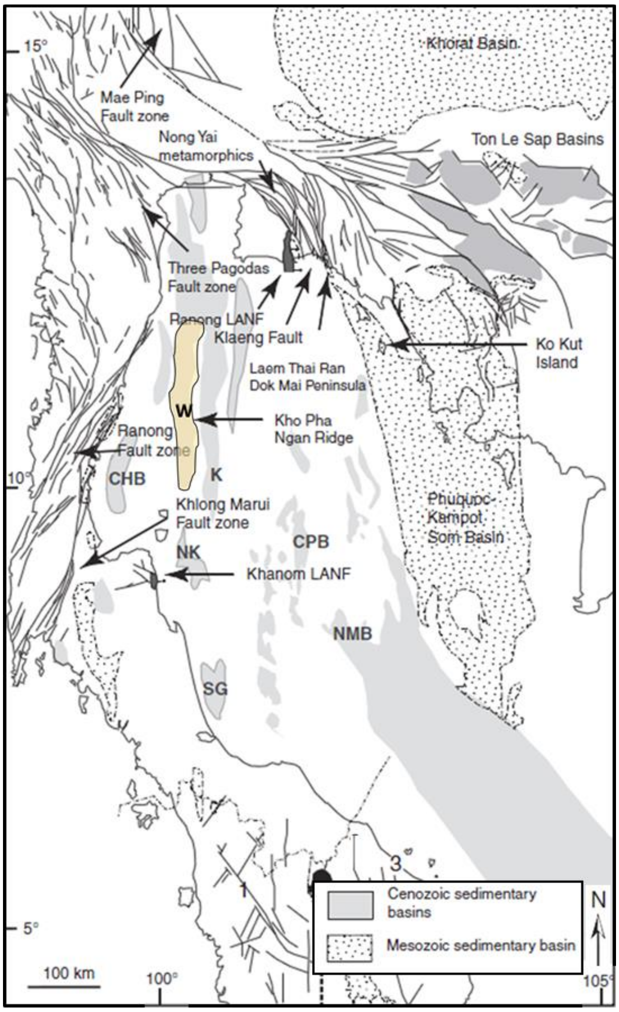

Figure 1 The sedimentary basins and hydrocarbon fields of Thailand, showing the location of the Western Basin (C.K. Morley, 2012)

2. Methodology

This study on reservoir identification and determination of depositional environment using seismic attributes and well log data will be focused on Sand A, Sand B, and Sand C. Well logs will be used for lithological determination and well log correlation to determine sand bodies distribution. The seismic attributes will be used to improve the quality of seismic for horizon and fault interpretation with enhancing an anomaly reflector on the interpretation section.

The procedure of data interpretation is following;

1) Observe seismic and well log data and conduct well to seismic tying.
2) Analyze and correlate well log data to identify sand bodies and its distribution.
3) Interpret the seismic data to determine geological structure and compare any seismic attributes and using it to improve the quality of interpretation.
4) Interpret both well and seismic data to determine sand bodies, sand distribution, and depositional environment.
5) Summarize all of results.

3. Results

3.1 Well log analysis

Well log curve analysis

All of the wells will use gamma ray log to define a rough depositional environment. The results are not definitive because it may have mixed lithological features. The well log curve analysis should be improved by core data.

The CU-1 well represents at depth 1111.7 to 2197.6 meters. The gamma ray log ranges are 17 to 264 gAPI and the shale cut off is 125 gAPI. The shapes of gamma ray curve shown in this well are cylindrical shape at the top, funnel and bell shape at middle part, and funnel shape at the lower part that can be used to identify the depositional environment as delta to fluvial environment.

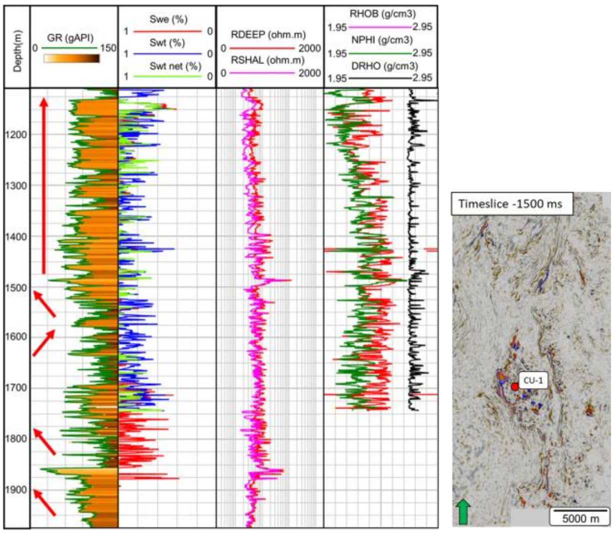

Figure 2 The well log curve which represent in CU-1 well with well location on seismic.

