

# IDENTIFICATION OF POTENTIAL SOURCE ROCKS USING SEISMIC ATTRIBUTES IN THE SYN-RIFT STRATIGRAPHIC SEQUENCE IN THE SOUTHERN PATTANI BASIN, GULF OF THAILAND

Chanmaly Chhun

Department of Geology, Faculty of Science, Chulalongkorn University,  
Bangkok, 10330, Thailand

Corresponding author email: chanmaly.itc@gmail.com

## Abstract

Estimation of source rock distribution is required to determine hydrocarbon charge in the reservoir. In the Gulf of Thailand, the southern Pattani Basin has limited wells that penetrate into the source rock and the size of the source rock volume is also unknown. Thus seismic facies mapping is the only way to map source rock distribution in the undrilled areas of the Basin. Mancharee\_1 and Mayura\_1 exploration wells drilled into Oligocene stratigraphy. Based on log analysis in the Oligocene interval, these two wells encountered organic-rich shale and a high radiogenic shale zone considered as the potential source rock due to their low AI (Acoustic Impedance) and high GR (Gamma Ray) values. This is the main characteristics of source rocks as they generally have decreasing AI due to increasing organic contents which reduces its density, velocity, and has a high GR. Based on AI difference, there will be contrasting reflections of source rock shale, sandstone, and shale in the study area. Matching well logs to seismic for seismic facies recognition of source rock showed that the top of source rock (top Oligocene) is represented as a trough. These potential source rocks give negative and positive reflection amplitudes. Consequently, the study of source rock distribution and mapping on seismic in areas of the Basin with no well penetrations including deeper parts of the Basin is very important for prediction of hydrocarbon generation. In deeper parts of the Basin, source rock formation would be expected to occur and have a possible high TOC content and maturity. This results in a decreasing AI in source rock compared to other rock types; hence the reflection amplitudes of source rock shales give strong negative and positive amplitudes. By using seismic data, the source rock delineation and thickness therefore can be mapped. The result of mapping source rock distribution is indispensable for petroleum system prediction.

**Keyword:** Oligocene stratigraphy, organic-rich shale, high radiogenic shale, amplitude

## 1. Introduction

The Pattani Basin is one of the most prolific areas for hydrocarbon exploration in the Gulf of Thailand. It is a Tertiary rift basin located in the center of the Gulf of Thailand. Exploration, development and production projects are carried out throughout this Tertiary Basin. To date, in the southerly area of Pattani Basin, there is very limited information concerned with the source rock evaluation and distribution as there are limited wells that have been drilled into source rock. These limited well penetrations into

source rock result in uncertainty in determining the hydrocarbon charge in this southern part of basin as the source rock volume is unknown. Seismic facies is the only way to map source rocks in undrilled areas. The present investigations attempt to identify potential source rocks using seismic attributes in the syn-rift stratigraphic sequence in southern Pattani Basin. The results obtained from this research will be useful for petroleum exploration to determine and delineate source rock distribution.



**Figure 1.** Location of study area, Southern Pattani Basin, Gulf of Thailand

### 1.1 Research Objectives

This research project is aimed at the identification of potential source rocks using seismic attributes in the syn-rift stratigraphic sequence in southern Pattani Basin. The main source rocks were deposited during Oligocene syn-rift section of the Basin. This study focuses on four main points:

- 1) identifying source rocks on well logs,
- 2) matching well logs to seismic for seismic facies of source rocks,
- 3) mapping seismic facies of source in Basin using 3D and 2D seismic,
- 4) calculating the potential minimum volume of source rocks from seismic.

The interpretation of depositional environment of this study was done by analyzing the source rock seismic facies mapping.

### 2. Methodology

This study mainly focuses on well log and seismic analysis by following steps: (1) identification of source rocks on wells by crossplotting Acoustic Impedance (AI) and Gamma Ray (GR) color coded by Density, (2) well to seismic correlation for identification of seismic facies of source rock by using synthetic seismogram, and (3) mapping source rocks in seismic data by using stratal slicing and amplitude mapping.

### 3. Results

#### 3.1 Well Log Analysis

Wire line logs and data are very useful for recognition of source rock or determination of its potential. Source rock properties will give the various responses in log data (Shayesteh, 2011). Mancharee\_1 exploration well penetrated significant thicknesses of source beds (Oligocene Stratigraphy).

