CHAPTER II

GEOLOGY

In order to fully understand the formation of the Li basin, it is considered that the geological setting of the study and neighbouring areas, stratigraphy as well as the tectonic framework and sedimentation of the basin should be well established.

The regional geology and stratigraphy of northern Thailand has been compiled exclusively out of previous investigations up to 1982, the most updated geological map of the Li basin and neighbouring area in the 1:50,000 scale has been prepared. In addition, detailed sub-surface information from the drilling exploration has been carried out by numerous organizations, notably, Department of Mineral Resources (DMR.), National Energy Administration (NEA.), Electricity Generating Authority (EGAT.) and Ban Pu Coal Co.,Ltd.,etc. including laboratory studies has been compiled for the present study. Factual information regarding this aspect is presented in this chapter.

2.1 Physiography of Northern Thailand

Northern Thailand is a basin and range province extends on to the great tract of north-south trending mountain ranges between the Salween and Mekong rivers. The average elevation of the mountains is about 1,600 metres above the mean sea level. The important mountain ranges in the north are Daen Laos range, Thanon Thongchai range, Phi Pan Nam range, and Luang Phrabang range. Thanon Thongchai

range consists mainly of mountains whose crests reach the altitude of more than 1,000 metres above the mean sea level, including Doi Inthanon (2565.3 metres), the highest peak in the country (Narong Thiramongkol, 1983). The topography of the hills and mountains in these ranges is strongly high degree of relief.

There are many large Cenozoic intermontane basins, such as, the Chiang Mai, the Lampang, the Chiang Rai, and the Phrae basins,etc. which are often 15 to 16 kilometres wide or more. The size and shape of flat alluvial plain in the central part of these basins is dependent on the size and shape of the basin and size of the stream, but usually not over 1 to 2 kilometres wide. The elevation of the basin ground surface is between 250 and 800 metres above the mean sea level. The basin streams are sluggish and commonly meander widely. Between the alluvial plains and the mountains, there are often broad belts of low rolling hills.

The mountain streams also occur as narrow and cut-steep ravines. It seems likely that the course of the stream is modified by the irregularities of the geological structures. The four major rivers of northern region are the Ping, the Wang, the Yom, and the Nan, flowing southwardly and joining each others to form the Chao Phraya river at Nakorn Sawan in the Central plain.

Geomorphology of lowland areas in the north are active floodplain, terraces and peneplain.

2.2 Geological Setting of Northern Thailand

Geological investigations of the northern Thailand were previously conducted by Bertil Hogbom (1911), Lee (1923), Heim and Herschi (1938), Brown and others (1951), Jumchet Charaljavanaphet (1969), Baum and others (1970), etc..

Geological map of northern Thailand shown in Figure 2.2.1 was compiled by Sanam Suensilpong and others (1979 a). Generally, thick complete sequences of the Precambrian to Jurassic with some Tertiary sediments are exposed in the western region, while the eastern region the known sediments are only of the Silurian-Devonian to the Cretaceous and possibly Tertiary age (Sangas Bunopas, 1976). The following description on the northern geology of Thailand was mostly based on Sangas Bunopas.

The Precambrian rocks are high grade metamorphic rocks, exposed in a linear north-south trend in the western mountains from Changwat Chiang Mai to Changwat Kanchanaburi. The rocks are mainly composed of paragneiss, mica schist, quartz schist, calc-silicate hornfels, biotite marble, amphibolite schist and granite-gneiss. Apparently, Precambrian gneiss series are unconformably overlain by less metamorphosed or unmetamorphosed Cambrian rocks.

East of Changwat Mae Hong Son and south of Changwat Tak and Changwat Kanchanaburi, the rocks are well bedded to massive quartzite, often cross-bedded with some conglomerate beds of up to 500 metres thick. These rocks are Cambrian in age as described by Sangas Bunopas (1976), and they are conformably overlain by Ordovician limestone. The Lower Paleozoic sediments of Cambro-

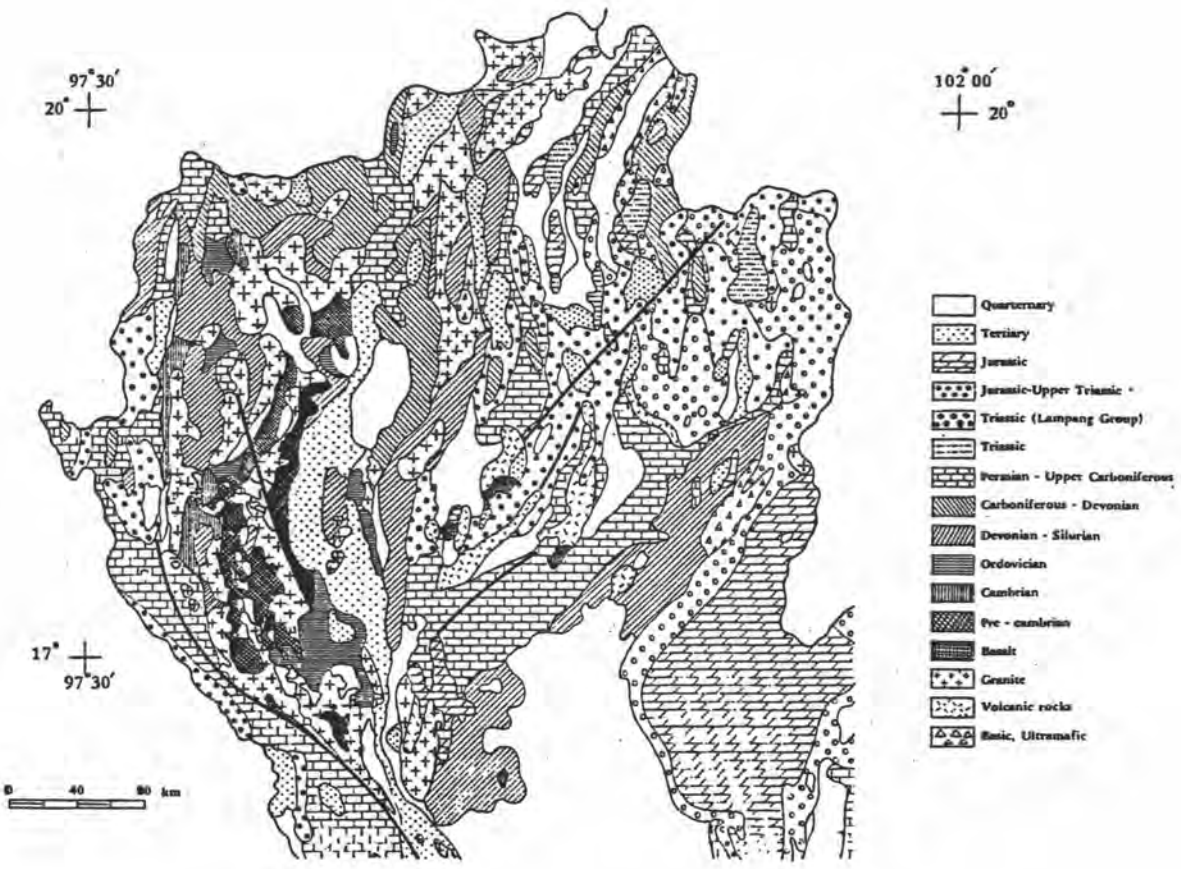


Figure 2.2.1 Geological map of northern Thailand

(After Sanam Suensilpong, 1978).

Ordovician age consist of quartzitic rocks , well bedded siltstone, sandstone with increasing amounts of shaly and calcareous intercalations in the upper part. The average thickness of the Ordovician limestone in the north ranges from 80 to 100 metres.

The Silurian-Devonian sedimentary rocks are presented in Changwat Mae Hong Son and throughout northern Thailand particularly to the southeast, west of Changwat Chiang Mai, Changwat Lampang and northeastern of Changwat Uttaradit. These rocks are graywackes, carbonaceous shales, cherts, and thin-bedded limestones.

The Carboniferous rocks are characterized by clastic sediment with some limestones or chert intercalations and agglomerate of Lower Carboniferous age. They are mainly exposed to the west of Changwat Mae Hong Son, north of Changwat Chiang Mai, southwestern part of Changwat Lampang and northern Changwat Uttaradit. The Lower Carboniferous rocks consist of thick sandstone with local conglomeratic arkose, shale with occasional limestone and chert intercalation. The average thickness ranges from 300 to 400 metres. The Upper Carboniferous sequence shows both marine and terrestrial facies. Marine sediments are chert, limestone, shale and conglomerate. Deposition of continental or non-marine clastic facies is documented by a thick red conglomerate, shale, sandstone and chert. The thickness of Upper Carboniferous sequence is up to 200 metres. Sangas Piyasin (1972) proposed the clastic rocks with andesite, rhyolitic tuff and agglomerate in the east of Changwat Chiang Mai as Carboniferous age. Clastic and marine facies continue into the Permian.

The Permian rocks consisting predominantly of limestone with minor sandstone and shale, conglomerate, volcanic conglomerate, agglomerate and tuff. In the central part of the northern Thailand , particularly between Changwat Lampang and Changwat Nan, the most complete succession is exposed. The rocks are predominantly clastic and rhyolitic, with some interbedded limestones. North of Changwat Chiang Mai and northeastern part of Changwat Mae Hong Son, the Permian rocks consist mostly of a thick limestone formation, the Ratburi Limestone. The thickness of the Permian limestone is about 100 to 150 metres.

The Permo-Triassic rocks are predominantly rhyolitic and andesitic in composition distributed in almost north-south direction from east of Changwat Chiang Rai to southern part of Changwat Lampang.

Chaiyudh Khantaprab and Kriangsak Kaewsaeng (1987) presented that the Mesozoic rocks in northern Thailand are characterized by a distinct depositional subdivision. The marine Triassic sediments rest unconformably on the Permian sediments to the south of Changwat Mae Hong Son and southeast of Amphoe Mae Sarieng and overlie the volcanic sequence in Changwat Lampang and Changwat Phrae. Marine Triassic sediments consist of shale and limestone with the facies change into a sandstone-shale sequence, described as resembling Alpine flysch (Sangas Bunopas, 1976).

The continental sedimentary environment appeared in Jurassic. These terrestrial sediments consist of red sandstone, mudstone, shale and characteristic volcanic member of mafic to intermediate

composition particularly in Changwat Nan and the east of Changwat Uttaradit, Changwat Sukhothai and Changwat Phichit.

The Cretaceous rocks are exposed in the eastern part of Changwat Uttaradit and Thai-Laos border. They consist mainly of quartz-sandstone and conglomeratic sandstone. In the area surveyed by the GGM., maximum thickness of the continental Mesozoic sediments may reach 1,000 metres.

Tertiary sedimentary rocks are consisting predominantly of lacustrine and fluviatile carbonaceous shale, sandstone, marl beds, fresh-water limestone, and mostly interbedded with organic sediments. In northern Thailand, the Tertiary sediments predominantly occur in lowland and basins with a distinct north-south trend, following the regional strike of the older formations (Sangas Bunopas, 1976).

Pleistocene terraces and Holocene flood plains are developed in basins all over the area. They lie unconformably over the older rocks.

