MAPPING BASEMENT AND BASEMENT FAULTS FOR PREDICTION OF POTENTIAL BASEMENT RESERVOIRS USING SEISMIC ATTRIBUTES IN WESTERN BASIN, GULF OF THAILAND

Sofiyah Syairah Saifulizan*

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

Abstract

The Permian Ratburi carbonate basement is a productive Pre-Tertiary karstified carbonate reservoir in the Gulf of Thailand, specifically in the Nang Nuan Oil Field in Chumphon Basin. However, its neighboring Western basin basement has yet to be extensively explored and studied. The integration of 3D seismic data, logging data of five wells as well as seismic attributes were used to identify the basement structural pattern and fault features in this study area located in Western basin. A depth structural map was generated for the top of basement formation. The basement is influenced by numerous N-S trending normal faults that have formed two block-faulted half-grabens in the structure. The faults are characterized by high-angle normal faults that become low-angle faults as they go into the basement. Some of these faults also show fault reactivations that have a higher displacement compared to the overlying sediments. Seismic attributes such as structure-oriented filter (SOF), relative acoustic impedance (RAI) and variance (edge) method attributes proved effective to enhance the basement images and fault features in this basin. High porosity zones were illustrated by high amplitude anomaly evaluated from the root-mean-square (RMS) amplitude attribute, mainly seen along the basement ridges. In conclusion, the structural highs with predicted higher porosity zones of the study area in Western basin are of interest as it shows better opportunities for potential hydrocarbon exploration as supported by the results in this study.

Keywords: Carbonate Basement, Faults, Seismic Attributes, Western Basin, Gulf of Thailand

1. Introduction

The field of study focuses on the basement rock located in Western Basin, Gulf of Thailand (Figure 1). The basement is made of Pre-Tertiary marine carbonates of limestone and dolomite (Virdy et al., 2013). Fractured basement can form an important hydrocarbon play e.g. similar to Cuu Long Basin in offshore Vietnam. Despite this, the basement in Gulf of Thailand is yet to be extensively explored and studied.

The primary objective of this study is to map the basement structures as well as interpret basement faults in the area using an integration of 3D seismic attributes and wire-line log data from wells available in the basin.

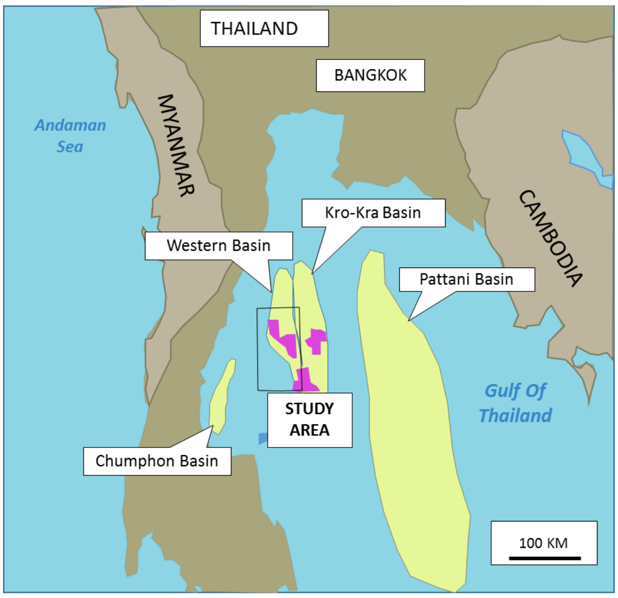

Figure 1: Location of study area

(Modified from SOCO, 2006)

2. Study area

South-West of the project area is a Pre-Tertiary karstified carbonate reservoir oil field called Nang Nuan located in Chumphon Basin discovered in 1987. Two wells were drilled on two different Pre-Tertiary structural highs, and they produced at an average of 3400 BBL/day and 5500 BBL/day respectively before being abandoned due to several problems (Lurprommas et al., 2016). However, the hydrocarbon potential of the Pre-Tertiary basement of Ratburi Carbonate in Western Basin is still uncertain and this thesis aims to advance the knowledge of the basement structures and evaluate the possibility of a petroleum exploration play type in the basin.

