Paleoenvironment study of a syn-rift stratigraphic unit in the northern Pattani Basin, Gulf of Thailand.

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ABSTRACT

The Oligocene syn-rift section associated with the Similan-Lanta structural trend on the northwest flank of the Pattani Basin, Gulf of Thailand is the focus of this study. The syn-rift section hosts the main source rock in the marginal areas of the Pattani Basin and the lack of success of some wells in this area suggests an incomplete petroleum system and the general model needs to be re-evaluated. This study is primarily based on seismic facies interpretation from a 3D seismic data set and supported by well log and geochemical data. A reconstruction of the Paleoenvironment during the syn-rift was done to analyze the relationship between the underlying basement structure and the potential source rock distribution. Three main depositional facies were identified from the study including fluvial plain, lacustrine and alluvial fan facies. The seismic facies analysis suggests that the initial stage of syn-rift development created a series of isolated lakes which developed adjacent to the rift boundary fault. During the middle syn-rift stage a fluvial system developed from the north and filled up the adjacent downstream accommodation space. This was subsequently superseded by a widespread lake which developed along the basin axis in the upper middle rift stage. The structural controls which created the various lacustrine environments controlled the depth and extent of the important source rock distribution. The source rock in this area is not widespread but the geochemical analysis suggests that it is within the generating oil window and does generate hydrocarbons. Migration pathways between syn-rift source rock deposits and potential traps need to be carefully considered when evaluating this areas hydrocarbon potential.

Keywords: Paleoenvironment, source rock, syn-rift stratigraphy, Pattani Basin

1. INTRODUCTION

The Pattani Basin in the Gulf of Thailand is a prolific hydrocarbon bearing basin. Most production is from the central deeper areas of the basin but more recently exploration development is extending to the margins of the basin. However, this has risks, mostly related to access to mature source rock. Success rate is lower and for this reason detailed analysis needs to be done to refine the petroleum system models. The area of this study is located on the northwest flank of the Pattani Basin, Gulf of Thailand and lies along the Similan-Lanta structural trend where a total of 18 exploration wells and several production wells have been drilled (Figure 1). The lack of success in some wells suggests an incomplete petroleum system and the petroleum system model need to be re-evaluated.

The objectives of this study are to understand the variations in pay encountered in the Similan-Lanta area in terms of the petroleum system elements with emphasis on the source rock distribution. The Oligocene age source or unit 1 (Jardine, 1997) was deposited during the syn-rift and has been penetrated by some of the drilled wells. The studies further aim is to improve understanding of the relationship between the underlying basement structure and the potential source rock distribution. The study is primarily based on seismic facies interpretation from a 3D seismic data set and is supported by well log and geochemistry data. A reconstruction of the Paleoenvironment during the Oligocene was done to analyze potential source rock distribution.

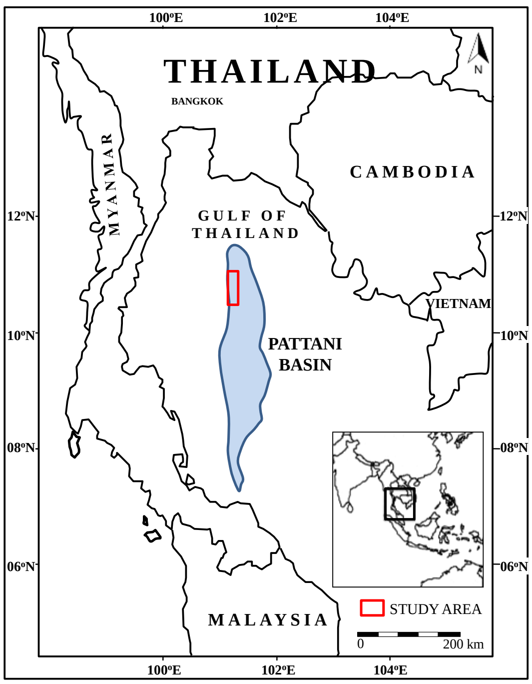


Figure 1 – Location map of study area in the northern Pattani Basin, Gulf of Thailand

2. METHODS

The methodology is mainly in seismic analysis and supported by wireline and geochemistry data. Key markers were identified and correlated from well to well. Faults and horizons were interpreted to understand the structural development and geometry that controlled the basin during the deposition of the source rock in syn-rift section. TWT structure maps were then generated along with an isopach map. The syn-rift section can be divided into three sub-horizons by using seismic character. These are lower, middle and upper middle horizons. Seismic facies analysis was used to aid in geologic interpretation and to help with the construction of Paleoenvironment maps, amplitude extraction maps were generated by calculating RMS attribute within various windows on sub-horizons. The geochemical data from 3 wells were included. Moreover, 1D basin modeling by Aukkanit (2011) was used to identify the maturity level of the source rock throughout the study area.

