CHAPTER 2

GEOLOGY

Five basins in northern Thailand were chosen for the research areas, namely Mae Moh coal field, Chiang Muan coal field, Mae Teep coal field, Ngao coal field. and Wang Nua coal field (Figure 1.2). They are located between longitude 99° to 101°east and latitude 18° to 19° north, with their descriptive geography and geology as follow:

2.1 Physiographic features

A general topographic feature of northern Thailand is the mountainous areas with four main tributaries, the Ping, Wang, Yom, and Nan Rivers. The mountain ranges are characterised by high mountain peaks extending from north to south. The highest peak is Doi Intanon at 2565 meters and the lower peaks not much different, like Doi Pha Hom Pok, 2288 meters, Doi Chiang Dao, 2225 meters, Doi Phu Soi Dao, 2102 meters, and Doi Lang Kha, 2030 meters. The mountain ranges are divided by the four major rivers and their tributaries forming lowland basins where people settled developing their communities, usually near the rivers. The lowland areas average 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 season between May and October. The annual rainfall varies from 1100 to 1500 millimeters, 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).

2.2 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 distribution pattern of these rocks reveals a nearly N-S strike. This phenomenon directly relates to the orientation of major geological structures including folding and faulting with curvature patterns occasionally forming slender S-like shapes as seen on maps.

Precambrian rocks are narrowly exposed forming 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 extending to Kanchanaburi. The rock is the high-grade metamorphic 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 orthoquartzite, sandstone and shale. The Ordovician rocks are argillaceous limestone, limestone, dolomitic limestone, 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, chert, and limestone.

Mesozoic rocks in northern Thailand are lithologically divided into two facies, marine and younger continental facies. The marine facies composes the Triassic Lampang Group (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 characterised by red bed 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 characterised by their isolation and there are graben and half-graben basins. The sediments comprise of Tertiary and Quaternary deposits. Tertiary sediments are unconformably covered by younger Quaternary deposits. Some Tertiary sediments

are naturally exposed along the basin margins, as well as along streams where water had removed the Quaternary sediments. The Tertiary deposits are characterised 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 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; Tankaya, 2001; Sitaratana and others, 2002, 2003 and 2004).

2.3 Study areas

2.3.1 Mae Moh coal field

The Mae Moh coal field is located at 18° 18' 21" north latitude and 99° 44' 02" east longitude, 26 kilometers east of the Lampang city and approximately 630 kilometers north of Bangkok. The oval shaped basin covers an area of 104 square kilometers.

Mae Moh basin is a coal-bearing Tertiary basin with the largest proven coal reserves of Thailand, about 1,400 million tons. Coal occurs in six zones, the S, R, Q, K, J, and I zones. Present-day mining is restricted to the Q, K, and some part of J

zones. The coal has been exploited by the Electricity Generating Authority of Thailand (EGAT) and used for power plants with capacities of 3x75 Megawatts, 4x150 Megawatts, and 4x300 Megawatts. The daily consumption of lignite is approximately 40,000 tons per day.

2.3.1.1 Geologic setting of the Mae Moh basin

The Mae Moh basin is Tertiary in age which developed in north-south faulted-bound graben, flanked by marine Triassic rock to the north, east, and west (Figure 2.1) (Jitapunkul and others, 1985). The marine Triassic Lampang Group consists mainly of limestone, shale, and sandstone. Five of seven formations of the Lampang Group surround the Mae Moh basin (Piyasin, 1972; Chaodumrong and Burrett, 1997; Charoenprawat and others, 1994a), as follows:

Phra That Formation: It consists of interbedded black shale, tuff and sandstone; 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 fossil *Claraia* sp., *Costatoria* sp., and other bivalves. This formation lie between Permo-Triassic volcanic and Pha Kan Formation. The lower boundary with the underlying unit is unconformable. The upper boundary of the formation with Pha Kan Formation is conformable.

Pha Kan Formation: It consists of gray limestone with minor gray to green shale. It conformably underlies the Hong Hoi Formation.

Hong Hoi Formation: It is a flysch sequence that consists predominantly of

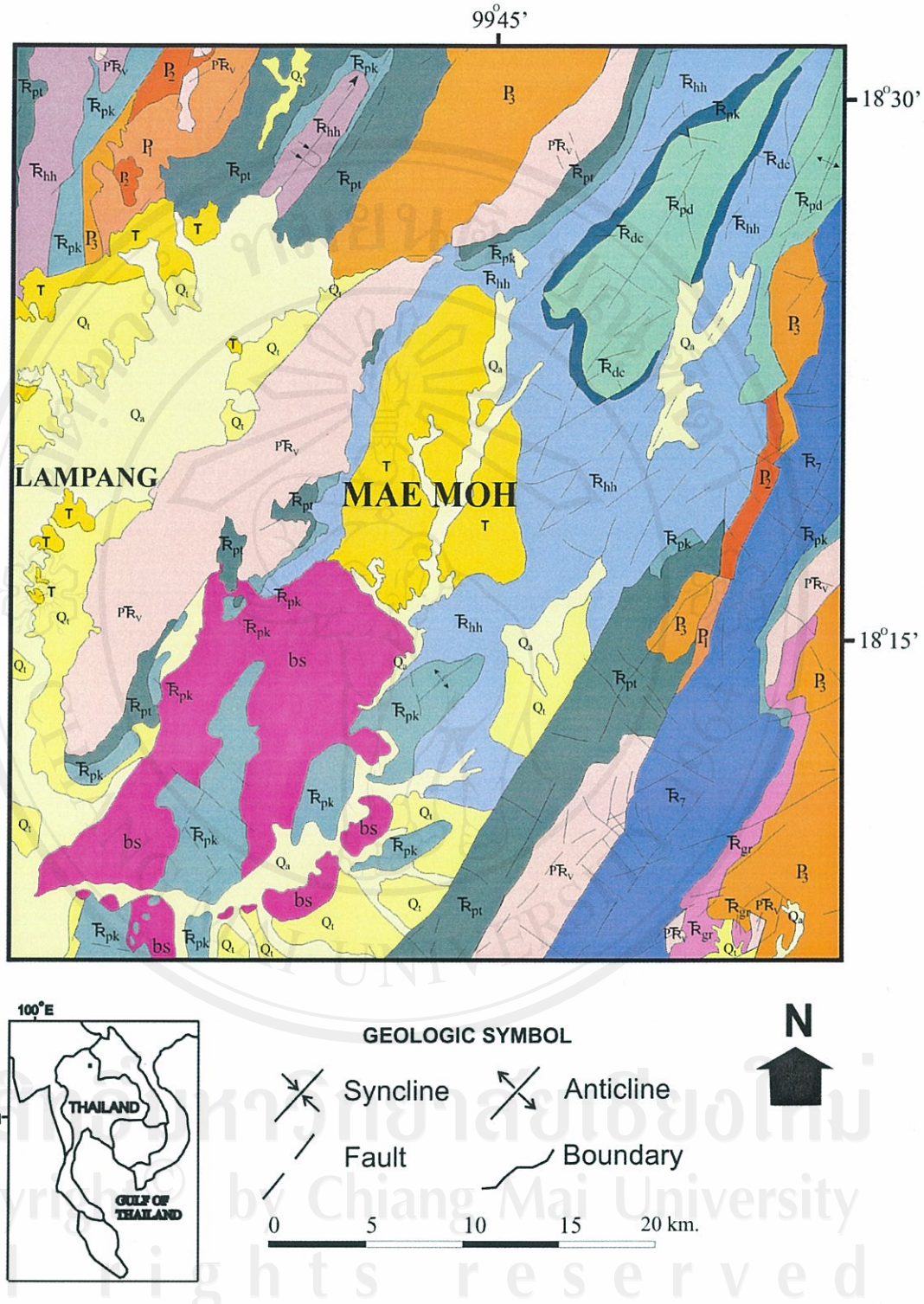


Figure 2.1 Geological map of the Mae Moh basin (modified from Charoenprawat and others, 1994a).

Explanation

Qa	Alluvial deposits: gravel, sand, silt, clay, and mud.
Qt	Terrace deposit: gravel, sand, silt, clay, and lateritic soil.
T	Interbedded claystone, sandstone, mudstone, diatomite, and shale with fossil leaves, stem, bone of fish and *Viviparus* sp.
T_{R7}	Shale and sandstone, gray to greenish gray; siltstone; mudstone; conglomerate; and limestone; with fossil *Halobia* sp., *Cassianella* sp., *Liostrea* sp., *Unionites* sp., and bivalves.
T_{Rpd}	Sandstone, red to reddish brown, cross-bedded; siltstone, conglomerate and shale.
T_{Rdc}	Limestone, gray to light gray, finely crystalline, massive; limestone conglomerate with fossils bivalves, brachiopods and gastropods.
T_{Rhh}	Silicified mudstone, gray to black, light brown to yellowish brown; intercalated with sandstone, light gray to dark gray, fine grained; tuffaceous sandstone, gray to browish gray, fine to medium grained, intercalated with shale, gray to dark gray; shale and siltstone, gray to greenish gray, with fossil *Halobia* sp., *Posidonia* sp.,and *Paratrachycerus* sp.
T_{Rpk}	Limestone, thin-bedded to massive, oolith, oncolith, fossiliferous; interbedded with shale, sandstone and mudstone, with fossils of *Daonella* sp., Crinoid stem, bivalves, coral, and algae.
T_{Rpt}	Interbedded black shale, tuff and sandstone; 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 fossil *Claraia* sp., *Costatoria* sp., and other bivalves.
P3	Interbedded black shale, gray sandstone, dark gray mudstone and gray limestone with chert nodules; intercalated with fossiliferous limestone and mudstone.
P2	Massive limestone, shale, calcareous shale and sandstone with fossil corals and crinoid stems.
P1	Phyllite, gray to purplish gray, sandstone and silt stone, brown; quartzite, quartzitic schist, agglomerate and tuff, with some micaceous.
bs	Olivine basalt, gray to dark gray, visicular texture, flow structure with some volcanic bomd and scoria.
gr	Biotite granite, medium to coarse grained, porphyritic; muscovite granite, fine to medium grained; biotite-hornblende-adamellite granite, medium to coarse grained, equigranular to porphyritic and tourmaline muscovite granite, fine grained.
PT_{RV}	Volcanic rocks: rhyolite, andesite, flow and dike; agglomerate; volcanic conglomerate; rhyolitic tuff and andesitic tuff.

Figure 2.1 continued.

gray to greenish gray shale, sandstone, siltstone, and conglomerate, and minor interbedded argillaceous limestone. These lithologies are commonly thinly bedded to 10-40 centimeters, occasionally reaching 2-3 meters. in thickness with fossil *Halobia* sp., *Posidonia* sp.,and *Paratrachycerus* sp.

Doi Chang Formation. It consists of a gray to light gray, finely crystalline limestone. It is predominantly massive, but becomes well bedded near the base and the top. The formation forms the crest of Doi Phae Chi and Doi Pha Tup to the east of the mine, and around the flank of the Doi Phae Daeng syncline in the Ban Tha Si area to the north-east.

Pha Daeng Formation: It consists of sandstone, red to reddish brown, cross-bedded; siltstone, conglomerate and shale. This formation is largely confined to the center of a board syncline to the north-east of the Mae Moh basin.

