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PATTERNS OF DISPLACEMENT ALONG BOUNDARY FAULTS: IMPLICATION FOR BASIN EVOLUTION IN NAKHON BASIN, GULF OF THAILAND

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Abstract

Nakhon basin is located in the western portion of the Gulf of Thailand. The northern part of the basin is oriented NW-SE and the southern part is oriented N-S. The rifting started in Eocene?/Early Oligocene along NW-SE oriented faults. According to displacement-distance (D-d) profiles, the Western Boundary fault displays three individual fault segments and Eastern Boundary fault displays two segments. These are also indicated by the distinct strikes of fault segments, the abrupt decrease in throw and strata thickness from depocenters to their tips and the location of transverse anticline. Sedimentation was controlled by main Western Boundary fault and Eastern Boundary fault until Late Oligocene. Thermal subsidence may play role during Early Miocene to Middle Miocene. Inversion anticlines were observed along Eastern Boundary fault of the northern part of the Basin. This local feature is interpreted as being caused by compression at the tip of the oblique-striking fault segments due to oblique extension with a dextral left stepping compression. Extensional fault systems in study area were influenced in a number of ways by oblique pre-existing fabrics as indicated by oblique orientation of intrabasinal faults and zigzag pattern of regional faults. This influence of pre-existing fabric is associated with Three Pagoda Fault zone which is cross cutting the study area.

Keywords: Fault linkage, Fault displacement, Fault evolution

1. Introduction

Major active normal faults are typically composed of overstepping (Peacock, 2002) and linked segments along strike over a wide range of scales. Investigation of normal fault from early rift stage to late rift stage has shown that large fault systems were formed by linkage of shorter fault segments. To understand the development and final geometry of normal faults, it is therefore vital to understand the function of segmentation and linkage (Peacock and Sanderson, 1996, Peacock, 2002).

2. Location

The Nakhon Basin is located in the western portion of the Gulf of Thailand (Figure 1). The Nakhon Basin is relatively small basin, situated adjacent to the Songkhla, Pattani and Chumphon basin. The study area covers approximately 2,400 Km^2 of area.

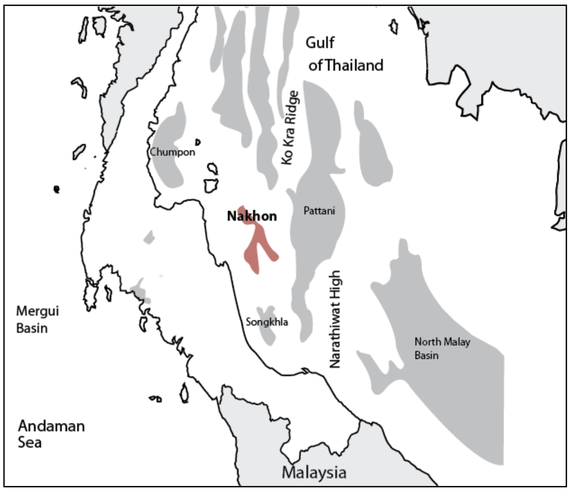

Figure 1. Location of study area (Morley & Racey, 2011)

3. Methods

The primary data set used for this study is 97 2D seismic lines covering 4350 Km and information of lithology based on the wireline log from three available wells. A set of four horizons were interpreted over the 2D seismic data set by tying to well log data of three available wells. Interpreted horizons are Pre-Rift Basement, Late Oligocene, Early Miocene and Middle Miocene. Displacement-distance (D-d) profiles were analyzed to understand fault segmentation.

Structural Framework

In the Gulf of Thailand, structural geological setting comprises a series of N-S trending grabens and half grabens, bounded to the north by the NW-SE trending Three Pagoda Fault and to the west by the NE-SW trending Ranong and Khlong Marui Fault Zones (Figure 2). The Nakhon Basin shows characteristics of western part of the Gulf of Thailand in terms of timing of extension (Morley and Racey, 2011). Rifting began in Eocene?/Oligocene and continued up to Miocene.

