CHAPTER IV

REGIONAL GEOLOGY

The following discussion on the regional geology is focusing upon Changwat Saraburi and neighbouring area in order to serve as a background for future detailed study under the present investigation. This includes the geomorphology, stratigraphy and distribution of rock types, geological structures, and the geological evolution. The target area concerned envelops approximately between the latitudes of 14°00' N. to 15°00' N. and longitudes of 100°30' E. to 102° 00' E., covering approximately 18,000 square kilometers.

4.1 Geomorphology

The topographic expression of the regional area, Changwat Saraburi and neighbouring areas, can be broadly divided into two main features, lowlands area and highlands area (Figure 4.1). The lowland area consists of alluvial plains, terraces and peneplain. Alluvial plains and terraces occupy almost half of the area under the present assessment mainly along the western and southern parts with some extension to the southern and southeastern parts, covering some parts of Lopburi river, Pa Sak river, Chao Phra Ya river, Nakhon Nayok river, and Prachin Buri river systems. The average elevation is approximately 50 meters above the mean sea level. The highland area consists of plateau and mountain range occupying mainly eastern and northeastern parts with some extension to the north. The mountain range can be distinguished into four different features, notably, volcanic mountain range, karst topography, isolated hills and knolls and cuesta. The volcanic mountain range shows a complex plateau and conical-shaped hills in the area of Khao Yai. The karst topography shows typical features of the mountain consisting of carbonate rocks

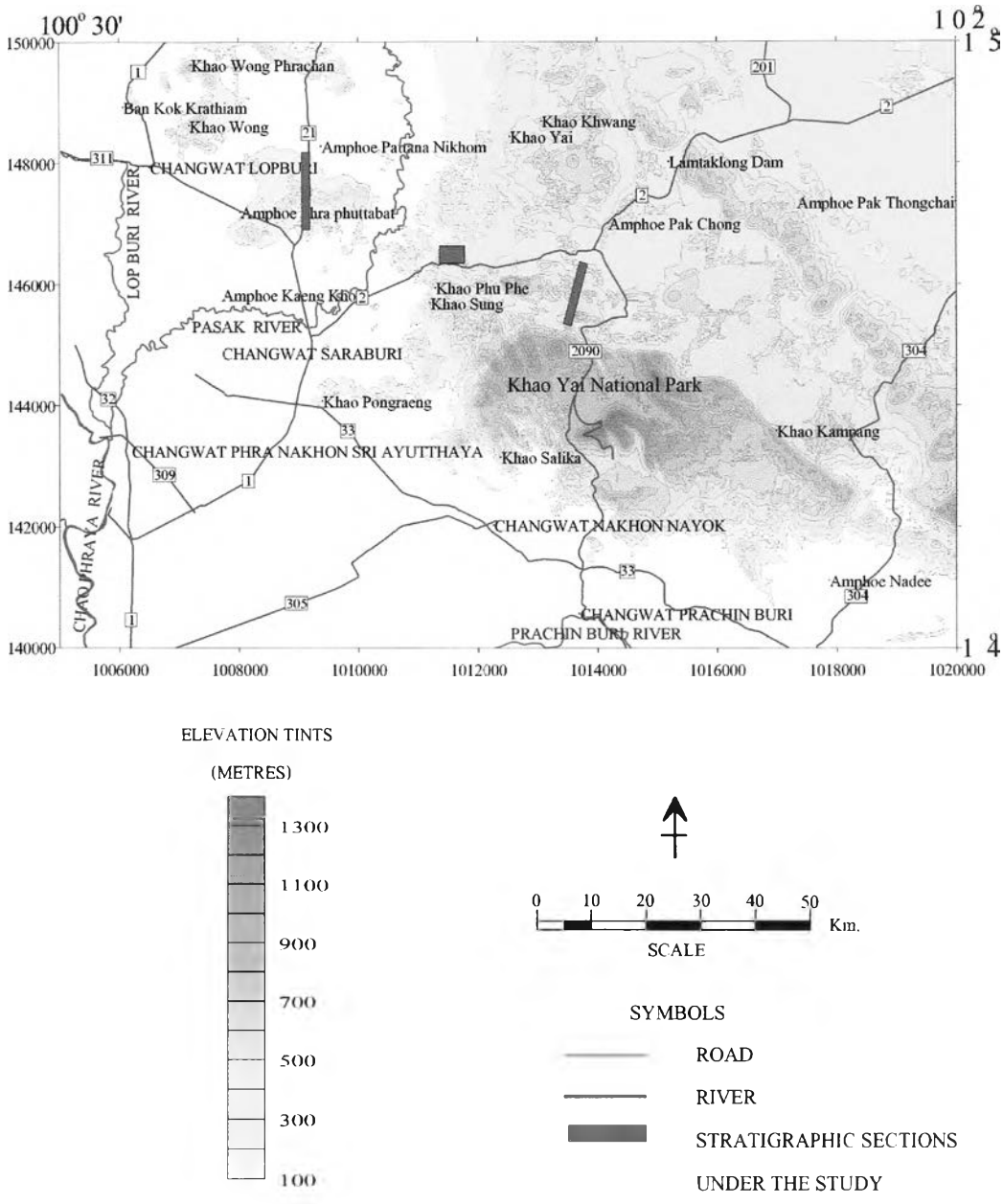

Figure 4.1 Hypsographic map of Changwat Saraburi and neighbouring area (Modified after Geological Map of Thailand sheet Changwat Phranakhon Si Ayuthaya, ND 47-8, DMR, 1985).

with sharp crest, sink-holes, lapies and terra rossa. Isolated hills and knolls are features present in the area underlain by shale, sandstone, siltstone and plutonic rocks. The cuesta features are present in the area underlain by extensive clastic sediments. Sedimentary sequences dipping northeastwardly mark the western margin of the Khorat plateau.

The drainage pattern in the area can be distinguished into four patterns, namely, braided pattern, dendritic pattern, annular pattern, and centripetal pattern (Figure 4.2). The braided pattern is restricted in the lowlands area of Lopburi, Pa Sak and Chao Phra Ya river systems on the western part of the area. The dendritic pattern, mostly abundant, is scattered in the plateau, mountain range as well as the alluvial plain. The annular pattern is recognised in the area underlain by plutonic rocks in the eastern part of Amphoe Pak Chong. The centripetal pattern is restrictedly present in the northeastern and eastern parts of Changwat Lopburi.

