Triassic Basin Inversion of the Khorat Plateau, Thailand

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ABSTRACT

The Khorat plateau in northeast Thailand forms part of the Indochina block. It is bounded on the northeast by the Mae Ping fault and on the southeast by the Red River fault, both of which accommodated deformation of Southeast Asia as Asia and India converged. During the Triassic, the Shan-Thai and Indochina blocks were welded together by the deformation of the Nan-Uttaradit suture. This was Indosinian orogeny I. After this collision and crustal extension in the Khorat plateau, Triassic pre-Khorat rocks were deposited in half-grabens and were capped by the lower part of Nam Phong Formation, which sealed the half-grabens. Following this, Late Triassic collision in western Thailand caused inversion of the half-grabens. This was Indosinian orogeny II and Triassic basin inversion I. Following Indosinian orogeny II, continental sediments, the Khorat Group, were deposited and inverted during the Middle Cretaceous and Early Paleocene. Triassic basin inversions II and III resulted from the West Burma-Shan Thai block collision and the Himalayan-Burma collision. These late inversions uplifted the Khorat plateau and generated broad folds in the Khorat Group.

KEYWORDS: Triassic pre-Khorat rocks, Triassic basin, basin inversion, Khorat plateau, synrift megasequence, Indosinian orogeny

INTRODUCTION

The northeastern part of Thailand, which forms part of the Indochina block, comprises two main areas, the Loei-Phetchabun fold belt and the Khorat plateau. The region's major structural elements are parallel to the Nan-Uttaradit sutures at the northern and western margins of the Indochina block. The Khorat plateau contains major structural elements that also are parallel to the sutures at the northern and western margins of the Indochina block (Figure 1). Northwest-southeast trending anticlines form the Phu Phan Range, which parallels the Song Ma suture (Lovatt-Smith and Stoke, 1997). Adjacent to the Nan-Uttaradit suture, the western north-south trending Loei- geological map of Thailand shows the outcrops Phetchabun fold belt is highly tectonised and eroded.

The geological map exhibits the outcrops that have been studied stratigraphically by several authors (Bunopas 1971; Chonglakmani and Sattayarak, 1978; Department of Mineral Resources, 1981; Bunopas, 1988, 1994). Most of the outcrops occur in the Loei-Phetchabun fold belt. The lack of outcrops limits establishing the litho-stratigraphy of the Khorat plateau.

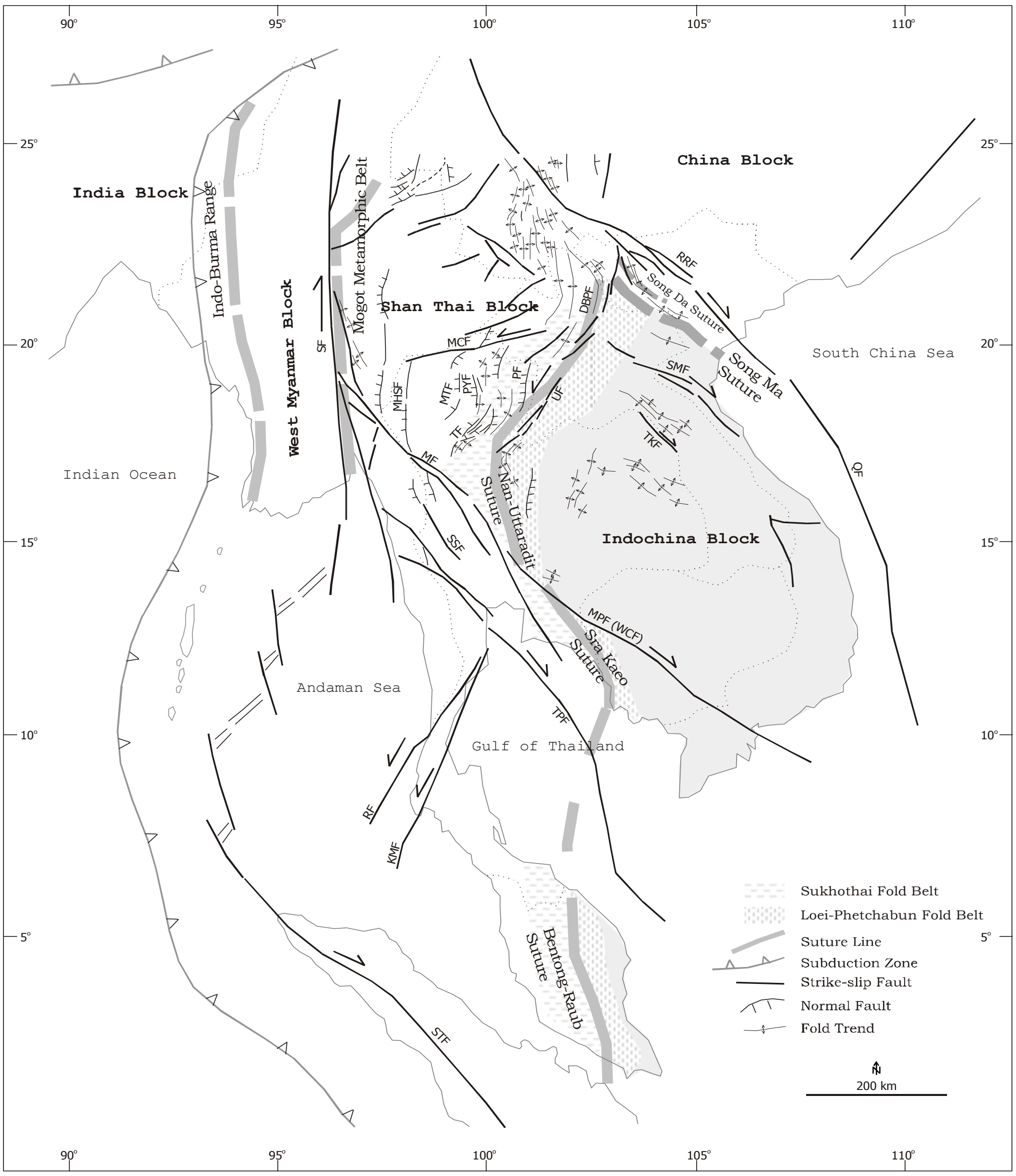

Figure 1 Tectonic setting of Thailand. (compiled from Harding and Henshaw, 1981; Copper and others, 1989; Altermann, 1991; Bunopas, 1994; Leloup and others, 1995; Lacassin and others, 1997; Singharajwarapan and Berry, 2000; Metcalfe, 2000; Wang and others, 2001; Morley, 2002; Carter and Bristow, 2003; Lepvrier and others, 2004.)

