

Evaluation of the Petroleum Systems in the Lanta-Similan Area, Northern Pattani Basin, Gulf of Thailand

Sirajum Munira

Petroleum Geoscience Program, Department of Geology, Faculty of Science,
Chulalongkorn University, Bangkok 10330, Thailand
Corresponding author email: munirageo28ju@gmail.com

Abstract

The presence of mature source rocks and numerous structural traps along the Lanta and Similan structural trends on the northwestern margin of the Pattani Basin make this area highly prospective for hydrocarbons. To analyze the factors which control hydrocarbon distribution and develop a petroleum system model for this study area 3D seismic data integrated with exploration and production well log data were used. Well log analysis was used for petrophysical evaluation and stratigraphic correlations and seismic data used for structural style interpretation. The results show hydrocarbons tend to be trapped better on up-thrown fault blocks than the down-thrown fault blocks. Moreover, lower net to gross sand percentages are evidence for good sealing capacity towards the eastern basinward part of the area compared to the higher sand percentage areas seen on the western basin flank. Vertical migration was dominant near the thicker source rocks and higher maturation levels in the eastern part whereas lateral migration pathways are limited to the west and southwestern part. Furthermore, small fault throws can leak out hydrocarbons in this area. Sand thickness is fairly uniform throughout the area and does not appear to be a factor in influencing the variable pay distribution of hydrocarbons. From this integrated analysis, it is observed that the probability of higher prospective areas is in the east along the Lanta trend due to the higher mature source rock with dominant vertical migration pathways, prominent up-thrown faults creating three-way dip closures and lower net to gross sand percentages. In comparison, the western side along the Similan trend has lower probability of prospectiveness. The northern Similan trend has better potential for hydrocarbons than the south because of greater fault throws leading to better sealing capacity.

Keywords: Transgressive, Fluvial system, Shallow Marine system, back-filled distributary channel

1. Introduction

The northwestern flank of the Pattani Basin is intersected by the N-S trending Lanta and Similan fault

systems which show significant variations in hydrocarbon pay along similar trends in similar structural positions (Figure 1). Some of these wells were unsuccessful and some have thick pay

in some areas. To evaluate these differences, it is necessary to understand the structural style and develop a petroleum system model. Analysis of the different petroleum system elements in the area was carried out which included source rock distribution and maturity, hydrocarbon migration pathways, reservoir quality and distribution and structural trapping style. The seismic data, wireline logs and previous geochemistry data were used in this research to determine the controlling factor of hydrocarbon distribution, focusing on higher prospective areas in this basin. Sequences 4 and 5 are the main reservoir intervals in the area and sequence 1-3 the main source rock interval (Figure 2).

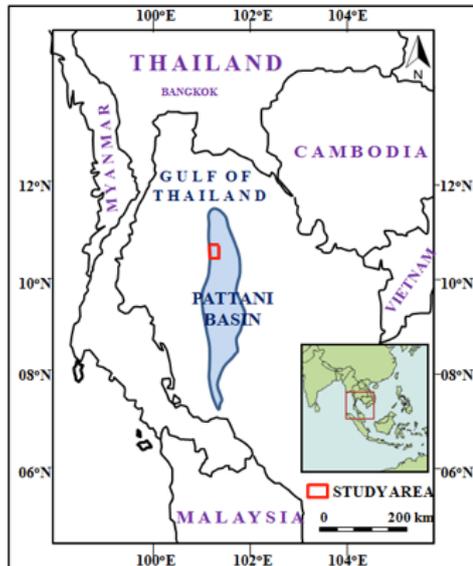


Figure 1. Location map of the study area.