##### 3.1.1 Lithological Determination

Cross plotting acoustic impedance and gamma ray logs color coded by density is used for separating lithology of study area. Lithologies of Mancharee\_1 (7467 ft to 10416 ft TVDSS) resulted in three rock types which were organic rich shale, shale with high and low radiogenic content, sandstone, as shown in Figure 2(A). In this well, the thin sand-shale interbedding can be seen on logs (Figure 2B). Sandstones have GR values up to 100 API; it can be assumed that these sandstones may have argillaceous contents. High radiogenic shale (200-500API) and low radiogenic shale (100-200API) are distinguished by GR value as defined in Figure 2(A). Organic-rich shales have very low AI, low density and GR up to 350 API. No coal was found in this well.

##### 3.1.2 Identify source rock on wells

Organic rich-shales, considered as source rocks, possibly have anomalous high Gamma Ray value compared to ordinary shales (Passey, 1990, and Schmoker, 1991). In addition, Tom (2013) also stated that shales with high Gamma Ray value are often associated with high total organic carbon (TOC) content. Source rocks exhibit low density, low kerogen velocity giving the result of low acoustic impedance (AI) which is the product of compressional velocity and density (Løseth et al., 2011). In the Mayura\_1 and Mancharee\_1 exploration wells, the organic rich shales have the high Gamma Ray values up to 350 API and typically low sonic transit time and low density as shown in Figure 2(A). Therefore they are considered as source rock. In addition, high radiogenic shales are also considered to

be potential as their GR value is 200-500API, low density less than 2.6 gm/cc and lower acoustic impedance compared to low radiogenic shale. Therefore organic-rich shale and high radiogenic shale are the potential source rock for this study area (Figure 2). However, three additional indicators to further evaluate potential source rocks such as organic matter of rock, organic matter quality and organic matter maturity grade (Shayesteh, 2011). Evaluation of those potential source rocks need other direct measurements data such as TOC and Hydrogen Index which are not included in this study.

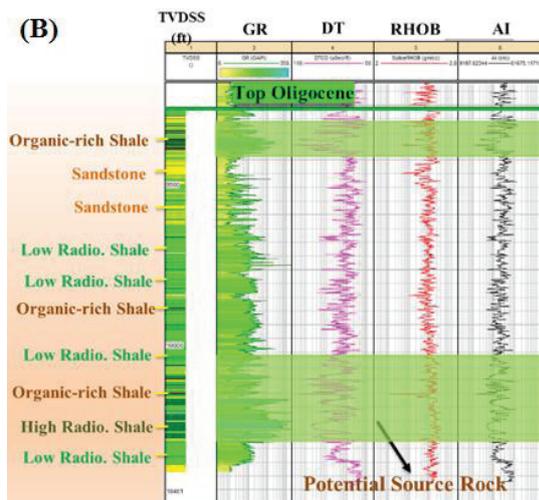
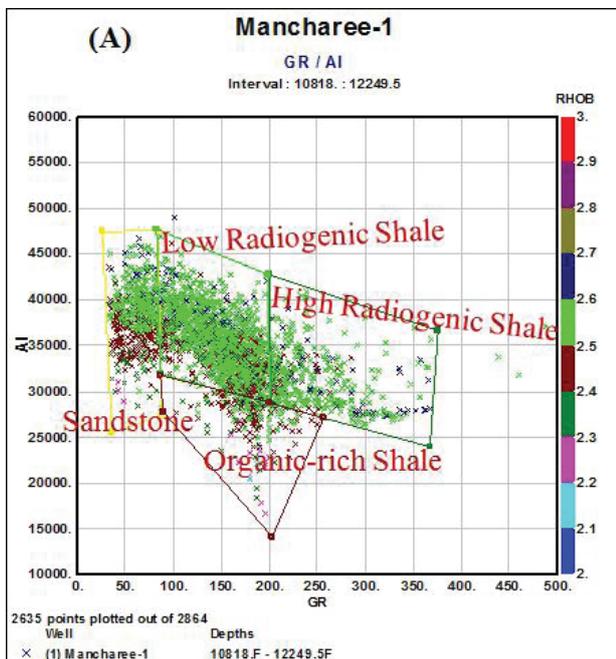