Abbreviation: KMF: Khong Marui fault; RF: Ranong fault; TPF: Three Pagodas fault; MPF: Mae Ping fault (or WCF: Wang Chao fault); RRF: Red River fault; DBPF: Dien Bien Phu fault; SMF: Song Ma fault; TKF: Tha Kaek fault; QF: Quinhon fault; SF: Sagaing fault; STF: Sumarta fault; SSF: Sri Sawat fault; UF: Uttaradit fault; MF: Moei fault; MCF: Mae Chan fault; TF: Thoen fault; PYF: Phra Yao fault; MTF: Mae Tha fault; PF: Pua fault; MHSF: Mae Hong Son fault.

However, the seismic and well data used in this study provide new insights concerning the distribution and significance of key megasequences in the Khorat plateau. The stratigraphy in the area, if compared to the area to the west, is the same age but concerns a different basin. This study uses the terms Permian rocks and Triassic pre-Khorat rocks for the strata deposited during the Permian and Triassic Periods. Although surface data show the Khorat plateau as having only two fold-belt trends, subsurface data show complex structures. This paper describes the half-graben basins, major unconformities, and basin evolution of the area.

This study is mainly based on two-dimensional seismic and well data (Figure 2) and their integration with surface data from geological maps. The subsurface data were acquired by oil companies that have explored due Khorat plateau since 1961. These companies have acquired approximately 27,000 kilometers of seismic survey lines across the region and have drilled more than 30 wells. Both seismic data and well data are available in Thailand's Department of Mineral Fuels.

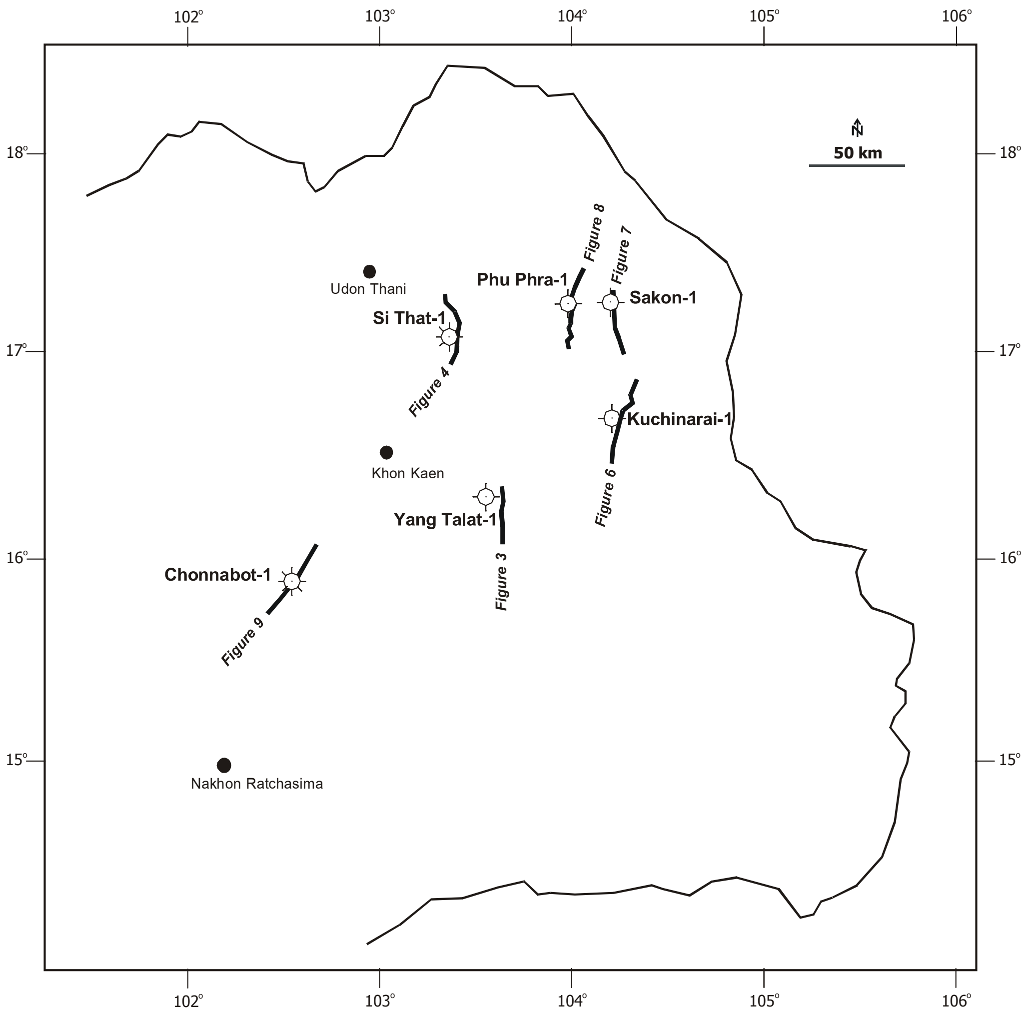

Figure 2. Seismic lines and well locations.