2. Methods

Various methodologies were used to assess each of the petroleum system elements. First, sands, shales, coals

and hydrocarbon signatures were interpreted from well log data. Next, key markers were correlated from well to well for sand mapping and horizon interpretation. Then, net to gross of sand in each interval were calculated. These well log analyses and the net to gross sand analysis helped to indicate the reservoir quality potential. After that, the thickness of sandstone in each well was calculated and posted as net to gross

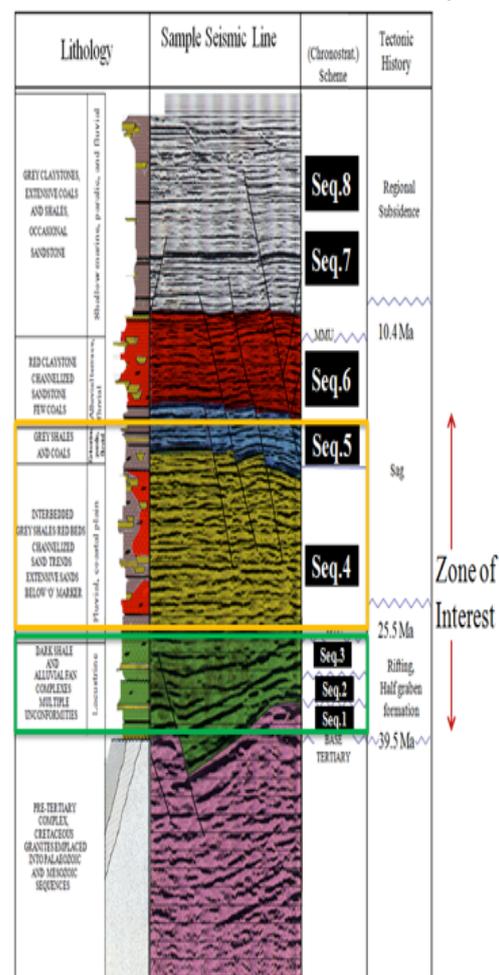


Figure 2. Stratigraphy of the northern Pattani Basin. Sequence 1-3 is the main source rock interval (green box) and Sequences 4-5 are the reservoir intervals (orange box). (Modified from Jardine, 1997).

percentage on a base map to generate the sand (reservoir) distribution maps within Sequence 4 and Sequence 5 to see the trend and areal extent of the potential reservoirs. Next, the source rock thickness was calculated from the isopach map of Basement to Sequence 3 interval and maturity levels were modified from previous studies. Structural maps and seismic cross-sections were analyzed to find the possible migration pathways from source kitchen to trap. Detailed mapping of the top sands in every key well were mapped to see the potential structural closure areas that hydrocarbons could be trapped in. Next, trap efficiency maps were generated and analyzed for three different fields to understand the variation in fault seal capacity.

3. Results

3.1 Structural Analysis

A key element and dominant feature of the petroleum systems in the Pattani Basin is the structural style which influences the migration pathways, trapping style and sealing capacity. Faults act as potential up-thrown and down-thrown structural traps and simultaneously act as seal along the two main structural trends in this area (Figure 3).

Structural maps of key horizons were mapped to determine whether wells were drilled within structural closures, and to note the variations of pay within these closures. Wells drilled outside the structural closures have no economic pay. The seismic cross-section from east to west (Figure 4) shows the source rock inter-

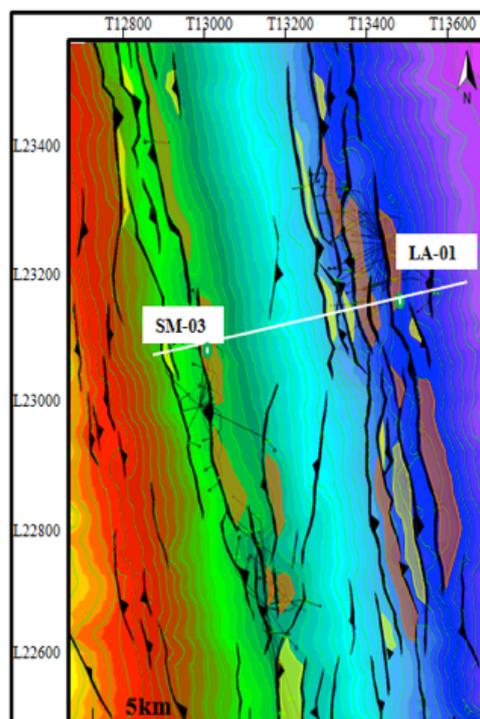


Figure 3. Top Sequence 4 structural map shows highly faulted surface with up-thrown and down-thrown structural closures.

