Chapter 2
Geological setting

The geological investigation of Thailand has been intensively conducted during the past 30 years. Geologic map at a 1: 250,000 scale covering the whole country had been compiled since 1981. Stratigraphy of Thailand which is based on the terrane or ancient microcontinent concept was published in 1992. Many geologists have applied the concept of plate tectonics to describe the geological development of Thailand. Most of these interpretations were based on the collision between the Shan-Thai and Indochina terranes. However, this collision is still unclear. Despite numerous studies that have successfully determined crustal structure in many area of Thailand, uniform compilations of these measurements at regional scales have not been realized to their full extent.

2.1 Regional geology of Thailand

The following description is based mainly on the Thailand geological investigation carried out by Bunopas (1982) and Cooper (1989). The geology of northern Thailand is dominated by mountain ranges oriented in N-E and NW-SE direction which containing pre-Tertiary rocks that record a complex history of deposition and tectonics. Major strike-slip faults are also dominant features in northern Thailand.

Precambrian rocks in Thailand were mentioned for the first time by Colonel Samak Buravas. From his pioneer studied of the high grade schistose rocks in the Pnom Sarakham area. Since then, many geologists have assigned all the high grade metamorphic rocks under examined to be of Precambrian sequence (Salyapongse 2002). Very little systematic work has been carried out on these rocks since the account of Baum et al., (1970). The rocks are mainly migmatised paragneisses and include quartzitic schists, biotite schists, calcsilicate schists and marbles which are penetrated by concordant and discordant veins and irregular masses of granodiorite and pegmatite. The rocks are in the amphibolite facies and pelitic rocks.

The northern, western and peninsular regions of Thailand are dominated by Palaeozoic rocks (Bunopas, 1982) with small, deformed outliers of Mesozoic strata and occasional small Tertiary basins (Figure 2.1). Upper Paleozoic rocks, Carboniferous and Permian sedimentary rocks mostly lie conformably on the Lower Paleozoic strata and widely distributed throughout Thailand. In most places, the Carboniferous and the Permian strata continued their depositions. The Permian rocks which contain mainly of limestone are being considerable more extensive and easily recognized because of their karastic landform (Raksaskulwong, 2002). The lower Paleozoic rocks are widespread in western mountain area extending from Kanchanaburi in the west to Chiang Mai, Mae Hong Son and Uttaradit in the north and to Chon Buri in the east (Wongwanich et al., 2002). The rocks in the Peninsula are widely distributed in north-south direction alongside of Khao Luang mountain range. The lower Palezoic sediments are locally regionally metamorphosed up to the greenschist facies and converted to schists and phyllites.

Mesozoic rocks of Thailand consist of both marine and non-marine deposits. Whereas the marine rocks are well distributed in the northern, western and southern parts of the country, the non-marine rocks are widespread in the northeastern part (khorat Plateau) and partly in the southern peninsular. The marine rocks consist mainly of limestones, mudstones, sandstones, dolomites, and conglomerates having been deposited in submarine fan and shallow water environment (Meesook et al., 2002). The non-marine Mesozoic rocks in the Khorat Plateau consist reddish-brown to light-grey sandstone, conglomeratic sandstones, siltstones and claystones. The rocks are interpreted as having been deposited by the meandering and braided rivers in semi-arid to arid conditions.

Cenozoic rocks are mainly fresh-water shale and sandstone in fault bounded intermontane basins in west, central and north Thailand and often contain lignite and oil shale. The rocks are mainly Upper Tertiary but Lower Tertiary fossils are known from some basins. A large part of central Thailand is blanketed by Quaternary fluvial sediments which conceal a number of basins formed associated with dextral shear on the Mae Ping – Three Pagodas Fault system during the Tertiary. Quaternary geologic sequence of the Central plain occurred on both the rims and on the plain itself. The rims

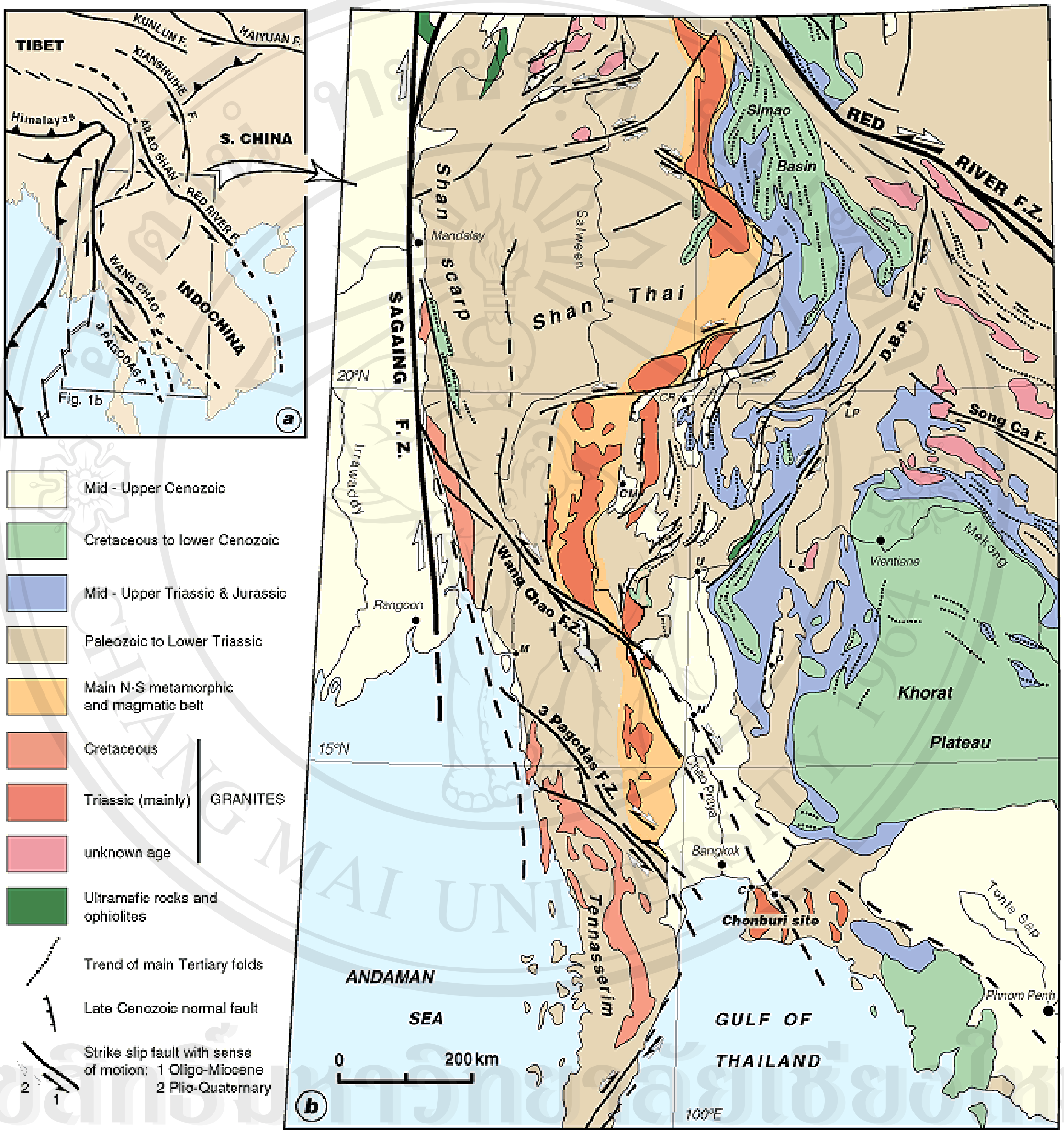

Figure 2.1 Simplified geologic map of major parts of Thailand and its adjacent areas (Lacassin et al., 1997).

of Central plain are the areas between mountain range and the plain. They are characterized by undulating terrain and hillslope with the elevation less than 100 meters. The Central plain of Thailand is sloping southward and divided into upper and lower Central plain. Upper Central plain comprises the flood plains of the Ping, Wang, Yom and Nan river flowing from the north combine to form the Chao Phraya river. Sediments in the upper central plain are mainly alluvium and fluvial deposited resting on the bed rock. They are found as exposure and underlay the younger sediments that slope to the deep basin of Lower Central plain (~ 30 m). The bed rock in the upper Central plain is shallow. The lower central plain or also known as Chao Phraya basin begins at Chainat until it reaches the Gulf of Thailand with the distance of about 200 km. Block faulting in Late Pliocene-Pleistocene formed deep horst and garbens in the lower central plain basements and caused thick accumulation of Quaternary sediment overlain the basement rocks (Sinsakul, 2002).