Figure 2. Mancharree\_1 well: A). Well log responses and B). GR and AI crossplot color coded by RHOB

### 3.2 Seismic Analysis

#### 3.2.1 Well tie to Seismic

With the check shot in Mayura\_1 and sonic data from Mayura\_1 and Mancharree\_1, the synthetic seismogram and time-depth curve are created in the Kingdom program. In order to generate an acoustic impedance log and then reflectivity trace, the velocity from each sonic log data is multiplied by the density (RHOB and RHOBCOMP). The synthetic trace is then created by the reflectivity trace convolved with a seismic wavelet. Then, this synthetic seismogram is correlated to the seismic traces on the seismic sections in Mayura\_1 and Mancharree\_1.

As seen on the sea bottom reflection, the polarity of data is zero phase with an increase in acoustic impedance to be a peak. It is important to relate the geological understanding of top and bottom interfaces to seismic data polarity of amplitude seismic characteristics. The deeper section of seismic data also shows the matching between the synthetic seismogram and seismic data in the study area (Mancharree\_1 well) confirming the normal polarity of this data as defined in Figure 3. The data in the deeper part of seismic section (Oligocene down to basement) has moderate quality of data, low frequency and decreasing signal to noise ratio (S/N ratio).

The reflection characteristics of low and high amplitude in the synthetic seismogram generated from the well log data exhibit the matching with the troughs and peaks of the seismic trace. The synthetic was stretched down approximately 12 msec using bulk and bound shift to tie the seismic trace. As a result, the correlation coefficient was equal to 59%. The display of synthetic seismogram on the seismic data with GR shading curve shows the matching of seismic characters in which the top of shale is represented by a trough. The section below top Oligocene is composed of potential source rock having low acoustic impedance trend as defined in Figure 3, and the upper layer of Oligocene consists of sandstone having higher AI.

