CHAPTER 2

BASINS AND STRATIGRAPHY

Five basins were chosen as the research areas, namely, the Li, Chiang Muan, Mae Moh, Mae Lamao, and Na Hong basins (Figure 2-1). The basin selection is based on the diversification of their geographical and geological features. Each basin is isolated from one another by high mountain ranges forming Cenozoic intermontane basins. All five basins are located in northern Thailand from longitude 98° to 101° east and latitude 17° to 20° north approximately.

2.1 PHYSIOGRAPHIC FEATURES

2.1.1 Topography and climates

A general topographic feature of northern Thailand is the mountainous area with four main tributaries, the Ping, Wang, Yom, and Nan Rivers (Figure 2-2). The mountain ranges are characterized by high mountain peaks extending from north to south, in general. The highest peak is Doi Intanon at 2565 meters above mean sea level (MSL) and the lower peaks but still prominent include Doi Pha Hom Pok (2288 meters above MSL), Doi Chiang Dao (2225 meters above MSL), Doi Phu Soi Dao (2102 meters above MSL), and Doi Lang Kha (2030 meters above MSL). The mountain ranges are divided by the four major rivers and their tributaries forming lowland basins where people established their communities, usually near the rivers. The lowland areas, on average, are 300 meters above mean sea level.

The climate of northern Thailand is strongly seasonal and is more similar in character to the monsoon climate of central India than to the wetter climate of southern Thailand. There are three distinct seasons, a cool dry season between November and February, a hot dry season from March to May, and a warm wet

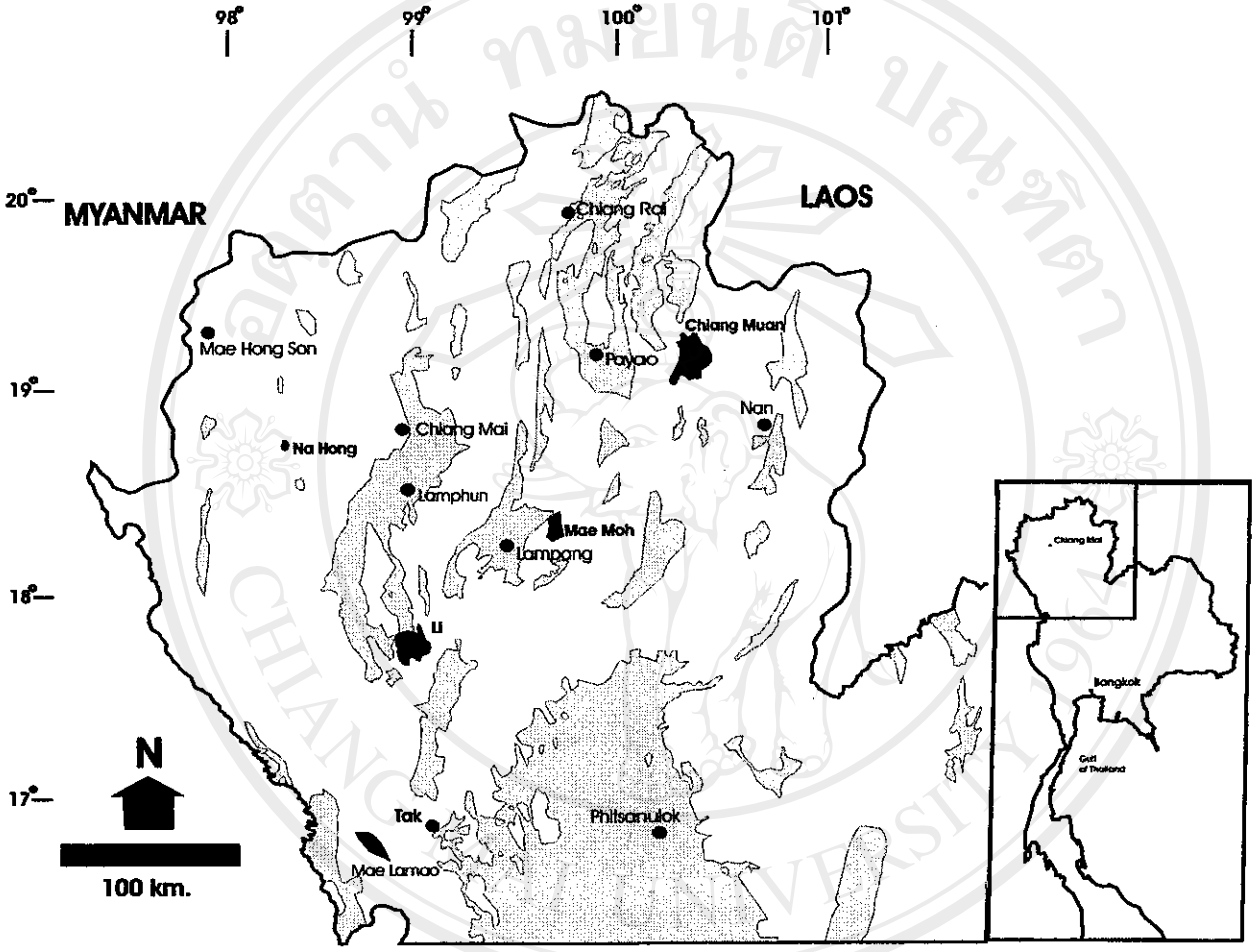


Figure 2-1 Map of northern Thailand showing distribution of Cenozoic basins and the five study localities, including Chiang Muan, Na Hong, Mae Moh, Li, and Mae Lamao basins.

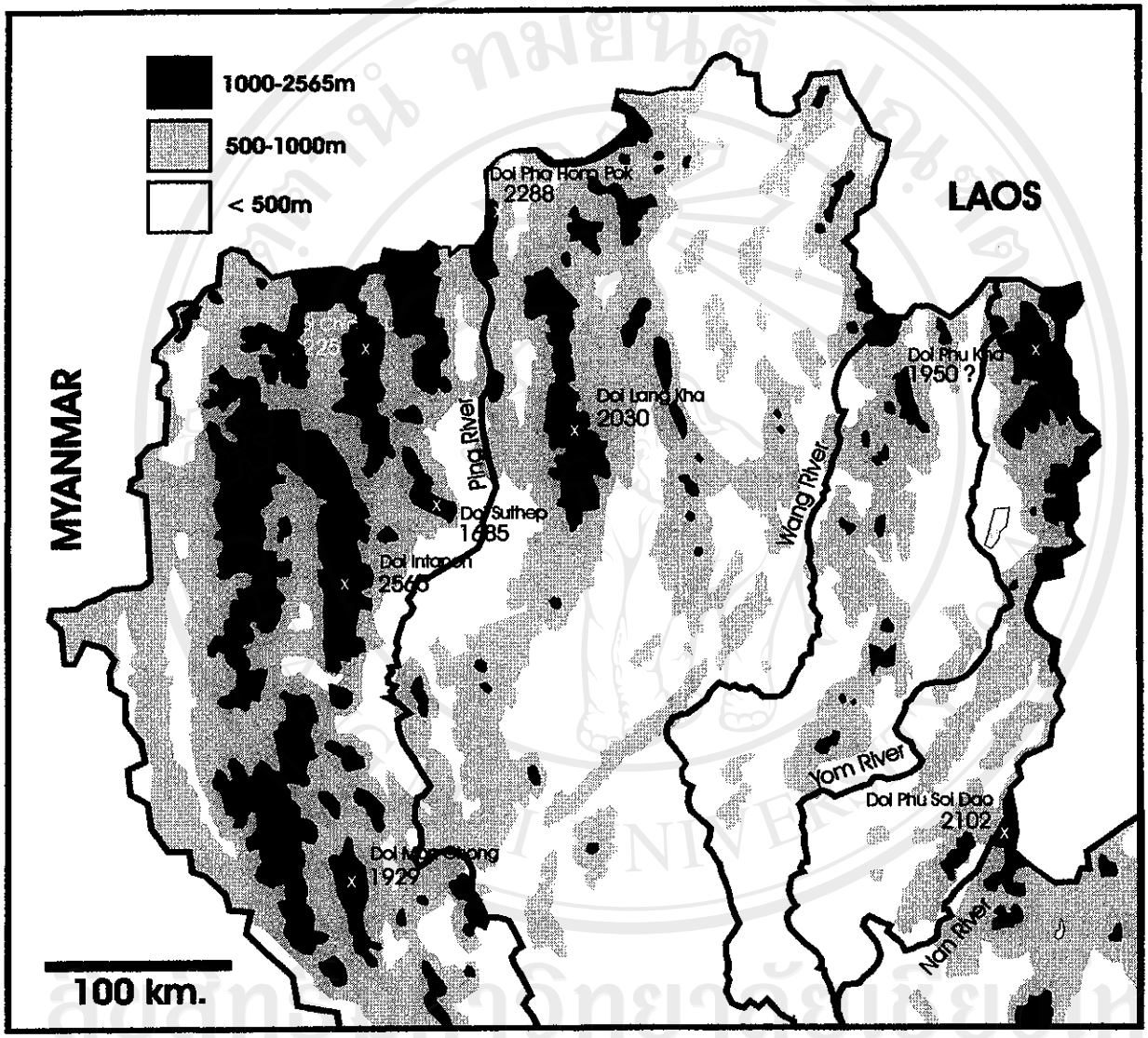


Figure 2-2 Map of northern Thailand showing ranges of topographic elevation with some peaks of high mountain and four major rivers flowing through lowland from north to south, including Ping, Wang, Yom, and Nan Rivers (Gardner and others, 2000).

season between May and October. The annual rainfall varies from 1100 to 1500 mm, with over 80% of the annual rainfall falling within the six months rainy season, whilst the months of December, January and February are virtually without rain. This pattern is rather uniform across the whole of the northern region, although the rainfall tends to be higher and more prolonged in mountainous areas and in the western provinces of Tak and Mae Hong Son (Gardner and others, 2000).

2.1.2 Vegetation

The forest types of northern Thailand are categorized depending on three main factors – moisture, altitude, and disturbance (Gardner and others, 2000). Altitude is used as a major factor in the categorization of lowland forests, mid-elevation forests, and highland forest. The lowland forest is the vegetation below 800 meters above MSL, mid-elevation forests between 800 and 1200 meters above MSL, and highland forest between 1200 and 2565 meters above MSL. Each forest type is further divided into three categories, moist areas, intermediate moisture, and dry sites. The disturbance factor is also considered for each forest type in both natural disturbance and human activities.

Lowland forests in the moist areas are mainly composed of trees, including *Acrocarpus fraxinifolius*, *Erythrina* spp., *Toona* spp., *Hopea odorata*, *Dipterocarpus alatus*, *Pterocymbium* spp., *Dracontomelon dao*, *Duabanga grandiflora*, and so forth. In dry areas commonly comprise *Dipterocarpus tuberculatus*, *Dipterocarpus obtussifolius*, *Shorea obtusa*, and *Shorea siamensis*.

Mid-elevation forests in the moist areas are very similar to the lowland counterparts in terms of canopy structure and tree species composition. Tree

composition in the dry areas is normally a mix between pine/dry evergreen species and dry dipterocarp species including *Dipterocarpus tuberculatus* and *Pinus merkusii*.

In the moist areas the highland forests are dominated by almost 100% evergreen species. The trees in this forest type typically comprise *Acer* spp., *Aesculus assamica*, *Fraxinus floribunda*, *Livistonia speciosa*, *Cephalotaxus griffithii*, *Podocarpus neriifolius*, and *Rhododendron*. The shrub layer includes *Pandanus*, *Pinnanga sylvestris*, *Areca triandra*, and the tree fern *Cyathea*. The distinctive feature of this forest type is the epiphytic *Schleffera* spp.

The dry areas of the highland forests contain less tree species than any other forest type in northern Thailand and are often dominated by less than 10 species. Bamboo and palm are absent except for the drought tolerant species *Phoenix loureri*. Pine forests typically contain two well-defined layers. The upper layer consists almost exclusively of *Pinus* spp., with a lower layer of *Vaccinium* spp., *Helicia* spp., *Myrica esculenta*, *Rhododendron* spp. and so forth. The commonest species of pine at higher elevations is *Pinus kesiya*.

2.1.3 General geology

Chronostratigraphically, rocks in northern Thailand can be divided into four categories including Precambrian rocks, Paleozoic rocks, Mesozoic rocks, and Cenozoic rocks/sediments. The outcrop pattern of these rocks reveals a nearly a N-S strike. This feature is directly related to the orientation of major geological structures including folds and faults with a curve pattern occasionally forming slender S-like shapes as seen on the maps.

Precambrian rocks are exposed in high mountain ranges extending from north to south in the west from Chiang Mai, Lampang, to Tak via Doi Intanon, Doi

Pui, Doi Suthep, and Lan Sang and through to Kanchanaburi. The rocks are high-grade metamorphics of amphibolite facies, first reported by Brown and others (1951) and the Precambrian age was first given by Baum and others (1970).

Paleozoic rocks in northern Thailand can be subdivided into three series, Lower Paleozoic, Middle Paleozoic, and Upper Paleozoic rocks.

Lower Paleozoic rocks include Cambrian and Ordovician rocks distributed in the western part of northern Thailand. The Cambrian rocks are quartzite, orthoquartzite, sandstone and shale. The Ordovician rocks are argillaceous limestone, limestone, dolomitic limestone, marble and shale.