2.2 Tertiary sedimentary basins in Thailand

Tertiary sedimentary basins in Thailand occurred throughout the country. At least 70 Tertiary basins have been named (Figure 2.2) with most of large basins also contain numbers of sub-basins. These Tertiary rocks are poorly exposed in natural outcrops and covered by Quaternary sediments except at the margins of the basins where the rocks were often brought to the surface by faults.

Tertiary basins in Thailand are known as isolated basins, but seem to show many characteristics in common (Chaodumrong et al., 2002) including:

1. The development of Tertiary basins in Thailand has been related to collision between India and Eurasia.

2. The basins are mainly intermotane and rift basins with garben/ half garben geometry, oriented in approximately N-S direction. Most of the basins are located west of the Nan Suture zone. They are both unconformably underlain and overlain by the older rocks and Quaternary sediments, respectively.

3. Basins in the same region formed in similar times. The basins in the south as well as in the Gulf of Thailand and the Andaman Sea formed relatively earlier than those in the north. The Krabi basin formed not later than the Late Eocene, whereas those in the

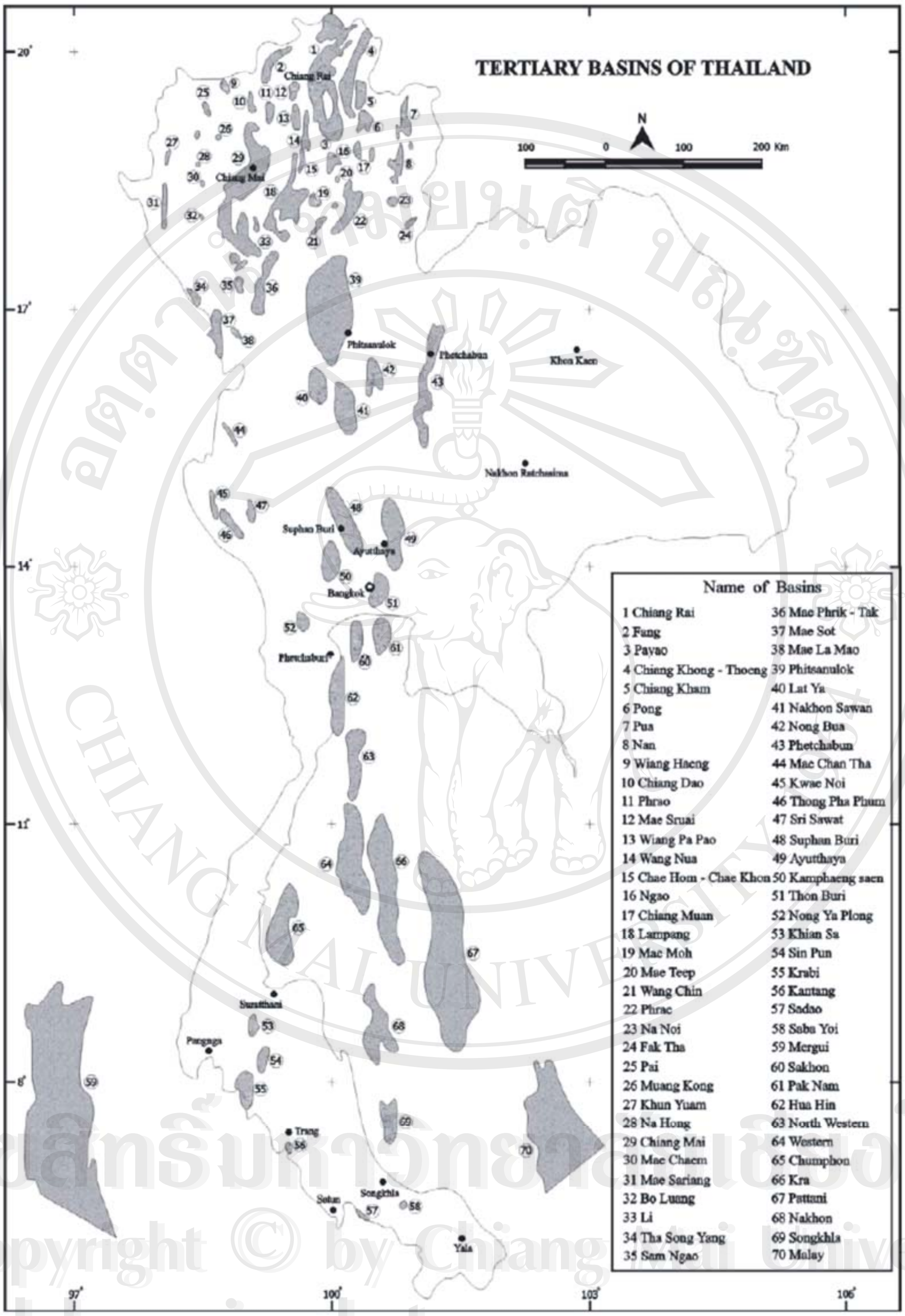

Figure 2.2 Tertiary basins of Thailand (Chaodumrong et al., 2002).

Gulf and Andaman sea in the Middle Oligocene. Most basins in the north yield Miocene age except in the NW of Thailand.

4. The Tertiary basins contain similar sequence of major sedimentary environments with alluvial environments in lower and upper parts of the sequence while lacustrine and swamp environments dominate the middle part. However, in details each basin has its own development history.

5. Regional unconformity of a Late Miocene age occurred widely in the central plains, indicated by changing from lacustrine environment upward to alluvial environment. This unconformable contact in the north is obvious only at the margin of the basin and can be correlated to conformable contacts in the middle of the basin.

2.3 Geological structures in Northern Thailand

The immense indentation of India into Asia induced both north-south shortening within the Himalayas, and extrusion of Indochina eastward out of the collision zone. Northern Thailand lies in the central part of the Shan Thai block (Figure 2.3), one of the major fault-bounded regions that lie within the extruded region. Extrusion accrued via movement along large strike-slip faults, including the Red River, Mae Ping and Three Pagodas faults (Tapponier et al., 1982). Extrusion implies that Indochina moved eastward and rotated clockwise as a set of more or less rigid blocks. The northern Thailand and range province, located between the Red River and Mae Ping faults, lies in the center of this zone of extrusion. The Tertiary history of northern Thailand is dominated by the opening of roughly north-south-trending basins, and arguably related slip along sets of northeast and northwest-trending strike slip faults (Polachan et al., 1991). Contrasting interpretations have been proposed for the Tertiary deformation of the northern Thailand (Rhoder et at., 2002).

Polachan et al. (1991) published a hypothesis suggesting that northern Thailand underwent transtensional, dextral simple shear between the Red River and Mae Ping faults. They suggested that the resultant east-west extension produced a nearly penetrative set of northeast-trending sinistral faults, conjugate to the Mae Ping and Red River faults, and caused the opening of the north-south basins along normal faults.