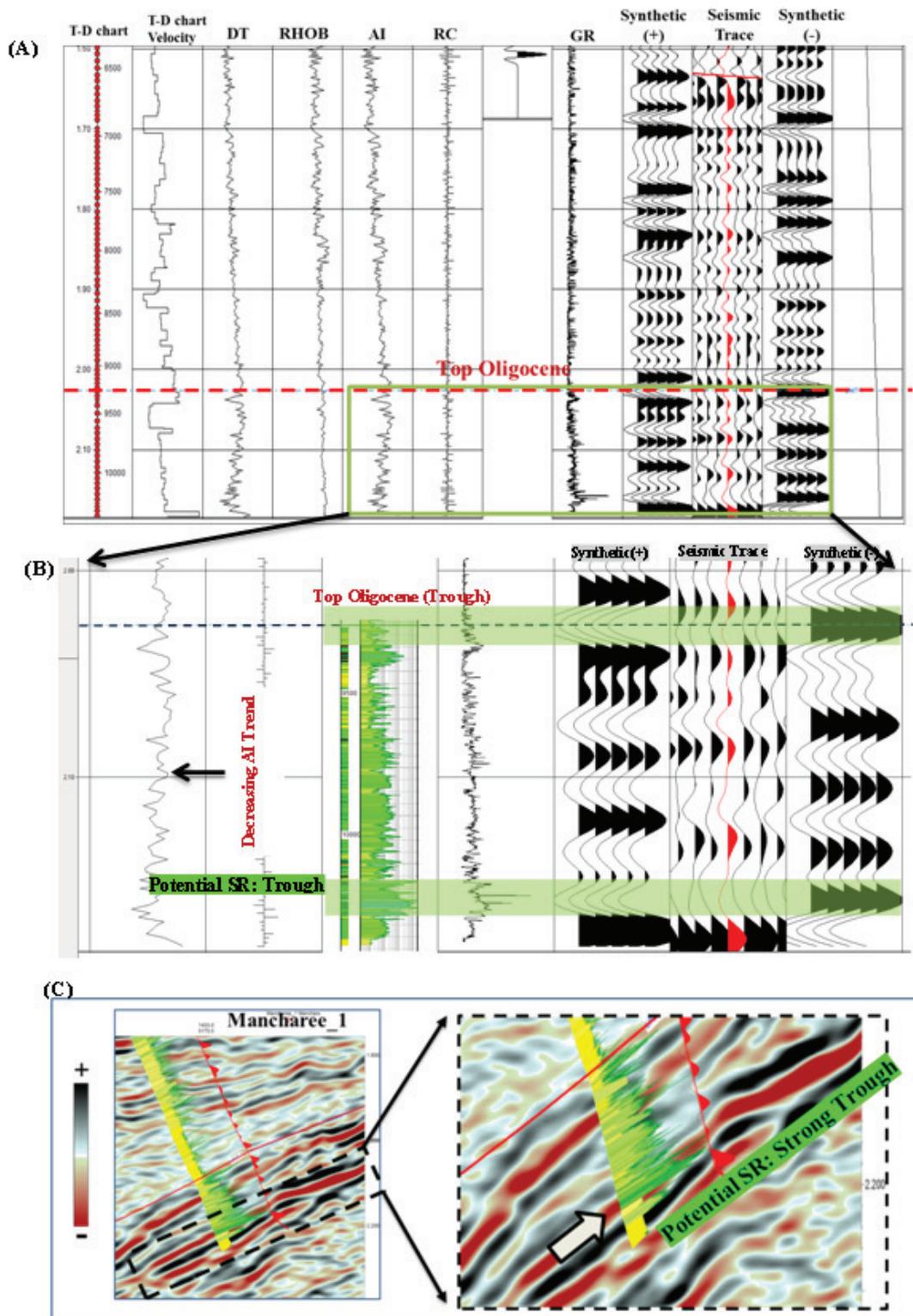


Figure 3. Synthetic seismogram in the well Mancharee\_1, A) Cross section showing the synthetic seismogram after shifting with adjustment of Ricker frequency 25 Hz, B). Synthetic seismogram focusing on the Oligocene interval, and C). Synthetic seismogram and GR shading overlaid with real seismic trace

The synthetic seismogram overlaid with the real seismic trace in the Oligocene interval shows that shale zones that consist of high radioactive shale and organic-rich shale considered as source beds resulted as trough which can be seen by high GR shading zone (Figure 3 B and C). This shows the contrasting of lithologies in this research area. As studied in Log cross plot, Organic-rich shales have very low AI ranging from 13000 to 25000 (ft/sec .gm/cc). Even though, the high radiogenic shales have lower AI compared to low radiogenic shale, the high radiogenic shale zone still resulted in an AI contrast from low radiogenic shale and sandstone in the synthetic seismogram overlaid with seismic data. This interpretation can be related to the research of LØseth et al., (2011) who pointed that source rock shale shows AI decreasing nonlinearly with increasing TOC percent. This gives the top and base of source rock reflection negative and positive high amplitudes. Therefore, amplitude mapping of source rock investigating down to the deepest area of the basin can be mapped by strong reflection amplitudes.

### 3.2.3 Stratal Slicing

The main objective of stratal slicing is to identify and map possible source rock shale in the zone of interest and extend the mapping into areas without well control. The shale in the Oligocene interval has previously been proven as a source rock in many blocks in the Pattani Basin.

Therefore, mapping source rock distribution using seismic data is an important aspect for petroleum exploration. The top Oligocene and Basement were interpreted and used for stratal slicing. Fifteen stratal slicings were used. This interval is thick in the lower structure and thin in the high structure area. The minimum and maximum window length of these stratal slices are respectively 20ms and 90ms (Figure 3 A and B).

As a result, East side of the stratal slices are parallel to the bedding, but the west side cut across dipping bedding, therefore the remapping of a new horizon parallel to beds is picked based on the strong amplitude anomaly as shown in Figure 3(C). It covers an area approximately

65 square kilometers.