4.2 Stratigraphy and Distribution of Rock Types

The oldest rocks of Changwat Saraburi and neighbouring areas are deposited in Lower Permian and the youngest are in Quaternary. They consist of sedimentary rocks igneous rocks as well as unconsolidated sediments. The sedimentary and igneous rocks are mainly distributed in the highland of the region located in the central, northern and eastern parts of the area whereas the unconsolidated sediments exist in the low lying area of the southern and western parts (Figure 4.3). Since 1951, many workers have conducted various geological studies of the region. As a result, a number of stratigraphic rock sequences have been established and are summarized in Table 4.1. Detailed description of each rock unit is outlined in the following paragraphs.

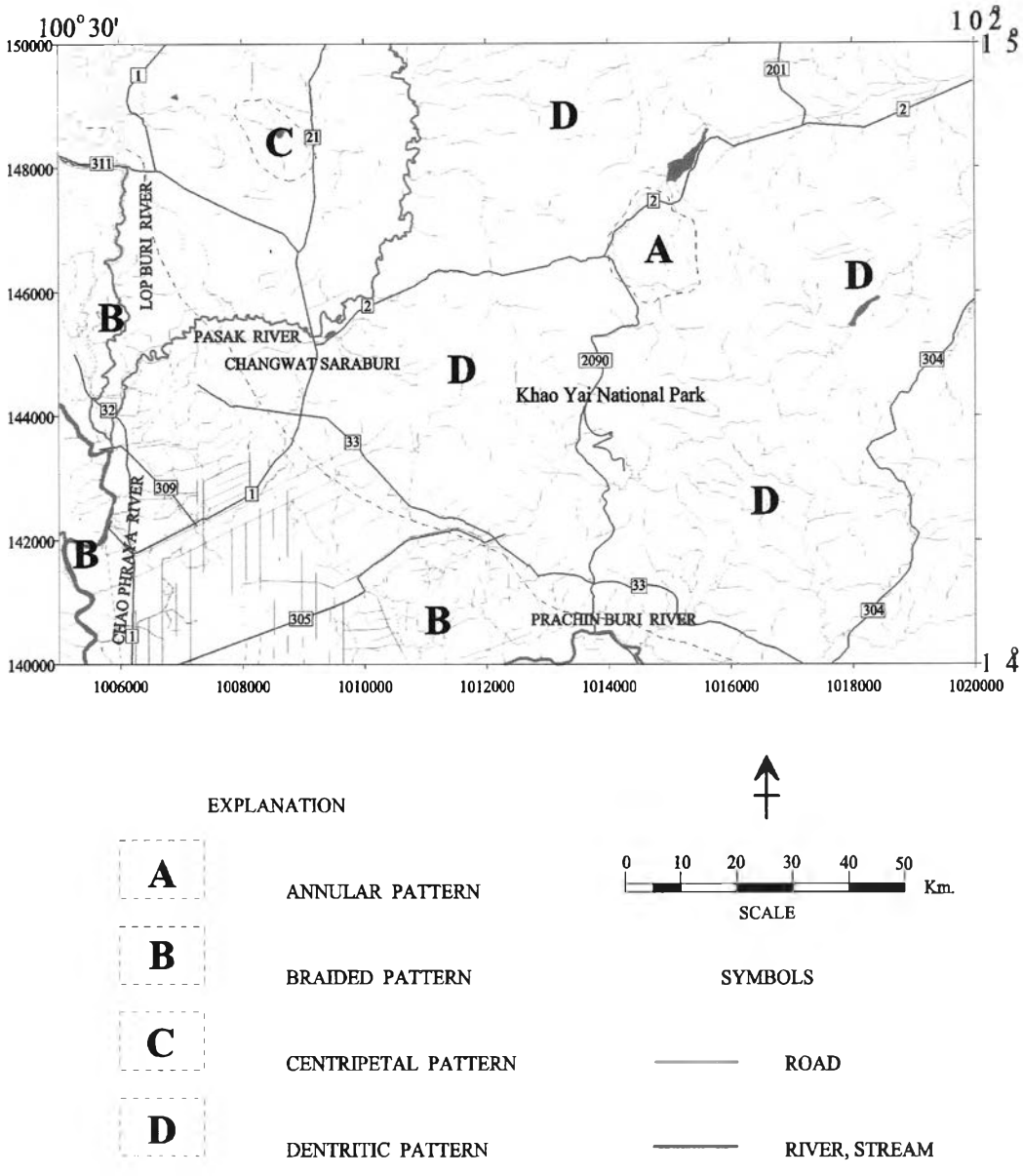

Figure 4.2 The drainage pattern map of Changwat Saraburi and neighbouring area (Modified after Geological Map of Thailand sheet Changwat Phranakhon Si Ayuthaya, ND 47-8, DMR, 1985).