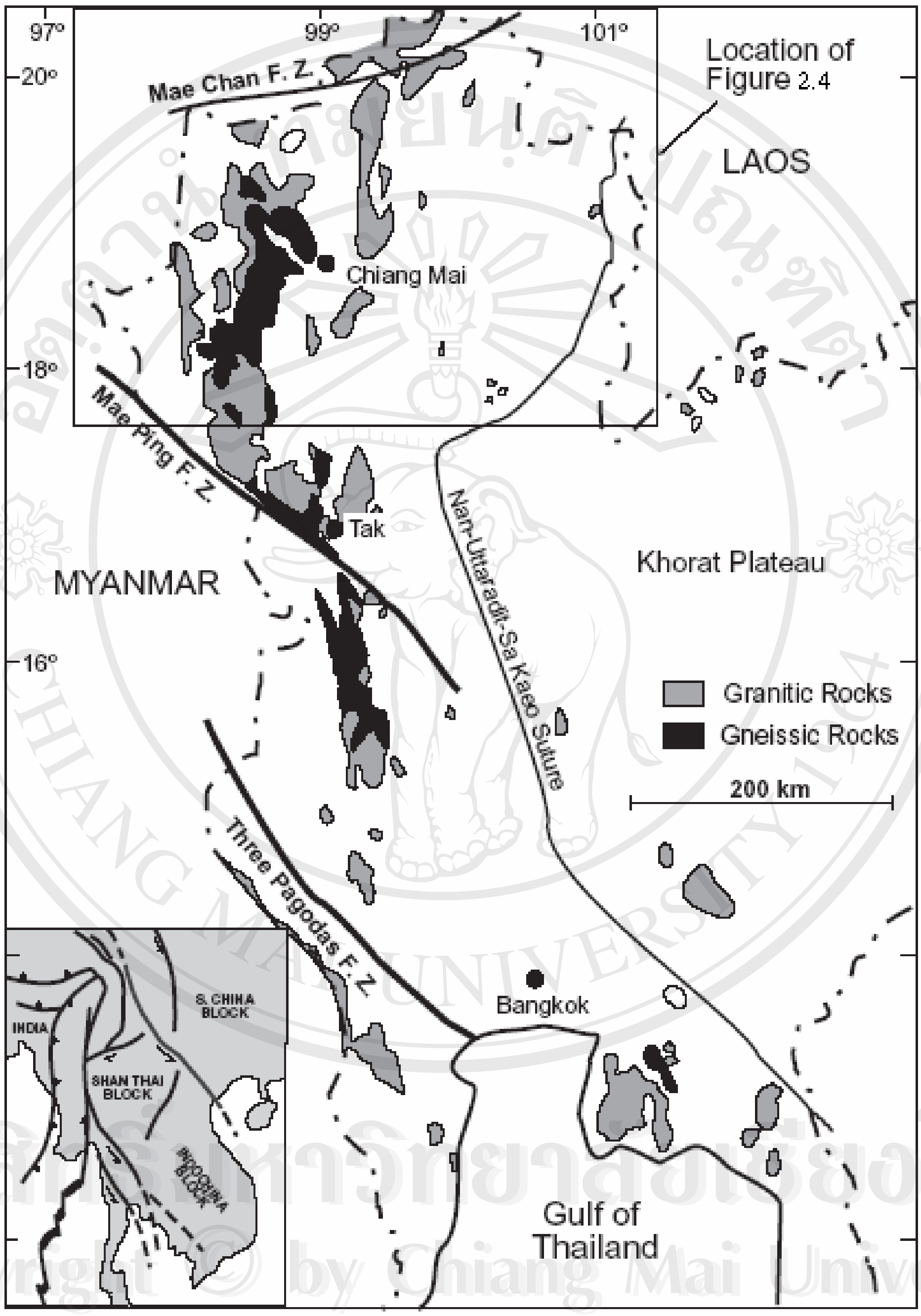

Figure 2.3 Index map of northern Thailand. Inset shows the regional tectonic setting of the Shan Thai block (Rhodes et al., 2005).

2.3.1 Strike-Slip faults in northern Thailand

Regional models of strike-slip escape tectonics in SE Asia focused particularly on the Red River Fault in Vietnam (e.q. Leloup et al., 1995, 2001; Wang et al., 2001). The role of large-displacement, but essentially secondary faults (Mae Ping and Three Pagodas faults), is regarded as less critical. The other major strike-slip fault in the region is the north–south dextral Sagaing Fault, which has probably undergone between 150 and 300 km displacement from the Late Miocene to Recent (Bertrand & Rangin 2003). The Mae Ping and Three Pagodas faults are typically shown as single NW–SE-striking faults that meet the north–south-striking Sagaing Fault.

Early studies of fault zone in Thailand consisted of interpretations of lineaments visible on satellite images, older aerial photographs, and 1:50,000 scale topographic maps (Rhodes et al., 2002). The major strike-slip faults are well exposed on the western side of the country and are generally poorly exposed in the central and eastern parts.

I. Mae Ping Fault

The northwest-striking Mae Ping fault (also named the Wang Chao or Papun fault) forms a major tear that extends from the Sagaing fault in central Burma to the Chao Praya basin in central Thailand (Figure 2.3). It offsets the major gneissic belts of the Western Ranges in Thailand with approximately 160 km of early Tertiary left-lateral offset (Lacassin et al., 1997; Tapponnier et al., 1986). A steeply inclined, 5 km-thick zone of mylonitic gneiss parallels the trace of the fault. Shear-sense indicators within the gneiss indicate uniform left-lateral slip. However, the Mae Ping fault apparently was reactivated with right-lateral slip during Quaternary time (Ledain et al., 1984).

II. Mae Chan fault

The Mae Chan fault extends for over 150 km across the northern part of northern Thailand (Figure 2.4). Its gently curved trace trends northeast-southwest to nearly east-west. Near its western end, its trace forms the northern border of the Fang basin whose north-south axis bends to the northeast where it meets the fault (Braun and Hahn, 1976). Its trace apparently offsets by 5-10 km both the east and west contacts of the Fang-Mae Suai batholith in a sinistral sense.

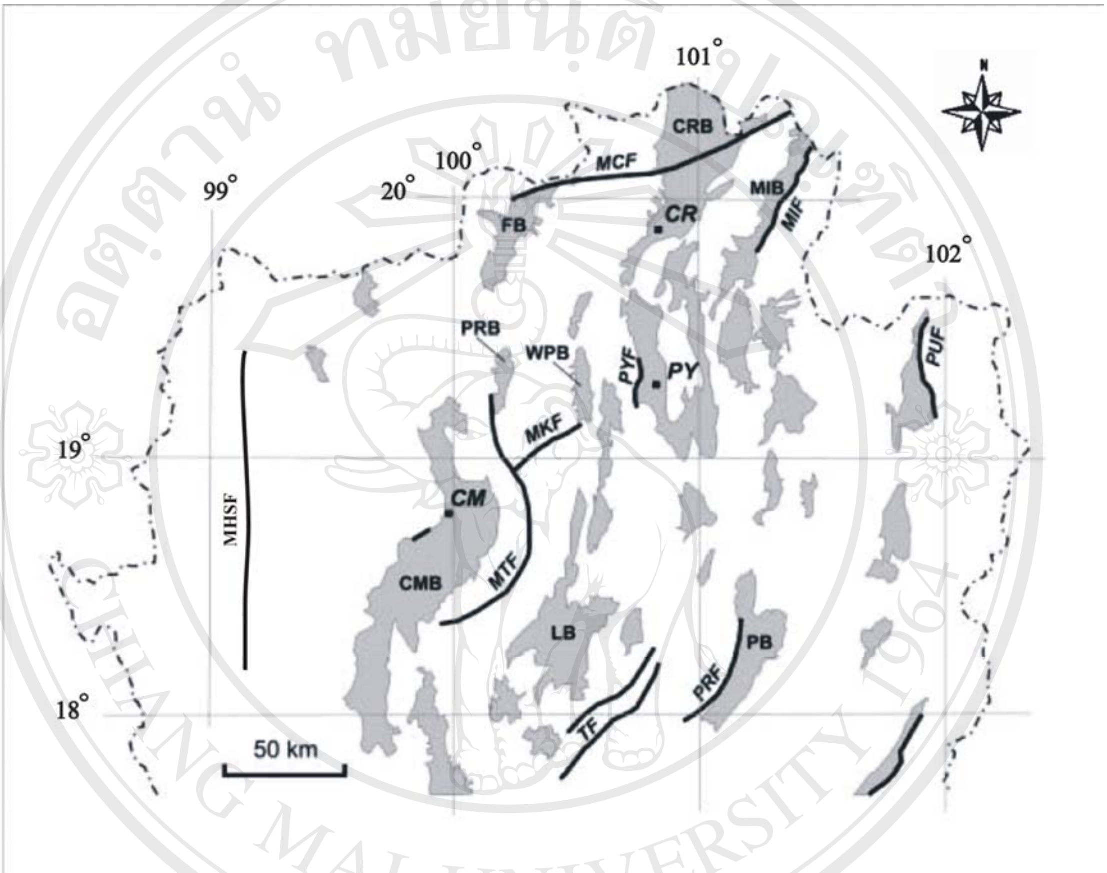

Figure 2.4 Map of northern Thailand showing the model of extension in the northern Thailand. Shading marks the location of the major basins of northern Thailand. The inset shows the stress field inferred by Polachan. Basin names are as follows: Ms = Mae Sai, Cr = Chiang Rai, Pu = Pua, P = Phayao, N = Nan, Cm = Chiang Mai, L= Lampang, Phr = Phrae, Ph – Phitsanulok, Mso = Mae Sot (modified from Rhodes et al., 2002).

2.3.2 Major fold belt

The mobile belt covering in northern and central Thailand can be subdivided into western Sukhothai fold belt and eastern Loei fold belt. The boundary between the two fold belts is situated at the Uttaradit-Nan ophiolite suture zone (Bunopas 1982).

I. Sukhothai fold belt

The oldest rocks recognized in the Sukhothai fold belt (Permo-Carboniferous) are in the Pha Som Metamorphic Complex along the eastern margin. Permian turbidites and limestone (Phrae Group) are distributed mainly in the central and eastern part of the Sukhothai fold belt. Permo-Triassic volcanic and volcaniclastic rocks occur in two areas, in the Lampang-Phrae area and in the Sirikit Dam area. (i.e. the central part of the Sukhothai Fold Belt) and in the Sirikit Dam area close to the boundary between the Sukhothai and the Loei fold belts (Singharajwarapan and Berry 2000).