3. Methodology

This study focuses on basement reflection interpretation such as picking horizon and creating surface maps as well as identifying the major faults cutting through the basement by applying different parameters of seismic attributes to data. The software used to interpret the horizon and faults, as well as generate seismic attributes in this study was Petrel 2017. The summary of the workflow for this study is illustrated in Figure 2.

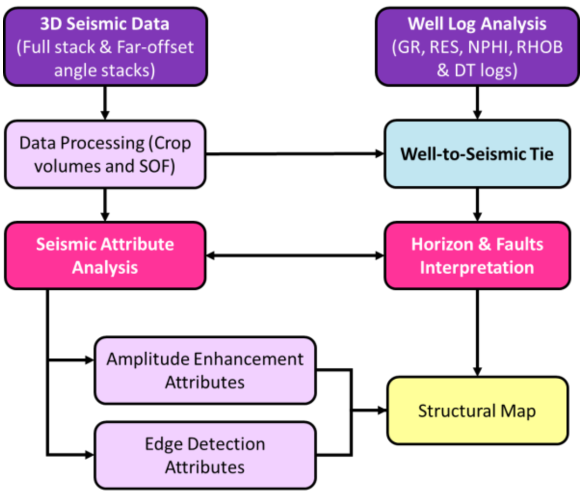

Figure 2: Thesis workflow

A cube of 3D post-stack time migrated seismic data (PSTM) of full-stacked (05˚-40˚) and far partial angle-stack of 30˚-40˚ were utilized in the interpretation. The seismic data has a reversed polarity and an increase in acoustic impedance is represented as a trough. The frequency of the bandwidth of seismic data from the amplitude spectral analysis is 5-40 Hz (Full) and 10-30 Hz (Fars). Well logs of 12 exploration wells are available in the Western Basin but only five wells reached and/or penetrated the basement and were used to analyze its petrophysical properties.

This study focuses on basement mapping and hence the original seismic vertical data were first 'cropped' to time range -750 to -2700 msec. This is later processed using Structure-Oriented Filtering (SOF) to remove noise that could affect the imaging and also enhance the acoustic impedance contrast of seismic reflections (increase signal-to-noise ratio). Each available well that penetrated the basement was then used to generate synthetic seismograms and time-depth conversion curves based on a single velocity function.

The Top of Ratburi Formation horizon was mapped with the help of well top data from well reports as reference points. The faults are observed and picked at basement reflection discontinuities on the seismic vertical sections. Seismic attributes such as Variance (Edge) method were applied and observed on time-slices to further assist on picking and verifying the faults as some fault plane reflections may not be definitive on the vertical section.

Finally, using the mapped basement horizon and faults, a depth structure map was constructed and this was later used to interpret the structural trends and identify the potential leads.

4. Observation and Interpretation

4.1 Basement Horizon Interpretation

The basement was picked based on the seismic responses, well reports as well as the log responses of the five wells which drilled into the basement according to the methodology mentioned above. Two N-S trending ridges were observed in the depth structural map (Figure 3). It shows the trend of the top of the basement structure which is relatively higher to the east of the study area and the depths generally varies from 1200 m to 3400 m.

The Ratburi Formation horizon was interpreted based on the continuous, bright reflectors displayed at most of the central section of the study area, however, some sections and at the outer edge of the study area have weak and blurred reflectors. This may be due to low amplitude contrast with the overlying interval or low seismic processing quality and/or data acquisition located out of range from the acquisition area.

Some areas inside the basement also have high amplitudes which complicate the picking initially, however, several other factors were taken into account to determine the continuation of the horizon. Figure 4 shows the seismic vertical section of crossline 1650 where several strong reflections were observed in this area. However at Inline 3767, well CU-6 reported that it encountered tight Ratburi limestone basement. This strong reflection below is not continuous throughout seismic and picking at inline does not correlate with the crossline and will cause miss-ties. The reflections in this basement are interpreted as fault plane reflections which will be discussed later in the fault section.