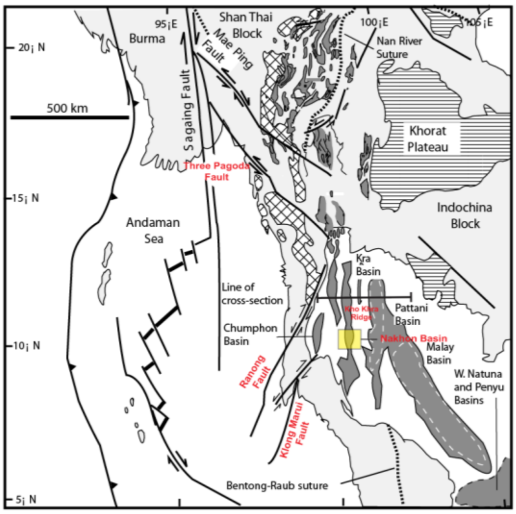

Figure 2. Tectonic framework Gulf of Thailand

4. Results

The longest fault in the area is the Western Boundary fault in the northern part of the Basin. The length of this fault is 40 Km and this is oriented NW-SE. The other major fault in the northern part is Eastern Boundary fault having length of 31 Km. The Eastern and the Western Boundary fault in the Southern Nakhon Basin are oriented N-S. Faulted margins of Northern Nakhon are parallel, and have convergent dip directions, forming symmetric rift basin with two faulted margins (Figure 3A). Faulted margin of the Southern Nakhon rift basin is composed of closely spaced, parallel, basement-involved normal faults. Border faults in the eastern margin of southern part have a stepping geometry and same dip directions with relay ramp structure (Figure 3B). The intrabasinal faults in study area are located in the both parts of the basin. A series of antithetic or synthetic normal faults developed in the hanging wall zone of the basin with strike orientation approximately oblique or parallel to the boundary faults (Figure 3). These faults generally have less displacement as compared to the boundary faults. The intrabasinal faults in the Southern Nakhon are oriented N-S. This part of basin is less faulted as compared to Northern Nakhon.

The upwards loss of displacement on basement-involved faults indicate the main rift faults nucleated from basement and propagated up into the rift basin sediments (Morley, Gabdi & Seusutthiya, 2007). The central part of the major boundary fault is a main rift fault that shows greatest offset in basement and the fault dies out upwards (Figure 4 and Figure 6). Some intrabasinal faults show downward loss of displacement on basement involved faults indicates that faults nucleated within the sedimentary basin section. The evolution of the two large fault systems that have linked and display main rift displacements is discussed below.

The major boundary fault population of the Nakhon Basin is composed of the main rift faults that propagated up from the Pre-Tertiary section and ceased development during the Early or Middle Miocene (Late rift stage). I have selected only two large faults for detail analysis because for many faults the displacement is too small to be observed on seismic data. Both of these faults are in the northern part of the basin and termed as Western Boundary fault and Eastern Boundary fault.

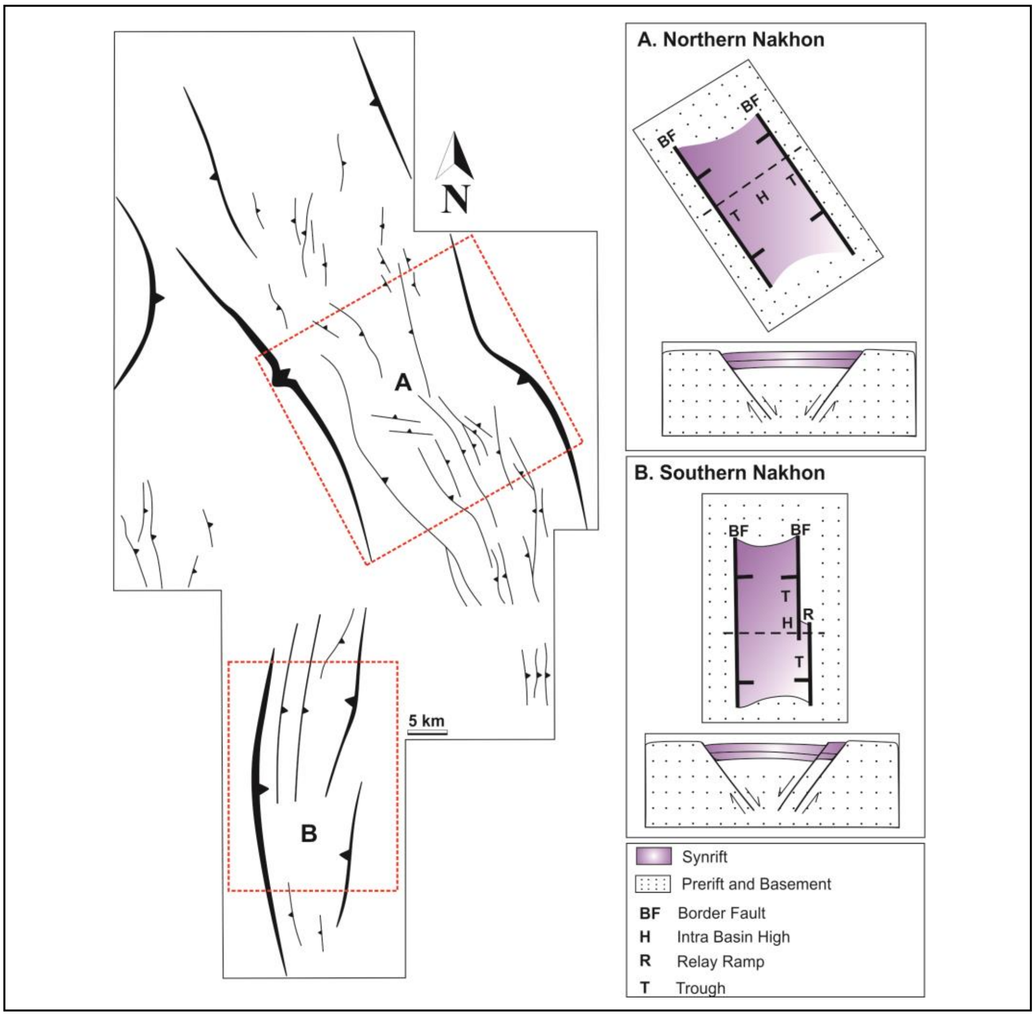

Figure 3. Arrangement of Nakhon Basin border faults within Basement interval (A). Faulted margin of Northern Nakhon (B). Faulted margin of Southern Nakhon