The Tertiary rocks of Mae Moh basin, refered to as the "Mae Moh Group" (Corsiri and Crouch, 1985) has been divided into 3 formations by the high-resolution reflection seismic profile (Longworth-CMPS Engineers, 1981) and deep borehole data. The Tertiary rocks consist of conglomerate, sandstone, siltstone, mudstone, claystone, and coal.

The southern part of the basin is overlain by recent Pleistocene alkaline basalt (Piyasin, 1972; Barr and others, 1976, 2000; Barr and Macdonald, 1978, 1981; Jungyusuk and Sirinawin, 1983, and Boonsoong, 1997). It consists of both massive and vesicular, gray to black, fine-grained, and amygdaloidal, with recrystallised secondary minerals (Boonsoong, 1997). 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 isotopic age dating evidence (Sasada and others, 1987).

Unconsolidated Quaternary fluviatile deposits form a thin veneer cover throughout the basin. These unconsolidated deposits consist of superficial gravel overlain by alluvium (Jitapunkul and others, 1985).

2.3.1.2 Mae Moh stratigraphic succession

The three formations of the Mae Moh Group are, in ascending order, the Huai King Formation, Na Khaem Formation, and Huai Luang Formation (Figure 2.2). Each formation consists of clastic rocks that differ strongly in lithology, sedimentary structure, degree of consolidation, and fossil types. Stratigraphic descriptions are as follows:

Huai King Formation is the lowermost formation of the Tertiary succession. It consists of semi-consolidated mudstone, siltstone, sandstone, conglomeratic sandstone, conglomerate, and some claystone. It is varigated in color, being red, gray, green, yellow, blue and purple, commonly calcrets in part, has a slight amount of calcareous cement, and has no macrofossils except gastropods. The typical character is a fining upward sequence that grades from conglomerate at the base to mudstone or claystone on top. Thickness varies from less than 15 meters on basin borders to 150 meters on the central part of the basin. The formation can be divided into 2 part (Chaodumrong, 1985) as follow:

The lower part of the formation consists mainly of coarse-grained sediments that grade upward from gray and purple conglomeratic sandstone to red

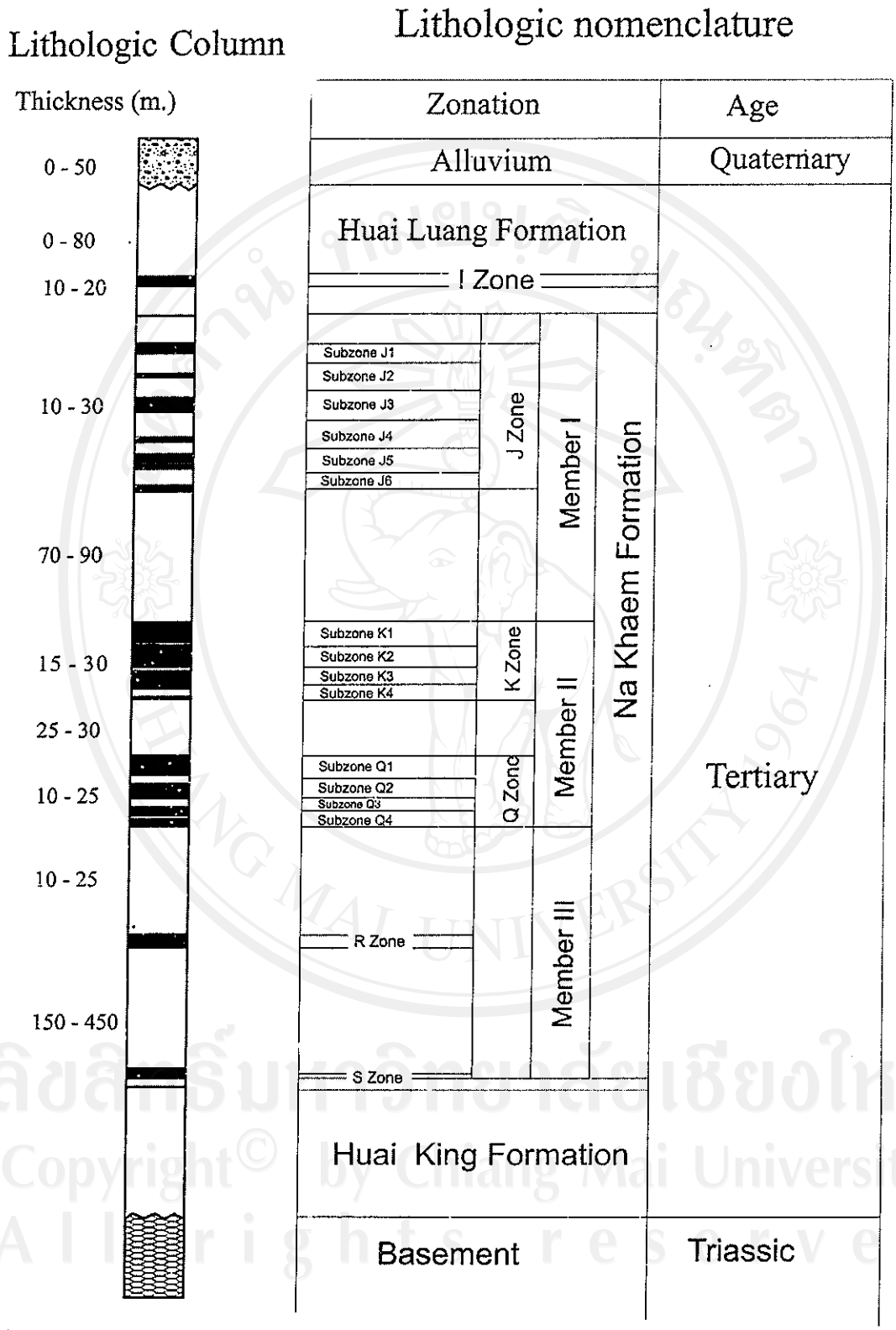


Figure 2.2 Stratigraphic sequence of the Mae Moh coal field (modified from Jitapunkul and others, 1985).

and gray clayey siltstone. Breccias of local origin were found at the base of the portion. Some thin carbonate layers of containing shelly debris occur within the silty material.

The upper part of the formation consists of the sequence of silty claystone. The fining upward sequences grade from sandstone or conglomeratic sandstone to interbedded red and gray claystone or silty claystone. Calcareous and mottled horizons are also present. There is an increase of organic material at the top of the formation that merges with the thin, low-grade lignite of zone S.

Na Khaem Formation is the middle formation of the Mae Moh Group. This formation is a coal-bearing formation that consists of semi-consolidated mudstone and five coal zones. The mudstone is gray to greenish gray and very fossiliferous, including gastropods, vertebrate, fish remains, ostracods, and plant remains. It is highly calcareous, contains load structures, flaser bedding, burrows, and borings and has an intraformational conglomeratic texture in some layers near coal zones. The formation's thickness varies from 250 to 400 meters. There are two major economic coal seams in the formation that can be separated by lithological criteria and economic aspects into three members, Member III, Member II, and Member I from the base (Chaodumrong, 1985).

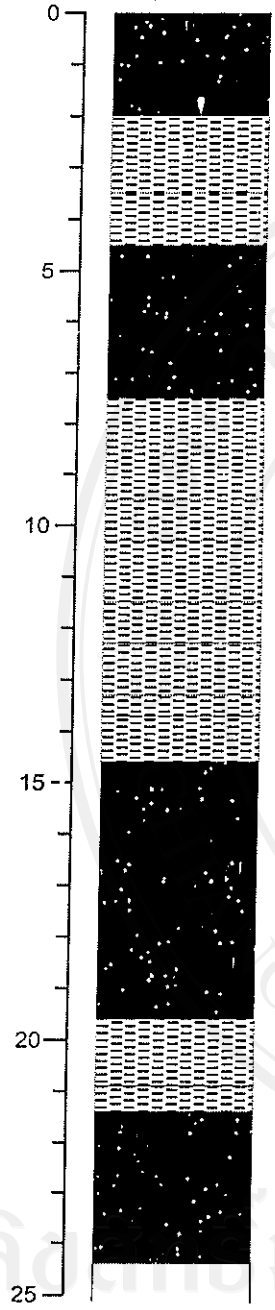
Member III (underburden) is the lowest unit, which consist of gray to greenish gray claystone and mudstone. Thickness of this member varies from 150 to 230 meters. These beds are laminated to thick bedded, planar type, are highly calcareous, and have abundant gastropod beds in the upper part, fish remains,

ostracods, and plant roots. The texture is intraformational conglomerate and the claystone is variegated near the lignite seams and layers. Burrows and borings and load casts are present. Two thin coal seams of 1 to 6 meters thick, are interbedded in the middle and lower portion. These seams are called the R-zone and S-zone. The boundary between coal zone S 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 coal zone Q. The lithofacies associations of this member are consistent with deposition in a lacustrine and swamp environment (Uttamo and others, 2003).

Member II is the most economically attractive coal sequence. It has three distinct zones, zone Q, Interburden, and zone K from the base.

Zone Q is the lower portion that contains the stratigraphically lowest coal exploited at Mae Moh. It consists of interbedded soft, brown to black coal with partings (about 30 %) of light brown claystone containing abundant siliceous or calcareous white spots of diatom, and plant remains. Total thickness varies from 25 to 30 meters. It is split in the north and south. The coal is divided into 4 subseams (Figure 2.3).

Q4: The basal coal subseam, up to 10 meters thick, contains mainly low ash, and coal. Some claystone partings occur towards the top. This seam is further subdivided into Q4B (at the base) and Q4A and persistent intervening white claystone parting. Q4B is hard and good quality coal. Q4A consists of carbonaceous claystone with occasional mudballs. A distinctive bed of brown gray claystone with a shell layer (*Bellamya* sp.) often occurs at the base of Q4B. A thin claystone is sometimes found at the top of Q4A.



Description

Q1 coal: massive, hard coal, bright, concoidal fracture, underlain by light gray claystone and dark gray claystone.

Q2 coal: massive and hard coal, bright, concoidal fracture, underlain by light gray claystone.

Q3 coal: massive and hard coal,bright, underlain by light gray claystone.

Q4 coal: hard coal, bright, with pyrite ball, underlain by light gray claystone of underburden with *Bellamya* sp.

Underburden: Light gray claystone with gastropod.

Figure 2.3 Stratigraphic sequence of the Q zone coal of Mae Moh coal field.

Q3: It contains good quality coal and numerous claystone partings and thins rapidly to the north in association with seam parting.

Q2: It contains poor quality coal and numerous partings. Mudballs are commonly scattered in both the coal and to a lesser extent in the parting.

Q1: It consists of good quality coal. Thickness varies up to 10 meters. It is separated from Q2 by a thin claystone. Subdivision is possible into 2 intervals, Q1B (at the base) that consists of a 3 to 6 meters interval of coal and Q1A. Ratanasthien and others (1997) reported principal macerals identified in the Q zone lignite is

- 80-90 % Huminite Group (densinite, gelinite, and gelified texto-ulminite)
- 5-10 % Inertinite Group (fusinite, semifusinite, and funginite)
- 0-5 % Liptinite Group (liptodetrinite and suberinite)

Interburden is approximately 10 to 30 meters thick sequence of brown, brownish gray, gray, green, and greenish gray claystone. This claystone lies between two major coal seams. The beds are laminated to thickly bedded, planar type, and commonly have coal flakes, fish remains, plant roots, and, rarely, ostracods. Intraformational conglomeratic textures are common in the lower part. Gastropods and load casts are common. Micro-slip planes are abundant. This interburden is thickest in the east part of the main basin and thins toward the west flank of the main basin.