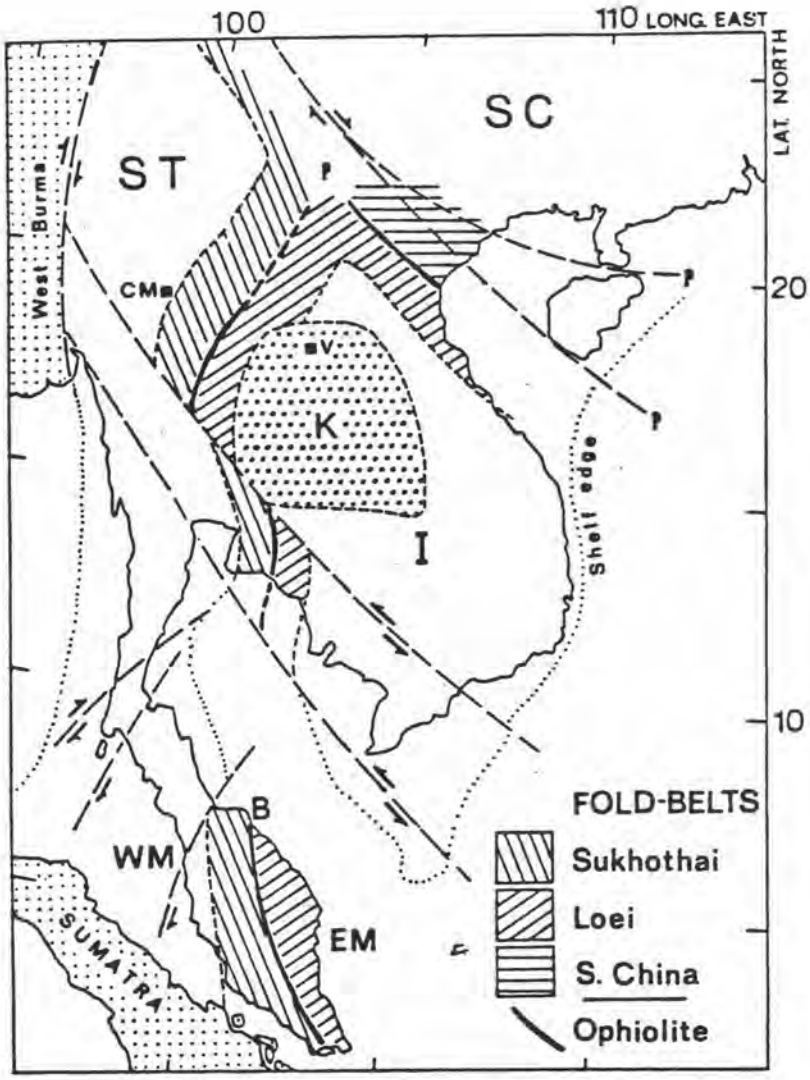
The GGM.'s final report (1972) concluded that plutonism in northern Thailand can be closely linked with orogenic events, namely, Carboniferous Orogeny and Mesozoic Orogeny (Indosinian Orogeny). The older orogeny started in Late Carboniferous producing granitic melts by the press of anatexis resulting in emplacement of some granitized material as intrusive bodies in Middle Carboniferous. The younger orogeny gave rise to the emplacement of biotite granite after Carnian/Norian time. A still younger plutonic phase was emplaced during Cretaceous and/or Tertiary time affecting granite region in the eastern part of the mountain ranges, west of Chiang Mai basin.

Sangas Bunopas and Vella (1983) suggested that the age of volcanics in the central part of northern Thailand extended from Late Permian to Early Triassic according to their category of volcanic belts. They also believe that the collision of the Shan-Thai with the Indochina cratons took place in Early Jurassic time marked by scattered occurrences of ultramafic rock to the east of Changwat Nan and northeastern Changwat Uttaradit.

The Pleistocene basaltic rocks distributed in northern Thailand at Changwat Lampang and Changwat Phrae have been investigated by Barr and others (1976), using the Potassium-Argon age-dating and paleomagnetic methods. They concluded that Lampang Basalt and the underlain pebble tools are Pleistocene age. The basalts to the north of Changwat Payao, Changwat Phrae, and the eastern part of Changwat Nakorn Sawan areas are probably of the same age as the Lampang Basalt.

2.3 Geology and Geological Evolution of Northern Thailand

Nowadays, Southeast Asia is situated in the southern part of the Eurasian Plate, the western part of the Philippine Plate, and a part of the Pacific Plate to the east, according to plate and plate boundaries of the world (Derry, 1980). Thailand is located along southern margin of Southeast Asia and it consists of two microcontinents, namely, Shan-Thai in the west and Indochina in the east (Sangas Bunopas and Vella, 1978 ; Sangas Bunopas, 1981 ; Burton, 1984). The sutured boundary between the Shan-Thai and the Indochina Blocks, namely, Nan suture is taken as the Pha Som-Sra Kaeo ophiolite belt in Thailand (Figure 2.3.1).



Ancient cratonic areas; I, Indochina (including eastern Thailand); SC, South China and ST, Shan-Thai (eastern Burma, western Thailand and Northwestern Malay Peninsula). Adjacent fold-belts are formed of thick mainly marine Paleozoic to Triassic sediments and tholeitic volcanic rocks that accumulated along the margins of the cratons. Ophiolites lie between contiguous fold belts. Sinistral faulting and oroclinal bending occurred mainly during the Jurassic and Cretaceous. K, Khorat Basin; CM, Chiangmai; V, Vientiane; WM, West Malay Peninsula; EM, East Malay Peninsula; B, Bentong ophiolite line.

Figure 2.3.1 Map showing tectonic elements of continental Southeast Asia (After Sangas Bunopas, 1981).

During the Precambrian to Lower Paleozoic it is nearly believed that the Shan-Thai and the Indochina Blocks were cratonic fragments of Gondwana Australia in the southern hemisphere. The Precambrian rocks of Shan-Thai are metasediments of amphibolite grade including marine impure carbonates and probably terrigenous turbidites. The Precambrian rocks of Indochina are similar to Shan-Thai in metamorphic grade and lithological characteristics.

According to Sangas Bunopas and Vella (1983), during Middle Paleozoic to Early Triassic the Shan-Thai Block and Indochina Block rifted and drifted to the Paleotethys. They moved from a low latitude southern hemisphere to a low latitude northern hemisphere position, and rotating nearly 180 degrees clockwise in the horizontal plane, during Early Carboniferous to Early Triassic. During the Middle Triassic, the Indochina Block trended to underthrust the Shan-Thai Block at the suture between these two blocks and the two microcontinents rapidly swung around clockwise to collide with South China block almost at the same time. Contrary to this view, it seems to Burton (1984) that the Shan-Thai and the Indochina Blocks were probably in contact by Middle to Late Permian times. The intrusion of the long belt of tin-bearing granites of Triassic to Early Jurassic age extending through Myanmar, west Thailand, the Malay Peninsula and northwest Indochina is associated with the collision of Shan-Thai and Indochina (Figure 2.3.2). When the collision was extinct, tensional tectonic regime should occur and create normal faults which deposited of Late Triassic to Cretaceous sediments. This collision is considered to be a part of the Indosinian Orogeny which terminated the marine deposition on Thailand almost permanently. Therefore, most

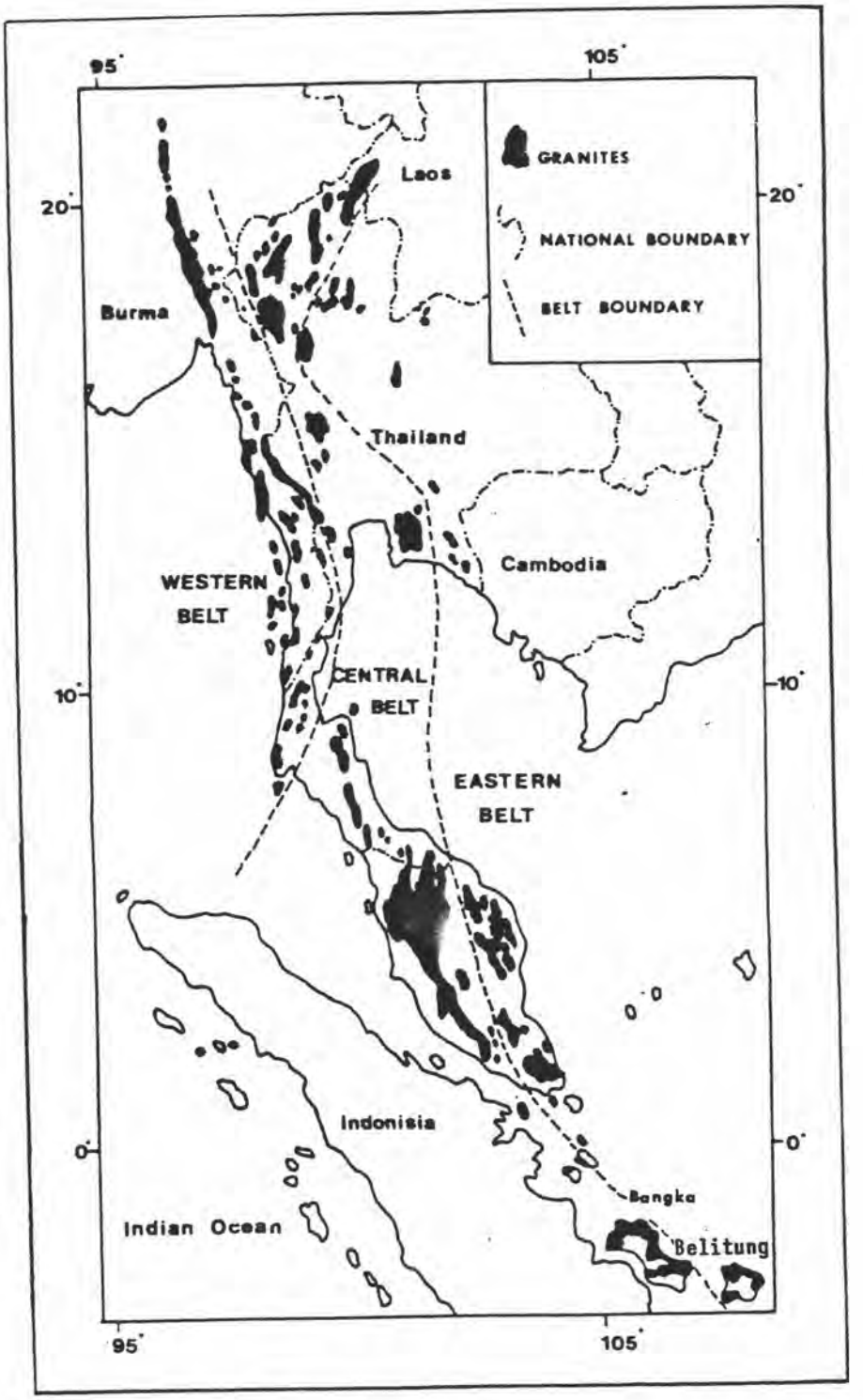


Figure 2.3.2 Regional distribution of granite belts in Southeast Asia (After Burton, 1984).

depositions are continental clastic sediments with minor small marine deposited locally. After the major orogeny, Indosinian Orogeny, mountains arose along the suture, particularly along the overthrusting Shan-Thai Block margin (Chaiyudh Khantaprab and Kriangsak Kaewsaeng, 1987). At the same time or soon after, granite intruded to high levels into the sediments [at the western as well as south-southwestern margins of the Li basin, granite emplaced into the Paleozoic rocks] and extrusive rhyolite, andesite and rhyolitic tuff on the land surface.

During Jurassic and Cretaceous, the tectonism was mainly sinistral strain manifested by northwest-southeast trending of Mae Ping and Three Pagodas [or Kwae Noi] strike-slip faults which are subparallel to the Red River strike-slip fault of which appears to be dextral at present (Pol Chaodumrong, 1985). The tin-bearing Cretaceous granites formed a belt subparallel to, and partly overlapping with the tin-bearing granites of the Late Triassic-Early Jurassic belt (Sanam Suensilpong and others, 1979 a ; Sanam Suensilpong, Prinya Puttapiban and Nopadol Mantajit, 1979 b ; Sangas Bunopas and Vella, 1983). The Mae Ping and Three Pagodas faults stopped moving in Late Cretaceous or Early Tertiary. These sinistral strike-slip faults dislocate the main geological province of Thailand and their trends have been modified by sinistral oroclinal bending that appears to be associated with the strike-slip fault (Sangas Bunopas and Vella, 1983) (Figure 2.3.3).

