Structural Evolution of the Songkhla Basin, Gulf of Thailand: A Palinspastic Restoration Study

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Abstract

The structure styles of Songkhla Basin are not well known as compared to other Cenozoic basins of the Gulf of Thailand. This study describes the results of 2D and 3D seismic data interpretation and restoration of key sections. Inversion occurred as local phenomena along eastern and western margin of the basin. The timing of initiation and cessation of the inversion is different in different parts of the basin. Onlap on anticlinal feature indicates that along the western margin in the center of the basin inversion ceased by Late Oligocene. While, in relatively southern part it ended in Middle Oligocene. Palinspastic restoration shows that rifting initiated along N-S oriented faults in the Eocene?, characterized by the thick syn-rift package in the western part of the basin. It also observed that along the eastern margin inversion started in Early Oligocene in northern sections while relatively southern sections show initiation of inverted features in Late Oligocene. This local inversion along the eastern margin lasted until Early Miocene. Coherency and phase slices show NW-SE discontinuity, which at some places cut cross the regional N-S faults. These are also associated with compressional features as observed on arbitrary perpendicular seismic sections. These discontinuities are interpreted as faults influenced by pre-rift fabric. Possible hydrocarbon traps are titled fault blocks, faulted anticlines and rollover close to boundary faults.

Keywords : Songkhla Basin, Palinspastic Restoration, Structural Style

1. Introduction

Songkhla Basin is located in the southwestern part of the Gulf of Thailand. It is N-S trending basin(Figure 1). Very little work related with structural evolution of Songkhla Basin has been published. Morley & Racey (2011) reported brief regional structure overview of Songkhla Basin. Racey (2011) also reported general petroleum geology of the basin. However, detail structural evolution of the basin was never been studied specially with reference to structural reconstruction. This project is focused on describing detail structure features observed in different parts of the basin and palinspastic restoration of key sections along the drilled wells to understand the tectonic

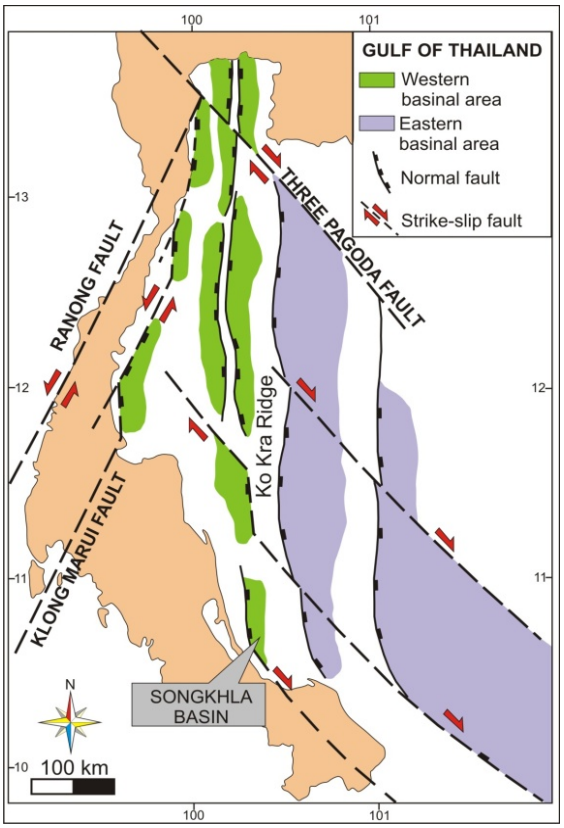


Figure 1. Basins & structural elements of the Gulf of Thailand (modified after Polachan et al., 1991).

evolution of different structures and hydrocarbon traps.

2. Methodology

Various methodologies were used to observe the structural geology of the Songkhla Basin. Horizons and faults were interpreted on the vertical seismic section. Palinspastic restoration was done to restore the key interpreted seismic sections. Palinspastic restoration is the restoration of the units to their pre-deformation configuration by exactly reversing the displacement that formed the structure (Groshong, 2008).