The CU-2 well represents at depth 1103.59 to 1820.03 meters. The gamma ray log ranges are 35 to 250 gAPI and the shale cut off is 125 gAPI. The shapes of gamma ray curve in this well are cylindrical shape at the top to middle part and bell shape at lower part that can identify the depositional environment as the upper part of delta to fluvial environment.

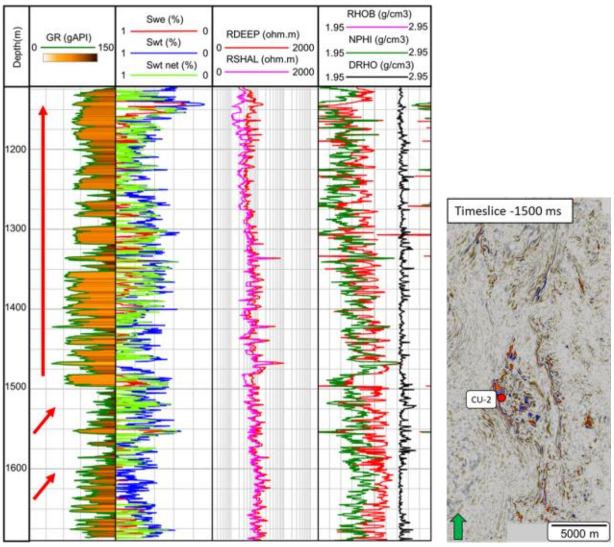

Figure 3 The well log curve which represent in CU-2 well with well location on seismic.

The CU-8 well represents at depth 1129.7 to 1988 meters. The gamma ray log range are 51 to 437 gAPI and the shale cut off is 125 gAPI. The shapes of gamma ray curve in this well are cylindrical shape in whole well that can be used to identify the depositional environment as turbidite channel to deltaic distributaries. The gamma ray value in this well are significantly higher than CU-1 and CU-2 wells therefore the sandstone might have a higher content of clay.

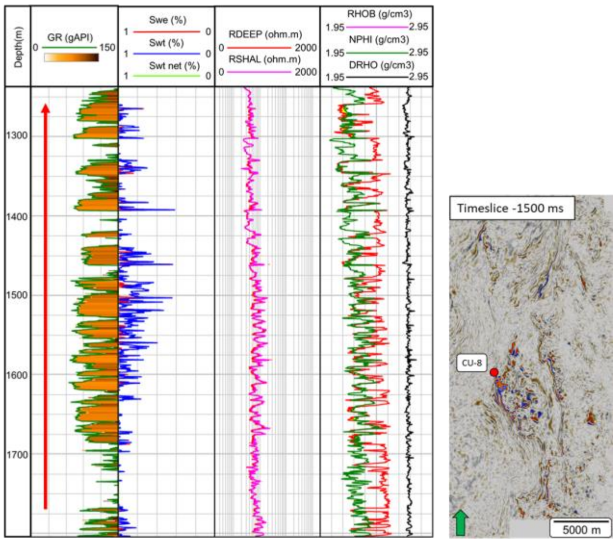

Figure 4 The well log curve which represent in CU-8 well with well location on seismic.

The CU-9 well represents at depth 920.0 to 1651 meters. The gamma ray log range are 23 to 758 gAPI and the shale cut off is 125 gAPI. The shapes of gamma ray curve in this well are cylindrical shape in whole well that can be used to identify the depositional environment as turbidite channel to deltaic distributaries. The gamma ray values in this well are significantly higher than CU-1, CU-2 and CU-8 well. It may be caused by a high clay content in sandstone.

