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FACTORS CONTROLLING RESERVOIR DISTRIBUTION IN THE SOUTH ERAWAN GRABEN, PATTANI BASIN, GULF OF THAILAND

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Abstract

The reservoirs in South Erawan Field, Pattani Basin, Gulf of Thailand are mostly thin sands where distribution is difficult to predict due to rapid vertical and lateral facies changes. Sand distribution may controlled by 1) faults or 2) sediment supply. Fault control was investigated in this study for stratigraphic units 3 and 4 which are the main hydrocarbon producing intervals. The study analysed 1) fault movement using isochore maps and expansion index, and 2) sand distribution using seismic attributes. Both analyses integrated a 3D seismic volume with all wells data in the study area. Expansion Indices are high at the bounding faults, indicating a high relative amount of fault movement, and decrease to the graben center faults. Upper stratigraphic unit 3 has the highest relative amount of fault movement. Sand distribution analysis in all intervals indicates that there is no fault control on sand distribution because sand spreads across faults and no sand is limited to a specific fault zone. Therefore, sand distribution probably was controlled by sediment supply as sedimentation rate was higher than the rate of fault movement.

Keywords: Fault movement, Expansion index, Sand distribution, Erawan Field

1. Introduction

The Pattani Basin, Gulf of Thailand, has a regional depositional environment that varies from fluvial to marginal marine. The reservoirs are mostly thin sands with limited lateral extent, although occasionally they form thick point bar successions. Sand distribution is difficult to predict due to the rapid vertical and lateral changes. Sand distribution is important to understand and it may be controlled by: 1) faults or 2) sediment supply. Fault control was investigated in this study**.**

The objective of this study is to understand the controlling factors in reservoir distribution in South Erawan, Pattani Basin, Gulf of Thailand (Figure 1). Seismic data in the study area illustrate that the strata in the graben thicken to the graben center. In order to understand the controlling factors, the study has been divided into two parts; 1) fault movement analysis using isochore maps, and 2) sand distribution analysis using seismic attributes.

2. Geological setting

The Gulf of Thailand consists of a series of Tertiary age north-south trending extensional basins. The Pattani Basin is one of the largest basins and is a major hydrocarbon province. The basin probably began extending during the Oligocene (or possibly late Eocene), and large-scale half-graben rifting ended in the late Oligocene (Morley and Westaway, 2006). The rift basins generally strikes north – south but locally follow other directions, in particular NW–SE trends, probably due to inherited pre-Cenozoic fabrics. Passing into the North Malay Basin, the dominant rift trend becomes NW–SE (Morley, et al. 2011) (Figure 1). The basin-fill is predominantly continental to marginal marine, with sediment shed from highland source areas to the north, east and west (Morley and Racey, 2011).

The Erawan graben system did not develop as a single graben system. It consists of a series of N-S grabens. The study area coalesced from at least 2 graben systems based on the greatest thickness located on the graben center which show 2 groups one on the north and another one on the south of study area.

Another reason is a different fault strikes. The east dipping bounding fault has changed from a N-S trend to a NNW-SSE trend in the middle of the study area (fault at upper unit 3 level, Figure 8), the one in the north and the

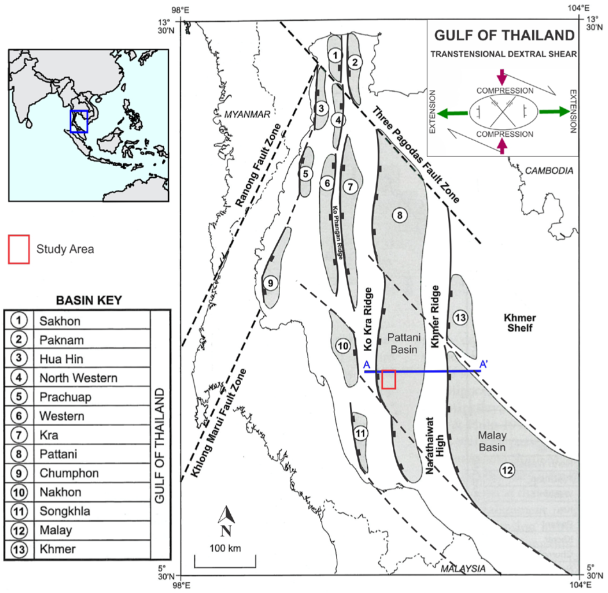
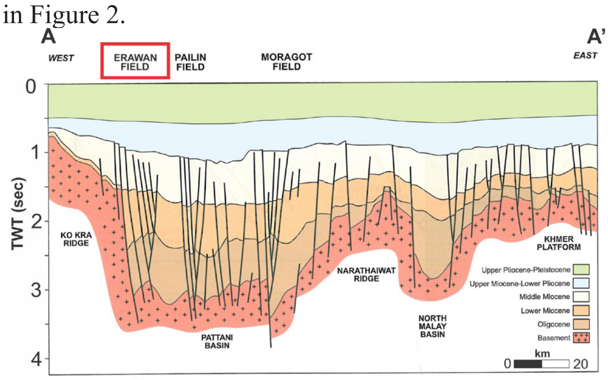


Figure 1. Principal basin and structural elements of the Gulf of Thailand (modified from Polachan & Stattayarak, 1989 and Racey, 2011). The study area is situated in the South Erawan field, Pattani basin (red square box). The A-A' line represents location of the cross-section shown in Figure 2.