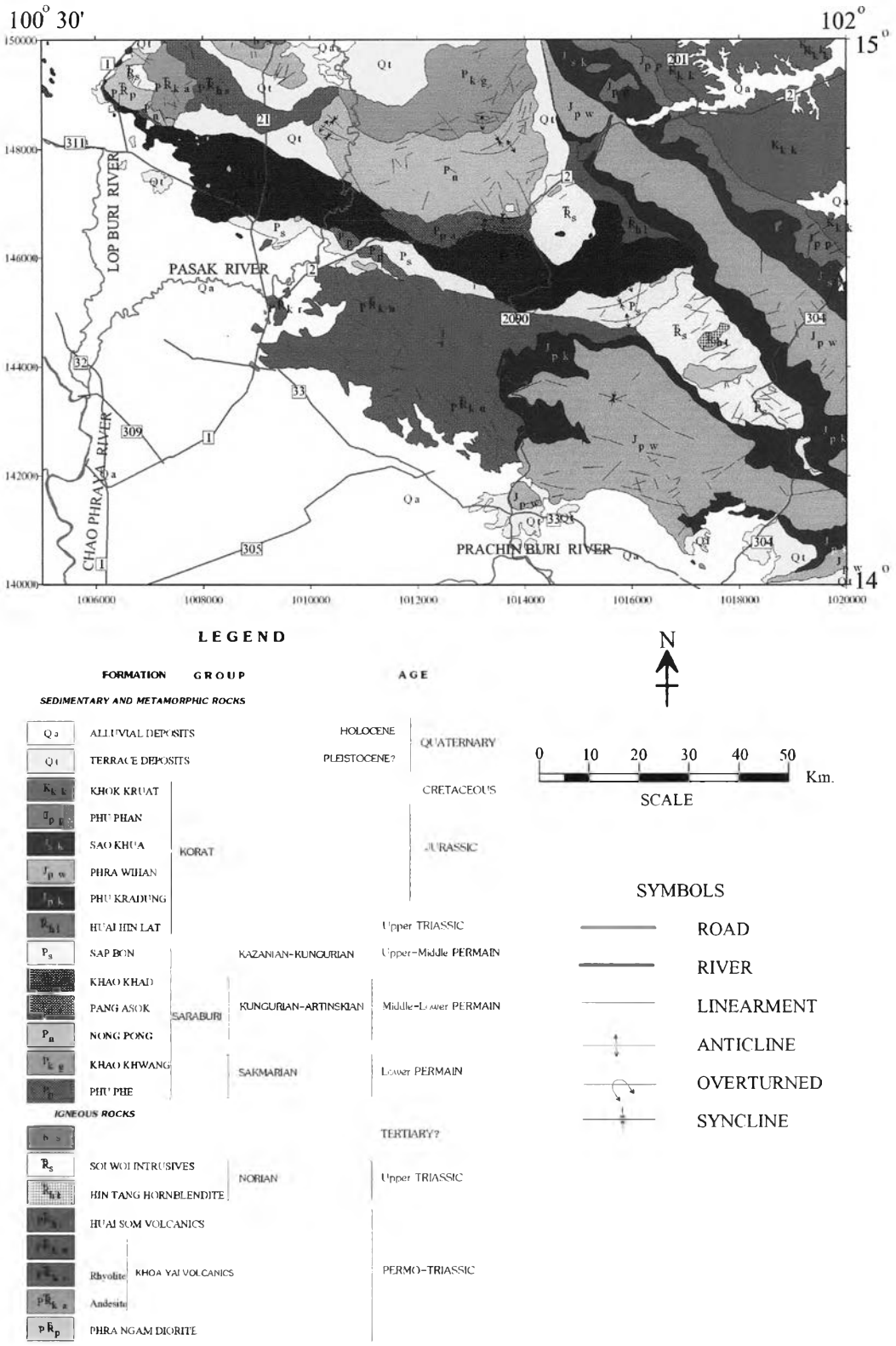

Figure 4.3 Geological map of Changwat Saraburi and neighbouring area (Modified after Geological Map of Thailand sheet Changwat Phranakhon Si Ayuthaya, ND 47-8, DMR, 1985).

Table 4.1 Stratigraphic classification and nomenclature of Changwat Saraburi and neighboring area.

Age	Brown et al. (1951)	Jalichan and Bunnag (1954)		Ward and Bunnag (1964)		Iwai et al. (1966)		Chonglakmani and Sattayarak (1978)	Bunopas (1981)	Hinthong et al. (1985)
Mesozoic	Khorat Series	Khorat Series	Phu Phan member Phra Wihan member Phu Kradung member	Khorat Group	Khok Kruat Formation Phu Phan Formation Sao Khua Formation Phra Wihan Formation Phu Kradung Formation Nam Phong Formation	Khorat Group	Khok Kruat Formation Phu Phan Formation Sao Khua Formation Phra Wihan Formation Phu Kradung Formation Nam Phong Formation Huai Hin Lat Formation	I Mo member Phu Hi member Dat Fa member Sam Khaen member Phu Hai member		
Permian	Ratburi Limestone								Saraburi Group	Sab Bon formation Khao Khad Formation Pang Asok Formation Nong Pong Formation Khao Khwang Formation Phu Phe Formation

4.2.1 Saraburi Group

The lowest lithostratigraphic rock units of Changwat Saraburi and neighbouring area had been studied by many workers (Brown et al., 1951, 1953; Bunopas, 1981; Hinthong et al., 1985). Up to the present, the Saraburi Group of Permian age (Bunopas, 1981) has been generally accepted. The Saraburi Group is further subdivided in to six formations (Hinthong et al., 1985), namely, Phu Phe Formation, Khao Khwang Formation, Nong Pong Formation, Pang Asok Formation, Khao Khad Formation and Sab Bon Formation, respectively in ascending order. The overall thickness of the Saraburi Group is 4,486 meters (Pianchroen, 1992). The detailed descriptions of the Saraburi Group are as follows:

a) Phu Phe Formation

The lithology of this formation is mainly characterized as well-bedded grey to very dark grey limestone. The upper part of the formation is essentially thick to very thick bedded limestone whereas the lower part displays the interbedding of light brown to brownish-grey shales, slaty shales with brownish-grey to dark grey lenticular and nodular cherts. The type section is at Khao Phu Phe, east of Kms 131-132, Friendship Highway with the thickness of 593 meters. The formation is mainly distributed along Phetchabun ranges and in the area northwest of the Khorat plateau. The age of the Phu Phe Formation is Lower Permian (Sakmarian).

b) Khao Khwang Formation

The lithology of this formation is mainly characterized as grey to dark grey, thick-bedded limestones dolomitic limestones and dolomites. Brownish grey chert nodules are scattered in the lower and middle parts and they become more abundant in

upper part of the sequence. Shales, sandstones, tuffaceous sandstones and volcanic rocks are rarely intercalated in some beds. The type section is designated at Khao Khwang, Changwat Saraburi, with the thickness of 490 meters. The rocks of this formation are mainly exposed in the northern part of the area under present assessment, Khao Khwang, Phetchabun ranges and northwest of the Khorat plateau. The age of Khao Khwang formation is Lower Permian (Sakmarian).

c) Nong Pong Formation

The lithology of this formation is characterised by interbedded shales and limestones. Shales are mostly brownish grey, greyish brown to light grey, bluish grey, and occasionally silty, sandy or siliceous. Limestones are medium to dark grey; bedded, banded to well laminated and argillaceous in some beds. Occasionally the limestones become lenses and lenticular beds especially in the upper part. Bedded cherts are generally intercalated in the upper part of the sequence. The type section is located at the east of Khao Khwang with the thickness of 673 meters. The formation is also distributed along the Phetchabun ranges, and the northwest of the Khorat plateau. The age of Nong Pong Formation is Lower Permian (Artinskian-Kungurian).