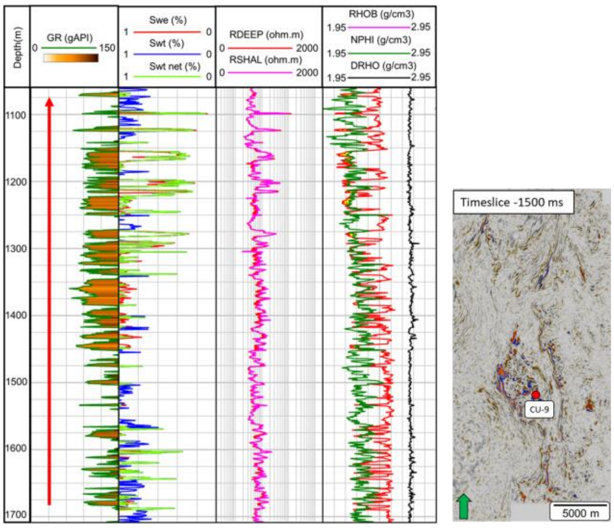

Figure 5 The well log curve which represent in CU-9 well with well location on seismic.

Lithological marker and well correlation

The marker points for reservoir identification were based on sandstone trends on gamma ray curve. It was divided into 5 markers in the study area which are Shale, Sand A, Sand B, Sand C, and Basement. The studied reservoirs are the 3 markers which are Sand A, Sand B, and Sand C. they are:

Sand A; The top sequence of sandstone unit. It occurs below shale marker and above Sand B marker. The characteristic of Sand A represents in thick layer which is dominant in sand on the well log data and it may represent intermediate to high amplitude and continuous reflectors on seismic.

Sand B; It occurs below Sand A marker and above Sand C marker and also has a sharp contact from Sand A to Sand B. The characteristic of Sand B represents a thick layer of sand on the well log data and it represents high amplitude and continuous reflectors on seismic.

Sand C; The bottom sequence of sandstone unit which has a sharp contact to Sand B. It occurs below Sand B marker and above Basement marker. The characteristic of Sand C represents a thin layer which is dominant in sand and shale on the well log and represents low to high amplitude and discontinuous to continuous reflectors on seismic.

3.2 Well to seismic tie

The well to seismic tie is the method that will be used to integrate well log data to seismic data that will be used to convert to depth domain from time domain. This process will generate synthetic seismograms from density log and sonic log then correlate with wavelet extraction from seismic data. The accuracy of well to seismic tie is very important for exploration stage; the good tie between the seismic trace and well logs is very useful for key horizons and interested zone picking. This process will define the layer of horizon interpretation. All well to seismic ties are using deterministic method with extended white algorithm.

CU-1 Well

The synthetic from Well CU-1 is displayed as a deviated well on the seismic data and shows a good tie of seismic character, the synthetic required a minor shift in the middle part where Sand B and Sand C are represented. The tops of Sand C were represented by an indistinct trough event.

CU-2 Well

The Well CU-2 is a vertical well that represents a very good tie of seismic character. Most of the synthetic trace is correlated to seismic data. The tops of all sands were represented clearly by trough events.

CU-8 Well

The Well CU-8 is a deviated well which displayed on the seismic data shows a very good tie of seismic character. The synthetic trace is more than 90% correlated to seismic data. The tops of all sands can be detected clearly by trough events.

CU-9 Well

The Well CU-9 is almost a vertical well but it was deviated on the lower part of well pathway. The well shows a very good tie with seismic character on the top to middle section, but it shows some shifted trace on the middle to lower section. The marker is not represented clearly in this well.

After that, the well to seismic tie should be attached to the seismic volume to represent the lithological markers that were interpreted from well log. The lithological marker will be used to guide the horizon picking to generate the reservoir mapping. The result of horizon picked from lithological marker show several shifted reflector layers when picking horizon through CU-1 well (Figure 6). It may be shifted because of the deviated well increases the difficultly in synthetic to seismic matching process, but this research will be mapping the horizon based on strong reflector in seismic volume.

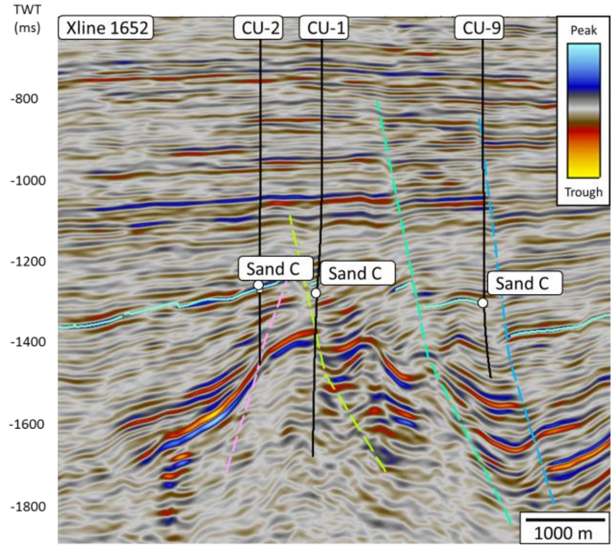

Figure 6 The result of well to seismic tie which shows the wells and the location of markers on the wells. The Sand C horizon display in blue line and basement horizon displays in orange line.