val (Sequence 1-3) and inter-bedded higher amplitudes which correlate to the reservoir intervals in Sequence 4 and 5.

3.2 Source Rock Evaluation

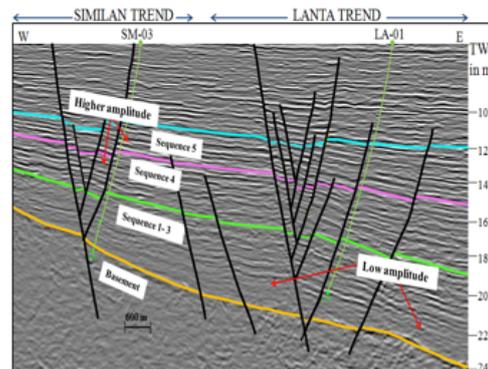


Figure 4. Low amplitude seismic reflections in Sequence 1-3 correlates with source rocks and high amplitude in Sequence 4 and 5 correlate with reservoir intervals.

The most important element in the petroleum system is the source kitchen. The maturation levels at the source interval was modified from previous studies (Aukkanit, 2011) and superimposed on the source interval isopach map. It shows that the higher maturity source rocks are in the eastern part of the area and are thicker. In contrast, the thickness of the source rock interval thins to the west towards the basin margin and has low to very low maturity levels.

3.3 Migration Pathway Analysis

Another key element in the petroleum system is the migration pathway and distance from source kitchen to trap. From the source rock analysis;

the main generation of hydrocarbons was basinward of the Lanta trend and the hydrocarbons migrated from east to west in up-dip direction predominantly through the faults (Figure 5). The higher possibilities of hydrocarbon charging is close to the mid-mature area along the Lanta trend, where LA-01, LA-02 and LA-04 wells were drilled.

However, the quantity of hydrocarbons reaching the Similan trend, where the SM-03, SM-04 and SM-01 wells are located, is likely to be reduced due to the longer distance from source kitchen to trap. Both vertical and lateral migration occurred although vertical migration is dominant through the many post-rift faults. The seismic