3. Results

SEISMIC INTERRETATION

The vertical seismic section shows the seismic character and several key structural features in the Songkhla Basin (Figure 2 and Figure 3). Six horizons were interpreted based on the 2D and 3D seismic data sets such as; Top Basement, Top Eocene?, Top Early Oligocene, Top Late Oligocene, Top Early Miocene, and Top Late Miocene. Key structural features observed in the Songkhla Basin are; east dipping normal fault in the western margin, tilted fault block in the center of the basin, synthethic-antithethic fault, and a compresional feature like folding and antiform structure. The compresional features are related to the inversion structures. The timing of beginning and ending of formation of inversion structures is variable throughout the basin as the onlap features are observed in different stratigraphic zones. This means that inversion along western margin ended earlier in the south as compared to the central part of the basin.

Horizon slices and 30 Hz discrete phase spectra of the Late Oligocene and Early Miocene show the oblique trend of discontinuities (NW-SE oriented) that cross

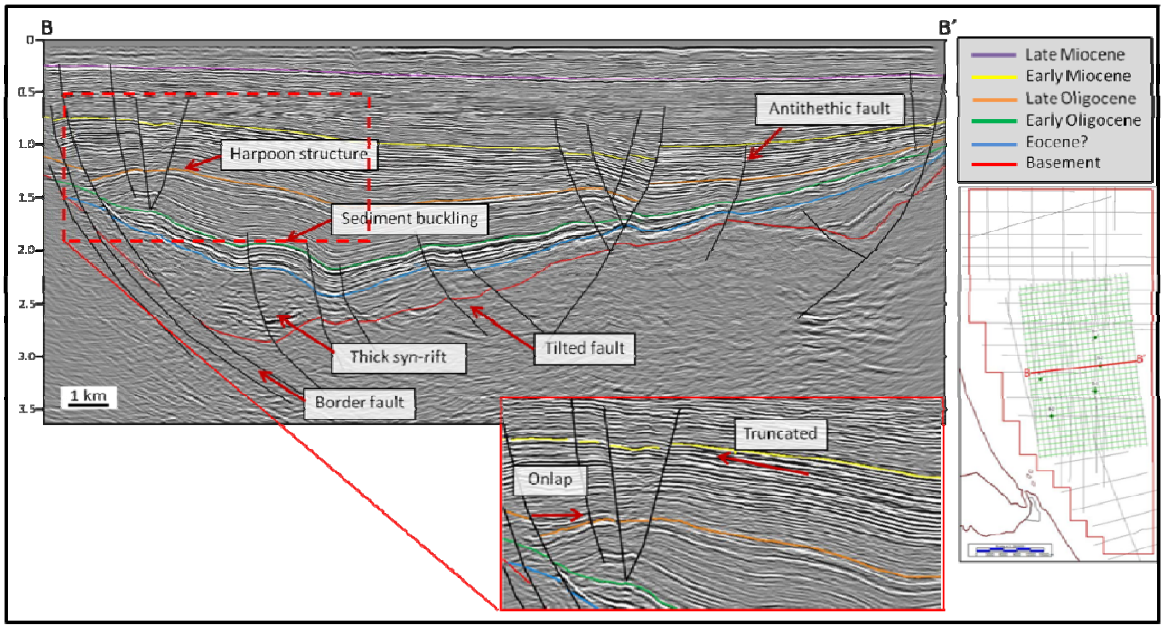


Figure 2. The interpreted seismic section in the middle part of the Songkhla Basin