Zone K is the upper portion of Member II. It consists of black to brownish black, brittle coal (10 to 30 meters), interbedded with soft coal and partings of light yellowish gray to gray silty claystone. Gastropod (family Planorbidae, Viviparidae, and minor *Melanoides* sp.), fish and plant remains are present. The zone splits both

to the north and south of the central mining area and can be separated into 4 subseams (Figure 2.4).

K4: The basal subseam, up to 3 meters. thick, consists of both coal and carbonaceous claystone, which grades locally into carbonaceous claystone. The coal has a high mineral content.

K3: It consists of good quality, dense, black coal, about 7.5 meters. thick. This subzone is further subdivided into K3B (at the base) and K3A. K3B is a persistent layer of hard lignite.

K3A is coal with a higher mineral content, and carbonaceous clay, in which scattered mudballs, pyrite balls, and siliceous or sideritic lens are common. A siliceous hard band is common about 0.1 to 0.3 meter. above the base of K3 and forms a key marker bed. Quartz crystals are occasionally found in the crack or void of this hard band.

K2: A sequence up to 17 meters. of lower quality coal with numerous claystone partings with numerous. Gastropod (family Planorbidae) layers. K2 is often separated from K3 by a 0.05 to 0.2 meter. marker bed of laminated dark brown claystone with mudstone lenses. Pockets of fine to very coarse sand are found in some places.

K1: The K1 subzone is separated from K2 by a dark brown claystone, about 1 meter thick. It consists of good quality, dense, black, bright coal, up to 11 meters. thick, with scattered gray claystone and mudstone towards the top. Subdivisions K1B (at the base) and K1A are recognized in the area where the seam splits. Diatoms were found in K1 coal.

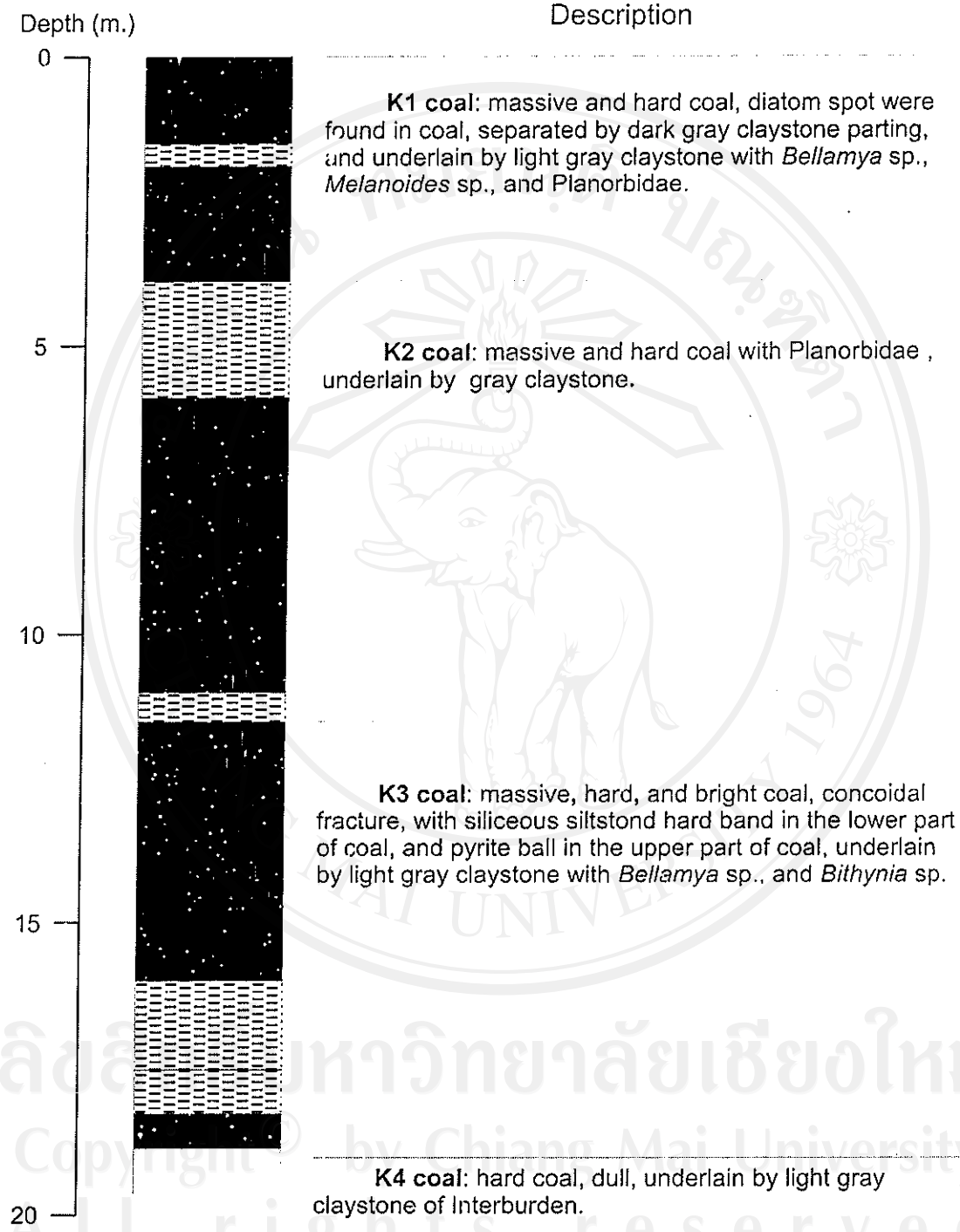


Figure 2.4 Stratigraphic sequence of the K zone coal of Mae Moh coal field.

Ratanasthien and others (1997) reported macerals of the K zone coal principally

- 70-80 % Huminite Group (texto-ulminite, gelinite, and densinite)
- 5-20 % Liptinite Group (telalginite, lamalginite, sporinite, cutinite, and liptodetrinite)
- 0-2 % Inertinite Group (fusinite and funginite)

Member I is the upper portion of Na Khaem Formation. This sequence consists of gray and greenish gray claystone and mudstone that occasionally has siltstone in some parts. These beds are laminated to massive, planar type, and highly calcareous. Fine pyrite concretions are common in some parts. The unit has abundant gastropods, fish remains, ostracods, plant remains, reptile skeletons, and load structures. Its has an intraformational conglomeratic texture and is varigated near coal seams. Mahatthanachai (1996) concluded that the intraformational conglomeratic texture consists of volcanic debris, especially pumice which shown the amygdaloidal texture. The upper part of this zone consists of two thin argillaceous layers, both less than 2 meters thick, and 18 thin coal seam. These coal seams are named J1 to J6 (Figure 2.5).

J6: In the lowest subseam of this zone, two distinct, black color coal horizons are present. J6B (at the base, and the thickest) and J6A separated by claystone, and total up 2 meters. in thickness. J6 and J5 were separated by gray claystone.

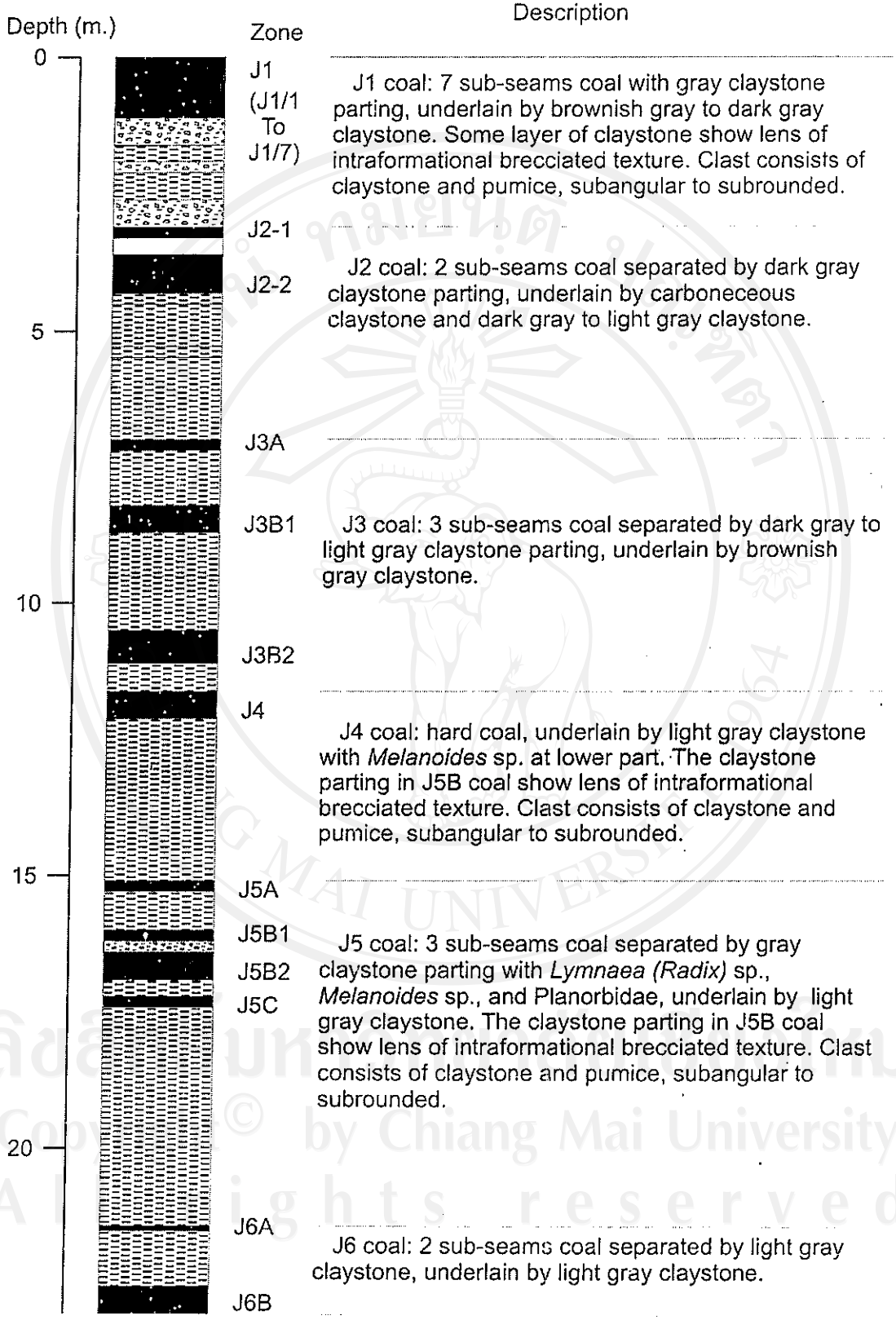


Figure 2.5 Stratigraphic sequence of the J zone coal of Mae Moh coal field.

J5: It consists of 3 black coal seams, 15 to 20 meters of thickness. J5C is about 0.4 meter thick, and low mineral content. J5B is about 1.5-2 meters, with claystone and mudstone interbed in the basal portion. There is intraformational conglomeratic texture claystone lens in J5B. J5A is about 1 m. above J5B, and less than 0.2 m. thick. The gastropod in this seam is *Lymnaea (Radix)* sp., *Bellamya* sp., *Melanoides* sp., and family Planorbidae.

J4: It is a single black coal seam, about 1.2 meters. thick. It consists black hard coal with numerous claystone and mudstone partings in the upper 0.5 meter.