d) Pang Asok Formation

The lithology of this formation is mainly shales and slaty shales intercalated with sandstones. The lowermost part of this formation is prominently light greenish grey to pale reddish brown sandstones intercalated with shales. Overlying the lowermost unit is pale reddish brown shale interbedded with light greenish grey arkosic sandstone and pale reddish brown shale interbedded with brownish grey limestone. The middle part of the sequence is mostly grey to greyish brown shale. The upper part is brown to dark grey shale, slaty shale intercalated with greenish grey

lenticular arkosic sandstone. The type section is located in the vicinity of the Pang Asok village close to the Pang Asok railway station with the thickness of 366 meters. The formation is distributed along the Phetchabun ranges, and the northwest of the Khorat plateau. The age of this formation is Lower Permian (Artinskian-Kungurian).

e) Khao Khad Formation

The lithology of this formation is dominantly grey to dark grey limestone, argillaceous limestone and dolomites. Nodular and bedded cherts are common intercalated. Shale and sandstone are frequently interbedded with limestone. Locally, marble, calcsilicate hornfels and volcanic rocks are present. The type section is designated at Khao Khad, Amphoe Phra Phuttabat, Changwat Saraburi, with the total thickness of 1,812 meters. The rocks of this formation trending approximately in east-west direction are widely exposed in many areas of Changwat Lopburi and Saraburi, the Phetchabun ranges and northwest of the Khorat plateau. The age of Khao Khad Formation is Lower Permian (Artinskian-Kungurian).

f) Sap Bon Formation

The lithology of this formation is mainly grey to brown tuffaceous sandstone, shale and cherts intercalated with grey limestone. The upper part of this sequence is mainly light grey to dark grey, thin-bedded limestone interbedded with light brown to rusty brown shale and siltstone. The type section is located at Ban Sap Bon teak plantation, Ban Sok Luk and Huai Sap Tai, Amphoe Muak Lek, Changwat Saraburi with the thickness of 1,103 meters. The rocks of this formation are exposed in many areas along Ban Phu Kae, Ban Nong Chan and Ban Sap Bon, northwest of the Khorat plateau. The age of this formation is Middle Permian (Kungurian-Kazanian).

4.2.2 Khorat Group

Overlying the lowest lithostratigraphic units of Changwat Saraburi and neighbouring area is very thick clastic sequence of Mesozoic rocks, namely, the Khorat Group (Ward and Bunnag, 1964). The Khorat Group had been studied by many workers, namely, Lee (1923), Brown (1951), Jalichan and Bunnag (1954), La Moreaux et al. (1959), Ward and Bunnag (1964), Iwai et al. (1966), Gardner et al. (1967), Chonglakmani and Sattayarak (1978, 1984), Maranate (1982), Bunopas et al. (1970), Bunopas (1976, 1981), Hahn (1982) and Sattayarak (1983, 1985). Six out of seven formal formations of the Khorat Group (Pianchroen, 1992) are present in the eastern and northeastern parts of the area consisting of Huai Hin Lat Formation, Phu Kradung Formation, Phra Wihan Formation, Sao Khau Formation, Phu Phan Formation, and Khok Kruat Formation, respectively in ascending order.

Detailed descriptions of the Khorat Group exposed in the area are as follows:

(a) Huai Hin Lat Formation

The Huai Hin Lat Formation was first proposed by Iwai (1966) to represent the basal conglomerate of the Khorat Group lies unconformably on the Permian rocks. The basal conglomerate consists of pebbles of Permian limestone, rhyolite and other rock fragments. The overlying sequence is grey to dark grey sandstone, siltstone, shale, and limestone conglomerate. Later on, Chonglakmani and Sattayarak (1978) further subdivided the Huai Hin Lat Formation into 5 member in ascending as follows:

(i) Phu Hai member consists mainly of volcanic rocks; tuff agglomerate, rhyolite and andesite including some intercalation of sandstone and conglomerate. The thickness is 210 meters at the type location.

(ii) Sam Khaen member consists of basal conglomerate intercalated with red siltstone, shale and locally limestone beds.

(iii) Dat Fa member consists of grey to black, carbon-rich calcareous, well bedded shale with numerous argillaceous limestone layers.

(iv) Phu Hi member consists of grey sandstone, shale and argillaceous limestone with some intercalation of conglomerate beds.

(v) I Mo member consists of diorite and its associated volcanic facies intercalated with the well-bedded grey shale, sandstone and limestone.

The type section of this formation is located at Huai Hin Lat, Km 108 Khon Kaen - Loei Highway with the total thickness of 140 meters. The formation exposes in the vicinity of Ban Sab Phu, Amphoe Pak Chong and in the southern part of Lamtaklong dam/reservoir. The age of this formation is designated at Triassic (Carnian-Norian).

(b) Phu Kradung Formation

The Phu Kradung member was first proposed by Jalichan and Bunnag (1954) without the stratigraphic section. Later on, Ward and Bunnag (1964) conducted a more detailed study and established the Phu Kradung Formation. This formation consists mainly of interbedded pink sandstone, red siltstone and red shale with occasionally thin-bedded fine conglomerate, greenish grey calcareous conglomerate. The type section of this formation is located at the eastern slope of the Phu Kradung mountain, Amphoe Phu Kradung, Changwat Loei, with the total thickness of 1,001 meters. The rocks of this formation are widely exposed along the edge of the Khorat plateau, including part of Khao Yai, encircling of Khao Kampang range, Ban Thung

Pho and the southeastern of the area under the present assessment. The age of this formation is assigned at Lower Jurassic.

(c) Phra Wihan Formation

The Phra Wihan member was first proposed as informal member by Jalichan and Bunnag (1954). Later on the Phra Wihan Formation was established (Ward and Bunnag, 1964). This formation consists predominantly of white to pink thick bedded, well sorted, medium-grained quartz sandstone with some thin lamination of red siltstone. The type locality of the formation is located at the southern slope of Khao Phra Wihan with the thicknesses of five measured sections varies from 56 to 136 meters. The rocks of this formation are extensively exposed along the edge of the Khorat plateau, represented by the ridges and escarpments above the top of the Phu Kradung Formation, including some areas of Changwat Nakhon Nayok and Changwat Prachin Buri, Khao Kampang range, Khao Rom, Khao Lam and some parts of Khao Yai. The age of this formation is given at Middle Jurassic.

