

CHAPTER 2

GEOLOGY

2.1 Cenozoic Tectonics and Tertiary Basin Evolution

Tectonic activity was strongly activated in the Indochina area during the Tertiary as a consequence of the collision of India and Eurasia, local tectonic events of Southeast Asia, and the collision of Australia and Sundaland in southeastern Indonesia (Hall, 2002). The Southeast Asia Tertiary basins, the Gulf of Thailand, and the offshore area of Vietnam have been driven by Himalayan escape tectonics. The formation of rift basins occurred as pull-aparts along strike-slip fault traces (Tapponnier *et al.*, 1982 and 1986; Polachan *et al.*, 1991; Leloup *et al.*, 2001; Replumaz and Tapponnier, 2003) (Fig. 2.1). The escape tectonics system has been identified as the change from left lateral to right lateral displacement on major northwest-southeast trending strike-slip faults, particularly the Three Pagodas, Mae Ping, and Red River fault zones. The time of this change for the Mae Ping and Three Pagodas fault zones was during the Late Oligocene. The Red River fault had a tendency for stability. However, a change in motion probably occurred around the latest Early Miocene. The beginning of dextral motion on this fault was probably during the Late Miocene to Pliocene (Leloup *et al.*, 1995; Lacassin *et al.*, 1997 and 1998).

The Tertiary basins of northern Thailand developed as relatively small basins, covering just a few square kilometers, to large basins, such as the Chiang Mai, Phrae, and Lampang basins, which are 20 to 40 kilometers wide, more than 140 kilometers



Fig. 2.1 Tectonic map of central-east Asia illustrating 'Extension' model and its relation with Cenozoic structures in the region. Number in white arrow indicates the relative order in which certain continental blocks were extruded toward the southeast (modified from Tapponnier *et al.*, 1982).

long, and 2 to 3 kilometers deep (Morley *et al.*, 2001). On the western margin of these Tertiary basins are the Doi Suthep and Doi Inthanon metamorphic core complexes (Dunning *et al.*, 1995; Rhodes *et al.*, 1997 and 2000; Barr *et al.*, 2002). Movement on the extensional detachments may have begun in the Eocene, whereas uplift and erosion of the core complexes occurred predominantly from the Late Oligocene to the Early Miocene (Upton *et al.*, 1997; Barr *et al.*, 2002; Rhodes *et al.*, 2002). The extensional trends in the Tertiary basins are mainly east-west to east northeast-west southwest and have a history from at least the Late Oligocene to the Late Miocene (Morley *et al.*, 2000). In addition, the reversal of motion, or inversion, on some extensional faults and folding occurred during the Miocene. Most regional inversion events took place around the Late Miocene/Pliocene boundary (Morley *et al.*, 2001).

The Late Tertiary to Recent fault patterns from Yunnan to northern Thailand resulted from unstable and continuous tectonic activity. In Yunnan, the maximum shear direction of northeast-southwest caused dextral motion on the north-south Sagaing, Nanting, and Gaoligong fault zones. Sinistral motion also occurred on east northeast-west southwest striking faults, which is still the sense of motion today for these faults. In northern Thailand, the dextral-sinistral switch is not tenable because the Fang basin is dominated by strike-slip deformation. Thus, northern Thailand has evolved predominantly by oblique extension. Thailand's Golden Triangle area marks the transition from trans-tensional deformation in the north to oblique extension in the south. However, this structural picture is not clear because of the multiple episodes of basin inversion that occurred in northern Thailand during the Miocene (Morley, 2005).

2.2 Geology of Mae Moh Basin

The Mae Moh basin is located in Mae Moh District in Lampang Province. It is 630 kilometers north of Bangkok and 26 kilometers east of Lampang city. It is a small Tertiary sedimentary basin approximately 16 kilometers long and 7 kilometers wide and it has more than 900 meters of Tertiary sedimentary fill. The open cast coal mine in the basin is approximately 3 kilometers wide east to west and 4 kilometers long north to south. The basin is bounded mostly by marine Triassic limestone, shale, and sandstone of the Lampang Group. In the southern part of the basin the Tertiary sequence is overlain by Quaternary basalt (Fig. 2.2) (Sasada *et al.*, 1987; Charoenprawat *et al.*, 1995; Chaodamrong and Burrett, 1997). Unconsolidated Quaternary fluvial deposits form a thin veneer cover throughout the basin. These Quaternary beds consist of gravel deposits in the lower part, lacustrine to fluvio-lacustrine deposits in the middle part, and alluvial deposits in the upper part (Chaodamrong, 1985; Jitapunkul *et al.*, 1985; Uttamo *et al.*, 2003).

The major trends of deformation around the basin are northeast to north-south. Tertiary succession in the basin is bounded by north-south trending normal faults that were the result of an extensional tectonic regime during the Tertiary and Quaternary.

The Tertiary Mae Moh Group of the Mae Moh basin has been divided into three formations. Each of these formations has different lithology, sedimentary structures, degree of consolidation, and fossils (Chaodumrong, 1985; Jitapunkul *et al.*, 1985; Songtham *et al.*, 2005a and b; Silaratana, 2005, Fig. 2.3).

Huai King Formation: This is the lowest formation of the Mae Moh Group. It unconformably overlies the Lampang Group, which forms the basin's basement.

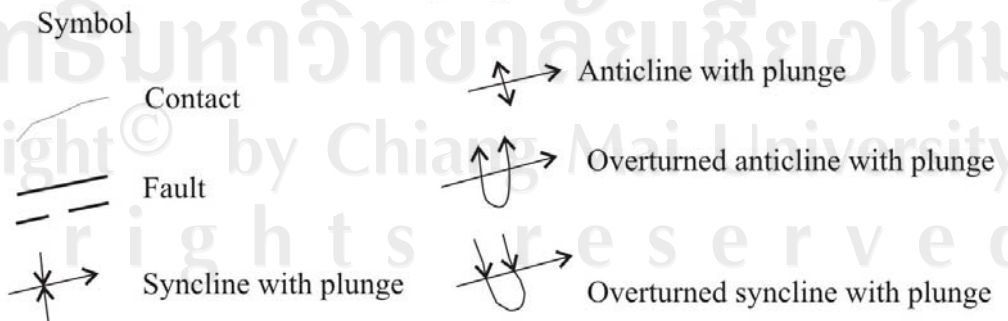
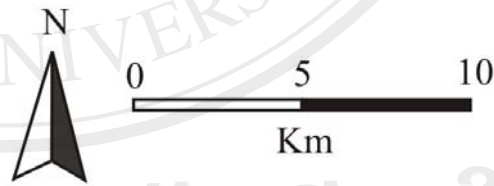
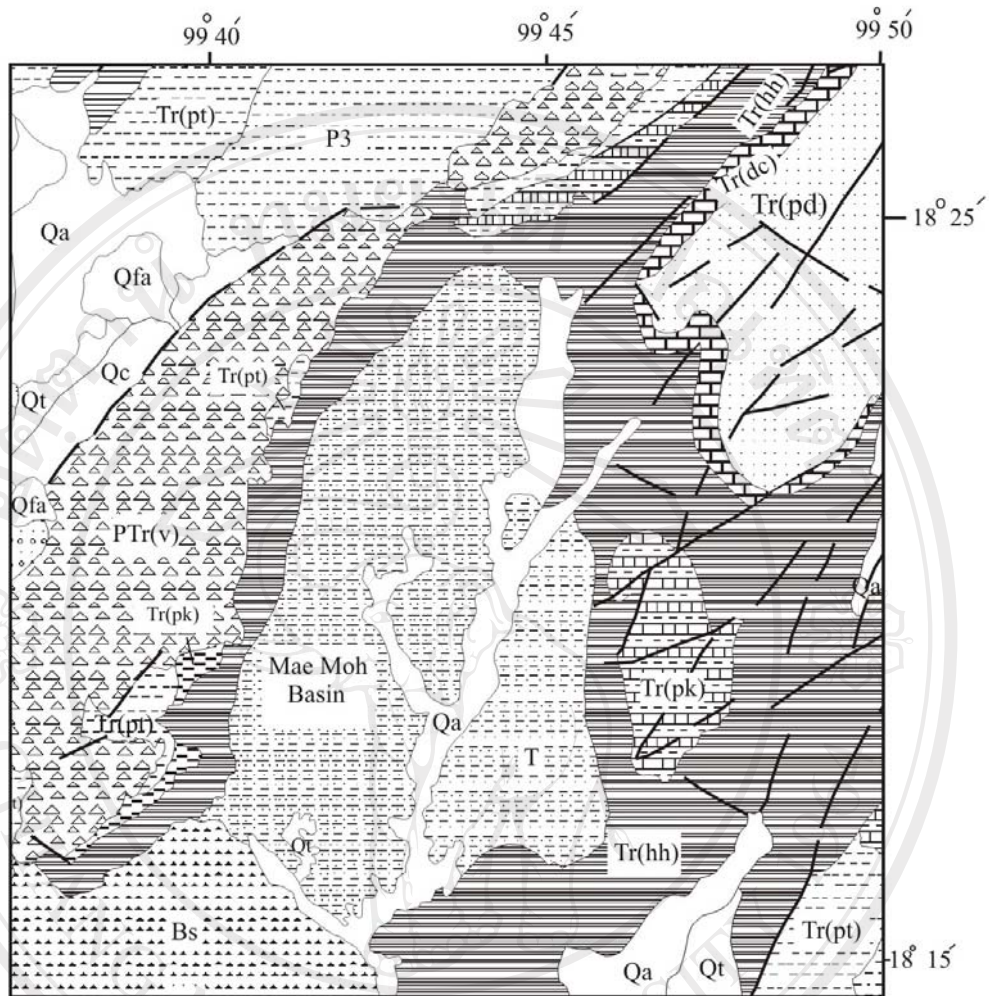


Fig. 2.2 Geologic map of Mae Moh basin (modified from Charoenprawat *et al.*, 1995).











Legend	Age	Rock Unit	Description
Sedimentary rock 	Quaternary	Mae Taeng Group	Alluvial fan sand and clay unit: sand, clayey and silty, light gray, interbedded with sandy clay. Alluvial deposits: gravel, sand, silt, clay and mud. Terrace deposits: gravel, sand, silt, clay, and lateritic soil. Colluvial unit: rock fragments, gray, orangish red, covered with clayey sand and laterite.
	Tertiary	Mae Moh Group	Interbedded claystone, sandstone, mudstone, diatomite, coal, and shale with fossil leaves, stems, bone of fish, and <i>Viviparus</i> sp. and vertebrate remains.
		Lampang Group	
	Triassic	Pha Daeng Formation	Sandstone, red to reddish brown, cross-bedded; siltstone, conglomerate and shale.
		Doi Chang Formation	Limestone, gray to light gray, finely crystalline, massive; limestone conglomerate with fossil bivalves, brachiopods and gastropods.
		Hong Hoi Formation	Silicified mudstone, gray to black, light brown to yellowish brown; intercalated with quartzite, light gray to dark gray, fine-grained; tuffaceous sandstone, gray to brownish gray, fine-to medium-grained, intercalated with shale, gray to dark gray; shale and siltstone, gray to greenish gray, with fossil <i>Halobia</i> sp., <i>Posidonia</i> sp., <i>Paratrachycerus</i> sp.
		Pha Khan Formation	Limestone, thin-bedded to massive, oolith, oncolith, fossiliferous; interbedded with shale, sandstone, and mudstone, with fossils of <i>Daonella</i> sp. crinoid stems, bivalves, corals, and algae.
		Phra That Formation	Lower part: Interbedded black shale, tuff and sandstone; Upper part: interbedded conglomerate, agglomerate, conglomeratic sandstone, tuff, sandstone, shale, mudstone, and siltstone, red, gray to dark gray and reddish brown; with limestone lens; locally developed phyllitic and slaty cleavage with fossils <i>Claraia</i> sp., <i>Costatoria</i> sp., and other bivalves.
	Permian	Kiu Lom Formation, Ngao Group	Interbedded black shale, gray sandstone, dark gray mudstone, and gray limestone with chert nodules; intercalated with fossiliferous limestone and mudstone.
Igneous rock 	Pleistocene volcanic		Olivine basalt, gray to dark gray, vesicular texture, flow structure (Pahoehoe) with some volcanic bomb and scoria.
	Permo-Triassic volcanic		Volcanic rocks: rhyolite, andesite, flow and dike; agglomerate; volcanic conglomerate; rhyolitic tuff, and andesitic tuff.