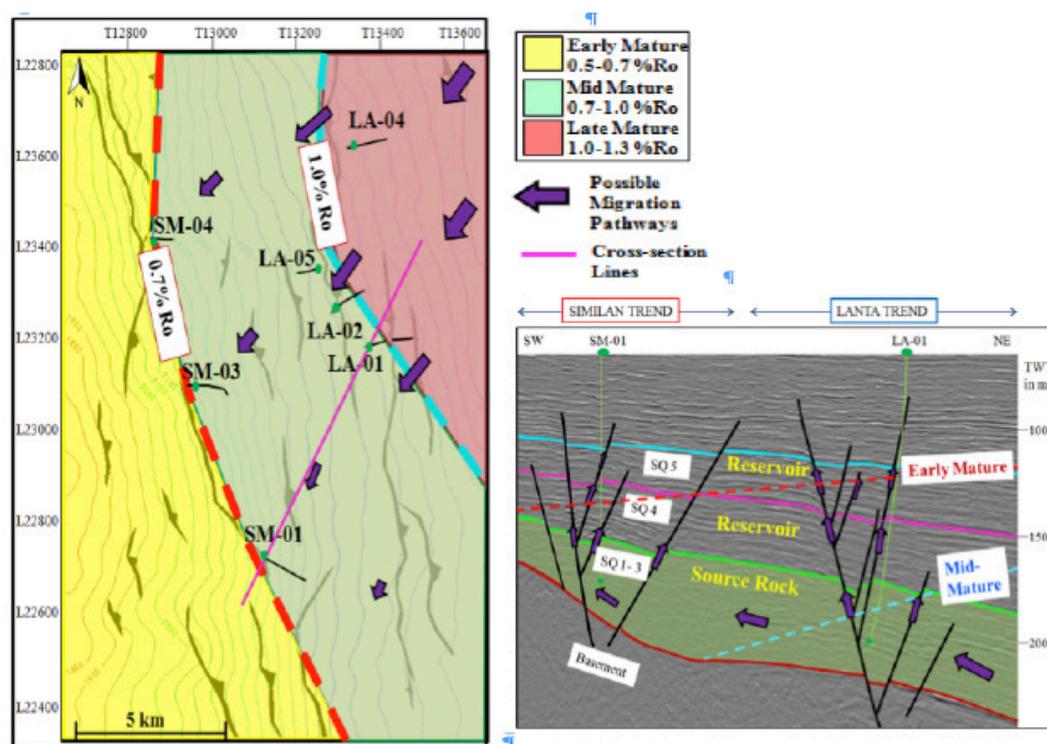


Figure 5. The base of Sequence 1-3 depth map shows higher maturation window to the east and northeast. Migration pathways are shown from basin center to basin flank. Both dominant vertical and limited lateral migration pathways are observed from the seismic cross-section.

section (Figure 5) shows dominant vertical migration along the Lanta trend above the higher maturation zone and limited lateral migration towards the Similan trend where there is also lower source rock maturation levels.

3.4 Reservoir Distribution

Another critical component for hydrocarbon accumulation is the reservoir distribution. The sand distribution pattern varies across the fault blocks (Figure 6). The sand thickness gradually increases towards the eastern part in Sequence 4 and is overall thicker compared to Sequence 5, where sands are areally extensive.

The net to gross sand percentage maps indicate possible depositional trends and also the trends in the fault

sealing capability. Low net to gross will tend to correlate with better sealing capacity of faults in an inter-bedded sand-shale section. Sequence 5 has higher sand percentages than the lower Sequence 4 suggesting poorer sealing capacity in this reservoir interval.

3.5 Trapping Style

The trapping style is one of the most important variables to account for the variations in pay observed here. There are two types of trapping mechanisms observed from the structural maps of Sequence 4 and 5 and also the seismic cross-sections in this study area, the up-thrown fault trap and the down-thrown fault trap.