TECTONIC EVOLUTION REVIEW

The Khorat plateau forms a continental block within Southeast Asia bounded by major Tertiary faults. Many existing tectonic models imply that this block is essentially undeformed. However, outcrop geology shows it to contain laterally continuous fold belts separated by gently dipping strata thought to overlie sedimentary basins. Two fold trends are present in the Khorat plateau. A north-south trend, the Loei-Phetchabun fold belt, dominates the western area and northwest-southeast trending Phu Phan Range dominates the central part (Figure 1). These fold belts are parallel to crustal-scale Late Palaeozoic structures: the Nan-Uttaradit and the Song Ma sutures (Figure 1). Both fold belts are believed to have resulted from the collision in the region during the Late Cretaceous to Early Tertiary (Copper and others, 1989; Sattayarak and others, 1989; Kozar and others, 1992; Booth 1998; Racey and others, 1997). These fold belt trends underwent two tectonic events (Sattayarak and others, 1989, 1997; Lovatt-Smith and others, 1996). The first event was the collision of the West Burma and Shan-Thai blocks (Sattayarak and others, 1989, 1997; Lovatt-Smith and others, 1996) during the Middle or Late Cretaceous (Metcalfe, 1996; Mitchell, 1981). The second event was the Himalayan orogeny that occurred during the Tertiary (Metcalfe, 1996; Copper and others, 1989; Sattayarak and others, 1989; 1997; Thanomsap, 1990, 1997; Kozar and others, 1992; Mouret and others, 1993; Lovatt-Smith and others, 1996; Chuaviroj, 1997). These tectonic events were responsible for compressive folding and reverse faulting and inversion of the basin pattern. Copper and others (1989) suggested that the north-south fold trend along the western rim of the Khorat plateau, the Loei-Phetchabun fold belt, developed from the inversion of Triassic half-grabens. In the Phu Phan Range, the northwest-southeast structural trend was generated by inversion of the Permian and Triassic basins (Kozar and others, 1992; Booth 1992; Mouret and others, 1993; Mouret, 1994; Racey and others, 1997) and by partial reactivation of underlying structures and faults (Booth, 1998; Mouret and others, 1993). This inversion and reactivation produced large-wavelength structures in the Korat plateau and resulted in major uplift and erosion (Sattayarak and others, 1989; Mouret and others, 1993; Mouret, 1994).

Several authors reporting previous investigations believed that Khorat plateau deformation was caused by two major tectonic events. This study, incorporating subsurface data, suggests that more than two events influenced the structural deformation of the area.

SUMMARY OF SOUTHEAST ASIA TECTONIC EVENTS

The following five major tectonics events may have influenced the deformation of the Khorat plateau from the Early Carboniferous to the Tertiary.

- The Indochina and South China blocks had sutured along the Song Ma suture during the Early Carboniferous (Hutchison, 1989; Metcalfe, 1991, 1996; Bunopas, 1994).
- From the Late Permian to Early Triassic, the Shan-Thai and Indochina blocks welded together (Hahn, 1984; Metcalfe, 1996; Hutchison, 1989; Cooper and others, 1989; Sattayarak and others, 1989) and subsequently deformed the Nan-Uttaradit and Raub-Bentong sutures (Bunopas, 1981).
- During the Late Triassic, the Yangzi block collided with the Sino-Korean block (Sengör, 1985; Wan and Zhu, 1991).
- During the Late Cretaceous the West Burma block collided with the Shan-Thai block (Hutchison, 1989, 1996; Tapponnier and others, 1986; Metcalfe, 1991, 1996, 1997; Charusiri and others, 1993; Mitchell, 1993; Lee and Lawver, 1995; Bertrand and Rangin, 2003).
- The collision of India with Asia, the Himalayan orogeny, since the Middle Eocene (Tapponnier and others, 1982, 1986; Dewey and others, 1989; Hutchinson, 1989; Daly and others, 1991; Lee and Lawver, 1995) has been the cause of the major Tertiary deformation in the Khorat plateau.

SEISMIC AND TECTONO-STRATIGRAPHY OF THE KHORAT PLATEAU

Seismic sequence stratigraphy, incorporating seismic interpretations and well data from the Khorat plateau, was used to established four intervals, or packages. In terms of tectono-stratigraphy that link to the tectonic evolution of the Southeast Asia, the Khorat plateau has five megasequences. These are pre-rift, synrift, earliest post-rift, post-rift, and post inversion.

Seismic Stratigraphy

Four seismic intervals, or packages, were recognized in the Khorat plateau's subsurface sequences. The characteristics of each of these are shown in Figures 3, 4, and 5.

- Package 4 is the upper package and is characterised by a dominant parallel stratal configuration.
- Package 3 is characterised by a group of divergent seismic reflections that thicken towards a border fault.
- Package 2 has parallel stratification that is partially truncated at an unconformity of packages 4 and 3.
- Package 1 is the lowest package and is characterised by chaotic reflections.