Fig. 2.2 (continued)


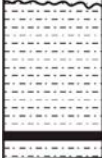












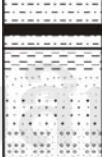
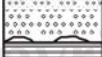


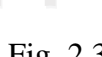
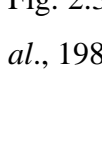




Lithology	Thickness (m)	Zonation	Lithologic Descriptions	Age
	0-50	Alluvium	Gravel, sand, silt, clay, and mud	Quaternary
	0-80	Huai Luang Formation I -Zone	Claystone, siltstone, and mudstone, lens of sandstone and conglomerate, semiconsolidated and unconsolidated sediments (Red bed) interbedded with gray and greenish gray mudstone and coal of "I-Zone", soft lignite with pyrite and gypsum.	Tertiary
	10-20			
	10-30	Subzone J-1	J-Zone coal: soft, fragmented; abundant of gastopod, fish remains, ostracod, plant remains, reptile skeletal. Overburden: claystone, mudstone, and siltstone; gray and greenish gray, lamination to massive, planar type, highly calcareous, fine-grained pyrite spots, volcanic debris (usually including of no economic lignite of J-4 to J-6 Subzones).	
		Subzone J-2		
		Subzone J-3		
		Subzone J-4		
		Subzone J-5		
		Subzone J-6		
	70-90	Member I	K- Zone coal: black to brownish black, brittle, with calcareous white spot, interbedded with soft lignite and silty claystone. Interburden: claystone, brown, brownish gray, gray, greenish, and greenish gray, lamination to thick bed. Q- Zone coal: black to brownish black, brittle, interbedded with soft lignite, claystone/silty claystone.	
	15-30	Subzone K-1		
		Subzone K-2		
		Subzone K-3		
		Subzone K-4		
	25-30	Member II	Underburden: claystone and mudstone, gray to greenish gray, lamination to thick bed, planar type, highlycalcareous. Lignite or carbonaceous mudstone : brown to brownish black (R -Zone and S -Zone).	
	10-25	Subzone Q-1		
		Subzone Q-2		
		Subzone Q-3		
		Subzone Q-4		
	150-450	Member III	Underburden: claystone and mudstone, gray to greenish gray, lamination to thick bed, planar type, highlycalcareous. Lignite or carbonaceous mudstone : brown to brownish black (R -Zone and S -Zone).	
		R -Zone		
		S -Zone		
		Huai King Formation	Mudstone, siltstone, sandstone, conglomerate: green, yellow, blue and purple, common calcrets, semiconsolidated, slightly calcareous cement, fining upward sequence grading from conglomerate to mudstone or claystone.	Triassic
		Basement	Limestone, sandstone, shale, conglomerate, tuffaceous sandstone, agglomerate, tuff.	

Fig. 2.3 Stratigraphic succession of Mae Moh coal mine (modified from Jitapunkul *et al.*, 1985).

The Huai King Formation consists of mudstone, siltstone, sandstone, conglomeratic sandstone, and conglomerate. The typical character is a fining upward sequence that grades from conglomerate to mudstone or claystone at the top. The formation is variegated red, gray, green, yellow, blue, and purple. Calcrete is common in places, as is the slight occurrence of calcareous cement. The only macrofossils occur in the southern part of the basin where *Viviparus* sp. is abundant in the lower portion of the formation. The formation's thickness varies from less than 15 meters on the basin's border to 150 meters in the central part of the basin (Jitapunkul *et al.*, 1985). The uppermost part of the formation is locally marked by a thin layer of coal called the O-Zone.

Na Khaem Formation: This formation is the main coal formation in the basin. It consists of semi-consolidated mudstone and five coal zones. It is gray to greenish gray and has abundant fossils, especially gastropods, fish, ostracods, plants, and other vertebrate fossils. It is highly calcareous, has load structure, burrows, and borings. Intraformational conglomeratic texture occurs in some layers near coal zones. The formation's thickness varies from 250 to 400 meters. It has two major economic coal seams and has been divided into three members, I, II, and III (Fig. 2.3).

Member III, the Underburden, is a sequence of gray to greenish gray claystone and mudstone with a thin layer of sub-bituminous coal, named the R-Zone. These beds are laminations to thick beds, planar type, highly calcareous, and have abundant gastropod zones in the upper part, *Brotia* sp. and *Bellamyia* sp. Along with gastropods there are fish remains, ostracods, and plant roots. This member has an intraformational conglomeratic texture, intermixed color near the coal seam or lignitic layer, is burrowed and bored, and has load casts. At the boundary of the Underburden

and underlying Q-Zone there is the ?*Paludina* Molluscan Zone (Songtham *et al.*, 2005b). Songtham *et al.* suggested that the Mae Moh basin was a shallow lake with a shore of quiet conditions and without nearby vegetation. Member III's thickness varies from 150 to 230 meters.

Member II is the most economically attractive coal sequence and has been divided into three units: Q-Zone, Interburden, and K-Zone.

The Q-Zone is a lower black to brownish black, brittle coal zone. It has abundant diatoms, pyritized *Viviparus* sp. gastropods, Planorbidae molluscs, and plant remains. The coal is sub-bituminous and has about 30 percent partings of light brown claystone and silty claystone. The coal seams are divided into Q-1 to Q-4 seams and their total thickness varies from 25 to 30 meters. However, in the north and south these seams have thicker interbeds of silty mudstone and the coal seams grade laterally into carbonaceous claystone and clay. The Planorbidae Molluscan Zone occurs at the Underburden/Q coal boundary and at the K-4/K-3 boundary. Planorbidae mollusks are common in some places, especially under the Q coal bed. These fossils indicate a swampy environment containing sparse to densely distributed vegetation (Songtham *et al.*, 2005a and b). A proboscidean fossil, *Gomphotherium*, was discovered in the Q-2 Subzone as informed from Mr. Phankant Permsook, a geologist of the Mae Moh coal mine.

The Interburden is a 10- to 30-meters thick sequence of brown, brownish gray, gray, green, and greenish gray claystone that lies between two major coal seams. These claystone beds are laminated to thick bedded, planar type, and have lignite flakes, fish remains, plant roots, rare ostracods, and *Bellamyia* sp. gastropods. They have an intraformational conglomeratic texture in their lower part, load casts, and

abundant micro slip planes. The Interburden is thicker on the east flank of the basin than on the west flank of the basin.

The K-Zone is a coal sequence in the upper part of Member II. This coal is black to brownish black, brittle, and highly calcareous. Diatomite occurs in the eastern part and separates the K-Zone into four layers. It is fossiliferous, having *Planorbis* sp., *Mellanoides* sp., and *Bellamyia* sp. gastropods, fish, turtles, and plant remains. It is interbedded with some sub-bituminous coal and it has partings of light yellowish gray to gray silty claystone. Its thickness varies from 10 to 30 meters. However, in the north and south it has thicker silty claystone partings and laterally changes to carbonaceous claystone. The coal beds are named K-1 to K-4. The K-4 Subzone is the thinnest coal layer and it has rare mollusc fossils. It is included in the Planorbidae Molluscan zone, which indicates swamp and lake deposits (Songtham *et al.*, 2005a and b). The thick *Bellamyia* and *Bithynia* bed occurs between the K-3 and K-4 Subzones. Its greatest thickness is 12 meters and it occurs along the southwest margin of the Mae Moh coal pit. Planorbidae occur in the K-3 and K-2 Subzones. Planorbidae in the K-2 Subzone are associated with ?*Paludina* in carbonaceous claystone. All taxa are missing from the carbonaceous claystone of the K-1 Subzone where mastodont remains were found (von Koenigswald, 1959; Sithiprasasna, 1959). Also, mastodont skeletons with tusks and molars were discovered in this K-Zone (Songtham *et al.*, 2005b). The boundary between the K-1 Subzone and the overburden claystone is indicated by the *Melanoides* sp. cf. *M. tuberculata* Molluscan Zone. This zone is covered by Overburden claystone and the J-Zone. The sulfur isotope of the pyrite in the Q-Zone, K-Zone, and the lower part of J-Zone indicates

that the source of sulfur was organic sulfur. This sulfur source indicates a freshwater environment (Silaratana *et al.*, 2004).

Member I is the uppermost part of the Na Khaem Formation and is composed of Overburden and J-Zone coal. The coal beds of the J-Zone are thin and have little economic value.

The J-Zone is a sequence of gray and greenish gray claystone, mudstone, and, occasionally, siltstone. These beds are laminated to massive, planar type, and highly calcareous. Fine-grained pyrite spots are common in some parts. The zone has abundant *Mellanoides* sp., *Physa* sp., and *Viviparus* sp. gastropods, fish remains, ostracods, plant remains, and reptile skeletons and is burrowed and bored. Load structures, intraformational conglomeratic texture, and an intermix color texture occur near coal layers. The J-Zone thickness is 100 to 150 meters. The upper part of this zone consists of two thin argillaceous layers less than 2 meters thick and 13 thin coal seams named J-1 to J-6. Sulfur isotope in the middle of the J-Zone indicates a volcanic source, but a marine incursion probably occurred during coal deposition in the upper part of the zone (Silaratana *et al.*, 2004).

Huai Luang Formation: It is the uppermost formation and consists of semi-consolidated and unconsolidated strata. It is typically red to brownish red but has some gray interbedded layers in some parts. Most beds are claystone, siltstone, and mudstone, though there are some sandstone and conglomerate lenses in the central part of the basin. No macrofossils have been found, though there is abundant gypsum and pyrite and some roots and flame structures. Thickness of this formation varies from less than 5 meters to 350 meters. The thickest part is the central part of the main basin and the western sub-basin. The formation thins rapidly towards the eastern and