During Cretaceous to present time, the northwards drift of the Indian Plate resulted in subduction along the eastern margin of the present Bay of Bengal, opening of the Andaman Sea, initiation of

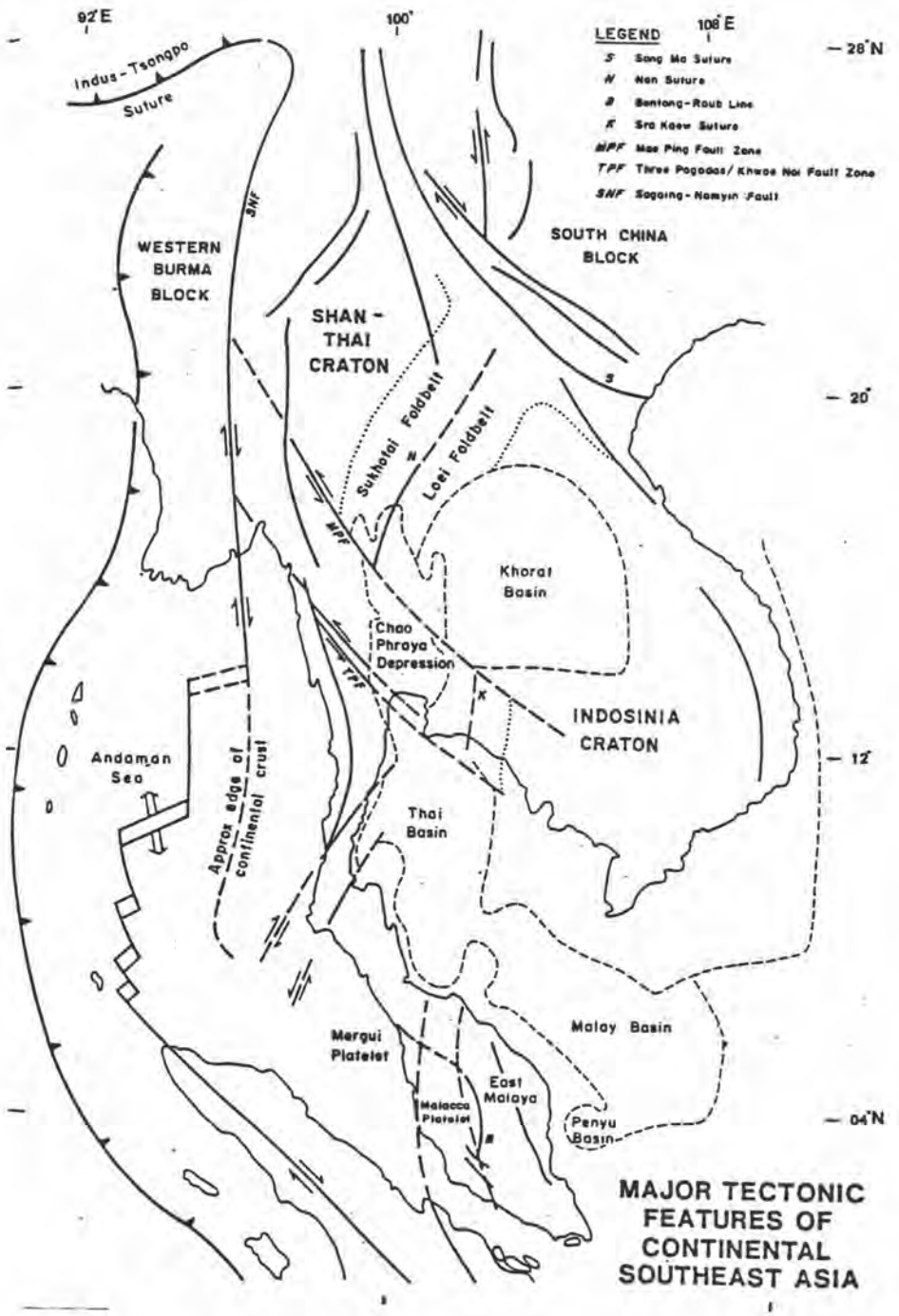


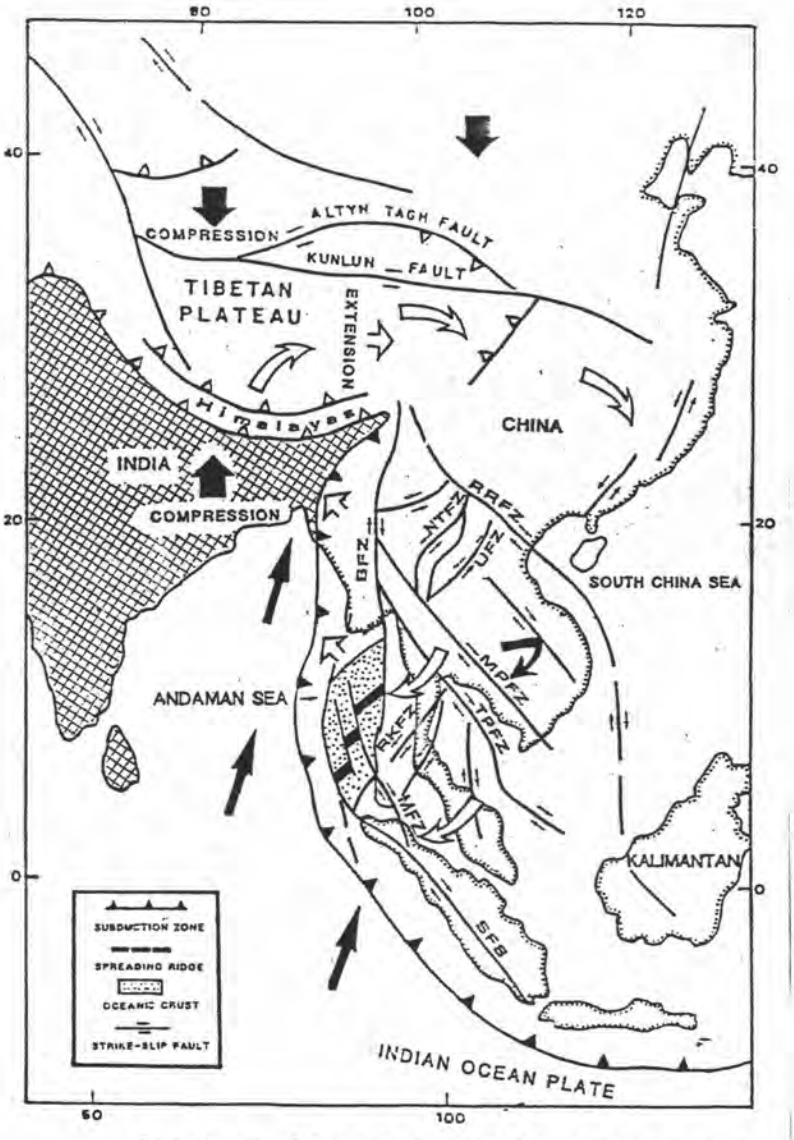
Figure 2.3.3 Major tectonic features of continental Southeast Asia (After Burton, 1984).

the Andaman-Nicobar chain, and opening of the Indian Ocean (Theerapong Thanasuthipitak, 1978 ; Sangas Bunopas and Vella, 1983 a). However, Sangas Bunopas (1983) proposed that the tin-bearing Cretaceous granites were probably resulted from this phase of subduction. The effects on the Himalayan Orogeny on the Indosinian were also found as the form of broad regional folding and block faulting. It was probably during the late stage of tectonic activity, in Paleocene or Early Eocene, that the emplacement of the Tertiary granite took place (Pol Chaodumrong,1985). This phase of granite intrusion can be regarded as post-orogenic and is generally found as dikes, stocks, or sub-batholiths superimposed on the pre-existing granites (Sanam Suensilpong and others, 1979).

According to Sangas Bunopas and Vella (1983), the India collision may have put a stop of clockwise motion of South China as well as mainland Southeast Asia. Certainly the twisting stress disappeared, Southeast Asia relaxed, and its western side gentle basin began to develop. During Tertiary, a tensional regime developed and a system of north-south trending normal faults appeared. The faults are nearly parallel to the present-day motion of oceanic crust descending beneath Indonesia along Java Trench. Tension probably started in the south with the opening of the Gulf of Thailand where many north-south trending faults have been revealed by seismic surveys and they have moved continuously during the deposition of sediments. Besides, these faults extend northwardly into northern Thailand, Myanmar and Laos. Rifting was east-west, at right angles to the trend of the normal faults.

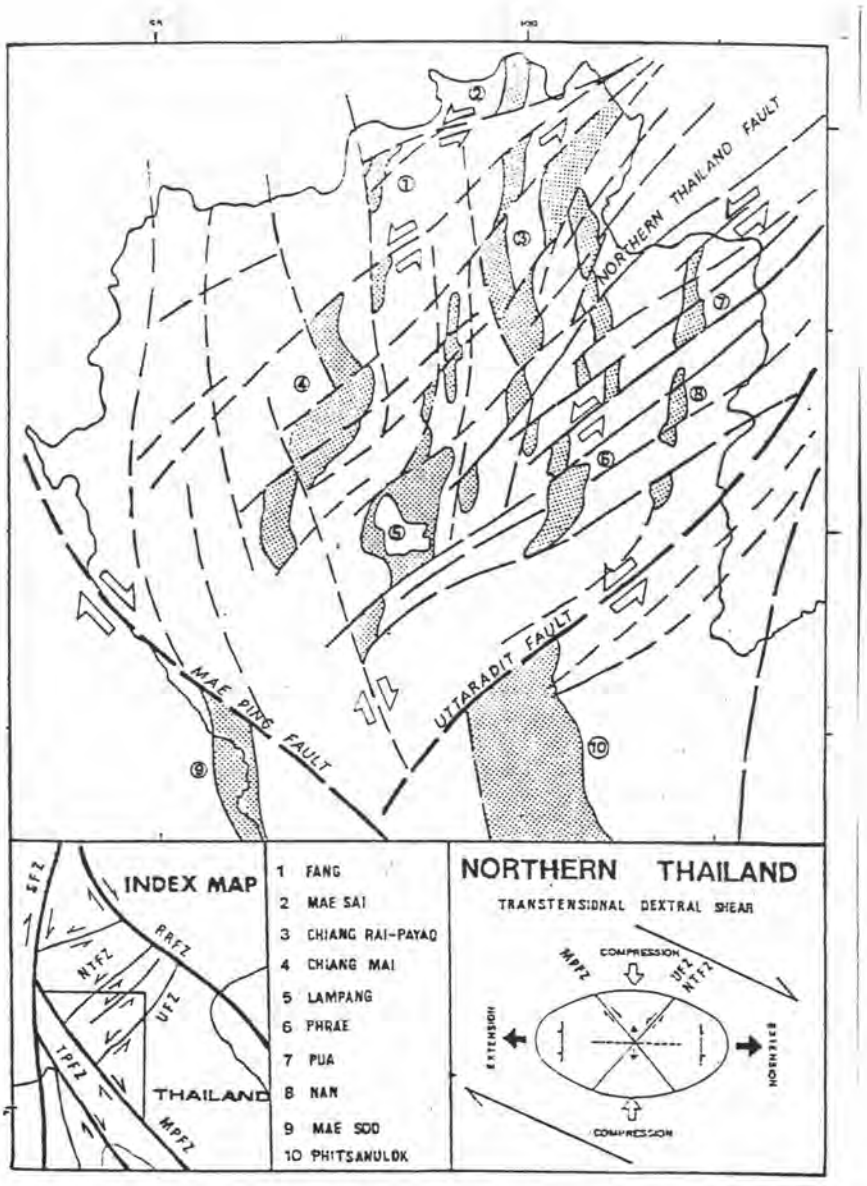
According to the study of Tertiary Mae Moh basin in northern Thailand by Vella (1983), he found that the Mae Moh basin was formed by post-Middle to Late Miocene normal faulting. Other basins in northern Thailand, some much larger than the Mae Moh basin, were probably formed at the same time under the same tensional regime. Furthermore, he suggested that the regional structure of northern Thailand seems to be like that of the northern half of the Gulf of Thailand.