3.2 Fault and horizon interpretation

Fault interpretation

The geological structure is the key to identify the sandstone reservoir for petroleum exploration. The structure that can be easily observed from seismic data is the fault which can be detected on the seismic by a discontinuity and chaotic character on the reflector. The fault interpretation is very importance for the seismic interpretation because most of basins in Gulf of Thailand are controlled by fault systems. The identification of seismic reflector terminations and subtle changes in dip and azimuth allows the interpreter to infer faults. A major difficulty in interpreting faults is the smearing across the discontinuity boundary of the seismic reflector.

For this study, the basin is dominated by east-dipping normal faults. These are represented in the seismic cross section from the study interval and was controlled by a faulting system that represents half-graben features and some of which are cutting through the basement (Figure 7).

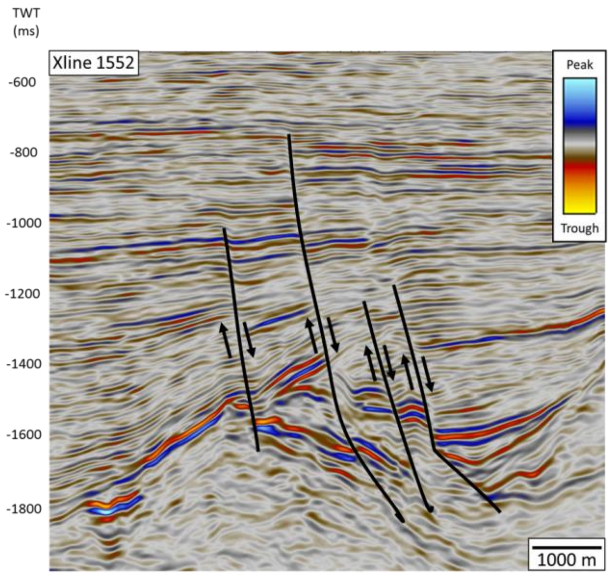

Figure 7 Fault in study interval which represent the horst-graben feature. Some of fault were cutting through the basement.

The overview of fault system in Western basin is N-S orientated half-graben that was characterized by Late Oligocene-Middle Miocene extension in half-graben basin and Late Miocene-Pliocene post-rift subsidence. Moreover, the coherence attribute can emphasize discontinuous events that can be used to improve the fault interpretation. The result of fault interpretation by manual picking are correlated to the coherence attribute (Figure 8).

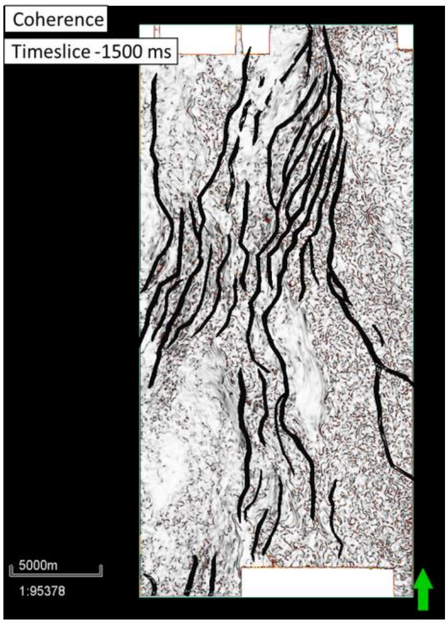

Figure 8 The result of fault interpretation correlation with coherence attribute.

Basement and Seismic Anomaly A Distribution

The Western basin contains thick sandstone layers which overlie a limestone basement. The basement was mapped based on seismic responses as high amplitude reflections due to strong contrast in acoustic impedance (Figure 9). The basement can be detected where the zone of Sand C horizon pinches out to the basement (Figure 10).

