Quantitative Seismic Geomorphology of Early Miocene to Pleistocene Fluvial System of Northern Songkhla Basin, Gulf of Thailand

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Abstract

Songkhla basin is located in southwestern part of the Gulf of Thailand. This is one of the hydrocarbon producing basins of Thailand. Reservoirs are sand systems of fluvial depositional environment. This study reports seismic geomorphologic analysis of the northern part of the basin from Early Miocene to Pleistocene. I applied quantitative seismic geomorphology approach to characterize and understand the channel systems in the area. In Early Miocene and from Late Miocene to Pleistocene large meander belts with an average size of 2014m and 1490m respectively were observed, whereas, in the Middle Miocene an average size of meander belt is 573m. Similarly, width to depth ratios are also significantly small (average 6) in the Middle Miocene. Large meander belts in Early Miocene may be due to prevailing syn-rift phase in the area. Narrow channel belts and very low width to depth ratios in Middle Miocene are the result of low accommodation. In Middle Miocene most of the tectonic activity stopped along the syn-rift faults within the area. Low width to depth ratios may be due to base level rise near delta plains. Relatively large meandering belts with large width to depth ratio developed from Late Miocene to Pleistocene. Sea level changes (drop at upper Middle Miocene) coupled with thermal subsidence controlled the channel morphology in this period. Relationship between sinuosity, meander belt width, channel width and channel depth were analyzed. These observations have important implications for understanding the heterogeneity of fluvial systems and provide useful information for application in hydrocarbon field development.

Keywords: Songkhla basin, Quantitative seismic geomophology, fluvial system

1. Introduction

The Songkhla basin is one of the productive basins, located in the south west Gulf of Thailand (Figure 1) and most of the reservoirs are fluvial sands of Cenozoic age. This study is focused on the interval from Early Miocene to Pleistocene in the northern Songkhla basin. This study reports mapping of fluvial systems by using seismic attribute techniques and presents quantitative analysis of depositional morphologies. This quantification approach provides deterministic data for hydrocarbon field development and helps in understanding the history and fill architecture of the basin.

Key objectives of the present study are summarized below:

- To map the depositional system by using seismic horizon and time slices of different attributes.
- To analyze GR log patterns within different depositional sequences of different geological times.
- To understand the depositional environment and evolution of channel morphology within different tectonic phases of the basin.
- To provide quantitative analysis of depositional morphologies observed on horizon and time slices.

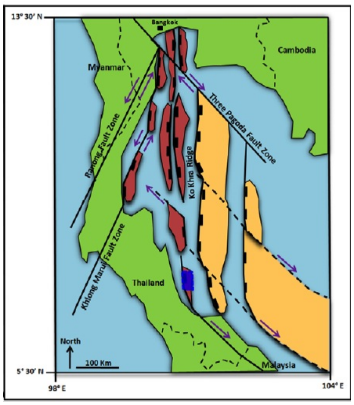

Figure 1. Location map of the Songkhla basin

2. Results

Horizon and time slices analyzed for the mapping of fluvial system are shown in seismic section (Figure 2). According to the synthetic seismogram, troughs represent the sands. The high amplitude troughs are an indicator of sands. The low amplitudes are indicator of shale. Therefore, all horizons were tracked on troughs to delineate sand zones

H40_Early Miocene horizon

High RMS values are scattered in the eastern and as well as western part of the area except within the faulted zone of eastern part. In the western part, high RMS values are mostly bounded by faults and no specific mender belt system can be observed within the faulted zone. The GR response more sandly at this interval is blocky in well X3 of west part contract with well Z1 in east part. In the central part of the area, we can see the large mender belt showing point bars indicated by high RMS and associated with low amplitude mud-filled channel (Figure 3a).