J3: It consists of 3 black coal seams, J3B2 (at the base), J3B1, and J3A, with interbedded claystone/mudstone partings totaling 4 to 5 meters in thickness. There is intraformational conglomeratic texture claystone parting. Seams are grouped into J3A is a thickest bed, but has a high mineral content.

Claystone/mudstone, about 0.2 to 3.5 meters. thick, overlies J3.

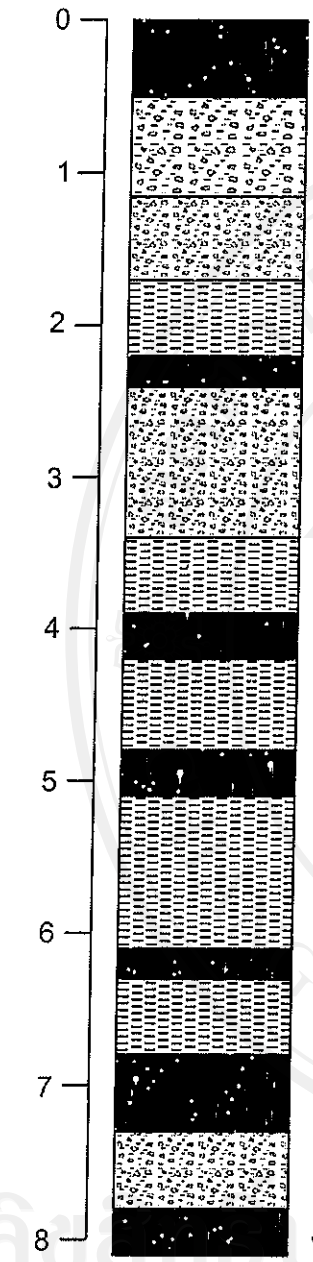
J2: It is a single black coal seam, about 1.2 meters. thick, with some interbedded thin claystone/mudstone parting.

Claystone/mudstone, about 1.5 to 3 meters. thick, overlies J2.

J1: It is a combination of thin seams and carbonaceous clay interbeds. Divisions J1/1-J1/7 are identified (Figure 2.6). Quality deteriorates upwards.

Ratanasthien and others (1997) and Promma (1992) reported macerals of this J zone coal principally:

- 60-70 % Huminite Group (gelinite, texto-ulminite, and densinite)
- 20-25 % Liptinite Group (alginite (10-15%), cutinite, sporinite, suberinite, and liptodetrinite)
- 0-5 % Inertinite Group (fusinite and funginite)



Zone	Description
J1/1	J1/1 coal: dense, dull coal, underlain by medium gray and light gray claystone with small pyrite ball (0.1-0.5 cm.). Claystone show lens of intraformational brecciated texture. Clast consists of claystone and pumice, subangular to subrounded.
J1/2	J1/2 coal: dense, bright coal, underlain by dark gray to light gray claystone with small pyrite ball (0.1-0.5 cm.). Claystone show lens of intraformational brecciated texture. Clast consists of claystone and pumice, subangular to subrounded.
J1/3	J1/3 coal: dense, dull coal, underlain by medium gray claystone, show lens of intraformational brecciated texture. Clast consists of claystone and pumice, subangular to subrounded.
J1/4	J1/4 coal: dense, dull coal, underlain by medium gray to light gray claystone.
J1/5	J1/5 coal: hard, bright coal, remained wood structure, underlain by brownish gray claystone.
J1/6	J1/6 coal: hard, bright coal, underlain by light gray claystone.
J1/7	J1/7 coal: hard, bright coal, underlain by brownish gray and gray claystone, show lens of intraformational brecciated texture. Clast consists of claystone and pumice, subangular to subrounded.

Figure 2.6 Stratigraphic sequence of the J1 zone coal of Mae Moh coal field.

The uppermost 15 to 20 meters. of Member I, the"Transitional Zone" (Unit TJ) is a distinctive suite of claystone, siltstone, and silty claystone of varied organic and mineral content and color. It marks the transition from the reducing environment of lacustrine deposition typical of the Na Kaem Formation to the oxidizing conditions characteristic of the alluvial deposits of the Huai Luang Formation.

Huai Luang Formation is the uppermost division of the Mae Moh Group. It consists mainly of red to brownish red with some interbedded gray layers semi-consolidated and unconsolidated sediments. It was named "Red Bed" by Longworth-CMPS Engineers (1981). The sediments are predominately claystone, siltstone, and mudstone with some lenses of sandstone and conglomerate in the central part of the basin. No macrofossils were found but abundant gypsum and pyrite, rare root structure and flame structure have been identified in the formation. Thickness of this unit varies from less than 5 to 350 meters.

The lower part of the formation consists of sandstone and siltstone. The gravel horizons were found at the base. There is pyrite ball in claystone lens in this part. Upper section the sediments consists of red, brown, yellow, and gray claystone and silty claystone, with patches of (calcrete), color mottling and small gypsum crystals. The red claystone becomes interbedded with gray and greenish gray claystone and the coal of "I zone". The coal is black, hard, and 2-3 meters. thick. Gastropoda (*Melanoides* sp., *Margarya* sp., and *Brotia* sp.) and Bivalvia (*Hyriopsis* sp. and family Unionidae) were found in the gray claystone above the coal seam. Some gastropod was replaced by pyrite. Red clastic sediments form the top portion of this formation.

The studies of the depositional environment of Mae Moh Mine (Chaodumrong, 1985; Jitapunkul and others, 1985; Evans and Jitapunkul, 1989; Ratanasthien and others, 1997; Uttamo and others, 2003; and Uttamo, 1998, 2000) can be concluded as described below and Figure 2.7.

The sediments of the Huai King Formation were fluvial representative of a braided river in the lower part and a meandering river with overbank deposit in the upper part of the sequence. Pebble lithologies, are mainly siltstone, sandstone, and rare limestone indicated the source of sediment to be mainly of derived from the Triassic sedimentary rocks, which now flank the basin. Composite channel cut and fill characteristics throughout the formation suggest a high-energy fluvial depositional environment. The top of the formation, which contains the coal of zone, S marks a change in depositional environments from that of a braided river to that of swamp.

The sediments in the Na Khaem Formation indicate deposition occurred in an alternating fresh water lake, swamp/marsh calcium-rich, and lacustrine environment. The north and south of upper portion of the formation are disturbed by fluvial deposits. In these areas erosional materials periodically entering the basin caused the lignite seams to split and alternate with clastic sediments. This formation consists of 5 cycles, which began as lacustrine and gradually change to a swamp environment. The deposition of sediments in Q-zone took place mainly in a shallow

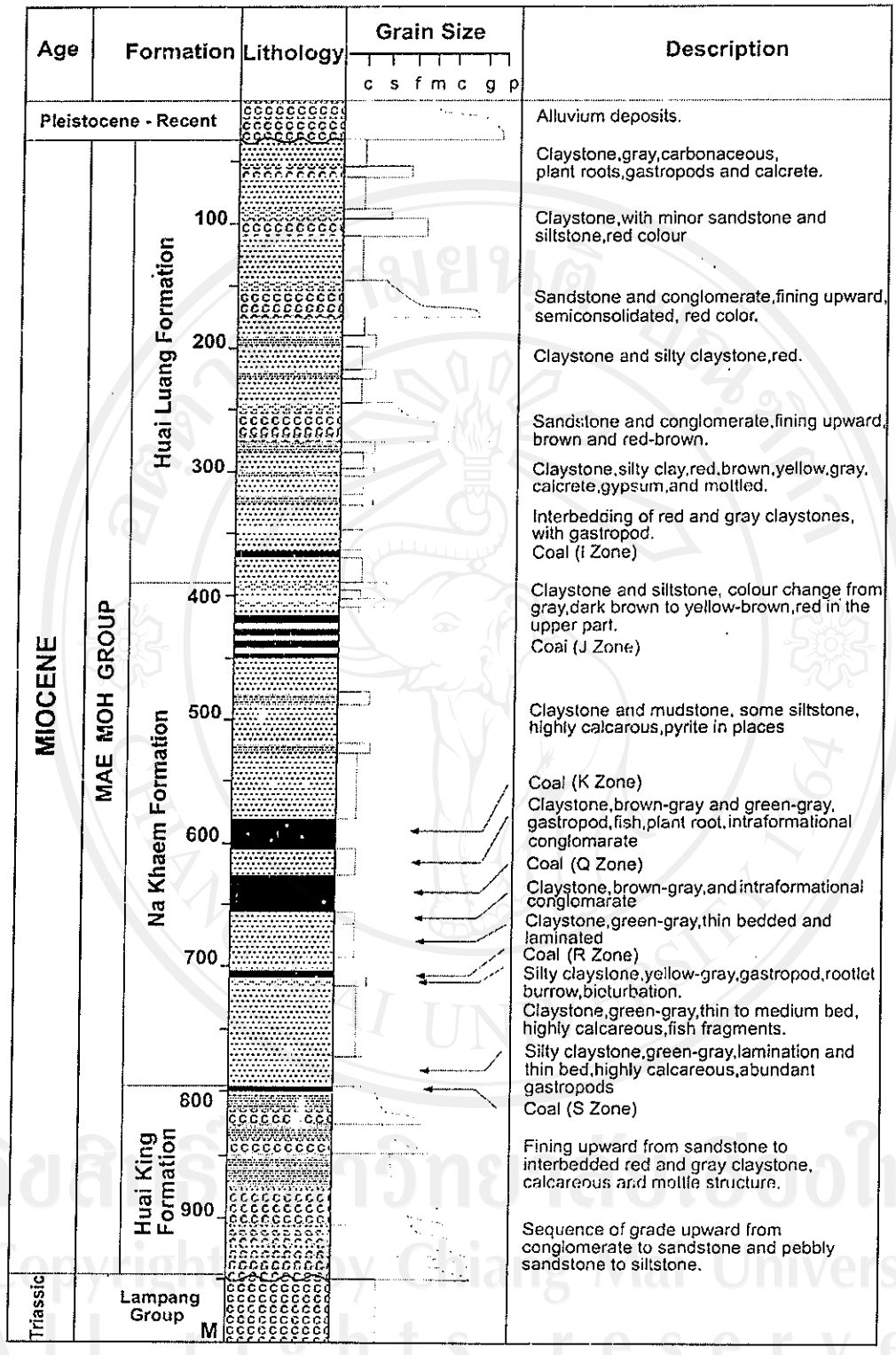


Figure 2.7 Lithostratigraphy of Mae Moh basin (modified from Sompong and others, 1996; Corsiri and Crouch, 1985; Chaodumrong, 1985; and Uttamo, 2000).

lacustrine or swamp environment. The highly dissolved organic matter and gelinite indicate that oxidation took place at the surface of the peat deposit. The end of Q-zone was caused by rapidly subsidence of water in the basin. A thick bed (approximately 10 meters) of *Bellamya* sp. in parting between K3 and K4 subzone shown that the depositional environment was changes from lacustrine to wetland.

Less supply of clastic sediments indicated that they were not transported by the debris flow in the waters. However, shell bed contains many shell fragments and poorly preserved individuals of the same species. Some specimens might be transported by the waves and current of the river or lake. The occurrence of *Bellamya* sp. should be suggested that they allochthonously concentrated in narrow place from all over the basin to look for their habitable waterbodies under the dry condition. The overlying sediments are mainly claystone, mud rocks, with diatoms, ostracod, and rare gastropod, indicating a lacustrine environment of intermediate water depth. The presence of lamalginite indicates that the water in the depositional basin was essentially fresh. The fusinite rich layer in the upper J-seam. Suggests that the water level changed from intermediate to shallow.

