Chapter 2
Geology of the study area

The geological structure of Thailand is largely related to the Triassic collision between the Sibumasu and Idochina Terranes and subsequent rifting in the Tertiary. The study area includes the eastern part of lower central Thailand and the western part of Eastern Thailand. The lower central Thailand comprises Quaternary unconsolidated marine to deltaic sediment, whereas igneous and metamorphic rocks crop out in the Eastern Thailand portion of the study area.

2.1 Regional geology of Thailand

Precambrian rocks in Thailand are mostly medium- to high-grade metamorphic rocks. They are composed of gneiss and schist with relict sedimentary structures (กรมทรัพยากรธรณี, 2544). Gneiss exposed in the Northwestern and Eastern Thailand has metamorphic segregation banding. Layers of schist, calc-silicate, and marble have been found. Due to multiple episodes of tectonic deformation, the high grade metamorphic rocks in the northwest are more complicated than those in other parts of the country. In Eastern Thailand, they crop out in Chachoengsao, Chonburi, and Rayong with a northwest-southeast regional trend. These important rock-forming minerals include biotite, feldspar and quartz.

Lower Paleozoic rocks consist of Cambrian, Ordovician, Silurian and Devonian rocks. They occur along the western ranges of Thailand and consist of low-grade regional metamorphic rocks and contact metamorphic rocks associated with (กรมทรัพยากรธรณี, 2544). The Cambrian-Ordovician rocks overlie the Precambrian rocks in the western ranges of the Shan-Thai terrane. There are two rock groups formed in the Early Paleozoic Era (Wongwanich et al., 2002). The first has the type section on the Tarutao Island, after which it is named. The Tarutao Group is a thick sequence of red sandstone, siltstone, shale, and conglomerate with Late Cambrian trilobites in the upper part. The second is the Ordovician Thung Song Group comprising a sequence of tropical limestone, dolomite and calcareous shale exposed at type sections in Nakhon Sri Thammarat and (Bunopas, 1992).

The Silurian-Devonian rocks overlie the Thung Song Group and can be differentiated into three north-south trending stratigraphic belts: the western, central and eastern belts (Figure 2.1) (กรมทรัพยากรธรณี, 2544, Bunopas, 1994). The Thong Pha Phum Group in the western belt is composed of black graptolitic and tentaculitic shale, chert, sandstone, siltstone, and variegated nodular limestone deposited on continental shelf and in a back-arc basin (Wongwanich et al., 2002). The Sukhothai Group in the Sukhothai fold belt of Shan Thai Terrane is within the Central belt. It is composed of black shale, chert, agglomerate, fine-grained tuff, and marble. The sedimentary rocks in the Loei fold belt of the Indochina Terrane are assigned to the Eastern Belt (Figure 2.1). These rocks include shale, limestone, chert, tuff, quartzite, phyllite and schist.

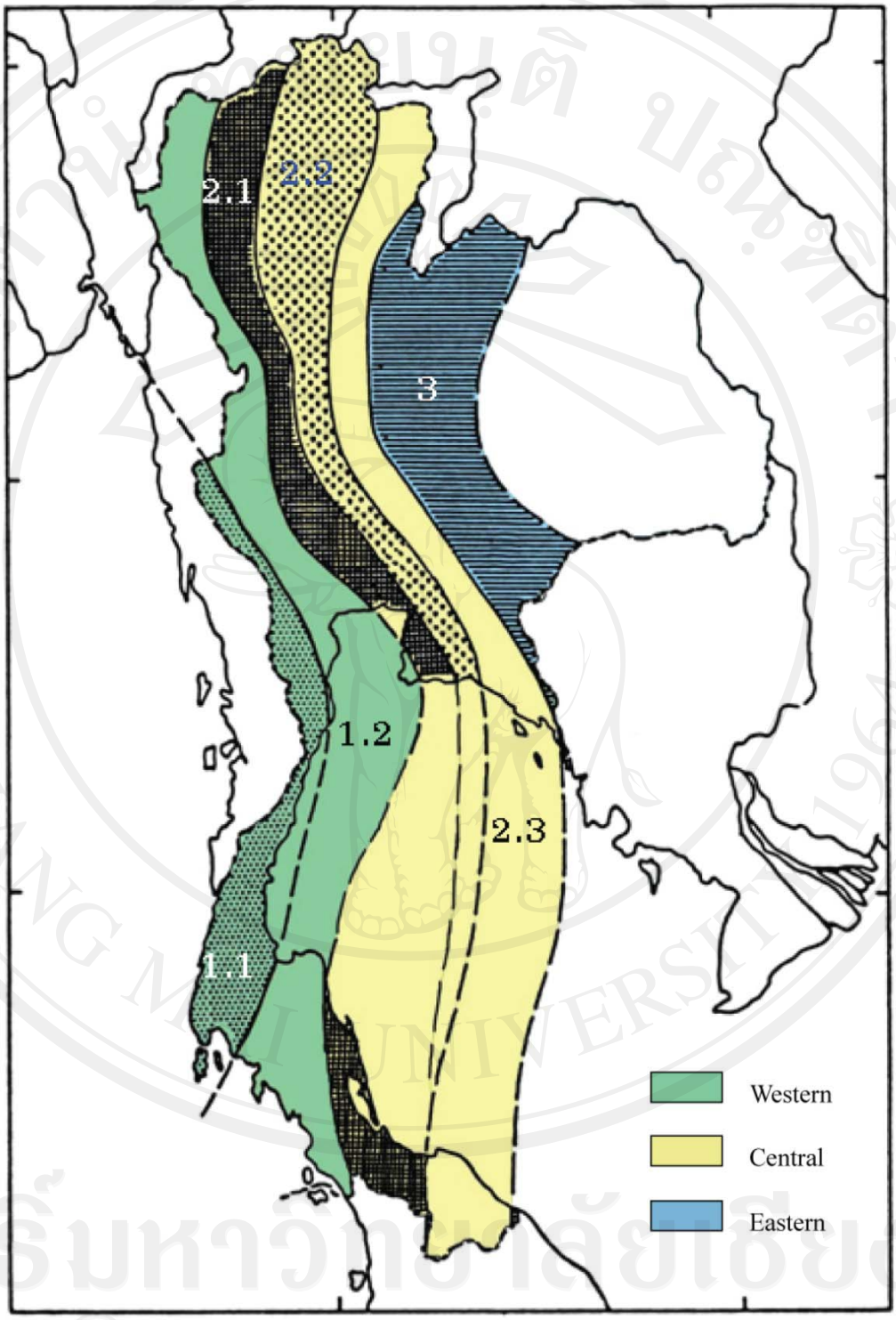

Figure 2.1 Map of the distribution of the Lower Paleozoic rocks of Thailand: (1) Western Belt, (2) Central Belt and (3) Eastern Belt (modified after Bunopas, 1992). Belts 1.1-1.2 are on the Shan-Thai Terrane, and belt 3 is on the Indochina Terrane.