(d) Sao Khua Formation

The Sao Khua Formation (Ward and Bunnag, 1964) consists of a thick sequence of non-resistant (poorly cemented) conglomeratic sandstone with interbedded red to pink quartz sandstone and red to purplish shales. The type section of this formation is located at Huai Sao Khua, Kms 35.2 to 41.5, Udon Thani-Nong Bua Lamphu road with the thickness varies from 404 to 702 meters. The formation covers the inner rim of the Khorat plateau. The age of this formation is designated at Upper Jurassic.

(e) Phu Phan Formation

The Phu Phan Formation was formerly proposed by Jalichan and Bunnag (1954) as a formal member. Later on, Ward and Bunnag (1964) proposed the Phu Phan Formation. This formation is represented by thick-bedded and cross-bedded conglomeratic sandstone, yellowish grey to pinkish grey sandstone interbedded with siltstone and shale. The type section of this formation is located at Phu Pha Phung of the Phu Phan range with the thickness of 183 meters. The rocks of this formation are widely exposed along the northeastern part of the area under the present assessment, around the Khorat Plateau and along the Phu Phan range. The age of this formation is put at lower Cretaceous.

(f) Khok Kruat Formation

The Khok Kruat Formation was first proposed by Ward and Bunnag (1964) to represent the sequence of interbedded, moderately consolidated, red siltstone, and red to white quartz sandstone, fine conglomerate and caliche conglomerate. The type location is between Km 207 and Km 209, Friendship Highway, with the thickness of 709 meters. The outcrops of this formation are rather poorly exposed in the Khorat plateau, the northeastern part of the area under the present assessment. The age of this formation is assigned at Upper Cretaceous.

4.2.3 Cenozoic Deposits

The upper most lithostratigraphic units of Changwat Saraburi and neighbouring area are clastic sequences of Cenozoic deposits consisting of terrace deposits and alluvial deposits. The Cenozoic deposits in the area had been studied by Hinthong et al. (1985).

(a) Terrace Deposits

The terrace deposits are mainly associations of unconsolidated gravel, sand and silt. However, in some areas the Cenozoic sediments are consolidated by calcareous or ferrugeneous cementation, laterites, calcrete or caliche, calcareous tufa or travertine. The terrace deposits cover some areas in the northern and locally the southern parts along the foothills above the alluvial plains. In the northern part, they cover some eastern areas of Amphoe Pak Chong and Ban Lam Phraya Klang. In the southern part, they cover some areas of Ban Dong Lakorn of Changwat Nakhon Nayok, Amphoe Nadee and the northern part of Changwat Prachin Buri. In addition, the terrace deposits also cover some areas of Ban Kok Krateum of Changwat Lopburi and Amphoe Phra Phuttabat of Changwat Saraburi. The thickness of the terrace deposits is unknown and the age is assigned at Pleistocene.

(b) Alluvial Deposits

The alluvial deposits are mainly unconsolidated gravel, sand, silt, and clay underlying the recent flood plains. The alluvial deposits cover nearly half of the studied area on western, southwestern and southern parts. They are the flood plain deposits of Lopburi river, Pasak river, Chao Phraya river, Nakhon Nayok river and Prachin Buri river. The age of these deposits is assumed as Holocene.

4.2.4 Igneous Rocks

The igneous rocks exposed in Changwat Saraburi and neighbouring area are both intrusive and extrusive in origin. The igneous rocks in the area were studied by Hinthong et al. (1985) and Charusiri et al. (1991). Hinthong et al. (1985) divided

intrusive igneous rocks in the area into three groups consisting of Phra Ngam diorite, Soi Woi intrusives and Hin Tang hornblendite. For the extrusive igneous rocks, he also divided into three groups consisting of Khao Yai volcanics, Huai Som volcanics and basalt.

a) Phra Ngam Diorite

The Phra Ngam diorite is characterised as a greenish-grey, green-to-black, granular, medium-to–fine-grained intrusive rock consisting of plagioclase, hornblende, diopsite and augite. The composition of plagioclase varies from andesine to labradorite, mostly alterated to sericite. Quartz is frequently present as inclusions in hornblende. The accessory minerals are sphene, apatite, epidote, biotite, muscovite, calcite and magnetite. The Phra Ngam diorite occurs as stocks and dikes in the areas on the eastern part of the Khok Kateum railway station, and at Khao Pu Ka and Khao Phra Bat Noi in Changwat Lopburi, Khao Than Tongdang in Amphoe Phra Phuttabat, Khao Man in Amphoe Kaeng Khoi of Changwat Saraburi, and in the vicinity of Khao Hin Tang in Amphoe Pak Thongchai of Changwat Nakorn Rachasima. The relative age of the Phra Ngam diorite is assigned at Late Permian to Early Triassic.

b) Soi Woi Intrusives

The Soi Woi intrusives are diverse associations of granodiorite, granite, quartz monzonite, quartz diorite and syenodiorite. These intrusives are exposed in two major areas, notably as a nearly circular area of 12 - 18 kms in diameter on the south-eastern part close to Amphoe Pak Chong, and as a belt of approximately 15x45 kms further south-eastern part of Amphoe Pak Chong along the northeastern margin of Khao Kampang range. In addition, the Soi Woi intrusives are also exposed as numerous small stocks on the north-western part of the study area, at Amphoe Khok Samlong,

and at Amphoe Muang of Changwat Lopburi, on the western part of Amphoe Pak Chong, and on the eastern part of the road from Kabinburi to Nakornrachasima between Km 31 to Km 40. The relative age of the Soi Woi intrusives is designated at Late Triassic, Norian. The Soi Woi intrusives exhibit the thermal metamorphic phenomena with the carbonate-clastic sequences of the Saraburi Group in almost all areas where the intrusives are present, whereas the extrusives apparently overlying the Saraburi Group in many areas.