Huai Luang Formation was deposited in low energy fluvial environment with the channel trend parallel to the central area of the basin. The sediments the lower part indicate sedimentation in a flood plain, whereas the coal in I zone suggest that deposition in the middle part of the formation took place in a swamp (sequence 3) (Uttamo, 2000). Sediments in the upper part of the formation indicate that the water level change from shallow to deep and back to shallow (sequence 4) (Uttamo, 2000). The deep lake sediments are dominated by carbonaceous shale, fossiliferous claystone and the shallow lake is represented by gray mudstone/claystone layers.

Fluvial sediments on the upper part of the formation have replaced the lake deposits (sequence 5) (Uttamo, 2000). This consists of coarse-grained, horizontal-bedded, red and brown sandstone, and thick siltstone. This large fining-upward sequence probably occurred as the product of a large braided river system.

Benammi and others (2002) study the paleomagnetic of Mae Moh coal field from underburden zone to upper J subzone coal of Na Khaem Formation (Figure 2.8). The age of Na Khaem Formation range from 12.1 to 13.5 Ma. The paleomagnetic study support the fossil age of proboscidean, *Stegolophodon* sp., rhinocerotid, *Gaindatherium* sp., and mustelid carnivore, *Siamogale thailandica* sp (Ginsburg and Uk-kakimapan, 1983; Ginsburg and Tassy, 1985). Watanasak (1988 and 1989) and Songtham (2003) concluded on the basis of pollen and spore content of core samples from a drill hole that the Mae Moh and referred to Middle Miocene.

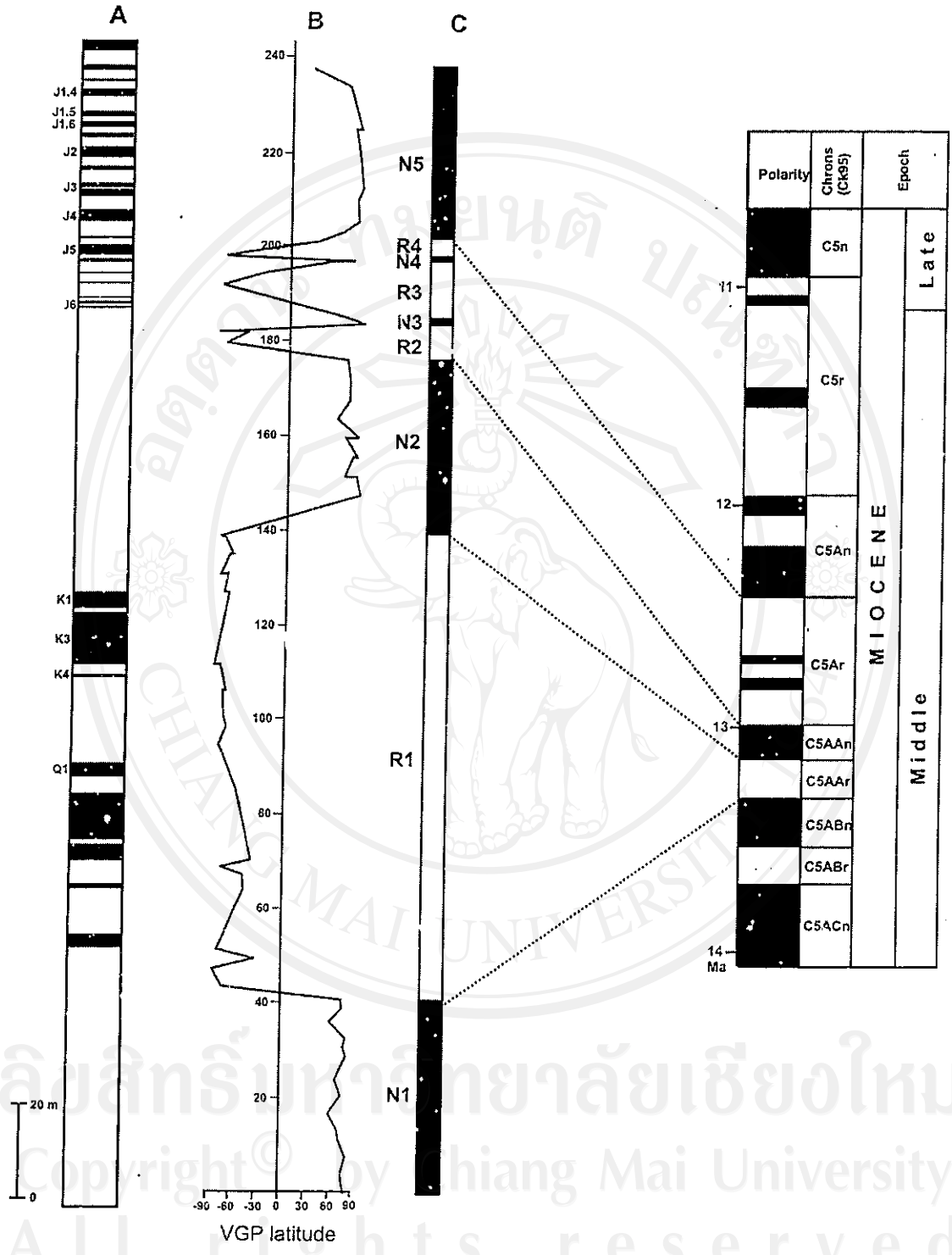


Figure 2.8 Schematic stratigraphic section of Mae Moh Group with magnetic polarity time scale (modified from Benammi and others, 2002)

2.3.2 Chiang Muan coal field

The Chiang Muan coal field is in the western part of the Chiang Muan basin, which is in Tambon Ban Sra, Chiang Muan District, Phayao Province, in northern Thailand. The Chiang Muan basin has an elongated shape, trends north-south, and parallels flanking mountains. The coal field is approximately 775 kilometers north of Bangkok and 90 kilometers east of Phayao township. It covers an area of 7 square kilometers at 18° 56' 00" north latitude, 100° 15' 00" east longitude. The Chiang Muan Mine Company mines good quality sub-bituminous coal from two of four coal-bearing intervals. These four coal intervals are the lower split coal seam, lower massive coal seam, upper coal seam 2, and upper coal seam 1.

2.3.2.1 Geologic setting of the Chiang Muan basin

The rocks that flank the Chiang Muan basin are marine Triassic and Jurassic red beds. These marine Triassic rocks form the Lampang Group (Figure 2.9) and are mainly of limestone, shale, and sandstone. The Triassic rocks show at the south and west of the basin. The Jurassic rocks are surrounding the basin.

The Triassic rocks consists of shale and sandstone, gray to greenish gray; siltstone; mudstone; conglomerate; limestone, gray, massive to bedded; with fossils *Halobia* sp., *Cassianella* sp., *Costatoria* sp, *Liostrea* sp., *Unionites* sp., bivalves and brachiopods. The Jurassic rocks surrounding the basin consists of sandstone,

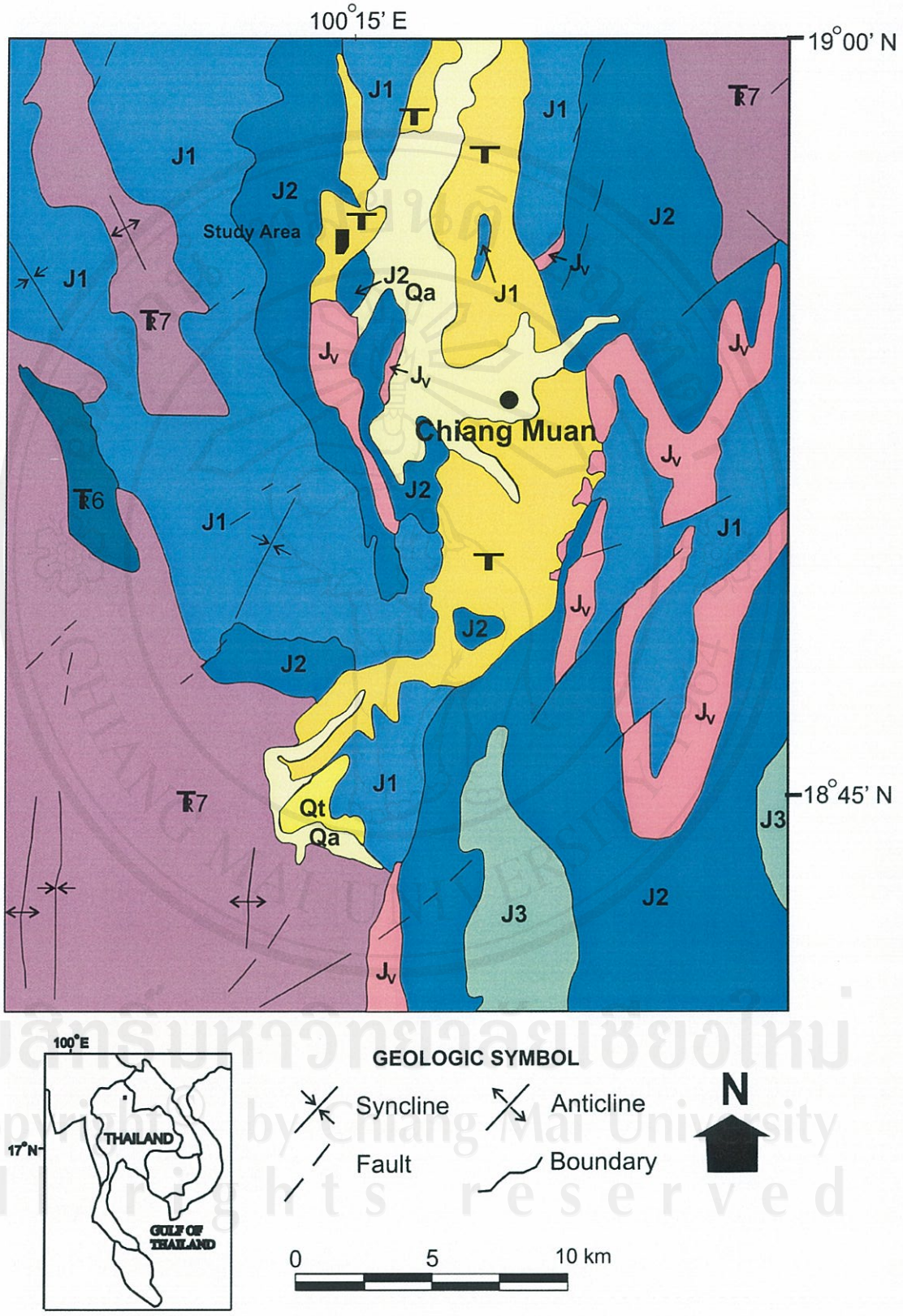


Figure 2.9 Geological map of the Chiang Muan basin (modified from Charoenprawat and others, 1994a).

Explanation

Sedimentary Rocks

Qa — Alluvial deposits: gravel, sand, silt, mud, and clay. (Quaternary).

Qt — Terrace deposits: gravel, sand, silt, clay, and lateritic soil.

T — Interbedded claystone, sandstone, mudstone, diatomite, and shale, with fossil leaves, stems, fish bones, gastropod fossils, *Brotia costula costula*, *Brotia costula varicosa, Melanoides* sp., *Bellamya* sp., and *Paludomus* sp., bivalve fossils, *Chamberlainia* sp. and *Indonaia* sp , and several taxa of vertebrate fossil.