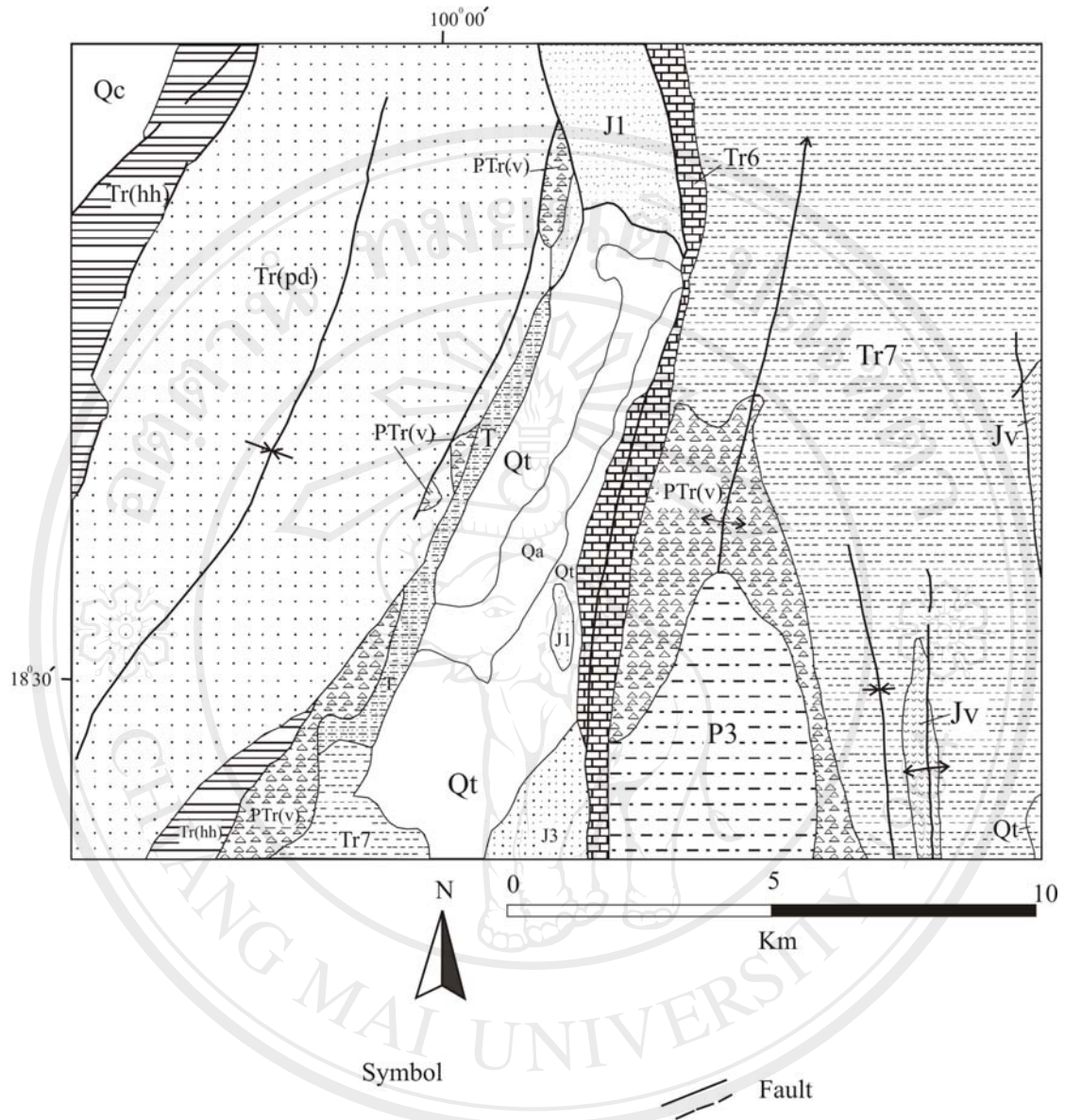
western basin margins, where it is entirely absent from the stratigraphic sequence or is only a few meters thick. This formation was called a red bed by Longworth, CMPS Engineers (1981), the red and brown colors being considered the result of oxidation of fine-grained pyrite and hematite that are disseminated throughout some layers within the formation. However, sulfur isotope results from the red bed zone indicate a sulfur source from marine sulfate. In contrast, the sulfur isotope result from pyrite in gastropods from I-Zone coal indicates a sulfur source from bacterial reduction of sulfate to sulfur (Silaratana *et al.*, 2004, Silaratana, 2005).

The mollusks in the I-Zone define the *Margarya* Molluscan Zone (Songtham *et al.*, 2005b). *Hyriopsis* sp. and family Unionidae bivalves and *Melanoides* sp., *Margarya* sp., and *Brotia* sp. gastropods are also associated in this zone (Silaratana, 2005). These fossils form dense aggregates about 50 centimeters thick in some places, though in other places they occur sparingly in dark gray, sandy claystone beds 1 to 2 meters thick.

Paleomagnetic investigations in the Mae Moh basin of the lower third of the Na Khaem Formation and of the Huai Luang Formation indicate that these sequences correlate with the geomagnetic polarity time scale from the C5ACn chron to C5An.2n chron, this between 13.5 and 12.2 million years ago. The average sediment accumulation rate was 17.5 centimeters per one thousand years. The ages of 12.5 and 12.8 million years ago can be extrapolated to the fossiliferous zones of the J-5, K-1, and K-2 coal beds (Benammi *et al.*, 2002).

2.3 Geology of the Mae Teep Basin

The Mae Teep basin in Ngao District in Lampang Province is located about 80 kilometers northeast of Lampang city. The basin is 3 kilometers wide and 10 kilometers long (Piyasin, 1972), and is surrounded by Permian-Triassic volcanic rocks and shale, sandstone, and limestone of the Triassic Lampang Group (Piyasin, 1972) (Fig. 2.4). The western rim of the basin is bounded by sandstone, siltstone, conglomerate, and shale of the Triassic Pha Daeng Formation. The Permian-Triassic volcanic rocks are also exposed to the north and south of the basin. The Triassic rocks along the basin's eastern rim have *Costatoria* sp. and brachiopod fossils. The basin's north rim is bounded by Jurassic sandstone interbedded with shale and conglomerate. In the south, the basin is bounded by shale, sandstone, siltstone, mudstone, conglomerate, and limestone. These beds contain *Halobia* sp., *Cassianella* sp., *Liostrea* sp., *Unionites* sp., and bivalve fossils that indicate a Triassic age. The Tertiary rocks in the Mae Teep basin consist of interbedded claystone, sandstone, mudstone, diatomite, shale, and coal. Fossils in these beds are leaves, stems, fish, and *Viviparus* sp. gastropods. Coal beds intercalated with shale occur along the Mae Nam Teep (Piyasin, 1972). The precise age of these strata is not known but they are presumed to be Tertiary by comparison with coal-bearing strata elsewhere in northern Thailand (Gibling and Ratanasthien, 1980). Exploratory surveying and drilling of the coal-bearing sequence by the Mineral Fuels Division, Department of Mineral Resources, during 1980 found that the strata on the western margin of the basin strike N30°E to N35°E and dip about 20 degrees eastward. Minor flexures and faults occur locally and some dips are as high as 40 degrees. The Tertiary sequence of the Mae Teep basin has been divided into three zones and is overlain by Quaternary gravel,



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Fig. 2.4 Geologic map of the Mae Teep basin (modified from Charoenprawat *et al.*, 1995).

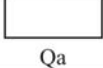
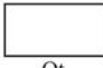



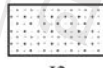



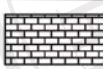

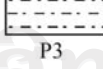
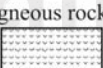
Legend	Age	Rock Unit	Description
Sedimentary rock	Quaternary	Mae Taeng Group	Alluvial deposits: gravel, sand, silt, clay, and mud.
 Qa			Terrace deposits: gravel, sand, silt, clay, and lateritic soils.
 Qt			Colluvial unit: rock fragments, gray, orangish red covered with clayey sand and laterite.
 Qc	Tertiary	Mae Moh Group	Interbedded claystone, sandstone, mudstone, diatomite, coal, and shale with fossils leaves, stem, bone of fish and <i>Viviparus</i> sp., and vertebrate remains.
 T			Jurassic
 J3	Sandstone, purplish brown, fine-grained, calcareous, interbedded with shale, reddish brown, limestone nodules; shale, gray, intercalated with sandstone, fine-grained; and conglomerate.		
 J1	Triassic	Lampang Group	Shale and sandstone, gray to greenish gray; siltstone; mudstone, conglomerate; and limestone; with fossils <i>Halobia</i> sp., <i>Cassianella</i> sp., <i>Liostrea</i> sp., <i>Unionites</i> sp., and bivalves.
 Tr7			Wang Chin Formation
 Tr6			Kang Pla Formation
 Tr(pd)			Pha Daeng Formation
 Tr(hh)			Hong Hoi Formation
 P3	Permian	Kiu Lom Formation, Ngao Group	Interbedded black shale, gray sandstone, dark gray mudstone and gray limestone with chert nodules; intercalated with fossiliferous limestone and mudstone.
Igneous rock	Jurassic volcanic		Rhyolite, purplish gray; tuffaceous shale and sandstone.
 Jv			Permo-Triassic volcanic
 PTr(v)			

Fig. 2.4 (continued)

sand, silt, clay, mud, and lateritic soil. The three zones are, from bottom to top, Underburden, Main coal seam, and Overburden (Fig. 2.5).

Underburden

This zone is the lowest part of the sequence, underlying the Main coal seam. It is a fining upward sequence of sandstone that has limestone pebbles and nodules and gravelly sandy mudstone that is white to gray in the lower part. The upper part of the zone is gray mudstone and carbonaceous mudstone. The thickness of the zone exceeds 45 meters.


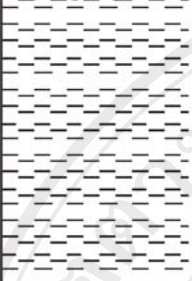

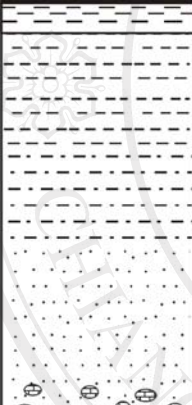
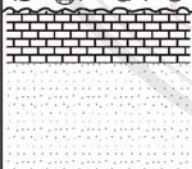
Main Coal Seam

This zone is the main economically attractive coal zone and it has three intervals. The coal is hard, dense, and black. The lower part consists of coal interbedded with carbonaceous mudstone. The middle part is coal interbedded with sheeted coal and carbonaceous mudstone. The upper part is coal interbedded with oil shale. The thickness of this zone is 8 to 12 meters. The coal rank is sub-bituminous to highly volatile bituminous C (Ratanasthien and Ruangvatanasirikul, 1984).

Overburden

This zone is the uppermost unit in the Mae Teep basin and consists of clastic rocks. Its thickness is more than 33 meters. The lower part of the zone is dark gray to black oil shale, which is 5 to 7 meters thick. The upper part of the zone is mostly black shale and mudstone and it is approximately 25 meters thick. Brown sandy mudstone alternations 15 to 20 centimeters thick occur in the upper part of the zone.

Fossils of fish, gastropods, and plant fragments are common.

Lithology	Thickness (m)	Description	Age
	> 72.6 commonly 4 to 10	Gravelly clayey sand, brown, loose, medium to very coarse-grained	Quaternary
— Unconformity —			
	> 33.5	Overburden: Mudstone, shale, oil shale, medium to dark gray, thick lamination to thin bedded, hard and dense. Fish, leaf and gastropod fragments.	Tertiary
	0 to 17.5 commonly 8 to 12	Main Coal Seam : Coal interbedded with oil shale and carbonaceous mudstone, brownish black to black, hard and dense. Fish fragments	
	14 to > 45	Underburden: Carbonaceous mudstone, mudstone, siltstone, sandstone. Limestone pebbles/nodules in sandstone. Medium to dark gray. Hard and dense.	
— Unconformity —			
	> 25	Limestone, calcareous sandstone and mudstone. Medium gray	Triassic