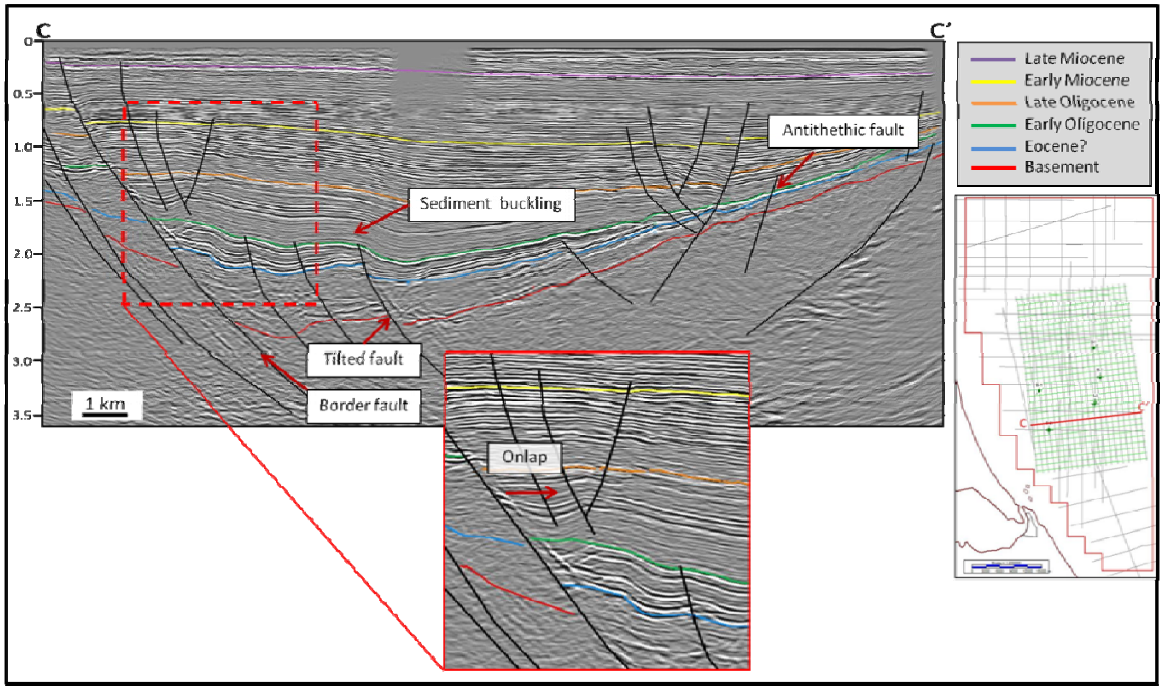


Figure 3. The interpreted seismic section in the middle part of the Songkhla Basin

cutting the regional N-S trending fault block (Figure 4 and Figure 5).

The seismic vertical sections perpendicular to these discontinuities shows fault segments with little displacement (Figure 6). This phenomenon can be observed in the Top Early Miocene and Top Late Oligocene. Mostly these faults are normal but at some locations (section FF' and GG'; Figure 6) within Late Oligocene they are associated with compressional features. According to Figure 6, the intensity of compression feature depends upon the gap between region N-S fault (in black color) and oblique fault (in red color).

PALINSPASTIC RESTORATION

One of the three restored cross-section will be shown in this paper, while the result of the other two sections will be mentioned in the discussion. This restored section is about 22 km long, it crosses the depocenter of the Songkhla Basin. A basin began to form as the pre-Tertiary basement was faulted (Figure 7A). The east-dipping faults were bounding the depocenter in the western part of the basin. The thickening of the sedimentation in the western part of the basin shows that the fault boundary was active during the depositional process (Figure 7B). Most of the faults in Early Oligocene, Late Oligocene and Early Miocene are normal except there is small amount of uplift in the eastern part of the basin (Figure 7C to Figure 7E). Reverse fault is observed on the eastern margin of the basin in Early Oligocene section.

Tectonic extension continued with a local tectonic uplift in Early Oligocene to Early Miocene. Small anticlinal feature is observed in the eastern part of the area (Figure 7E). This uplifted feature latter collapsed because of extension in the area (Figure 7F).

Palinspastic restoration shows 0.04% of shortening during Late Miocene (Figure 7F). Total strain elongation from pre-Tertiary to present is 1.04 km (4.96%) indicating that the terrain was dominant by the extensional forces.

4. Discussion

Structural reconstruction of Songkhla Basin shows that the basin formed when the pre-Tertiary basement began to deform during Eocene?. The rifting process started by initiation of the N-S faults and sedimentation occurred along tilted fault blocks. Inversion structure can be observed along western border fault especially in the center part of the basin. The timing of cessation of inversion is variable as observed from onlap feature over anticline feature. In the southern part of the basin, this inversion phase ended in middle of Oligocene. Whereas, inversion phase ended in the center part of the basin by Late Oligocene (Figure 2, Figure 3).

Moreover, palinspastic restoration indicates inversion at the eastern part of the basin (Figure 7). Inversion episode at eastern margin started earlier in the northern part as we can observe reverse fault in Early Oligocene (Figure 7C) as compared to the southern basin restored sections. The inversion episode along the eastern margin lasted until Early Miocene (Figure 7E), and the maximum inversion occurred in the center part in Late Oligocene.