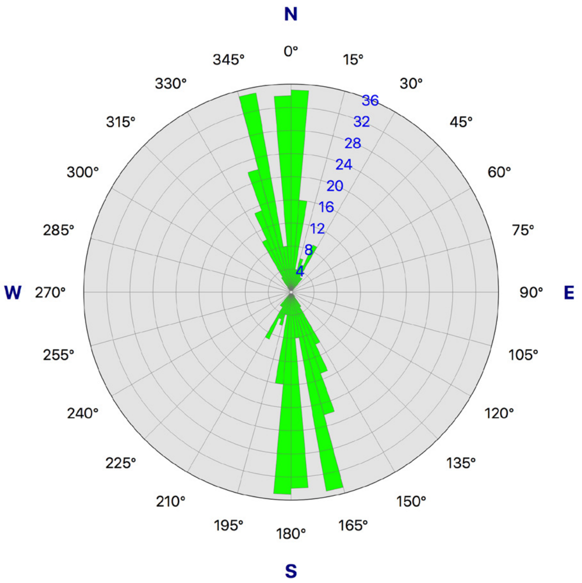


Figure 3. Fault strike rose diagram at the Upper Unit 3 level

and the other in the south. The rose diagram of fault strikes at upper unit 3 level also supports that there are 2 main directions (Figure 3).

The stratigraphy is divided into five stratigraphic units (Figure 4). Morley and Racey, (2011) explain that: Unit 1 is a late Eocene-Oligocene age syn-rift sedimentary section with alluvial fans, fluvio-deltaic and lacustrine depositional environments. Unit 2 is early-mid-Miocene age sediment that includes fluvial, lower delta-plain and intertidal. Unit 3 is mid-Miocene age sediment. The lithology is mainly grey shale and coals deposited fluvial to marginal marine environments. Sandstones in this unit may not be restricted to fluvial meander belts, but may have been deposited in marginal marine environment. Unit 4 is middle to late Miocene age sediment. This unit was deposited by avulsion of meander belt systems, as indicated by stacked point bar accretion and discontinuous fluvial channels. The upper unit contact is clearly marked by a major regional unconformity known as the Middle Miocene Unconformity (MMU). Unit 5 is late Miocene-Recent age sediment with marginal marine deposition. This study focuses on unit 3 and unit 4 which are the main hydrocarbon bearing intervals in south Erawan Field.

3. Database

The Pre-stack Time Migration 3D

4. Methodology

The study has been divided into two parts, which are fault movement analysis using isochore maps and sand distribution analysis using seismic attributes.

The main markers are: 1) B marker, which represents the top of unit 4 instead MMU marker because the MMU is difficult to recognize on both seismic and well log data. The average different depth between B and the MMU is approximately 100 m in the study area. 2) C marker which is the base of unit 4 and top of unit 3. 3) F marker is the middle of unit 3. 4) K marker which is the