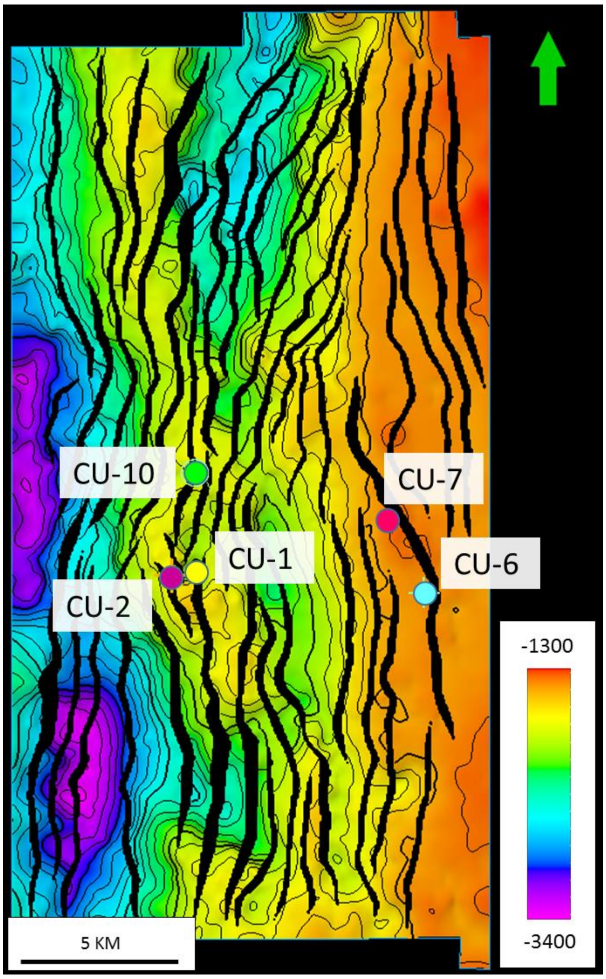

Figure 3: Final depth structure map of Ratburi basement

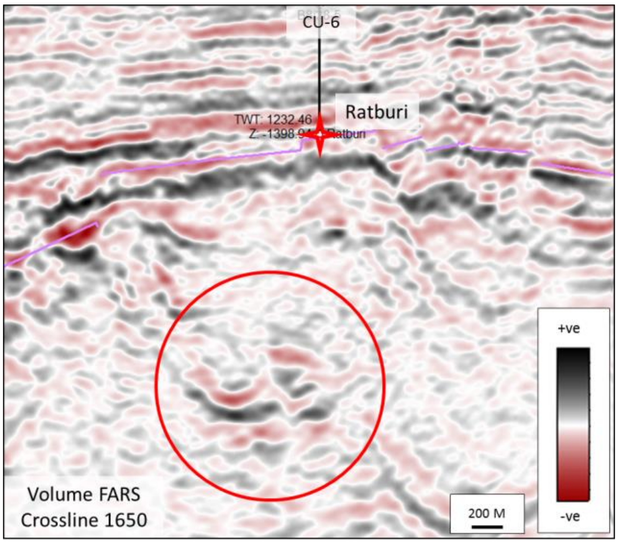

Figure 4: Crossline 1650 shows strong seismic reflections in the basement, these are later interpreted as fault reflections.

4.2 Fault Interpretation

Fault trends are mainly in the N-S, with NE-SW and NW-SE at some places. Most of the major faults that cut from the younger overlying sediments above and into the Pre-Tertiary basement are high-angled normal faults. However, as these faults go into the basement section, they are observed to have low-angled faults and the type of low-angle faults is unknown as no distinct indication of normal or thrusting from the basement carbonate sediments were observed (Figure 5). Morley (2009) discussed that the Triassic-Early Jurassic Indosinian orogeny resulted in the formation of such low-angled, east-dipping compressional fabrics with a weak plane which later caused the occurrence of these low-angle faults in the Gulf of Thailand.

Some of these major faults are further observed for evidence of reactivation faults on existing weaker fault planes potentially caused by the several structural activities occurring throughout the rifting and closing events of the basin of the Gulf of Thailand (Racey, 2011). Multiple fault events were encountered especially along the major normal fault planes cutting into the basement, where underlying sediments seem lengthened having a high displacement of (vertical) fault throws compared to the overlying sediments (Figure 6).