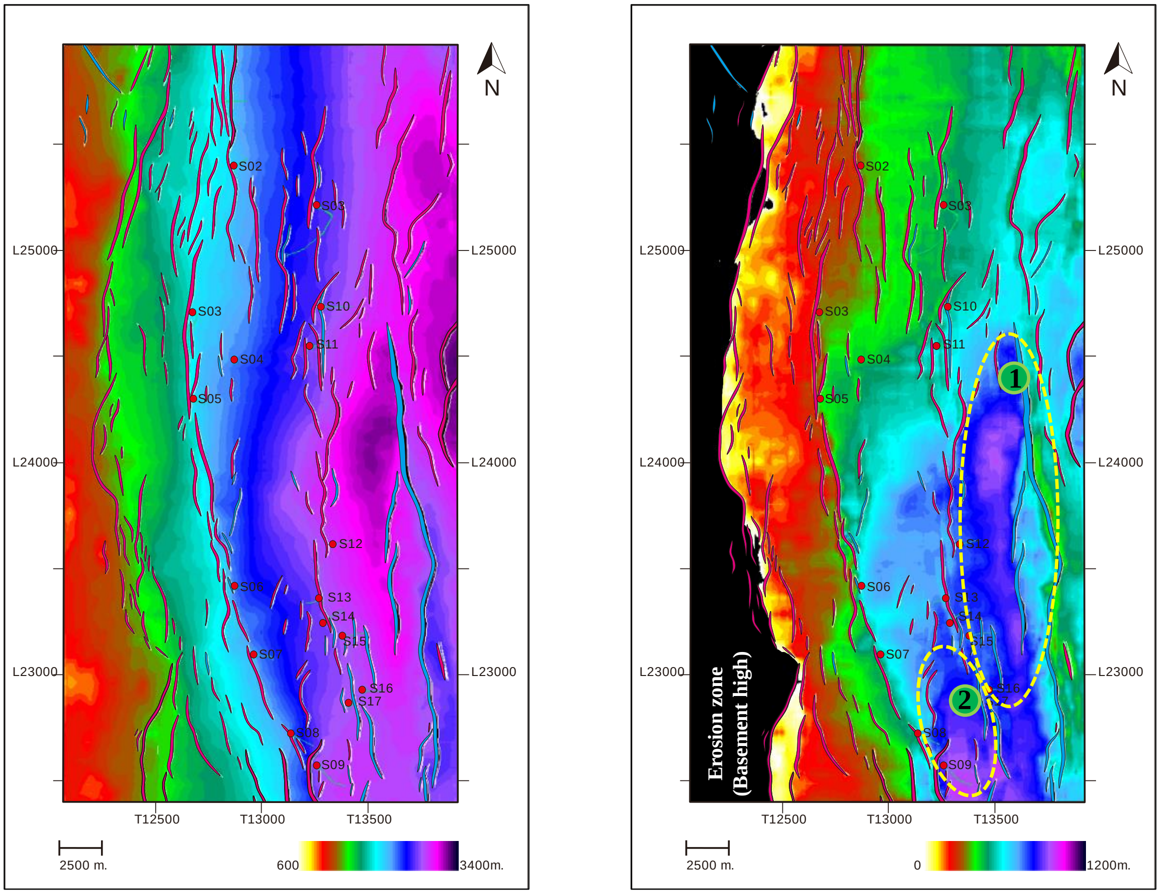
3. RESULTS

Well log analysis and well correlation

Two key markers were identified from the well logs which represent the top of unit 1 and the basement markers. A correlation of wells across the area shows the general character of the syn-rift interval. The identified markers in the well data were tied to the seismic data and were further loop tied in the regional area.

Seismic Interpretation

A depth structural map of basement (Figure 2) shows a significant shallowing from the east to the west in the study area towards the margin of the basin. The structure in the study area is a dominantly half-graben geometry which is controlled by a large west dipping boundary fault on its eastern flank which is the main rift fault and was active in controlling the deposition of this unit. The fault produced a large rift that created the accommodation space for sediments deposited. At times this might have been



(a) (b)

Figure 2 - (a) Depth structural map of the basement, and (b) isopach map of syn-rift section.

filled up by water and subsequently, produced a lake environment.

The isopach map of the syn-rift interval shows the thickness increasing into the eastern bounding fault (Figure 2). There are notably two zones of thick sedimentation. The first zone forms a thick deposit in the central part of the basin adjacent to the large west dipping bounding fault. The second zone is formed at the south western flank. The isopach highlights the areas where the faults were active during Oligocene and which ones controlled sedimentation and depositional environment.

Seismic facies analysis

The basement is generally characterized by a strong reflection displaying a positive polarity. The internal character of the basement shows chaotic facies and along the western flank of the basin a highly erosional surface is observed. In the syn-rift section, the seismic reflector character clearly changes in both vertical and lateral facies sense and three main depositional environments are observed; lacustrine, fluvial plain and fluvial coarse sediments.