Western Boundary Fault

The Western Boundary fault trends approximately N-S in the southern part and curves into a NW-SE direction (Figure 4). A series interpretations of 2D seismic lines crossing the fault zone are shown in Figure 4. Strike patterns of Western Boundary fault shows apparently three segments. The vertical section shows that throw decreases upwards from the base syn-rift, where the maximum displacement lies within the syn-rift section and dies out upward (Figure 4). Figure 5 shows the variation in displacement- distance (D-d) profile for two key horizons. Values of displacement are obtained by measuring the vertical component of the total displacement (throw) of strata in TWT. Figure 5B). I have only one Time-Depth chart, therefore true displacement in depth cannot be measured accurately. Figure 5C represents the displacement at one interval subtracted from the next higher interval. If the fault displays a positive number it suggests fault motion during the the interval. (Morley, Gabdi & Seusutthiya, 2007). The method approximates how much displacement occurred for a particular time interval. The fault dip angle varies along strike. The fault angle is higher in the areas of high displacement and considerably lower in the areas of low displacement (Figure 5A). Figure 5B shows that there are two places along the Western Boundary fault where displacement is decreasing (at locations 1 and 2). This pattern suggests that Western Boundary fault consists of three segments. The southern N-S striking segment shows less displacement. This displacement increases as we move northward until the

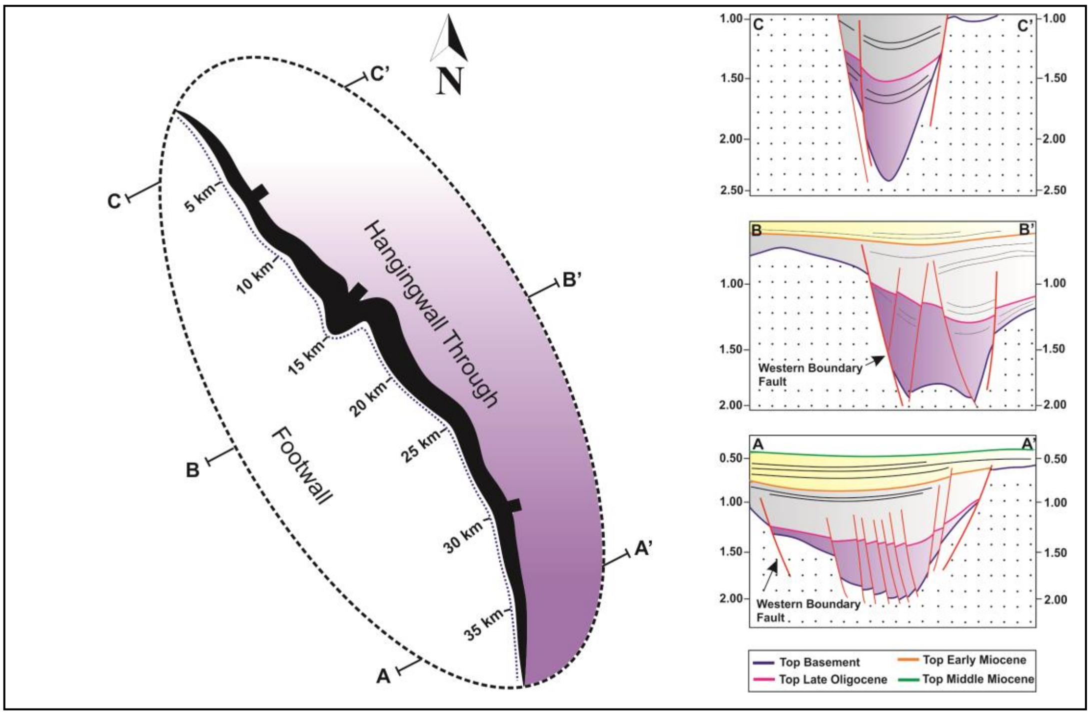

Figure 4. Map view of a Western Boundary fault

fault segment curves into NW-SE direction (Figure 5). The decreasing of displacement at location 1 and 2 indicates that these points are linkage points for different fault segments (Morley, Gabdi & Seusutthiya, 2007, Su et. al., 2011).