The Upper Paleozoic rocks (Carboniferous-Permian rocks) mostly conformably overlie the lower Paleozoic rocks (Mantajit, 1997). The Kaeng Krachan Group in western and peninsula Thailand is a clastic succession deposited during the Ordovician to Carboniferous without any break. It comprises pebbly sandstone, mudstone and shale (Bunopas, 1992). The late Caboniferous to Lower Permian, Mae Hong Son Group in the north consists mainly of chert, sandstone and shale. Dan Lan Hoi (Mae Tha) Group in the middle part of the Sukhothai fold belt is composed of shallow-marine sandstone, shale, greywacke, chert and agglomerate (Bunopas, 1992, Mantajit, 1997). Wang Saphung Formation in the Loei fold belt comprises sandstone, shale, limestone lenses, and conglomerate (Mantajit, 1997).

Permian rocks are dominantly limestone of variable ages exposed in the Western Mountains, the Sukhothai Fold Belt and the Loei Fold Belt (Bunopas, 1992). The Ratburi Limestone (Brown et al., 1951) or the Ratburi Group in western and Peninsula Thailand comprises karstic limestone. The Saraburi Group in the western and southern edges of the Khorat Plateau consists of limestone interbedded with siliciclatic strata and chert (Mantajit, 1997).

The Mesozoic sequences in Thailand can be lithologically divided into marine facies and younger continental facies (Mantajit, 1997). The marine Triassic rocks largely crop out in the north (Lampang – Phrae – Nan), the south (Phangnga – Songkhla), and the west (Kanchanaburi – Mae Sariang) (กรมทรัพยากรธรณี, 2544). They range in age from Early Triassic to early Middle Jurassic and consist mainly of limestone, mudstone, sandstones, dolomite, and conglomerate. The Jurassic-Cretaceous Khorat Group occurs extensively in northeastern Thailand. It consists

predominantly of continental red beds: sandstone, siltstone, and mudstone (Mantajit, 1997).

Cenozoic rocks are mainly fresh-water shale and sandstone in fault bounded intermontane basins in western, central and northern Thailand (Bunopas, 1992). Tertiary basins are mostly N-S trending half grabens and grabens. These basins were initiated in the Late Oligocene (Mantajit, 1997); the Tertiary basins in the south were initiated in the Eocene (กรมทรัพยากรธรณี, 2544). The basin fills consist mainly of conglomerate, sandstone, shale, carbonaceous shale, lignitic layers, coal beds, oilshale, claystone and freshwater limestone. The Quaternary succession of Thailand comprises fluviatile, coastal, eolian, lateritic, volcanic and lacustrine unconsolidated sediment (Dheeradilok, 1987). They were deposited in the central plain and in the intermontane basins of the northern region.

2.2 Igneous rocks

Igneous rocks are widely distributed in Thailand. Granite is the most common intrusive rocks, and intermediate, mafic and ultramafic rocks are subordinate groups (Putthapiban, 2002). The granite can be divided into three belts based on their field occurrence, petrography and chemical characteristics: Eastern Belt, Central Belt, and Western Belt (Figure 2.2). These granite belts are N-S trending and extend northward to Myanmar and China and southward to Malaysia, Singapore and Indonesia.

The Eastern Belt granite ranges in age from Lower to Upper Triassic and crop out west of the Khorat Plateau including parts of Loei, Phrae, Tak, Krabin Buri, Sra

Kaeo and Chantaburi (Putthapiban, 2002). It occurs as small plutons to large batholiths of zoned and unzoned plutons. The rocks are mostly equigranular hornblende-biotite granite associated with diorite, andesite and basaltic dikes (Dheeradilok et al., 1992). The Cu-Fe-Au mineralizations related to I-type granite are locally found in this belt (Charusiri et al., 1993).

The Central Belt granite mainly occurs as coarse-grained porphyritic batholiths with large K-feldspar phenocrysts (กรมทรัพยากรธรณี, 2544, Putthapiban, 2002). Because the granite intruded into the Lower Paleozoic sedimentary sequences, in most cases, it shows close association with migmatite and high grade metamorphic rocks. This granite belt includes the area of Chanthaburi and Rayong in the study area. Chappel and White (1974) classified the granite in this belt as a group of S-type affinity.

The Western Belt granite crops out along the Thai-Myanmar border and the western part of Peninsula Thailand, including the Phuket Island. They occur in small batholiths and plutons mostly intruded into the Permo-Carboniferous pebbly mudstone and sandstone (กรมทรัพยากรธรณี, 2544, Putthapiban, 2002). Some Western Belt granite intruded into the older Central Belt granite. The intrusions of the Western Belt are coarse-grained porphyritic granite containing large K-felspars phenocrysts. Both I-type and S-type granites are present in this belt (Charusiri et al., 1993, Dheeradilok et al., 1992).