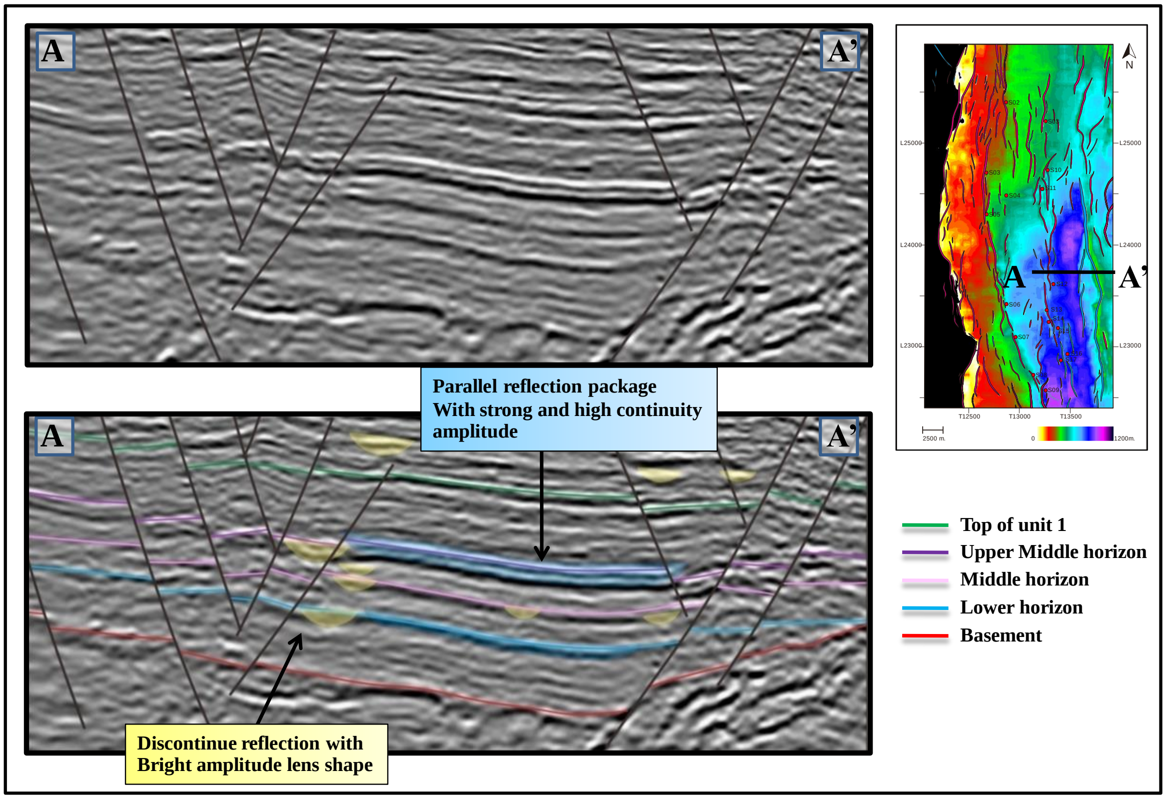


Figure3 - Seismic facies of syn-rift section showing different seismic reflection packages in central area