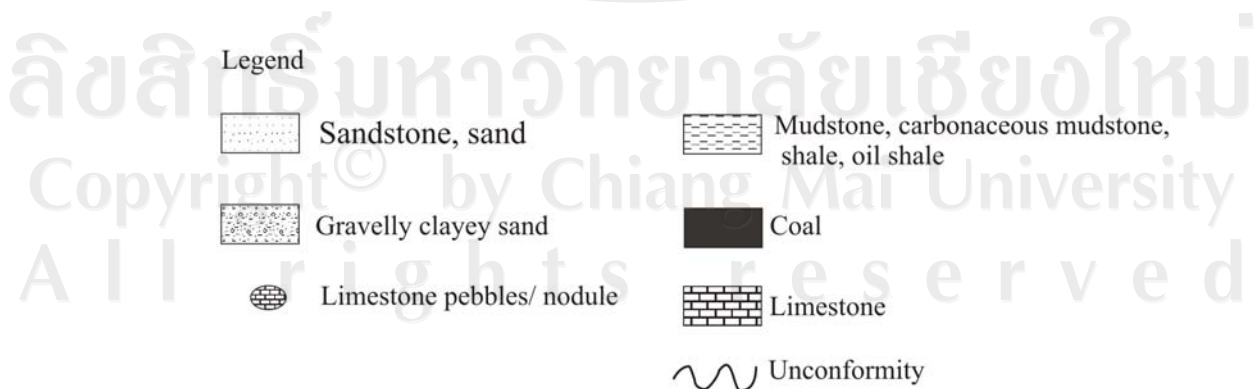
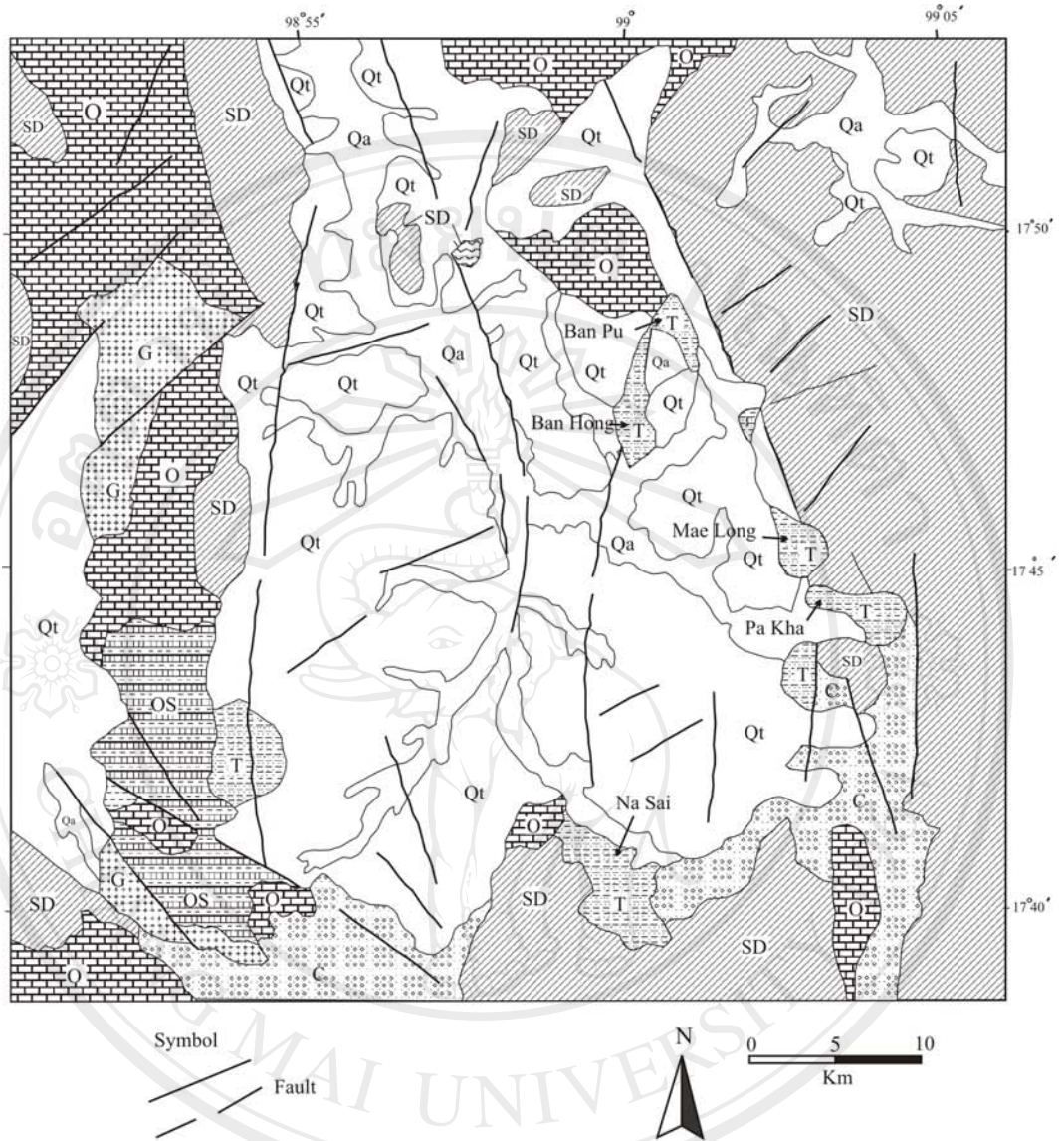


Fig. 2.5 Stratigraphic succession of the Mae Teep basin (modified from Ukakimaphan *et al.*, 1981).

2.4 Geology of the Li Basin and Ban Na Sai Sub-basin

The Li basin is located south of Lamphun Province, about 150 kilometers south of Chiang Mai city. It extends 55 kilometers in a north-south direction, being narrow in the north and widening to 20 kilometers in the south. This Tertiary basin is underlain by a basement of Ordovician rocks referable to the Thung Song Group. These Thung Song rocks are mainly massive, re-crystallized, grayish to blackish, argillaceous limestone that has thin intercalations of shale. This Ordovician limestone is scattered along the north and west rims of the Li basin and also crops out in a two-kilometer square area of the southern rim near the Ban Na Sai sub-basin. Silurian-Devonian rocks, being mainly quartzite, phyllite, and quartz schist, conformably overlie the Ordovician rocks. Carboniferous rocks are overlain by Silurian-Devonian rocks as a result of faulting and are exposed only on the southern rim of the basin. These Carboniferous rocks are light to dark gray sandstone and shale that have intercalations of limestone and chert. Triassic rocks bound the southeast flank of the Li basin. These rocks consist of conglomerate with various rounded to sub-rounded pebbles, sandstone, and sandstone with intercalated shale. The sandstone has a feldspathic composition and there are numerous quartz veins (Chaodumrong *et al.*, 1982; Snansieng and Maneekut, 1985; Ratanasthien, 1990) (Fig. 2.6).

Snansieng and Maneekut (1985) subdivided the Li Basin into four sub-basins by subsequence tectonism. These four are the Ban Pa Kha, Ban Pu, Ban Na Sai, and Mae Long sub-basins. They classified the basin's onshore Tertiary sequences, named the Li Group, into two formations. The Li Formation was proposed for the Paleogene strata of the Ban Pa Kha and Ban Pu sub-basins.



Legend	Age	Rock Unit	Description
Qa	Quaternary	Mae Taeng Group	Alluvium sediment
Qt			Terrace gravel, sand, silt, mud, and clay
T	Tertiary	Li Group	Shale, claystone, siltstone, sandstone, and coal
G	Triassic		Biotite-hornblende granite, prophyritic granite, pinkish granite, quartz veins, granodiorite, and aplite
C	Carboniferous	Mae Tha Group	Light gray to red conglomerate, sandstone siltstone and shale
SD	Silurian-Devonian	Don Chai Group	Quartzite, quartz-schist, slate, and phyllite
OS	Ordovician-Silurian	Nam Tok Ko Formation	Limestone interbedded with shale siltstone and sandstone
O	Ordovician	Thung Song Group	Limestone with argillaceous, arenaceous lamination

Fig. 2.6 Geologic map of the Li basin (modified from Tantasuparuk, 1991).

The second formation is the Mae Moh Formation and it occurs in the Ban Na Sai and Mae Long sub-basins. It is a Miocene sequence and its fossil assemblage correlates with that of the Mae Moh coal mine. To avoid a confusion of formation names, Songtham (2003) changed the name of the underlying Li Formation to the Ban Pha Kha Formation and the that of the overlying Mae Moh Formation to the Mae Long Formation, as in Ratanasthien (1990). Tertiary Ban Pu, Ban Hong, Ban Na Klang, Ban Pa Kha, and Mae Long Bok Formations crop out along the eastern margin of the basin and were drilled in exploratory holes and exposed in mining cuts.

The Ban Pa Kha Formation (Songtham, 2003) consists of conglomerate, sandstone, mudstone, shale, oil shale, and coal beds. These strata accumulated in fluvial and lacustrine environments. The numerous reports of the occurrence of fossil floras, including leaves, cones, catkins, and sporomorphs, in this formation strongly suggests a warm temperate flora was abundant during the Oligocene to Early Miocene when the formation was deposited (Endo, 1964 and 1966; Ratanasthien, 1984; Meesuk, 1986; Watanasak, 1989; Songtham, 2003; Songtham *et al.*, 2005a). No vertebrate remains have been reported from this formation.

Mae Long Formation (Ratanasthien, 1990) is characterized by thin laminated strata, or paper shale, lying on the top of mudstone and coal seams. The formation rests unconformably on Carboniferous and Silurian-Devonian rocks. The type section at the Mae Long reservoir extends to the Ban Na Sai coal mine, where the formation consists of coal and paper shale.

The Ban Na Sai sub-basin is located 18 kilometers southwest of the Li District office. This sub-basin covers a large area of the southern Li basin. Its Tertiary beds have been faulted and uplifted. The uppermost sequence of the Ban Na Sai sub-basin

is light gray mudstone, shale, sandstone, and conglomeratic sandstone. It also has some gypsum and fish fossils, along with mastodont, suid, rhinocerotid, and anthracotherid mammalian fossils. The underlying sequence is lignite that contains gastropod and fish fossils. This lignite is interbedded with light gray to dark gray claystone, shale, and sandstone and with some carbonaceous shale and conglomeratic sandstone. Mammalian fossils and fossil turtles, crocodiles, gastropods, leaves, and fish are in this bed. The top of the uppermost sequence of the Ban Na Sai basin was eroded and subsequently covered by Quaternary and fluvial beds (Fig. 2.7).

2.5 Geology of the Chiang Muan Basin

The Chiang Muan basin in Chiang Muan District in Phayao Province is bounded on its north, south, and west sides by a sequence of Jurassic red beds (Charoenprawat *et al.*, 1995, Fig. 2.8). These Jurassic rocks are rhyolite, tuffaceous shale, and sandstone that are purplish to pale gray in color. The Jurassic Phu Kradung Formation is fine-grained, calcareous sandstone interbedded with shale and conglomerate. The Cretaceous Sao Khua Formation is sandstone interbedded with micaceous and tuffaceous shale and conglomerate. Quaternary gravel, sand, silt, clay, mud, and lateritic soil occur in the east part of the basin. The basin's coal mine is narrow and long, being about 300 meters wide east to west and over one kilometer long north to south. Beds strike north-south in the southern part of the mine and northeast in the northern part of the mine. The youngest strata are along the eastern margin of the mine and the oldest strata are along the mine's western margin. Cenozoic strata in the basin include sandstone, claystone, carbonaceous claystone, and coal. Nagaoka and Sukanuma (2002) designated the Tertiary strata in

Stratigraphic Unit	Lithology	Description	Thickness (m)	Age
Mae Taeng Group		Sand and gravels: Reddish brown top soil compose mostly of sand and gravels.	3-10	Quaternary
Unconformity				
Mae Long Formation		Mudstone, shale, sandstone and conglomeratic sandstone: Sequences of light gray mudstone, shale, sandstone and conglomeratic sandstone with intercleration of alternation layer of 1-2 mm thick, light gray, greenish gray to dark gray shale, with some gypsum, carbonates, and fish remains. Fossils: <i>Stephanocemas rucha</i> , <i>Spanocricetodon</i> sp., and <i>Spanocricetodon khani</i> , <i>Kanisamys benjavuni</i> , <i>Antemus thailandica</i> , <i>Diatomys liensis</i> , <i>Atlantoxerus</i> sp., <i>Tarsius thailandica</i> .	10-80	Middle Miocene
		Lignite: Soft to hard, dull to bright black lignite with gastropod bed and fish remains. Fossils: <i>Stegolophodon</i> , fish of <i>Cypriniformes</i> and <i>Siluriformes</i> and unidentified crocodile, turtle, gastropod and fish remains, and leaves.	2-7	
		Claystone, shale, sandstone and conglomeratic sandstone: Sequences of light gray to dark gray claystone, shale and sandstone with carbonaceous shale and conglomeratic sandstone in part.	2-70	
		Lignite (Ban Pa Kha): Massive, black to brownish black	30-250	Lower Miocene
		Claystone, shale, sandstone, and conglomeratic sandstone		
Unconformity				
Mae Tha and Don Chai Groups		Basement: Basement of limestone, sandstone and phyllite.	Base rock of Carboniferous and Silurian-Devonian	

Fig. 2.7 Stratigraphic succession of the Mae Long Formation at the Ban Na Sai coal mine, Li basin (modified from Ratanasthien, 1990).