Detailed lithological characteristics of these intrusives are as follows:

i) Granodiorite

The granodiorite is characterised as a grey, greenish grey, dark green, medium- to coarse-grained rock showing granular hypidiomorphic and allotriomorphic texture. The essential minerals are quartz, orthoclase, microcline, microperthite, plagioclase, hornblende and biotite. The composition of plagioclase varies from oligoclase to andesine. The accessory minerals are apatite, calcite, chlorite, sericite, epidote, sphene, magnetite, hematite and muscovite. Quartz and plagioclase sometimes show the myrmekitic texture.

ii) Granites

Two types of granites are recognized based on their characteristic mafic minerals, namely, hornblende-granite and biotite-granite. They are whitish to pinkish grey, fine-to-medium–grained rocks showing mainly granular and occasionally porphyritic texture. The essential minerals are quartz, hornblende, biotite, orthoclase, microcline and muscovite. The accessory minerals are apatite, zircon, rutile and magnetite.

iii) Quartz Monzonite

The quartz monzonite is characterised as a grey-to-greenish-grey, medium-grained rock with hypidiomorphic granular texture. The essential minerals are quartz, orthoclase, microcline, perthite, microperthite, oligoclase, pyroxene and biotite. The accessory minerals include epidote, chlorite, sericite, calcite, clay-minerals, magnetite and zircon.

iv) Quartz Diorite

The Quartz diorite is a grey-to-dark-green, medium-grained rock exhibiting allotriomorphic granular texture. The essential minerals are quartz, orthoclase, microcline, and calcic oligoclase to medium andesine. The accessory minerals are apatite, chlorite, epidote, sericite and sphene.

v) Syenodiorite

The syenodiorite is a greenish-grey-to-grey, fine-to-coarse-grained rock displaying hypidiomorphic granular texture to porphyritic texture. The essential minerals are quartz, orthoclase, microcline, calcic-sodic andesine, biotite, hornblende and pyroxene. The accessory minerals are apatite, calcite, sericite, epidote, sphene and magnetite.

c) Hin Tang Hornblendite

The Hin Tang hornblendite is a black, coarse-grained rock showing hypidiomorphic granular texture. The essential minerals are mostly hornblende with minor quartz, orthoclase and sodic plagioclase. The Hin Tang hornblendite occurs as

stocks in the vicinity of Khao Hin Tang, the border of Amphoe Pak Chong and Amphoe Pak Thongchai. The relative age of the Hin Tang hornblendite is approximately Triassic.

d) Khao Yai Volcanics

The Khao Yai volcanics are associations of rhyolite, andesite, rhyolite and andesite porphyries, volcanic breccia, agglomerate and tuff. They occur mainly as flows (minor as dikes and sills) covering a large area of the central part of the study area, especially, the Khao Yai national park and some parts of Changwat Saraburi as well as Changwat Nakorn Rachasima. The relative age of the Khao Yai volcanics is Permo-Triassic.

The rhyolite is characterised as a yellowish-brown-to-light-brown, reddish-brown, fine-grained rock locally with porphyritic texture. Flow structures can be recognised in some areas. The rhyolite covers the area of the Khao Pongraeng, Khao Nom Nang, Khao Phra Buddha Chay, Khao Sung, Khao Salika, eastern part of Amphoe Kaeng Khoi and the Khao Yai national park.

The andesite is a greenish-violet, violetish-brown, fine-grained rock locally with porphyritic texture. The andesite, which commonly associates with rhyolite, covers scattered area of Khao Wong and Khao Wong Phrachan in Changwat Lopburi, eastern part of Khao Phu Ka and Khao Phu Lon in Changwat Saraburi, along the Pasak River in Amphoe Kaeng Khoi, Huai Wang Takai in Changwat Nakorn Kayok, and is commonly present as dike in carbonate rocks.

The volcanic breccia is a brown rock consisting of various types of angular volcanic fragments cemented mainly by rhyolite. In some areas the volcanic breccias

form as thick layers, the orientation of fragments may be recognised as layering. The volcanic breccias cover scattered area of Khao Phra Buddha Chaay, Khao Yai, Nang Rong water-falls and Wang Muang water-falls.

The agglomerate is characterised as a white-to-light-brown rock consisting of rounded pebbles of igneous rock fragments as well as volcanic bombs cemented by volcanic materials. The agglomerate covers some areas of Changwat Nakorn Nayok, Salika water-falls.

e) Huai Som Volcanics

The Huai Som volcanics are volcanic complex similar to the Khao Yai volcanics. The Huai Som volcanic complex consists mostly of undifferentiated rhyolite and andesite porphyries, rhyolitic and andesitic vitric tuffs, and lesser amount of andesitic basalt. They are pinkish brown, green to dark green, fine-grained, often porphyritic with phenocrysts of white and pinkish feldspar. The Huai Som volcanics cover area in the vicinity of Amphoe Phattana NiKhom, Ban Di Lang, Ban Nong Bua and Ban Khok Salung, of Changwat Lopburi. The relative age of Huai Som volcanics is Permo-Triassic.

f) Basalts

The basaltic rocks are mostly black-to-dark-green, fine-grained, olivine basalts. They are restricted to the northeastern part of study area along Khao Phra Yajon, Khao Salad Di and Khao Phraya Dernthong. They overly shale, schist and fine-grained sandstone. The relative age of these basalts is approximately Tertiary.

4.3 Geological Structures

The regional strike of the Saraburi Group is oriented approximately in the east-west direction with the variation ± 25 degrees and the sequences dip approximately 30 to 54 degrees northwardly and southwardly. Various types of minor fold both anticline and syncline, namely, isoclinal overfold, zig-zag fold or chevron fold are commonly present in the clastic sequences with the fold axes parallel to the regional strike (Figure 4.3). The symmetrical curvilinear fold is commonly present in the limestone sequences. The sedimentary sequences of the Khorat Group exhibit the northwest-southeast regional strike direction and dip approximately 5 to 25 degrees eastwardly with relatively gentle folding in some parts. The board major anticlinal structure is present in the eastern part of the area in the vicinity of Khao Kampang range.

Faulting is common in the Permian rocks (Figure 4.3). There are two major fault zones being recognized in the area. They are oriented roughly in the northwest-southeast and southwest - northeast directions. Various types of faulting are found, namely, normal fault, thrust fault, strike-slip fault and strike fault. The normal faults are mostly found in the carbonate rocks. There are three zones of left-lateral strike-slip fault oriented in northwest-southeast direction, namely, Pa Sak fault, Pang Asok fault, and Pak Chong fault. The thrust faults are recognised at the Khao Nam Tok and Khao Phu Phe.

It is noted that there is an angular unconformity between the carbonate-clastic sequences of the Saraburi Group (striking in the east-west direction) and the clastic sequences of the Khorat Group (striking in the northwest-southeast direction).