Eastern Boundary Fault

The Eastern Boundary fault trends NW-SE along much of its length and curves westwards in central part at distance point of 10 Km (Figure 6). The fault forms the eastern boundary of Northern Nakhon Basin. A series interpretations of 2D seismic lines crossing the fault zone are shown in Figure 6. Strike pattern of Eastern Boundary fault shows apparently two segments. Both are oriented NW-SE separated by E-W bend in fault. The vertical section shows that throw decreases upwards from the base syn-rift, where the maximum displacement lies within the syn-rift section and dies out upward. The fault plane has relatively steeper dip in the southern part (Figure 7A). The fault displacement varies considerably along strike. The overall trend of Eastern Boundary fault shows decreasing displacement from southern to northern part (Figure 7B). Fault throw does not clearly show the southwards decrease in displacement towards the fault tip due to limited available seismic data (Figure 3). The northern part shows low offset at the basement level. The fault is 31 Km long and in the central area, the fault curves sharply to westward. The Eastern Boundary fault does not show any clearly defined segments. There is one low displacement area marked as 1 in Figure 7B. This point may be linkage point of two fault segments. Moreover, this point also coincides with location of deflection point of the fault on the map. Most of displacement in the southern part occurred in early rift stage before Late Oligocene (Figure 7). Whereas, in the northern part of the fault early rift stage produced less displacement as compared to displacement occurred in Late Oligocene (Figure 7).

5. Discussion

Analysis of the structural geometry and displacement-distance (D-d) profiles suggests that the Western Boundary fault zone initially consists of three individual fault segments and Eastern Boundary fault consists of two individual fault segments that are subsequently linked to each other. This is indicated by (1) the distinct strikes of fault

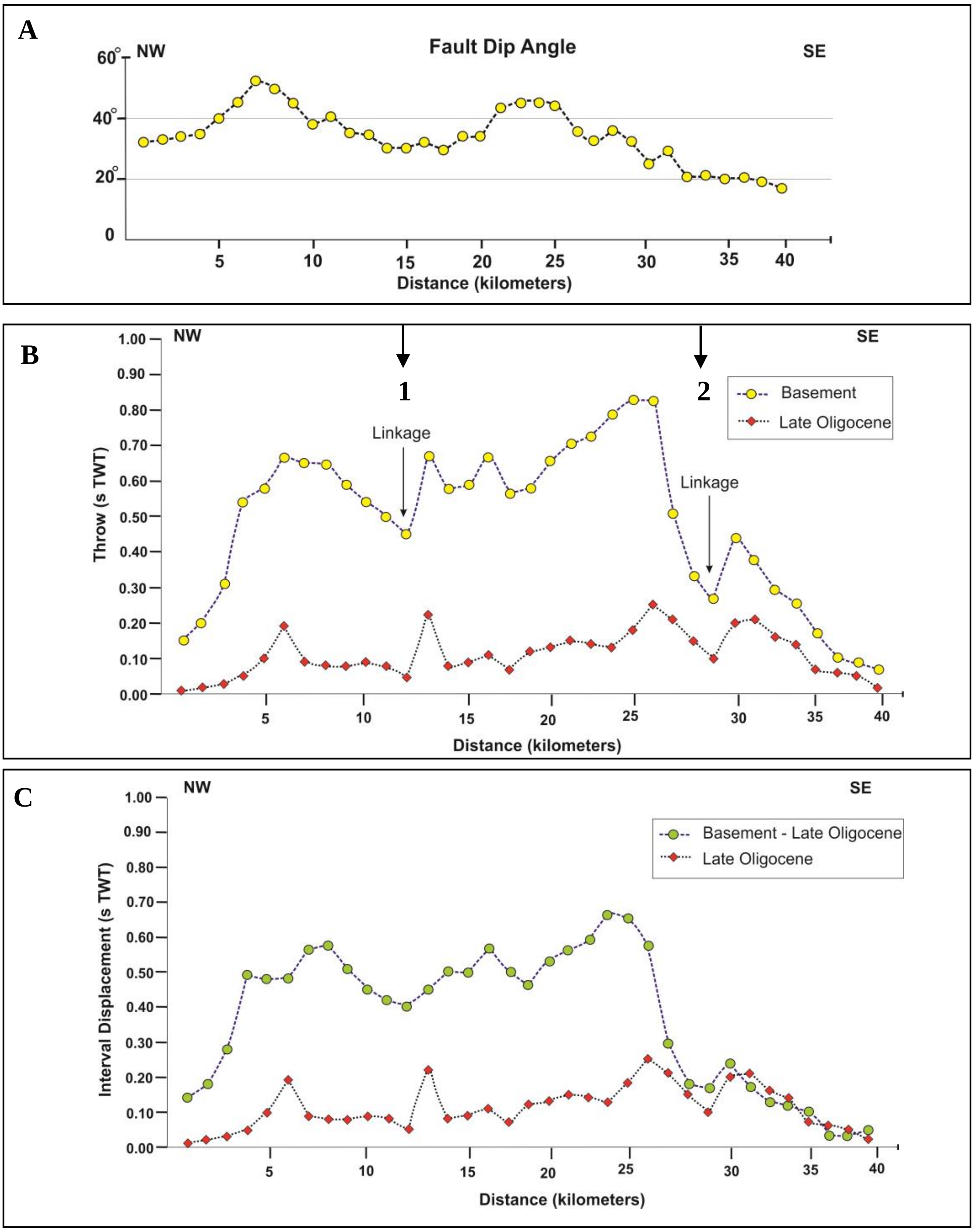

Figure 5. (A). Fault dip angle along the fault strike (B). Displacement-distance (D-d) profile for key horizon (C). Interval displacement profile generated from the next higher interval