According to Songpope Polachan and Nares Sattayarak (1989), the Cenozoic basins in Sundaland can be explained in terms of a major transtensional shear couple resulting from the collision of India with Asia (Figure 2.3.4). Cenozoic basins in Sundaland are mainly north-south trending basins and developed by reactivation of basement structures in Oligocene. Seismic data obtained from petroleum exploration in this area have revealed that these north-south syn-sedimentary normal faults are clearly associated with northwest-southeast trending dextral right lateral strike-slip faults and north/northeast-south/southwest trending sinistral left lateral strike-slip faults which have been active since that time. In northern Thailand, the principal dextral wrench fault is the Mae Ping fault, whereas the conjugate wrench faults are the Uttaradit and the Northern Thailand fault (Figure 2.3.5). The northwards progressive collision of the Indian Craton with Southern Asia, caused a progressive rotation of Southeast Asia results in an increasingly oblique plate convergence on the southwestern margin of Southeast Asia. This led to movements on the strike-slip faults with the associated development of transtensional basins in Thailand.



Tectonic map of S.E Asia and South China showing the main fault patterns and the relative movement of crustal blocks in response to the collision of India with Asia. SFS (Sumatran Fault System); MFZ (Mergui Fault Zone); SFZ (Sagaing Fault Zone); RKFZ (Ranong and Klong Marui Fault Zones); TPFZ (Three Pagodas Fault Zone); MPFZ (Mae Ping Fault Zone); UFZ (Uttaradit Fault Zone); NTFZ (Northern Thailand Fault Zone) and RRFZ (Red River Fault Zone).

Figure 2.3.4 Tectonic map of Southeast Asia and South China (After Songpope Polachan and Nares Sattayarak, 1989).



Structural map of Northern Thailand showing relationship between conjugate strike-slip faults and the development of N-S trending pull apart basins.

Figure 2.3.5 Structural map of northern Thailand

(After Songpope Polachan and Nares Sattayarak, 1989).

The Cenozoic basins of Thailand was probably initiated on an eroded pre-Tertiary surface with varying degrees of topographic expression during Paleogene time especially Oligocene (Knox and Wakefield, 1983). As in Phitsanulok basin, and also other onshore basins, the basin fill consists of Oligocene to Lower Miocene fluviatile clastics with local development of lacustrine facies which was followed by wide spread of Lower to Middle Miocene lacustrine facies. Prominent unconformities in the central basin and some onland Tertiary basins are the Pleistocene-Pliocene and late Middle Miocene unconformities (Pol Chaodumrong and others, 1983). During Middle Miocene time, major tectonic and/or climatic change result in the disappearance of the paleo-lake as indicated by K/Ar radiometric age (Knox and Wakefield,1983) dated as 10.3$\pm$ 0.2 million years of the basaltic lava provides a dating for the shallow basin-wide unconformity. Other onland basalt which is found on Ko Kut Island, eastern Gulf of Thailand dated as 8.5$\pm$ 1 million years (Barr and Macdonald, 1978). The Middle Miocene unconformity is also clearly identifiable in the Gulf of Thailand (Wollands and Haw, 1976). The unconformity appears to represent a major episode of uplift which followed by an influx of coarse to fine clastic sediments. Late Tertiary to Early Quaternary basalts were widely distributed in northern, central and southeastern parts of Thailand. Judging from the fact that basalt is overlying the gravel bed at Nam Mae Jang and overlying the pebble tools at Changwat Lampang, northern Thailand. The K/Ar radiometric age of Lampang basalt dated as less than 1.7 million years (Barr and others, 1976). The present-day topography of northern Thailand has been determined by the Late Tertiary and/or Pleistocene events such as normal faulting and uplifting (Baum and

others, 1970).

2.4 Geology of Li Basin

The geology of the Li basin and the adjacent areas were previously reported by numerous workers, namely, Department of Mines (1961), Phumval Komalarachun and others (1961), Sangas Bunopas (1962), Verasak Nakintarabordi (1965), Thawat Japakasetr and others (1973), Charal Achalabhuti (1974), Pol Chaodumrong and others (1982), Sathien Snansieng and Niwat Maneekut (1985), etc.. An attempt has been made here to revise the geological map of the area with emphasis on the areal extent of Tertiary deposits (Figure 2.4.1 a,b). It is noted that the lithostratigraphic boundaries of rocks are slightly modified. However, the units name used in this study remain unchange according to Sangas Piyasin (1972).

2.4.1 Basement Stratigraphy of Li Basin and Neighbouring Area

There are various rocks exposed in the surrounding areas of the Li basin ranging in age from Paleozoic to Holocene. The high-landed ranges to the west, the south and the east of the basin are composed of Paleozoic rocks ranging from Cambro-Ordovician to Permian periods. They are both clastic and carbonate rocks, slightly to intensively metamorphosed (Figure 2.4.1 a, b).

The Cambro-Ordovician rocks are referred to as Tarutao Group which locally exposed in the further southwestern part of the Li basin. The rocks are mainly bedded sandstone to quartzitic sandstone, gray reddish-violet to brown, thin to thick bedded, with shale intercalations increasing from bottom to top. The upper part of the sequence is calcareous sandstone interbedded with limestone and

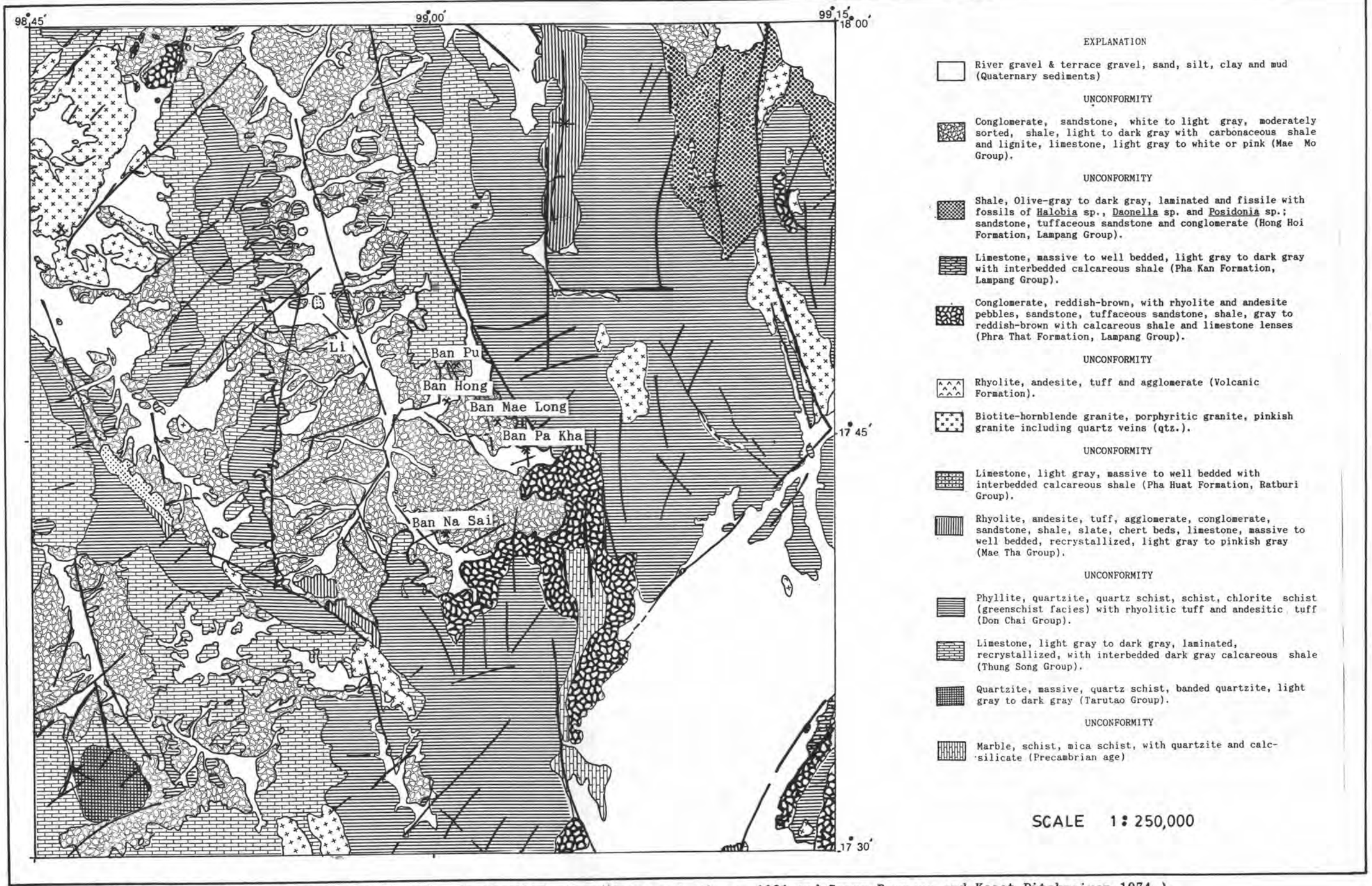


Figure 2.4.1.a The geological map of the Li basin (Compiled from Braun and others, 1981 and Saman Buravas and Kaset Pitakpaiwan,1974).

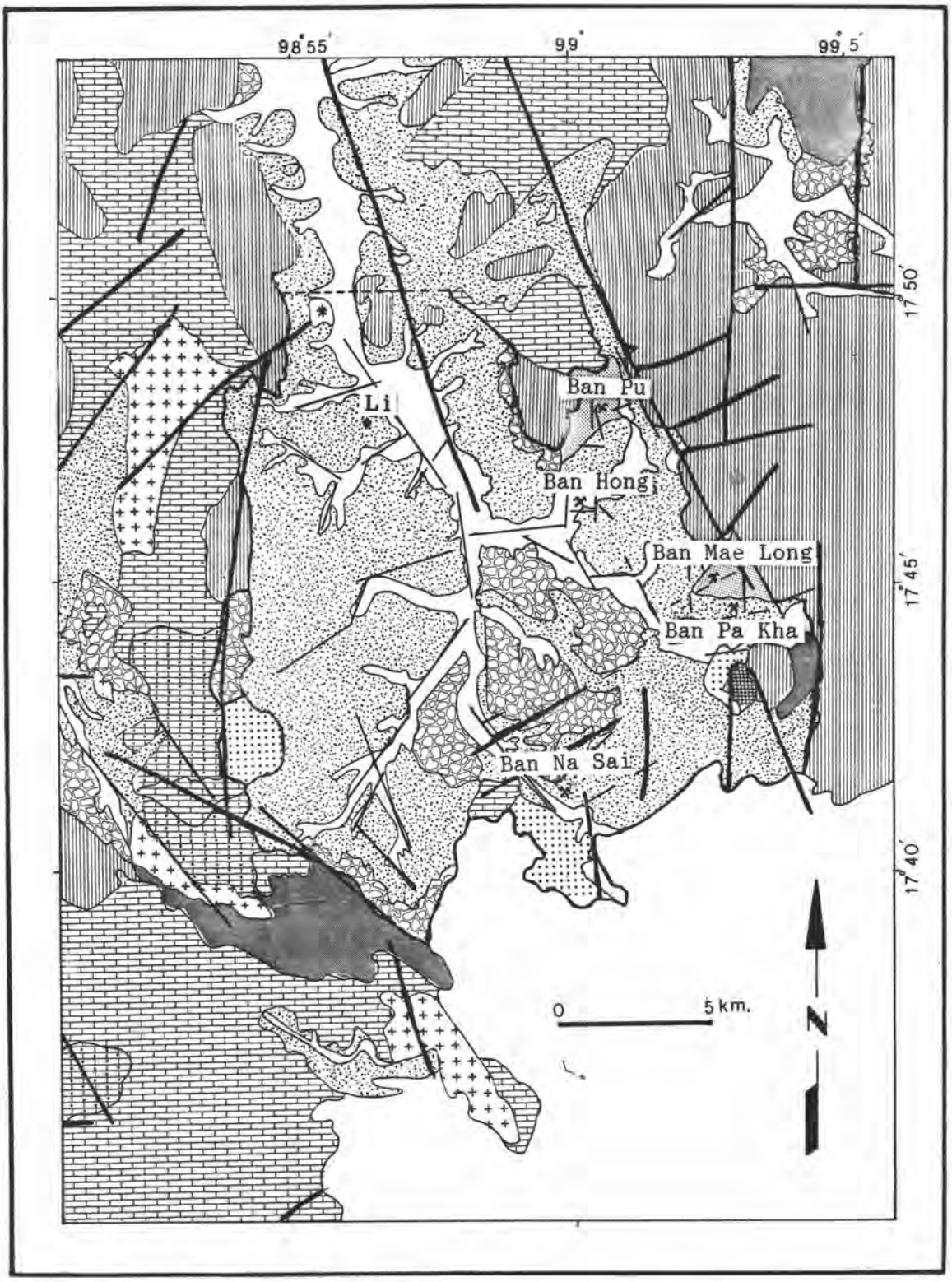


Figure 2.4.1.b The geological map of the Li basin (Compiled from Pol Chaodumrong and others, 1985 ; Somchat Boripatkosol and others, 1985 ; Pol Chaodumrong and Suwit Chiemton, 1986 and Somchat Boripatkosol, 1986).