However, these inversion phases are localized and it occurred at different time and in different parts of the basin. The sedimentation was no longer controlled by

main border fault in the Late Miocene and this is beginning of thermal subsidence period of the basin.

Oblique discontinuities that are observed on phase and coherence time/ horizon slices are apparently cross cutting the regional north-south faults. This step or zig-zag patterns on map view indicate oblique extension (influenced by pre-existing fabric) or strike-slip fault systems (Morley et al., 2004).

According to Morley et al., 2001, strike-slip movement along major faults close to Gulf of Thailand was ceased before Oligocene. Moreover, the vertical cross section perpendicular to these faults indicates that these faults are terminating in Late Oligocene sequence and not penetrating beyond Early Oligocene (Figure 6), but the shift in N-S regional faults is also observed in Top Eocene? map. Therefore, this apparent shift or lateral movement may not related with strike slip motion of NW-SE discontinuities.

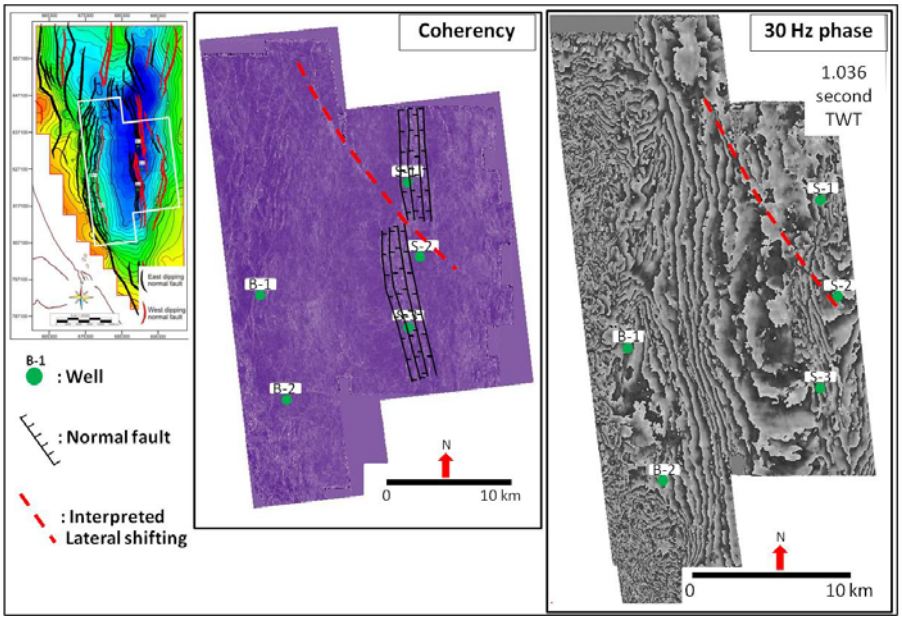


Figure 4. The interpreted coherency slice (left) and phase slice (right) of the Top Late Oligocene.