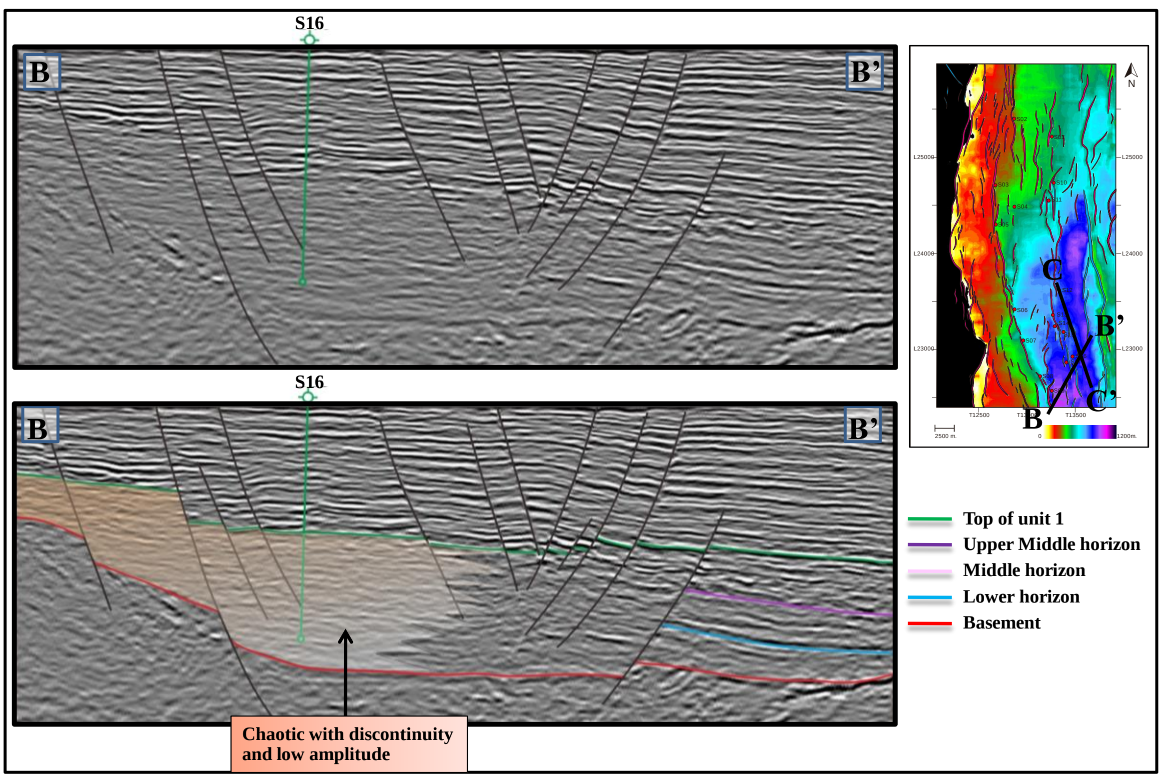


Figure 4 - Seismic facies of syn-rift section showing different seismic reflection packages in the south showing interpreted fluvial coarse sediment deposited.

A series of high amplitude, laterally continuous parallel reflection seismic facies has been associated with oil prone lacustrine source rocks observed in many rift basins in SE Asia (Sladen, 1997, Longley et al., 1990 and Flint et al., 1988). These seismic features have been observed at multiple stratigraphic levels along the basin axis and boundary fault (Figure 3). Also, they are most prevalent in the middle stratigraphic level when fault displacement is most active. (Lambiase, 1990: Lambiase and Bosworth, 1995) The fluvial plain channels were interpreted from discontinuous changes in the amplitude of reflectors. The reflections are highly discontinuous with bright lens shaped reflectors. In map view they often show up with linear to low sinuousity pattern. The south central area of the basin shows an excellent example of the third dominant fluvial depositional environment with coarse sediment deposited within a relative isopach thick (Figure 4) which shows a chaotic reflection pattern. Some thick sands interbedded with shales are observed in well S16 in the syn-rift section (Figure 5).The lateral variation in seismic facies seen is associated with a basinward change in depositional environment from fluvial coarse grained deposit to fluvial plain to lacustrine as discussed by Maynard et al., (2002).