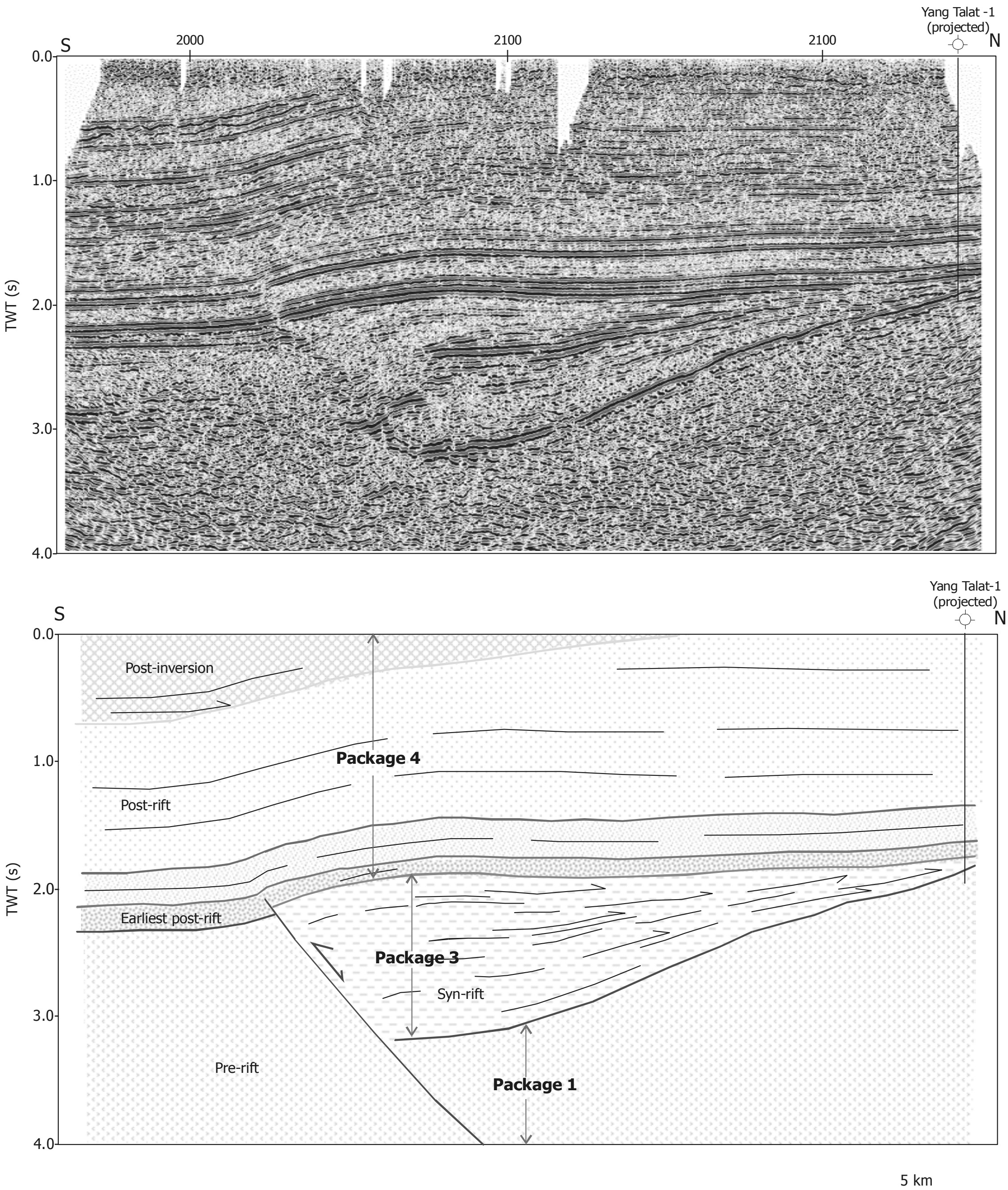

Figure 3. Seismic profile and Yang Talat-1 well show the key horizons and seismic packages.

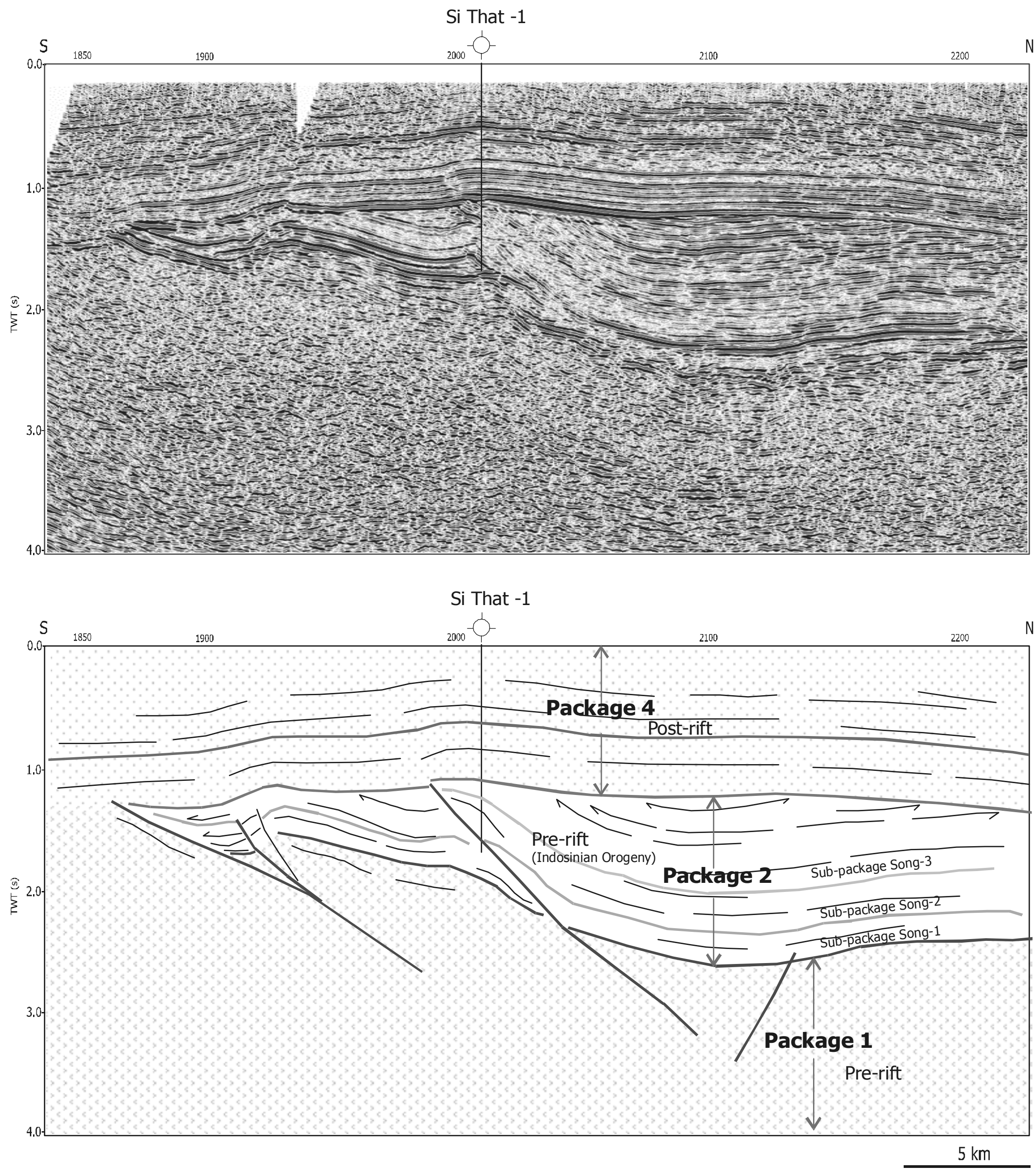

Figure 4. Seismic profile and Si That-1 well show the key horizons and seismic packages.