II. Loei fold belt

Preliminary geochemical data from volcanic rocks in the Loei fold belt, to the east of Nan suture, support subduction-related arc volcanism in that area, but Intasopa and Dunn (1994) showed that these volcanic rocks have diverse tectonic settings of eruption and range in age from Late Devonian to Triassic. The present evidence suggests that most of volcanic rocks in the Loei province are older than that in the Sukhothai fold belt and are probably related to an older arc.

2.4 Geotectonic subdivision in Thailand

The tectonic framework of Thailand and SE Asia have received much attention and become the subject of interest. It is currently well established that Thailand, on the basis of Bunopas (1982)'s model, comprises a complex assembly of two separate microcontinents (or terranes) namely Shan-Thai and Indochina. Indochina comprises northeast Thailand, Combodia, almost all of Laos, Vietnam and eastern Malaysia. Shan-Thai terrane includes western and peninsular Thailand, eastern Myanmar, northern Laos, southeastern Yunnan, western Malay peninsular, and eastern Sumatra. These two tectonic terranes were completely allocthonous to Asia and amalgamated together along the

Nan-Uttaradit suture zone. The basement complex forming the crust exposed on both terranes are metamorphic complex of amphibolite, or high grade elsewhere outside Thailand.

I. Shan-Thai Terrane

Shan-Thai is bounded to the west and southwest by the Shan Boundary Fault, Andaman Sea basin, and the Woyla suture in Sumatra (Barber 2000). Its eastern boundary has been regarded as the Bentong-Raub suture in Peninsular Malaysia, the Nan-Uttaradit-Sra Kaeo Suture (Singharajwarapan and Berry, 2000) and the Changning-Menglian and Lancangjian suture in western Yuannan and Tibet. However, many recent papers point out that the eastern boundary of this terrane in Thailand is equivocal. The Shan-Thai terrane is an elongate allochthonous continental terrane trending north-south at present day.

II. Indochina Terrane

The Indochina terrane component is bounded to the north-east by the Song Ma suture zone and to the west by the Uttaradit-Nan-Sra Keao-Raub sutures in Thailand and Malaysia, respectively. This terrane is also an elongate allochthonous continental terrane, and composed mainly of Precambrian rocks and Late Paleozoic marine strata overlain by Mesozoic continental deposits. The basement of the Indochina terrane comprises a Precambrian core of granulite facies rocks exposed in Vietnam (Workman 1997). There is no information available on the nature of the crust underlying the Khorat plateau of northeastern Thailand.

As reported by Bunopas (1982), the Nan-Uttaradit suture (or Nan or Nan-River or Nan-Uttaradit-Srakhaew) is widely believed to be the suture zone between two main fold belt (Sukhothai fold belt and Loei-Phetchabun fold belt) along which mafic and ultramafic suites occur typically in the Nan-Uttaradit area. Nevertheless, the geometry of collision has been controversial. However, the Sukhothai fold belt which was related to the plate tectonic of northern Thailand was studied by Singharajwarapan and Berry (2000). From their study, they concluded that the lithology, deformation history, and metamorphism of Pha Som Metamorphic Complex are consistent with those observed in ancient and modern accretionary complexes in many parts of the world. As S_2 is the dominant foliation that they correlated with accretionary processes, the eastward transport associated with this structure is interpreted to indicate an originally west-dipping subduction zone of Indochina terrane dipping under the Shan Thai terrane.

Recent discoveries of oceanic and seamount rock association in the Chiang Mai-Chiang Dao area of western Thailand, are interpreted as representing the main Paleo-Tethys suture zone in northern Thailand. This suture zone is here termed the "Chiang Mai Suture" (Metcalfe, 2002 and Charusiri et al., 2002). The rock associations of the Chiang Mai suture in the Chiang Mai and Chiang Dao area equate well with similar rock suites of the same ages in the Changning-Menglian suture in western Yunnan to the north (Haoruo et al., 1995). They also reported the southern extension of the Changning-Menglian suture into Thailand, but this topic is still controversial especially about the position of the suture. Immediately south of the Changning-Menglian suture is that region of Burma, Laos, and Thailand known as the "golden triangle" which is poorly documented geologically. The lack of data in English literature from this entire region is reflected in the very different positioning of sutures by different authors (Figure 2.5). Barr et al. (1990) show possible Chiang Mai volcanic belt would link northward directly with the Changning-Menglian suture but the suggested correlation (Figure 2.6) is not without challenge, nor is it well substantiated in this poorly documented area. However, Barr and Macdonald (1987) rejected any correlation between the Changning-Menglian suture and the Chiang Mai belt because of the lack of ophiolitic characteristics in the latter.

III. Simao Terrane

The Simao terrane, as seen in China, is bounded by the well defined sutures of Changning-Menglian to the west and the Ailaoshan to the east. The terrane is largely covered by late- to post-orogenic Mesozoic and Cenozoic red beds although Palaeozoic strata appear from under the cover sequence in limited areas on the eastern and western margins of the terrane. Precambrian metamorphic rocks (Lancang Group) are also present on the western margin. The only palaeontologically well-dated lower Palaeozoic strata occur on the eastern margin (Haoruo et al., 1995). New information on the Ailaoshan and

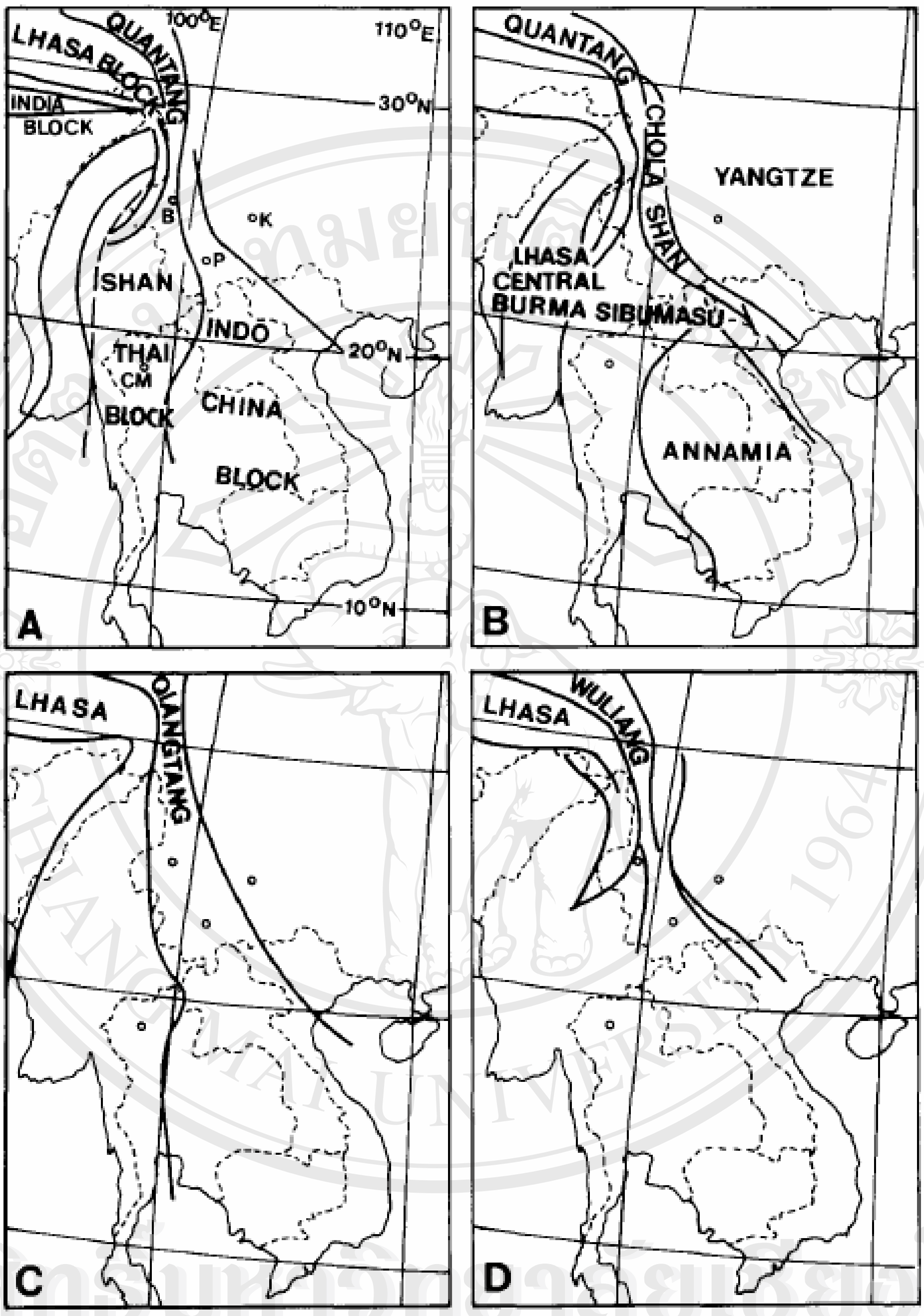

Figure 2.5 A selection from the many and varied interpretations of the suture pattern (and hence terranes) in Southeast Asia. The thick lines represent the sutures identified by the various authors and in each part the tectonic elements are named as in the source publication. *B = Baoshan; CM = Chiang Mai; P = Puer; K = Kunming. Sources: (A) Mitchell, 1989; (B) Sengor et al., 1988; (C) Smith, 1988; (D) Hutchison, 1989b* (modified after Haoruo et al., 1995).