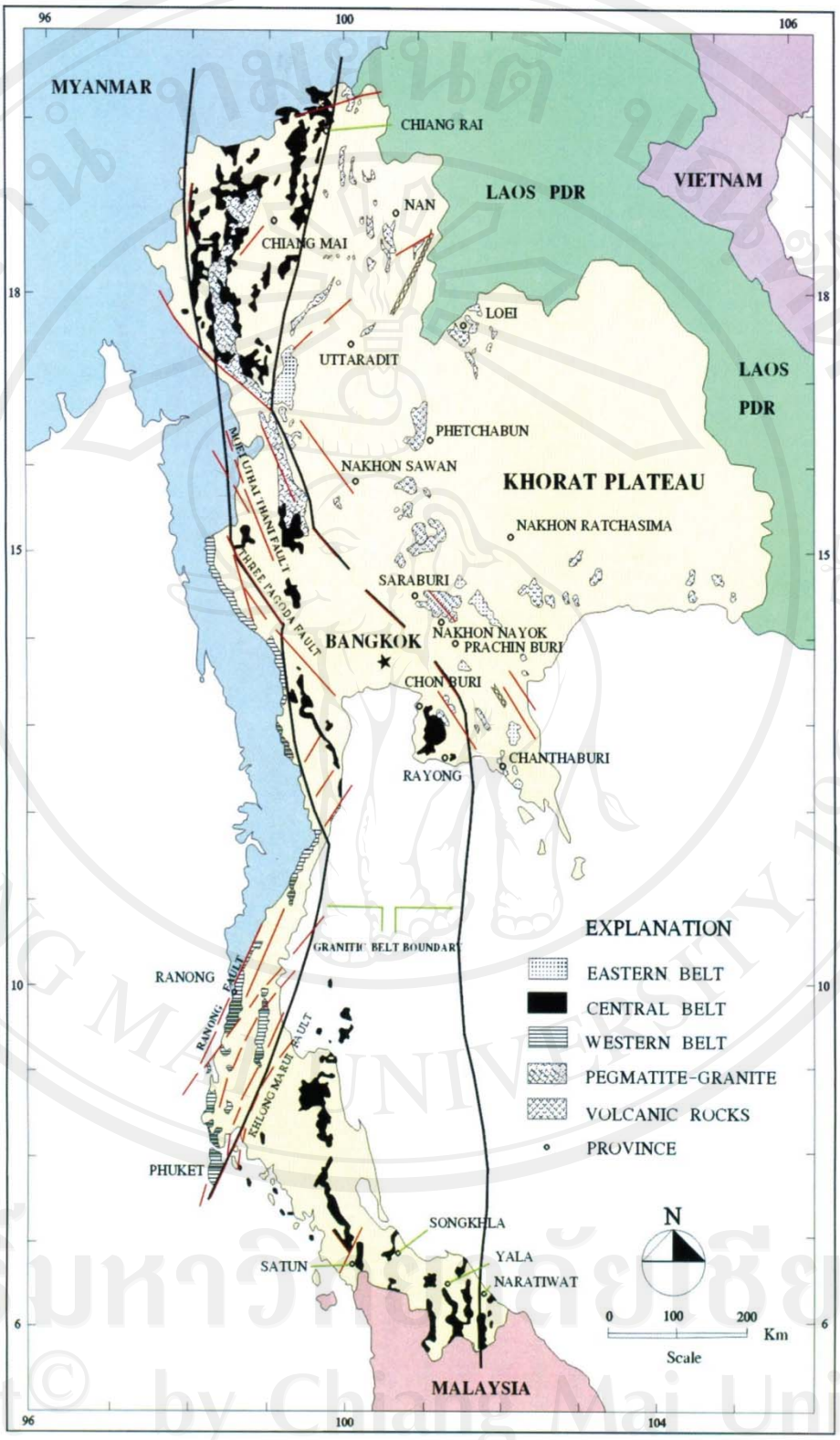

Figure 2.2 Map of three igneous belts of Thailand (Putthapiban, 2002).

Volcanic rocks are widely distributed in Thailand. Andesite, rhyolite, agglomerate and tuff in northern Thailand are the oldest volcanic rocks in the country. These volcanic rocks result from volcanic activities during the Silurian to Devonian (กรมทรัพยากรธรณี, 2544, Dheeradilok et al., 1992). Carboniferous andesite, rhyolite, agglomerate and tuff crop out in Lampang and Phrae. Rhyolite, agglomerate and tuff of the Late Permian – Early Triassic ages occur in Tak, Chiang Mai and Chiang Rai. Predominantly andesite and rhylite are exposed along the western margin of the Khorat Plateau and Sra Kaeo in Eastern Thailand with various subordinate basaltic rocks (Putthapiban, 2002). The volcanic activities in this area likely commenced as early as Middle Devonian (กรมทรัพยากรธรณี, 2544). Quaternary basalt is the youngest volcanic rocks in Thailand (Barr and Macdonald, 1978). These basaltic rocks are mostly lava flows and scattered throughout Thailand except in the south. Barr and Macdonald (1978) categorized the basalts into gem-bearing basanitoids and gem-barren hawaiite basalts.

2.3 Tectonic evolution of Thailand

It has been proposed that tectonically Thailand comprises two continental terranes (Bunopas and Vella, 1983, Bunopas and Vella, 1992, Mantajit, 1997, Hirsch et al., 2006). The Sibumasu or Shan-Thai Terrane includes northern, western and southern Thailand. The Indochina Terrane comprises almost the whole part of northeastern Thailand. There are magmatic-arc terranes and suture zones between the Sibumasu Terrane and the Indochina Terrane (Singharajwarapan and Berry, 2000,

Sone and Metcalfe, 2008). Bunopas (1981) divided Thailand into three tectonic regions: Western Province, Central Province, and Eastern Province. However, Barr and Macdonald (1991) proposed a further subdivision that consists of the Western Zone, Inthanon Zone, Sukhothai Zone, and Phetchabun Zone (Figure 2.3). A recent tectonic province subdivision has been proposed by Sone and Metcalfe (2008) (Figure 2.4).