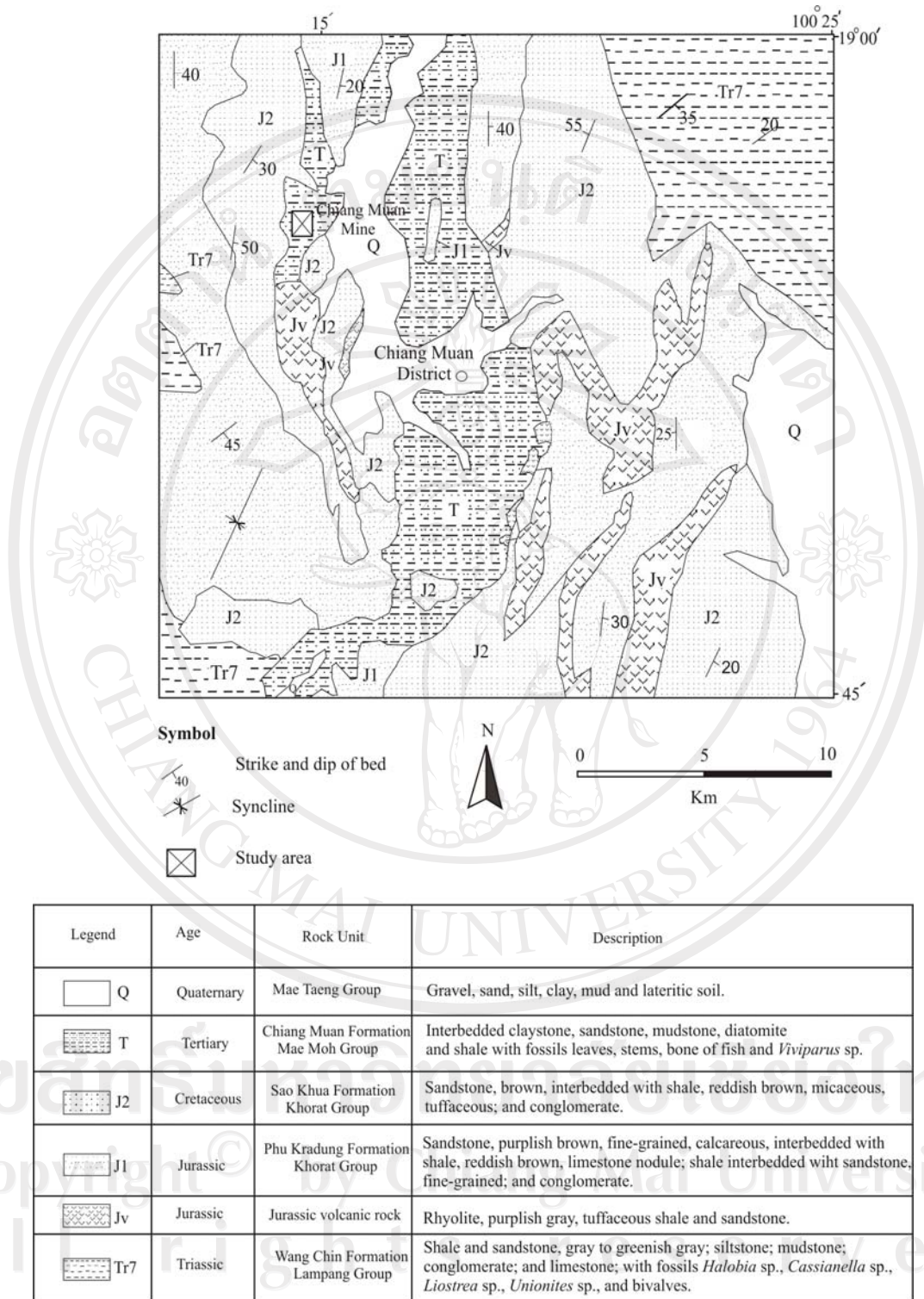


Fig. 2.8 Geologic map of Chiang Muan basin (modified form Charoenprawat *et al.*, 1995).

the Chiang Muan mine as the Chiang Muan Formation. This formation is composed, from bottom to top, of Underburden, Lower Coal Zone, Interburden, Upper Coal Zone, and Overburden units. Songtham (2003) studied the palynology of the mine's sequence, using names for each unit in an unpublished document of the Chiang Muan Company Limited. However, Fukuchi *et al.* (2007) named each unit on the basis of sedimentary deposition, these units being correlated to the former studies as in Fig. 2.9. This study followed the document of the Chiang Muan Company Limited in Songtham (2003).

Underburden

This unit is the lowermost unit and unconformably overlies Cretaceous and Jurassic red beds. It includes sandstone, pebbly sandstone, muddy sandstone, sandy mudstone, mudstone, and claystone and is moderately reddish brown and light gray to yellowish gray. It has red paleosols, with light gray paleosols intercalated locally (Thasod *et al.*, 2007). The top of the unit is massive carbonaceous mudstone. This unit was named the Sa Nua Member (Fukuchi *et al.*, 2007). The type section of the Sa Nua Member is exposed in the northern part of the mine, where it is 50 meters thick. The thickness of the unit varies but is generally more than two meters. The claystone in this unit swells when it becomes wet.

Lower Coal Zone

The lower coal zone is separated into two sub-units, a lower split coal seam and a lower massive coal seam. The lower sub-unit is characterized by intercalations of carbonaceous mudstone, silty claystone, and shaly coal in its lower part and by thicker coal beds in its upper part. The coal is brownish black (Thasod *et al.*, 2007). There are several fossils in this lower coal zone and its age is about latest Middle

Lithology	Thickness (m)	Zone name	Lithological Description	Rock Unit	Age
	1-21	Q	Sand, silt, clay, and gravel: moderate reddish brown, unconsolidated.	Mae Taeng Group	Quaternary
Unconformity					
	1-60	OB	Sandy mudstone, clayey sandstone, silty mudstone, and mudstone: medium reddish brown, light gray, fine- to coarse-grained, and moderately hard.	Mae Moh Group Chiang Muan Formation	Thung Nong Mudstone and Sandstone Member
	0.3-8	U1	Coal, carbonaceous mudstone, and mudstone: brownish black to light gray.		
	10	IB1	Sandy mudstone, silty mudstone, muddy sandstone: light gray, fine- to coarse-grained, and moderately hard.		
	5-12	U2	Coal, carbonaceous mudstone, mudstone, siltstone: brownish black to light gray.		
	45-90	IB2	Muddy sandstone, sandy mudstone: moderate reddish brown to light gray, fine- to coarse-grained, moderately hard. Gravelly sandstone and conglomerate: greenish gray to purplish gray, poorly sorted.		Sa Sandstone and Conglomerate Member
	30-120	LM	Coal; brownish black, moderately bright, hard, brittle.	Sa Tai Lignite Member	
		LS	Carbonaceous mudstone, coal, silty claystone: brownish black, moderately hard.		
	>5	UB	Sandstone, pebbly sandstone, muddy sandstone, sandy mudstone, silty claystone and mudstone: moderate reddish brown, light gray to yellowish gray, fine- to very coarse-grained, sub-angular to sub-rounded, medium hard.	Sa Nua Mudstone Member	
Unconformity					
	Basement		Sandstone, Conglomerate, Andesitic tuff.	Khorat	Cretaceous and Jurassic

Fig. 2.9 Stratigraphic succession of Chiang Muan mine (compiled from Chiang Muan Company Limited (unpublished document) in Songtham, 2003; Nagaoka and Sukanuma, 2002; Sukanuma *et al.*, 2006; Fukuchi *et al.*, 2007).

Miocene based on fossil assemblage and paleomagnetic analysis (Nakaya *et al.*, 2002 a, b, c; Pickford *et al.*, 2004; Suganuma *et al.*, 2006).

The lower massive coal seam is massive, moderately bright, hard, and brittle coal (Thasod *et al.*, 2007). This unit was named the Sa Tai Member by Fukuchi *et al.* (2007). Its thickness varies, ranging from 30 to 120 meters.

Interburden 2

This unit is a thick sequence of clayey sandstone, sandy mudstone, gravelly sandstone, and conglomerate. It is moderately reddish brown, yellowish red, light gray, and greenish to purplish gray. The sandstone is fine- to coarse-grained (Thasod *et al.*, 2007). The conglomerate has granules and pebbles of quartz, sandstone, chert, mudstone, and rarely feldspar. The thickness of the unit varies from 45 to 90 meters (Chiang Muan Company Limited unpublished paper; Songtham, 2003; Fukuchi *et al.*, 2007). The unit is a prominent oxidized zone and was named the Sa Sandstone and Conglomerate Member (Fukuchi *et al.*, 2007).

Upper Coal Zone 2

This unit comprises coal, carbonaceous mudstone, mudstone, and silty claystone. It is brownish black and light gray and varies in thickness from 5 to 12 meters. Vertebrate remains and seeds are common. The unit has a high sulfur content in the form of pyrite lenses and pyrite replacement of plant structures in coal. Some of this pyrite is altered to sulfate and has formed gypsum (Thasod *et al.*, 2007). This unit is in the lower part of the Kon Lignite Member (Fukuchi *et al.*, 2007) and is late Middle Miocene in age (Suganuma *et al.*, 2006).

Interburden 1

This unit is intercalations of sandy mudstone, siltstone, and muddy sandstone. It is generally light gray and its sandstone is fine- to coarse-grained. The unit's thickness is about 10 meters. There are abundant leaf and fruit remains, as well as mollusks in some horizons. Slumps occur in some layers when water is absorbed (Thasod *et al.*, 2007). This unit is in the middle part of the Kon Lignite Member (Fukuchi *et al.*, 2007).

Upper Coal Zone 1

This coal zone has both carbonaceous mudstone and coal. There are three main carbonaceous mudstone layers intercalated with light gray mudstone. However, in the northern part the carbonaceous mudstone is separated into nine layers. The thickness of the coal zone is 0.3 to 8 meters. High sulfur content occurs in some places in the form of pyrite and gypsum (Chiang Muan Co. Ltd., 2002, personal communication; Thasod *et al.*, 2007). This unit is in the upper part of the Kon Lignite Member (Fukuchi *et al.*, 2007).

Overburden

This unit is a series of mudstone and sandy mudstone intercalations. The lower part is light gray to deep greenish gray and the upper part is yellowish brown to gray. The thickness of the unit varies, ranging from 10 to more than 60 meters. This zone has the characteristics of a paleosol, as indicated by root traces and burrows (Thasod *et al.*, 2007). This unit was named the Thung Nong Mudstone and Sandstone Member (Fukuchi *et al.*, 2007).

This Tertiary sedimentary sequence is capped by brownish red to orange Quaternary gravel and sand that are clayey in part.

2.6 Geology of the Mae Soi Locality

The Mae Soi locality in Chom Thong District is located about 60 kilometers southwest of Chiang Mai city (Fig. 2.10). The locality has two sub-localities, Doi Chang and Kew Hoi Tal. Mastodont remains were found at latitude 18°17' N, longitude 98°36' E in silty sandstone at the Doi Chang sub-locality. Moreover, some fossils have been found in both sub-localities. The Mae Soi locality has Neogene gravel, sand, silt, and clay and conglomerate, sandstone, siltstone, and shale (Fig. 2.11). These beds unconformably overlie Silurian-Devonian rocks and Ordovician limestone and shale. Paragneiss occurs in the north and southwest parts of the locality. Faults in the western and northern parts of the area characterize a half-graben basin.