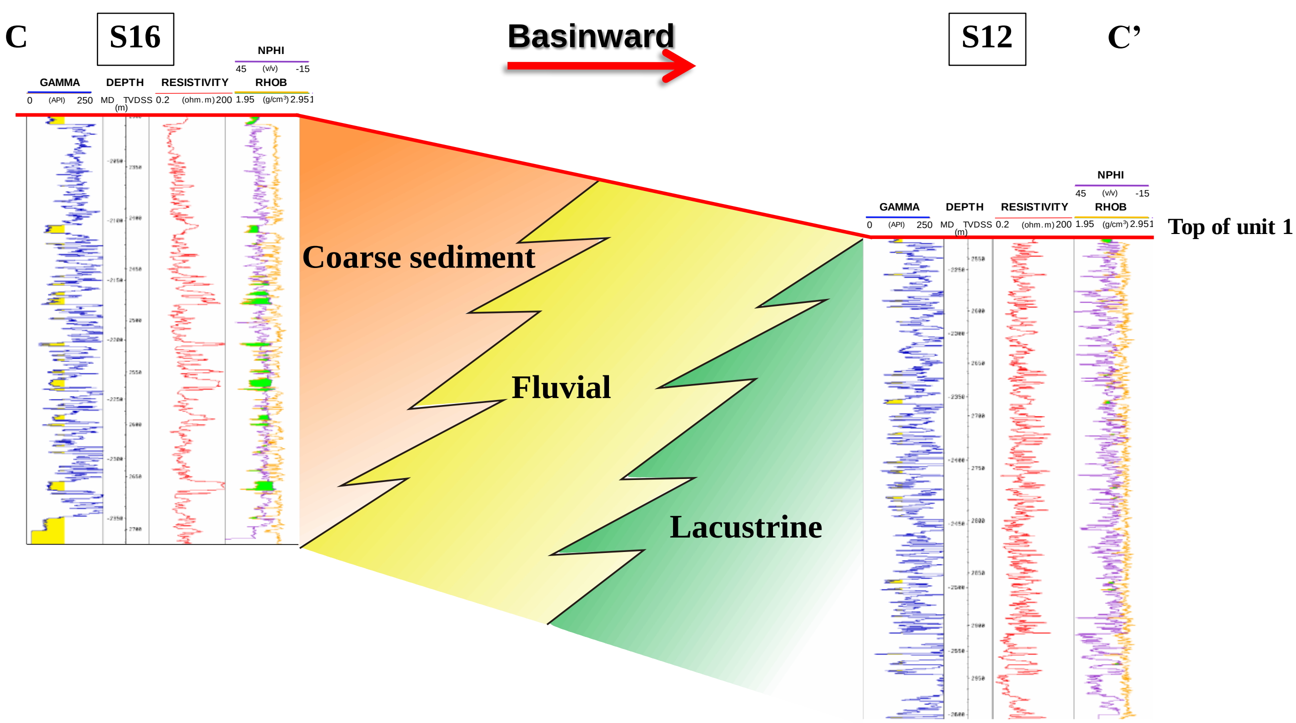


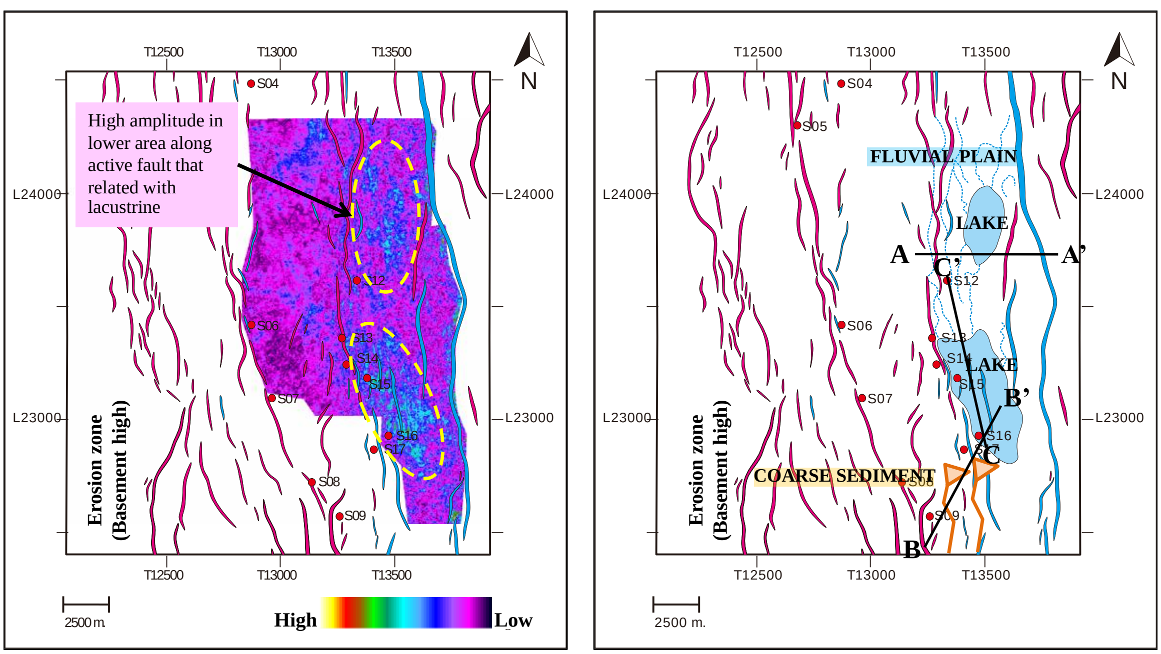
Figure 5 - Lateral facies changes observed from proximal margin to boundary fault area. Fluvial coarse sediment deposited was deposited adjacent to basin margins then sediment can be transported to basin by fluvial complex systems and finer grain material deposited in lacustrine environment (Maynard *et al*., 2002)

RMS amplitude

The RMS amplitude map of the lower horizon (Figure 6) shows two homogeneous high amplitude anomaly zones elongated along the boundary fault that was active during the deposition of a syn-rift section. These high amplitude zones can be interpreted as lacustrine deposits that can be indicative of fine-grained organic rich sediment (Burton and Wood, 2010; Ginger et.al, 1993). The seismic sections confirm the correlation of this high RMS amplitude anomaly with a strong continuous reflector package consistent with a lacustrine interpretation. Moreover, fluvial plain features were also observed on the RMS map which shows low sinuosity linear anomalies to the north which correlates to lens shaped reflectors on the seismic line

The RMS amplitude map of the middle horizon (Figure 7) shows a high amplitude anomaly at the southern part of the basin only. The presence of low amplitude slightly sinuous patterns in the north can be interpreted as meandering river systems which potentially feed into the lake to the south. Near the western basin margin can be observed another large fluvial system.

The RMS amplitude map of the upper middle horizon (Figure 8) shows a large high amplitude anomaly along the central graben axis. The high amplitude anomaly adjacent to the active fault during Oligocene is related to the thick shale section on the log and to the strong, parallel, continuous reflector on the seismic section. The high amplitude with channelized features associated with bright amplitude lens shaped on the up-dip seismic section can be interpreted as channel and point bar deposits.