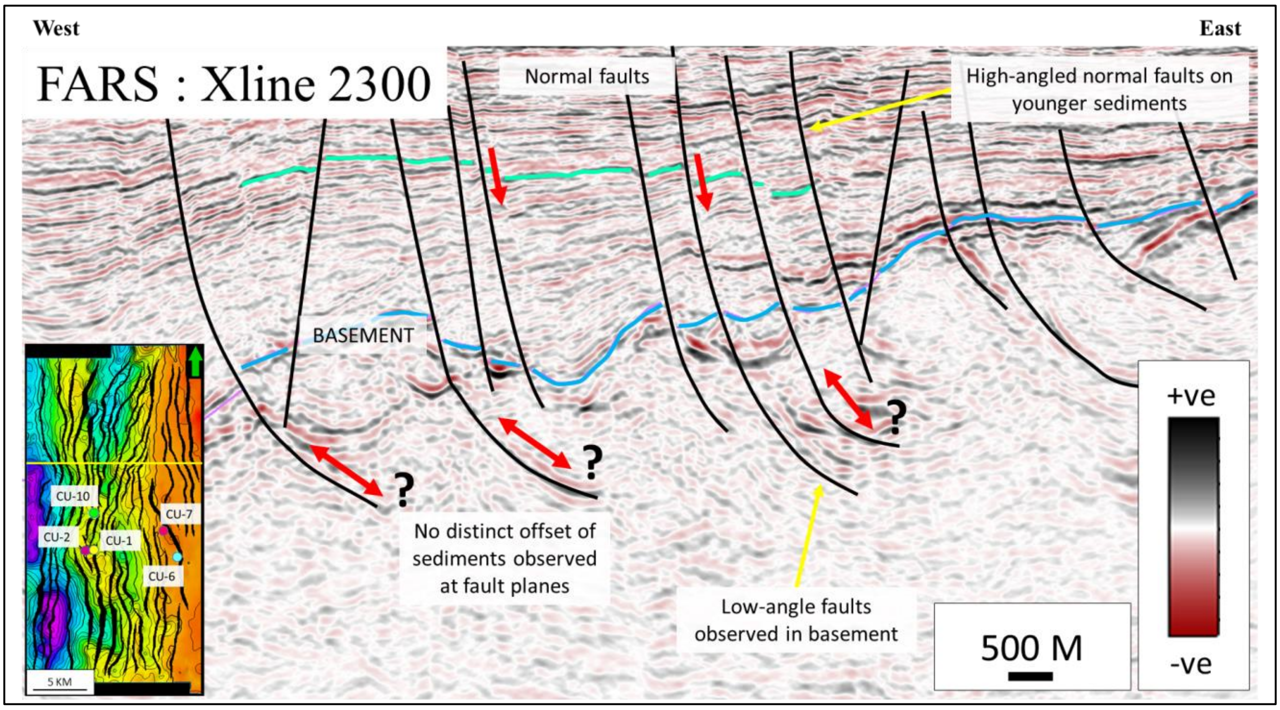

Figure 5: Seismic Crossline 2300 showing high-angle faults on younger, overlying sediments into low-angle faults in the basement. The low-angle faults have no apparent indication of the fault type i.e. normal or thrust faults.