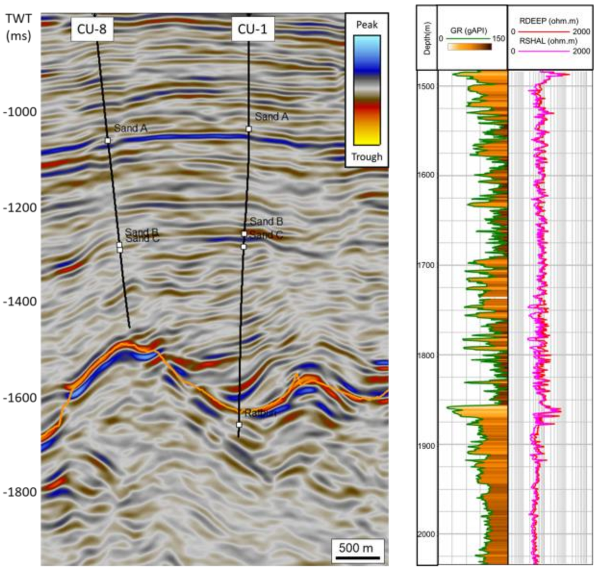

Figure 9 The well data from CU-1 well near the basement which displayed on seismic volume that the basement was detection below the end of well.

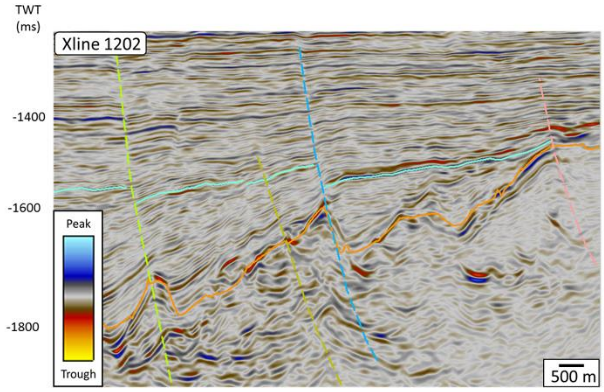

Figure 10 The seismic section display the onlapping of Sand C horizon into basement in red circle. The green horizon is Sand C and the basement display in orange.

Horizon interpretation

The seismic volume contains a lot of noise and discontinuous reflectors that makes it very difficult for picking a horizon, but it can be resolved by picking a closer grid horizon picking. The horizons interpretation in time domain were picked by using a grid of 25x25 lines because the horizon interpretation by using a grid of 50x50 and 100x100 resulted in many mis-ties and its surface represents a low resolution of detail on the seismic volume.

The horizon picking will be used to generate the surface map to represent a surface of Sand B in detail for structural control and shape of Sand B that can be used to identify the possible sandstone body geometry and possible hydrocarbon accumulation. The surface that was generated by using a horizon picking grid of 50x50 and 25x25 show the trend of surface as similar, but the surface from a horizon picked by 25x25 lines has more detail in the eastern parts of study area. This area represents the structural high areas where sediments were deposited against basement that could be sealed laterally by basement. In addition, the sediments could be deposited and laterally sealed by basement at the areas above the eroded basement crest. In contrast, the surface from horizon picked by 50x50 lines can image only the structural high in the western part of study area, but it cannot detect the onlapping feature of Sand B into basement on the eastern part (Figure 11).