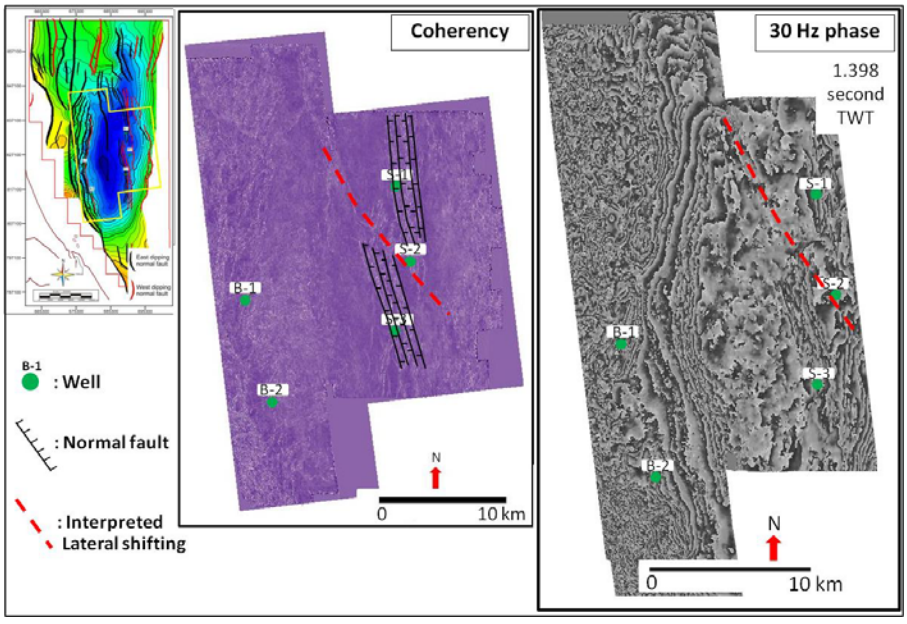


Figure 5. The interpreted coherency slice (left) and phase slice (right) of the Top Early

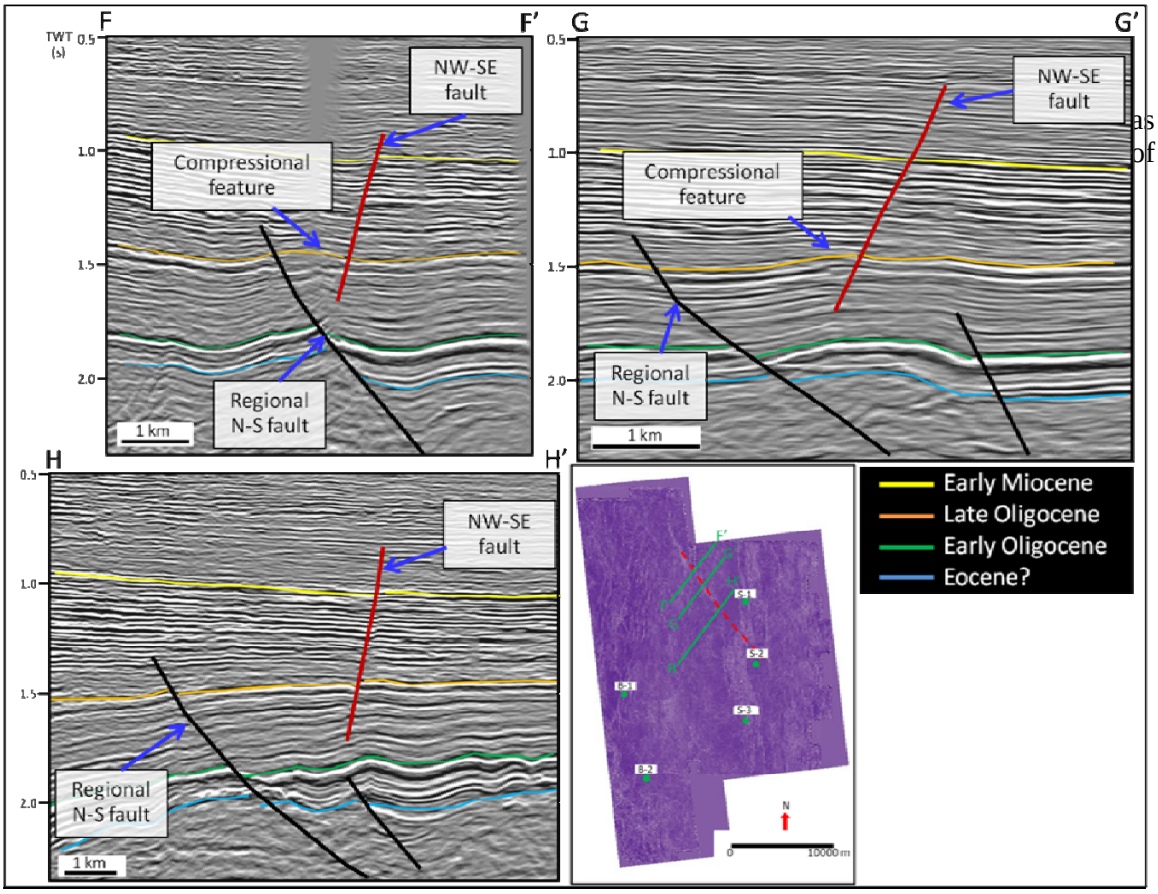


Figure 6. Arbitrary line of the seismic section perpendicular to the lateral shifting trend. Black color fault is regional N-S fault. Oblique fault is marked by red color.