EXPLANATION


Gravel, sand, silt and clay.


Colluvium, lateritic soil with iron and manganese nodules, gravel, sand, silt and clay.


Gravel beds with clasts of quartzite sandstone, quartz, chert, phyllite and matrix of sand, silt and clay.

UNCONFORMITY


Claystone and mudstone, greenish-gray,calcareous cemented, fossils of Miocene age,coal, sandstone, conglomerate (Mae Moh Formation, Krabi Group).


Mudstone, marl bed, coal, oil shale, shale, sandstone, plant fossil, gastropods, bivalves, fish remains and shell arthropods (Li Formation, Krabi Group).

UNCONFORMITY


Sandstone interbedded with shale, reddish-brown (Pha Daeng Formation, Lampang Group).

UNCONFORMITY


Rhyolite, andesite and tuff


Biotite-granite,hornblende-biotite-granite to leuco-granite.

UNCONFORMITY


Limestone, marble, light gray to gray with fusulinid and coral (Pha Huat Formation, Ratburi Group).


Sandstone, light gray, thin to thick bedded, shale, dark gray (upper unit, Mae Tha Group).


Red bed: sandstone, conglomerate, siltstone and shale, fining upward sequence, ripple mark, rain prints and mud cracks (lower unit , Mae Tha Group).

UNCONFORMITY


Quartzite, quartz-schist, mica-schist, phyllite, slate, shale, gray to brownish-gray, graywacke, light gray to greenish gray (Don Chai Group).


Limestone, thin to thick bedded, interbedded with black shale at the lower part, sandstone, siltstone and shale at the upper part, fossil of nautiloids indicate Silurian-Devonian age (Nam Tok Ko Formation).


Limestone, laminated to thin bedded, interlayered with calcisilite and calcarenite, shale, marble, fossil of nautiloid indicate Ordovician age (Thung Song Group).

shale. The Cambro-Ordovician rocks underlie conformably the Middle Ordovician limestone.

The Ordovician sediments of the Li basin are referred to as the Thung Song Group characterized by mainly massive, recrystalline, grayish to blackish argillaceous limestone with thin intercalations of shale. The distributions of the Ordovician limestone are scattered through the northern and western outer-rim of the Li basin as mountains. However, in the vicinity of Ban Na Sai sub-basin, the Ordovician rocks crop out in low-lying area of about 2 square kilometres. The age of this limestone was also proposed by Braun and others, 1981 in Geological Map of Thailand, scale 1:250,000 sheet Amphoe Li as Ordovician age.

The Ordovician-Silurian rocks are locally exposed in the southwestern rim of the Li basin. The rocks are referred to as the Nam Tok Ko Formation (Pol Chaodumrong and others,1985) characterized by thin to thick bedded, gray to greenish gray limestone at the lowermost of the sequence, grading to clastic sediments of fine-grained sandstone, siltstone, shale at the uppermost of the sequence.

The Silurian-Devonian rocks, or Don Chai Group (Piyasin,1972) is composing of quartzite, quartz-schist and phyllite, overlie conformably the Ordovician - Silurian rocks earlier described. These Silurian-Devonian rocks are exposed on the western, southern, eastern and northern edges of the Li basin, bounded the basin in nearly all directions by fault and/or unconformity contacts. The continuous succession of the Silu-Devonian and the Ordovician rocks can be observed at the western edge of the basin and further to the

northern edge of the basin in the vicinity of Mae Thoei Barite Mines.

The Carboniferous rocks, referred to as Mae Tha Group?, is consisting of two formations. The lower formation is red beds, consisting of fine- to coarse-grained sandstone, fine-grained conglomerate, laminated to thin bedded siltstone and shale with fining upward sequence as well as various types of sedimentary structures. The upper formation is medium- to coarse-grained, thin to very thickly bedded, light gray sandstone with load cast, dark gray shale. The Carboniferous rocks are exposed at the southeastern and southern rims of the Li basin (Pol Chaodumrong and others, 1985).

The Permian rocks exposed in this area are referred to as Pha Huat Formation of the Ratburi Group. The rocks are limestone, light gray, massive to well bedded with interbedded calcareous shale, exposed at the southern, southwestern and eastern rims of the Li basin and the low-lying area near the Li river (Sangas Bunopas, 1976; Braun and others, 1981).

Volcanic Formation is exposed in the southern part of the study area as a high mountain range elongated almost in the north-south direction. Normally, the formation overlies unconformably Pha Huat Formation and underlies disconformably the marine Triassic of Lampang Group. The lithology is characterized by rhyolite, tuff, agglomerate and andesite which are exposed at Paholyothin highway (km. 520 to km. 523), Mae Arb Reservoir and Li-Thoen road (Somchat Boripatkosol, 1986).

Granitic rocks mostly flank the western part of the study area and some are exposed in the eastern and southern parts of the Li basin. The rocks are biotite-hornblende granite, porphyritic granite, pinkish granite including quartz veins, leuco-granite, granodiorite and aplite dike which are present as stocks and dikes (Sangas Piyasin, 1972; Braun and others, 1981; Pol Chaodumrong, Suwit Chiemton and Sathien Snansieng, 1985; Somchat Boripatkosol, Niwat Maneekut and Sathien Snansieng, 1985 ; Pol Chaodumrong and Suwit Chiemton, 1986; Somchat Boripatkosol, 1986).

The Triassic rocks, referred to as Lampang Group are proposed by Sangas Piyasin (1972) which can be further subdivided into 5 formations, namely, Phra That, Pha Kan, Hong Hoi, Doi Chang and Pha Daeng Formations in ascending order. Four formations except Doi Chang Formation are exposed in this area.

Phra That Formation is exposed as small area in the southeastern part of the study area consisting of sandstone, siltstone and conglomerate with occasionally intercalated bedded limestone. These rocks are generally coarse grained and red in colouration at the base, and gradually decreasing in grain size upward with green to gray colour. The thickness of this sequence is greater than 300 metres. They are believed to have been deposited in near-shore and partly continental environments (Thanit Wongwanich and Srisopa Maranate, 1984). The age of this formation from previous works ranges from Scythian to Anisian [Lower to Middle Triassic] (Somchat Boripatkosol, Niwat Maneekut and Sathien Snansieng, 1985).

Pha Kan Formation overlies conformably Pha That Formation and underlies conformably the Hong Hoi Formation. This formation is exposed in the eastern part of the study area consisting of light gray to gray limestone, with intercalated calcareous shale. The thickness of this sequence is greater than 150 metres. At one locality, the pelecypod fossil has been found and later correlated with that of Ban Tha Si, Changwat Lampang. The age of this formation from previous works ranges from Anisian to Ladinian [Middle Triassic].

Hong Hoi Formation is exposed in the eastern side of the study area at Ban Mae Turn. The lithology is characterized by predominant gray to greenish gray shale with ellipsoidal fracture and greenish gray to gray sandstone, tuffaceous sandstone and conglomerate. This sequence is greater than 500 metres thick. Numerous marine bivalves and ammonoids, specially Halobia sp. and Daonella sp. are found in this formation indicating the age range from Ladinian to Carnian [Middle to Upper Triassic].

Pha Daeng Formation is proposed by Sangas Piyasin (1972) as in Lampang Group. Now, Pha Daeng Formation is excluded from the Lampang Group because of its continental origin and believed to be equivalent to the Nam Pha Formation of the continental Khorat Group (Chongphan Chonglakmani, 1983). Pha Daeng Formation is exposed as small areas in the northwestern part of the study area at Doi Prabat Tamor and the mountain range that divided Changwat Lamphun and Changwat Chieng Mai [km.6 on Li-Doi Tao road]. The rocks are reddish brown in colour consisting of medium- to fine-grained sandstone, intercalated with shale. The thickness is greater than 200 metres.

The age of this formation ranges from Rhaetian to Norian [Upper Triassic] (Somchat Boripatkosol, 1986).

2.4.2 Tertiary Stratigraphy of Li Basin

The Tertiary sediments of intermontane basins in northern Thailand, including Li basin, overlie unconformably pre-Tertiary rocks and underlie unconformably the unconsolidated sediments of the Quaternary age. The lithology is described as sediments of lacustrine and fluviatile origins, and almost all of them are believed to contain organic deposits such as coal, petroleum, oil shale and diatomaceous earth. Various macrofauna and flora have been found and identified. However, these fossils were collected from a limited stratigraphic interval which has led to conflicting age assignment of the basins. Due to the fact that almost all of the Tertiary deposits are not exposed and all of the drill - holes are carried out for economic purpose which penetrated only a few metres below the coal, oil shale or prospecting materials. Very limited boreholes reached the basement of pre-Tertiary rocks. Therefore, the knowledge on the overall Tertiary stratigraphy of those basins are very limited, even in the Li basin where the stratigraphy of the basin is partly established recently in 1985.

The Tertiary sediments of the Li basin had been first studied by Sangas Bunopas in 1962. Because of the inefficient technique in borehole drilling process and high ground water level, only shallow boreholes were drilled. He was defined the lithological log of Li sediments at Huai Mae Van of Amphoe Li, Changwat Lamphun that could be concluded as shown in Table 2.4.2.1.

Table 2.4.2.1 Lithological log of Li sediments at Huai Mae Van of Amphoe Li, Changwat Lamphun (Summarized after Sangas Bunopas, 1962).

Description	Thickness(m.)
Soil deposits	0 - 1
Terrace and alluvial deposits : silt, sand, gravel and boulder, gray to reddish gray, gradually decreasing in grain size upward (1/4 to 2 feet) grains are quartzitic to conglomeratic boulder while matrix is gray to reddish gray shale.	1 - 6.85
----------unconformity----------	
Oil shale: light to dark gray, reddish gray, brown, slightly hard, locally with coal fragments, commonly plant fossils, latitude of beds commonly north/northwest-south/southeast with dipping mostly in western direction.	1.3 - >5.36
----------gradational contact----------	
Coal : black,hard, coal plies interbedded within coal seam, blocky fraction, attitude of coal seam is the same as in oil shale but one locality has dipping in the east direction, partings of gray shale with coal fragments.	3.29 - 9.04
----------?----------	
Sandstone : green to greenish gray, coarse-grained, loose.	unidentified thickness

In 1969, the geological map of Thailand in 1:1,000,000 scale has been prepared by Jumchet Charaljavanaphet. He proposed the name Krabi Group for all of Tertiary sediments in Thailand and divided Tertiary rocks of northern Thailand into 2 formations, Mae Mo Formation for the upper formation and Li Formation for the lower one. The Mae Mo Formation is present in Mae Mo, Fang and Mae Sot basins, whereas the Li Formation is present in Li basin.