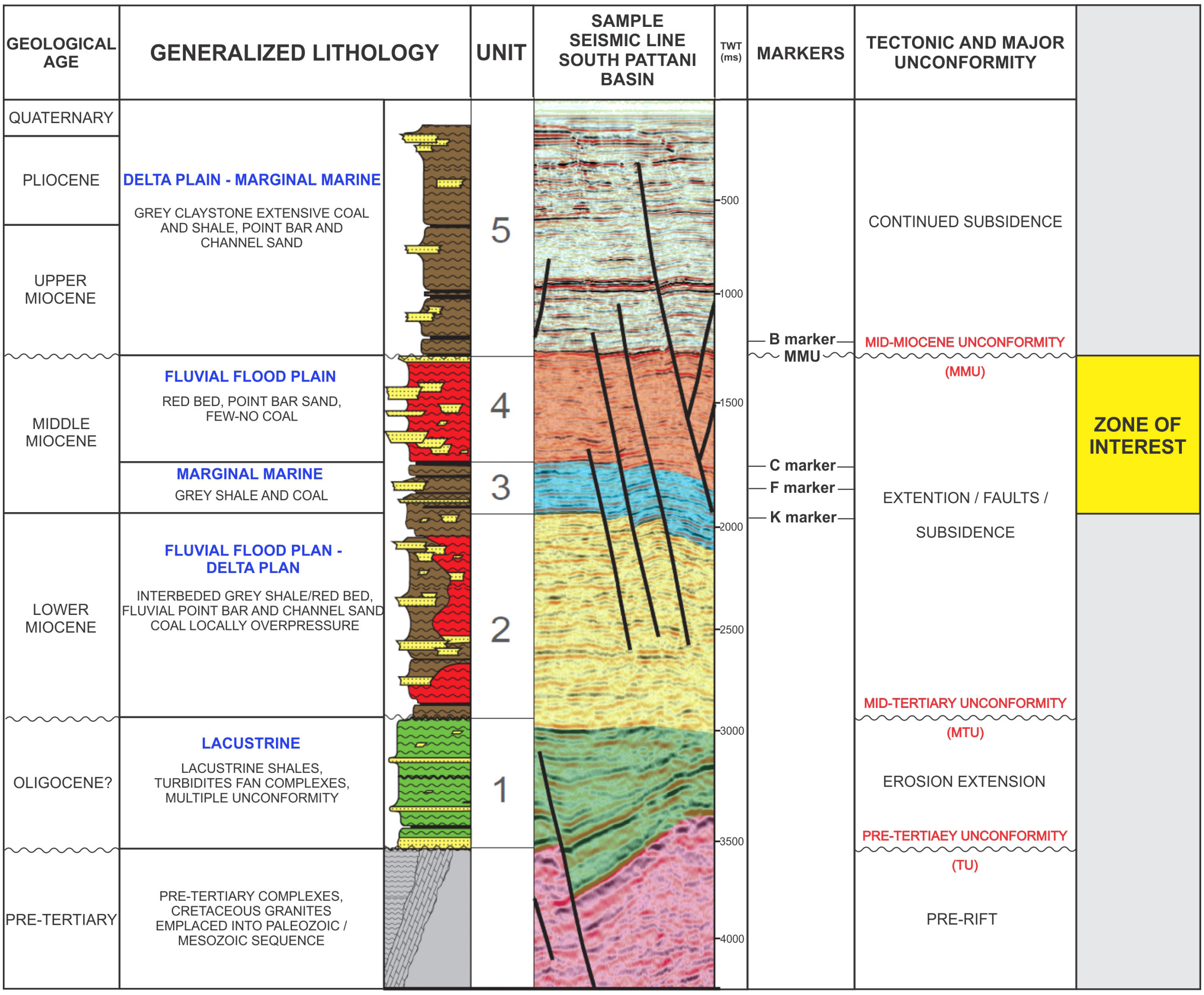


Figure 4. Stratigraphic Units of Pattani Basin (modified from Jardine, 1997)

base of unit 3. Isochore maps were created for B to C, C to F, and F to K to analyze fault movement in the area by using the Expansion Index method (Thorsen, 1963). The thickness data from wells were used for creating the isochore maps, plus thicknesses from seismic data by converting time to depth thickness by using the time-depth curve from the Erawan field. The reference horizon of each isochore map is the middle level between each two markers.

In general, isochore maps are true vertical thickness maps while most wells are deviated and provide TVD (true vertical depth thickness) not TVT (true vertical thickness). However, the thickness differences from the different measurement directions are small because the strata in the study area dip less than 15 degrees.

The Expansion Index (Thorsen, 1963) describes growth fault development by using the thicknesses on both sides of each fault, where the Expansion Index is the upthrown thickness divided by the downthrown thickness. Commonly, expansion indices are illustrated in a bar graph for comparing the relative amount of fault movement. This method was applied to identify which intervals were strongly effected by fault movement.

Sand distribution was determined using seismic attributes along sandy horizons. Representing sand horizons in each isochore interval were mapped from well data, then extended across the study area. Five Seismic attributes were used to determine the distribution of sand, including Root Mean Square (RMS), Reflection Strength, Sweetness, Instantaneous Sweetness, and Spectral Decomposition. All five attributes gave similar results for sand distribution, but the difference is in resolution for each attribute, with Reflection Strength being the most reliable.

5. Results

5.1 Stratigraphic Unit 4 (B to C Marker)

5.1.1 Fault Movement Analysis

The Unit 4 Isochore map (B to C Isochore map) (Figure 5) indicates the thickness of stratigraphic unit 4 is 576 to 881 m, which is the thickest interval and represents the longest time period (approximate 4 Ma.). The greatest thickness is in the graben center.

The large difference in thickness between the upthrown and downthrown sides of faults is on the graben bounding faults, this relationship relates to the relative amount of fault movement.