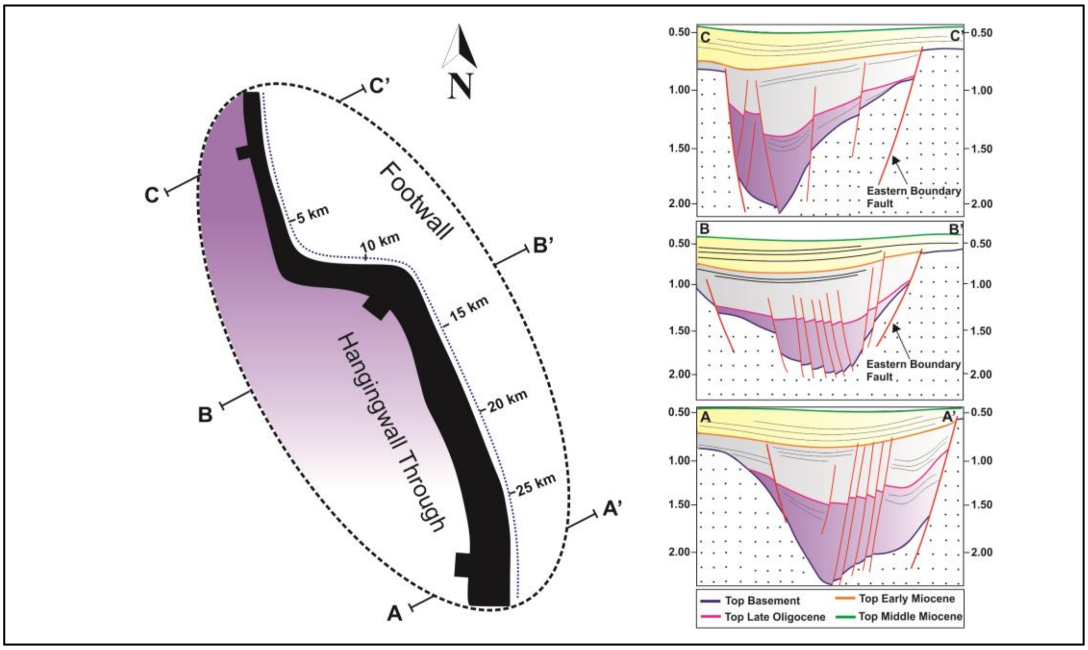

Figure 6. Map view of a Eastern Boundary fault

segments (Figure 4 and Figure 6), (2) the abrupt decrease in throw and strata thickness from depocenter to their tips (Figure 5 and Figure 7) and (3) the location and style of the transverse anticline (Figure 8). The gradual variations in displacement along boundary faults were predicted to affect the location and thickness of syn-extension sedimentary rocks deposited at various stages of boundary fault development (Schlische and Anders, 1996) (Figure 8). It has been recognized that along-strike or transverse anticlines boundary faults can represent variable displacement related to linkage of previously separate faults (e.g., Morley, 1999, Morley, 2002, Schlische, 1995, Schlische and Anders, 1996).

Segmented fault systems are commonly associated with multiple displacements minimum and maximum along displacement-distance (D-d) profile (Morley, 1999, Morley et. al., 2007) (Figure 5 and Figure 7). For the hanging wall of the Western Boundary fault, synclines form at local displacement maximum, located near the centers of the fault segments, whereas anticlines form at local displacement minimum, located near fault segment boundaries (Figure 8). The synclines are wider than the anticlines. The anticlines are associated with fault tips and relay ramp (Figure 8). As the fault propagates laterally and begins to join, a transverse anticline forms, and separates two depocenters in the hanging wall in the northern and central part of the Western Boundary fault. For the hanging wall of the Eastern Boundary fault, syncline forms at local displacement maximum, located near the center of the fault segment in the central part. Anticline structure is not observed due to end of available seismic 2D line (Figure 8).