4.4 Geological Evolution

The continental terrains forming a portion of Thailand has been mentioned for a long time that they were consisting of two old allochthonous continental terrains, namely, Shan-Thai and Indochina (Bunopas, 1981). Recently, however, a somewhat newer and slightly modified model is being proposed by Metcalfe (2002) and Wakita and Metcalfe (2005), that there are three continental terraines, namely, Shan-Thai, Indochina and Simao. The Shan-Thai or Sibumasu terrain is located western part on the country including Sukhothai fold belt, eastern Myanmar and northwestern Malaysia peninsular. The Indochina or Annamia terrain is located eastern part of the country including Loei fold belt, Laos, Cambodia, Southern Vietnam and eastern Malaysia peninsular. The Simao terrain is located between Shan-Thai and Indochina terrains in the vicinity of Chiang Mai and Chiang Rai which bounded by Chiang Mai suture to the west and Nan Uttaradit suture to the east. All three terrains were drifted northward from the Gondwanaland in the southern hemisphere (Bunopas, 1981; Burrett and Strait, 1985; Metcalfe, 1990; Mouret, 1994; Metcalfe, 1996). The timing of rifting of these plates has been debated by many authors, e.g. Bunopas (1981), Burret and Stait (1985), Metcalfe (1990), Hada et al. (1994), Mouret (1994), Metcalfe (1996), Metcalfe (2002) and Wakita and Metcalfe (2005). Recently, Metcalfe (2002) proposed that the Indochina terrain rifted from the Gondwana land since Middle Devonian Period whereas the Shan-Thai terrain was a part of northwest of Gondwana land until the Late Sakmarian. The Simao terrain was spitted from the Indochina terrain by back-arc spreading in the Lower Carboniferous (Wakita and Metcalfe, 2005). During the Permian, the Indochina Plate was located at nearly 10° south of the palaeoequator, suggesting a tropical climate (Scotese and Langford, 1995). The Shan-Thai terrain was collided with Indochina terrain and Simao terrain during Early Triassic Period (Wakita and Metcalfe, 2005; Figure 4.4).

During the Permian period, an extensive carbonate platform developed on the margin of the Indochina Plate and near to a coeval and deeper siliciclastic-dominated marine basin. The facies groups of the platform environments include restricted platform, platform interior, and outer platform. The facies groups of the basin environments include basin margin and basin plain. Minor layers of volcaniclastics and green color tuffites are interbedded with both the platform carbonate layers and basin pelagic layer, suggesting active volcanism during sedimentation (Tabakh and Utha-Aroon, 1998).

A Thick sequence of mixed clastic-carbonate sediments of the Saraburi Group were deposited under the marine shelf environment. During Late Permian, a spreading ridge development in the ocean floor between Shan-Thai and Indochaina and a pair of subduction zones was formed, one dipping relatively westward beneath the Shan-Thai, whereas the other dipping relatively eastward beneath Indochaina (Bunopas, 1981). The passive continental margin with an extensive carbonate platform (the Pha Nok Khao Platform) was developed along the western-rifted margin of the Indochina plate during early and middle Permian (Tabakh and Utha-Aroon, 1998). The age of different lithology of the Pha Nok Khao Platform is based on fusulinid biostratigraphy as early Asselian (286Ma) to late Guadalupian (250Ma) (Kozar et al., 1992; Weilchowsky and Young, 1985). A siliciclastic-dominated basin (the Nam Duk Basin) was formed over the western, outer part of the Indochina Plate and separated the eastern Indochina Plate from the Khao Khwang Platform on the western Shan Thai Plate (Tabakh and Utha-Aroon, 1998).

Indosinian orogeny probably started since Late Permian where the convergence of the Shan-Thai and Indochaina were eventually collided in Early Triassic (Bunopas, 1981; Cooper et al., 1989; Mitchell, 1989; Matcalfe, 1990; Figure 4.5). This caused the emergence of the former shelf sea followed by strong foldings

in such area, the Loei and Phetchabun fold and thrust belts which align in north south trending (Tabakh and Utha-Aroon, 1998). The post-collision igneous activities were mostly taken place during Late Triassic to Early Jurassic. Permo-Triassic volcanicity resulted from subduction tectonics of the two plates (Panjasawatwong, 1991) resulted in input of volcanic material into the basin (Tabakh and Utha-Aroon, 1998). Layers of volcaniclastics and green coloured tuffites are found interbedded with both the platform carbonate layers and basinal hemipelagic layers. These volcaniclastics suggest that active volcanism occurred during sedimentation (Tabakh and Utha-Aroon, 1998).

Consequently, the region became once a part of an enlarged stable Indochaina land-mass. This large areas was deposited by continental sediments of fluvio-lacustrine and aeolian origins occasionally covered by inland sea during Late Triassic to Late Cretaceous of the Khorat Group (Hinthong, 1985).

The final shaping of the present-day land form has been mainly achieved by the Himalayan orogenic movements in Late Cretaceous to Early Tertiary. The effects of this orogeny on this area were in the form of board regional foldings and block-faultings or epeirogeny. Such an epeirogenic movement might cause eruptions of the Cenozoic basalts probably through the newly-created faults and the ones development along the pre-existing faults in Tertiary (Hinthong, 1985).