Changing color along the downthrown side of one fault represents different amounts of movement on that fault and the number of faults in the early stage. For example, the west dipping bounding fault (the east pink fault) has 3 main thick zones along its downthrown side, meaning that initially at least 3 primary faults that coalesced into one fault.

Some examples of the Expansion Index of faults for unit 4 indicate the east dipping bounding fault has a higher value than the west dipping bounding fault and the bounding faults are higher than the faults in the graben center (Figure 6), where the high values relate to high relative fault movement. The high relative amount of fault movement on the bounding faults are the most probable locations where the fault will control sand distribution.

The east dipping bounding faults are the synthetic faults which have higher amounts of fault movement than antithetic faults. This evidences match with the regional geology because the area located on the west of Pattni Basin which the east dipping bounding fault should be the synthetic fault of the basin.

5.1.2 Sand Distribution

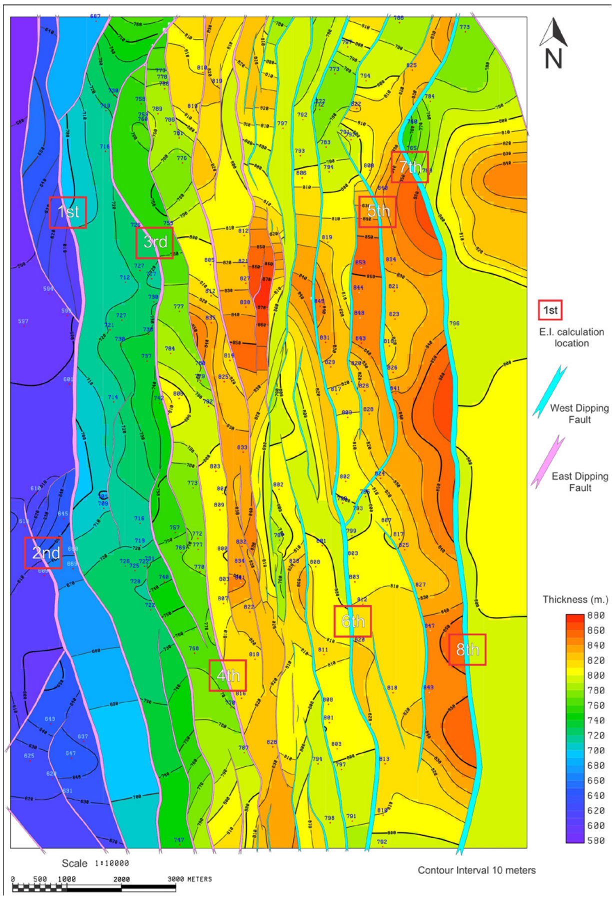


Figure 5. Unit 4 Isochore map (B to C Isochore map) and location of Expansion Indies (E.I.) calculations

The Reflection Strength seismic attribute map shows the sand distribution from U-16 well at depth 1512 m on the north of the area in stratigraphic unit 4. The sand at well location is 30 m thick. Hot colors on the map represent sand (mostly green and yellow) (Figure 7).

Most sands are located in the northern part of the study area. This sand does not have a good channel-like features but still showingsome directional sand body which is east-west trending. The trend is illustrated on the eastern part of map as a sharp boundary across faults. Sands cross faults without any indicate of fault control. Thus, Unit 4 has no fault control on the sand distribution, even at bounding faults with high relative fault movement.

5.2 Upper Stratigraphic Unit 3 (C to F Marker)

5.2.1 Fault Movement Analysis

The Upper Unit 3 Isochore map (C to F Isochore map) (Figure 8) indicates the thickness

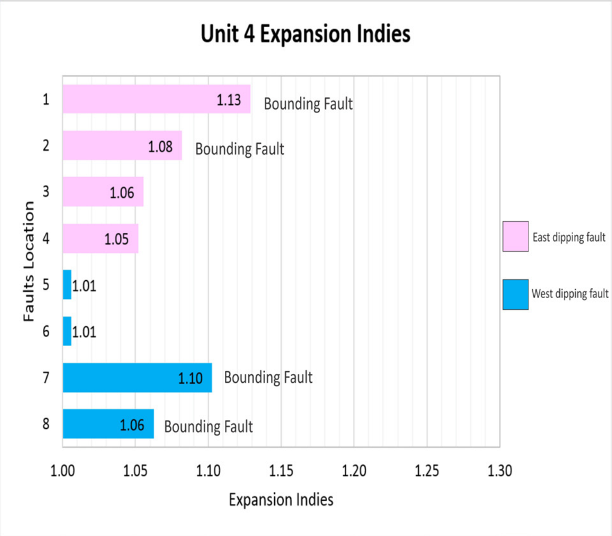


Figure 6. The Expansion Indies of faults for Unit 4, the locations are shown in figure 5.