Inversion anticlines were observed along Eastern Boundary fault of the northern part of the Basin. According to Morley et. al., 2004, local inversion can occur at compressional stepping geometries (sinistral right-stepping, dextral left stepping). Local inversion feature in Nakhon Basin is interpreted as being caused by compression at the tip of the oblique-striking fault segments in Eastern Boundary fault due to oblique extension with a dextral left stepping compression (Figure 9). Time structure and isopach maps reveal that rifting initiated along major boundary faults. During early syn-rift, two depocenters were formed along Western Boundary fault. Sediment thickness shows each fault segment has a maximum thickness near the center that decreases to the fault tips. In Late Oligocene-Early Miocene, there is only one depocenter

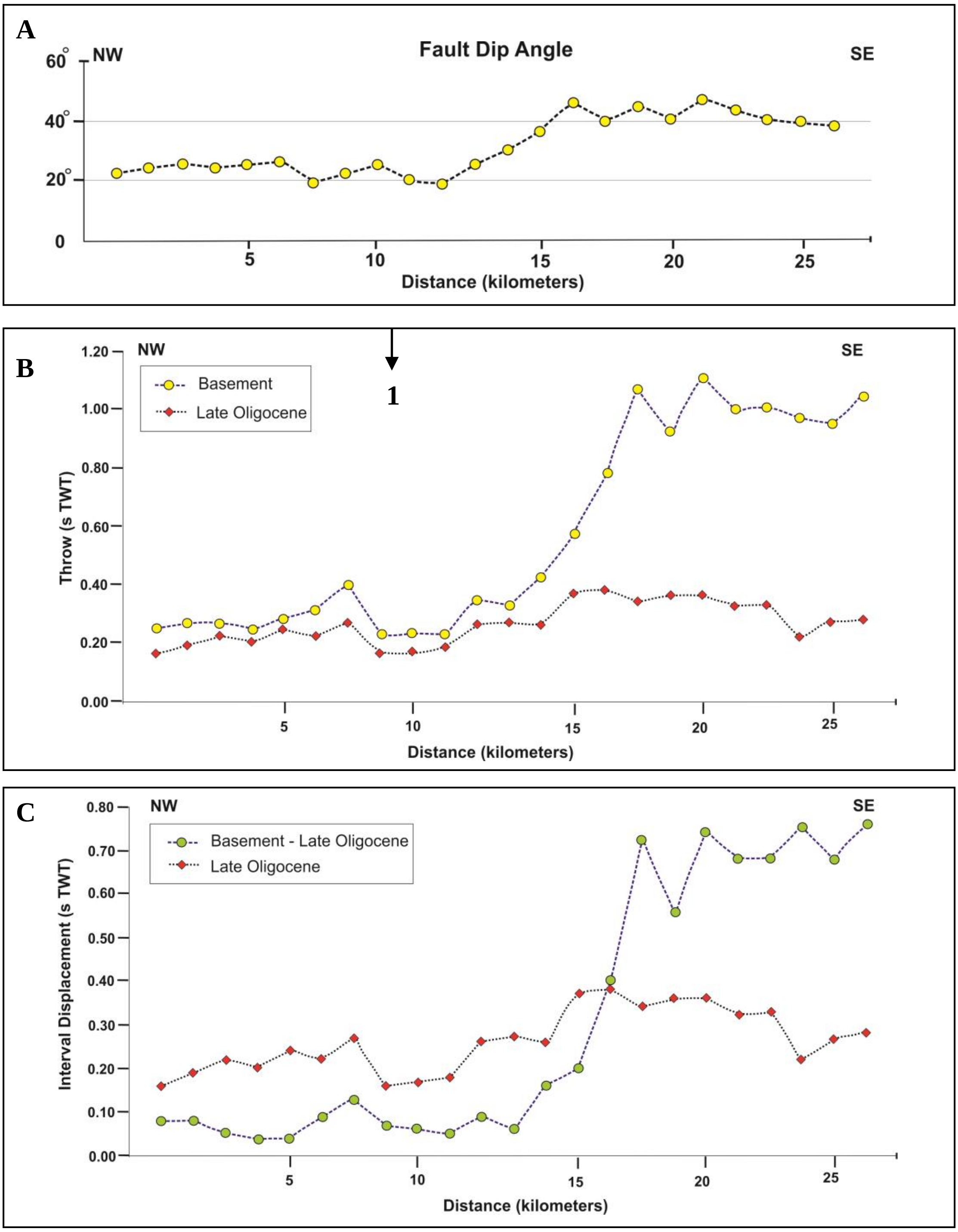

Figure 7. (A). Fault dip angle along the fault strike (B). Displacement-distance (D-d) profile for key horizon (C). Interval displacement profile generated from the next higher interval.