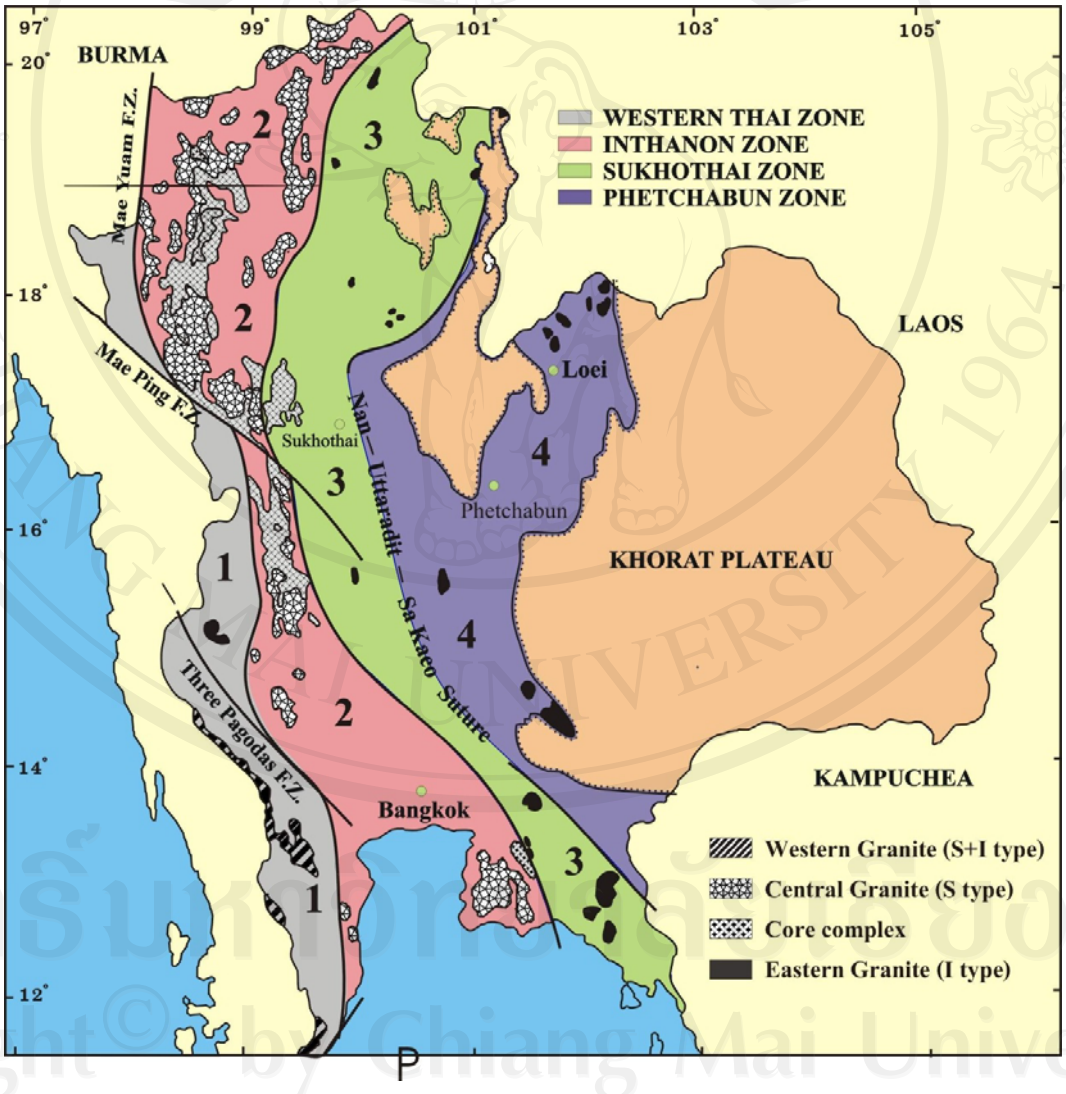

Figure 2.3 Tectonic provinces of Thailand (กรมทรัพยากรธรณี, 2544).

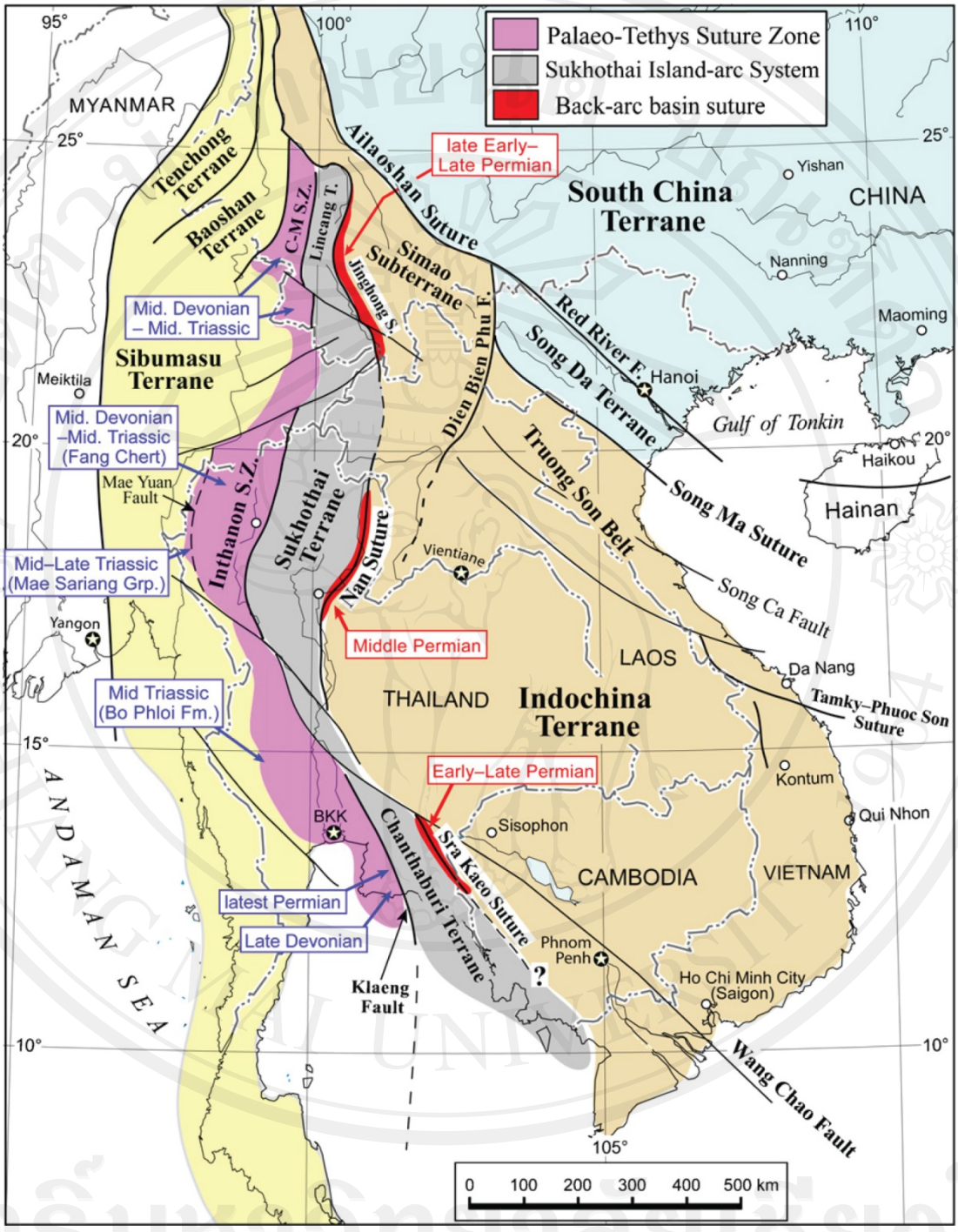

Figure 2.4 Subdivision of mainland Southeast Asia, showing the Palaeo-Tethys Suture Zone and back-arc sutures (Sone and Metcalfe, 2008). The occurrence of deep-sea sediment in each suture is indicated.