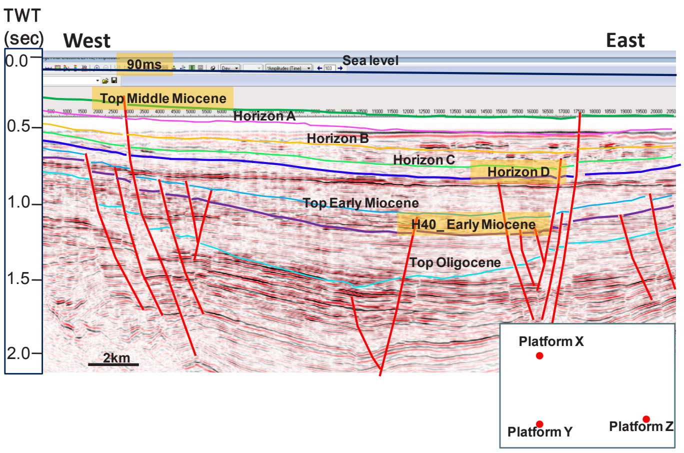

Figure 2. Seismic section in the middle part of the SongKhla Basin

This low amplitude mud-filled channel can also be seen on the vertical seismic section (Figure 3b). The width of this mud-filled channel is 200m and observed depth on depth converted section is 50m. The total width of the channel is 2.2 km. Based on Ischron map of Oligocene to H40, the deepest part of the basin is in the center. Therefore, most probably the flow direction of channel is from north to south (Figure 3c).

Horizon D- Middle Miocene

High RMS values are mostly observed in the southern part of the basin (Figure 4a). In the northern part, which is the study area, RMS values are relatively low as compared to southern part of the basin. Therefore, in this time mostly shale dominant of the basin. The well log pattern mostly is funnel shape. Narrow meander belts have been observed in the western part of the area. Whereas, in the central and eastern part no significant meander belt is observed. Based on Isochron map, paleo-flow directions of channels

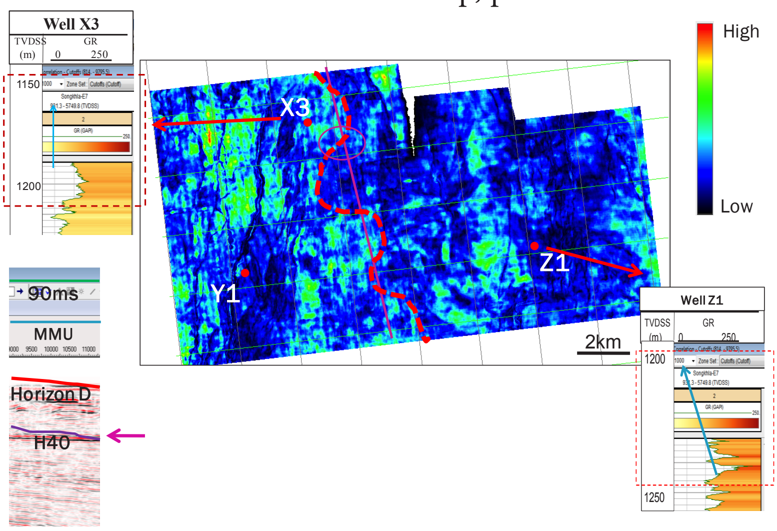

Figure 3a. RMS attribute map at H40_Early Miocene horizon slice

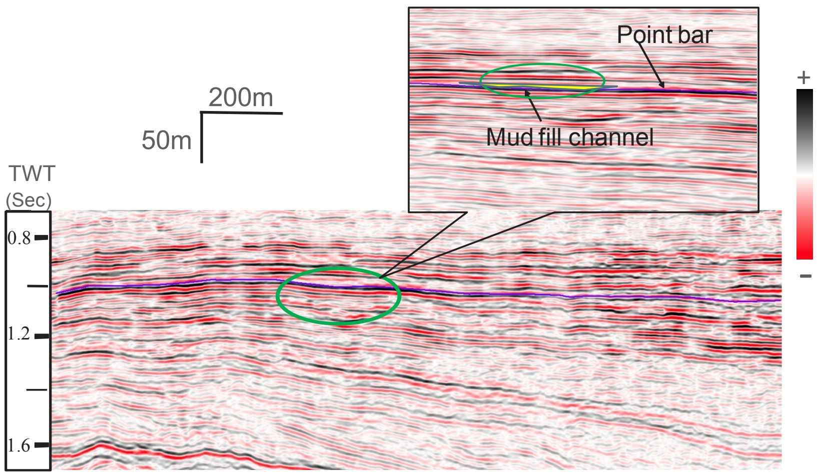

Figure 3b. Seismic cross section showing channel at H40 horizon slice

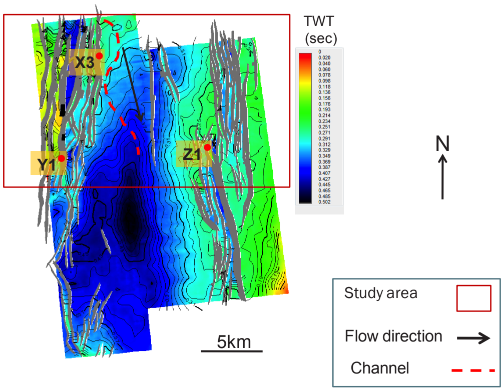

Figure 3c. Isochron map Oligocene-H40 showing probable flow direction of the channel.

are shown in Figure 4b.