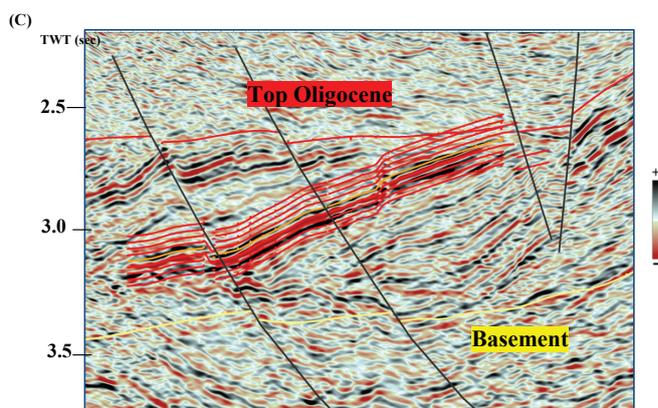
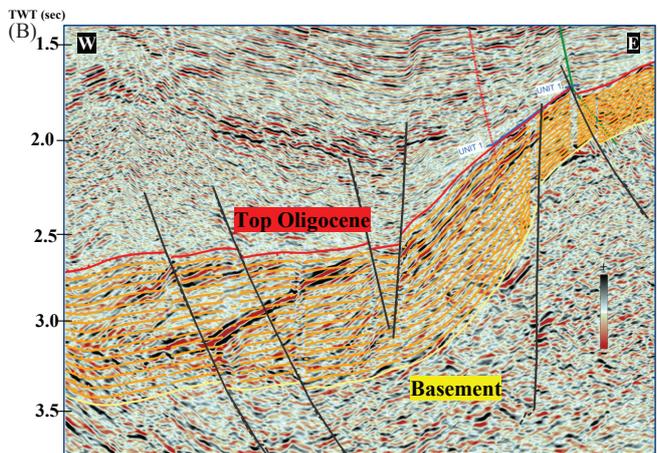
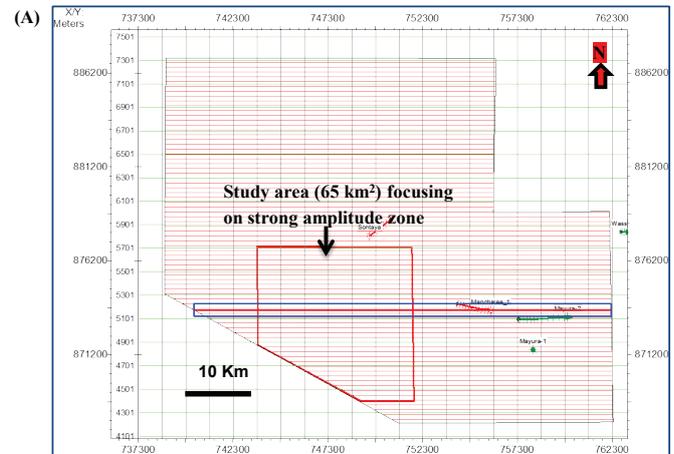
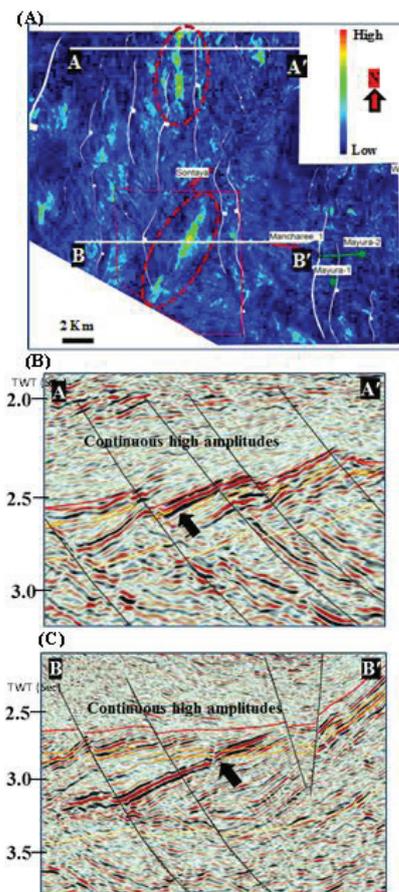