Middle Paleozoic rocks include Silurian-Devonian rocks consisting of phyllite, carbonaceous phyllite, and quartzitic phyllite normally distributed from north to south in the central part of northern Thailand from Chiang Rai via Chiang Mai to Lampang.

Upper Paleozoic rocks include Carboniferous-Permian rocks including conglomerate, sandstone, shale, slate, chert, and limestone.

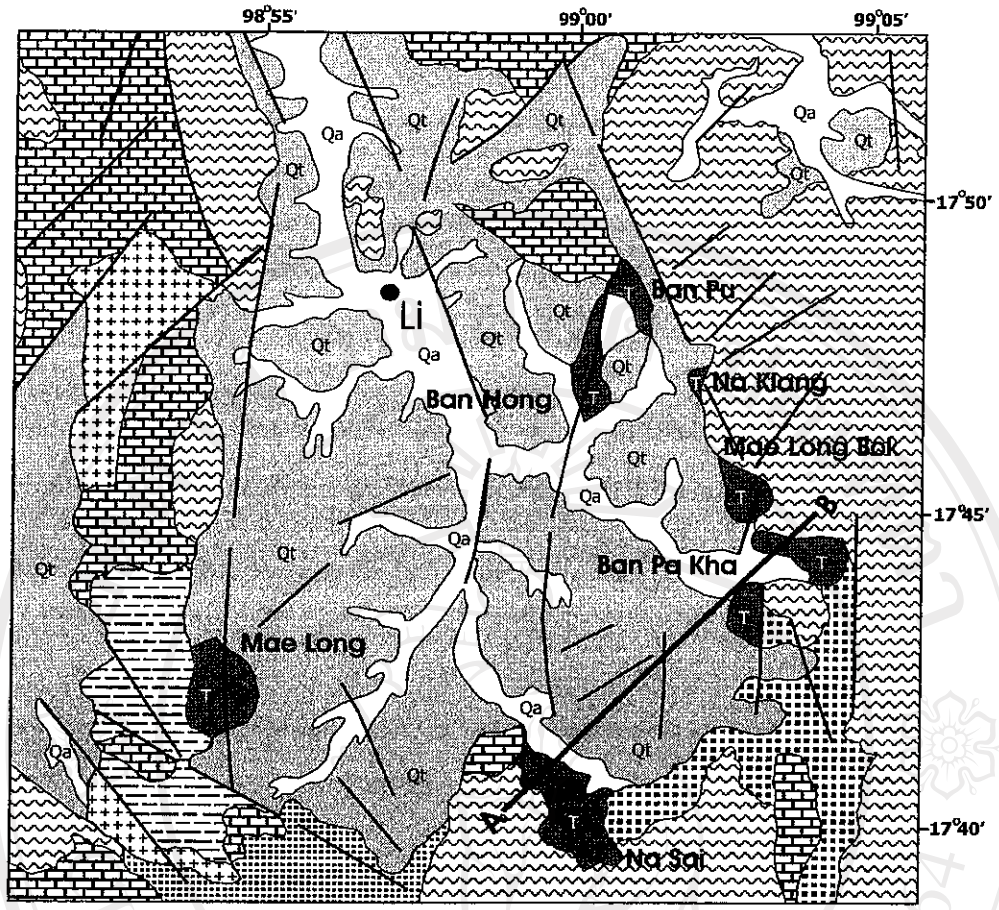
Mesozoic rocks in northern Thailand are lithologically divided into two facies, marine and younger continental facies. The marine facies are composed of the Triassic Lampang Group (see Chaodumrong and Burrett, 1997), the Upper Triassic to Jurassic Mae Moei Group, the Triassic Nam Pat Formation, and the Jurassic Huai Pong, Hua Fai, and Umphang groups. The continental facies is characterized by red sandstone, siltstone, mudstone, with conglomerate, relatable to the red bed Khorat Group in the Khorat Plateau, together with Triassic igneous rocks including migmatites and granite. There is also a wide distribution of granite and granodiorite ranging from Cretaceous to Carboniferous in age.

Cenozoic sediments occur in the intermontane basins in both lowland and highland, even in small basins on the high mountain complexes. The basins are characterized by their isolation and there are graben and half-graben basins. The sediments consist of Tertiary and Quaternary deposits. Tertiary sediments are unconformably covered by younger Quaternary deposits. Some Tertiary sediments are exposed along the basin margins, as well as along streams where erosion had removed the Quaternary sediments. The Tertiary deposits are characterized by semi-consolidated sediments consisting of mudstone, siltstone, sandstone, conglomerate, oil shale, coal, and diatomite together with fossil fauna and flora. Fang and Phitsanulok basins contain crude oil and are being exploited. Coals with lignite to sub-bituminous rank are commonly mined from many basins. Oil shale occurs in many basins but is more common in the Mae Sot basin. Diatomite is extensively exposed in the Lampang basin. Watanasak (1988) created two palynological zones, Oligocene to Early Miocene zone (Siam-I) containing temperate palynological elements and Early to Middle Miocene zone (Siam-II) containing tropical palynological elements. Tertiary basins in northern Thailand mainly formed within a lacustrine depositional environment with evidence of some marine incursions (Meesuk, 1986; Ratanasthien, 1989; Waton, 1996; Tankaya, 2001; Silaratana and others, 2002, 2003).

2.2 LI BASIN

2.2.1 Geographical setting

The Li basin is located about 80 kilometers south of Lamphun Province between longitude 98° 54' and 99° 04' east and latitude 17° 40' and 17° 50' north (Figure 2-3) covering four RTSD topographic map sheets (scale 1: 50,000) including 4744-I, 4744-II, 4844-III, and 4844-IV. It covers an area of about 500 km^2 in Li



Legend

Qa	Quaternary alluvium.
Qt	Quaternary terrace and colluvium.
T	Shale, claystone, siltstone, sandstone, conglomerate, and coal of Tertiary age.
	Light gray to red conglomerate, sandstone, siltstone, and shale of Carboniferous age.
	Quartzite, quartz-schist, slate, and phyllite of Silurian - Devonian age.
	Limestone interbedded with shale, siltstone, and sandstone of Ordovician - Silurian age.
	Limestone with argillaceous, arenaceous lamination of Ordovician age.
	Granitic rock.

Figure 2-3 Geological map of the Tertiary Li basin showing the locations where the Tertiary outcrops exposed and geology of the surrounding areas (Ukkakimapan, 1992).

District of Lamphun Province. The basin has a north-south elongation with an average width of 10 kilometers. The elevation of the ground surface is around 300 meters above mean sea level and surrounded by mountainous area. There is a water gap in the northern part where the Li River flows northwards to join the Ping River at Wiang Nong Long Sub-district in Lamphun Province.

The access to the Li basin is via highway 106 from Lamphum, on which the basin about 80 kilometers to the south. The study areas consist of two coalfields, Ban Pa Kha and Na Sai. Access is still via highway 106 from Li District to the south. Ban Pa Kha coalfield is to the east of the highway and belongs to Lanna Resources Public Company Limited (former name is Lanna Lignite Public Company Limited). Na Sai coalfield is about 10 kilometers west of highway 106 from the kilometer 45 with a good asphalt sealed road. The mine is near Ban Na Sai (a village) and close to small hills. The coal mine belongs to Taan (Thailand) Company Limited.

2.2.2 Geology

The basin contains Tertiary sediments over 120 meters thick and covered by about 40 meters of Quaternary sediments. The basin is bounded by Ordovician massive and laminated limestone and shale (Thung Song Group), Silurian-Devonian quartzite, quartz-schist, and phyllite (Don Chai Group), with some Carboniferous conglomerate, sandstone, and shale (Figure 2-3). Gravity investigations indicate that the Li basin comprises a series of N-S trending horst and graben systems as a result of normal faulting. The western boundary of the basin is bounded by a set of large displacement normal faults showing very steep basement profile. A large N-S trending horst plunging to the south which can be traced continuously from a basement ridge near the northern margin close to the western side of Ban Pu and Ban Hong coal deposits, through the central part of the basin and ending at the southern

margin close to the western side of Na Sai coalfield. This basement horst separates Li basin into two sub-basins, the Western and Eastern sub-basins (Ukkakimapan, 1992). The basin is considered to be a rift basin formed under an approximately east-west extension with at least five episodes of predominantly NNW-SSE to NE-SW oriented compression, interrupting the extensional development of the basin. The compression was probably related to the extrusion tectonics of the Himalayan orogeny (Morley and others, 2000, 2001).

Tertiary deposits in the basin have been named "Li Group", comprising two formations, Paleogene Li Formation and Neogene Mae Moh Formation (Snansieng and Maneekut, 1985). In this study, the two formations are renamed for practical reasons on the basis of the International Stratigraphic Guide. "Li Group" should not contain a "Li Formation" and the word "Mae Moh" is derived from Mae Moh Basin in Lampang Province (Salvador, 1994). This renaming is to avoid confusion in using the geographical names. The underlying Li Formation would be changed to Ban Pa Kha Formation as a new designation. The overlying Mae Moh Formation would be changed to Mae Long Formation as erected by Ratanasthien (1990) (Figure 2-4).

Ban Pa Kha Formation is mainly exposed in some coalfields in the eastern part of the basin including Ban Pu, Ban Hong, Ban Na Klang, and Ban Pa Kha coalfields (Figure 2-3). There is, however, no evidence indicating that the Mae Long Bok locality is either Ban Pa Kha Formation or Mae Long Formation. This formation consists of both fluvial and lacustrine sediments including conglomerate, sandstone, shale, oil shale, and coal (Chaodumrong and others, 1982; Jitapankul, 1992; Ukkakimapan, 1992). The type section is in the Ban Pa Kha coalfield as previously described by Jitapankul (1992) with some modifications made in this study (Figure 2-4).

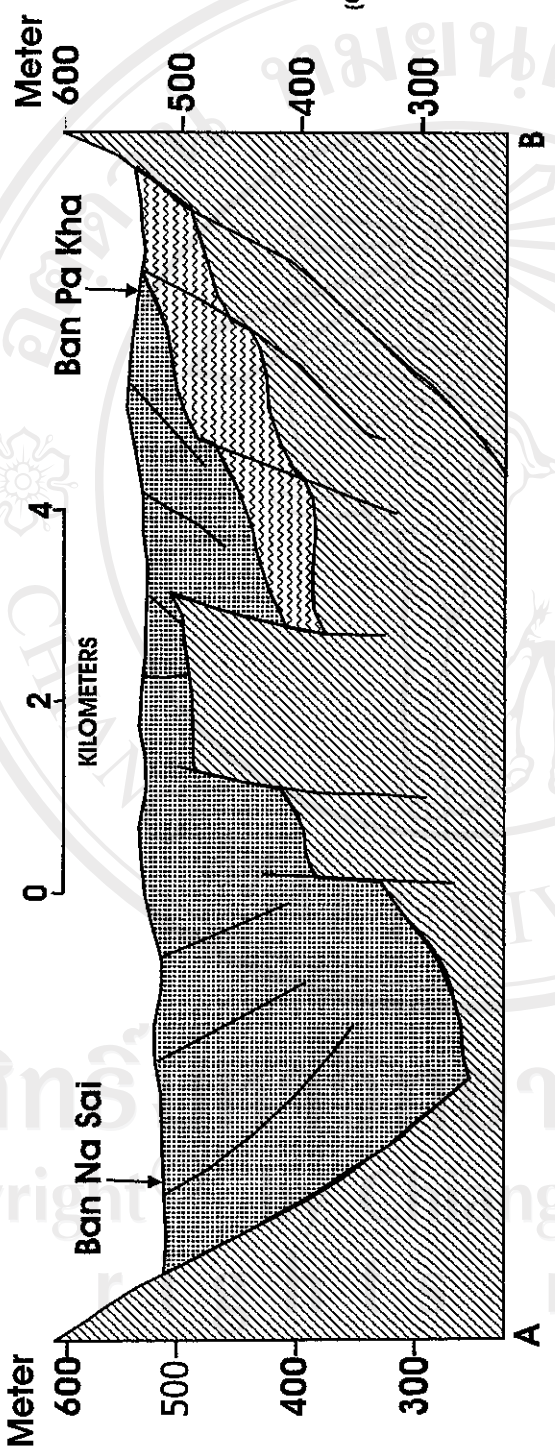


Figure 2-4 Geological cross section across the Na Sai and Ban Pa Kha coalfield along line A-B on figure 2-3 (modified after Snansieng and Maneekut, 1985; Ratanasthien, 1990).