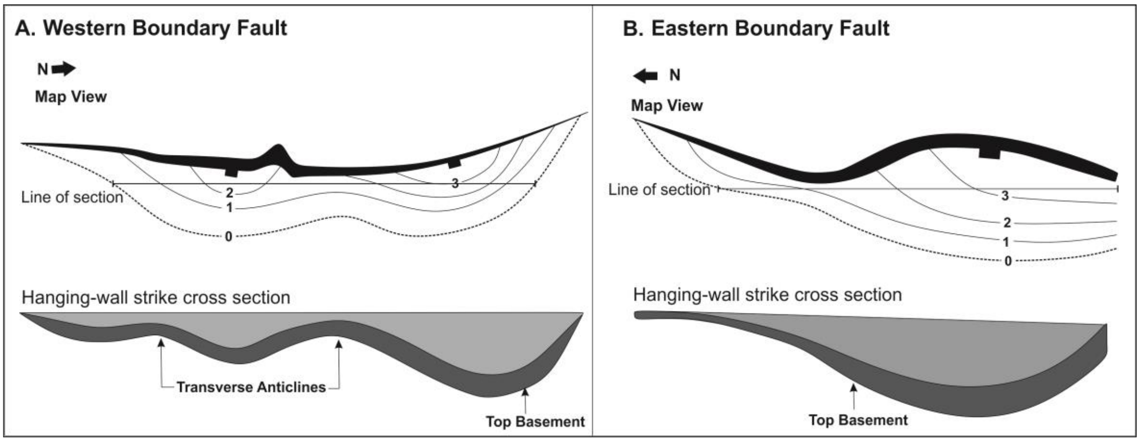

Figure 8. (A). Geometry of Western Boundary fault (B). Geometry of Eastern Boundary fault

in the northern part along Western Boundary fault. In Late Oligocene-Early Miocene the northern part of Western Boundary fault is more active as compared to central part because there is less sediment deposition in this part. It implies that after the Late Oligocene, the central part of the fault became inactive and activity shifted to northern part of the fault. The activity of growing normal fault is considered the main factor that controls the pattern of subsidence in the northern part. Along Eastern Boundary fault during early syn-rift stage the thickest sedimentation was observed in the southern part. Whereas in Late Oligocene-Early Miocene maximum thickness shifted northward. Therefore, the central part of the Eastern Boundary fault was mostly active during this time.

Main Western and Eastern Boundary fault controlled sedimentation until Late Oligocene. In Early Miocene to Middle Miocene, sedimentation is not influenced by basin bounding faults. Thermal subsidence may play role during this time. Exact timing of linkage of different faults are difficult to estimate. However, due to shift in depocenters in Late Oligocene-Early Miocene, it can be inferred that most probably fault linkage occurred before Late Oligocene.

Oblique Fault and their Origin

In the center of the basin there are some short strike length and low displacement faults, which are oblique to the regional boundary faults (Figure 10). These faults are observed from Pre rift Basement to Late-

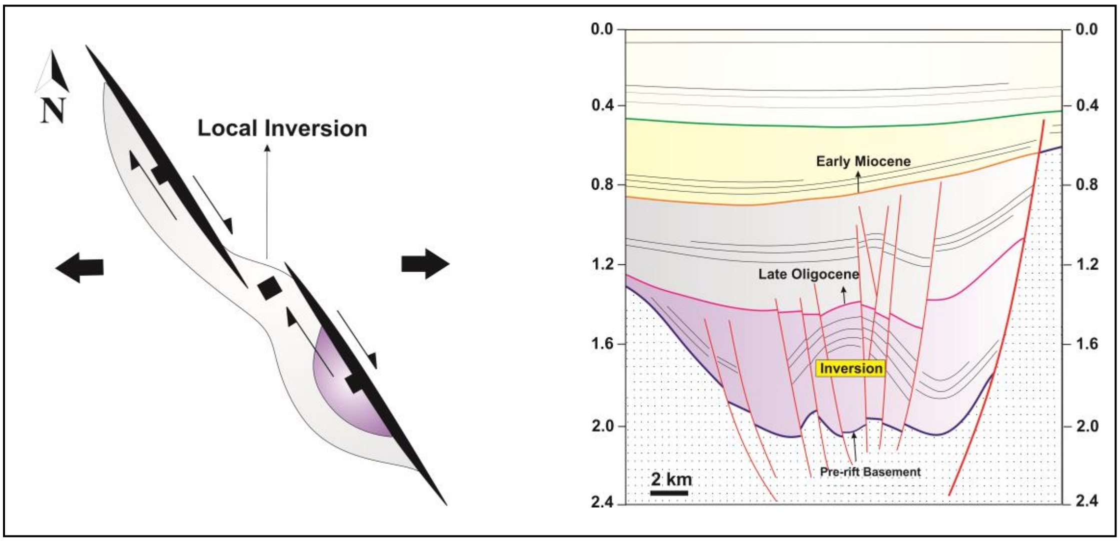

Figure 9. Dextral left stepping compression in oblique extension system in Eastern Boundary fault (Morley et. al., 2004).

Oligocene (Figure 10). These Intrabasinal oblique faults are active until Late Oligocene and we cannot observe these faults in younger time structure maps of Early Miocene and Middle Miocene (Figure 10). Regional basin boundary faults show bends or zigzag pattern oriented in the direction of these oblique faults. The possible origins of oblique faults may be due to following reasons (Kornsawan and Morley, 2002, Morley, 1999, Morley, 2007):

1. They are related in some way to active strike slip faulting.
2. They are related to some kind of passive pre-existing basement fabrics.