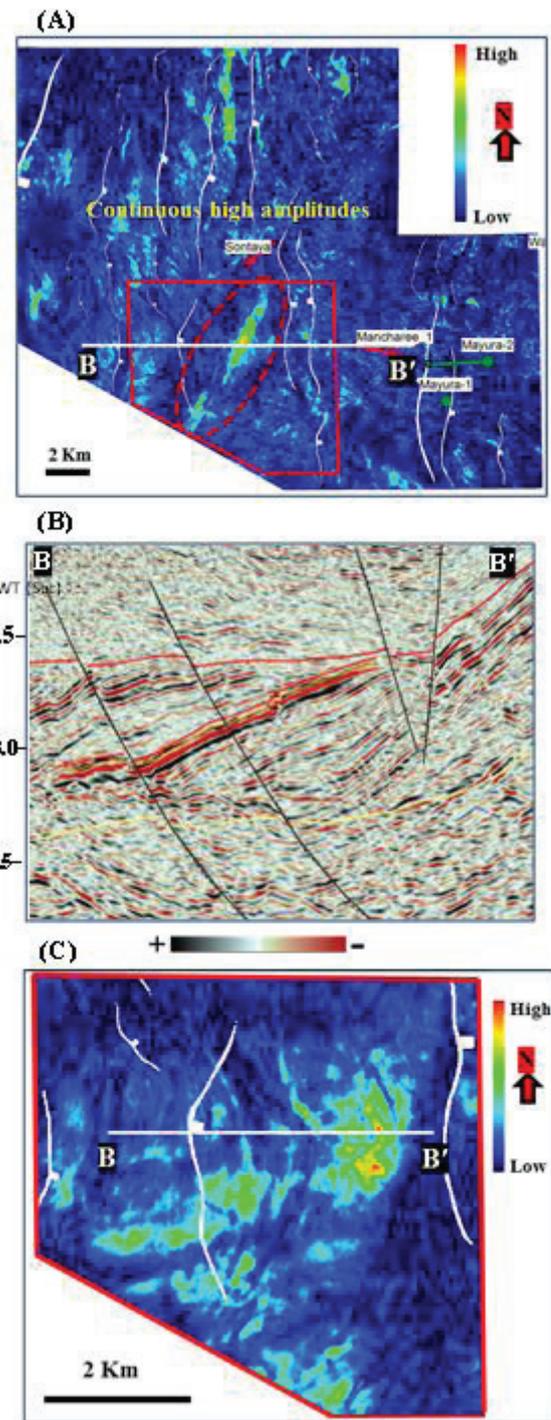
Figure 4. Stratal slices: A). Base map of 3D study area and the focus zone having strong amplitudes and B). Stratal slicing with 15 intervals between top Oligocene and basement and C). Cross section IL 5175 slicing with window length  $\pm 25$  msec.

### 3.2.4 Amplitude Mapping

An interval between Top Oligocene and Basement is imaged with fifteen stratal slices which are used for seismic analysis to determine source rock beds' reflection. The seismic RMS amplitude mapping is extracted from those fifteen stratal slices and used for optimizing the interpretation of source rock beds' reflection as well as estimating source rock distribution for this study area. All of the RMS amplitude maps show the common patterns which are two homogeneous high amplitude anomaly zones in the fault zone that have strongly tectonic control. The zones were formed during the deposition of sediments in the syn-rift deposition. Those high homogenous amplitudes can be seen in Northern and South-West parts on RMS amplitude maps where they are located in the deepest part of this basin as shown on the seismic section.



**Figure 5.** Amplitude mapping, A). RMS amplitude map in the Stratal slicing 4 and 5 showing continuous laterally high amplitudes (red circles) B). Cross section IL 7195 showing high amplitudes (Black arrow) C). Cross section IL 5175 showing high amplitudes (Black arrow)



**Figure 6.** Amplitude mapping, A). RMS amplitude map in the Stratal slicing 4 and 5 showing continuous laterally high amplitudes (red circles) B). Cross section IL 5175 showing amplitude extraction using window length  $\pm 25$  msec. C). RMS amplitude map in the focused strong amplitude area

In addition, this anomalous amplitude area is affected by structural control. Figure 5 shows amplitudes with high amplitude anomaly.

Northern area of continuous high amplitude in RMS amplitude map is consistent with the high reflection on the cross section AA' (Figure 5 A and B). However the southern area of continuous high amplitude in RMS amplitude map resulted from the stratal slice cutting across the dipping bedding (Figure 5A and C). This is a reason to remap this area again by focusing on the strong amplitude event. As a result, a RMS amplitude map of this detailed stratal slice on the dipping beds shows a larger positive amplitude reflection in the same southern part of this study area (Figure 6).