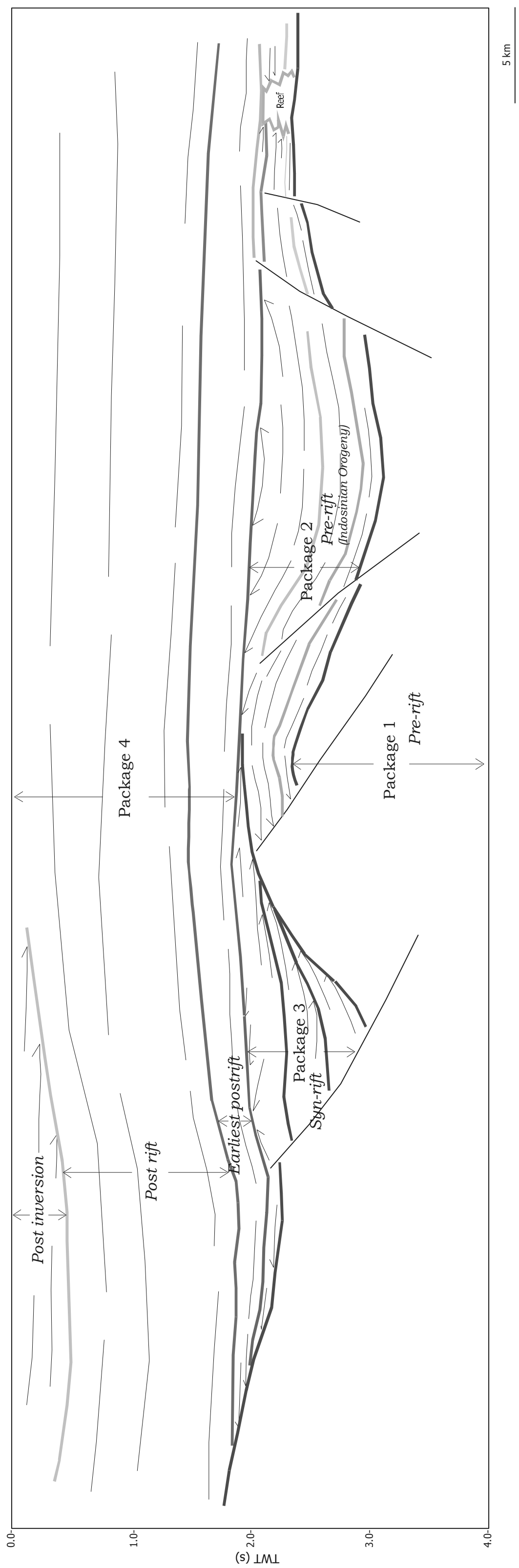

Figure 5 Schematic seismic stratigraphy of the Khorat Plateau. (after Chantong, 2005).

All of the two-dimensional seismic profiles were interpreted and divided into seismic packages. No seismic profile includes all four seismic packages. Some profiles have three packages, with the exception being package 2. Other profiles do not contain package 3. Given this, the two best profiles that illustrate the subsurface structure and stratigraphy of the Khorat plateau are seismic profiles K79A910 (Figure 3) and U81A6 (Figure 4). These two seismic lines are located in the central part of the study area. They both have reflection continuity and high amplitudes that clearly show the subsurface structure. Also, two wells, Yang Talat-1 and Si That-1, were drilled on shot points of these profiles and data from them aided interpretation of the seismic profiles.

A composite section made up of seismic profiles K79A910 and U81A26 illustrates the four subsurface sequence packages of the Khorat plateau. Package 4 is the youngest and package 1 is the oldest. Four packages can be identified from younger to older. These are packages 4, 3, 2, and 1. Seismic profile K79A910 shows the seismic characteristics of packages 4, 3, and 1. Seismic profile U81A6 shows the seismic characteristics of package 2. Figure 5 shows the relationship among these four packages.

Tectono-Stratigraphy

Inter-regional unconformities define package boundaries that relate to the tectonic history of the Khorat plateau. There are four unconformity-bounded packages into which the stratigraphy of the Khorat plateau from the Permian to the Middle Cretaceous can be classified. The oldest of these are packages 1 and 2. These packages are Permian marine strata that are a pre-rift megasequence, deformed by Indosinian orogeny I. The overlying package 3 is a Triassic syn-rift megasequence within half-grabens. Package 4, above package 3, is the uppermost package. Its lower part is the Nam Phong Formation that seals underlying normal faults and which is an early post-rift megasequence. This formation is capped by an unconformity that is gently folded, presumably because of the first episode of Triassic basin inversion. The upper part of package 4 is the Khorat Group, being a later post-rift megasequence that onlaps the early post-rift megasequence unconformity. During the Middle Cretaceous, Triassic basin inversion II reactivated faults. No syn-inversion package is in the Khorat plateau because of rapid uplift relative to sedimentation. The Mahasarakham and Phu Tok Formations were deposited as the post-inversion megasequence. During the Tertiary early Paleocene, Triassic basin inversion III reactivated faults and generated broad folds in the Khorat plateau. Figure 6 is an integration of seismic data, well log data, and tectonic events that document the geologic history of the Khorat plateau from the Permian Period to the Tertiary Period.

Integrating seismic interpretation, well data and tectonic event, this study can document the relationship of these data as Figure 6.