In 1974, Sangas Piyasin prepared the geological map of Uttaradit in the 1:250,0000 scale. He proposed that the Tertiary rocks of Ban Pa Kha, Amphoe Li to be the Mae Mo Group. Contrary to this view, Phutorn Sukkato (1979) classified these rocks as Li Formation of the Krabi Group.

Sanam Suensilpong and others (1979) classified Tertiary sediments into Krabi Group which is further divided into 2 formations, Li Formation for the lower formation and Mae Mo Formation for the upper formation, almost similar to Jumchet Charaljavanaphet in 1969 but slightly different in the age assignment.

Pol Chaodumrong and others (1982) studied the Tertiary sediments of Thailand in order to understanding the origins and characteristics of sediments and associated organic deposits. Li basin is chosen in this study. They proposed that the rocks under the erosional surface under the uppermost gravel bed to be the Li Formation of the Krabi Group. The rocks are claystone, mudstone, coal and oil shale. They noticed that coals are found in many areas specially in the east at Ban Pa Kha and Ban Pu Coal Mines, Li river, Huai Pong Kong and Huai Siri of Ban Na Sai (Figure 2.4.2.1). The

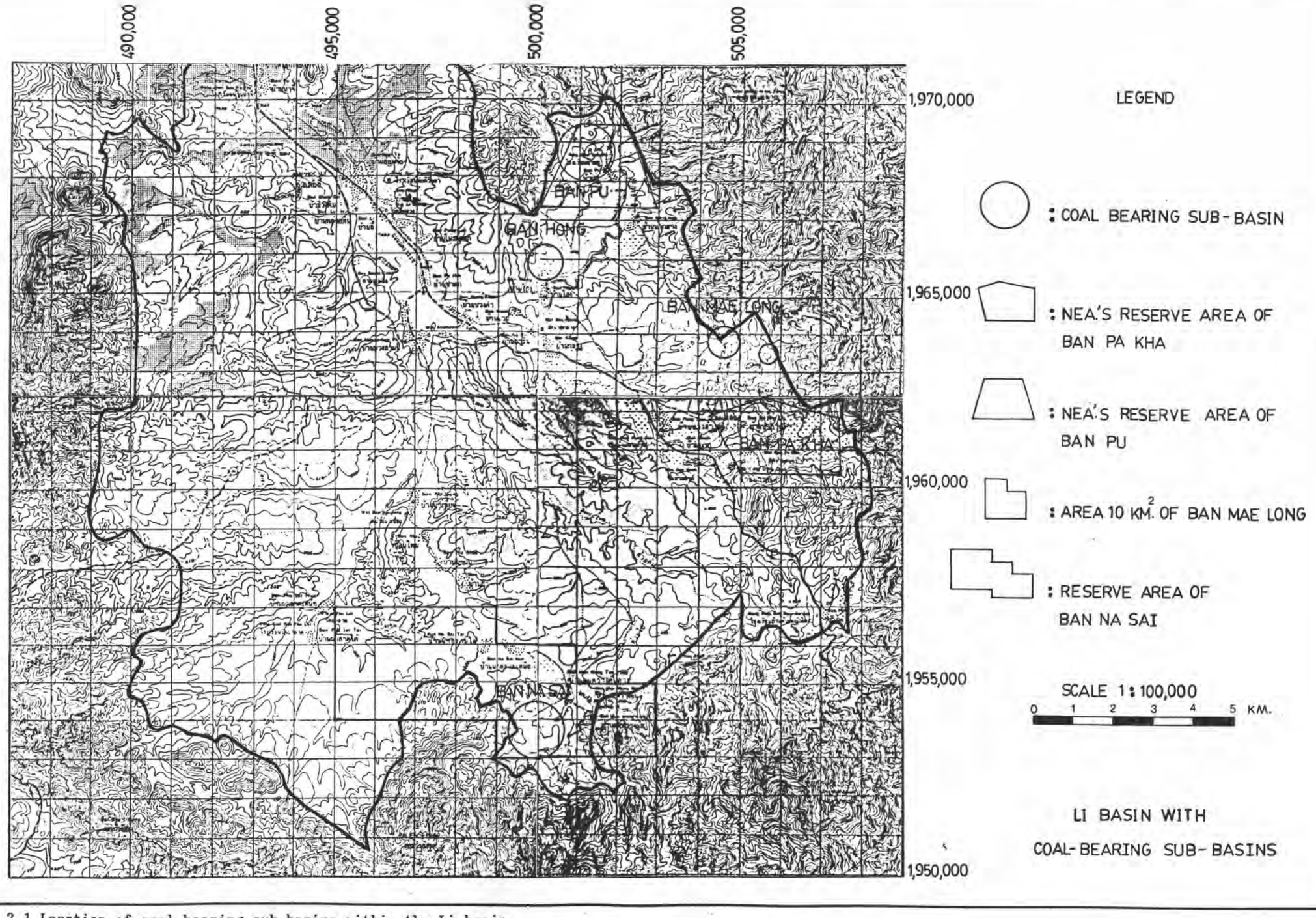


Figure 2.4.2.1 Location of coal-bearing sub-basins within the Li basin.

stratigraphic columns and descriptions of each area are reported as follows :

+ Ban Pa Kha sub - basin is a structural basin within the Li basin. The length of the sub - basin is approximately 2.5 kilometres and about 1 kilometre in width. In 1966, Krupp Rohstoffe concluded that coal seams in this basin are limnic coal and borehole data indicate two coal seams, the upper and the lower seam, with thick clay parting between these two seams. The average thicknesses of coal seams are 8.7, 2.7 metres, respectively ; whereas that of the parting is 5.9 metres. The stratigraphic column measured at the southern part of Ban Pa Kha mine pit (from the ground surface to the upper coal seam) is shown in Figure 2.4.2.2. Fossils founded in this section indicate fresh water environment and depositional conditions changed from coal forming swamp to shallow lake condition. Proximate analysis of the coal indicates that it is of high volatile C bituminous rank (ASTM. Classification of Coal by Rank, 1977).

+ Ban Pu sub - basin is another economic sub-basin within the Li basin. The coal outcrops are exposed in 4 areas, World Fuel Coal Mine, NEA. Coal Mine, Li river and Huai Mafai. The deepest borehole data shows that the thickness of Tertiary sediments is greater than 82 metres. The variation in the depth to the coal measure that is generally greater in western direction is influenced by almost north-south trending normal faults. Displacement of faults caused the erosion of the sediments in the eastern side. The tree stump in growth position that found in light gray claystone, under the coal seam at the southern part of this area indicates the in situ origin of well - drained swamp. Figure 2.4.2.3 shows the stratigraphic

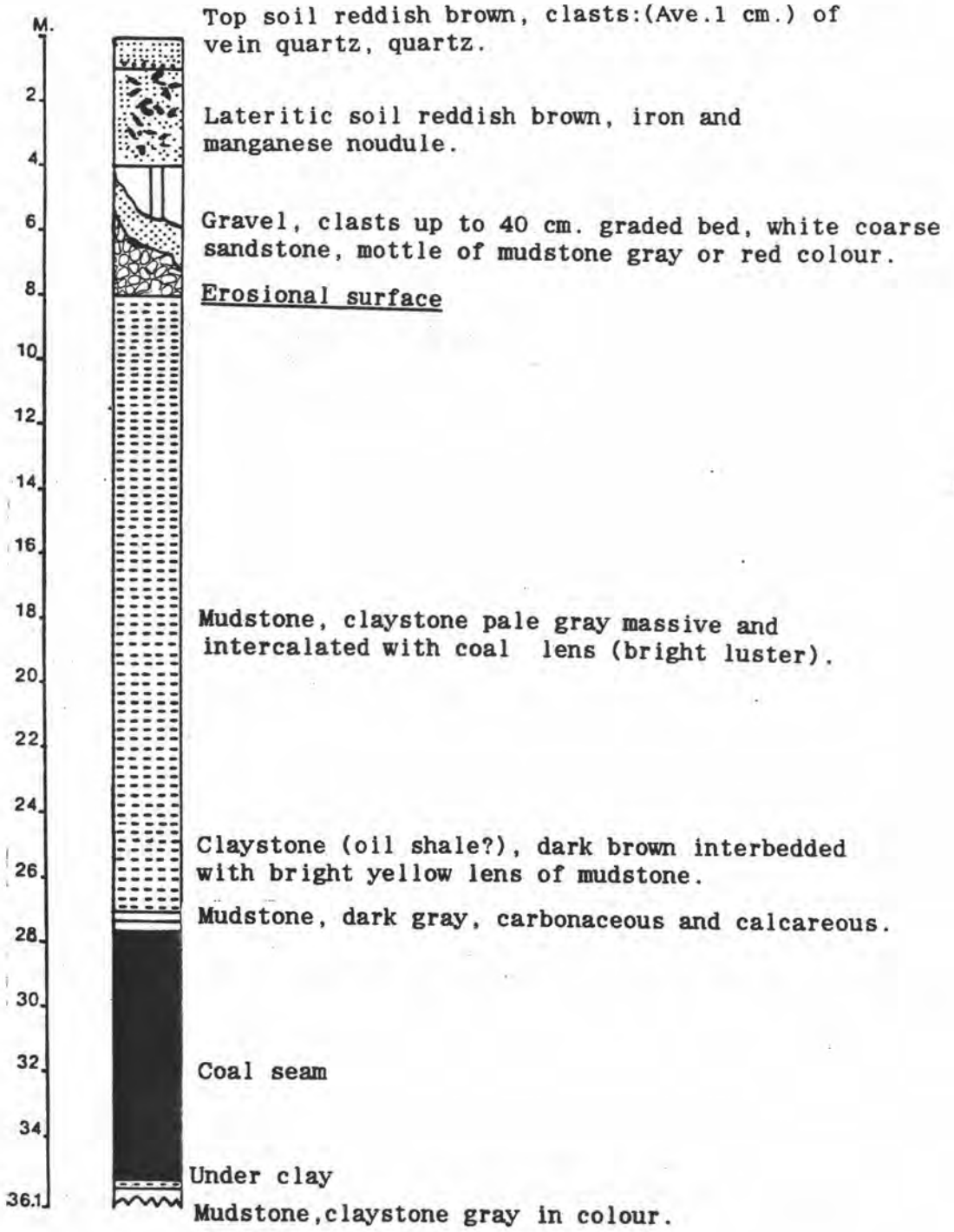


Figure 2.4.2.2 The stratigraphic sequence of the Tertiary sediments at the southern part of Ban Pa Kha mine pit (from the ground surface down to the upper coal-seam)(After Pol Chaodumrong and other, 1982).