2.7 Geology of the Sop Mae Tham Locality

The Sop Mae Tham locality in Serm Ngam District in Lampang Province is located in a Tertiary basin that overlies Silurian-Devonian metamorphic rocks (Fig. 2.12). The Tertiary strata in the area consist of interbedded mudstone, sandstone, and conglomerate that are reddish yellow to yellowish red in color (Fig. 2.13). The Quaternary sediments in the area are gravel, sand, silt, clay, and rock fragments.

2.8 Geology of the Tha Chang Sand pits

The Tha Chang sand pits in Chaloeam Phra Kiat and Non Sung Districts of Nakhon Ratchasima Province are in Quaternary alluvial sediments (Fig. 2.14). These sediments are flood plain and swamp deposits of gravel, sand, silt, and clay. In the Tha Chang sand pits these sediments are subdivided into two units,

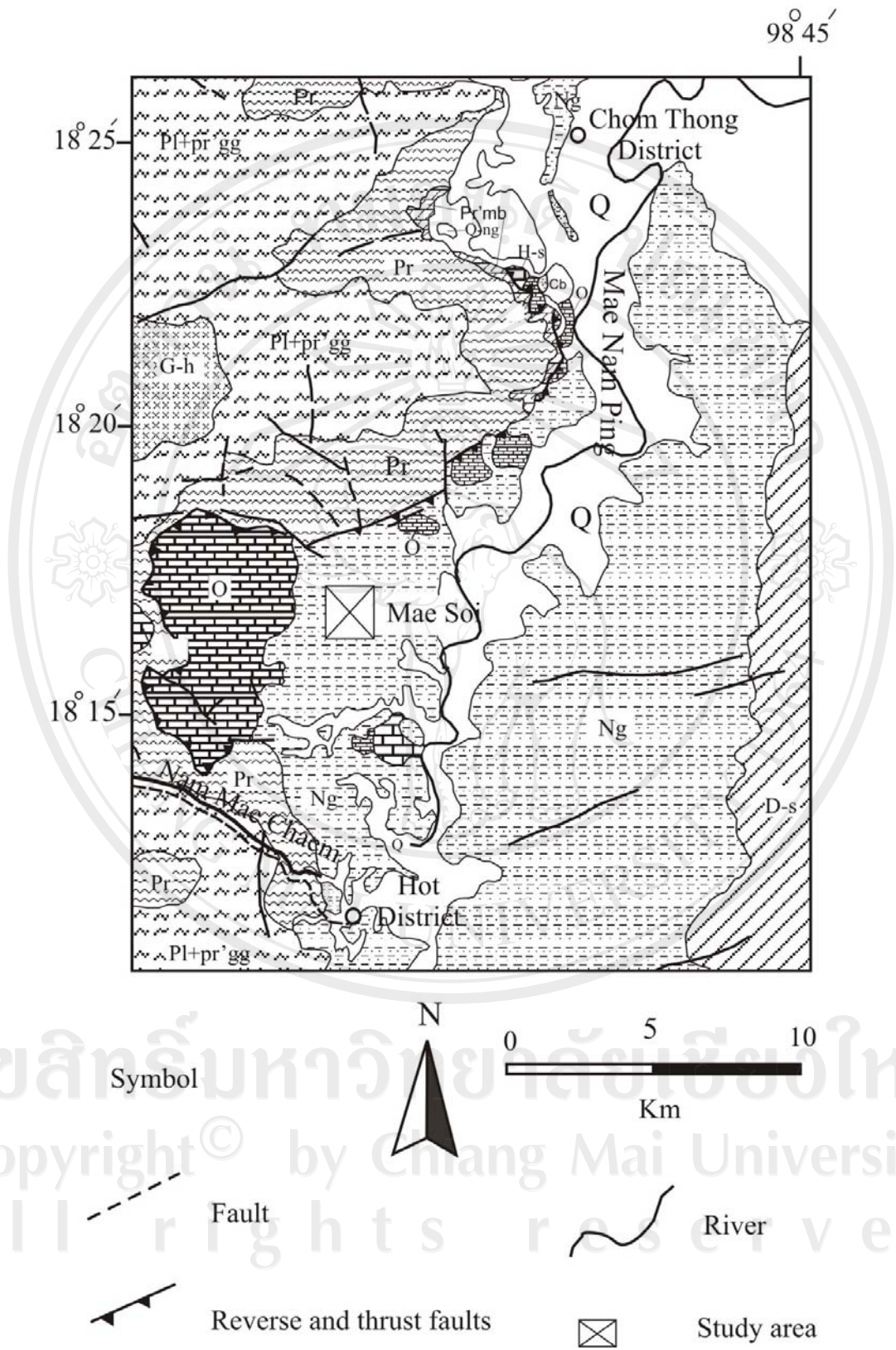


Fig. 2.10 Geologic Map of the Mae Soi locality (modified from Baum *et al.*, 1982).








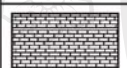





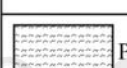
Legend	Age	Rock Unit	Description
 Q	Quaternary	Mae Taeng Group	Unconsolidated sediment: gravel, sand, silt, and clay.
 Q-ng	Quaternary		Semi-consolidated sediment: sand, gravel, silt, and clay.
 Ng	Tertiary	Mae Moh Group?	Semi-consolidated to consolidated sediment: gravel/conglomerate, sand/sandstone, silt/siltstone, and shale.
 T-p	Permian -Triassic	Ngao Group	Sandstone, tuffaceous sandstone, shale, and phyllite.
 P-h	Permian-Carboniferous		Phyllite, quartzite, siliceous shale, with limestone lense.
 H-s	Devonian-Carboniferous	Thong Pha Phum Group	Phyllite, carbonaceous shale, and sandstone.
 D-s	Silurian-Devonian	Sukhothai Group	Chert, tuff, meta-volcanics, and limestone.
 O	Ordovician	Thung Song Group	Fossiliferous limestone, argillaceous limestone, grayish black, massive.
 Cb	Cambrian	Tarutao Group	Sandstone: reddish brown color; quartzite, shale, Trilobite
 Pr'mb	Precambrian	Lan Sang Gneiss Complex	Marble, high grade metamorphosed
 Pr	Precambrian		Paragneiss, schist, calcsilicate, and marble.
 G-t	Triassic Granite		Granite, granodiorite, prophyritic texture.
 G-h	Lower Carboniferous Granite		Stressed granite, biotite-muscovite granite
 Pl+pr'gg	Lower Carboniferous		Antextitic aureole of Paleozoic granite with relics of lower Paleozoic and Precambrian rocks.

Fig. 2.10 (continued)

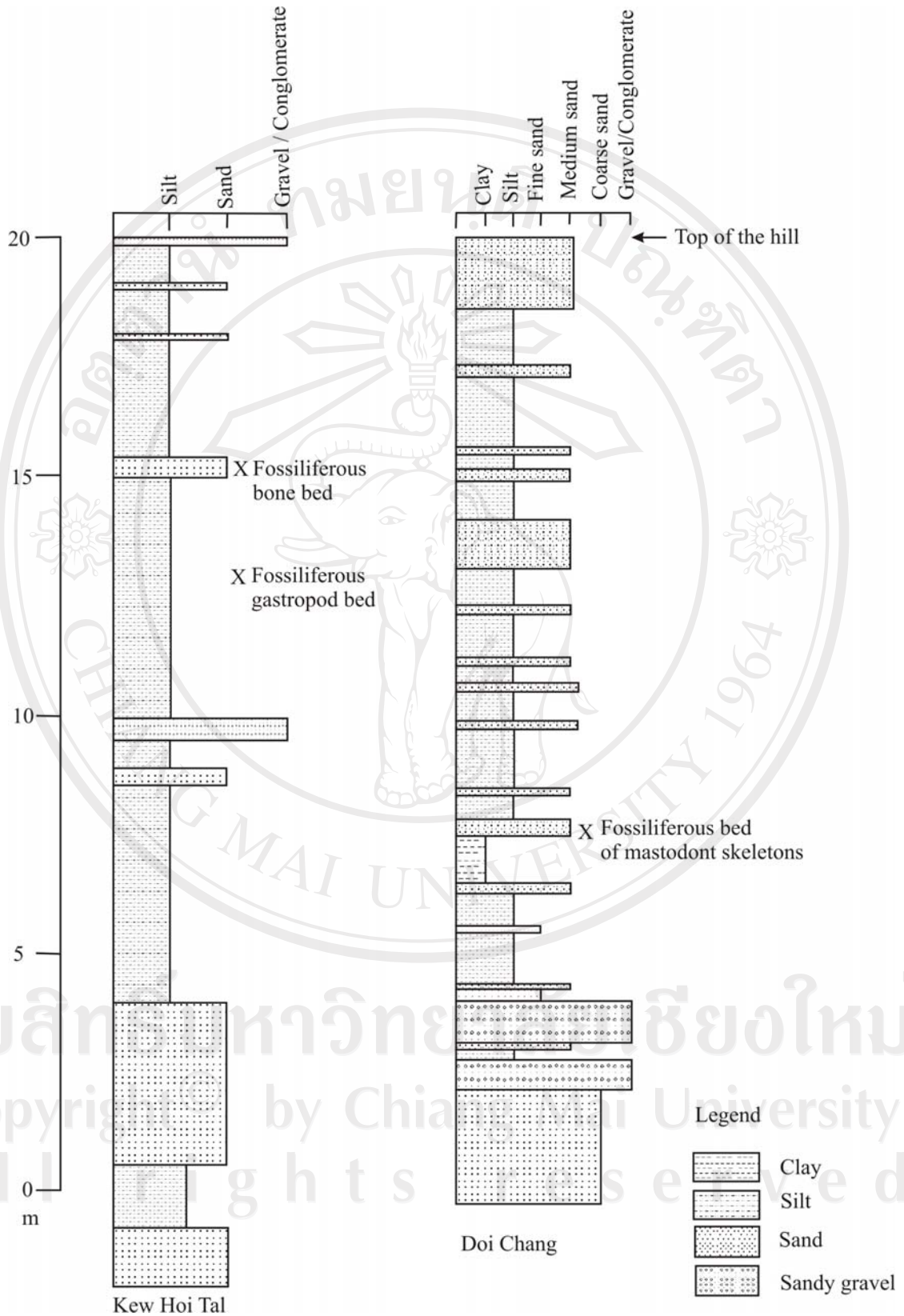


Fig. 2.11 Stratigraphic succession of the Mae Soi locality (Kew Hoi Tal sub-locality (left) and Doi Chang sub-locality (right) (after Saegusa *et al.*, 1999).