J3 — Arkosic sandstone, whitish gray to greenish gray, intercalated with conglomerate and shale.

J2 — Sandstone, brown, interbedded with shale, reddish brown, micaceous, tuffaceous; conglomerate.

J1 — Sandstone, purplish brown, fine-grained, calcareous, interbedded with shale, reddish brown, limestone nodules; shale, gray, intercalated with sandstone, fine-grained; and conglomerate.

Tr7 — Shale and sandstone, gray to greenish gray; siltstone; mudstone; conglomerate; limestone; with fossils *Halobia* sp., *Cassianella* sp., *Liostrea* sp., *Unionites* sp., and bivalves.

Tr6 — Limestone, gray, massive to bedded; shale and sandstone, gray To greenish gray; with *Costatoria* sp., and brachiopods.

Igneous Rocks

J_v — Rhyolite, purplish gray, tuffaceous shale and sandstone.

Figure 2.9 continued.

purplish brown, fine-grained, calcareous, interbedded with shale, reddish brown, limestone nodules; shale, gray, intercalated with sandstone, fine-grained; and conglomerate. Sandstone, brown, interbedded with shale, reddish brown, micaceous, and tuffaceous. The Jurassic rocks surrounding the mine show northeast direction of bed and 20° to 50° of dip angle. The Jurassic volcanic rock of rhyolite, purplish gray, tuffaceous shale and sandstone show at the west of the basin and south of the mine. The Tertiary rocks of the Chiang Muan basin consists of conglomerate, sandstone, claystone, and lignite. Quaternary fluvial deposits form a thin veneer cover throughout the basin. These fluvial deposits are up to 21 meters thick and consist of dark gray and light to medium brown unconsolidated topsoil, clay, silt, and gravel. The gravel occurs at the base of these deposits and the alluvium deposits are on the top.

2.3.2.2 Chiang Muan Stratigraphic succession

The Tertiary clastic sequence in the Chiang Muan coal field has nine zones. These zones are, from bottom to top, underburden or UB, lower split coal seam or LS, interburden 3 or IB3, lower massive coal seam or LM, interburden 2 or IB2, upper coal seam 2 or U2, interburden 1 or IB1, upper coal seam 1 or U1, and overburden or OB. Figure 2.10 shows the stratigraphy of the coal field.

Underburden, UB, is the lowest part of the sequence. It consists of reddish brown and gray conglomerate, conglomeratic sandstone, sandstone, clayey sandstone, sandy claystone, silty claystone, and claystone. Thickness of the zone exceeds 20 meters.

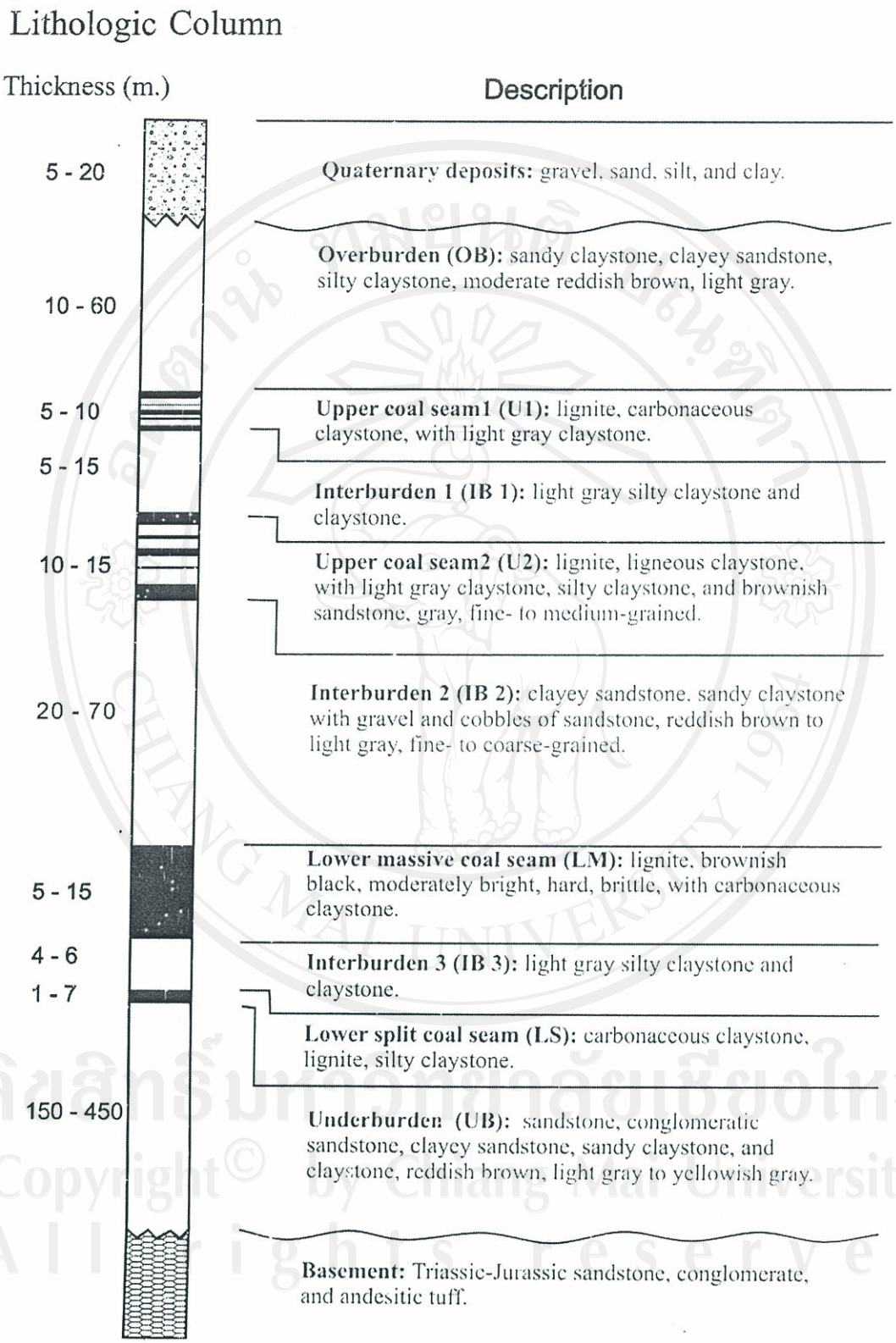


Figure 2.10 Stratigraphic column of Chiang Muan coal field. (Courtesy of Chiang Muan Mine Company Limited).

Lower split coal seam, LS, consists of gray to black clastic beds. Its thickness varies from 1 to 7 meters. The zone's lower portion is dark gray carbonaceous claystone. Fossils in this lower part are the skeletons, teeth, and tusks of Gomphotheriidae of *Tetralophodon* cf. *xiaolongtanensis*, pig bones and teeth, crocodile bones and teeth, bird bones, fish bones and teeth, and turtle plates. The upper part of the zone is poor quality brownish black coal 0.5 to 1.5 meters thick.

Interburden 3, IB3, is light gray and pink silty claystone. It is medium hard and is 4 to 6 meters thick. No fossils were found in the zone.

Lower massive coal seam, LM, is the main economically attractive coal zone. It consists of gray to black clastic beds made up mainly of tree trunks and its thickness varies from 10 to 15 meters. The lower portion of the zone is dark gray carbonaceous claystone. Fossils found in this claystone are the skeletons, teeth, and tusks of Gomphotheriidae of *Tetralophodon* cf. *xiaolongtanensis*, hominoid teeth, rhinocerotid teeth, deer skeletons, turtle temora and plates, a Suidae pig molar, and pig bones. The upper part of the zone is good quality black, hard coal that is 7 to 10 meters thick.

Interburden 2, IB2, consists of reddish brown, yellow, yellowish gray, and gray clastic beds. Poorly consolidated granule and pebble conglomerate occurs in small lenses and thin layers in the lower, middle, and upper parts of the zone. Boulders and cobbles of sandstone occur in the upper part. The zone's thickness varies from 35 to 70 meters. No macrofossils were found in the zone.

Upper coal seam 2, U2, is mainly gray claystone and coal. Its thickness varies from 15 to 30 meters. The coal occurs in the middle part and is separated into five cycles by light gray claystone. The zone contains hominoid teeth of cf. *Lufengpithecus chiangmuanensis*, rhinocerotid teeth, deer skeletons, turtle temora and plates, a Suidae pig molar, and crocodile fossils. The thickness of coal beds in this zone varies from 0.5 to 5 meters.

Interburden 1, IB1, consists of light gray, medium hard, silty claystone and gray, non-silty claystone. Its thickness varies from 4 to 10 meters. Crocodile bones and turtle fossils occur in this zone.

Upper coal seam 1, U1, consists of gray, fine-grained clastic beds and its thickness varies from 10 to 15 meters. There are five cycles of interbedded claystone and coal in the zone's lower part. The thickness of these coal beds varies from 0.5 to 1 meter. The middle part of the zone is greenish gray claystone that has mastodon bones, crocodile teeth, and plant seeds and leaves. The shells found in this zone (U1 Unit) were identified by Dr. Gulung Damayanti, a Nepalese paleontologist, as follow: gastropod fossils: *Brotia costula costula*, *Brotia costula varicosa*, *Melanoides* sp., *Bellamya* sp., and *Paludomus* sp., bivalve fossils: *Chamberlainia* sp. and *Indonaia* sp.. The zone's upper part is greenish gray to reddish claystone and carbonaceous claystone. Gypsum and pyrite occur throughout the zone.

Overburden, OB, is the uppermost unit of the sequence and divides into two parts. The lower portion is gray sandy claystone, claystone, and mudstone.

There are two hard calcareous bands. The upper part is yellowish brown and brown sandy claystone, clayey sandstone, and clayey siltstone. No fossils were found in this zone. The zone's thickness varies from 5 to 60 meters.

The vertebrate fossil remains were commonly found in the carbonaceous claystone and coal. Nagaya and others (2002), Pickford and other (2004), and Kunimatsu and others (2004) identified and reported the vertebrate as the listed below:

OSTEICHTHYES

AVES

REPTILIA

Testudines

Squamata

Serpentes

Crocodylia

MAMMALIA

Primates

Hominoidea

?*Lufengpithecus keiyuanensis*

Proboscidea

Gomphotheriidae

Tetralophodon cf. *xiaolongtanensis*

Perissodactyla

Rhinocerotidae

Chilotherium (*Subchilotherium*) *intermedium*

Artiodactyla

Tayassuidae

Pecarichoerus sminthos

Suidae

Suinae

Hippopotamodon cf. *hyotherioides*

Tetraconodontinae

Parachleuastochoerus sinensis

Conohyus sindiensis

Tragulidae

Dorcatherium sp.

Bovidae

The age of the mammalian fauna from Chiang Muan was determined by two prelominary paleomagnetic studies suggesting late Middle Miocene to early Late Miocene or about 12 to 10 million year old (Suganuma and others, 2002), 11 to 12 million year old (Kunimatsu and others, 2004), 13.5 to 10.8 million year old (Benammi and others, 2003; Chaimanee and others, 2003), and 13.5 to 13 million year old (Pickford and others, 2004) as show in Figure 2.11 and 2.12.