The Ban Pa Kha Formation is a Tertiary sedimentary succession of claystone, sandstone, shale, oil shale, and coal overlying the pre-Tertiary rock basement and capped by Quaternary deposits. The succession is classified into five units, including underburden, lower coal zone, interburden, upper coal zone, and overburden from bottom to top. The underburden comprises claystone and sandstone. Claystone is light gray to gray in color, compacted, and poorly bedded. Sandstone is gray in color, lowly compacted, and poorly sorted. The bottom part gradually changes to pebbly sandstone and conglomerate with some fragments of basement rock, mainly composed of quartzite and greenish gray sandstone. The overlying lower coal zone comprises silty to sandy claystone, and thin coal layers in the lower part defined as lower split coal. The coal is characterized by deposits of trunks and twigs, with annual rings clearly defined in the trunks. The succession changes upward into massive coal in the upper part of the zone. The interburden consists of oil shale in the lowermost portion and changes upward into claystone. The upper portion is white sandstone. The oil shale and claystone of the interburden contains common leaf remains. Huge specimens were collected and identified by Yabe (2002). The megafloral assemblage consists of 30 types of woody dicotyledonous leaves along with infructescences and inflorescences of alders and winged-seeds of maple, as well as conifers. The leaf remains are normally pyritized and pyrite nodules are common in some horizons. The overlying upper coal zone is dominated by coal, brown to black in color, and hard, with dull and bright coal interbedded. The coal is commonly interbedded with thin layers of claystone (probably limonite) and ligneous claystone. The zone contains the main coal seam for mining. The uppermost unit is overburden. It is a succession of oil shale, claystone, sandstone, with some thin layers of coal. The oil shale overlies the coal layer with a gradation upward into sandstone and capped with thin coal layer.

There are at least three individual sequences of this. These sediments were collected for palynological analyses. The samples include oil shale, claystone, coal, with some sandy claystone. The coal and carbonaceous fine-grained sediments were mainly collected (Figure 2-5).

The stratigraphic successions of Ban Pa Kha, Ban Na Klang, and Ban Pu are correlatable by green sand/sandstone horizons as a key marker corresponding to the concentration of some significant elements derived from basic igneous rocks (Ratanasthien and Promkotra, 1994). Elementary analyses of the coal were reported from Ban Pu, Ban Hong, and Ban Pa Kha. Ash contents are 2.80, 2.92, and 4.27% respectively (Ratanasthien and others, 1992). There are numerous reports on the occurrence of fossil floras including leaves, cones, catkins, and sporomorphs strongly suggesting warm temperate floras of Oligocene to Early Miocene age (Endo, 1963, 1964, 1966; Ratanasthien, 1984; Meesuk, 1986; Watanasak, 1988; Songtham and others, 2001, 2003). No vertebrate remains have been reported from this formation.

Mae Long Formation was named and described by Ratanasthien (1990). It is characterized by thin laminated sediments or the so-called "Paper-Shale" overlying mudstone and coal seams. Type section description was done on the basis of drilling investigations (Ratanasthien, 1990). The type section at Mae Long Reservoir extends to the Na Sai coalfield and this can be divided into coal-bearing and paper-shale bearing parts. Elementary analysis of the coal was reported from Na Sai, where ash content is 42.57% (Ratanasthien and others, 1992). Numerous vertebrate remains were reported from both the Mae Long and Na Sai localities including fish, bird, snake, turtle, otter, rodent, pig, elephant, rhinoceros, and deer suggesting Middle Miocene and perhaps including upper Early Miocene (Jaeger and others, 1985;

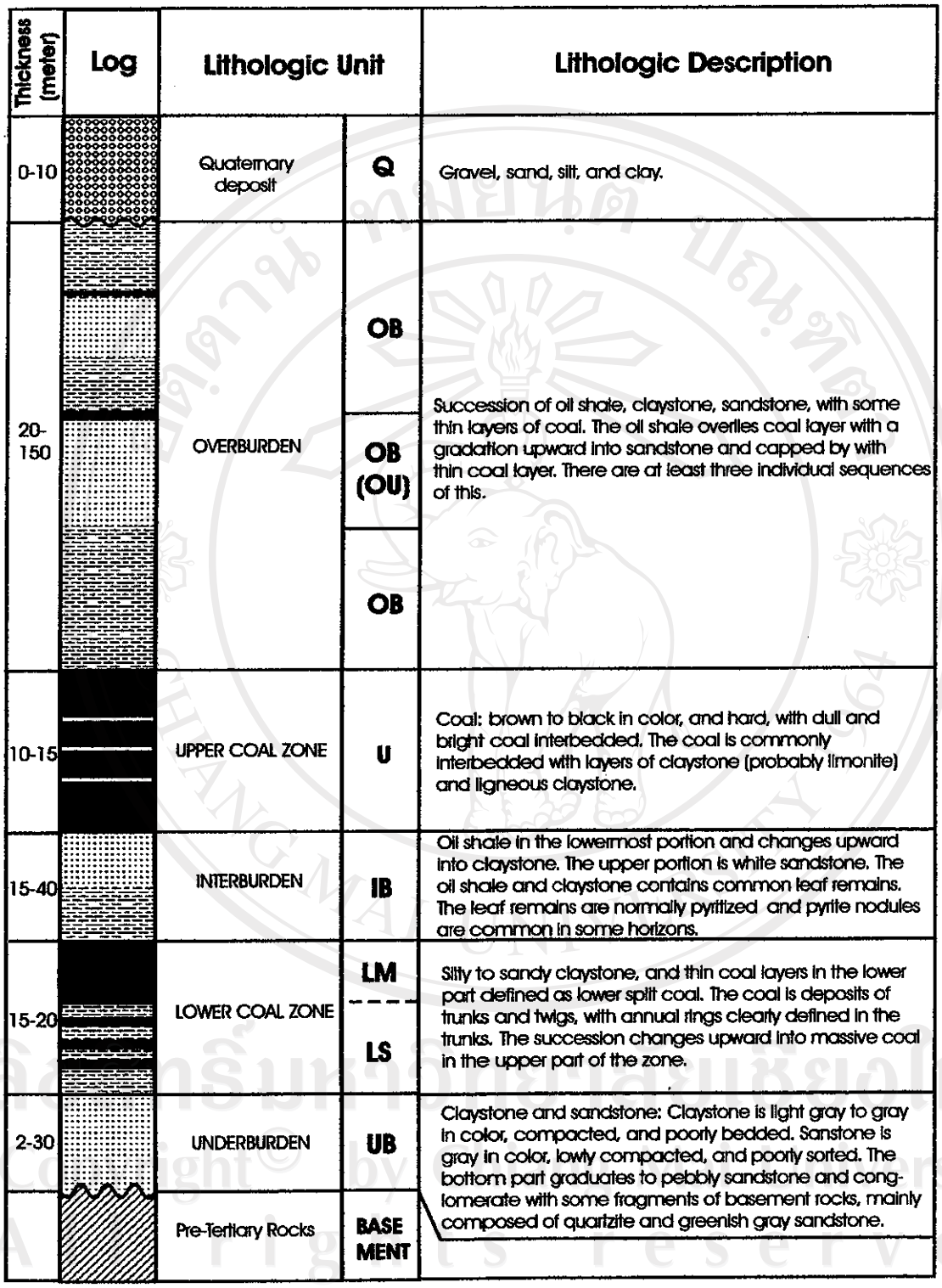


Figure2-5 Schematic stratigraphic succession of Ban Pa Kha Formation (Jitapankul, 1992).

Ginsburg and Tassy, 1985; Buffetaut and others, 1989; Mein and others, 1990; Ducrocq and others, 1994, 1995).

A twelve meter-thick section from the Na Sai coalfield was described. It is a partial stratigraphic succession of the whole sequence of the Mae Long Formation (Figure 2-6). The lowermost part is claystone. The overlying part is a six meter-thick coal seam containing some vertebrate remains. The coal is brown to black, dull, with a high sulphur content. The overlying layer is the fossiliferous horizon. It contains abundant molluscs with fish bones, and crocodile teeth and plates. The upper sequence of the section is a light greenish gray claystone with sandstone in the upper portion. Twelve sedimentary samples were collected. They are claystone and coal (Figure 2-6).

2.2.3 Paleontology and age determination

2.2.3.1 Faunas

Vertebrate remains in the Li basin were recovered only from the Mae Long and Na Sai sub-basins, none are reported from Ban Pu and Ban Pa Kha sub-basins. The Department of Mineral Resources (DMR) set up the Thai-French Project on Vertebrate Fossils of Thailand in 1980. In the Li basin, the first discovery was from the Mae Long sub-basin by Yongyuth Ukkakimapan (DMR) in 1982, along a small outcrop of claystone which had been excavated during the construction of a small dam, the Mae Long Reservoir. Thereafter, they were identified as indeterminate mastodon and a new species of deer *Stephanocermas rucha* (Ginsburg and Ukkakimapan, 1983) and late Middle Miocene to early Late Miocene was accepted as the age of the faunas. Rodents were later found from the Mae Long and described as cf. *Diatomys* sp. and *Antemus thailandicus* and by comparison to *Antemus primitivus* from the Chinji Formation of the Siwaliks, the age of the fauna was given as Middle

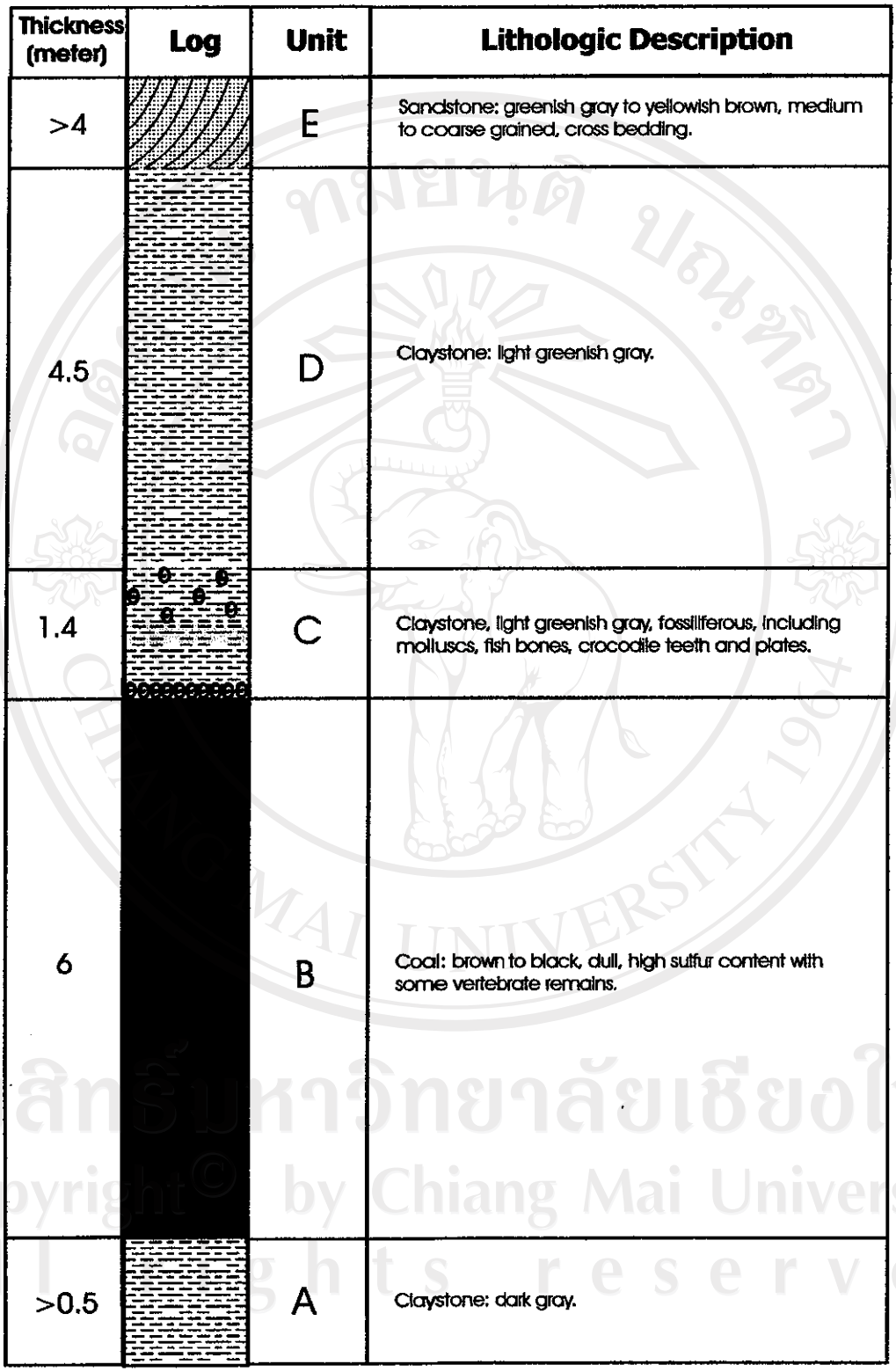


Figure 2-6 A partial schematic stratigraphic succession of Na Sai coalfield.

Miocene (Jaeger and others, 1985). The occurrence of *Antemus thailandicus*, *Spanocricetodon khani*, *Kanisamus benjavuni*, and *Diatomys liensis* from Mae Long, suggested an age of upper Lower Miocene to lower part of Middle Miocene (MN3-MN4) (Mein and others, 1990; Cheneval and others, 1991; Tassy and others, 1992).

Based on the drilling investigations and the occurrence of *Stegolophodon* remains from the Na Sai Tassy and others (1992) dated the Na Sai faunas as being older than the Mae Long. Lower Miocene or MN3 was proposed.