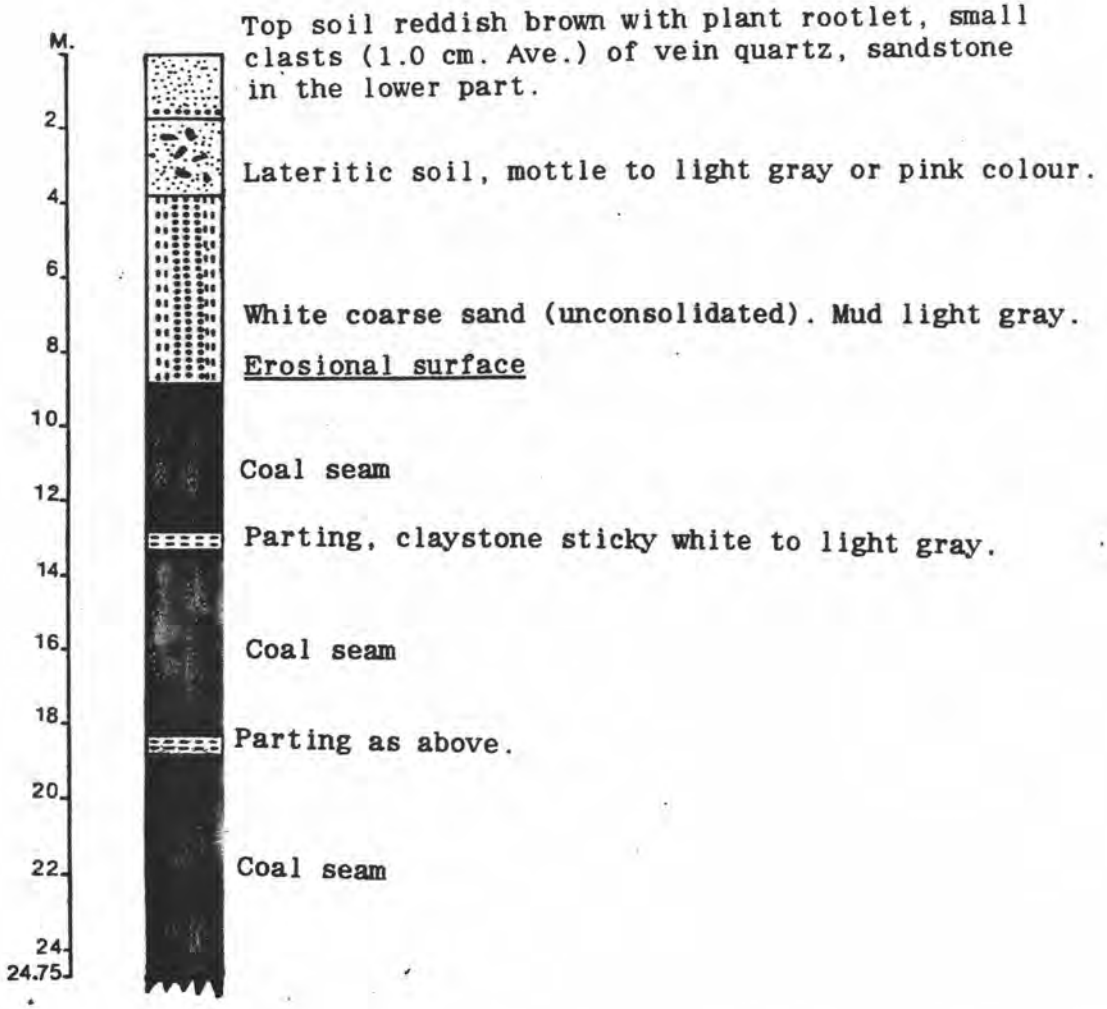


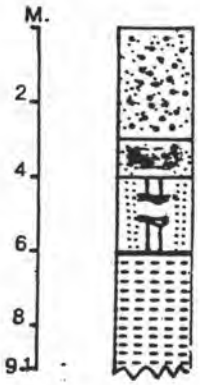
Figure 2.4.2.3 The stratigraphic sequence of the Tertiary sediments at the World Fuel mine, the central part of Ban Pu sub-basin (After Pol Chaodumrong and other, 1982).

column measured at the World Fuel Coal Mine. Parting of the coal seam is white to gray claystone, 2 to 50 centimetres thick, while the thickness of coal seam is greater than 15 metres. Proximate analysis of coal indicates that it is of sub-bituminous coal rank (ASTM. Classification of Coal by Rank, 1977).

+ Huai Pong Kong area : the coal crops out along the Huai Pong Kong ravine. Coal beds lie subparallel to the ravine in northwestern direction with westward high angles dipping. Bright, metallic luster suggests the sub-bituminous coal rank. The thickness of this coal seam is greater than 8 metres and lying under lateritic soil, gravel and sand of Quaternary age.

+ At Mae Long reservoir,coal bed crops out on the bench surface of the reservoir. The stratigraphic column is shown in Figure 2.4.2.4. The lower part of the sequence is mudstone, light gray claystone with secondary gypsum (sugary texture). Coal bed of lignite rank is overlain by mud with caliche lens. NEA.'s borehole data suggest that the coal deposit in this area is not economically significant.

+ Ban Na Sai sub - basin is located in the southern part of the Li basin . The rocks are crop out at Huai Siri, lying in the northwest-southeast direction on quartzitic basement. This unit is overlain by gravel, sand and lateritic soil of Quaternary age. Coal bed is characterized by brown to dark brown, earthy luster of lignite rank (ASTM. Classiification of Coal by Rank, 1977). Each coal beds is approximately 30 centimetres thick. However, the coal seam thickness is about 3 to 5 metres. Stratigraphic column of Huai Siri



Lateritic soil

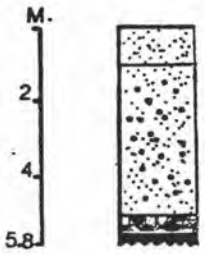
Gravel; clast of vein quartz, sandstone, 0.5 cm. (Ave. size). matrix:mud light gray.

Mud, caliche in upper part.

Lignite bed.

Mudstone, claystone light gray, sticky with secondary gypsum (sugary texture).

Figure 2.4.2.4 The stratigraphic sequence of the Tertiary sediments at Mae Long reservoir within Ban Mae Long sub-basin (After Pol Chaodumrong and other, 1982).



Top soil

Lateritic soil, laterite

Gravel, fragment of lignite.

Lignite brown to dark brown, earthy luster.

Figure 2.4.2.5 The stratigraphic sequence of the Tertiary sediments at Huai Siri, the Ban Na Sai sub-basin (After Pol Chaodumrong and other, 1982).

sequence is shown in Figure 2.4.2.5.

Sathien Snansieng and others (1983) proposed that the Tertiary sediments of the Li basin were deposited in the intermontane fault - bound basin. The Tertiary sediments of the Li basin can be classified into Paleogene and Neogene sediments. The Paleogene sediments are well exposed at the eastern rim at Ban Pa Kha whereas the Neogene sediments can be observed at the western of south-western rim at Ban Na Sai (Figure 2.4.1.b). The thickness of sediments within the Li basin is greater westwardly. The composite stratigraphy of the Cenozoic sediments within the Li basin is presented in Table 2.4.2.2.

Sathien Snansieng and Niwat Maneekut (1985) divided Tertiary sediments of the Li basin into 2 formations, namely, Mae Moh Formation and Li Formation of upper part or Neogene age and lower part or Paleogene age respectively. They also divided the basin into 4 sub-basins, Ban Pu and Ban Pa Kha sub-basins are located on the eastern margin of the major Li basin from north to south whereas Ban Na Sai and Mae Long sub-basins are located on the western side of the Li river (Figure 2.4.1). Paleogene sediments of Ban Pa Kha and Ban Pu sub-basins, or the Li Formation, consist of shale, mudstone, sandstone, oil shale and coal beds of swamp and lacustrine origins. The stratigraphic columns from drill holes are shown in Figure 2.4.2.6 and 2.4.2.7.

Neogene sediments of Ban Na Sai and Mae Long sub-basins, of presumably Mae Moh Formation, consist mainly of marlstone, calcareous mudstone and claystone, shale and coal beds. The correlation of

Table 2.4.2.2 The composite stratigraphy of the Cenozoic sediments within the Li basin (After Sathien Snansieng and others, 1983).

Rock unit	Description	Thickness	Age
Alluvium	Unconsolidated gravel,sand,		Holocene
Terrace	clay,laterite		U.Pleistocene
Mae Taeng Formation	Semiconsolidated gravel bed, sand, silt	100+	L.Pleistocene
	unconformity		
Mae Moh Formation (Na Sai Formation)	Sandstone, claystone (calcareous) marlstone (Viviparus bed) lignite mudstone	200+	Neogene (Pliocene - Miocene)
	unconformity		
Li Formation (Pa Kha Formation)	Shale, oil shale lignite to sub-bituminous mudstone, sandstone lignite gray shale, carbonaceous shale claystone	150+	Paleogene (Oligocene - Eocene)
	unconformity		
Basement	Mesozoic (Dark gray shale) Paleozoic (Quartzite, phyllite)		

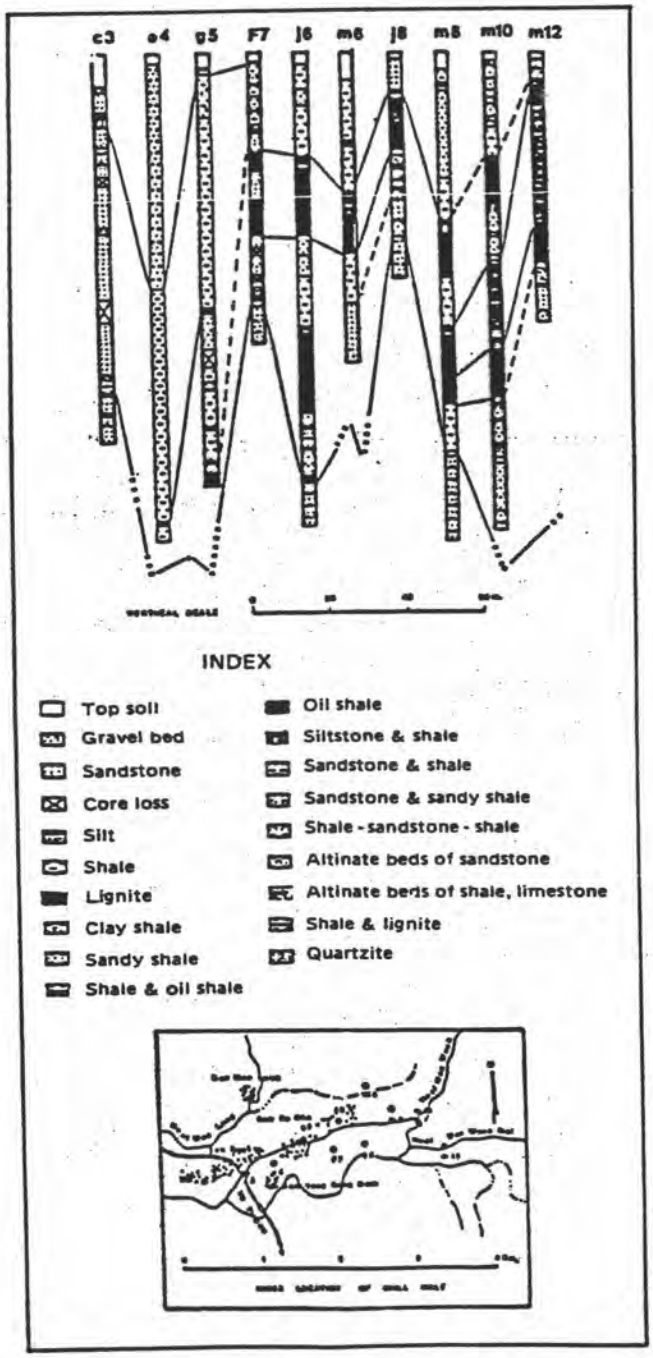


Figure 2.4.2.6 The correlation of the coal-bearing Paleogene formations at Ban Pa Kha sub-basin ; data from the diamond drill-logs by the Non-Metallic Project, Economic Geology Section, DMR. 1964 (After Sathien Snansieng, 1985).