The Lanta field in Sequence 4 highlights that the dominant up-

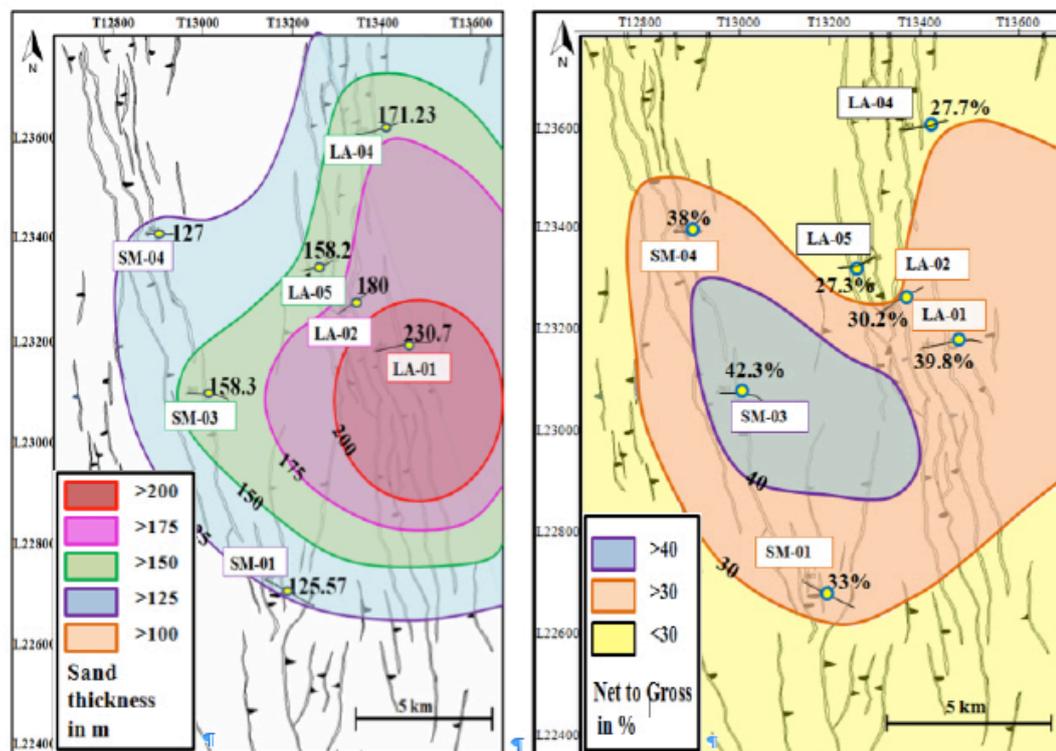


Figure 6. A comparison of sand thickness and net to gross sand map in Sequence 4 showing thick sand and low sand percentages along the Lanta trend, indicate a higher potential trend.

thrown trapping style have higher net pays than the down-thrown trapping style due to the upward migration tendency of hydrocarbons (Figure 7 and 8). Moreover, it is obvious that the hydrocarbons can be more efficiently trapped in thin sands surrounded by thick shales in Sequence 4 than the more sandy intervals in Sequence 5. As a result, Sequence 4 has better potential for trapping the hydrocarbons within the three-way dip closures with fault traps. Figure 8 shows the net pay distributions on seismic sections.

Along the Similan trend, the LAWB field has well defined up-thrown structural closures which have higher

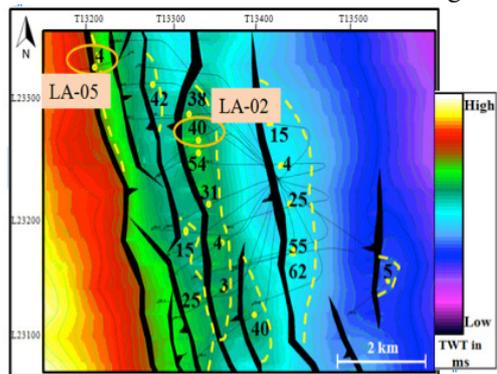


Figure 7. The LA-02 well drilled within up-thrown structural closure showing higher pay than well LA-05 in down-thrown fault trap in Sequence 4.

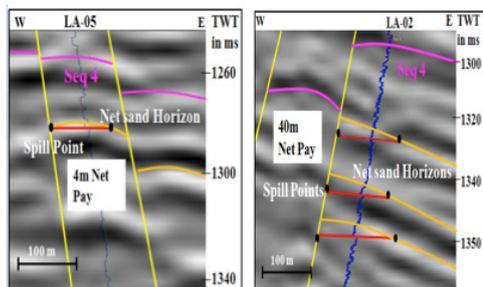


Figure 8. The LA-05 well shows low net pay in down-thrown fault trap compared to well LA-02 with up-thrown fault trap in Sequence 4.

pays than the LAWE field to the south where there are smaller fault throws which are not connected and along irregular structural trends.