Top Middle Miocene

Generally, high values of RMS are observed on this horizon slice. In the eastern part of the area, low values of RMS are found. Two major meander belts can be observed on this horizon slice. The western part of the area GR patterns are blocky and in the eastern part thin sand and fining upward pattern is observed at overbank of the channel M1 (Figure 5a). Probable paleo flow direction of channel could be Southwest to Northeast (Figure 5b).

90 time slice

This is the shallowest studied seismic image. Three channels can be delineated easily on this time slice (Figure 6).

3. Discussion

3.1. Lithology variation and depositional environment

The lithology variation and depositional environment interpretation was analyzed by integrated GR log analysis, available core data and morphology interpreted from horizon slices. In Early Miocene GR patterns are the blocky with low GR values and bell shape (Figure 7).). RMS attribute map shows high values, which means this is sandstone dominant area. The core

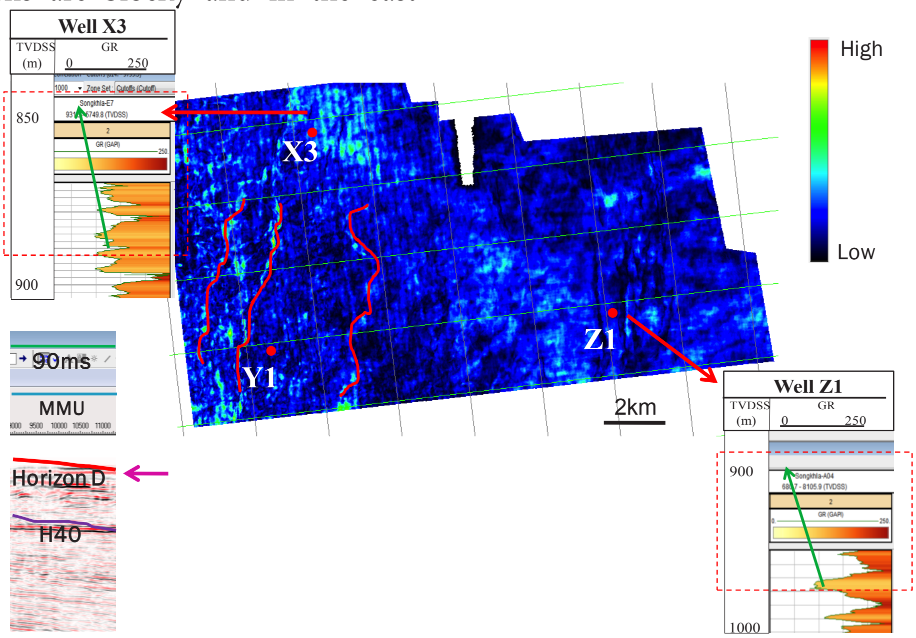

Figure 4a. RMS attribute map at Horizon D_Middle Miocene

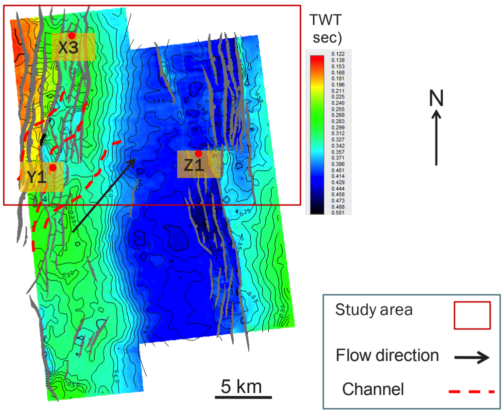

Figure 4b. The isochron map of Early Miocene to Horizon D showing the probable flow direction of the channel is SW-NE

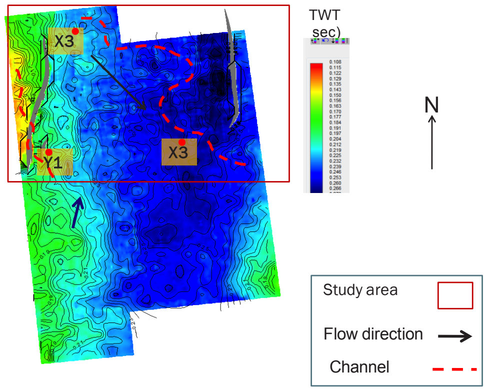

Figure 5b. The isochron map of Early Miocene to Horizon D showing the probable flow direction of the channel is SW-NE