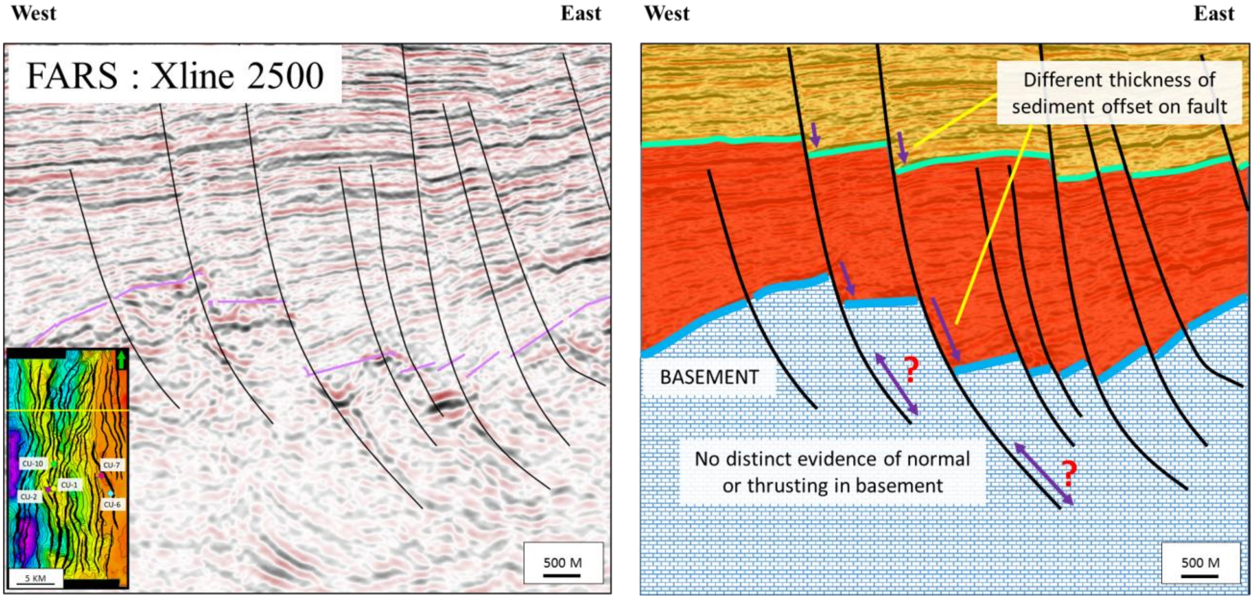

Figure 6: Crossline 2500 shows the evidence of reactivation faults illustrated on fault planes that have different sediment offset thickness as seen in the interpreted section of far-offset seismic volumes.

4.3 Seismic Attribute Analysis

Amplitude Enhancement Attributes

Amplitude Enhancement Attribute such as Relative Acoustic Impedance (RAI) was used to determine the continuation of the basement picking especially when some areas in the basement have no distinct boundary between overlying sediment and basement. The RAI attribute essentially assists in reducing the low-frequency noise from seismic data particularly around the basement and intensified the acoustic contrast of basement reflections producing improved visualization of the basement as seen in Figure 7A. Basement porosity and fractures can be observed by using the Root-Mean-Square (RMS) amplitude attribute. High amplitude anomalies indicating potential high porosity zone were seen mostly along the basement high ridges (Figure 7B). This was confirmed by well CU-2 and CU-7 that drilled into this area and both had experienced loss circulation. CU-2 encountered a highly fractured zone while permeable limestone with large karst holes was seen in well CU-7. However, observations from the stratal and time-slices on the RMS attribute did not see any distinct basement fractures.

Edge Detection Attributes

Edge Detection Attribute such as variance (edge) method was applied on both the full-stacked and far partial-angled stack seismic volumes and along horizon slices and time slices to help identify the faults. This is to compare which of the seismic volume shows more distinct fault images as well as remove the seismic artifacts from seismic. The interpreted faults present on time slices of seismic attribute Variance (Edge) method are shown in Figure 8.