3.6 Fault Sealing Capacity

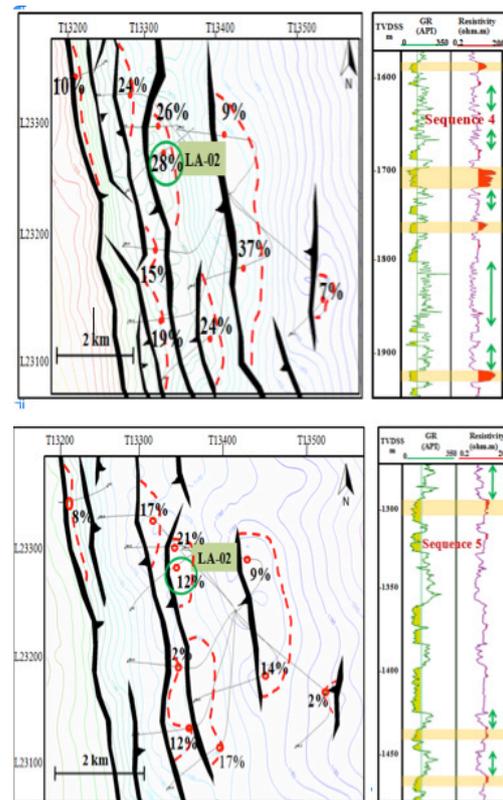


Figure 9. Trap efficiency map showing sealing capacity in Sequences 4 and 5. The orange shadow in well log represents net pays.

Faults act as the main up-dip seal in the Pattani Basin which is the most critical factors in trapping the hydrocarbons. If faults act as poor seals then the hydrocarbons can leak out but if it has good sealing capacity, there is possibility to accumulate sufficient hydrocarbons. One measure of this fault sealing capacity is trap efficiency which is defined as the net pay encountered in a particular well within three-way dip closure, divided by the total sand

within that same closure. A low trap efficiency percentage suggests the fault seal is poor whereas a high percentage suggests good fault sealing capacity. A typical well log in Sequence 4 (LA-02) in the LAWA field shows low net to gross in this interval which correlates to higher trapping efficiency.

In comparison, the well log through Sequence 5 in the same well shows higher sand percentages which lowers the trap efficiency. Hydrocarbons can be better sealed by large antithetic faults and surrounding shale formations (Figure 9).

Along the Similan trend, sealing capacity is better along the large faults in the LAWB field than the smaller fault throws in LAWE field which have higher possibilities to leak out the hydrocarbons.

4. Discussion

After analyzing each of the petroleum system elements of this study area, a general petroleum system model can be summarized in Figure 10. The

first critical factor is the source rock maturation and migration pathways. The higher maturity and thicker source rock is in the deeper basin to the east rather than the basin flank to the west. The wells drilled in this mature zone (near the source kitchen) along the Lanta trend have higher possibility of potential pay than the wells located to the southwest along the Similan trend (far from the source kitchen) which tends to have lower pay due to limited lateral migrations. In the case of reservoir, the widespread sand distribution along both structural trends implies that it has little influence on variation in pay counts. The third critical factor is the up-thrown and down-thrown fault traps which have a large impact on hydrocarbon accumulations. Wells located within a combined three-way dip closure and up-thrown fault trap have higher pay than the down-thrown fault traps as the hydrocarbons tend to migrate upwards. In contrast, wells drilled at the edge or close to the structural closure have very poor pay due to poor trapping mechanism. The final critical

factor is the sealing capacity. If there is a good trapping mechanism but low net pay, it indicates a poor sealing capacity of the faults. Therefore, greater fault throws lead