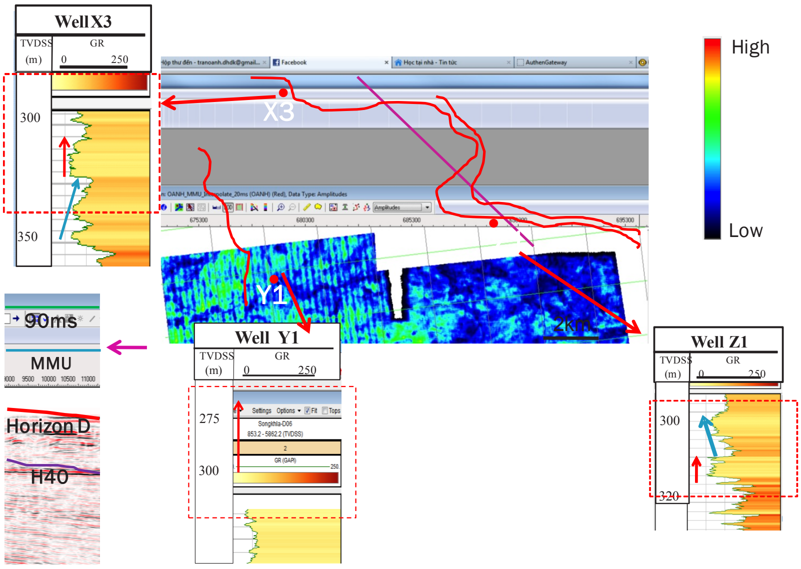

Figure 5a. RMS attribute map at Top Middle Miocene

analysis data indicated fluvial dominant sands and has some marine influence indicated by bioturbation at this level (Figure 8).

For Middle Miocene interval, we do not have core and biostratipraphic data to interpret deposition environment. GR patterns are funnel shape and this interval is mostly shale dominant. (Figure 9). RMS attribute map also display low values, which may also indicate fine grains within this interval. Biostratigraphic data from southern part of the basin indicates marine influence throughout Middle Miocene period. This interval is interpreted as fluvial systems, which were affected by marine influence during flooding events.

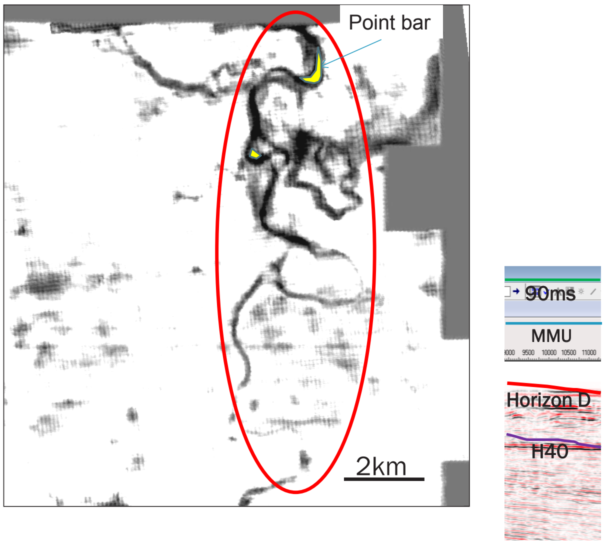

Figure 6. The RMS attribute map of 90 time slice.

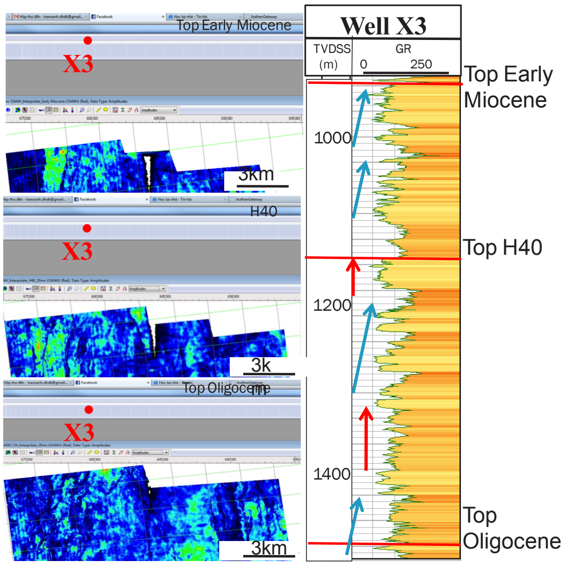

Figure 7. Comparison of RMS attribute maps and GR log in the upper part of the Early Miocene