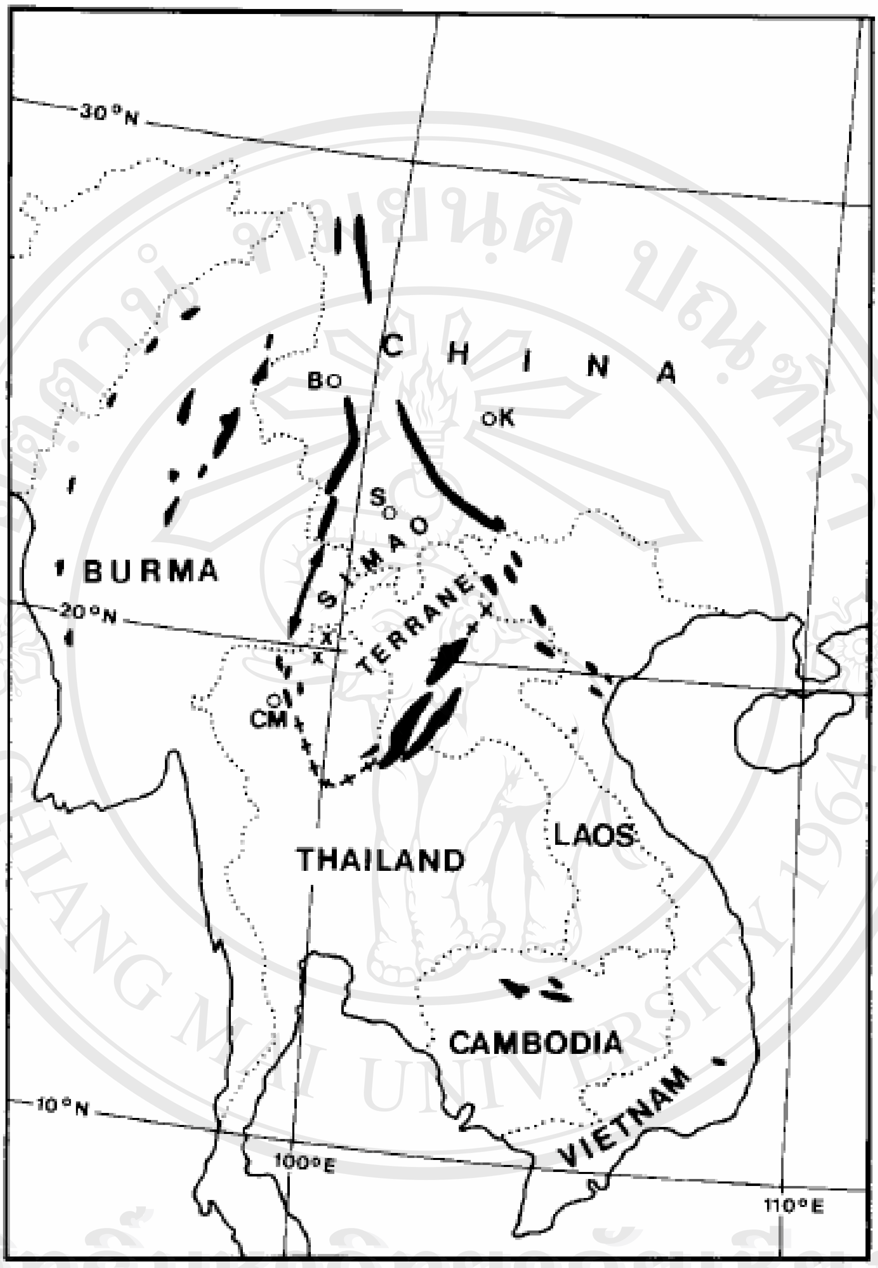

Fig. 2.6 A regional sketch map indicating the possible southern extension of the Changning-Menglian suture, and the possible extent of the Simao terrane. The black areas near Chiang Mai *(CM)* in Thailand show the extent of the Chiang Mai volcanic belt and the crosses mark older mafic rocks in the district. *B = Baoshan; CM = Chiang Mai; K = Kunming; S = Simao* (Haoruo et al, 1995).

Nan-Uttaradit suture zones in SW China and Thailand, respectively, indicates that these sutures probably represent a marginal back-arc basin (Metcalf, 2002). The main Tethys ocean was identified along a suture in the Chiang Mai-Chiang Dao area of northwestern Thailand (Figure 2.7). Recently, Metcalfe (2002) suggested that the main Paleo-Tethys ocean is presented by the oceanic rock-association distributed in the Chiang Dao-Chiang Mai area of western Thailand, and that association should be termed the "Chiang Mai suture". Charusiri et al., (2002) did recognize the Simao Block in their tectonic reconstruction but called this the "Lampang-Chiang Rai" Block which they considered to have separated from the Shan-Thai terrane by back-arc spreading.

Wonganan (2002) adopted the tectonostratigraphic schemes of Barr & Macdonald (1991) but integrated more data based on paleontology (radiolarians and foraminifers), sedimentology, and lithology investigations. According to his work, mainland Thailand can be subdivided into at least five main tectonostratigraphic zone or belt, and four distinct areas or subzones. The main tectonostratigraphic zones are the western zone, Mae Hong Son-Chiang Mai zone, Chiang Rai zone, Lampang-Phrae zone and Nan-Uttaradit zone, from west to east respectively (Figure 2.8).

2.5 Tectonic model of northern Thailand

Plate tectonic interpretations of the geology of northern Thailand have been proposed by Bunopas & Vella (1978), Asnachinda (1978) and Thanasuthipitak (1978) following earlier models by Hutchison (1973), Bunopas (1976) and Mitchell (1976). Several authors agree that Thailand is composed of two continental terrains. Early Lower Paleozoic rocks in western Thailand represent shelf sediments deposited over the Shan-Thai Craton. In Silurian times subduction of the ocean floor commenced along the eastern margin of Shan-Thai Craton (Figure 2.9). Westward subduction of the ocean floor continued until the early Mesozoic, with the production of a series of superimposed volcanic arcs, extruded during Siluro-Devonian, Carboniferous-Early Permian, late Permian-Early Triassic and Late Triassic-Jurassic times. Bunopas & Vella (1978) suggest that the collision of the Shan-Thai Craton with Indochina Craton took place in Early Jurassic times. The collision zone is represented by Nan-Uttaradit Suture in Central