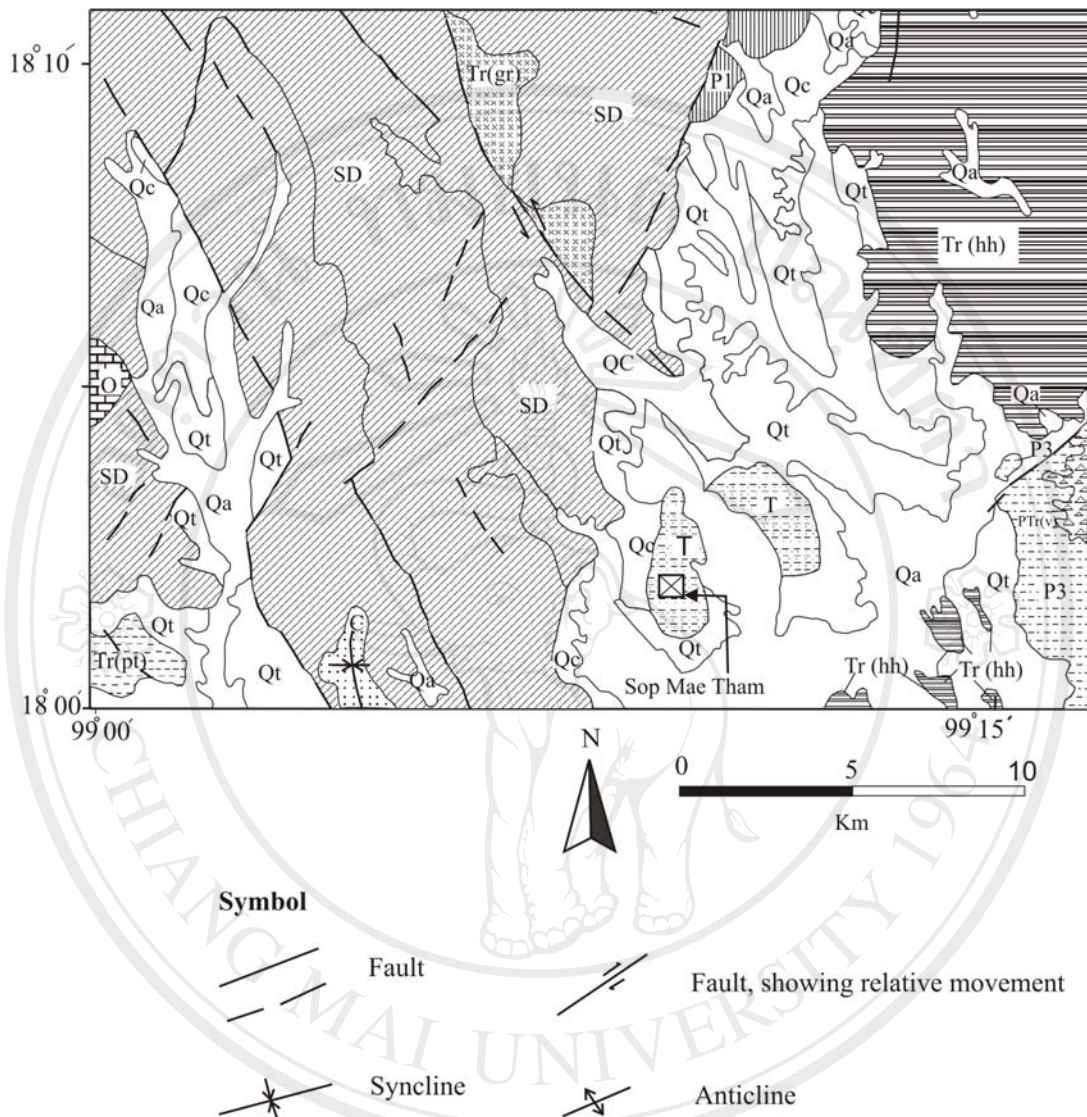


Fig. 2.12 Geologic map of the area surrounding the Sop Mae Tham locality (modified from Charoenprawat *et al.*, 1995).















Legend	Age	Rock Unit	Description
Sedimentary rock			
 Qff	Quaternary	Mae Taeng Group	Fluvial clay unit: clay, gray to light gray, partly intercalated with gravelly sand lenses.
 Qa			Alluvial deposits: gravel, sand, silt, clay, and mud.
 Qt			Terrace deposits: gravel, sand, silt, clay, and lateritic soil.
 Qe			Colluvial unit: rock fragments, gray, orangish red, covered with clayey sand and laterite.
 T	Tertiary	Mae Moh Group	Interbedded claystone, sandstone, mudstone, diatomite, coal, and shale with fossil leaves, stems, bone of fish, mammalian remains, and <i>Viviparus</i> sp.
 Tr(hh)	Triassic	Hong Hoi Formation Lampang Group	Silicified mudstone, gray to black, light brown to yellowish brown; intercalated with quartzite light gray to dark gray, fine grained; tuffaceous sandstone, gray to brownish gray, fine- to medium-grained, intercalated with shale, gray to dark gray; shale and siltstone, gray to greenish gray, with fossil <i>Holobia</i> sp., <i>Posidonia</i> sp., <i>Paratrachycerus</i> sp.
 Tr(pt)	Triassic	Phra That Formation Lampang Group	Lower part: interbedded black shale, tuff and sandstone; upper part: interbedded conglomerate, agglomerate, conglomeratic sandstone, tuff, sandstone, shale, mudstone, and siltstone, red, gray to dark gray and reddish brown; with limestone lens; locally developed phyllitic and slaty cleavage with fossils <i>Claraia</i> sp., <i>Costatoria</i> sp., and other bivalves.
 P3	Permian	Huai Tak Formation Ngao Group	Interbedded black shale, gray sandstone, dark gray mudstone and gray limestone with chert nodules; intercalated with fossiliferous limestone and mudstone.
 P1	Permian	Kiu Lom Formation Ngao Group	Phyllite, gray to purplish gray; sandstone and siltstone, brown; quartzite, quartzitic schist, agglomerate and tuff, with some micaceous.
 C	Carboniferous	Mae Tha Group	Quartzitic and feldspathic sandstone; consisting of graywacke, arkosic, protoquartzitic and ortoquartzitic; quartzite and shale; white-light green to dark brown, medium to thick and well bedded with quartz veinlets.
 SD	Silurian - Devonian	Don Chai Group	Phyllite, quartzite, quartzitic sandstone, quartzofeldspathic schist and schist.
 O	Ordovician	Thung Song Group	Limestone light to dark gray.
 Tr(gr)	Triassic Granite		Biotite granite, medium-to coarse-grained, porphyritic; muscovite granite, fine- to medium-grained; biotite-hornblend-adamellite granite, medium-to-coarse-grained, equigranular to porphyritic and tourmaline muscovite granite, fine-grained.
 PTr(v)	Permo-Triassic Volcanic		Volcanic rocks: rhyolite, andesite, flow and dike; agglomerate; volcanic agglomerate; rhyolitic tuff and andesitic tuff.

Fig. 2.12 (continued)

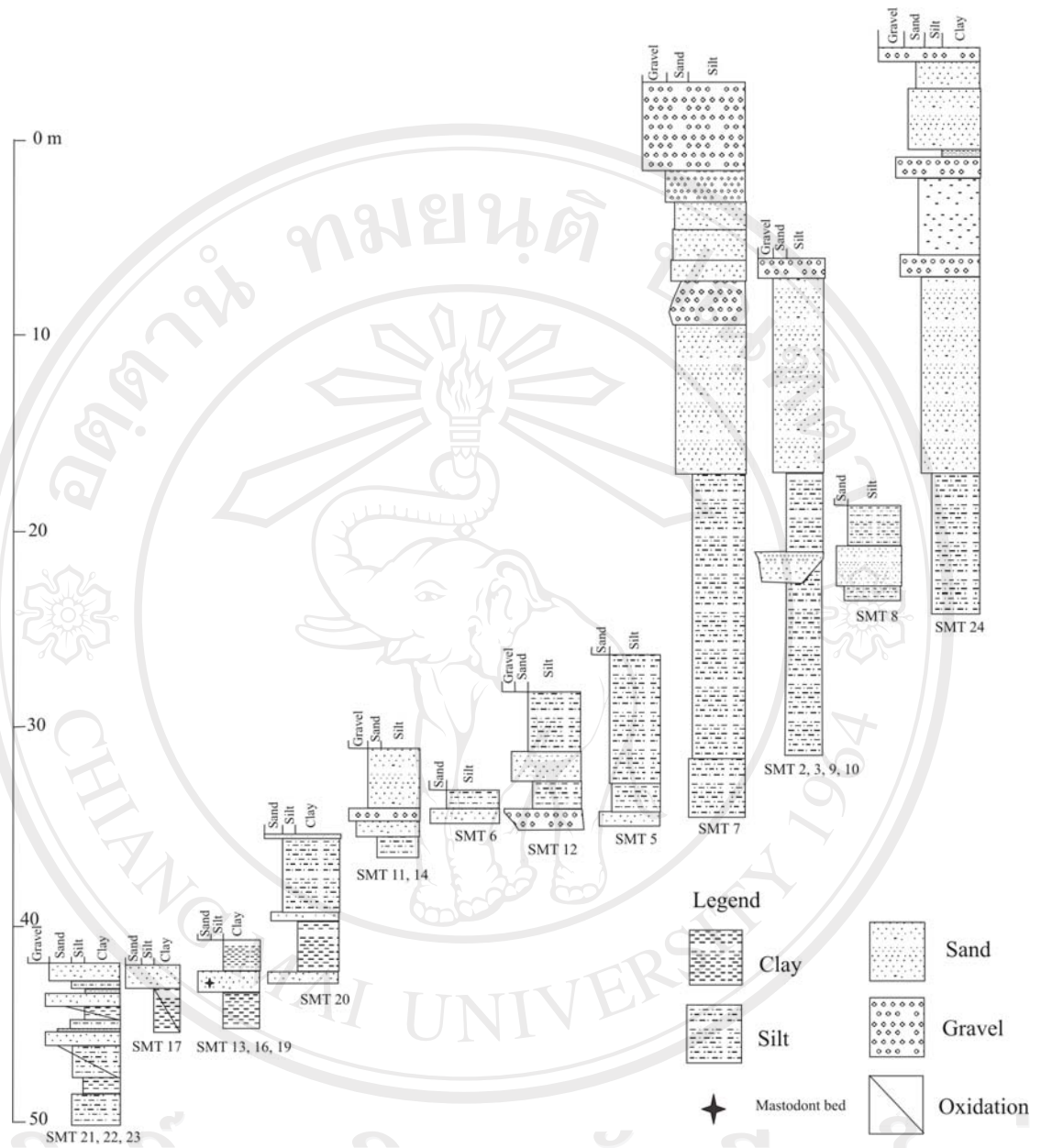
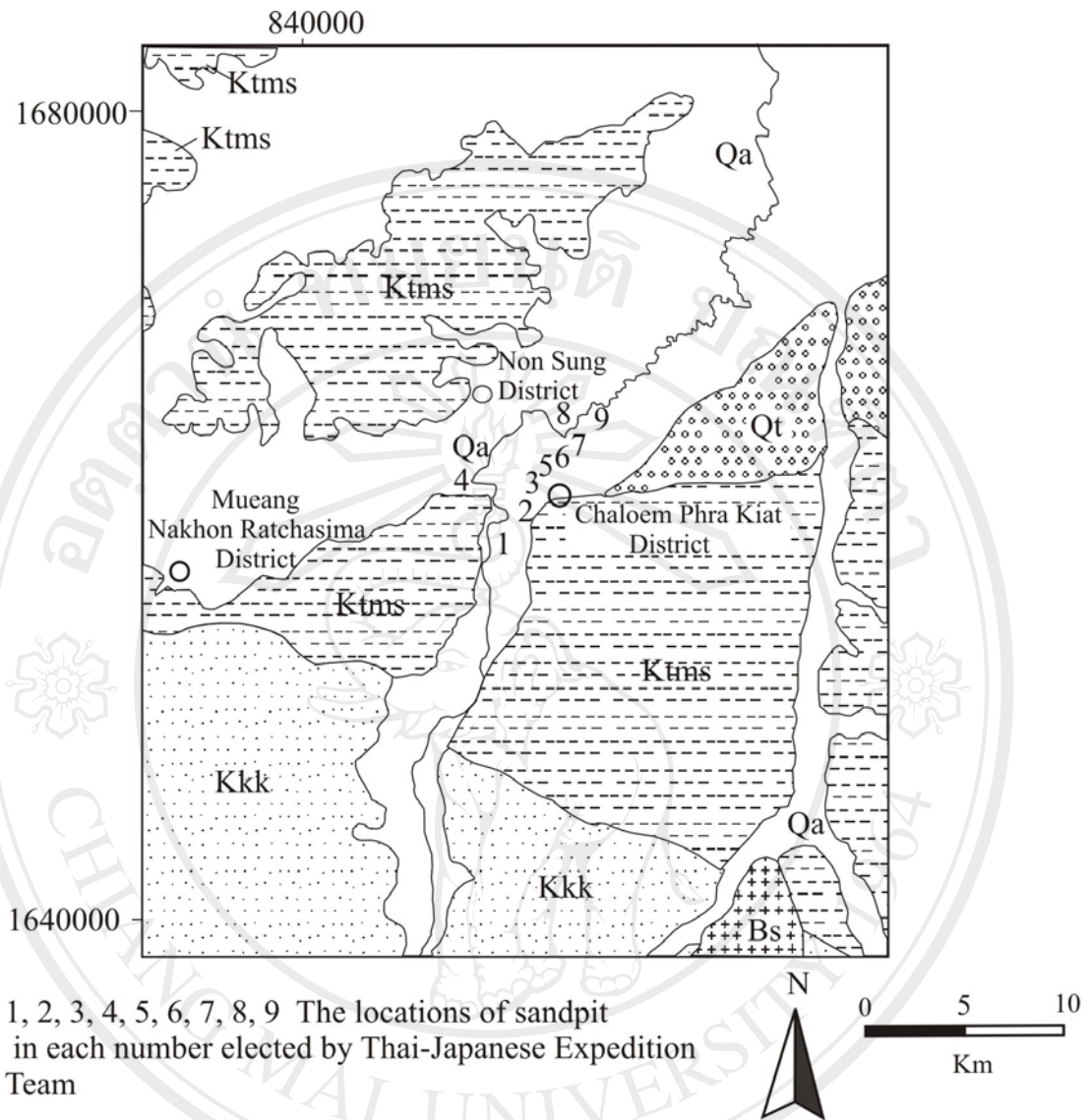


Fig. 2.13 Stratigraphic succession of the Sop Mae Tham locality (modified from Nagaoka, 2002, unpublished document).