2.3.3 Mae Teep coal field

The Mae Teep coal field is located in Mae Teep basin, Ngao District, Lampang Province. The basin is situated some 20 kilometers south of Ngao District

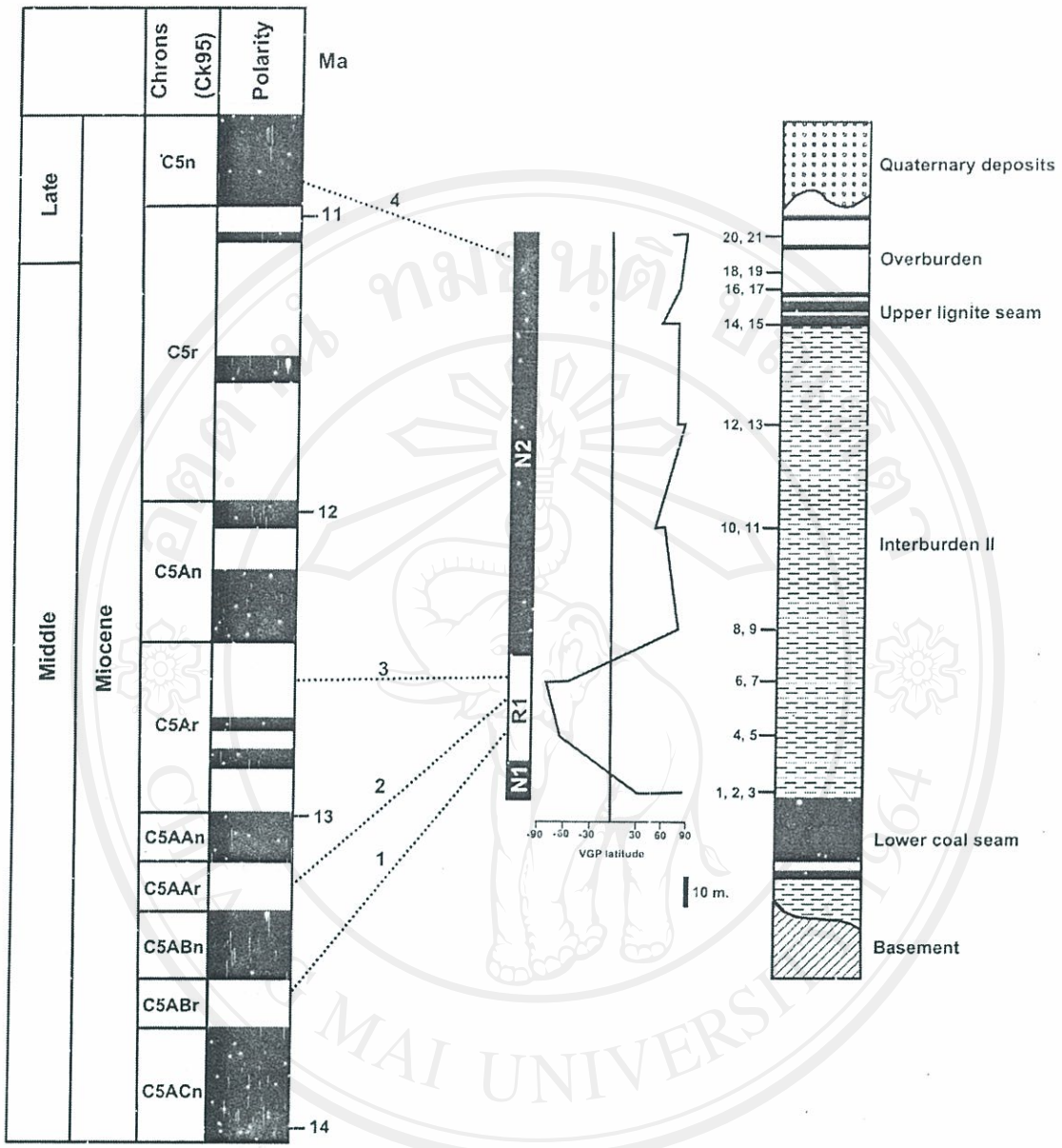


Figure 2.11 Schematic stratigraphic section of Chiang Muan Formation with magnetic polarity time scale (modified from Chaimanee and others, 2003).

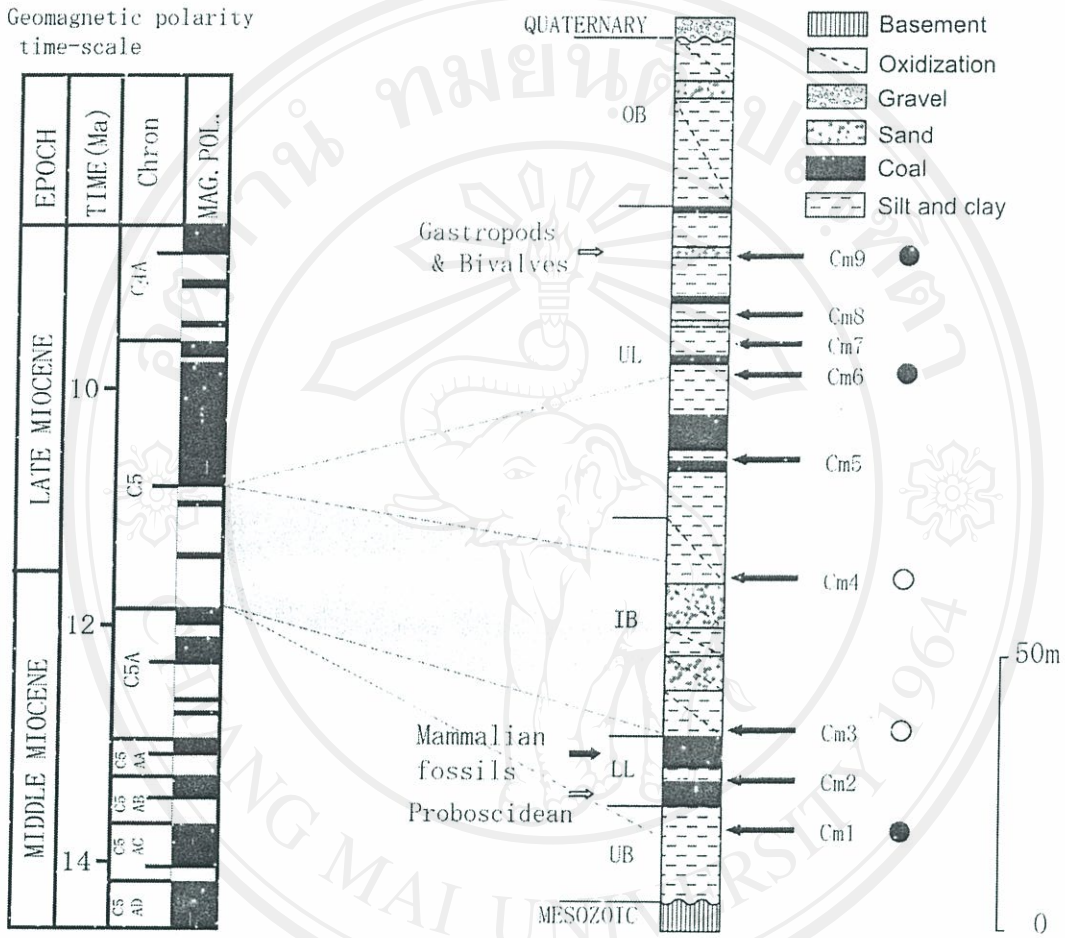


Figure 2.12 Schematic stratigraphic section of Chiang Muan Formation with magnetic polarity time scale (modified from Suganuma and others, 2002).

between kilometers 47 and 50 of the Phrae-Ngao highway. This basin covers an area of 120 square kilometers at 18^0 35' 11" north latitude, 100^0 00' 41" east longitude. The basin has an elongated shape, trend northeast-southwest, and parallels flanking mountains. The coal quality is sub-bituminous to high volatile bituminous C (Ratanasthien and Ruangvatanasirikul, 1984).

2.3.3.1 Geologic setting of the Mae Teep basin

Geologically, the Mae Teep basin developed as a Tertiary northeast southwest faulted graben. The Permian rocks are shown at the east of the basin, which is surrounded by Triassic and Jurassic rocks at the north, south, east, and west. The Permo-Triassic volcanic rocks are show at the east and west of the basin (Figure 2.13). The Permian rocks consist of Interbedded black shale, gray sandstone, dark gray mudstone and gray limestone with chert nodules; intercalated with fossiliferous limestone and mudstone. The Triassic rocks of Lampang Group (Pha Daeng Formation) are in the west of basin, which consists of sandstone, conglomerate, and shale, red to reddish brown, cross-bedded. Moreover the Triassic rock of Unit 7 from Charoenprawat and others (1994a) are show at the northeast and south of the basin, which consists of shale and sandstone, gray to greenish gray; siltstone; mudstone; conglomerate; and limestone; with fossil *Halobia* sp., *Cassianella* sp., *Liostrea* sp., *Unionites* sp., and bivalves. The Jurassic rocks unit 1 (J1) show in the north of the basin. It consists of sandstone, purplish brown, fine-grained, calcareous, interbedded with shale, reddish brown, limestone nodules; shale, gray, intercalated with sandstone, fine-grained; and conglomerate. While the Jurrasic rock unit 3 (J3) show in the south of basin, which consists of arkosic

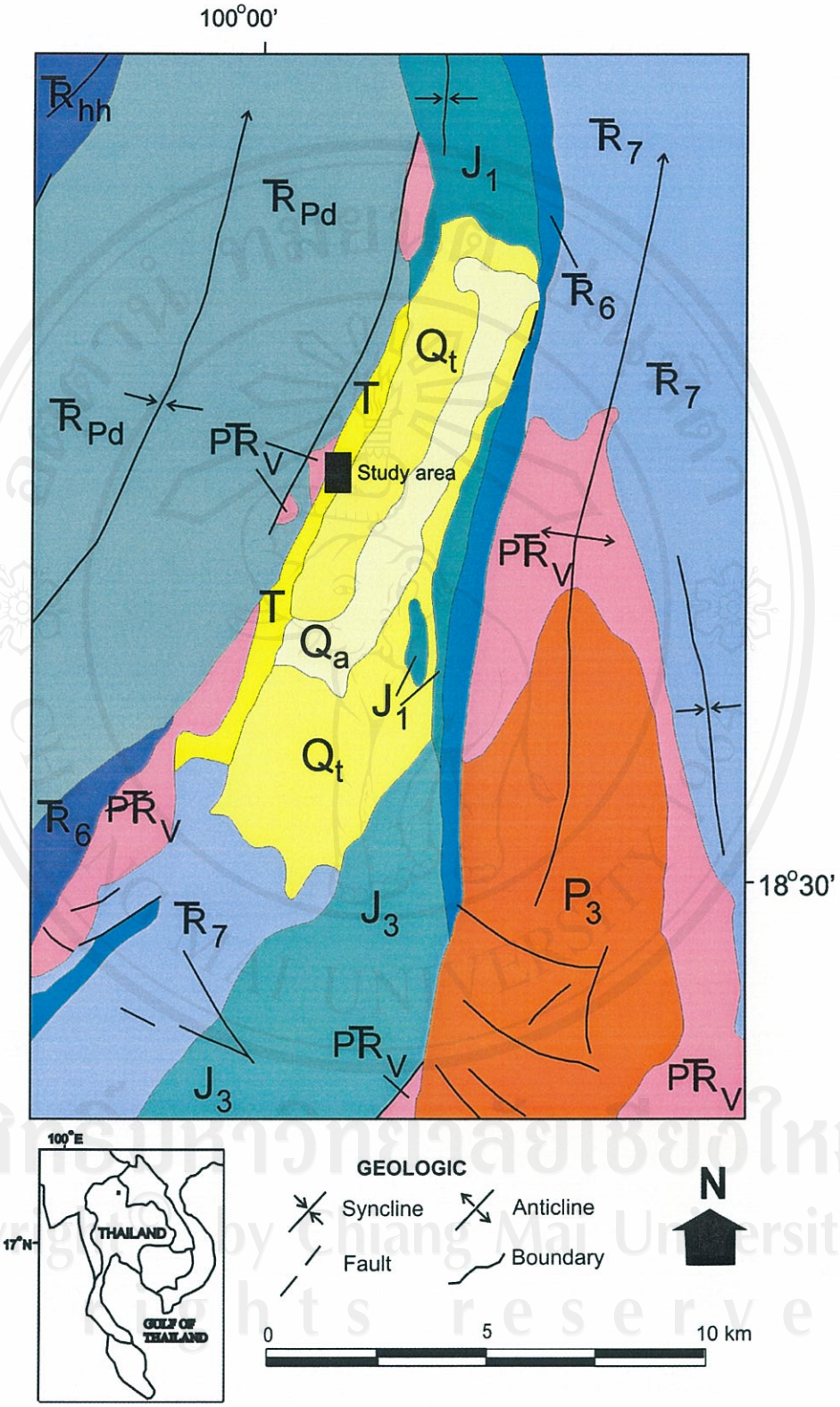


Figure 2.13 Geological map of the Mae Teep basin (modified from Charoenprawat and others, 1994a).