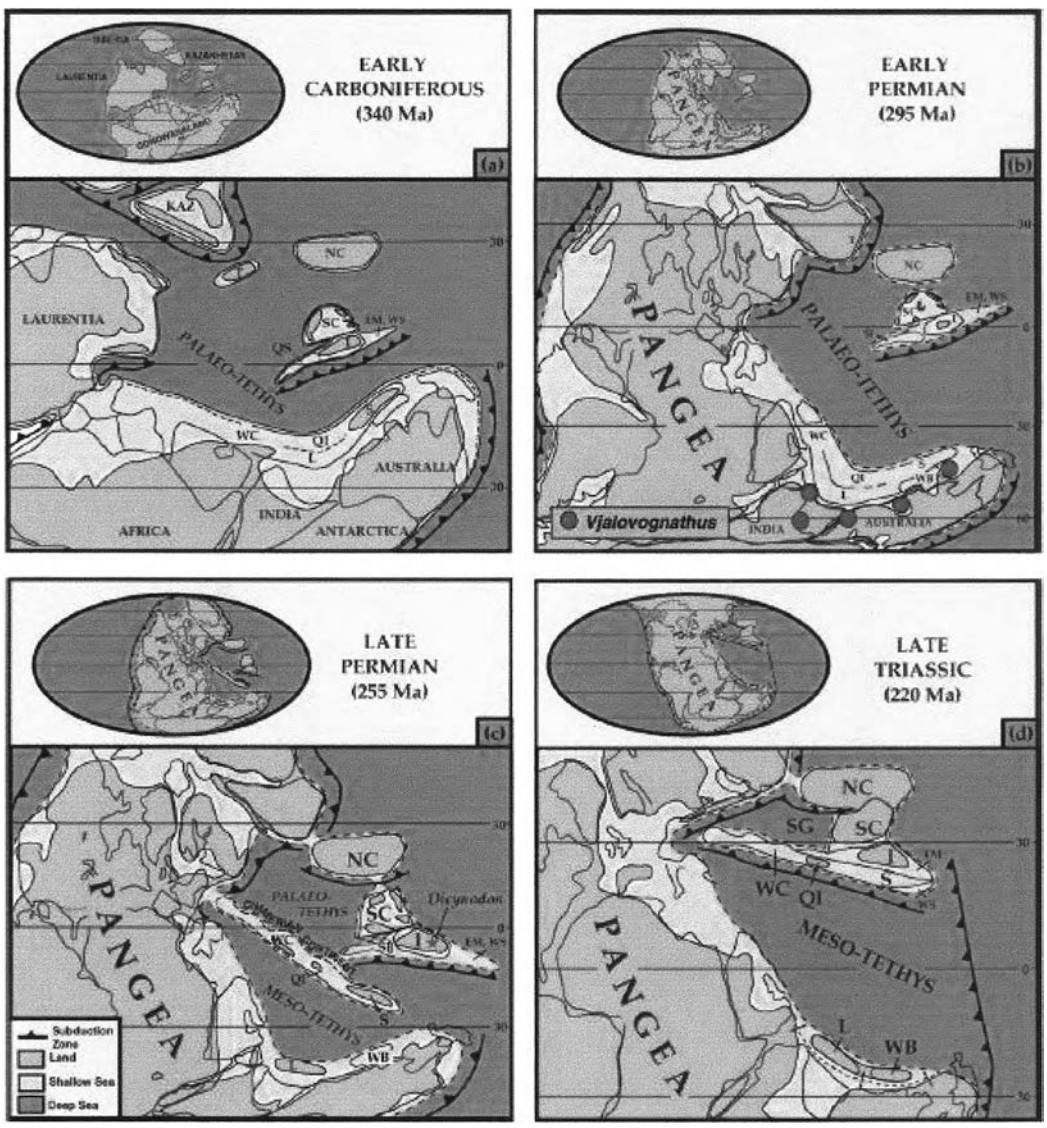

Figure 4.4 Schematic diagram of plate tectonic model of Tethyan region during Early Carboniferous to Late Triassic (Wakita and Metcalfe, 2005).

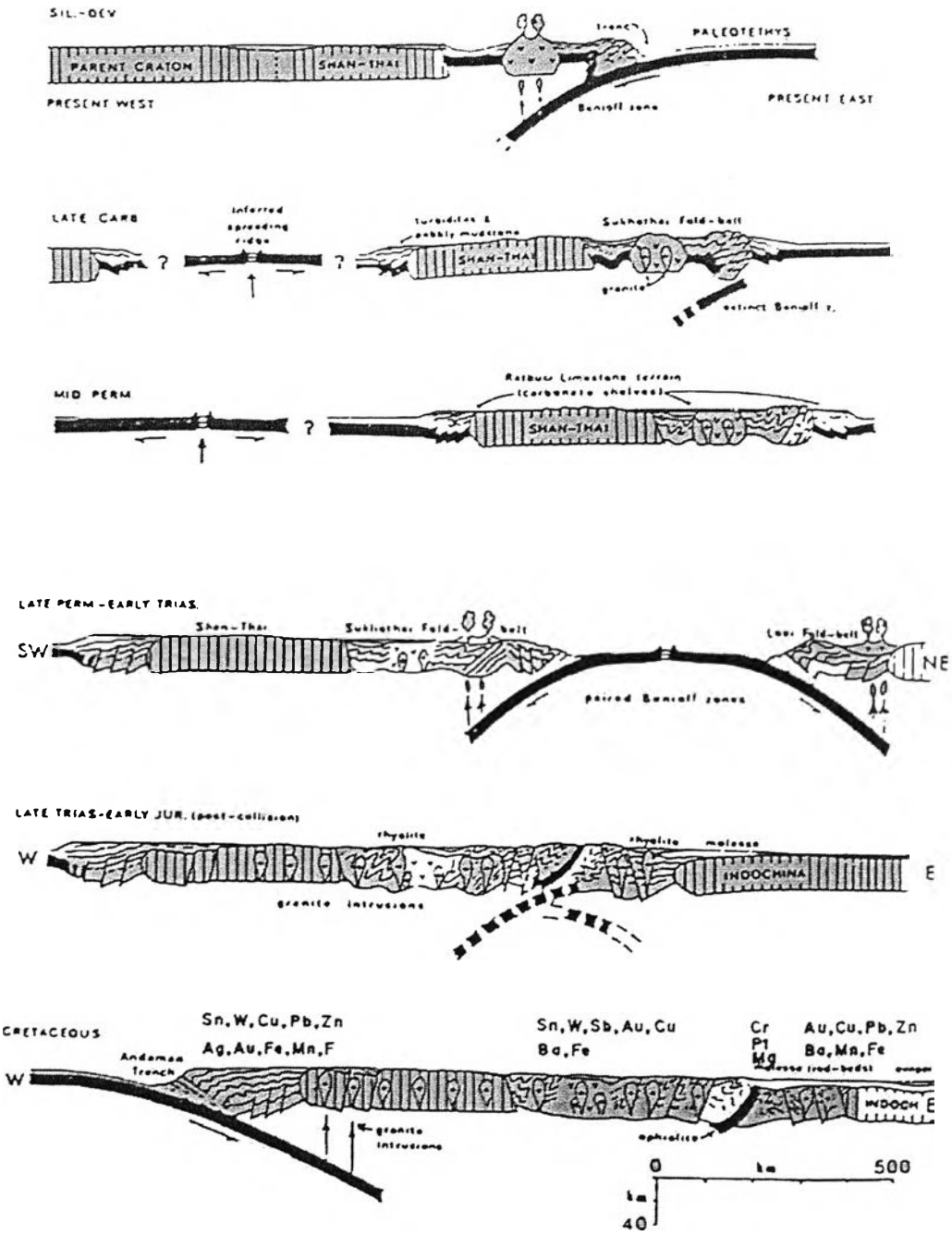

Figure 4.5 Schematic diagram of plate tectonic model of Thailand during Middle Carboniferous to Cretaceous (Bunopas, 1981).