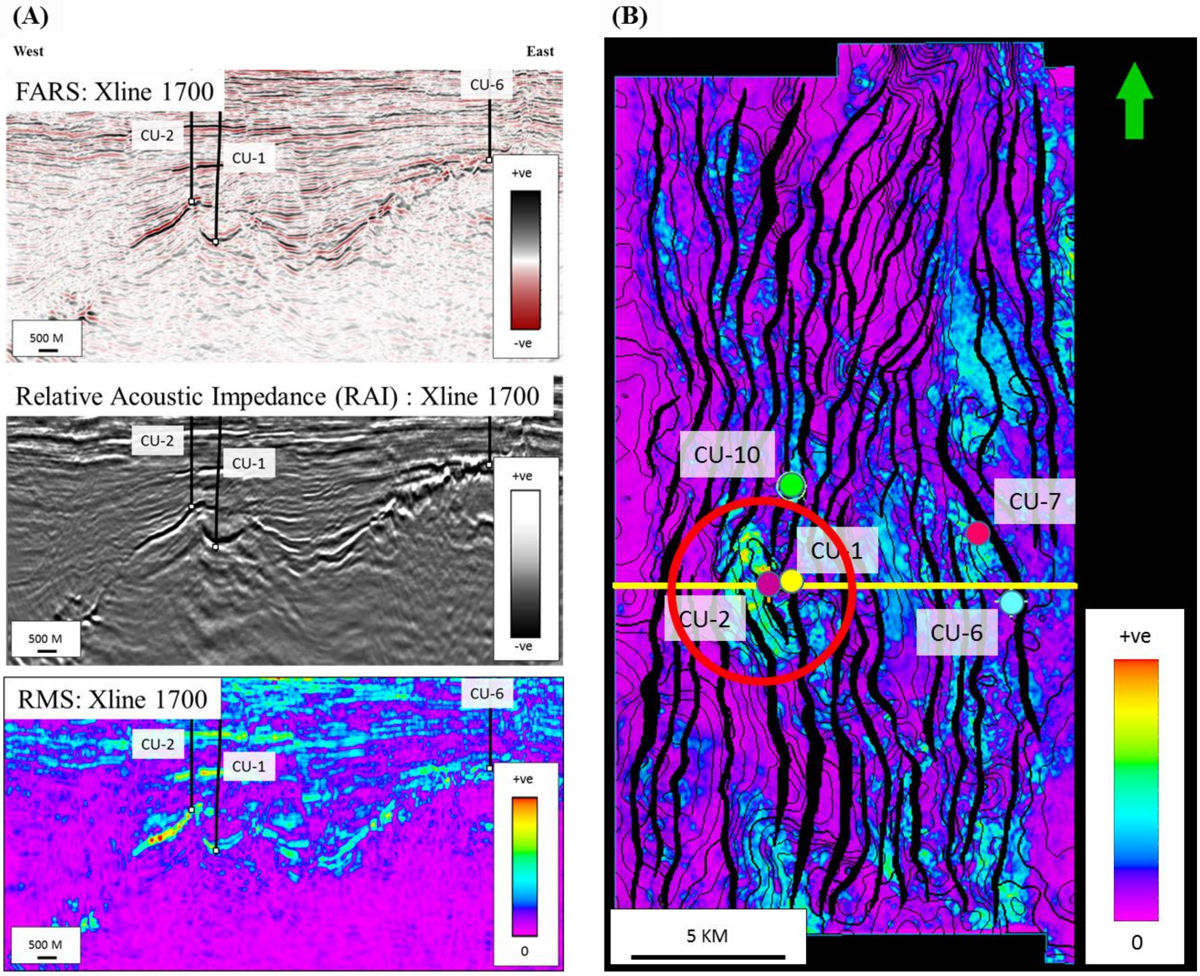

Figure 7: (A) Seismic vertical section of Crossline 1700 in Far-offset, Relative Acoustic Impedance and Root-Mean-Square attributes (B) Stratal-slice of Basement horizon overlain with RMS attribute: Red circle shows porous zones

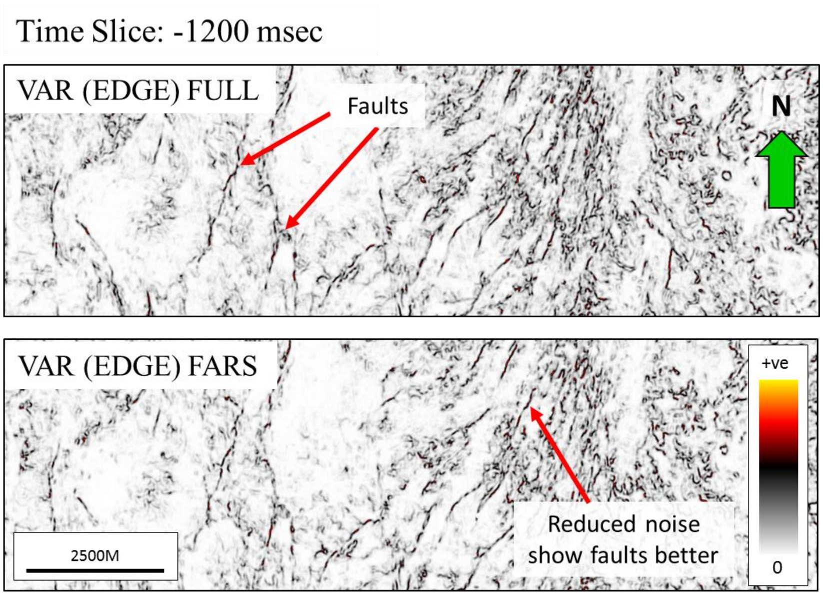

Figure 8: Time-slice section at Z:-1200 showing comparison of Variance (Edge) method attribute in Full-stacked and Far-offset volumes to identify faults

5. Discussion

This study suggests that these structures of basement highs are significantly influenced by the tectonic evolution in the area. From the depth structure map, two well-defined high basement ridges aligned in the N-S direction were observed. These faults are controlled by the transtensional rifting events in the Gulf of Thailand.