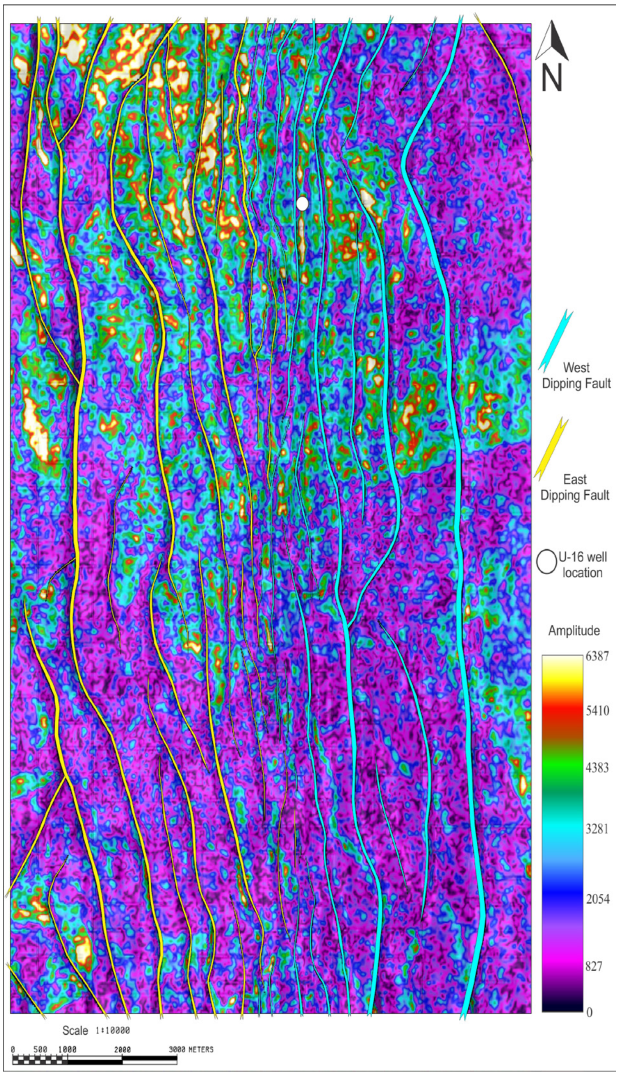


Figure 7. Sand distribution map using Reflection Strength for Stratigraphic Unit 4

of upper stratigraphic unit 3 is 136 to 280 m, which is the thinnest interval and represent the shortest time period (approximate 0.5 Ma.). The greatest thickness is in the graben center on the northern part.

The large difference in thickness between the upthrown and downthrown sides of faults is still same as previous interval over on the graben bounding faults and decreases to graben center faults, this relationship relates to the relative amount of fault movement.

This map does not illustrate any significant coalescing fault feature as the unit 4 interval represents significantly different amounts of movement along one fault.

The samples of Expansion Index of faults for upper unit 3 interval shows the east dipping bounding faults have a higher value than the west dipping bounding fault and the bounding faults are higher than the faults in the graben center (Figure 9). The high relative amount of fault movement at the bounding faults are the most probable locations where the fault will control sand distribution.

The east dipping bounding faults are the synthetic fault which has high amount of fault movement than antithetic fault. This evidences match with the regional geology because the area located on the west of Pattni Basin which the east dipping bounding fault should be the synthetic fault of the basin.

5.2.2 Sand Distribution Analysis

The Reflection Strength map uses the sand horizon, which was mapped from sand in F-26 well at depth 1673 m in the northwest of the area, in order to represent the sand in upper stratigraphic unit 3. The sand at well location has 19 m thick. Hot colors on the map represent sand (mostly green and red) (Figure 10).

Sands are widespread in the study area. Two main channel-like features were observed: 1) on the northwest of the map, sand has a northeast-southwest orientation and changes to north-south then to west-east with a sharp boundary across faults in the north, 2) A west-east orientation in the south of the area. Sands distribution