(a) (b)

Figure 6 - (a) The RMS amplitude and (b) Paleoenvironment map of the lower horizon interval. Location of Figures 3, 4 and 5 shown.

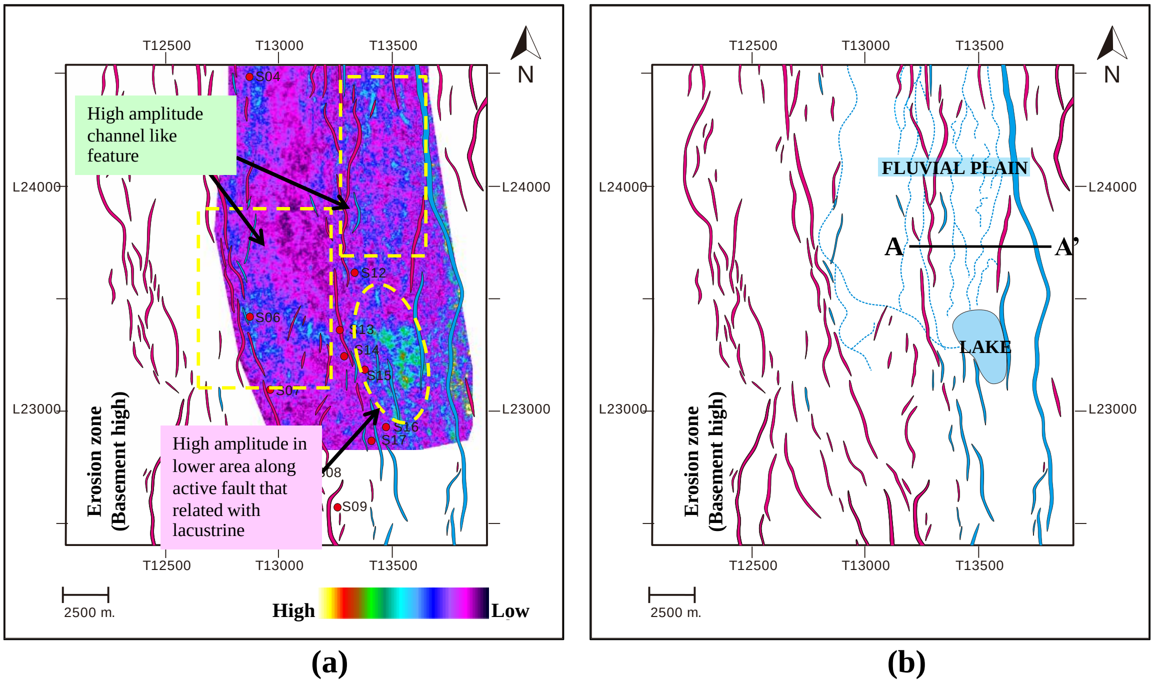


Figure 7 - (a) The RMS amplitude and (b) Paleoenvironment map of the middle horizon interval. Location of Figure 3 shown.