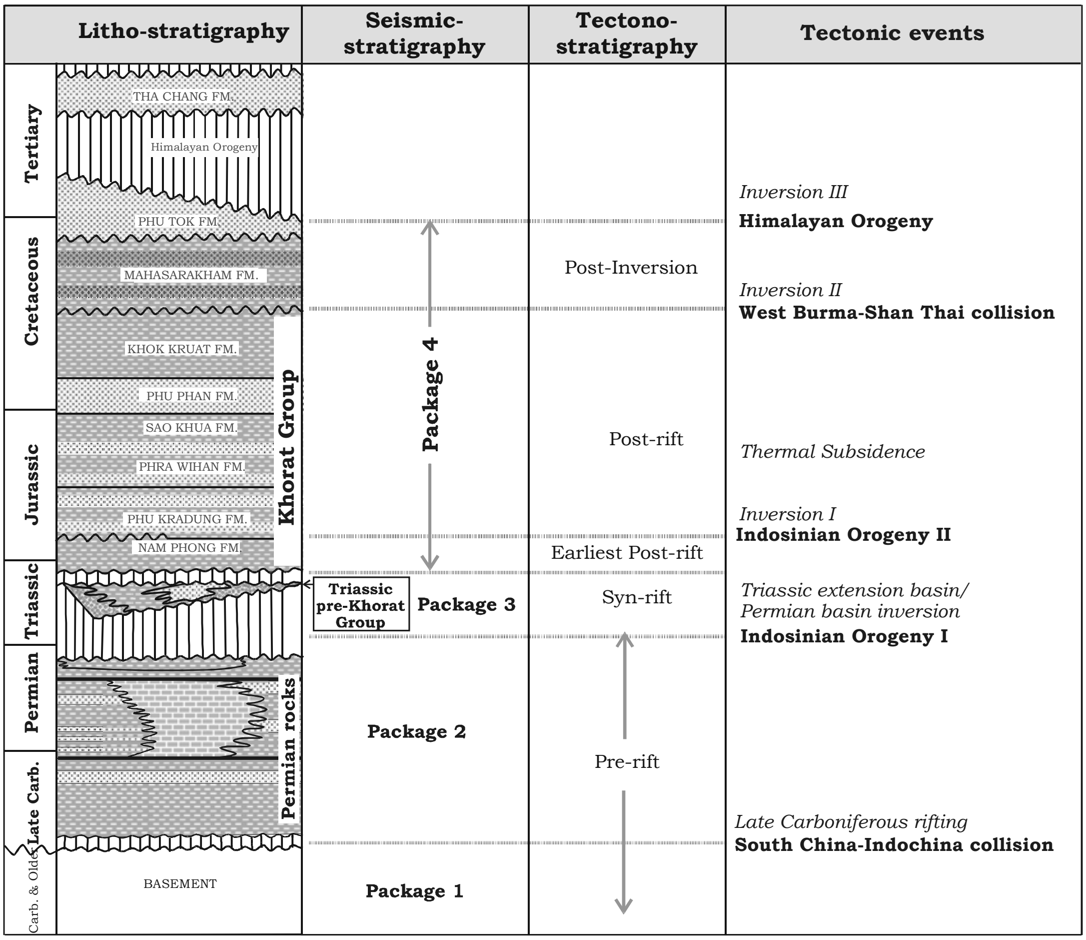

Figure 6 The relationship between the litho-stratigraphy, seismic stratigraphy, tectono-stratigraphy, and tectonic events (complied from Department of Mineral Fuels, 2005 and Chantong, 2005).

TRIASSIC BASIN INVERSION AND BASIN EVOLUTION

Kuchinarai, Yang Talat, Sakon, Chonnabot, and Phu Phra are Triassic half-grabens in the Khorat plateau (Figures 7 to 10). The location of seismic lines in these half-grabens is shown in Figure 2. The characteristics of these half-grabens are similar but the basement and sedimentary fill are different from one to another. The basal conglomerate outcrops in the Na Pho Song-Phetchabun area of the Khorat plateau do not contain Permian limestone clasts. The Triassic sequence in this area is only red beds of quartz sandstone, black lacustrine sandstone, and shale. In contrast, in the Sap Phlu basin in the southwestern area of the Khorat plateau, the Triassic sequence has a basal conglomerate that has Permian limestone clasts, brown lacustrine sandstone, and shale.