2.2.3.2 Floras

First floral remains were reported by Endo (1963; see also Endo, 1964, 1966) who studied leaf, scale, catkin, and cone remains of warm temperate plants from the Ban Dong Dam (Ban Pa Kha coalfield today). They consist of *Alnus thaiensis* Endo, *Sequoia langsdorfii* Heer, *Taxodium thaiensis* Endo, *Sparganium thaiensis* Endo, *Carpinus* (?) sp., *Glyptostrobus europaeus* Heer, *Ficus eowightiana* Endo, *Fagus feroniae* Ung., *Quercus lanceaefolia* Roxb., *Quercus* cf. *Q. protoglauca* Endo, and *Salix* (?) sp. Endo proposed Paleogene as the age of the floras. These warm temperate floras were confirmed by warm temperate sporomorphs and Oligocene to Lower Miocene was considered as the age of the microfloras (Songtham and others, 2001, 2003).

Warm temperate sporomorphs were also reported from the Ban Pu coalfield by Ratanasthien (1984), Meesuk (1986), and Watanasak (1988) on the basis of palynology. Oligocene to Lower Miocene was proposed as the age of the floras (Ratanasthien, 1984; Watanasak, 1988).

Songtham and others (2003) reported on sporomorphs from the Na Sai coalfield and reported some definite tropical sporomorphs such as *Crudia*,

Calophyllum, *Radermachera*, *Lagerstroemia*, and Dipterocarpaceae. They used Middle Miocene (probably including Lower Miocene) as the age of the floras, based upon age determinations by vertebrate paleontology.

2.3 CHIANG MUAN BASIN

2.3.1 Geographical setting

Chiang Muan basin is in Chiang Muan District, about 90 kilometers east of Payao city. It has a north-south elongated shape located between 100° 10' and 100° 25' east longitude and 18° 45' and 19° 05' north latitude (Figure 2-7). The Yom River flows from north to south along the western flank of the basin. The basin contains Tertiary sediments covered with Quaternary deposits. Coal is now exploited as a small mine, Chiang Muan Mine, to the west of the basin.

From Chiang Mai city, access to the basin is through highway 118 by passing Doi Saket up to the mountainous areas and down to Mae Kha Jan, a village before Wiang Pa Pao. At Mae Kha Jan, the highway changes by turning right to enter highway 120 by passing Wang Nua to Payao. Travelling from Payao to Dok Kham Tai is along highway 1021 and from Dok Kham Tai, turning right to highway 1251 passing mountainous areas, and down the hills to the Chiang Muan basin. Chiang Muan Mine is north of the highway about one kilometer prior to joining highway 1091 (Pong-Chiang Muan highway). The mine is on a topographic map sheet Ban Sa (5046 IV) in the area of Tambon Sa, Chiang Muan District, Phayao Province. It is located at 100° 14' longitude east and 18° 56' latitude north. The ground surface elevation around the mine is about 270 meters above mean sea level.

2.3.2 Geology

The basin is bounded by a sequence of Jurassic red bed as a series of sandstones with conglomerate and shale intercalation. Dinosaur bones were discovered in 2002 from the red beds and are now being excavated and studied by the Department of Mineral Resources. There are some outcrops of rhyolite with tuffaceous shale and sandstone to the west and the east of the basin (Figure 2-7).

The basin contains sequences of Cenozoic sediments comprising sandstone, claystone, ligneous claystone, and coal classified into seven units (Figure 2-8) with detailed description given below:

Underburden (UB Unit): This unit is the lowermost unit unconformably overlying pre-Tertiary Jurassic red beds. It comprises sandstone, pebbly sandstone, clayey sandstone, sandy claystone, and claystone. Its color is moderately reddish brown, light gray to yellowish gray. The thickness of the unit varies but is generally more than two meters.

Lower coal zone (L Unit): Coal dominates the unit. The lower part varies from one to seven meters in thickness. It is characterized by ligneous claystone, lignite, silty claystone, brownish black in color (LS sub-unit). The upper part is massive coal (LM sub-unit). The unit is characterized by massive lignite coal, moderately bright, hard, and brittle. The thickness varies from one to ten meters.

Interburden (IB-2 Unit): This unit is a thick sequence of clayey sandstone and sandy claystone. It is moderate reddish brown to light gray. The sand is fine to coarse grained. The thickness of the unit varies from 45 to 70 meters. The unit is a prominent oxidized zone.

Upper coal zone (U-2 Unit): The unit comprises lignite, ligneous claystone, claystone, and silty claystone. It is characterized by brownish black and light gray in

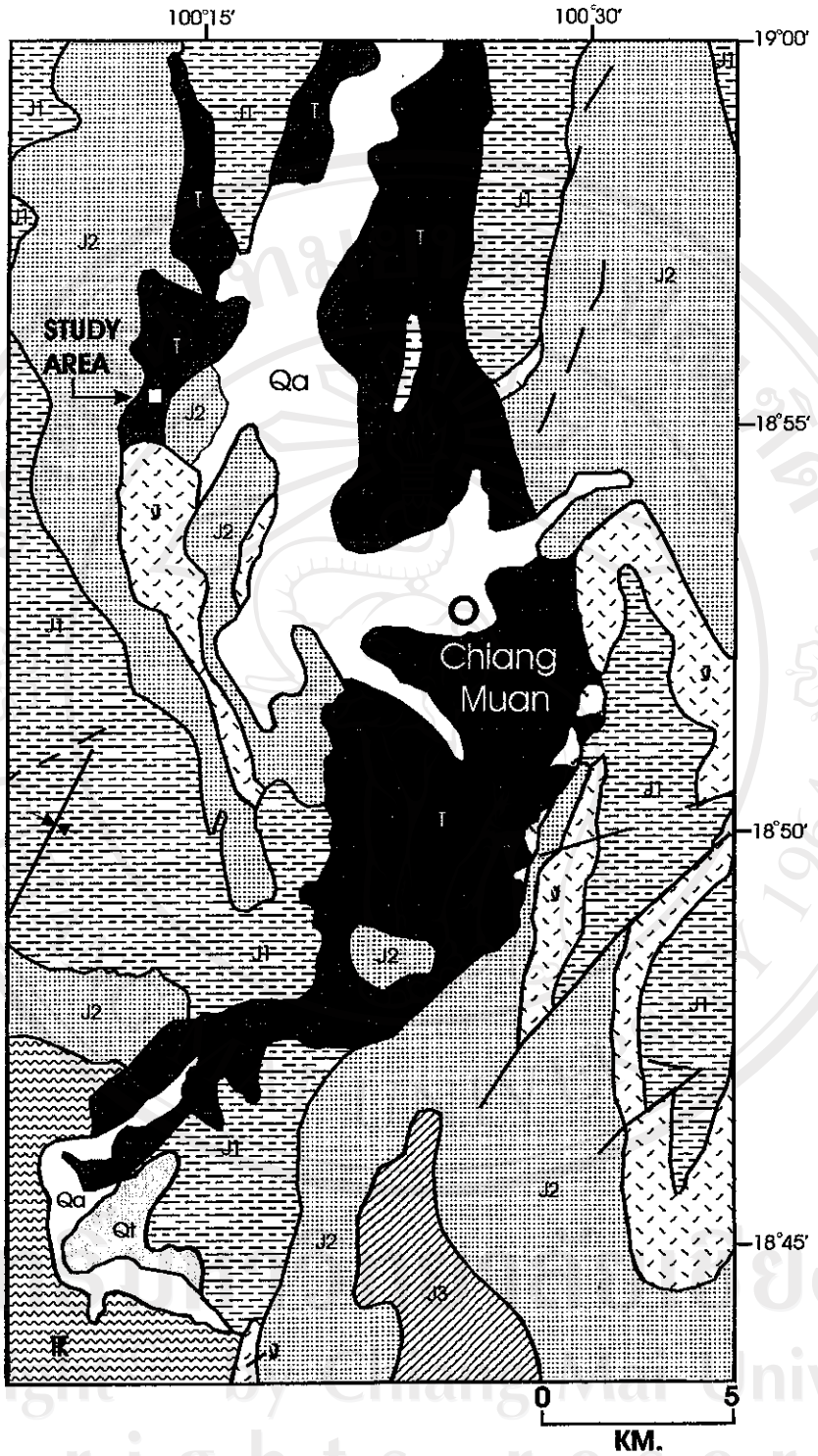


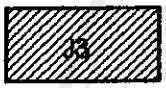
Figure 2-7a Geological map of the Tertiary Chiang Muan basin showing study area and geology in the surrounding areas, see legends and explanations on the next page (Charoenprawat and others, 1995).

SEDIMENTARY ROCKS

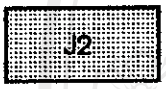
Alluvial deposits: gravel, sand, silt, clay, and mud. (QUATERNARY)

Terrace deposits. (QUATERNARY)

Interbedded claystone, sandstone, mudstone, and shale with fossil leaves, stems, bone of fish, molluscs, and several texa of vertebrate remains. (TERTIARY)



Arkosic sandstone, whitish grey to greenish grey, intercalated with conglomerate and shale. (JURASSIC)

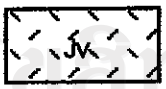


Sandstone, brown, interbedded with shale, reddish brown, micaceous, tuffaceous; and conglomerate. (JURASSIC)

Sandstone, purplish brown, fine grained, calcareous, interbedded with shale, reddish brown, limestone nodules; shale, grey, interbedded with sandstone, fine grained; and conglomerate. (JURASSIC)

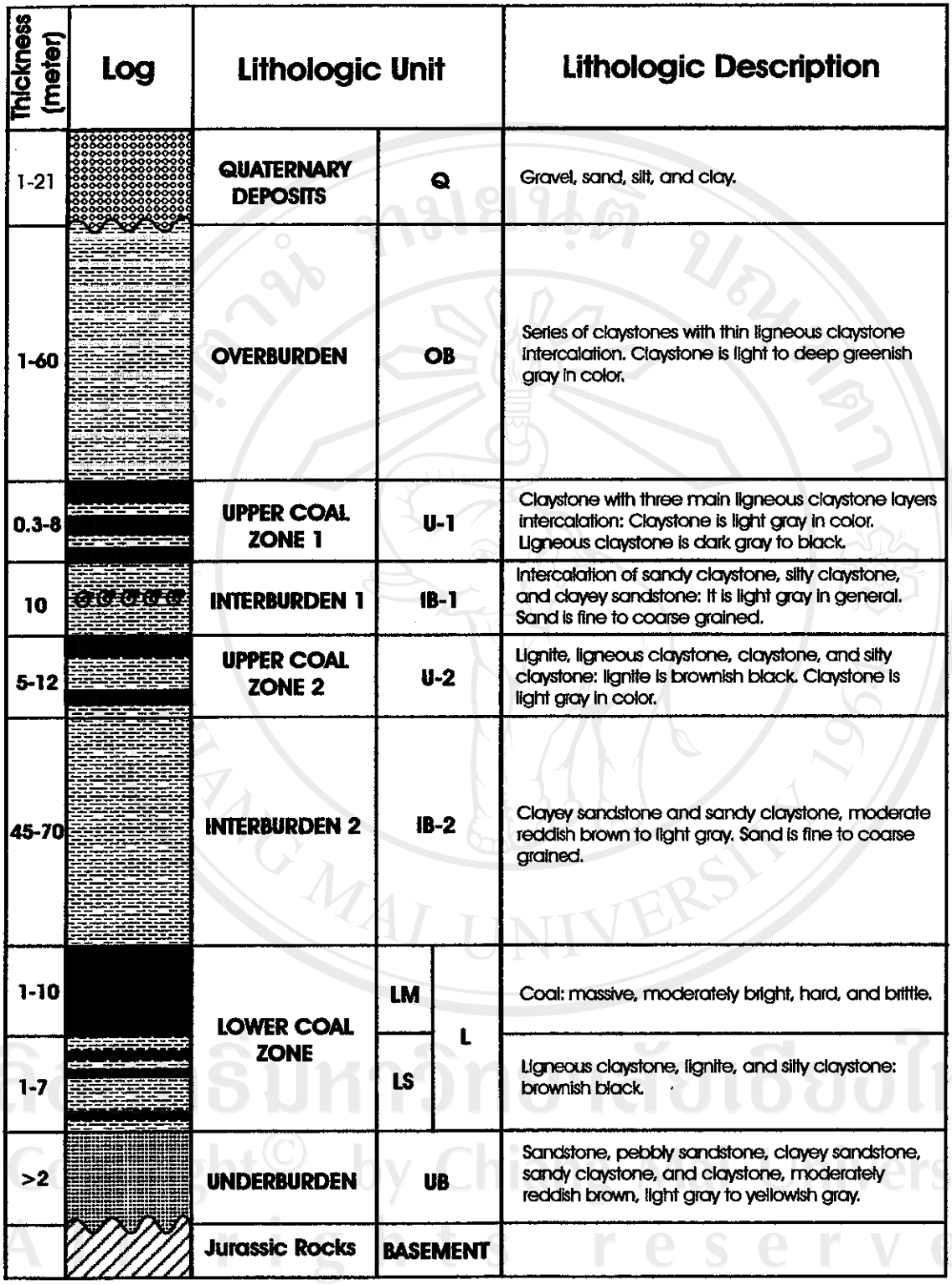
Shale and sandstone, grey to greenish grey; siltstone; mudstone; conglomerate; and limestone; with fossils Halobia, Cassianella, Liostrea, Unionites, and bivalves. (TRIASSIC)

IGNEOUS ROCKS



Rhyolite, purplish grey, tuffaceous shale and sandstone. (JURASSIC)

Figure 2-7b Legends and explanations for geological map of Tertiary Chiang Muan basin on figure 2-7a, the previous page (Charoenprawat and others, 1995).