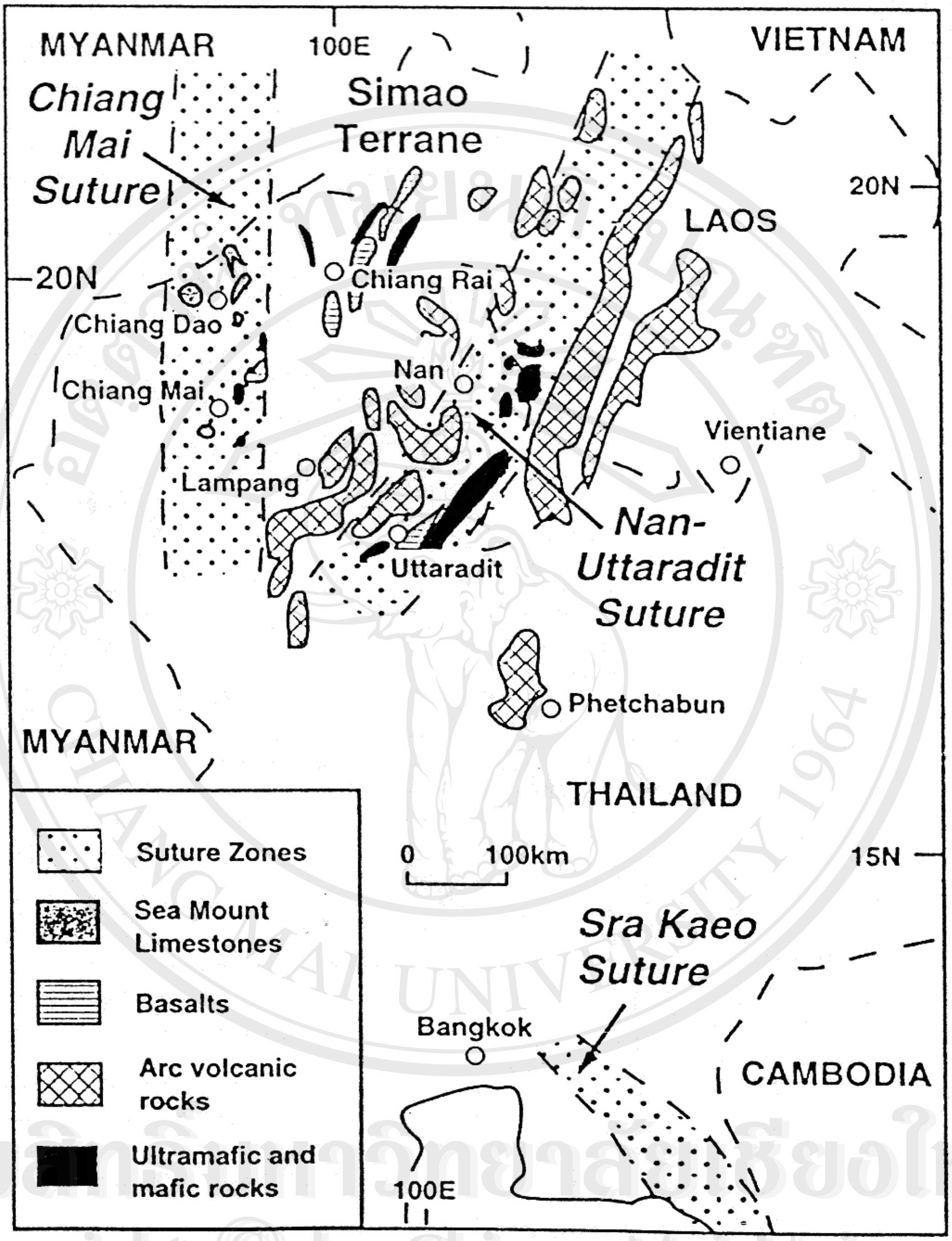

Figure 2.7 Sketch map showing the Chiang Mai, Nan-Uttaradit and Sra Kaeo suture zones of Thailand, the southern part of the Simao Terrane, and distribution of volcanic arc rocks, basalts, ultramafic and mafic rocks and sea-mount carbonates in northern Thailand (Metcalfe 2002).

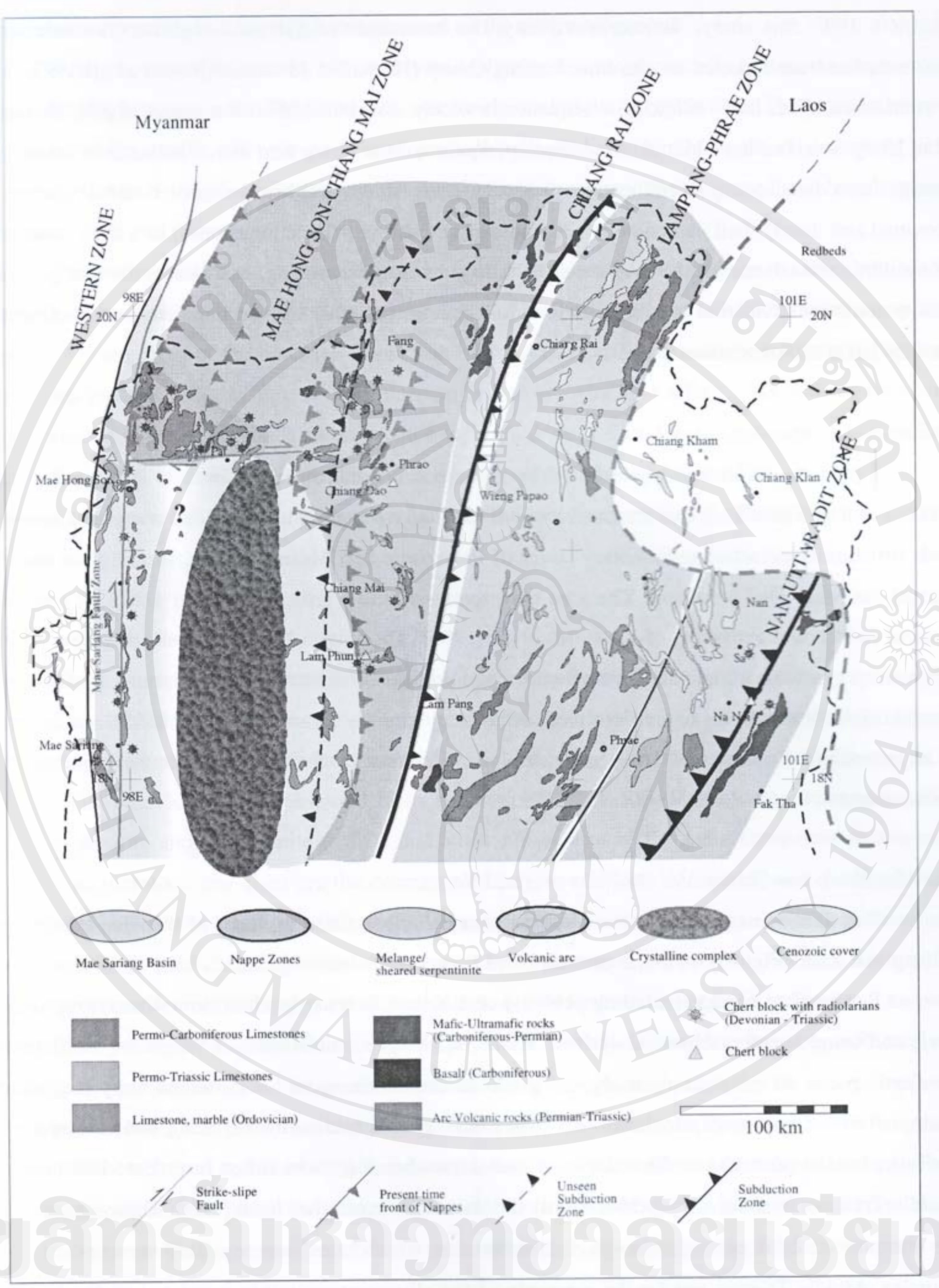

Figure 2.8 Map of northern Thailand, showing the tectonostratigraphic divisions referred in major structures; the western zone, Mae Hong Son-Chiang Mai zone, Chiang Rai zone, Lampang-Phrae zone, and Nan-Uttaradit zone, from west to east respectively (Wonganan 2002).