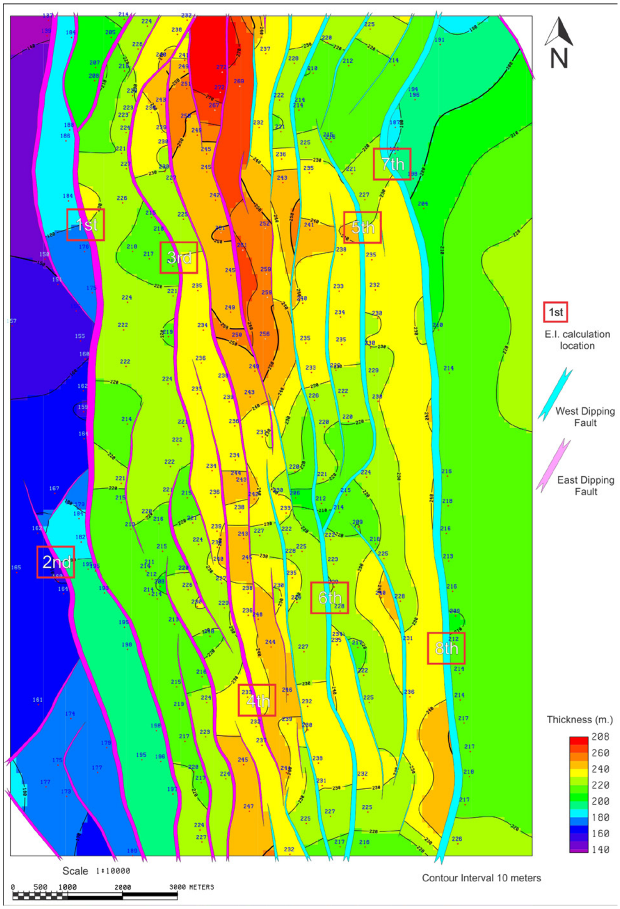


Figure 8. Upper Unit 3 Isochore map (C to F Isochore map) and location of Expansion Indies (E.I.) calculations

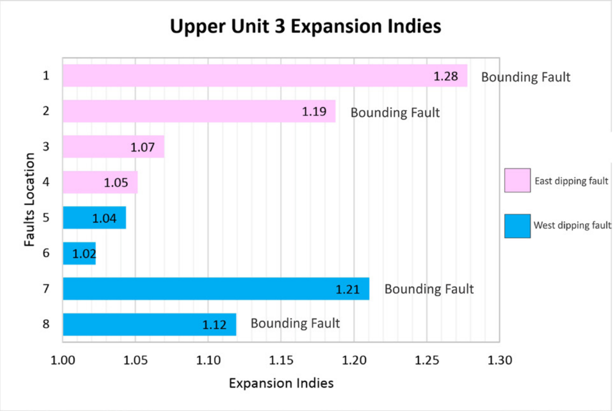


Figure 9. The Expansion Indies of faults for Upper Unit 3, the locations are shown in figure 8.

spreads across faults without any fault control. Thus, the Upper Unit 3 has no faults controlling the sand distribution, even at the bounding faults which has a high relative amount of fault movement.

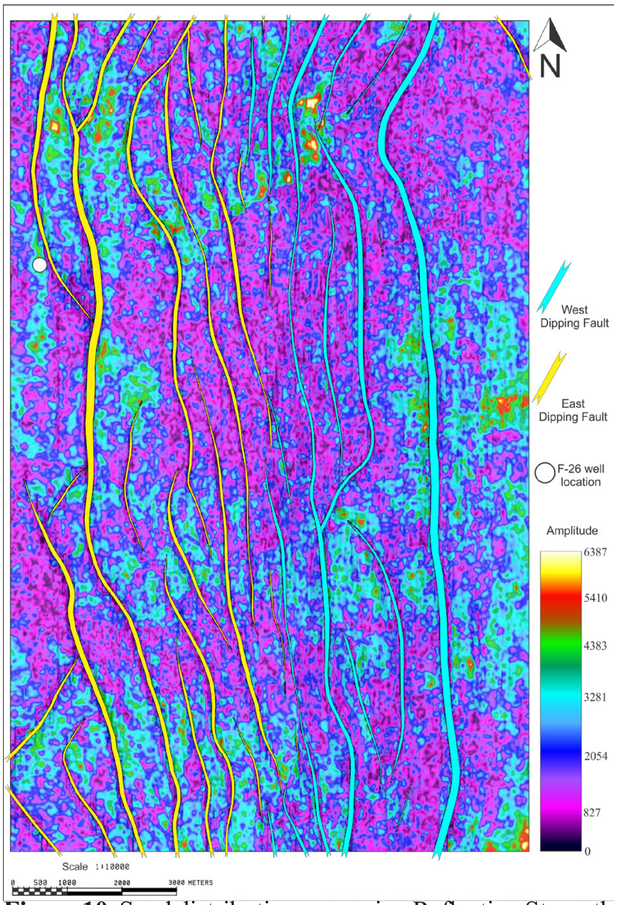


Figure 10. Sand distribution map using Reflection Strength for Upper Stratigraphic Unit 3

5.3 Lower Stratigraphic Unit 3 (F to K Marker)

5.3.1 Fault Movement Analysis

The Lower Unit 3 Isochore map (F to K Isochore map) (Figure 11) indicates the thickness of lower stratigraphic unit 3 is 302 to 543 m, which represents a time period of approximately 1 Ma. The highest thickness is in the graben center in the north, which is similar to previous interval.