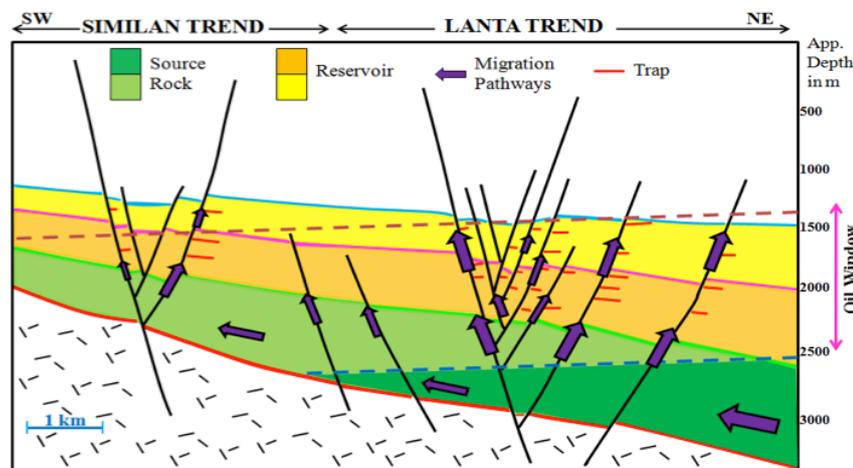


Figure 10. Schematic model of the petroleum systems along the Lanta and Similan trend.

to better sealing capacity with thicker shale formations than the smaller fault throws.

By combining these factors, the prospective areas based on probability can be highlighted from this model (Figure 11). The Lanta trend which includes the LAWA field is best due to the thick and high source rock maturation, good charging potential through vertical migration and prominent up-thrown fault trapping mechanism with good sealing capacity. On the other hand, along the Similan trend prospectivity is moderate due to the more distant location from the source kitchen and lower maturation. The trapping mechanism is similar in the two fields along this trend but sealing properties within large fault blocks are better in the LAWB area which makes it a more prolific pay zone than the LAWE area due to the irregular, more complex fault trends.

Based on this distribution and the petroleum system model up-thrown fault traps to the north and south of LAWA in the Lanta trend are highly prospective. The under-explored northern Similan trend is also prospective.

5. Conclusions

The petroleum system in this area is robust and the most critical factors are the structural trap and fault seal capacity which affects the significant pay variations along similar structural trends. The petroleum system evaluation of this study area can be characterized as follows:

1. Source rock maturity analysis from

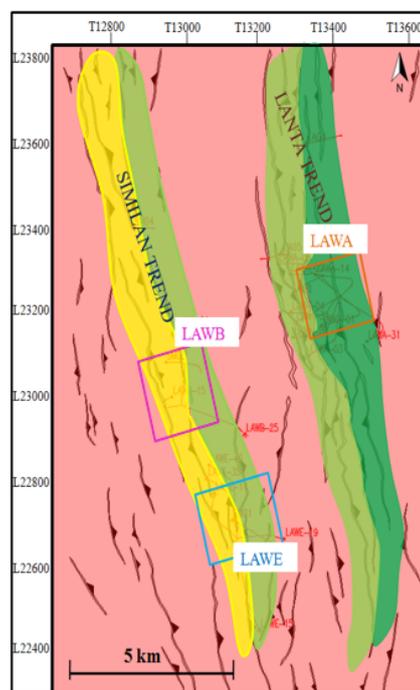


Figure 11. Combined probability based on the distribution of petroleum system elements highlighting the prospective areas.

previous work shows the source kitchen of the study area is in the oil window in the eastern part.

2. Vertical migration is prominent in basinward eastern part with limited lateral migration occurring in the western part that is farther from the source kitchen.

3. The potential reservoir distribution shows that good quality sands are generally extensive. However, the sands deposited in deeper section are thicker than the shallower basin margin area.

4. The combination of three-way dip closures with fault trap in the up-thrown fault blocks are categorized as best potential trapping mechanism compared to the down-thrown trapping mechanism.

5. Fault sealing capacity is the most critical factor controlling pay variation

in this area. Thin sands have tendency to trap with a fault seal and thick shale formations rather than the thick sand formations. Small faults have higher possibility to leak the hydrocarbons. Therefore, understanding fault throws and geometries is critical in understanding the main sealing properties in this area.

Prospective areas based on this analysis of the petroleum system elements have been highlighted and can be used to locate future exploration well locations.

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