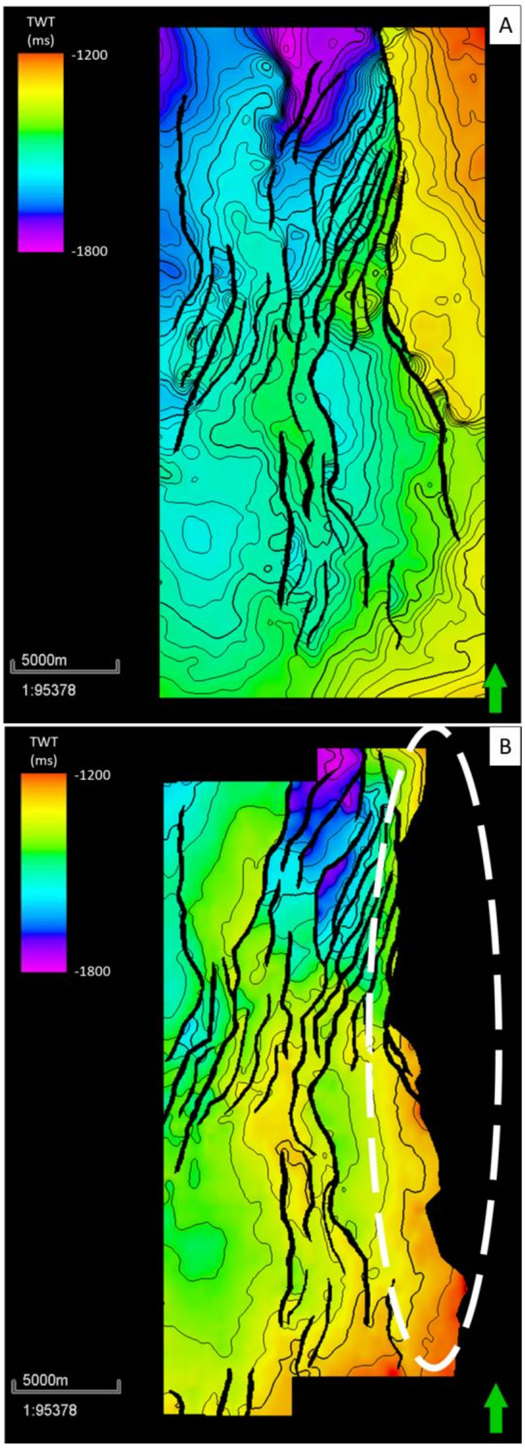

Figure 11 The surface map which generated from horizon picking in 50x50(left) line and 25x25 line(right). The area of Sand C horizon were pinched out on white circle.

3.4 Seismic facies analysis

The Seismic facies are the group of seismic reflections which are classified by a series of reflection characteristics, discontinuity, and reflection amplitude. For this research, the seismic facies can be divided into 3 facies (Figure 12). Which are;

Seismic facies I is characterised by high amplitude, strongly continuous to discontinuous seismic reflector.

Seismic facies II is characterised by medium to high amplitude, parallel, and continuous seismic reflector.

Seismic facies III is characterised by low to high amplitude, parallel to subparallel continuous to discontinuous seismic reflector.

The seismic facies on the study reservoir are representing only facies III. The seismic facies I and II occur at below and above Sand C unit which are basement zone and Sand B unit respectively.

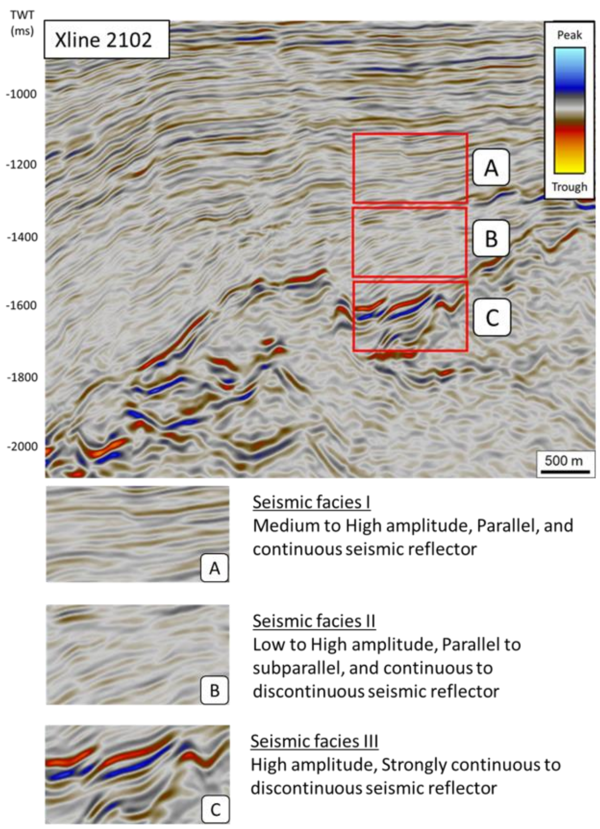

Figure 12 The seismic facies in the seismic volume comprise of 3 types of seismic facies.

3.4 Stratal slice

The stratal slice is the method that is useful to detect the sandstone geometry because most of the reservoirs in Thailand are small sized channels that are difficult to detect for reservoir geometry. This method will generate a phantom horizon in different time domain which detect the reservoir geometry by the horizon that cross the reservoir body. For this research, the stratal horizon were generated at –25, -50, and -75 ms below the picked horizon (Figure 13).

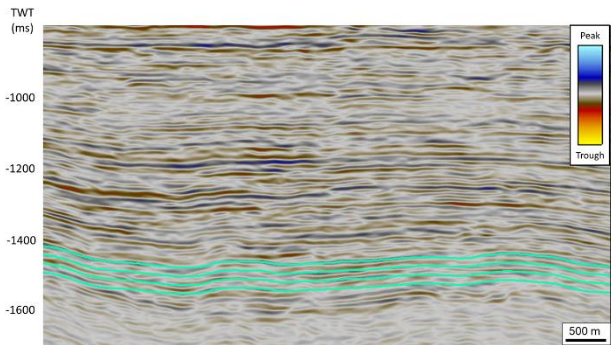

Figure 13 The stratal slice were generated in every 25 milliseconds below the Sand C horizon.