Thickness (meter)	Log	Lithologic Unit		Lithologic Description
1-21		QUATERNARY DEPOSITS	Q	Gravel, sand, silt, and clay.
1-60		OVERBURDEN	OB	Series of claystones with thin ligneous claystone intercalation. Claystone is light to deep greenish gray in color.
0.3-8		UPPER COAL ZONE 1	U-1	Claystone with three main ligneous claystone layers intercalation: Claystone is light gray in color. Ligneous claystone is dark gray to black.
10		INTERBURDEN 1	IB-1	Intercalation of sandy claystone, silty claystone, and clayey sandstone: It is light gray in general. Sand is fine to coarse grained.
5-12		UPPER COAL ZONE 2	U-2	Lignite, ligneous claystone, claystone, and silty claystone: lignite is brownish black. Claystone is light gray in color.
45-70		INTERBURDEN 2	IB-2	Clayey sandstone and sandy claystone, moderate reddish brown to light gray. Sand is fine to coarse grained.
1-10		LOWER COAL ZONE	LM / L	Coal: massive, moderately bright, hard, and brittle.
1-7			LS / L	Ligneous claystone, lignite, and silty claystone: brownish black.
>2		UNDERBURDEN	UB	Sandstone, pebbly sandstone, clayey sandstone, sandy claystone, and claystone, moderately reddish brown, light gray to yellowish gray.
		Jurassic Rocks	BASEMENT	

Figure 2-8 Schematic stratigraphic succession of Chiang Muan Formation (courtesy of Chiang Muan Mine Company Limited)

color with thickness varying from 5 to 12 meters. Vertebrate remains and seeds are common. The unit has a high sulphur content.

Interburden (IB-1 Unit): This unit is an intercalation of sandy claystone, silty claystone, and clayey sandstone. It is light gray in general. The sand is fine to coarse grained. The thickness is about 10 meters. There are abundant occurrences of leaf and fruit remains as well as molluscs in some horizons.

Upper coal zone (U-1 Unit): In fact, this seam is not real coal, but a ligneous claystone. There are three main layers of ligneous claystone intercalated by light gray claystone. The unit ranges from 0.3 to 8 meters thick varying from place to place. High sulphur content occurs in some places.

Overburden (OB Unit): This unit is a series of claystones with thin ligneous claystone intercalations. The claystone is light to deep greenish gray in color. The thickness of the unit varies from place to place ranging from 1 to 60 meters.

The Tertiary sedimentary sequence is capped by Quaternary deposits including mainly gravel and sand with some clay in part.

2.3.3 Paleontology and age determination

Fossil shells, fruit, seeds, leaves, and vertebrate remains are common in the coal seams. The shells found in the upper coal seam (U1 Unit) were identified by Dr. Gulung Damayanti, a Nepalese paleontologist, namely *Brotia costula costula, Brotia costula varicose, Chamberlainia, Melanoides, Bellamya, Paludomus, Indoncia*, of which vertebrate remains as well as some fruit seeds were found in association.

Vertebrate remains were commonly found in the carbonaceous claystone in the lower split coal seam, including bones, teeth, and tusk of ancient elephant, head bone and teeth of crocodile, bird bone, and bone and teeth of fish. Some bones were also found in the lower massive coal seam including barking deer, plates and temolar

of turtle, bones and lower third molar of pig. Nakaya and others (2002) identified and reported the vertebrate remains as listed below:

MAMMALIA

Primates

Hominoidea

fam., gen., *et* sp. indet.

Proboscidea

Gomphotheriidae

Tetralophodon sp.

cf. *T. xiaolongtanensis*

Perissodactyla

Rhinocerotidae

gen. *et* sp. indet.

Artiodactyla

Suidae

gen. *et* sp. indet.

Suinae

gen. *et* sp. indet.

Tragulidae

Dorcatherium spp.

Cervidae

gen. *et* sp. indet.

Bovidae

gen. *et* sp. indet.

AVES

ord., fam., gen. *et* sp. indet.

REPTILIA

Testudines

fam., gen. *et* sp. indet.

Squamata

Serpentes

fam., gen. *et* sp. indet.

Crocodylia

fam., gen. *et* sp. indet.

OSTEICHTHYES

ord., fam., gen. *et* sp. indet.

The age of the mammalian fauna from Chiang Muan was determined by two preliminary paleomagnetic studies suggesting late Middle Miocene to early Late Miocene age or about 10 to 13.5 million years old (Suganuma and others, 2002; Chaimanee and others, 2003; Benammi and others, 2003) as Figure 2-9.

2.4 MAE MOH BASIN

2.4.1 Geographical setting

The Mae Moh basin is a coal-bearing Tertiary basin with the largest proven coal reserves of Thailand, about 1,400 million tons. The lignitic coal has been exploited by the Electricity Generating Authority of Thailand (EGAT) and used for power plants with capacities of 3x75 MW, 4x150 MW, and 4x300 MW. The daily consumption of lignite is 40,000 tons a day.

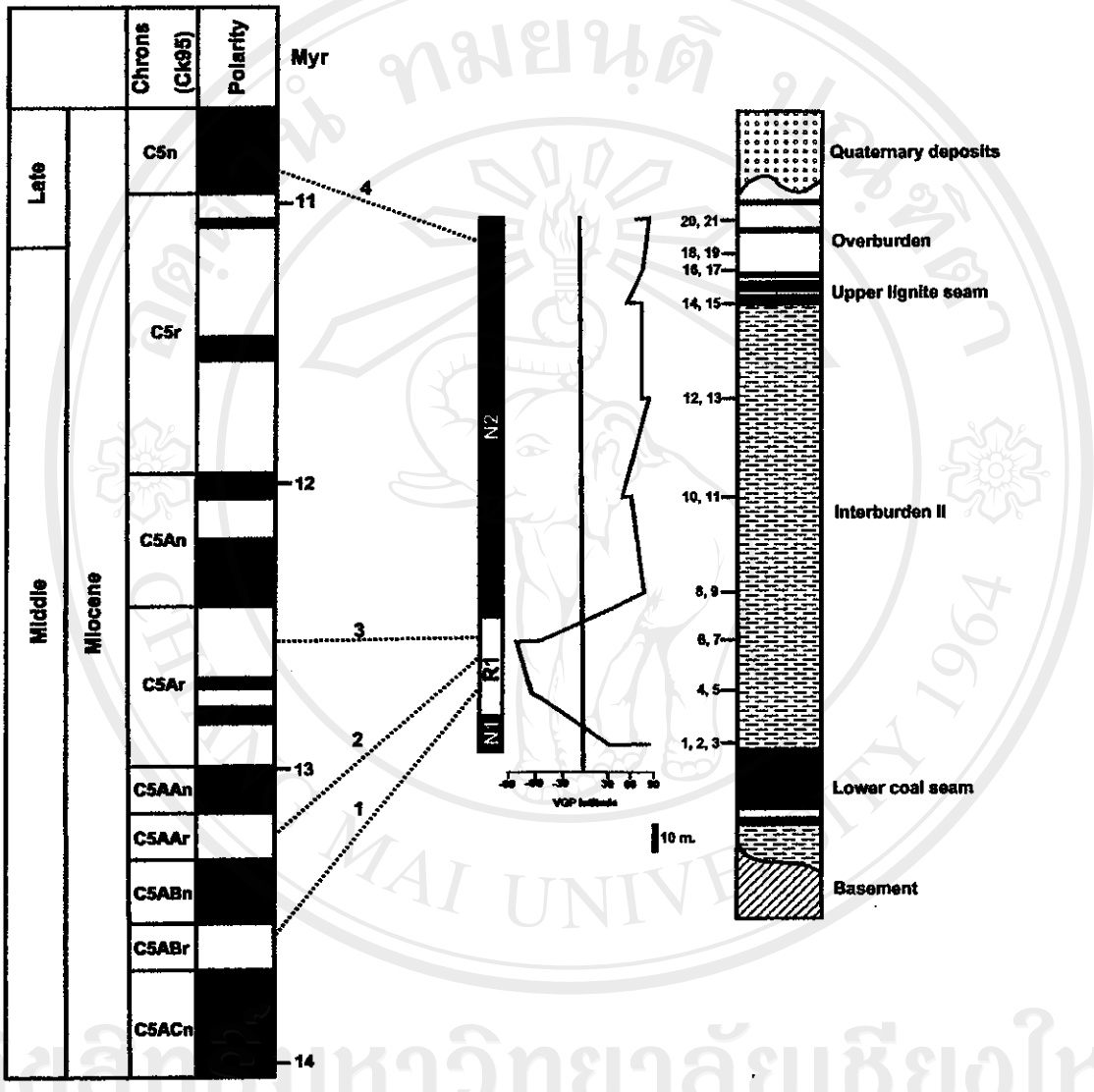


Figure 2-9 Schematic stratigraphic section of Chiang Muan coalfield with magnetic polarity timescale (Chaimanee and others, 2003).

The basin is located in Mae Moh District of Lampang Province about 26 kilometers east of Lampang city. It covers an area of about 80 square kilometers and is 7 kilometers wide and 16 kilometers long. The basin floor is about 320 meters above mean sea level.

From Chiang Mai city, the shortest and most convenient access to Mae Moh is by highway 11 passing Lamphun, Mae Tha, crossing Khun Tarn mountain, and down to Hang Chat, and to Lampang city via a four lane concrete-sealed highway. From Lampang, via highway number 11 (Lampang-Denchai highway), turn left and head directly to the Mae Moh mine on an asphalt-sealed road.

2.4.2 Geology

The basin is a fault bounded basin of a graben type. North-south normal faults cut the Tertiary sediments into many segments. The segments along the basin margins are usually exposed but the inner segments are covered by younger sediments. The Tertiary sediments are bounded by a series of pre-Tertiary rocks including the Hong Hoi Formation, of the Triassic Lampang Group (Chaodamlong and Burrett, 1997). There are a series of Quaternary basalt flows covering the area in the south of the basin (Figure 2-10). The age of the basalts are either 0.69 or 0.95 Ma by paleomagnetic polarity changes (Barr and others, 1976) and 0.6±0.2 to 0.8±0.2 Ma by K/Ar isotopes (Sasada and others, 1987).

The Tertiary sediments in the basin have been divided into 3 formations, the Huai King Formation, Na Khaem Formation, and Huai Luang Formation from the base (Figure 2-11).

Huai King Formation is the lowermost formation of the Tertiary succession unconformably overlying the basement of the Upper Triassic Lampang Group. It consists of semiconsolidated mudstone, siltstone, sandstone, conglomeratic sandstone,

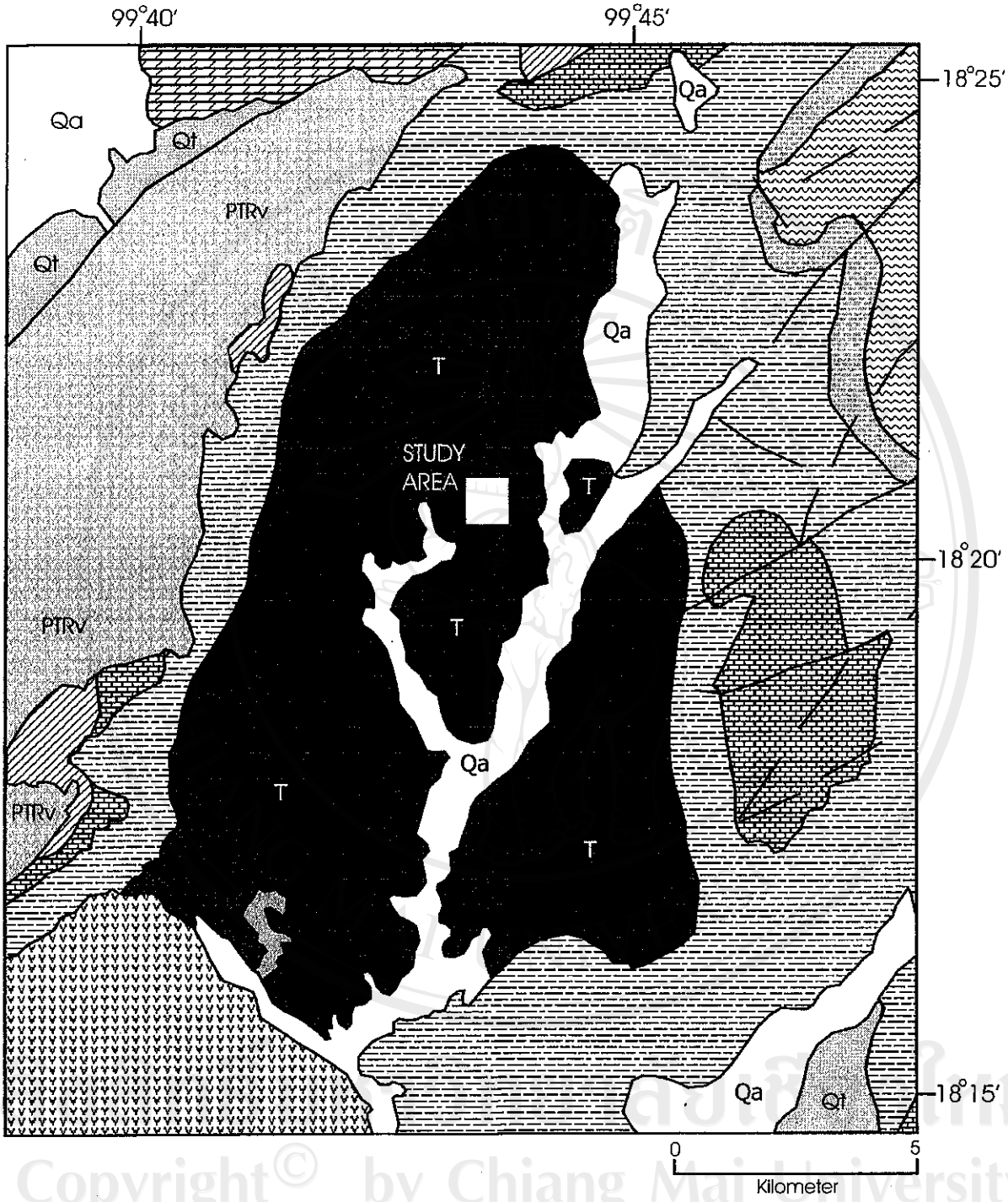


Figure 2-10a Geological map of Tertiary Mae Moh basin showing study area and geology in the surrounding areas, see legends and explanations on next page (Charoenprawat and others, 1995)