These oblique faults cannot be related to strike slip movement because most of the strike slip motion along major faults in Thailand ceased before Oligocene prior to the formation of the Nakhon Basin (Watcharanantakul and Morley, 2002). Therefore, most probably these oblique faults are due to pre existing fabric. There are three strike slip faults close to the study area. Two of them Ranong fault and Khlong Marui faults are oriented NE-SW, where Three Pagoda Fault is oriented NW-SE direction. Hence, these oblique faults are influenced by pre-existing fabric related with Three Pagoda Fault.

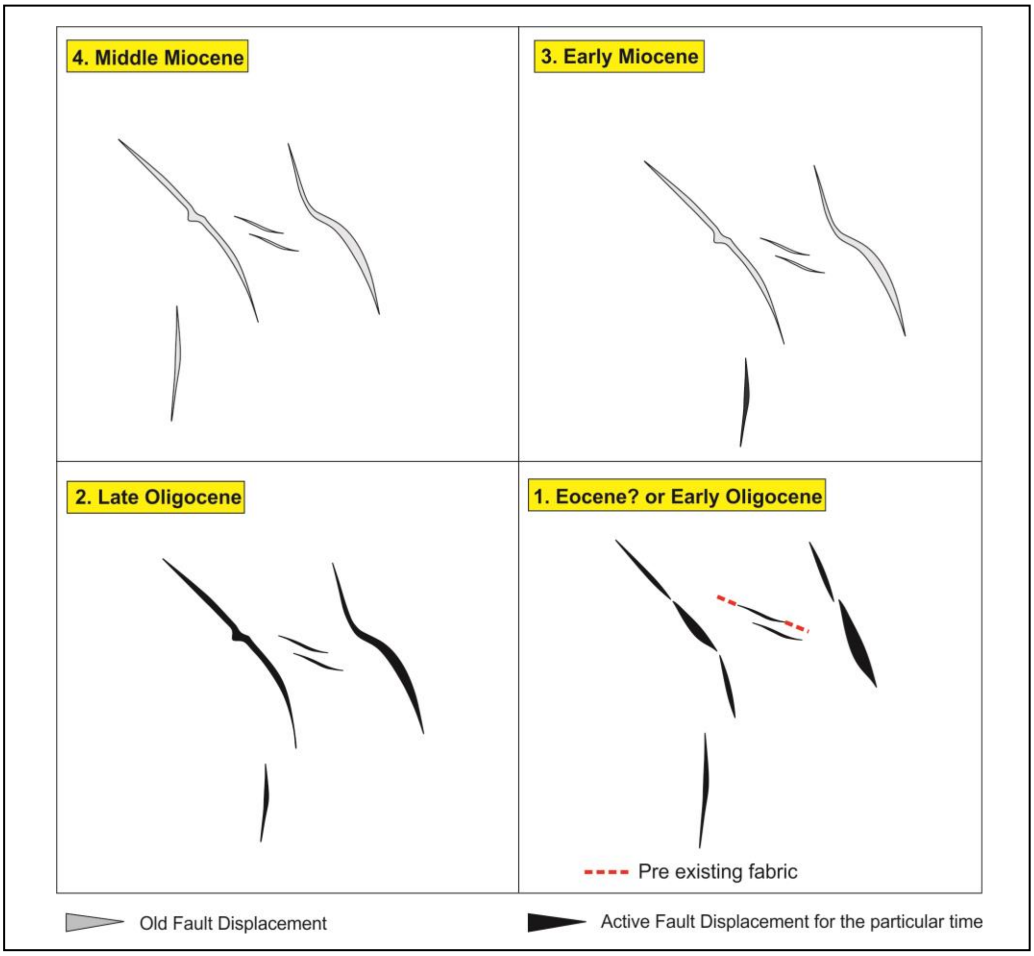

Figure 10. Schematic illustration of the displacement evolution on fault trends of different orientation through time.

6. Conclusions

- Nakhon Basin was formed as result of oblique extension. The rifting probably started in Eocene?/Early Oligocene along NW-SE oriented faults.
- Analysis of the structural geometry and displacement-distance (D-d) profiles suggests that the Western Boundary fault zone initially consists of three individual fault segments and Eastern Boundary fault consists of two fault segments. The same is also inferred from distinct strikes of fault segments, the abrupt decrease in throw and strata thickness from several depocenters to their tips, and the location and style of the hanging wall transverse anticline.
- In early syn-rift, Eastern Boundary fault of the northern Nakhon Basin, Western Boundary fault of Northern Nakhon Basin and Eastern Boundary fault of southern Nakhon Basin were active. Whereas, in Late Oligocene-Early Miocene the northern part of Western Boundary fault is more active as compared to other faults as indicated by less deposition of sediment along these faults.
- Main Western and Eastern Boundary fault controlled sedimentation until Late Oligocene. Thermal subsidence may play role during Early Miocene to Middle Miocene because during this period sedimentation is not close to the boundary faults
- Local inversion in Nakhon Basin is interpreted due to oblique extension with a dextral left stepping compression along the Eastern Boundary fault.
- Intrabasinal oblique faults are associated with pre-existing fabric of Three Pagoda Fault. These faults are generally NW-SE oriented.

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