The general porosity of the basement highs was also observed but their porosities are proven not to be homogenous throughout the central as well as the Eastern ridge. Three wells penetrated the central ridge and wells CU-1 and CU-10 encountered tight, non-porous dolomite and limestone respectively while CU-2 encountered the top of highly fractured basement according to the well reports. The remaining two wells are located in the Eastern ridge, 2078 m apart from each other and both wells show different porosity types where tight limestone and permeable limestone were encountered by well CU-6 and CU-7 respectively. As a result, the general porosity for each ridge cannot be determined thus far. Nonetheless, the high porosity zones can be ascertained by using seismic attributes such as root-mean-square (RMS) attribute with high anomaly areas indicating high porosity as discussed previously.

6. Conclusions

The integration of 3D seismic data, well information, as well as seismic attributes in this study, was essential to successfully map the structures of the Pre-Tertiary Ratburi carbonate basement as well as the basement faults in the Western basin. The development of this study helps to gain an understanding of the basement and can be beneficial to investigate potential hydrocarbon plays in the region.

Two N-S block-faulted basement highs were observed from the generated depth structure map believed to form due to the multiple tectonic events that occur in the basin. From seismic sections, numerous high-angled, normal faults are seen cutting through the basement forming these half-grabens throughout the study area. The top of the basement was validated by available well information penetrating the basement. High amplitude anomalies inside the basement were also observed which may complicate the picking. These strong seismic reflections are interpreted as low-angle faults. Also, most of the re-activation faults occur on these major faults going into the low-angled basement faults.

Several seismic attribute analysis were tested to determine the best attributes to help enhance the visualization of the basement and structural features such as faults. Moreover, seismic attributes such as root-mean-square (RMS) amplitude attribute are also beneficial to predict the highly porous or fractured zones in the basement and help determine the location for drilling potential prospects. Based on the characteristics established from the effective seismic attributes, the location and distribution of high porosity zones in the basement were later identified in the whole study area. Several of these are located on the basement highs with structural closure, hence have a great potential for future hydrocarbon exploration.

7. Acknowledgments

My deepest appreciation to my thesis advisor, Mr. Angus Ferguson for his knowledge, patience, and persistent reminders to believe in myself.

I would also like to thank all my lecturers, the administrative staff as well as my colleagues for making this program memorable and made me feel at home throughout my stay in Thailand.

I am very grateful to Chulalongkorn University for this scholarship opportunity to pursue my MSc studies, and to Ophir Ltd. for the permission to use their data for this study.

Finally, my very profound gratitude to my parents and family for providing me with unfailing support and continuous encouragement throughout my studies.

8. References

Lurprommas, T., Hamon, Y., Lerat, O., & Nantawuttisak, J., 2016, Reservoir Characterization and Modelling of the Nang Nuan Oil Field Thailand: International Petroleum Technology Conference, doi: 10.2523/IPTC-18870-MS

Morley, C. K., 2009, Geometry and evolution of low-angle normal faults (LANF) within a Cenozoic high-angle rift system, Thailand: Implications for sedimentology and the mechanisms of LANF development. Tectonics, 28, doi: 10.1029/2007TC002202

Racey, A., 2011, Petroleum Geology, Ridd, M. F., Barber, A. J., & Crow, M. J., eds., The Geology of Thailand: Geological Society of London, p. 351-392.

SOCO, 2006, Annual report and accounts: http://www.socointernational.co.uk/cache/downloads/1kgbdwqvxckgkwok88csc0wco/soco_ara_2006.pdf, p. 74.

Virdy, M.K., Adams, S., Kearney, T., Ross, S., and Koysamran, S., 2013, Bualuang Oilfield, Gulf of Thailand: A success story utilizing integrated field development planning: SEAPEX exploration conference, Singapore, p. 22.