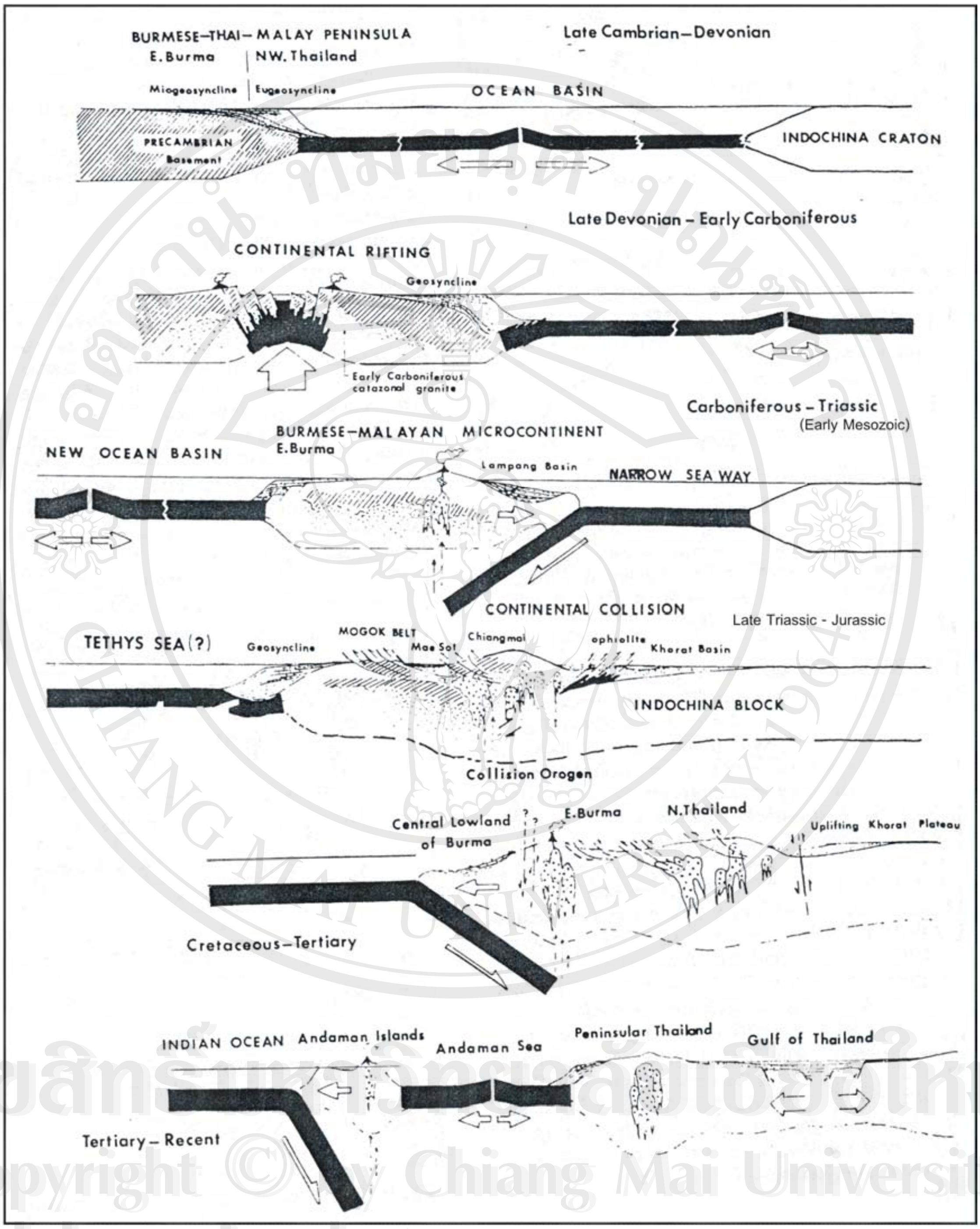

Figure 2.9 Plate tectonic evolution of Thailand and Malay Peninsular (Asnachinda 1978).

Thailand, marked by scattered occurrences of ultramafic rocks which are interpreted as fragments of an ophiolite complex (Figure 2.9).

Charusiri et al., (2002) presented a new synthesis of geotectonic evolution of Thailand. Two newly proposed, smaller tectonic blocks intervened between Shan-Thai and Indochina, namely the paleotethyan "Nakhon Thai" ocean floor to the east and the "Lampang-Chiang Rai" volcanic arc to the west (Figure 2.10). The geologic evolution of Thiland can be subdivided into four major tectonic episodes, namely Archeotectonic, Paleotectonic, Mesotectonic, and Neotectoic. In Neotectonic stage (Miocene to Recent), the amalgamated terranes of mainland SE Asia (west Burma, Shan-Thai, Lampang-Chiang Rai, Nakhon Thai, and Indochina) remained at their paleopositions until the Middle Eocene when India started to underthrust in the N to NE direction with Asia (10 and 11 in Figure 2.11). The interaction of India and Asia, which in turn closed the Neotethys, marked a change in tectonic stage of Thailand and SE Asia by operating continental extrusion tectonics. Reactivation of the fault movement with the opposite direction may have formed. Rifting may have taken place all over SE Asia, causing the development of basins in northern Thailand, opening of the Gulf of Thailand, South China and Andaman Sea. The culmination Neotectonic stage is marked by the generation of mantle-derived gem-bearing and barren basalts (12 in Figure 2.11).

Other data onshore and in the Gulf of Thailand enable a revision of Tertiary tectonic evolution of SE Asia as presented by Morley (2002). In the original escape tectonics model (e.q. Tapponnier et al., 1986), two main wedge-shaped crustal blocks in SE Asia were defined: the Sundaland or Indochina block (in this case Indochina block means both Shan-Thai and Indochina terranes) bounded to the west by the N–S striking Sagaing fault and to the east by the NW–SE striking Red River Fault (Figure 2.12). Subdividing the Sundaland block are two large faults that lie predominantly in Thailand: the Three Pagodas and Mae Ping (or Wang Chao) fault zones. The China block lies north of the Red River fault. Consequently, the large strike-slip faults associated with escape tectonics are predicted to dominate the geological evolution of SE Asia. However, resent results investigating strike-slip faults, rift basins, and metamorphic core complexes are reviewed and revised tectonic model for SE Asia by Morley (2002). In northern Thailand,

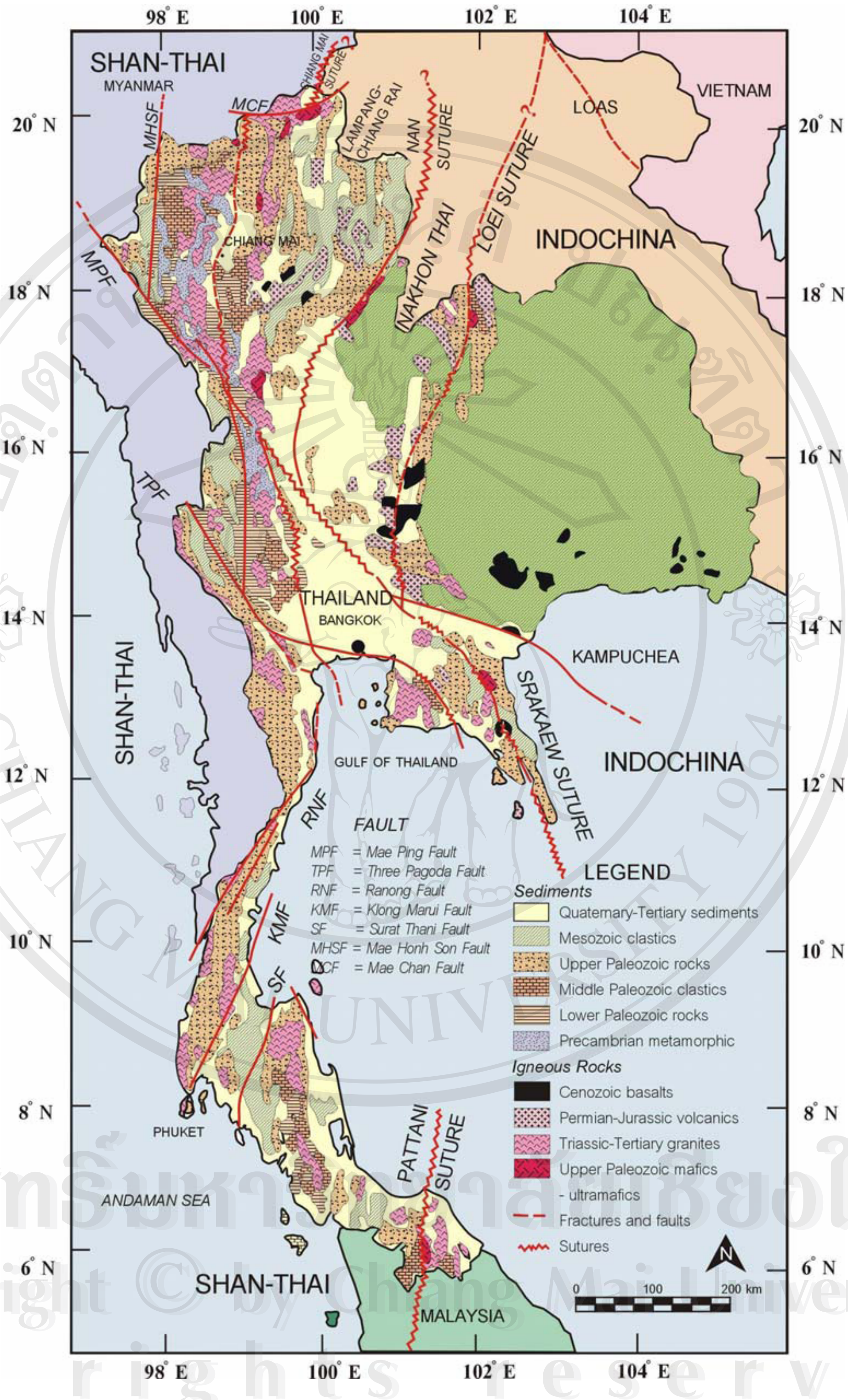

Figure 2.10 Simplified geologic map of Thailand showing the distribution of rocks of various ages, significant tectonic plate and major sutures/fault systems (Charusiri et al., 2002).