The large difference in thickness between the upthrown and downthrown sides of faults is the same as in previous intervals on the graben bounding faults and decreases to graben center faults, this relationship relates to relative amount of fault movement.

This map did not illustrate any significant coalescing faults as the unit 4 interval represents significantly different amounts of movement along one fault. However, the thicknesses are not exactly equal along the downthrown side of the same fault, meaning that fault movement varied.

Examples of Expansion Index of faults for lower unit 3 interval indicate the east dipping bounding fault has a higher value than the west dipping bounding fault and the bounding faults are much higher than the faults in the graben center (Figure 12). The high relative amount of fault movement on the bounding faults are the most probable location where faults control sand distribution.

The east dipping bounding faults are the synthetic fault which has high amount of fault movement than antithetic fault. This evidences match with the regional geology because the area located on the west of Pattni Basin which the east dipping bounding fault should be the synthetic fault of the basin.

5.3.2 Sand Distribution Analysis

The Reflection Strength map uses sand horizon which was mapped from sand in F-28 well at depth 2411 m in the middle of the area in order to represent the sand in lower stratigraphic unit 3. The sand at well location has 25 m thick. Hot colors on the map represent sand (mostly green and red) (Figure 13).

Sands are small and widespread in all areas but are not abundant. Most sand is located in the northwest and southeast. This sand does not have any significant channel-like features and also nor any sand deposits within faults zones. Thus, no faults control the sand distribution in Lower Unit 3, although the bounding faults have relatively high fault movement.

6. Discussion

Sand distribution in the study area was controlled by sediment supply, i.e. the sedimentation rate was higher than the fault movement rate. This conclusion is supported by the Tertiary Paleogeographic by Shoup, et al. (2012). The mid-Miocene paleogeographic map, which represents the time of stratigraphic units 3 and 4 (Figure 14), place the study area near the west boundary of Pattani Basin and close to a source of sediment (gray area) to the west.

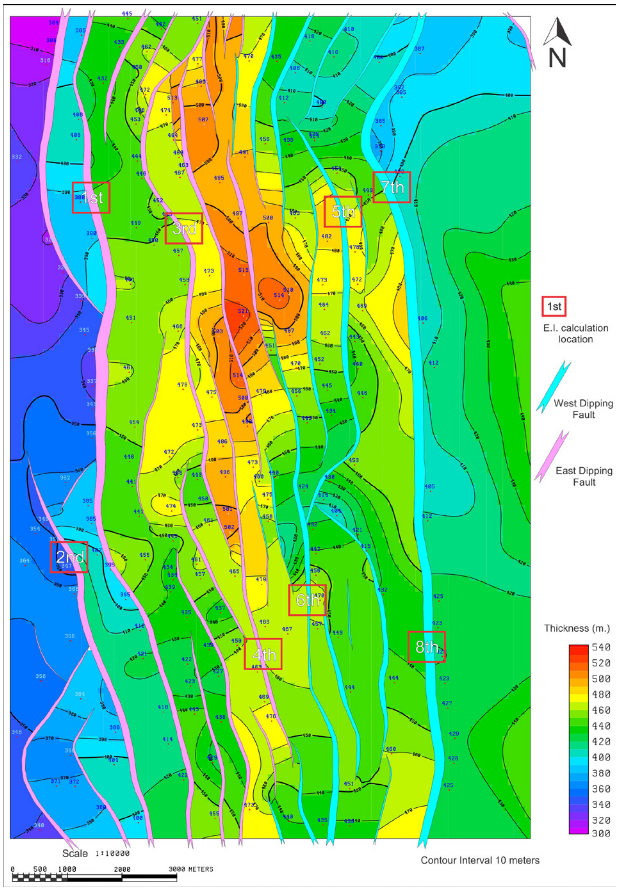


Figure 11. Lower Unit 3 Isochore map (F to K Isochore map) and location of Expansion Indies (E.I.) calculations

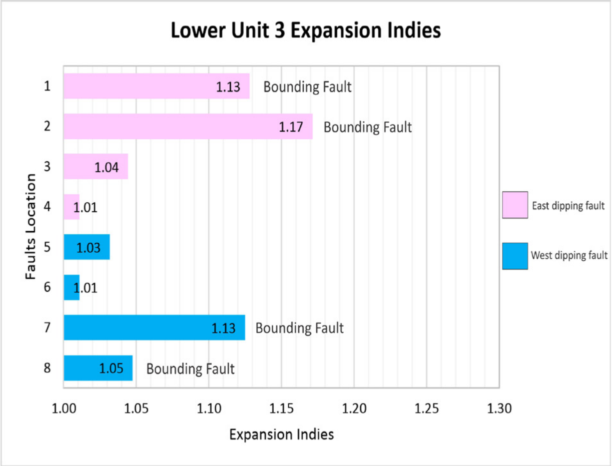


Figure 12. The Expansion Indies of faults for Upper Unit 3, the locations are shown in figure 8.