3.4 Seismic attribute analysis

The seismic attribute is a quantity extracted or derived from seismic data which can be analyzed in order to enhance information that might be more subtle in a traditional seismic image, leading to a better geological or geophysical interpretation of the data. The seismic attributes that were used to identify the reservoir geometry in this research are RMS amplitude and Sweetness.

RMS amplitude attribute

The RMS (Root mean square) amplitude attribute helps to better define the sand geometry and depositional environments based on seismic character. Defining the extracting windows is the main criteria needed to run the RMS attribute analysis, as well as the intervals of investigation needed to best image the more significant sand intervals.

The Sand C horizon and the stratal slices of sand C horizon were used to identify the sand geometry in Sand C interval detected by the trend of high amplitude anomalies in the eastern part which represent channel forms (Figure 14).

The channel A is represented as a high amplitude on timeslice and stratal slice which show a small meandering channel feature in N-S trend. In the seismic section, Channel A can be detected by the seismic reflector as a U shape form. Other channels in north area and western area that were imaged in stratal slices are not detected in the vertical seismic section. The channel may be a very thin layer or in a complex structure that results in a seismic response that is a low amplitude and discontinuous reflector.

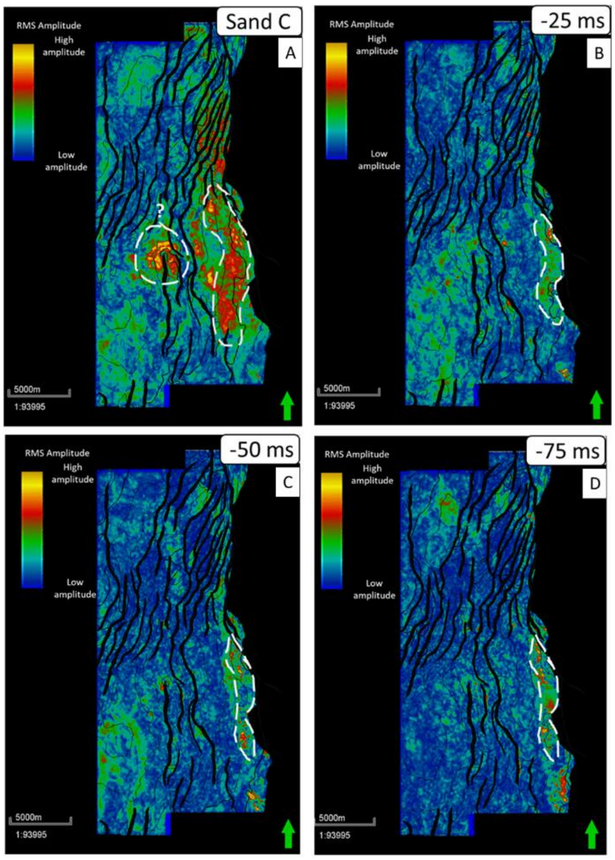

Figure 14 The stratal horizon slice of RMS Amplitude attribute display in a stratal slice at Sand C horizon (Figure 18a), -25 ms (Figure 18b), -50 ms (Figure 18c), and -75 ms (Figure 18d) below Sand C horizon. The white polygon represent the shape of channel on stratal slice.

Sweetness attribute

The sweetness attribute is a composite seismic attribute used to highlight thick, clean reservoirs, along with hydrocarbons contained within it.

The reservoir detection of Sand C horizon and stratal slice are detected only in the eastern part of study area and representing the reservoir geometry of Channel A similar to the reservoir detection on RMS amplitude. The channel A is represented by high amplitudes on both timeslice and stratal slice which show a reservoir feature similar to RMS amplitude attributes (Figure 15), but it is more clearly displayed on Sweetness attribute. For other channels, the other anomalies are not clearly imaged because the anomalies do not correlate to a channel characteristic of a reflector on seismic section.