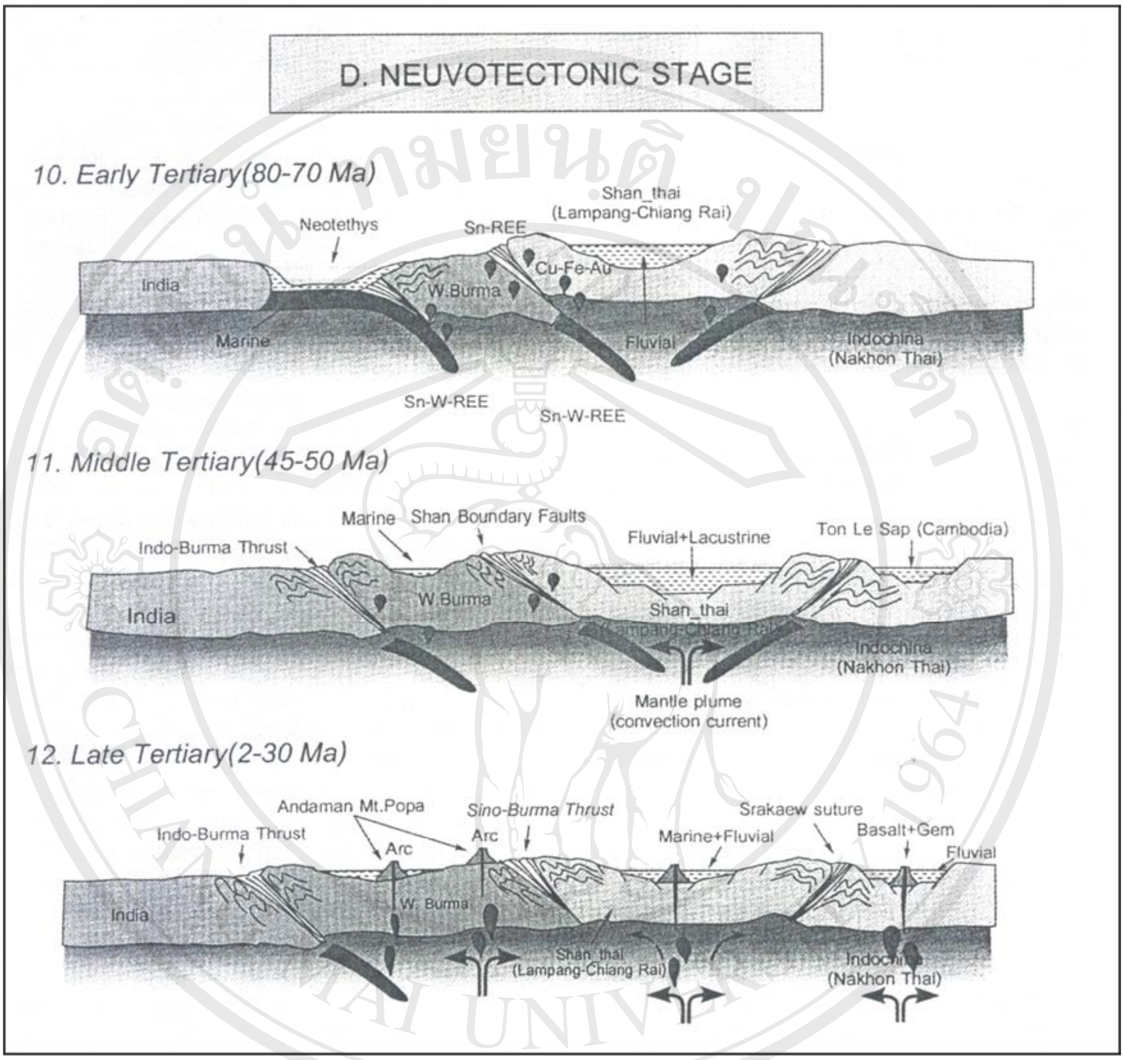

Figure 2.11 Plate-tectonic reconstruction of major plates in Thailand during Tertiary (Charusiri et al., 2002).

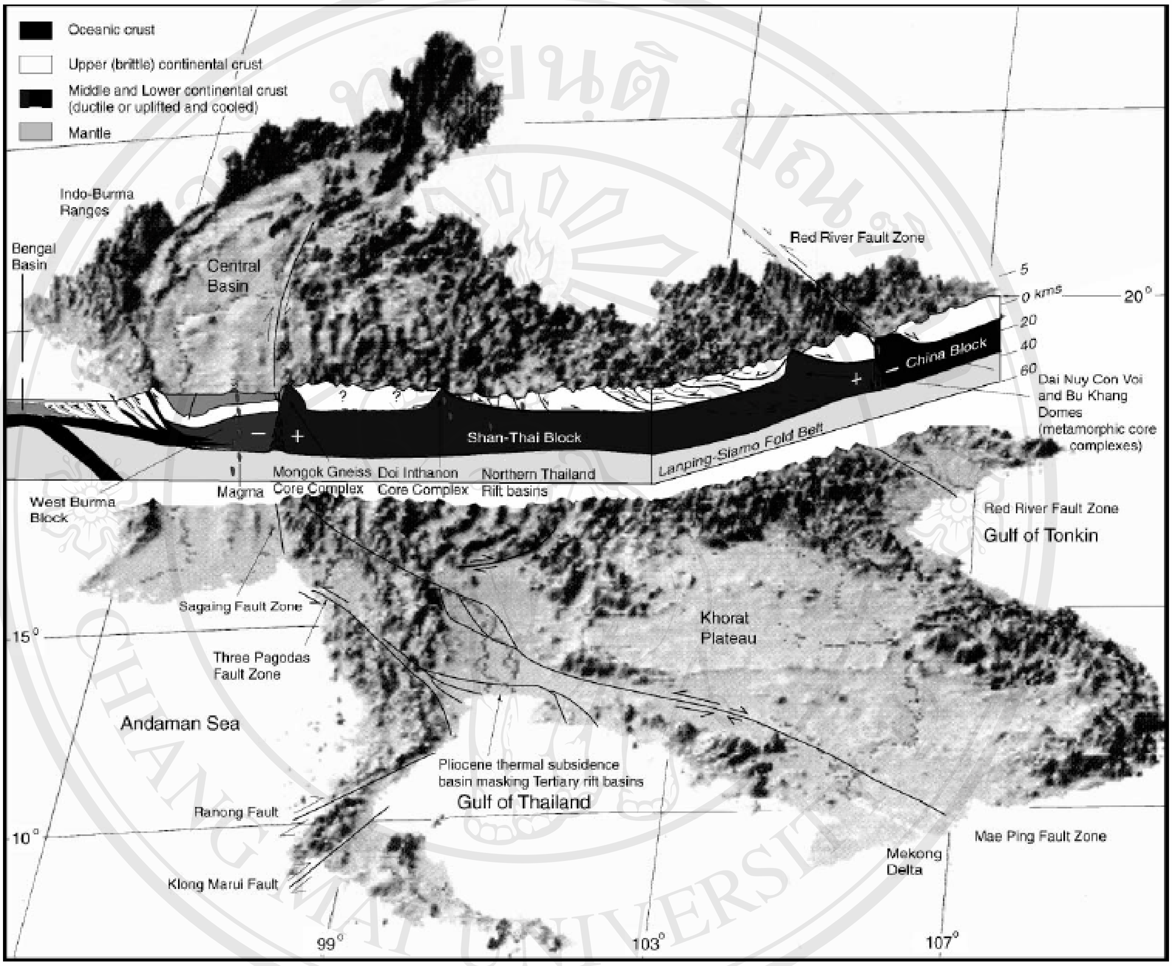

Figure 2.12 Tectonic model illustrate key Tertiary geological features and their link with topography. The crustal-scale geological cross-section is very schematic, and the geology at depth is not well constrained (Morley 2002).

west of the main belt of extensional basins, lies a highland area (west of Chiang Mai) composed of granite, gneiss and Paleozoic cover rocks, which appear to be part of several metamorphic core complexes (Rhodes et al., 1997). Possibly, collision of the West Burma block with western Sundaland (Shan–Thai block) produced a crustal thickening event and intrusion of granites (Western Granite Belt). At least three important regions of metamorphic core complex development affected Indochina from the Oligocene–Miocene (Mogok gneiss belt; Doi Inthanon and Doi Suthep; around the ASRR shear zone). The presence of these regions is a departure from the rigid block theory of escape tectonics, and shows that in Paleogene crustal thickening, buoyancy-driven crustal collapse, and lower crustal flow are important elements of the Tertiary evolution of Indochina (Figure 2.12).