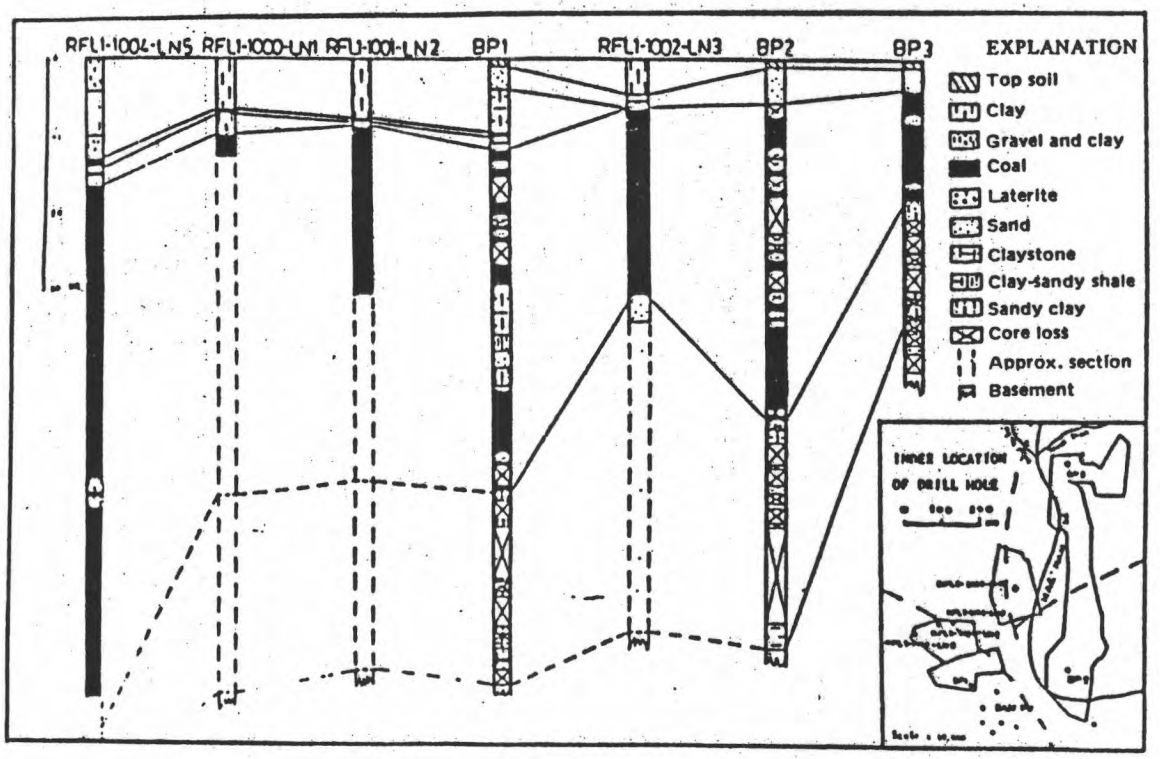


Figure 2.4.2.7 The correlation of drill-holes at Ban Pu sub-basin (After Sathien Snansieng, 1985).

drill- holes at Ban Na Sai sub-basin are shown in Figure 2.4.2.8. The Ban Na Sai and Mae Long sediments are chronologically correlated with Mae Moh sediments by fossil assemblages and the presence of marlstone beds without definite stratigraphic successions. The presence of marlstone or calcareous constituents in Neogene sediments play the leading role in the differentiation of Neogene sediments from the Paleogene sediments. Due to the fact that the thickness of sediments within the Li basin is greater westwardly, they also proposed that the average thickness of all Cenozoic sediments is exceeding 160 metres. Almost all the area of Li basin is covered by Quaternary clastic sediments of approximately 40 metres thick, whereas some Tertiary sediments are cropping out only in the marginal areas of the basin including the area of coal exposures at Huai Pong Kong, Ban Na Sai, etc..

2.4.3 Structural Features in the Neighbourhood of the Study Area

Generally, the major structural trend in the neighbourhood of the study area lies approximately in the northwest-southeast direction with conjugated north/northeast-south/southwest direction. This trend is a part of the regional trend in northern Thailand which swings in a curved-or "S-shape" concaving north-westerly toward Changwat Chieng Mai. The shape of the intermontane Tertiary basins in the north are slightly conformable to this regional trend. However, the mechanism which created this regional trend are uncertain.

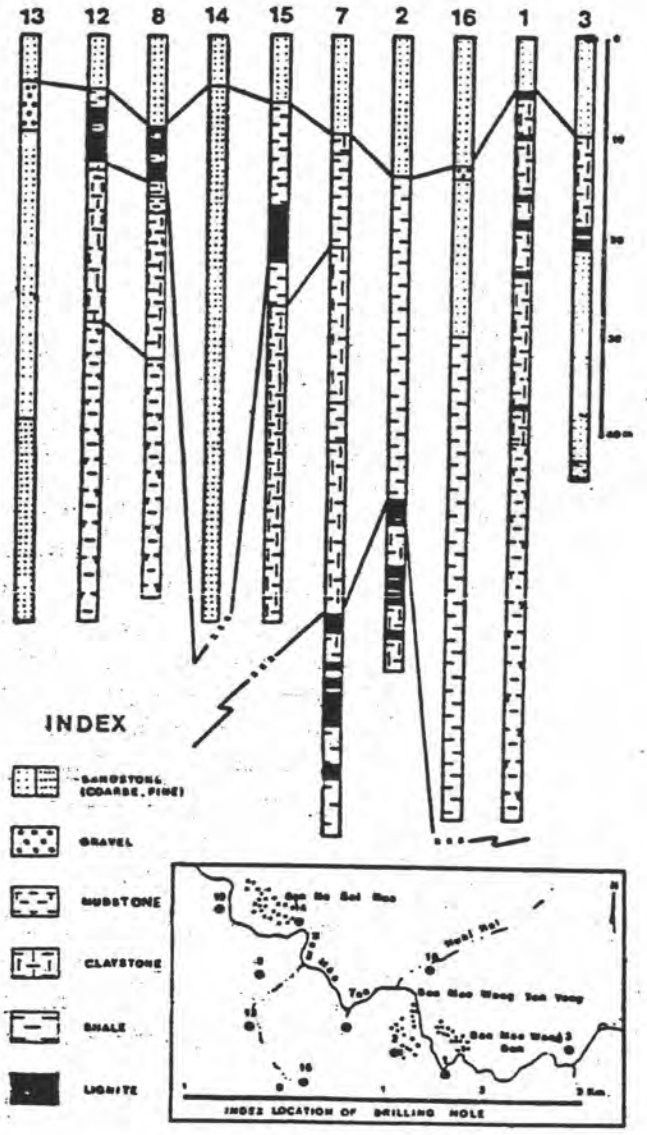


Figure 2.4.2.8 The correlation of drill-holes at Ban Na Sai sub-basin (After Sathien Snansieng, 1985).

2.4.3.1 Faults

In the vicinity of the study area, faults are generally oriented in the northwest-southeast and the north/northeast-south/southwest directions. The trend of fault is normally conformably with the orientation of the mountain ranges (Figure 2.4.1 a and b and 2.4.3.1). Some of these are sinistral type at Huai Ya Ka Dai, Huai Mae Ong, Huai Mae Tak, Huai Mae Arb Luang (Pol Chaodumrong, Suwit Chiemton and Sathien Snansieng, 1985 ; Pol Chaodumrong and Suwit Chiemton, 1986). The Tertiary sediments of the Li basin are strongly faulted and similar faulting also occurs in the basement rocks, specially Silurian-Devonian rocks. The basin is also bounded by faults and the deposition of sediments within the basin is considered to be periodically originated by many sets of faulting since Paleogene. They are normal faults, throwing down towards the central part of the basin, and the maximum throw is over 150 metres (Sathien Snansieng and Niwat Maneekut, 1985).

2.4.3.2 Folds

The general structures of the Tertiary sediments in the Li basin is homocline with localized syn-form homocline. The fold axis is generally parallel to the north/northwest-south/southeast direction of the basin elongation. These folds are considered to be part of the sets of folds affected the northern part of Thailand (Sathien Snansieng and Niwat Maneekut, 1985). In the vicinity of the study area, it is also noted that the pre-Tertiary rocks underlying Tertiary strata are folded as syncline and overturned anticline based on the presence of chert beds of Carboniferous rocks at Li-Thoen road

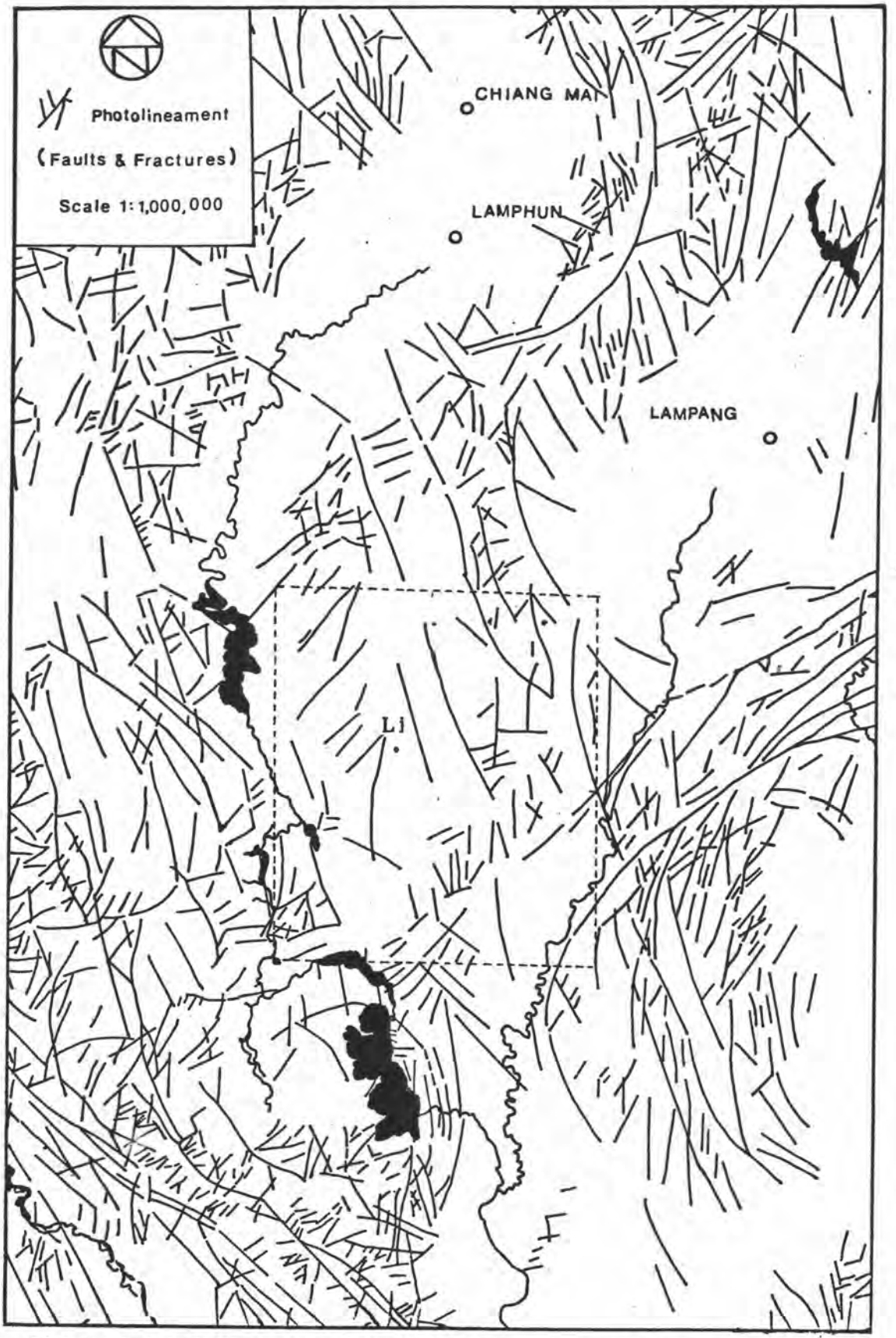


Figure 2.4.3.1 Photolineament and folding map of the study area (After Aramprayoon,1981).

and Silurian-Devonian rocks at Huai Mae Arb Luang with beds dipping in the southeastern direction.

2.4.3.3 Unconformities

Generally, the Tertiary strata in northern Thailand overlie unconformably the pre-Tertiary rocks and underlie unconformably the surficial unconsolidated sediments of the so-called "Mae Taeng" Group. Late Middle Miocene unconformity is reported to occur widespreadly elsewhere in the Gulf of Thailand, Chao Phraya basin, Phitsanulok basin and the Sundaland area of Southeast Asia. Sathien Snansieng and Niwat Maneekut (1985) presented that excluded the basement rocks, two Unconformities within the basin sediments are observed at Li basin. There are the Paleogene-Neogene Unconformity of probably Lower to Middle Miocene age and the Neogene-Pleistocene Unconformity. The Former is marked by the abrupt change of lacustrine sediments to fluviatile sediments and the erosional surface of Paleogene coal beds, and the latter is marked by the gravels of ?Mae Taeng Formation.