The other possible explanation of this lateral shift may be related with basement fabric, which is mostly oriented in NW-SE or NE-SW direction in Gulf of Thailand (Kornsawan and Morley, 2002; Morley et al., 2004). The schematic diagram showing the influence of pre-existing fabric on fault geometry is shown in Figure 8. Influence of pre-existing fabrics of basement may be transferred to upper sediments and develop as a fault due to change in extensional forces. Compressional features are observed along these NW-SE faults (Figure 6). The intensity

regional N-S fault and NW-SE fault. These two faults are close together in NW.

The main structure traps in the basin are tilted fault blocks, anticlinal faults and rollover close to the basin margin faults. Structural reconstruction shows that extensional tectonic with minor inversion occurred during Eocene to Early Miocene at the eastern margin of the basin.

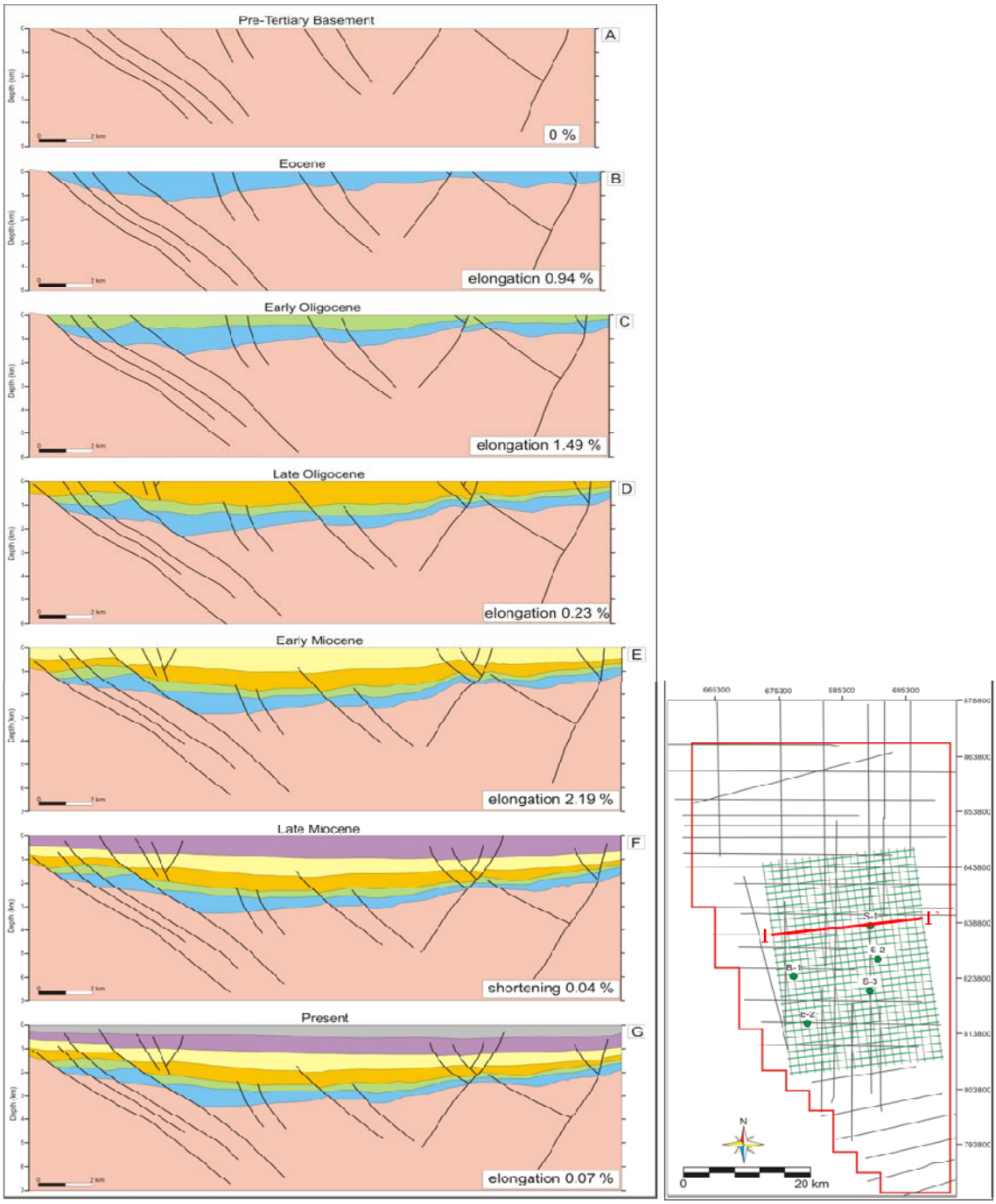


Figure 7. Palinspastic restoration of the E-Wcross section in the center part of the Songkhla Basin.

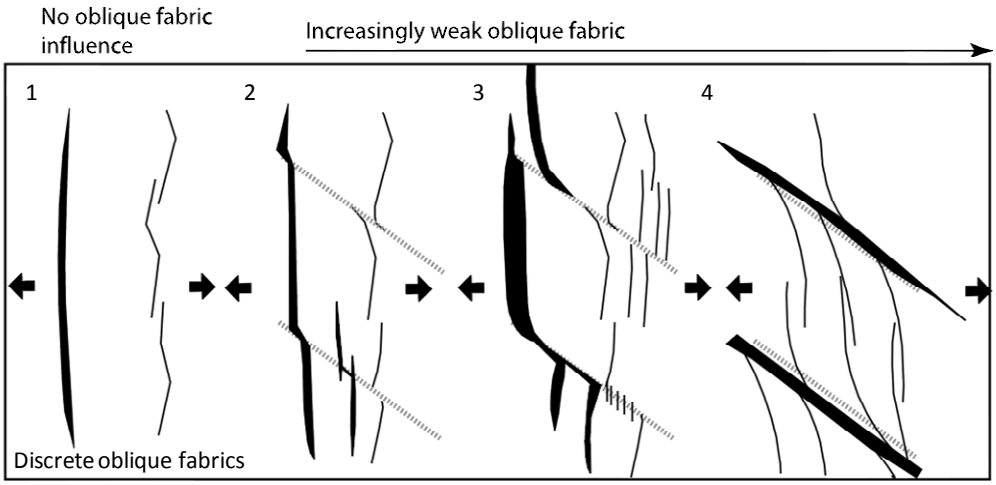


Figure 8. Schematic plan view illustration of how extensional fault may change depending upon the type of pre-existing strength anisotrophy and the relative weakness of the strength anisotrophy (Morley et al., 2004).

Inversion produced anticlinal structure in Early Miocene at the eastern margin of the basin. These structures were collapsed due to post rift thermal subsidence until Late Miocene. The timing of activation of faults coincides with the maturation of Eocene and Oligocene source rocks, which is Middle Miocene (Supriatna, 2011). Therefore, this is an uncertainty for entrapment of hydrocarbon along faulted blocks of the eastern margin of the basin.

5. Conclussions

The conclusions of Songkhla Basin structural study are summarized as:

- Songkhla Basin was formed as result of E-W extension. The rifting probably started in Eocene along N-S oriented faults.
- Extensional tectonic regime was dominant since Eocene – Late Miocene, though localized minor inversion occurred from Late Oligocene – Early Miocene
.
- Pre-rift fabrics were involved in creating NW-SE oriented discontinuities, which has an oblique direction to the regional N-S faults. Compressional features were observed along these oblique discontinuities.
- The inversion occurred along eastern and western margin faults independently and this may be local phenomena. Along the eastern margin, it started early (Early Oligocene) in the north as compared to the south. While along western margin,
- inversion occurred early in the south as compared to the north.
- Possible hydrocarbon traps are tilted fault blocks and anticlinal features along the faults. Moreover, compression features along NW-SE discontinuity can also act as trap.
- Subsidence occurred along eastern and western margins during Early Miocene to Late Miocene. This coincides with the timing of maturation in the area. Therefore, there may be uncertainty for

hydrocarbon entrapment along N-S faulted blocks and NW-SE faults. Detail basin modeling and migration pathway study is required to reduce the risk.

6. Acknowledgements

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