This relationship may apply to other parts of Pattani Basin such as to the west of the study area, where there are few wells, sediment supply should control sand distribution in that field because it is located closer to the source of sediment. Conversely, to the east of study the

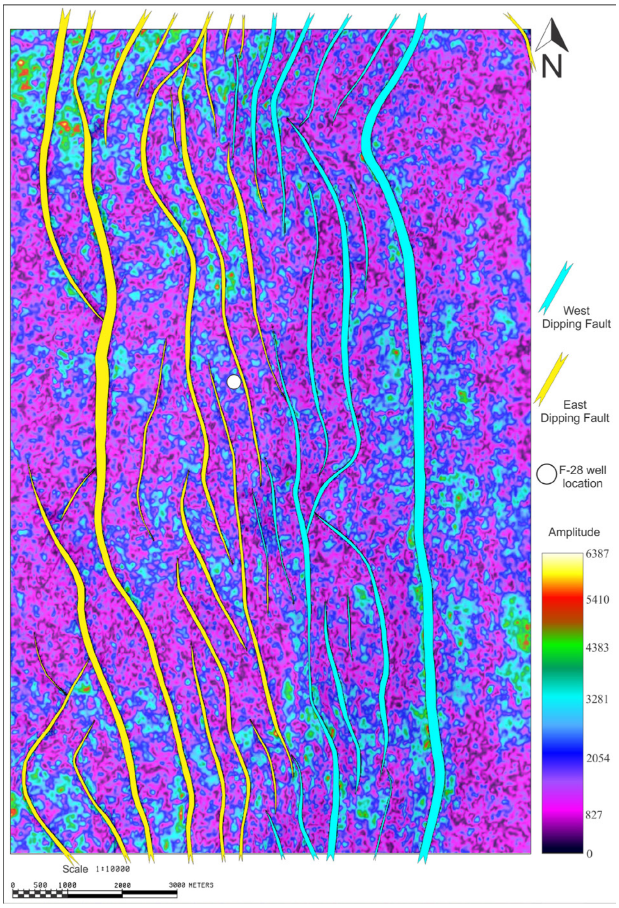


Figure 13. Sand distribution map using Reflection Strength for Lower Stratigraphic Unit 3

area should be lese effected by sediment supply because it was far from a source of sediment. In the northern and southern part of study area, the fault pattern has changed a lot from graben shift and also significant strike shifting. For more understanding about fault movement and sediment supply, the isochore maps and sand distribution should done for all stratigraphic units and also divided into small interval in each unit. Furthermore, sand distribution may be confirmed using sand correlation from well data.

7. Conclusions

The 3D seismic data with interpreted faults and horizons, and interpreted lithology and marker picks from wire-line log are integrated to investigate controls on sand distribution. The study finding are:

1. Isochore maps can differentiate the number of primary graben based on the highest thicknesses located in graben centers and strike changes.
2. The isochore map can differentiate the number of primary faults using the thickness along the downthrown side of same fault.
3. The bounding faults have higher amounts of fault movement than the faults in graben center.
4. The east dipping synthetic fault has a higher rate of fault movement than the west dipping antithetic fault.
5. The area with high relative amount of fault movement are the locations where the highest potential for fault controlled sands distribution.
6. For stratigraphic units 3 and 4 in south Erawan Field, Pattani Basin there is no fault control of sand distribution.
7. For stratigraphic units 3 and 4 in south
8. Sand distribution, in stratigraphic units 3 and 4 within south Erawan field, cannot be predicted using faults locations.

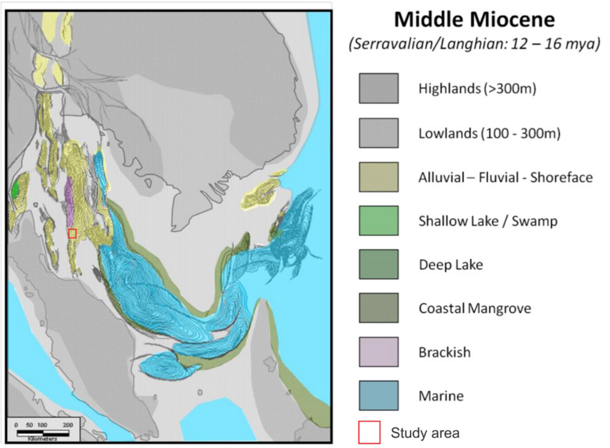


Figure 14. Middle-Miocene paleogeographic map Shoup, et al. 2012)

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