SEDIMENTARY ROCKS

Alluvial deposits: gravel, sand, silt, clay, and mud. (QUATERNARY)

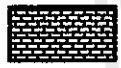
Terrace and colluvial deposits. (QUATERNARY)

Interbedded claystone, sandstone, mudstone, diatomite, and shale with fossil leaves, stem, bone of fish, *Viviparus*, and vertebrate remains. (TERTIARY)

Pha Daeng Formation: sandstone, red to reddish brown, cross-bedded; siltstone, conglomerate, and shale. (TRIASSIC).

Doi Chang Formation: limestone, limestone conglomerate with fossil bivalves, brachiopods, and gastropods. (TRIASSIC)

Hong Hoi Formation: silicified mudstone, gray to black; intercalated with quartzite; tuffaceous sandstone; shale and siltstone, with fossil *Halobia*, *Posidonia*, and *Paratrachycerus*. (TRIASSIC)



Pha Khan Formation: limestone, thin bedded to massive, oolith, oncolith, fossiliferous; interbedded with shale, sandstone, and mudstone, with fossil *Daonella*, crinoid stem, bivalves, coral, and algae. (TRIASSIC)

Phra That Formation: lower part: interbedded black shale, tuff, and sandstone; upper part: interbedded conglomerate, agglomerate, conglomeratic sandstone, tuff, and sandstone; locally developed phyllitic and slaty cleavage with fossil Clarala, Costatoria, and other bivalves. (TRIASSIC)

IGNEOUS ROCKS

Olivine basalt, gray to dark gray, vesicular texture, flow structure (pahoe hoe) with some volcanic bomb and scoria. (QUATERNARY)

Rhyolite, andesite, flow and dike; agglomerate; volcanic conglomerate; rhyolitic tuff and andesitic tuff. (PERMO-TRIASSIC)

Figure 2-10b Legends and explanations for the geological map of Tertiary Mae Moh basin on figure 2-9a, the previous page (Charoenprawat and others, 1995).

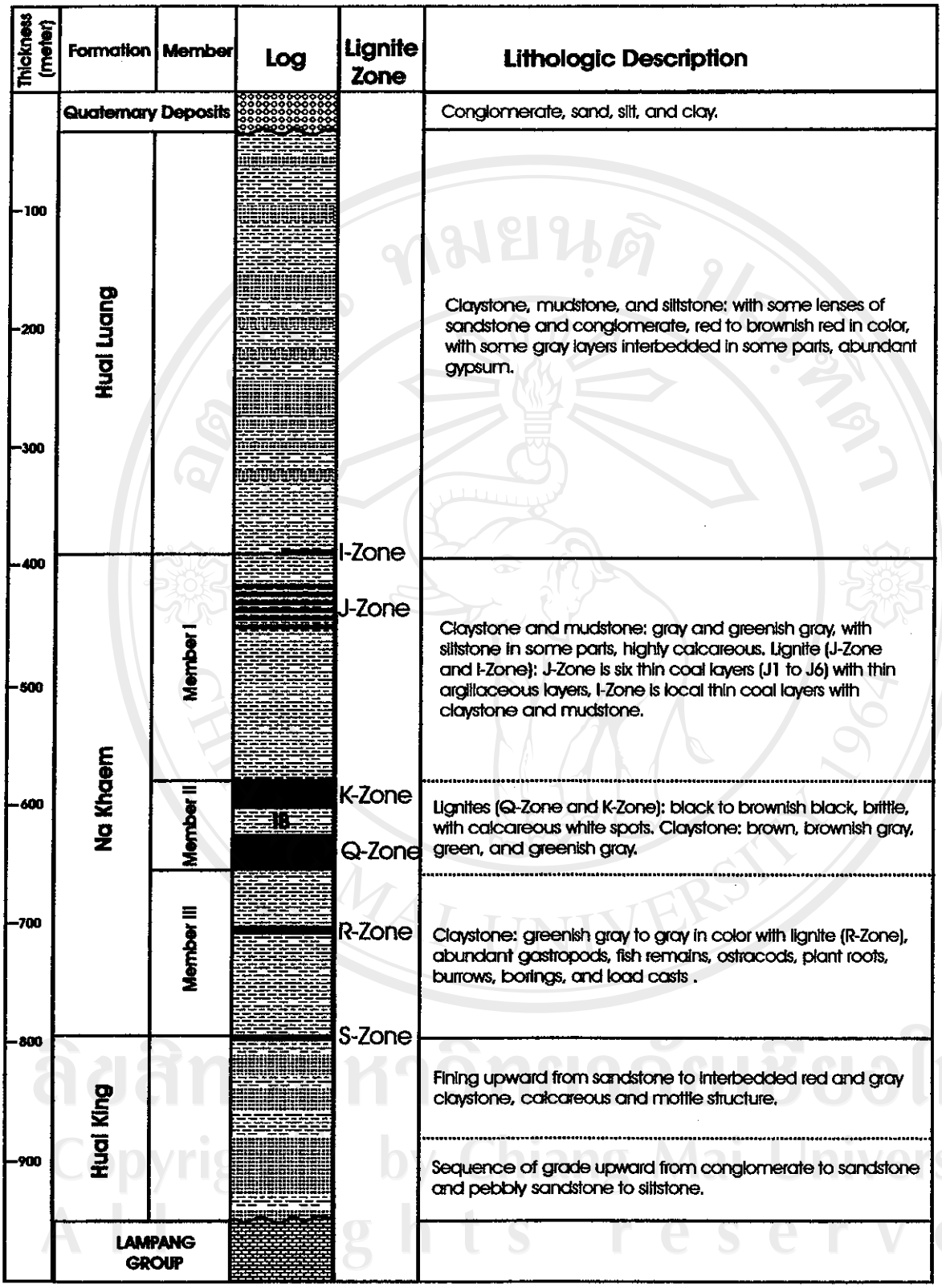


Figure 2-11 Schematic stratigraphic succession of Mae Moh Group (Chaodumrong, 1985; Uttamo and others, 2003).

conglomerate, and some claystone. It is variegated in color with red, gray, green, yellow, blue, and purple, with calcretes common in parts, slightly calcareous cement, and with *Viviparus* molluscs as only the macrofossils. The variation of the formation thickness is probably the result of the paleogeography of the basin. The sediments are a mix of fluvial channel sandstone and fine-grained alluvial and ephemeral lake deposits (Sompong and others, 1996). There is no report of any indicative fossils from the Huai King Formation but it must be older than the Early Miocene judging from a palynological assemblage from the lowermost part of the overlying Na Khaem Formation (Watanasak, 1988).

Na Khaem Formation is the middle unit of the Mae Moh Group conformably overlying the Huai King Formation. It is characterized by a fine-grained clastic association with some medium grained clastics. It is a coal measure formation consisting of semiconsolidated mudstone, gray to greenish gray, abundant fossils, highly calcareous, and with load structure, flaser bedding, burrows, borings, and intraformational conglomeratic texture in some layers. Its thickness varies from 300-420 meters (Uttamo and others, 2003). This formation has been classified into 3 zones including Member III, Member II, and Member I from the base (Chaodumrong, 1985).

Member III is 150 to 230 meters thick and consists of greenish gray to gray calcareous claystone. These laminated beds are of the thick, planar type, and highly calcareous. Abundant gastropods occur in a bed in the upper part (*Viviparus* and *Physa*). Fish remains, ostracods, plant roots, intraformational conglomeratic texture and intermix color texture near lignite seams or lignitic layers, burrows and borings, load casts also occur. The boundary between lignite zone S of the Huai King Formation and the claystone of this member has been interpreted as a flooding surface

(Sompong and others, 1996). The upper boundary of this member is the lowermost surface of the lignite zone Q. The lithofacies associations of this member are consistent with deposition in a lacustrine and swamp environment (Uttamo and others, 2003).

Member II of the Na Khaem Formation consists of lignite zones Q and K. The thickness of these Q and K zones are up to 30 meters and they are separated by claystone that is up to 22 meters. The Q zone coal is black to brownish black, brittle, with abundant siliceous and calcareous white spots (diatoms), pyritized gastropods (*Viviparus*), and plant remains. The seam is technically divided into 4 sub-seams, Q1 to Q4, with total thickness varying from 25 to 30 meters. It is split in the north and south with thicker silty claystone partings and lateral change of lignite to ligneous claystone and clay. Gypsum occurs abundantly in the uppermost sub-seam (Q1). The depositional environment of this Q zone coal is a swamp and shallow lake (Uttamo and others, 2003) which occasionally dried up (Tankaya, 2001).

The interburden is a sequence of brown, brownish gray, gray, green, and greenish gray claystone lying between two major coal seams (Q and K seams). These beds are laminated to thick, planar type, lignite flakes common, fish remains, plant roots, rare ostacods, intraformational conglomeratic texture common in the lower part, gastropod (*Viviparus*) common, load casts, and abundant microslip planes. This interburden is thicker to the east and thinner to the west flanks of the main basin.

K zone is a sequence of coal in the upper part. It is black to brownish black, brittle, with calcareous white spots, common gastropod (*Viviparus* and *Mellanoides*), and rare fish and plant remains. It is interbedded with some soft lignite and partings of light yellowish gray to gray silty claystone. Thickness varies from 10 to 30 meters. It is split in the north and south with thicker silty claystone partings and lateral changes

to ligneous claystone/clay. The coal series are named K1 to K4 from upper to lower. The K1 is the place where mastodon remains were found, and K3 is marked by the abundance of *Planorbis*. Depositional environments of the K coal zone are a freshwater swamp, poorly-drained plain, and crevasse spray (Tankaya, 2001; Uttamo and others, 2003)

Member I of the Na Khaem Formation is a sequence of gray and greenish gray claystone and mudstone with occasional siltstone in some parts. It is 80 to 180 meters thick (Uttamo and others, 2003). These beds are laminated to massive, planar type, and highly calcareous, with fine-grained pyrite spots common in some parts, abundant gastropods (*Mellanoides*, *Physa*, *Viviparus*), fish remains, ostacods, plant remains, reptile skeletal, load structures, intraformational conglomeratic texture and intermix color texture near lignite seams or lignite layers, burrows and borings. The upper part of this zone consists of 2 thin argillaceous layers (thickness less than 2 meters) and thin seams of lignite are named J1 to J6 from upper to lower. The lithofacies associations of the lower and middle parts of Member I represent deposition in lacustrine and swamp environment, whilst the upper part of the member is considered as a deposit in a well-drained flood plain environment (Uttamo and others, 2003).

Huai Luang Formation consists of semiconsolidated and unconsolidated sediments. Red to brownish red color is characteristic, with some gray layers interbedded in some parts. Almost are claystone, siltstone, and mudstone with some lenses of sandstone and conglomerate in the central part of the basin. Local lenses of mudstone and claystone with thin seams of lignite overlying the J1 was recently discovered by miners and has been named "I Zone". No macrofossils have been reported. Abundant gypsum and pyrite, rare root structures and flame structures occur.

Thickness of this formation varies from less than 5 meters to 400 meters. It is thickest in the center of the main and western sub-basin, thinning rapidly towards the eastern and western margins. This formation is red bed due to oxidation of fine-grained pyrite disseminated throughout certain layers within the formation.

Uttamo and others (2003) reconstructed the depositional environments into four stages. First stage started with a well-drained floodplain, alluvial fan, and ephemeral streams and ponds under semi-humid to semi-arid climate. The second stage was a poor-drained floodplain, swamps, peat swamps, and ponds under a humid climate. Subsequently, it was a lacustrine and fine-grained fluvial channel. It ends up as a large braided-river. A marine incursion probably occurred during the red bed zone formation as indicated by marine pyrite and gypsum (Tankaya, 2001).