Sibumasu Terrane collided and amalgamated with Indochina Terrane in the early Late Triassic (Sone and Metcalfe, 2008). Based on a recent interpretation by Sone and Metcalfe (2008), the Sibumasu microcontinent rifted from Gondwana by the Middle Devonian and moved northward. As a result, the Palaeo-Tethys was subducted under the Indochina Terrane in the Latest Carboniferous or very Early Permian (Figure 2.5).

This subduction formed an island arc which is referred to as the Sukhothai Terrane along the margin of the Indochina Terrane. In the Earliest Permian, a back-arc basin relating to Nan Suture and Sra Kaeo Suture was opened. The back-arc basin then was closed in the Late Permian, and the Sukhothai Arc was consequently amalgamated into the western part of Indochina. The subduction of the Palaeo Tethys under the Sukhothai Arc continued in the Early-Middle Triassic. The Sibumasu Terrane collided with Sukhothai Arc not later than the early Late Triassic. Accretionary prism of Palaeo-Tethys along the Inthanon Suture was thrust upon part of the Sibumasu Terrane. In summary, the collisional crustal thickening probably started in the early Late Triassic, and magmatism of the Sukhothai Arc stopped by the end of the Triassic due to the cessation of subduction.

2.4 Major fault zones of Thailand

Fault zones in Thailand trend N-S, NW-SE and NE-SW (Figure 2.6) (กรมทรัพยากรธรณี, 2544, Chuaviroj, 1990). NW-SE trending fault zones were thought to be left-lateral strike-slip fault zone. However, there is evidence that the Mae Ping and

Three Pagoda Faults have minor right-lateral motion in the Miocene (Charusiri et al., 2002, Charusiri et al., 2007, Morley, 2002).

There are two important faults in the study area: the Mae Ping Fault and Three Pagodas Fault. The Mae Ping and Three Pagodas Faults were active in the late Oligocene as a result of the collision between the Indian Plate and the West Burma Block (Morley, 2002). The Mae Ping Fault extends southeastward to Phra Nakhon Si Ayutthaya through to Nakhon Nayok in the middle of the study area. It extends further as far as Prachinburi. The Mae Ping Fault is a left-lateral strike-slip fault which splays from the Sagaing Fault in central Burma (Rhodes et al., 2004). The evidence from 40Ar/39Ar geochronology by Lacassin et al. (1997) showed that left-lateral slip most likely occurred between approximately 40 and 30 Ma. It was subsequently reactivated with right-lateral slip probably during the Tertiary and Quaternary time.

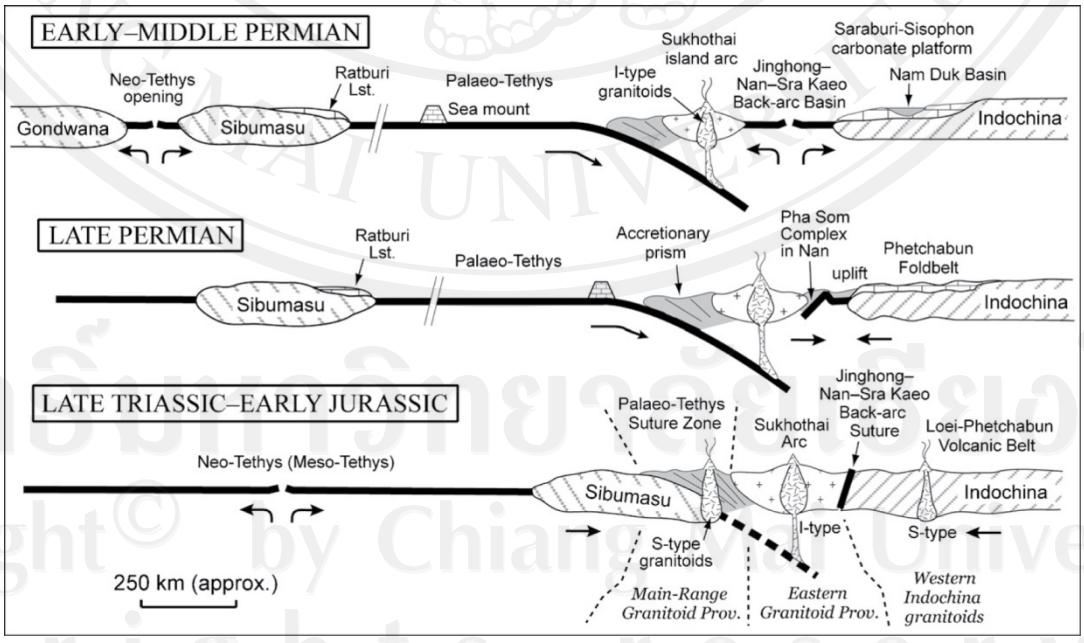

Figure 2.5 Tectonic evolution of mainland Southeast Asia during the Permian to Early Jurassic (Sone and Metcalfe, 2008).