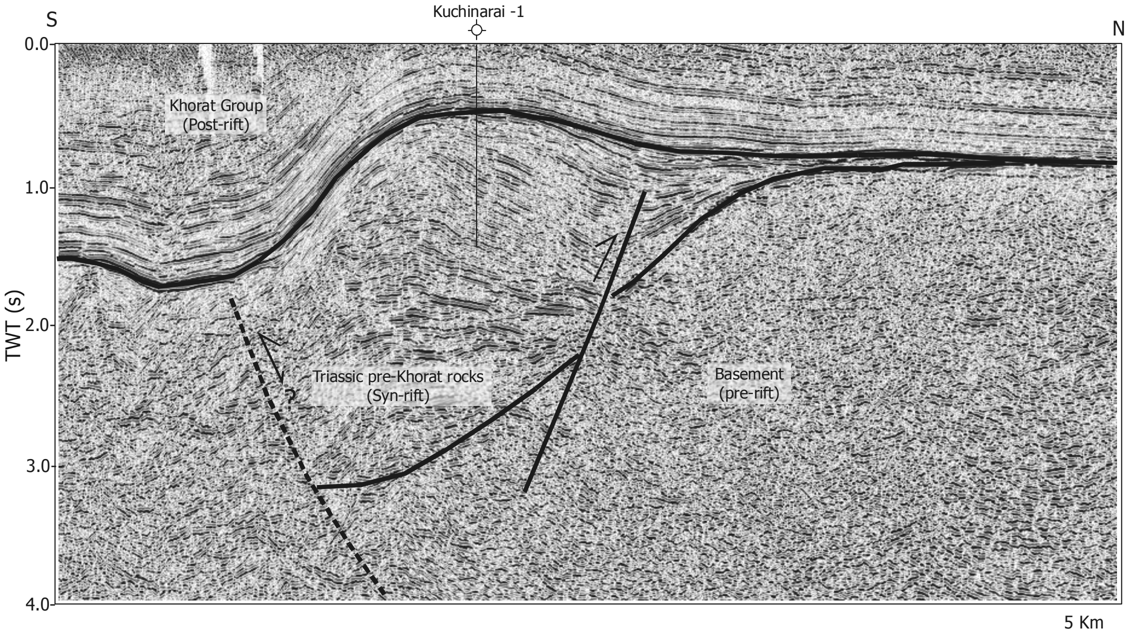

Figure 7 Kuchinarai half-graben

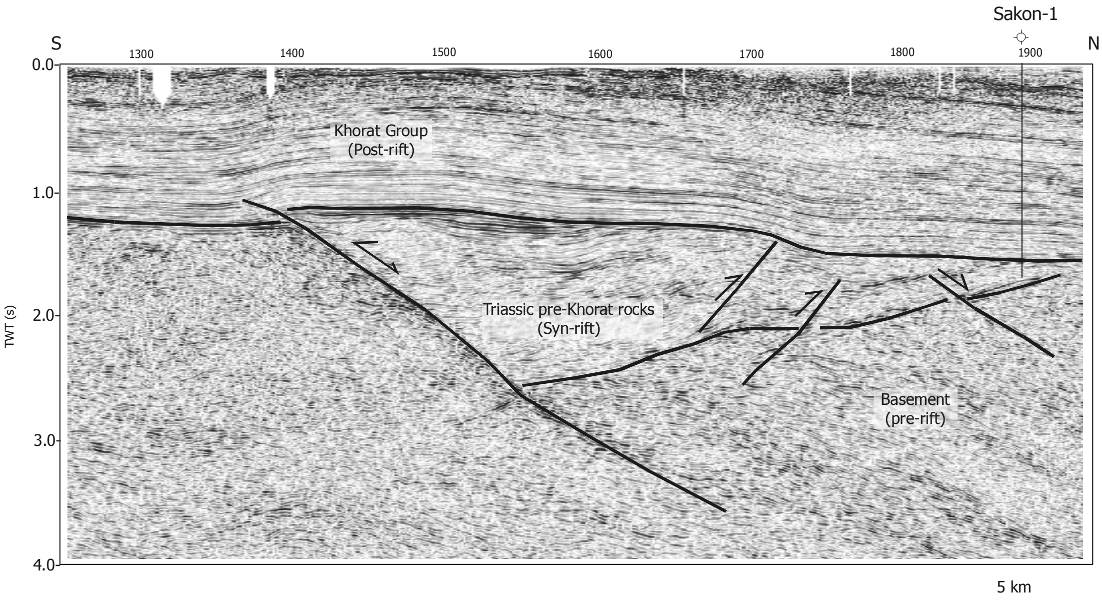

Figure 8 Sakon half-graben

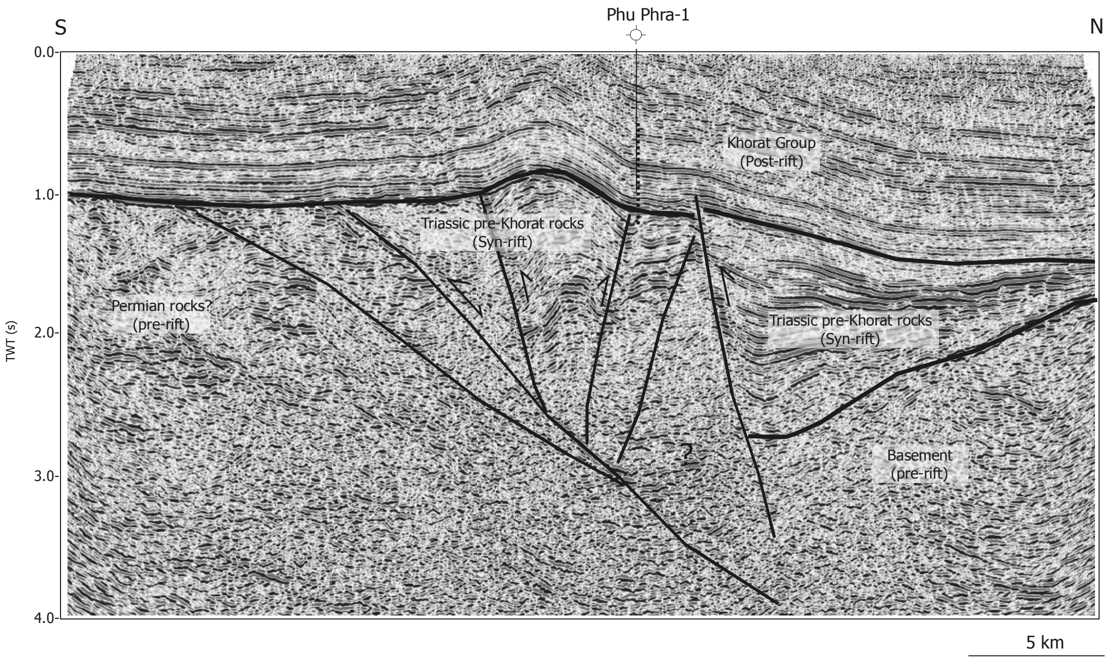

Figure 9 Phu Phra half-graben

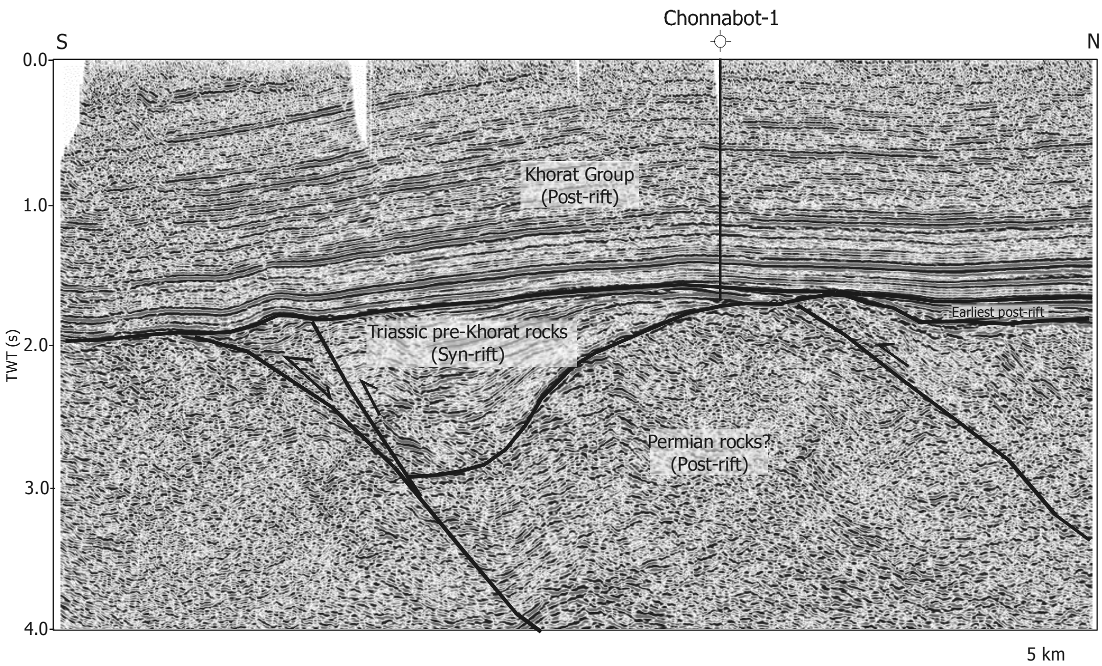

Figure 10 Chonnabot half-graben

The Korat plateau's basin evolution is shown in Figure 11. This evolution, linked to the tectonic history of Southeast Asia, is summarised as follows:

- Late Carboniferous and Permian rifting and collision between the Indochina and South China blocks caused rifting along the Song Ma suture. Major Carboniferous rifting probably culminated in the formation of the Esarn Sea (Sattayarak and others, 1989), which is now located underneath the Phu Phan Range. During the Late Carboniferous and Permian, Permian rocks were deposited in the Esarn Sea and in the Nam Duk Sea. The Esarn Sea was oriented northwest-southeast and was located beneath the Phu Phan Range. The Nam Duk Sea was oriented north-south in the western Khorat plateau. During this time, the western Indochina block was the Nam Duk Sea and the site of deep marine sedimentation. The Esarn Sea during this same time was the site of shallow marine sedimentation.
- Permian deposition ceased by the time of the Indosinian orogeny I during the Early Triassic. The Permian basins were inverted and pre-existing structures were reactivated. However, some Triassic basins formed almost immediately away from, but parallel to, the Nan-Uttaradit suture. These basins were sites of lacustrine deposition, this being the syn-rift megasequence.
- The lower Nam Phong Formatio sealed the Triassic basins and is considered to be the earliest post-rift megasequence. The Yangzi block collision with the Sino-Korean block during the Late Triassic is Indosinian orogeny II. This orogeny caused inversion of half-grabens and grabens and is Triassic basin Inversion I.
- After Indosinian orogeny II, the region subsided and allowed deposition of Khorat Group strata. A high rate of subsidence probably occurred in the southwest Khorat plateau area. This is suggested by the Phu Kradung Formation onlap of the Nam Phong Formation (Figure 11). In the Middle Cretaceous, the West Burma block collided with the Shan-Thai block. This was followed by inversion, Triassic basin inversion II, in the Khorat plateau. This inversion formed a rimmed intermontane basin that became the site of hypersaline deposition that was followed later by aeolian deposition.
- The Tertiary deformation of the Khorat plateau is the result of the on-going India and Eurasia collision that commenced in the Middle Miocene. This major tectonic event caused uplift of the Khorat plateau and generated the two fold belts existing today. This is Triassic basin Inversion III.

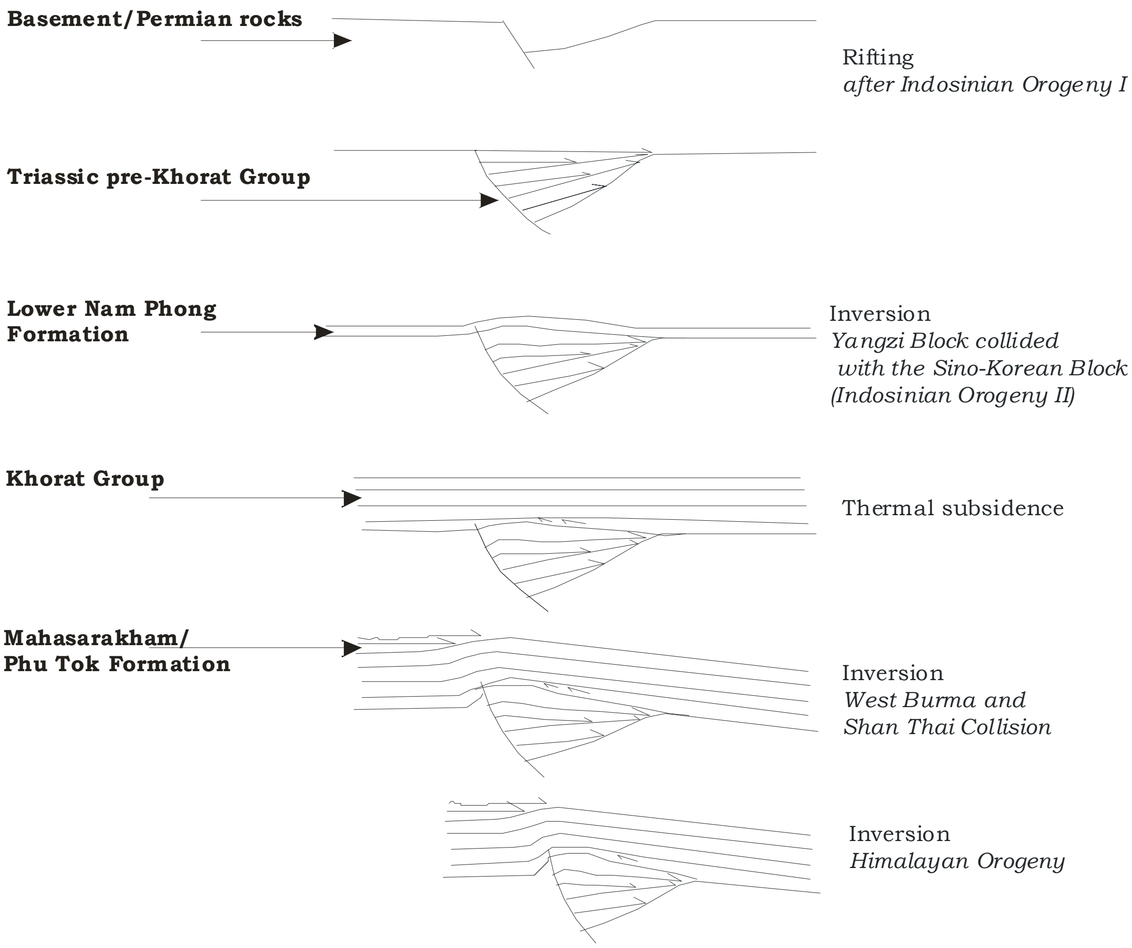

Figure 11 Cartoon presents the basin evolution of the Khorat Plateau and focuses on the generation of the Triassic half-graben.

CONCLUSIONS

During the Late Permian to Triassic, the Shan-Thai block collided with the Indochina block, this being Indosinian orogeny I, and caused the formation of half-grabens and grabens in the Indochina block. The Triassic pre-Khorat Group was deposited in these Triassic half-grabens and grabens and its deposition was followed by the deposition of the lower part of the Nam Phong Formation. This lower Nam Phong deposition sealed these half-grabens and grabens. Indosinian orogeny II occurred during the Late Triassic and caused the inversion and subsequent erosion of some half-grabens. This period of uplift and erosion was Triassic basin inversion I. After Indosinian orogenies I and II, a period of tectonic quiescence and thermal subsidence occurred in the Indochina block. This quiescence and subsidence allowed deposition of the Khorat Group in the Middle Cretaceous. The West Burma block collision with the Shan-Thai block in the Middle Cretaceous affected the Khorat plateau by causing inversion and uplift. This was Triassic basin inversion II. This second inversion episode led to the

Khorat plateau becoming a rimmed intermontane basin that became the site of hypersaline and eolian deposition.

The Tertiary deformation of the Khorat plateau is a result of the India and Eurasia collision in the Middle Miocene. Especially the Phu Phra and Kuchinarai Triassic half-grabens were inverted along their initial faults. This period of uplift was Triassic basin inversion III.

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