3.2. Quantitative seismic geomorphology.

Quantitative Seismic Geomorphology involves quantitative analysis of depositional morphologies, imaged by using 3D seismic data to understand the history, processes and fill architecture of a basin (Wood, 2007). Different studies (Wood & Mize-Spansky, 2009) have been made to establish empirical relationships between different measured channel belt properties to classify and understand the processes of channel systems.

Relationship between meander belt width and sinuosity.

Meander belt width defines the area, within which channel may migrate laterally. This is one of the important parameters, which defines the extent within which a reservoir can develop. Cross plot between meander belt width and sinuosity indicates that these are directly proportional. Meander belt increases as sinuosity increases. Middle Miocene measured data (green points) shows relatively low sinuosity and small size meander belt widths. Whereas Early Miocene and Late Miocene fluvial systems have relatively high sinuosity and larger meander belt widths (Figure 10). Sinuosity and meander belt width are function of slope. If slope increases sinuosity and meander belt size increases (Wood & Mize-Spansky, 2009).

Relationship between Channel belt width and channel width

Channel width defines cross section size of channel fills. Reasonable correlation exists between meander

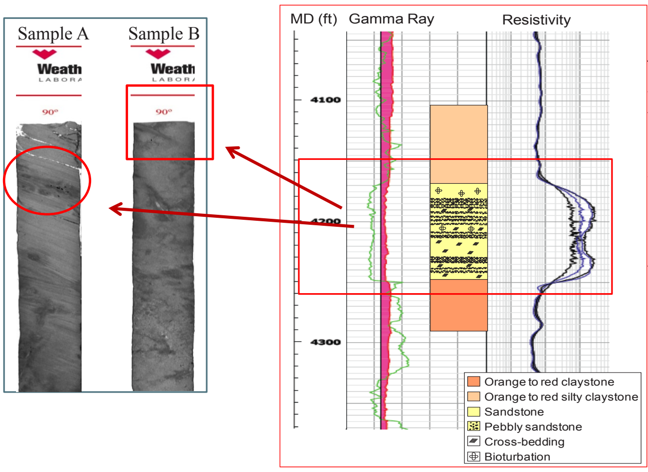

Figure 8. Core image shows that this interval is fluvial channel and marine influence in inferred on the basin of bioturbation

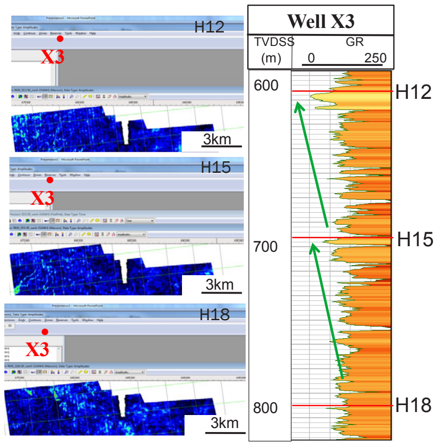

Figure 9. Comparison of RMS attribute maps and GR log in the upper part of the Middle Miocene

belt and channel width (Figure 11). In Middle Miocene, meander belt width and channel width are small. It looks in Middle Miocene channel systems were confined to limited space as meander belts have smaller sized as compared to meander belts of other similar channel widths. This graph suggests that meander belts in the study area can be used to predict the size of channels within meander belt. This observation has important implication for understanding the reservoir variations in the area. Generally, these channels are mud-filled and may act as barrier between two sand systems.

Relationship between the channel width and channel depth

Cross plot of channel width and channel depth shows fair correlation between these two measured values. Relatively lower of values (200 to 300 meters) channel width shows sharp increase of channel depth with increase of channel width (Figure 12) and lower values shows good correlation. However higher values of channel width (>300 meters) does not show good correlation with channel depth. This means the relationship of channels with greater channel widths (>300 meters) have different relationship with channel depth. Gilbling (2006) classified channels depending upon width to depth ratios. He used log-log plot for this classification. Cross-plot on logarithmic scale for channel width and depth is shown in Figure 13. According to this plot Middle Miocene channels are of very low width to depth ratio (less than 10), could be related to delta distributaries. Whereas, other intervals also have larger ratios greater than 10. These low ratios may be related to base level in Middle Miocene.