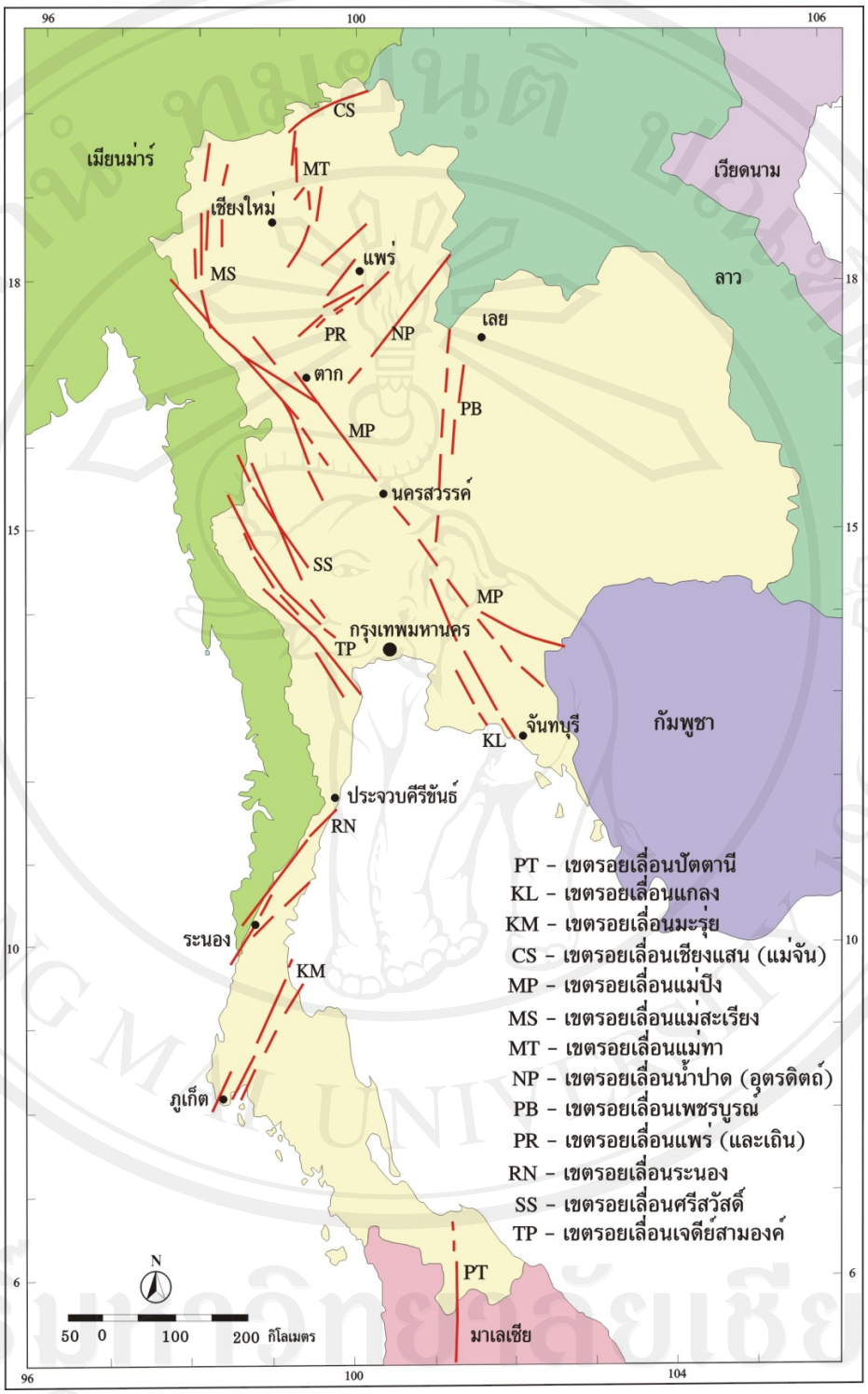

Figure 2.6 Map of the major fault zones of Thailand (กรมทรัพยากรธรณี, 2544). Abbreviations: CS- Chieng Soen Fault Zone; MS- Mae Sariang Fault Zone; MT- Mae Tha Fault Zone; PR- Phrae Fault Zone; NP- Nam Pat Fault Zone; MP- Mae Ping Fault Zone; PB- Phetchaburi Fault Zone; SS- Si Sawat Fault Zone; TP- Three Pagoda Fault Zone; KL- Klaeng Fault Zone; RN- Ranong Fault Zone; KM- Khlong Marui Fault Zone; PT- Pattani Fault Zone.

The Three Pagodas and Klaeng Faults are parallel to the Mae Ping fault and run through Samut Prakan, Chonburi and Rayong in the southern part of study area. It is likely that the Klaeng Fault is a segment of the Three Pagodas Fault (Morley, 2002). Morley (2002) suggested that the Three Pagodas Fault probably passes through Chonburi and runs towards the Gulf of Thailand. The Three Pagodas Fault is a left-lateral strike-slip fault with minor right-lateral motion. Lacassin et al. (1997) studying geochronology in Western Thailand reported that the left-lateral motion of the Three Pagodas Fault ended about 33 to 36 Ma, and right-lateral motion began about 24 and continued to the Present-day (Le Dain et al., 1984).

2.5 Geology of the Lower Central Plain of Thailand

The Lower Central Plain is a large flat plain in which Bangkok, capital of Thailand, is situated. The plain is located north of the Gulf of Thailand and bounded in the east and west by mountain ranges, fluvial terraces and alluvial fans. It consists mainly of fluvial and marine deposits. The main rivers flowing through the Lower Central Plain are the Chao Phraya, Tha Chin, Bang Pakong, and Mae Klong rivers. The total area of the Lower Central Plain is approximately 36,000 km2. The landform and stratigraphical section is shown in Figure 2.7.

The Structure beneath the Lower Central Plain consists of a series of grabens and horsts formed in the Late Pliocene-Pleistocene (Nutalaya and Rau, 1984, Nutalaya et al., 1984). The basins are dominated by major NW-SE and N-S trending faults: the Mae Ping, Three Pagodas, and Chao Phraya Faults. Approximately 500 to 2,000 m of unconsolidated basin fill overlie the basement of sedimentary, igneous and

metamorphic rocks of Paleozoic to Mesozoic ages. Information on the stratigraphy of the Lower Central Plain is available to about 600 m depth (Nutalaya and Rau, 1984, Nutalaya et al., 1984, Sinsakul, 2000, Phien-wej et al., 2006). On the plain is a complex sequence of Pleistocene and Holocene alluvial, fluvial and deltaic sediment. The Pleistocene sediment consists of sand, silt, clay and gravel. Fluvial and tidal processes are important in the development of the floodplains during the Holocene. The floodplains contain suspended-load clay, silt and sand. Figure 2.8 is a geological map of the Lower Central Plain.