#### 4. Discussion

##### 4.1 Source Rock Beds from Well Log Interpretation

According to both well plots, the Oligocene section has values of GR up to 500 API. This represents both high clay contents and anomalous values. Organic-rich beds are interlayered with low and high radiogenic shale zones. The log plots also exhibited thinning sands. Mayura\_1 well in previous studies proved that Oligocene section deposited by lacustrine source rock has average TOC 1%. In Mancharee\_1 well, there is no TOC or HI data, therefore it is difficult to determine source rock maturity or to do potential source rock evaluation in this area. Further supporting data such as well cuttings, geochemistry report are needed to further understand the source beds in logs.

Moreover this well penetrated near the flank of basin, for this point, the investigation to the deepest part of the basin is more beneficial for source rock delineation. As noticed, sand, low and high radiogenic shale in the Oligocene interval cannot separate these lithologies which were deposited in the deeper depths and affected by compaction. Hence density, AI, and velocity are quite similar. However, AI in organic-rich rock are very low compared to other rock types. Moreover, the zone which consists of

organic-rich and high radiogenic shale appear as contrasting reflections from sandstone and low radiogenic shale as studied in synthetic seismogram. It can be expected that there will be strongly different reflections of the potential source rock investigation down to the deeper part of basin. In deeper parts of the Basin, source rock formation would be expected to occur and have a possible high TOC content and maturity for hydrocarbon generation. This results in a decreasing AI in source rock compared to other rock types. Moreover, based on the log response, there is no carbonates, and AI shows the decreasing value for the identified source rock in this study area. Consequently, the seismic analysis for the source rock beds can be identified by amplitude mapping discussed in the following part.

##### 4.2 Source Rock Beds from Seismic Interpretation

The two main seismic markers top Oligocene and Basement are interpreted based on the presence of the relative continuous reflections within the syn-rift section.

All of the RMS amplitude maps show the common patterns which are two homogeneous high amplitude anomaly zones in the fault zone that was strongly tectonic and active during their deposition in the syn-rift deposition. The structural trends of this basin are from Northwest to Southeast which were formed when the rifting developed by East-West Extension. The axial basin then filled with the sediment deposits. The high homogenous amplitudes in these sediments are interpreted as the source rock beds' reflection due to 1). The evidence of source rock represented low acoustic impedance identified from the well, 2). The regional geology indicating the possibility of source rocks in the deeper area of this basin, and 3). Reflections show high negative on Minimum Magnitude amplitude maps and positive amplitudes due to decreasing acoustic impedance. This low AI may be due to increasing TOC percentage in the shales.

Thus, these highly anomalous amplitudes are indicative of organic-rich sediments considered as potential source rock. This high and low amplitude anomaly with the strong continuous reflector package is consistent with the seismic section which is interpreted as source rock beds. In Figure 7 One of the stratal slicing intervals shows the high and low amplitude anomaly representing as source beds' reflection.

is reported to have penetrated into Oligocene source rock shale. The beds have TOC with average 1.0 %, indicative Kerogen type II with moderate type III influence and marginally mature (T max. less than 400 degree C) with the ranging of Hydrogen Indices ranges from 266-700 mg HC/g TOC, together with the pristane/phytane ratio of 1.72.