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่
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Legend	Age	Rock Unit	Description
Qa	Quaternary		Alluvial deposit: gravel, sand, silt, mud, and clay
Qt			Terrace deposit: gravel, sand, silt, clay, and lateritic soil
Ktms	Cretaceous-Tertiary	Maha Sarakham Formation	Evaporite, rock salt, and clay
Kkk	Cretaceous	Khok Kruat Formation	Red claystone, sandstone, and conglomerate
Bs	Quaternary	Nakhon Ratchasima Basalt member	Basalt

Fig. 2.14 Geologic map of Tha Chang locality, Chaloem Phra Kiat District, Nakhon Ratchasima Province (modified from Hintong *et al.*, 1984; Yuyen and Sirinavin, 1985).

a lower reducing unit, Unit A, and an upper oxidizing unit, Unit B, in Haines *et al.*, (2002) (Fig. 2.15).

The lower reducing unit comprises stratified to massive, cross-bedded sand and gravel and mud lenses. The entire unit is a reducing gray sediment. Fossils are abundant in this unit, both Neogene fauna and flora (Suteethorn *et al.*, 1997; Sato, 2002, Howard *et al.*, 2003; Nakaya *et al.*, 2002; Nagaoka, 2002, unpublished document). The section of sand pit number 8 after Nagaoka (2002, unpublished document) is shown in Fig. 2.16. This figure shows abundant plant fossils throughout the section. Mammalian fossils *Stegolophodon* and *Merycopotamus* were found at a depth of 18 meters. This lower unit also contains logs that were deposited in two distinct horizons. North of the Tha Chang sand pits, at Chumpuang, logs are more evenly distributed throughout the exposed sediment. Deposition of these logs resulted from floods (Howard *et al.*, 2003).

The upper unit is oxidized and contains layers of sand, fine gravel, and mud. Rare small tree trunks, *Elephas maximus*, polished stone tools, and fragments of ceramics were found in this unit and indicate a very recent time period. This unit was deposited in channels and on flood plains of the modern meandering Mun River in historical time (Sato, 2002; Howard *et al.*, 2003).

Tektites are present in the third horizon of Sato (2002) and in Unit 3 of Charusiri *et al.*, (2002) at depths of 2 to 3 meters. The age of these tektites ranges from ca. 0.623 to 4.338 million years by thermoluminescent dating (Charusiri *et al.*, 2002).

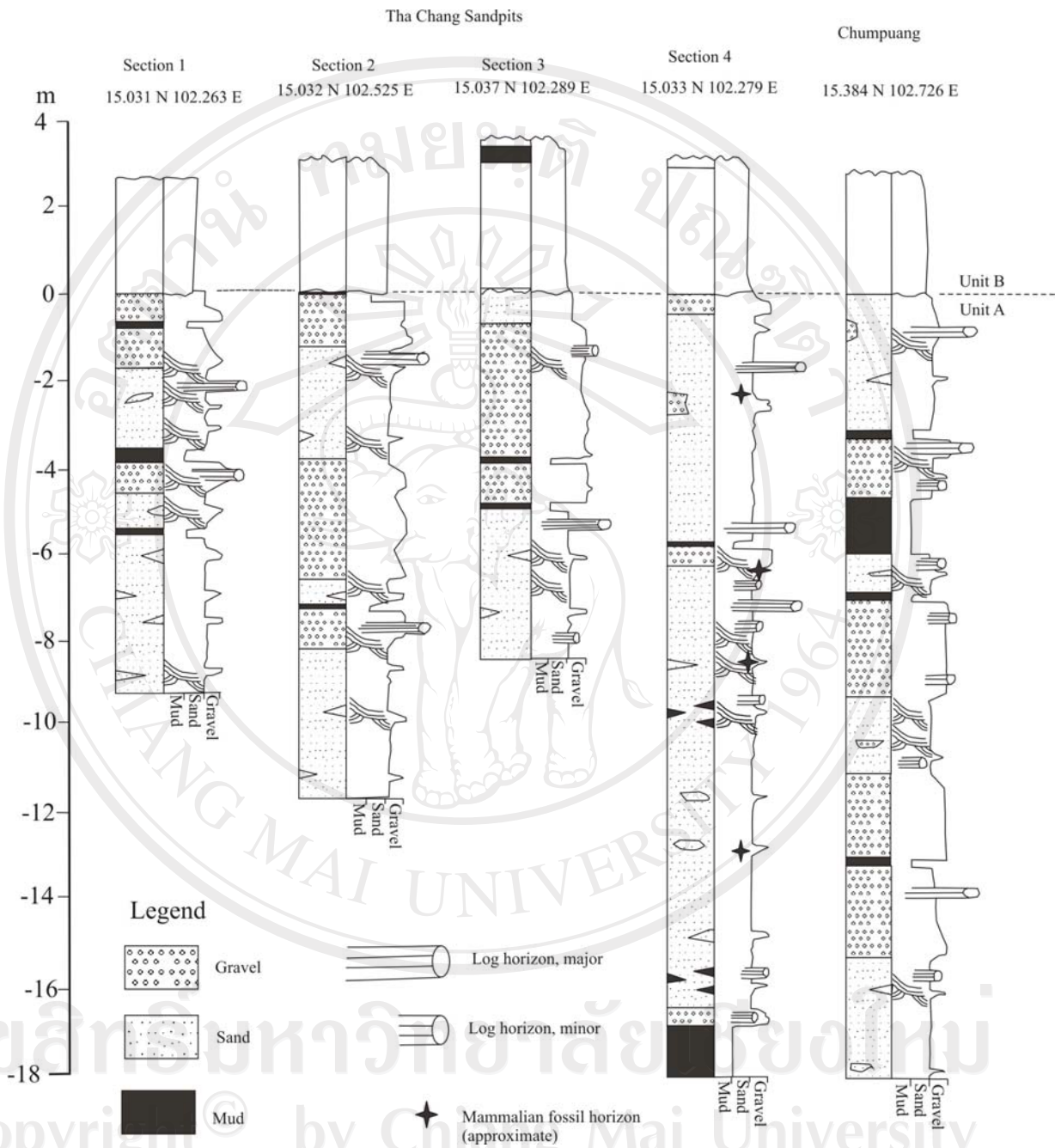


Fig. 2.15 Stratigraphic successions of the Tha Chang and Chumpuang sand pits (after Howard *et al.*, 2003).

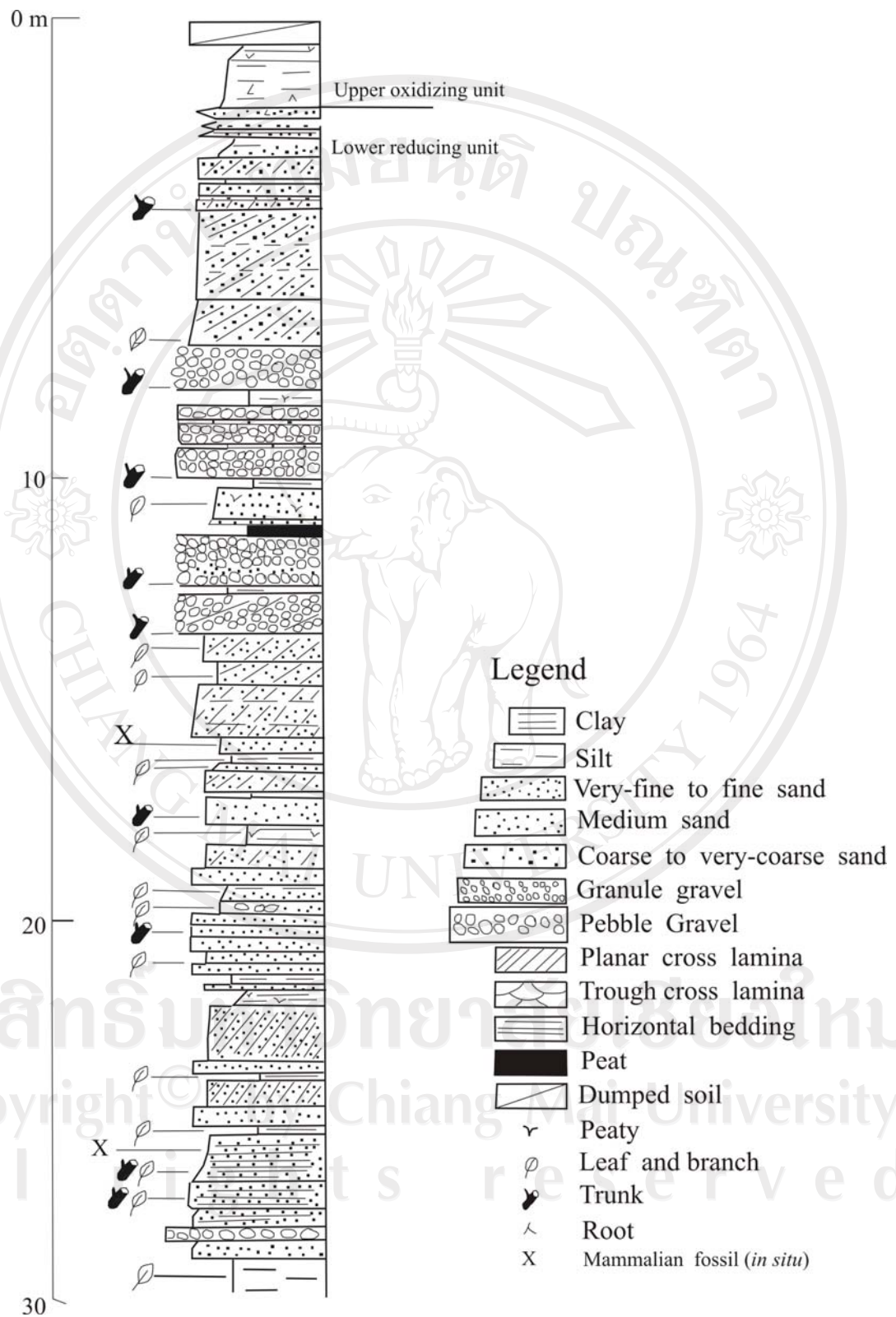


Fig. 2.16 Stratigraphic succession of the Tha Chang sand pit number 8 (after Nagaoka, 2002, unpublished document).