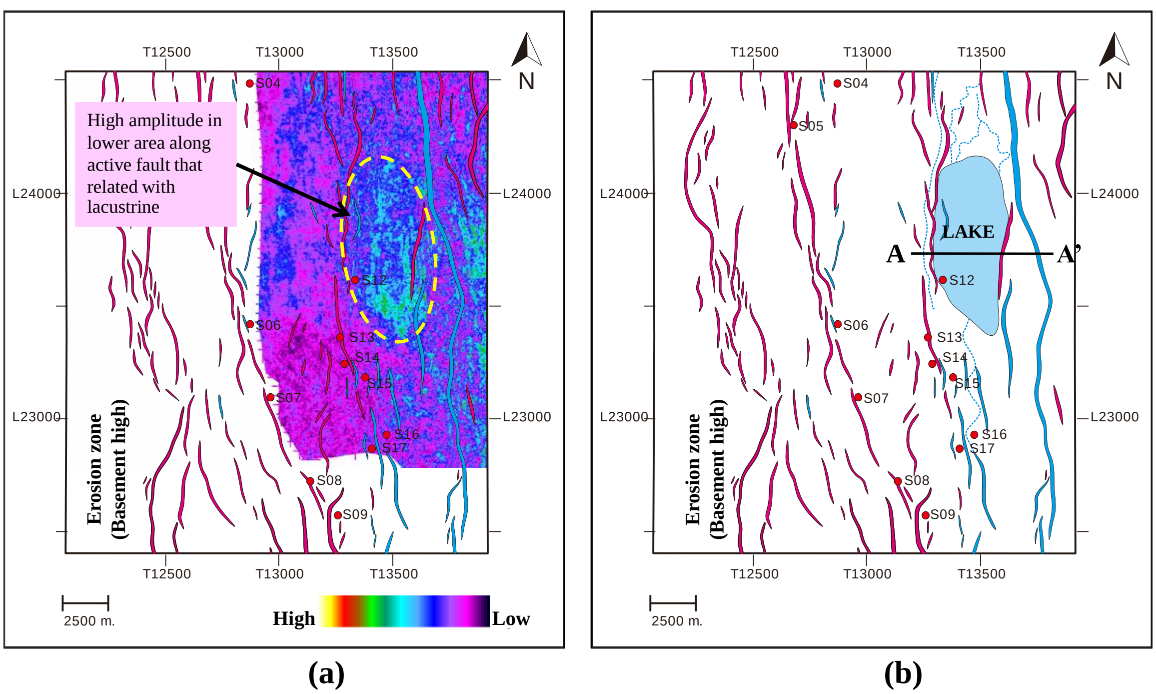


Figure 8 - (a) The RMS amplitude and (b) Paleoenvironment map of the upper middle horizon interval. Location of Figure 3 shown.

Paleoenvironment maps

The lower syn-rift stage shows a series of isolated rift lakes which developed in the central part of the basin adjacent to the boundary fault in the isopach thick. The rift basin development in the early syn-rift stage is generally in small and isolated lows (Lambiase, 1990). Fluvial systems are interpreted to be oriented north to south along the axis of the rift.

The middle syn-rift stage is comprised of a fluvial complex system observed to the north. The small, isolated lakes of the early system change and the northern lake shallows and is filled up with sediments displacing the volume of water (Lambiase, 1990). The river system formed replaces the lake and transports sediments to fill up the adjacent downstream accommodation space.

The upper middle syn-rift stage is dominated by lacustrine facies which is characterized by an elongate lake along the basin axis. The lake that was initially formed in middle stage is extended to cover a broader area as rifting becomes more active. Fluvial channels are observed feeding the lake from the north.

Geochemistry analysis

The well samples lie in an up-dip location and are associated with fluvial plain facies.

The Hydrogen Index (HI) (mg/g) versus Tmax (0^C) diagram (Figure 9) shows that most of the samples in this section belong to Type III kerogen with only one sample identified to be of Type I kerogen. This plot suggests that the origin of the source rock encountered in these wells is mainly terrestrial sediment with a minor lacustrine component.

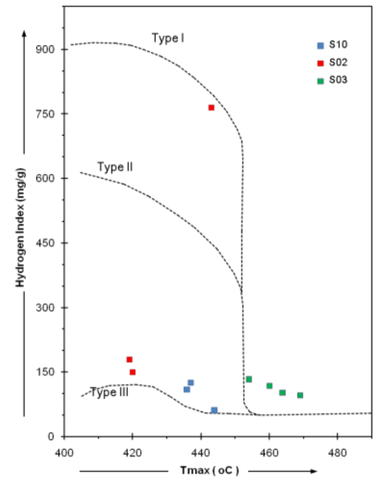


Figure 9 - The Hydrogen Index (HI) (mg/g) versus Tmax (0^C) diagram

In addition, the Hydrogen Index (HI) versus total organic carbon (TOC, %) diagram shows a fluvio-deltaic trend. The TOC values of the terrestrial samples are low at 0.5-1.1%. This implies that the terrestrial origin of the source rock in this area has low organic matter. It is also possible that samples from the deeper interval may already have entered into wet gas and condensate phase and hence the organic matter content was reduced.

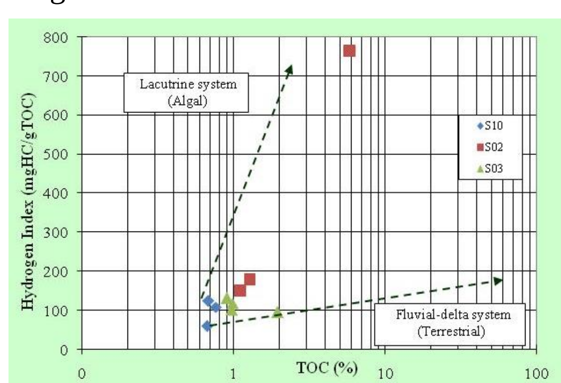


Figure 10 - Hydrogen Index (HI) versus total organic carbon (TOC, %) diagram

Based on the 1D maturity modeling analysis by Aukkanit (2011), the base of unit 1 at present time shows that the source rock has just reached mid-maturity in the central area and is more immature along the flanks of the basin. To the east, the lacustrine source rock is within the oil window phase. Hydrocarbon generated at the deeper intervals potentially migrated into up-dip traps.