2.4.3 Paleontology and age determination

Sithiprasasna (1959) reported the occurrence of mastodon teeth, fish remains, molluscs, turtle lip and back plates, fossil wood and grass, and the end of a fish tooth in the Mae Moh shale (K coal seam). Von Koenigswald (1959) identified the mastodon teeth as *Stegolophodons praelatidens* as a new species without any diagnosis and description. The name *Stegolophodons praelatidens* was thus *nomen nudum* under the International Code of Zoological Nomenclature and the name was thus rejected (Ginsburg and Tassy, 1985). A faunal assemblage including otter (*Siamogale thailandica*), Rhinoceros (cf. *Gaindatherium*), and mastodon (*Stegolophodons*) indicates an age of Middle Miocene.

Watanasak (1988) studied fossil sporomorphs from the LM2813S borehole, in Mae Moh basin. Two palynological zones were described, Siam-I and Siam-II Zones. Siam-I Zone is probably related to the S lignite seam, the lowermost portion of the Na Khaem Formation. *Alnipollenites verus* dominates this zone and

Echiperiporites cf. *E. estelae* is absent. The age of the zone was assigned to the early Early Miocene. The Siam-II Zone is possibly related to the overlying sequence of the S lignite seam and the R lignite seam but not the Q lignite seam. The zone contains various forms of sporomorphs of both warm temperate and tropical affinities. The age of the zone was assigned to the middle to late Early Miocene. The samples above these probably include samples from Q lignite seam onwards including K lignite and J lignite seams. The zone commonly contains the same assemblage as the underlying sequence but *Alnipollenites verus* disappears. This part is also related to the Siam-II Zone and the age of the zone was considered to be Middle Miocene. An age range of 12.5 and 12.8 Ma (late Middle Miocene) was proposed for the fossiliferous levels (J5, K1, and K2 lignite zones) on the basis of magnetostratigraphy (Benammi and others, 2002) as Figure 12. Accordingly, the age of the Mae Moh sediments ranges from Early to Middle Miocene.

2.5 MAE LAMAO BASIN

2.5.1 Geographical setting

The name Mae Lamao derived from a village name in Pawor Sub-district, Mae Sot District of Tak Province. It is a small intermontane basin located at latitude 16°41′ to16°51′ north and longitude 98°43′ to 98°54′ east on topographic map scale 1: 50,000 sheets 4742-I (Ban Pang San) and sheet 4742-IV (Amphoe Mae Lamat). The basin covers an area of about 90 square kilometers, about 65 kilometers from Tak city, north of the Tak-Mae Sot highway (highway 103). The coal has been exploited by the Suje Lignite Company Limited.

From Chiang Mai, access to the basin is via highway 11 to Lampang, then turn right to highway 1 directly to Tak Province by a four lane concrete-sealed

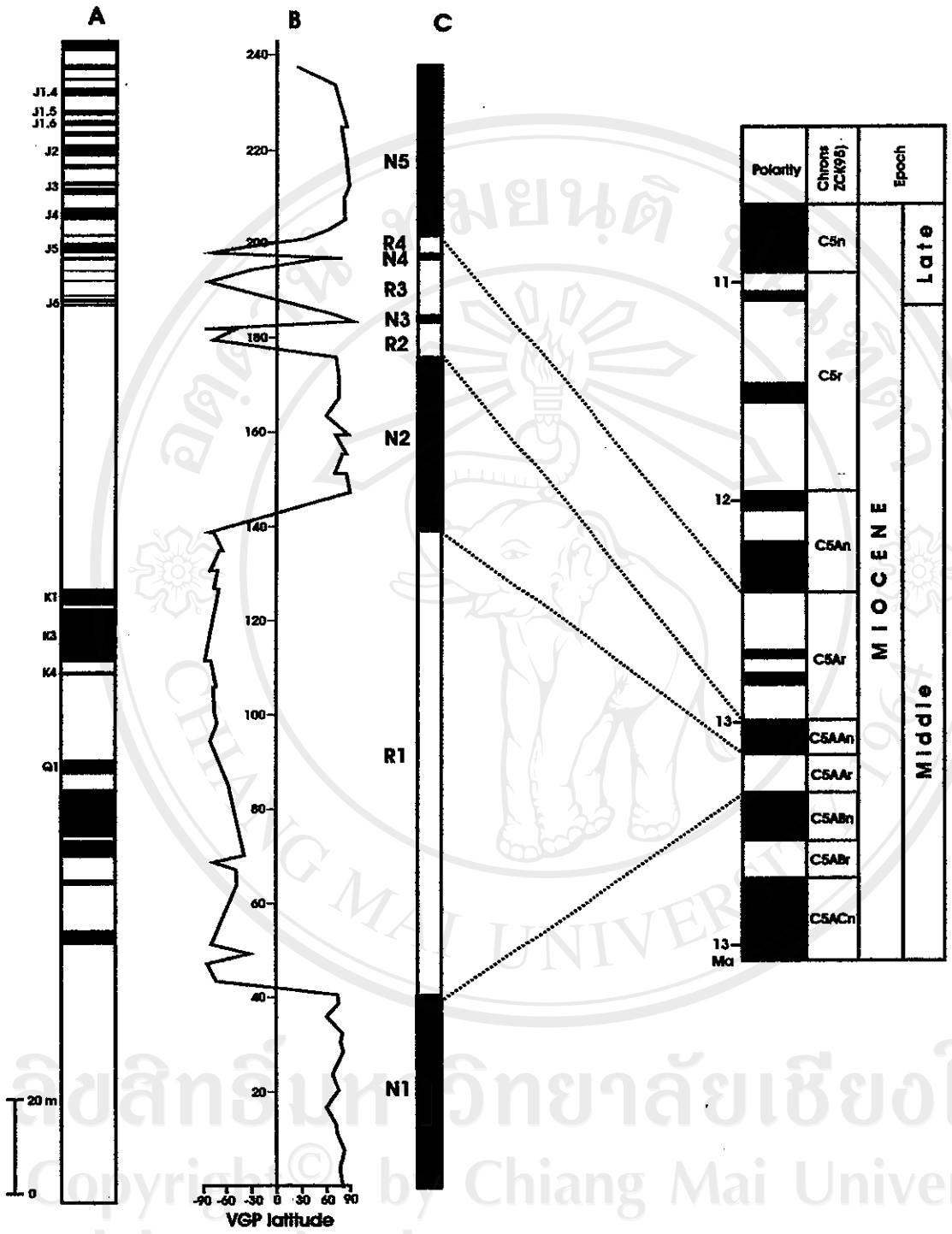


Figure 2-12 Schematic stratigraphic section of Mae Moh Group with magnetic polarity timescale (Benammi and others, 2002).

highway for about 265 kilometers. Next 1 to 2 kilometers from the Tak city turn right to enter highway 103 (Tak-Mae Sot highway). In the area of Pawor sub-district, turn north to Mae Lamao village. Suje Mine is located near Huai Mae Lamao (a stream) not very far from the village. The access from the village to the mine is a heavy truck road sealed with laterite for about 2 kilometers and is accessible during dry season.

2.5.2 Geology

The graben of Mae Lamao trends north-northwest and is surrounded by black shale, slaty shale, fine-grained sandstone and a quartzitic phyllite sequence of Silurian-Devonian age on the east and north of the basin. To the west and south are banded limestones with chert nodules, gray shale, sandstone, and carbonaceous shale of Carboniferous to Permian ages. A small outcrop of Triassic limestone, calcareous siltstone, shale, and chert is on the northwestern edge of the basin (Figure 2-13).

The basin contains Tertiary sediments. The Tertiary outcrops exposed in the coal mine are only part of the whole sequence. During the time of the field investigation, excavation of the mine was begun. About 25 meter-thick sedimentary sequence was investigated. The main coal seam was not available at that time. Only 30 samples were collected from the available section provisionally divided into four units, Unit A, Unit B, Unit C, and Unit D from the base (Figure 2-14).

Unit A is greenish gray claystone commonly containing leaf remains. This unit is somewhat homogenous in character and about 11 meters in thickness. Unit B is alternation between claystone and coal of 1.5 meters in thickness. The coal has a high sulphur content. Unit C is a conglomerate, about 6.5 meters thick with a thin claystone layer in the middle part. Unit D is claystone about 6.9 meters thick. The claystone generally splits along the bedding plane forming very thin layers looking like a stack

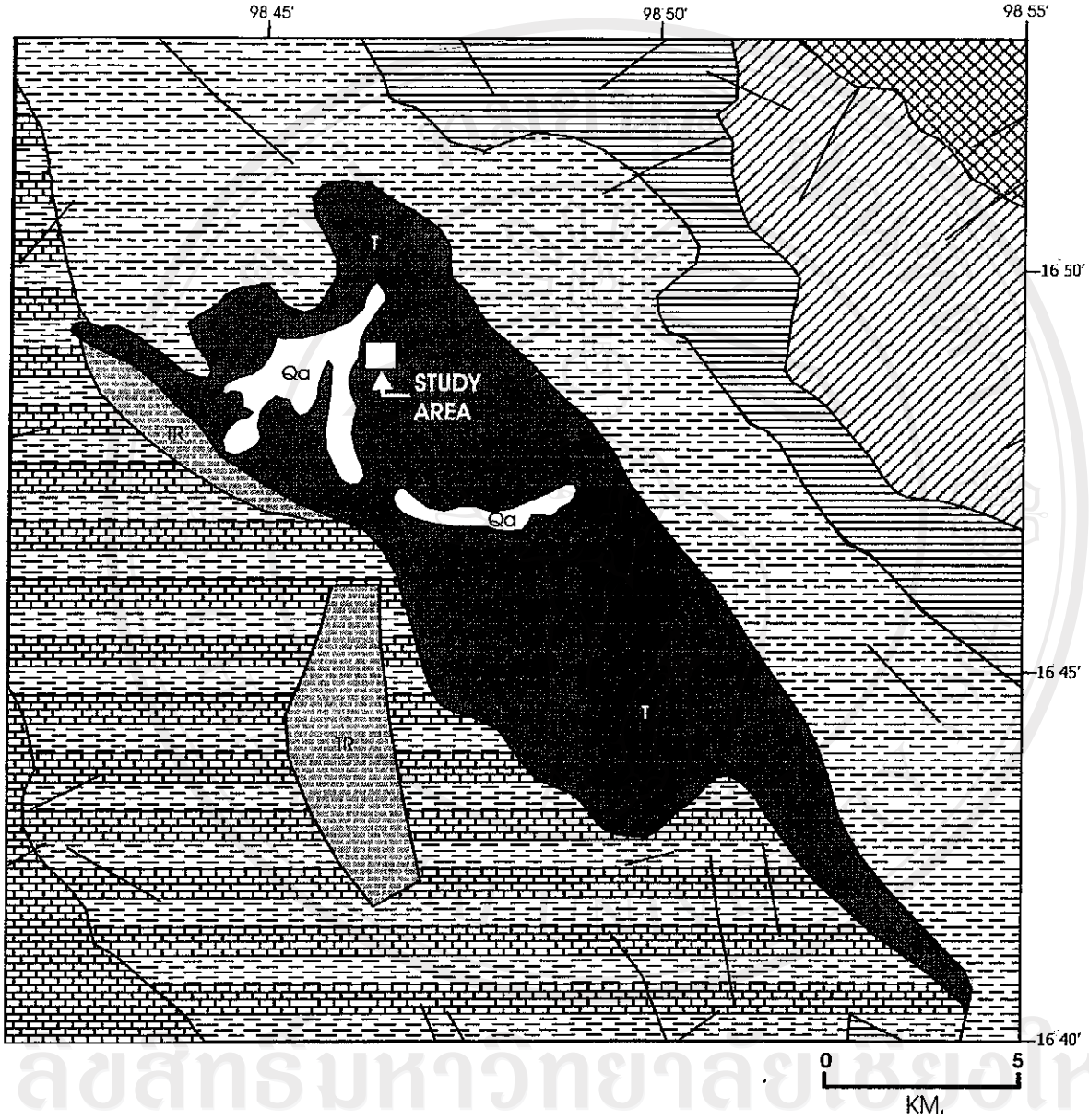
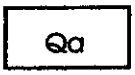


Figure 2-13a Geological map of Tertiary Mae Lamao basin showing study area and geology in the surrounding areas, legends and explanations see figure 2-11b, the next page (Sukto and others, 1984).



Alluvial deposits: gravel, sand, silt, and clay. (QUATERNARY).

Shale and oil shale with fossil fishes, insect, and plants; conglomerate; sandstone; limestone, gray to light gray with gastropods; lignite; and marl. (TERTIARY)

Limestone; calcareous siltstone; shale; and chert. (TRIASSIC)

Massive limestone, dolomitic; gray limestone; shale; and sandstone. (PERMIAN)

Limestone, banded, with chert nodules; shale, grey; sandstone; and carbonaceous shale. (CARBONIFEROUS-PERMIAN)

Shale, black; shale, slaty; sandstone, fine-grained; and white quartzitic phyllite. (SILURIAN-DEVONIAN)

Limestone, banded, well bedded and massive, argillaceous; limestone, mica-bearing; shale, greenish grey; and sandstone. (ORDOVICIAN)

Quartzite, bedded and massive; with phyllite and quartz-schist interbeded. (CAMBRIAN)

Metamorphic complex, augen gneiss, granite gneiss, biotite-microcline gneiss, quartz-feldspathic gneiss, biotite schist, banded quartzite, calc-silicate and marble; commonly well layered, laminated and bedded. (PRECAMBRIAN)

Figure 2-13b Legends and explanations for Tertiary Mae Lamao basin on figure 2-11a, the previous page (Sukto and others, 1984).