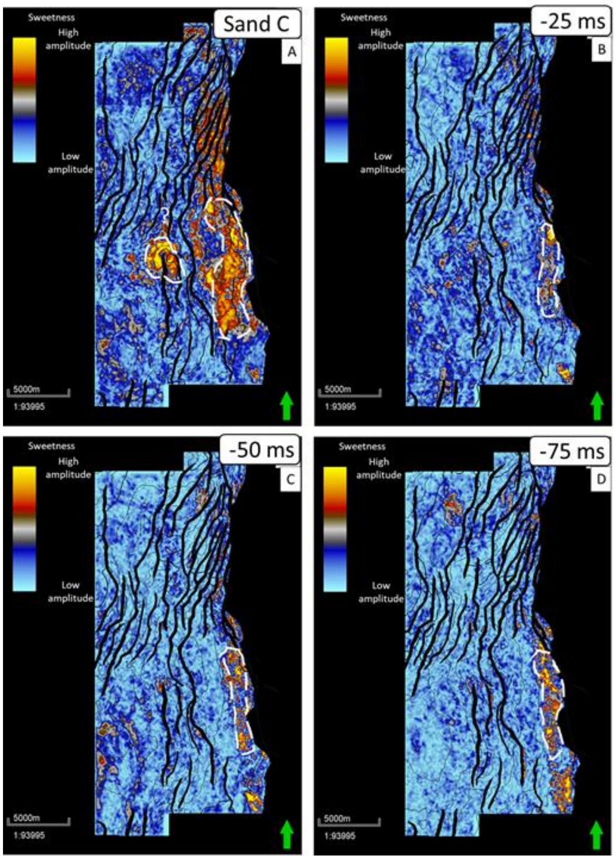

Figure 15 The timeslice of sweetness attribute display in a stratal slice at Sand C horizon (Figure 19a), -25 ms (Figure 19b), -50 ms (Figure 19c), and -75 ms (Figure 19d) below Sand C horizon. The white polygon represent the shape of channel on stratal slice.

3.4 Depositional environment

According to the well log interpretation, the depositional environment from well log analysis can identify the depositional environment as fluvial environment. For the seismic interpretation, it can detect fluvial environments that were correlated with well log data. The fluvial environment was interpreted by the channel detection on seismic section which show the U-shape characteristic (Figure 16).

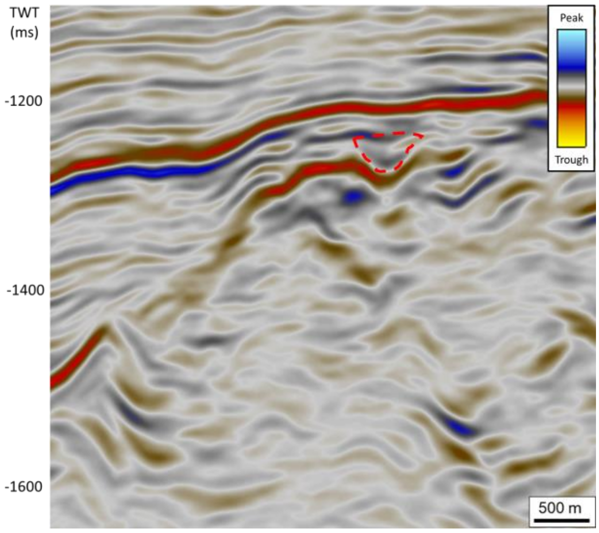

Figure 16 The channel feature that were detected by U-shape characteristic on the seismic volume.

4. Conclusions

The identification of reservoir geometry has been studied using seismic attributes analysis. The conclusions are summarized as following lists;

1) Seismic attribute is a good technique to identify and improve the visualization of reservoir features. The integration of seismic attributes with well log curve can help to identify reservoir distribution.

2) The reservoir in the study area occur in small channels parallel to the fault trends and therefore may have been controlled by structure. The Sweetness and RMS amplitude attribute cannot detect the reservoir geometry clearly.

3) The depositional environment determination from well log analysis may not be certain because it was analyzed based on gamma ray logs. The interpretation can be improved by cross checking with core data.

4) The onlap feature that was observed on seismic sections at the basement contact does not always imply deposition controlled by the basement. The imaged channels are independent of basement location and may not indicate shoreline features.

5) The imaged channelized features from seismic interpretation correlate to the well log analysis that can be used as evidence of fluvial depositional environment in the syn-rift event.

5. Recommendations

The following are recommendations and new ideas for further studies and hydrocarbon exploration and development.

1) Recommend to applying additional seismic attribute techniques to identify reservoir geometry.

2) It may be that a lot of thin sands are thinner than the seismic tuning thickness found at the study interval, therefore many seismic reflectors are possibly not a sand response. It is important to compare the seismic anomaly to any available wells data.

3) Recommend to applying more well data to correlate the well to seismic because the structural setting of study area contains many faults.

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