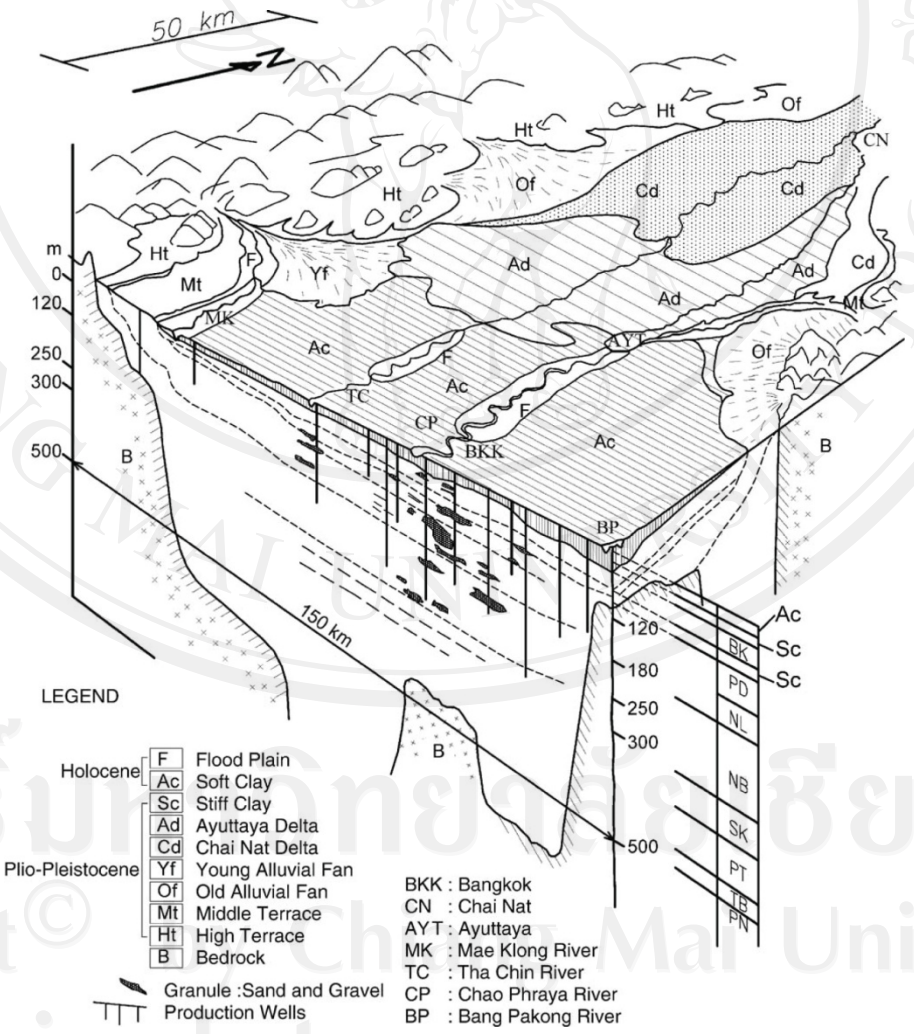

Figure 2.7 Three-dimensional sketch of landform and stratigraphical section of the Lower Central Plain (Phien-wej et al., 2006).

2.6 Geology of the Eastern Thailand

Eastern Thailand including parts of the study area is bordered in the north by the Khorat Plateau, in the west by the Gulf of Thailand and Central Plain, and in the east by the Thailand-Cambodia border. The regional trend of geological units in Eastern Thailand is NW-SE. The rocks vary in age from Precambrian to Quaternary. There are Precambrian rocks in the middle part and Paleozoic outcrops in the western part of the region. Both sedimentary and igneous rocks of Triassic age crop out in Sa Kaeo and Chanthaburi. Mesozoic volcanic rocks occur along the eastern coast and west of Trat. Most granitoid rocks are exposed in Chonburi, Rayong and Chanthaburi.

Subduction of the Palaeo-Tethys Ocean resulted in a complex igneous rock assemblages in Eastern Thailand (Figure 2.9). However, these igneous rocks can be divided into three different areas (กรมทรัพยากรธรณี, 2544). The batholith southeast of Chon Buri and Rayong and smaller batholiths northeast of Klaeng in Rayong are medium- to coarse-grained porphyritic biotite-muscovite granite. A batholith north and south of Chanthaburi is medium- to coarse-grained porphyritic biotite-hornblende granite.