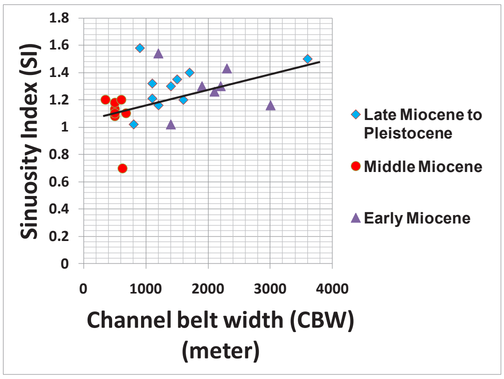

Figure 11. Crosspot between the channel belt width and channel width

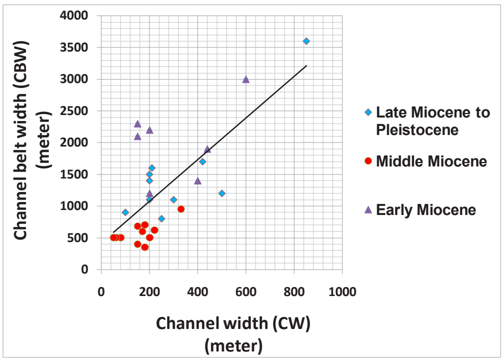

Figure 12. Cross-plot between channel width and channel depth

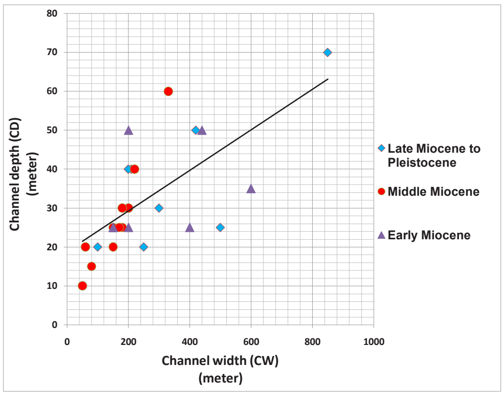

Figure 13. Cross plot of width versus depth on log scale

3.3 Fluvial system evolution and controlling factors for meander belt morphology.

In Early Miocene observed channels have moderate to high sinuosity. The computed area and volumes are large within Early Miocene. These large meander belts are located in the center of the basin. However, on the western part of the basin no significant meander belt can be observed though sand is distributed in this area. This may be because of complex syn-rift faulting. This part of the study area may have narrow meander belts bounded by rift fault systems in Early Miocene. The maximum thickness in Early Miocene is along the rift related boundary faults. Hence, it is inferred that channel morphology is controlled by rifting in Early Miocene. Large accommodation produced by rifting is responsible for significant larger meander belts. Marine influence is inferred from bioturbation on the core sample of Early Miocene. Paleo-flow direction of channels in Early Miocene is from NW-SE in this part of the basin.

All channels within Middle Miocene have small meander belt width and relatively low sinuosity. Flow direction is from SW-NE. The area and volume of point bars are relatively small with respect to Early Miocene Fluvial systems. In Middle Miocene sediments thickness is no more controlled by rifting faults as isochron map shows that maximum thickness of sediments shifted eastward in Middle Miocene. Moreover, the intensity of faults is less in the Middle Miocene interval. According to Miall (2002), low sinuosity rivers with little lateral migration are characterized by very low slope and low accommodation. The meander belts measured on the Top of Middle Miocene are large and show change in flow direction of paleo channels. The flow direction is now NW-SE. According to Miller (2011), the sea level dropped in the Late Miocene to Pleistocene. In Songkhla basin, do not have any tectonic activity at top of Middle Miocene. Therefore, the accommodation space for these meander belts were created due to sea level drop at that time.

4. Conclusion

Quantitative data of seismic geomorphology can provide useful information for reserve estimation of hydrocarbon field.

Channel belt morphology changes from Early Miocene to Pleistocene: Early Miocene: mostly large channels in the center of the basin, Middle Miocene: mostly narrow channels in the west of the basin, Top Middle Miocene to Pleistocene: mostly large channels in the center of the basin.

Flow direction controlled by tectonics: Early Miocene: NW-SE, Middle Miocene: SW-NE, Top Middle Miocene to Pleistocene: NW-S

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