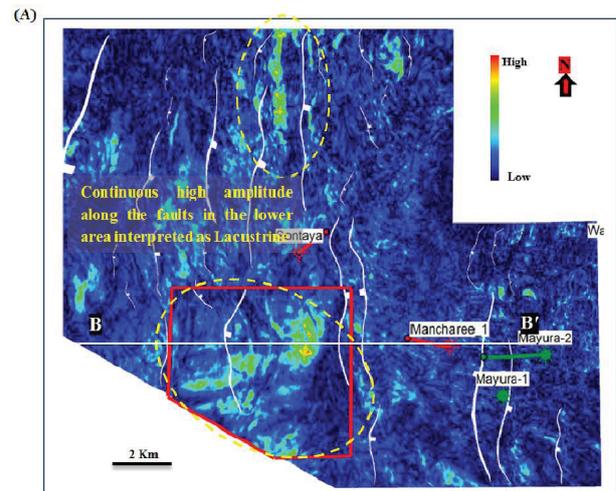
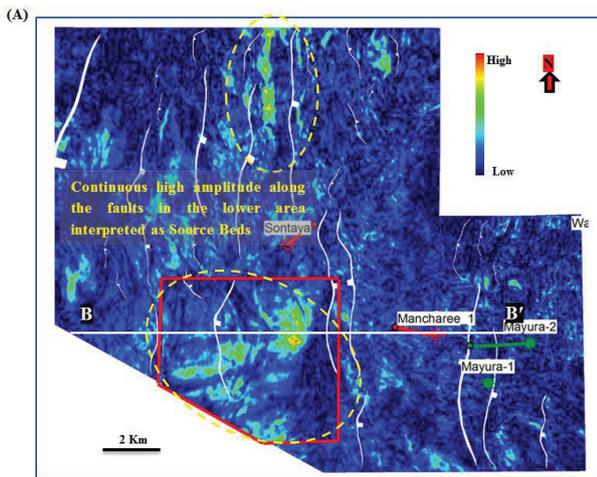


Figure 7. Seismic facies for source rock mapping by RMS amplitude maps showing high continuous and lateral amplitudes interpreted as source beds

### 4.3 Additional Interpretation for Depositional Environment

From the seismic facies overview, a series of high amplitude, laterally continuous parallel reflection seismic facies has been related to oil prone lacustrine source rocks in many rift basins in SE Asia (Sladen, 1997, Longley et al., 1990). In the study area, similar seismic features are observed at many stratal slice interval of RMS amplitude maps and are correlated with multiple stratigraphic levels along the basin. The high amplitudes interpreted as source beds deposited in a lacustrine environment are most prevalent in the middle stratigraphic level when fault displacement is most active. This is consistent with the research by Lambiase 1990, and Lambiase and Bosworth 1995 (Figure 8).

Further evidence of the source beds deposited in a lacustrine depositional environment is in Lockhart et al., (1997) where the Mayura-1 well

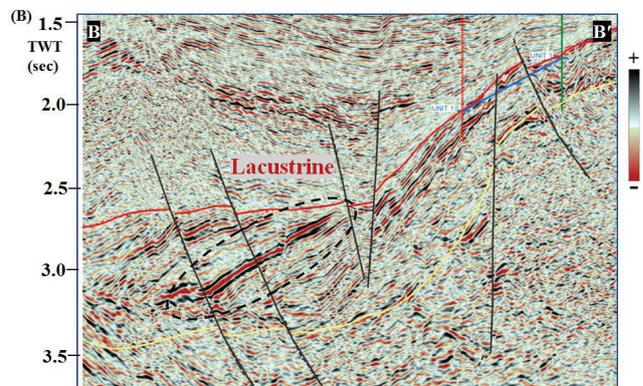


Figure 8. Interpretation of depositional environments, A) Lacustrine and fluvial flood plain based on seismic facies analysis, B). Seismic section showing the homogenous continuous high amplitude interpreted as Lacustrine

### 5. Conclusion

In conclusion, Oligocene source rocks in the syn-rift stratigraphy in the southern Pattani Basin, Gulf of Thailand are interpreted and analyzed by well log analysis and seismic data. The key findings are the following:

- The organic rich shale and high radiogenic shale considered as source rock has GR value 200-500 API, low density (<2.6 gm/cc), high sonic transit time (70-110  $\mu$ sec/ft) and low acoustic impedance (17500-40000 gm/cc x ft/sec).

- The acoustic impedance of the potential source rock shale in the Mancharee\_1 and Mayura\_1 is lower than sandstone and low radiogenic shale. Due to low AI of source rock shale, it gives strong reflection different from sandstone and ordinary shale.

- RMS amplitude map shows high amplitude reflection for source rock beds.

- Based on seismic facies analysis, lacustrine facies can be determined by laterally continuous high amplitude pattern adjacent to the bounding fault.

Overall, the hydrocarbon source rock can be identified by seismic data which is indispensable for petroleum exploration where limited well penetrations into source rock prevent using log data to map source rock distribution.

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