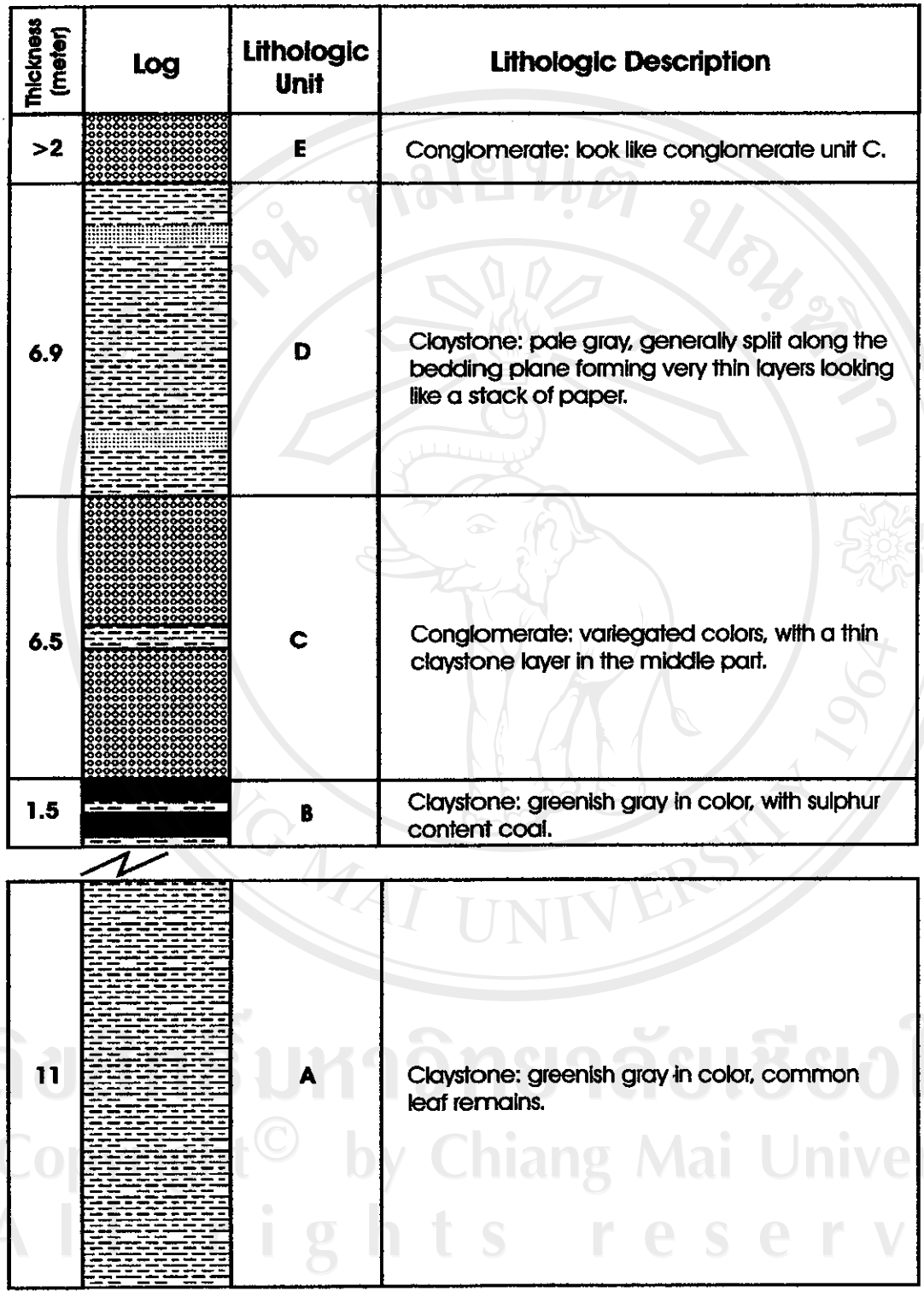


Figure 2-14 A partial schematic stratigraphic succession of Mae Lamao coalfield.

of paper or "Paper Shale". There is so far no vertebrate remains reported from Mae Lamao sediments.

Ratanasthien (1989) reported on the former coalfield (now abandoned and flooded) about 500 meters from this active mine and described it as follows:

The organic layers are thin beds ranging from 0.2 to 6 meters associated with claystone and sandstone. The number of layers and thickness varies from place to place and from one thick layer to many thin layers. The coal is of lignite to subbituminous in rank, characterized by thin to very thin-bedded carbonaceous shale or coal in the lower part of the seam gradually thickening towards the top of the seam with better coal quality. The color is black to brownish black, dull, with 10 to 15 percent vitrain interlayers. Petrological study reveals the coal in the two major seams to be similar, dominated by approximately 15 to 20 percent vitrinite composed mainly of gelovitrinite and detrovitrinite. The liptinite group is approximately 15 to 20 percent, composed mainly of sporinite, alginite, cutinite, and resinite. The inertinite group is approximately 5 percent, consists only of sclerlotinite. The vitrinite reflectance in oil ranges from 0.42 to 0.52 with a mean of 0.45 percent. Proximate analysis shows the moisture ranging from 11 to 24 percent, volatile matter (dry base) 34 to 43 percent, fix carbon (dry base) 35 to 54 percent, and ash (dry base) 3 to 34 percent. Sulphur is generally higher in the upper seam than the lower seam and varies from 1.2 to 4 percent. Heating value (dry base) varies from 4,600 to 6,300 kcal/kg or 19 to 26.5 mJ/kg.

2.5.3 Paleontology and age determination

There is no report on the occurrence of fossils excepted palynological research run by Ratanasthien (1989). The palynological assemblages were mostly tropical elements particularly palms and mangroves. The mangrove palm pollen,

Spinizonocolpites spp., the *Nypa*-type, was reported to be rare. However, the common occurrence of *Florschuetzia trilobata* and *F. semilobata* (cf. Sonneratiaceae-type) together with *Zonocosites ramonae* (Rhizophoraceae-type) suggested that the sediments in the Mae Lamao basin belong to riparian facies in the inner part of an estuary not very far from a coastal swamp. The age of these Tertiary sediments was given as Oligocene to Lower Miocene according to the presence of the *Florschuetzia trilobata* and *F. semilobata* (Ratanasthien, 1989).

2.6 NA HONG BASIN

2.6.1 Geographical setting

Na Hong basin is a small coal-bearing Tertiary basin located approximately 30 kilometers north of Mae Chaem District, Chiang Mai Province. It lies between 98° 19' and 98° 21' east longitude and between 18° 42' and 18° 43' north latitude. It is on topographic map sheet 4646 II (Ban Mae Na Chon sheet), scale 1: 50,000, and covers about 10 square kilometers. The elevation of the basin floor varies from 700 to 800 meters above mean sea level, and the basin is surrounded by mountain chain complexes 800 to 1,100 meters high. The drainage in the basin is dominated by sub-parallel flow from north to south, which joins a main river, the Nam Mae Yot, to the south of the basin. The coal mine was operated by Laem Thong Lignite Company Limited and was abandoned by the end of the year 2000 and is now flooding.

From Chiang Mai city, there are two ways to access Na Hong basin. The first is highway 108, from Chiang Mai passing Hang Dong, San Pa Tong to Chom Thong District. From Chom Thong uses highway 1009 to Doi Intanon National Park and uses a narrow road (number 1192) to Mae Chaem District. This route is quite dangerous especially from Chom Thong up Intanon mountain and down to Mae

Chaem District. However, another more convenient route is available. From Chom Thong use highway 108 passing Hot District to Ob Luang National Park then turn right on highway 1088 to Mae Chaem District along a winding road. The later route is more convenient but somewhat longed. From Mae Chaem drive northwards on an alternately unsealed and sealed road. The sealed parts are generally along the community areas. About 30 kilometers from Mae Chaem pass Ban Mae Na Chon then drive up a mountain, Na Hong basin is beyond the mountain.

2.6.2 Geology

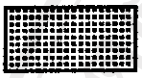
Na Hong basin was first reported as a Tertiary basin by Baum and others (1982). The basin is bounded by Devonian-Carboniferous sedimentary rocks except in the northwest part where it is bounded by Upper Carboniferous conglomerate, sandstone, and shale (Figure 2-15). The Tertiary sedimentary strata in the basin consists of conglomerate, gravel, sandstone, sand, shale, oil shale, and coal. Sedimentary strata are classified into two units, unit A and unit B (Figure 2-16). Unit A is dominated by fine-grained sediments including oil shale, shale, coal, with thin layers of sand and sandstone intercalated. Unit B is dominated by coarse-grained sediments including sandstone, conglomeratic sandstone, and conglomerate in the upper most part with thin coal seams intercalated.

The Tertiary strata in the basin are bounded by pre-Tertiary rocks of Late Silurian to Devonian and Carboniferous ages described previously by Baum and others (1970, 1982). The Silurian to Devonian rock is exposed in the eastern and southern parts of the basin. It is a series of shale, sandstone, greywacke, and chert with occasional limestone intercalations. This limestone is lithologically similar to the Ordovician limestone. The western side of the basin is bounded by an Upper Carboniferous clastic rock sequence. Clastic sedimentation continued from Devonian

SEDIMENTARY ROCKS

Gravel, sand, silt, and clay. (QUATERNARY)

Gravel, conglomeratic sandstone, sandstone, shale, oil shale, and coal. (TERTIARY)



Conglomerate, sandstone, and shale. (UPPER CARBONOFEROUS)

DEVONIAN - CARBONIFEROUS

Limestone, shale. (ORDOVICIAN)

Sandstone. (CAMBRIAN)

IGNEOUS ROCKS

Granite, granodiorite, porphyritic. (TRIASSIC)

Granite. (CARBONIFEROUS)

Figure 2-15b Legends and explanations for geological map of Tertiary Na Hong basin on figure 2-13a, the previous page (Baum and others, 1982).

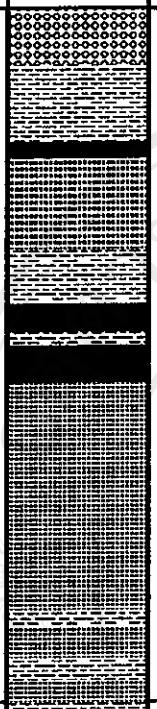
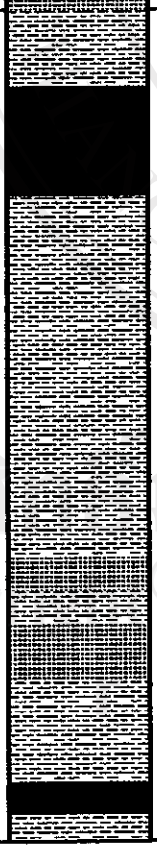
Thickness (meter)	Log	Lithologic Unit	Lithologic Description
25		B	Sandstone, shale, oil shale, and conglomerate: Sandstone is greenish gray, light gray to purplish gray, finning upward into conglomerate in the upper portion, with tuffaceous in some layers. Shale is greenish gray, thin layers in thick sandstone layers with oil shale in some layers. Conglomerate is in the uppermost part, consisting of rock fragments of shale, andesite, and quartz, angular to subangular.
30		A	Oil shale, coal, sand, and sandstone: oil shale is dark gray, black, gray to greenish gray in color, brittle. Coal is black in color, hard, massive, cube fractured with pyrite filled, dull to bright, with annual rings. Sand is greenish gray to light brown in color, unconsolidated.

Figure 2-16 A partial schematic stratigraphic succession of Na Hong coalfield.

to Carboniferous without any conspicuous break. The rock consists of a thick sandstone complex. The basin is characterized as a fault-bounded basin. The fault trends mainly northeast-southwest and nearly north-south.

2.6.3 Paleontology and age determination

Ratanasthien (1997) studied the algae-type of oil source rocks in northern Thailand, include that of the Na Hong basin. She concluded that the association of *Botryococcus* algae with suberinite in coal and oil shale from the Na Hong basin indicated a swamp to lake environment that finally ended up with temperate forest swamps. The gradual change of algae type from thick yellow mass *Botryococcus* to lamaginite also indicated a change in chemistry or depositional environment to a lacustrine environment before the development of temperate forest swamps.

Songtham and others (2000) classified sedimentary strata in the Na Hong coalfield into two zones on the basis of palynology. The lower zone is *Pediastrum* Zone and the upper zone is *Inaperturopollenites dubius* Zone. The lower zone strongly indicates a lacustrine depositional environment and changes up to temperate forests in the *Inaperturopollenites dubius* zone dominated by warm temperate elements viz. *Inaperturopollenites dubius*, *Pinuspollenites*, *Piceaepollenites*, *Tsugaepollenites igniculus*, *Alnipollenites verus*, *Liquidambarpollenites stigmosus*, and *Momipites coryloides*. Oligocene to Lower Miocene was proposed as the age of the palynofloras.