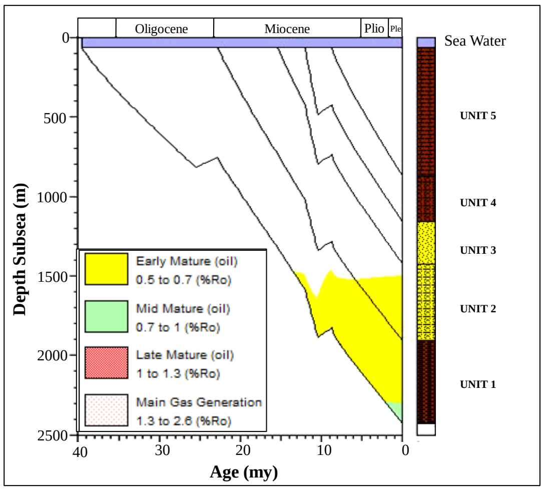


Figure 11 - 1D basin modeling from Aukkanit, (2011) shows the maturity of middle horizon at well location S04 (Fipresent day time

4. DISCUSSION

The interpreted paleoenvironment have similar character to several other syn-rift sections in South East Asia (e.g. Burton and Wood, 2010; Phillips et al., 1997; Maynard, 2002; Doust and Summer, 2007).

In the Pattani Basin, the main factor that controls the basin structure is the interaction of trans-tensional stresses on a pre-existing structural fabric. During rifting the displacement of boundary faults creates the accommodation space for deposition of a thick sediment. Minor offsets on fault trend can be seen in the study area which can subtlely affect depositional environments.

Various models of rift basin development suggest that a series of isolated lacustrine environments can develop in the early syn-rift phase e.g. Lambiase, (1990) and as the rifting continues, axial fluvial systems can fill and spill into some of these lake deposits. With further active subsidence, lakes can increase or decrease in size depending on the balance between accommodation space and climate (Katz, 1991; Lambiase, 1990; Carroll and Bohacs, 1999).

In terms of the petroleum system, Type I oil has been discovered. However, geochemical analysis shows a dominance of Type III kerogen because most of drilled wells penetrated the source rock interval within the fluvial dominant section with low TOC values. However, the paleoenvironment mapping indicates that lacustrine environments with potential Type I source rocks were deposited at equivalent times at down-dip locations in the topographically lower syn-rift deposits (Figure 12)

In conjunction with this, the 1D modeling from previous work shows the source rocks reached high maturity in the deeper parts of the basin and tends to be more immature along the flank of the basin.

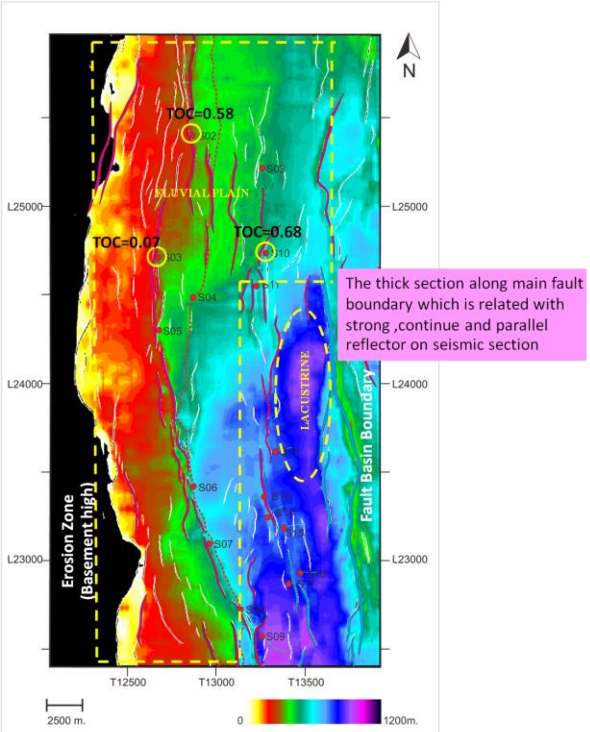


Figure 12 - Low TOC values were encountered in Type III kerogens associated with fluvial dominant facies. The thick lacustrine shale is associated with possible source rock down-dip from sampled wells. Window is shown by the red dash line on map

5. CONCLUSIONS

• Three main depositional facies in the syn-rift section were; fluvial plain, lacustrine and fluvial coarse sediment deposits.

• Lacustrine facies were recognized by their homogenous high amplitude and laterally continuous reflection pattern adjacent to the basin bounding fault and are associated with potential source rock.

• The tectonic activity and pre-existing structural fabric controls the distribution of source rock deposited in lacustrine depositional environments.

• Paleoenvironment reconstructions show that potential lacustrine source rocks are deposited in isolated areas along the rift, which vary in position as the fault activity changes.

• Lacustrine source rocks in the study area are not widespread but geochemical analysis shows that they are within the oil generating window where present. The source rock is highly mature in the deeper parts of the basin and immature along the western flank.

• Migration pathways need to be carefully considered when evaluating this areas hydrocarbon potential.

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