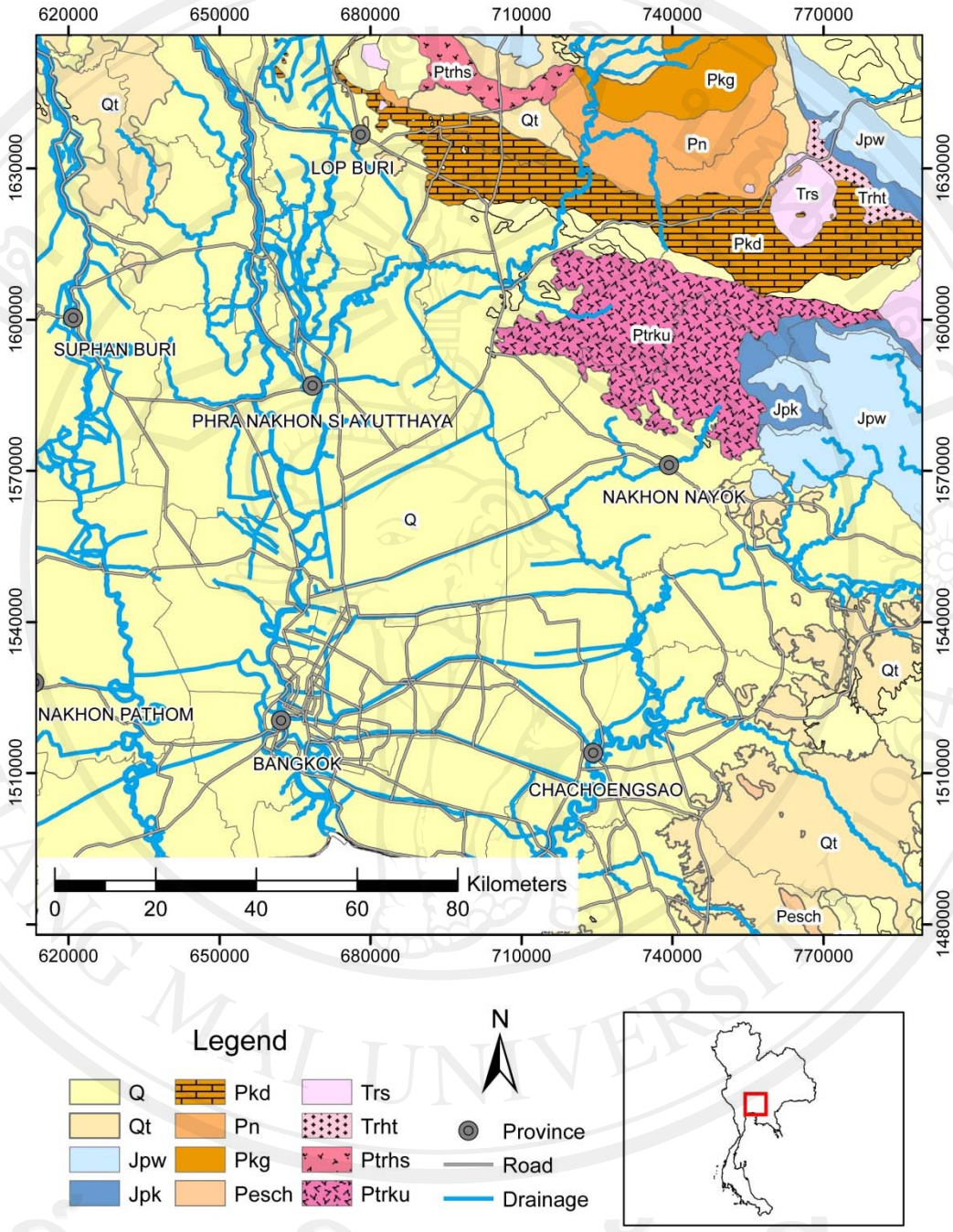

Figure 2.8 Geological map of the Lower Central Plains of Thailand (modified from Department of Mineral Resources (DMR), 1985, 1999). Abbreviations: Q = Quaternary unconsolidated sediments; Qt = Quaternary terrace sediments; Jpw = Middle Jurassic sedimentary rocks, Jpk = Lower Jurassic sedimentary rocks; Pkd = Middle Permian sedimentary rocks; Pn = Lower-Middle Permian sedimentary rocks; Pkg = Lower Permian sedimentary rocks; Pesch = Precambain sedimentary rocks; Trs = Upper Triassic igneous rocks; Trht = Upper Triassic igneous rocks; Ptrhs = Permo-Triassic igneous rocks; Ptrku = Permo-Triassic igneous rocks.

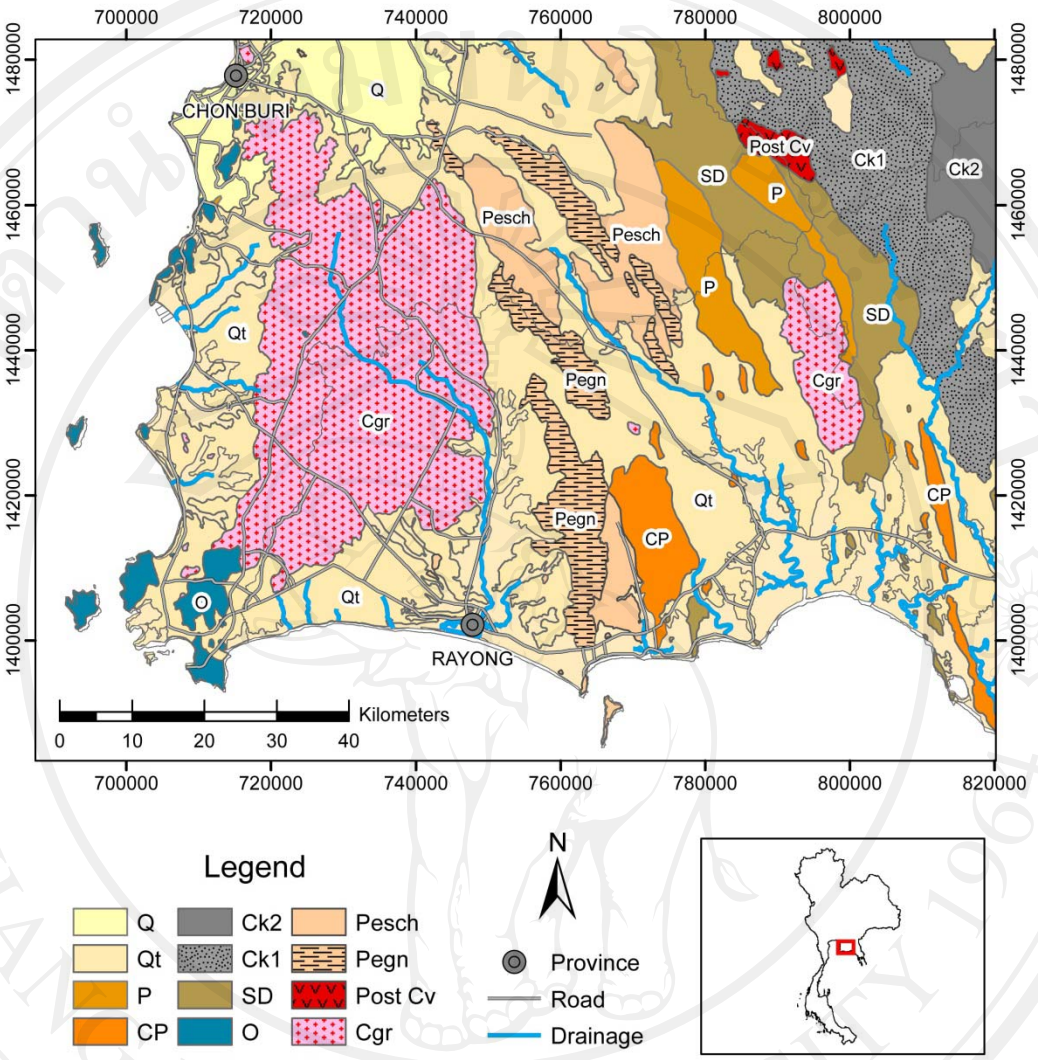

Figure 2.9 Geological map of the Eastern Thailand (modified from Department of Mineral Resources (DMR), 1985, 1999). Abbreviations: Q = Quaternary unconsolidated sediments; Qt = Quaternary terrace sediments; P = Permian sedimentary rocks; CP = Permian-Carboniferous sedimentary rocks; Ck1 = Carboniferous-Permian sedimentary rocks; Ck2 = Carboniferous-Permian sedimentary rocks; SD = Silurian-Devonian sedimentary rocks; O = Ordovician sedimentary rocks; Pesch = Precambrian metamorphic rocks; Pegn = Precambrian metamorphic rocks; Post Cv = Post-Permian igneous rocks; Cgr = Carboniferous igneous rocks.