Explanation

Qa	Alluvial deposits: gravel, sand, silt, clay, and mud.
Qt	Terrace deposit: gravel, sand, silt, clay, and lateritic soil.
T	Interbedded claystone, sandstone, mudstone, diatomite, and shale with fossil leaves, stem, bone of fish and *Viviparus* sp.
J3	Arkosic sandstone, whitish gray to greenish gray, intercalated with conglomerate and shale.
J1	Sandstone, purplish brown, fine-grained, calcareous, interbedded with shale, reddish brown, limestone nodules; shale, gray, intercalated with sandstone, fine-grained; and conglomerate.
$\bar{T}R_7$	Shale and sandstone, gray to greenish gray; siltstone; mudstone; conglomerate; and limestone; with fossil *Halobia* sp., *Cassianella* sp., *Liostrea* sp., *Unionites* sp., and bivalves.
$\bar{T}R_6$	Limestone, gray, massive to bedded; shale and sandstone, gray to greenish gray; with *Costatoria* sp., and brachiopods.
$\bar{T}R_{pd}$	Sandstone, red to reddish brown, cross-bedded; siltstone, conglomerate and shale.
$\bar{T}R_{hh}$	Silicified mudstone, gray to black, light brown to yellowish brown; intercalated with sandstone, light gray to dark gray, fine grained; tuffaceous sandstone, gray to browish gray, fine to medium grained, intercalated with shale, gray to dark gray; shale and siltstone, gray to greenish gray, with fossil *Halobia* sp., *Posidonia* sp.,and *Paratrachycerus* sp.
P3	Interbedded black shale, gray sandstone, dark gray mudstone and gray limestone with chert nodules; intercalated with fossiliferous limestone and mudstone.
$P\bar{T}R_V$	Volcanic rocks: rhyolite, andesite, flow and dike; agglomerate; volcanic conglomerate; rhyolitic tuff and andesitic tuff.

Figure 2.13 continued.

sandstone, whitish gray to greenish gray, intercalated with conglomerate and shale. The Permo-Triassic volcanic rocks of rhyolite, andesite, flow and dike; agglomerate; volcanic conglomerate; rhyolitic tuff and andesitic tuff are show in the east and west of the basin. The Tertiary rocks of the Mae Teep basin consists of claystone, lignite, oil shale, and shale. A thick veneer of Quaternary fluvial sediments, ranging up to 20 meters in thickness, covers the basin.

2.3.3.2 Mae Teep stratigraphic succession

The Tertiary sequence of the Mae Teep coal field has three zones of sedimentary rocks (Figure 2.14). These zones are Underburden, Main coal seam, and Overburden, from bottom to the top of the sequence as below:

Underburden, UB

This zone is the lowest part of the sequence, underlying the Main coal seam. It consists mainly of gray claystone at the upper portion and gravelly sandy claystone, white to gray color at the lower portion. Thickness of the zone is more than 50 meters.

Main coal seam, MS

This zone is the main economically attractive coal zone. It consists of 3 portions. The lower portion consists of black coal, hard and dense, concoidal fracture, interbedded with carbonaceous claystone. The middle portion consists of

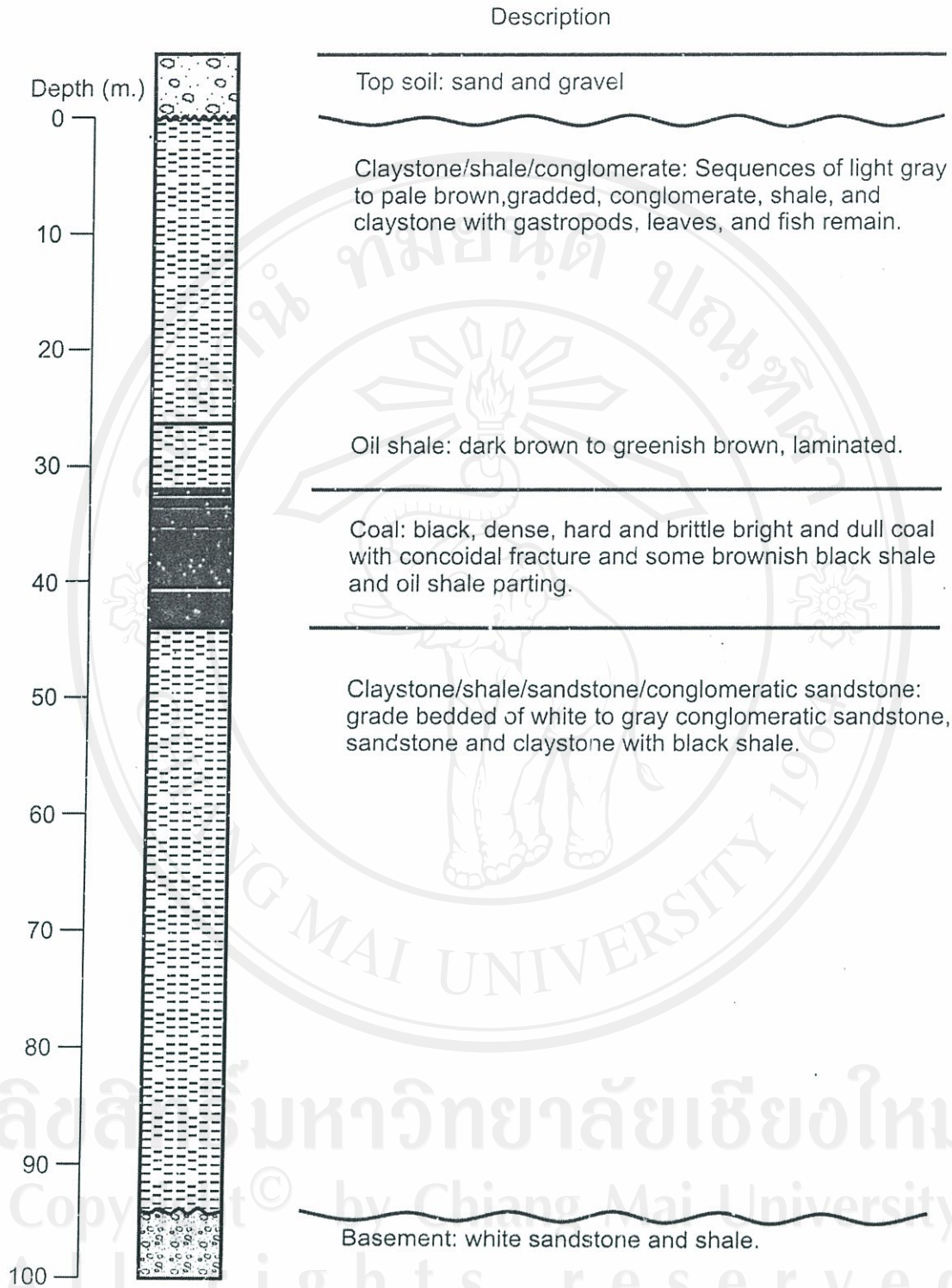


Figure 2.14 Stratigraphic column of Mea Teep coal field. (modified from Sananseang and Chaodumrong, 1980; Ratanasthien and Ruangvatanasirikul, 1984).

hard and dense black coal interbedded with sheet coal, and carbonaceous claystone. The upper portion consists of black coal, hard and dense, concoidal fracture, interbedded with oil shale. The thickness is approximately 30 meters. Coal quality ranks from sub-bituminous to high volatile bituminous C (Ratanasthien and Ruangvatanasirikul, 1984).

Overburden, OB

This zone is the uppermost unit of the sequence and consists of clastic rocks. The lower part of the zone is dark gray to black oil shale. The thickness is 5-7 meters. The upper part of the zone consists of mostly black shale and claystone. The thickness is approximately 25 meters. There is brown sandy mudstone, hard and dense, 15-20 centimeters of thickness.

2.3.4. Ngao coal field

Ngao basin is in Ngao District, Lampang Province, in northern Thailand. The basin is approximately 80 kilometers northeast of Lampang Province, 710 kilometers north of Bangkok and 55 kilometers south of Phayao Province. This basin covers an area of 195 square kilometers at 18° 45' 00" north latitude, 100° 00' 00" east longitude. The Ngao basin has an oval shape, trend northwest-southeast, and parallels flanking mountains. The coal quality is lignite B to lignite A (Water Resource Engineer (Ltd.) company, 1998). The geological reserve is approximately 90 million ton.

2.3.4.1 Geologic setting of the Ngao basin

The rocks that flank the Ngao basin are Permo-Triassic and Triassic rock (Figure 2.15). The Permo-Triassic rocks are mainly andesite, rhyorite, tuff, and agglomerate at the south of the basin. The Triassic rocks consist of sandstone, mudstone, shale, and limestone which occur along the north, east, and west flanks of the basin. Quaternary fluvial deposits form a thin veneer cover throughout the basin. These fluvial deposits are unconsolidated topsoil, clay, silt, and gravel.

2.3.4.2 Ngao stratigraphic succession

The Tertiary clastic sequence in the Ngao basin can be divided into 3 units by using the bore hole data and seismic data (Figure 2.16) (Water Resource Engineer (Ltd.) company, 1998)

Unit A is the lower part of the sequence, overlying the Triassic limestone and breccia. It consists mainly of brown and grayish brown color mudstone and sandstone. There are gray color and pinkish gray color limestone in the lower portion. This unit is approximately 160 meters thick.

Unit B is the middle unit of the sequence. This unit consists mainly of gray, brown, and black color of mudstone, claystone, and coal. The coal occurred in the upper part of the unit. This unit is approximately 100 meters thick.

Unit C is the upper unit of Ngao sequence, which consists of yellowish brown to brown color of mudstone, sandstone, and conglomerate. This unit is underlying the semiconsolidated to unconsolidated sediments of Quaternary. Unit C is approximately 100 meters thick.

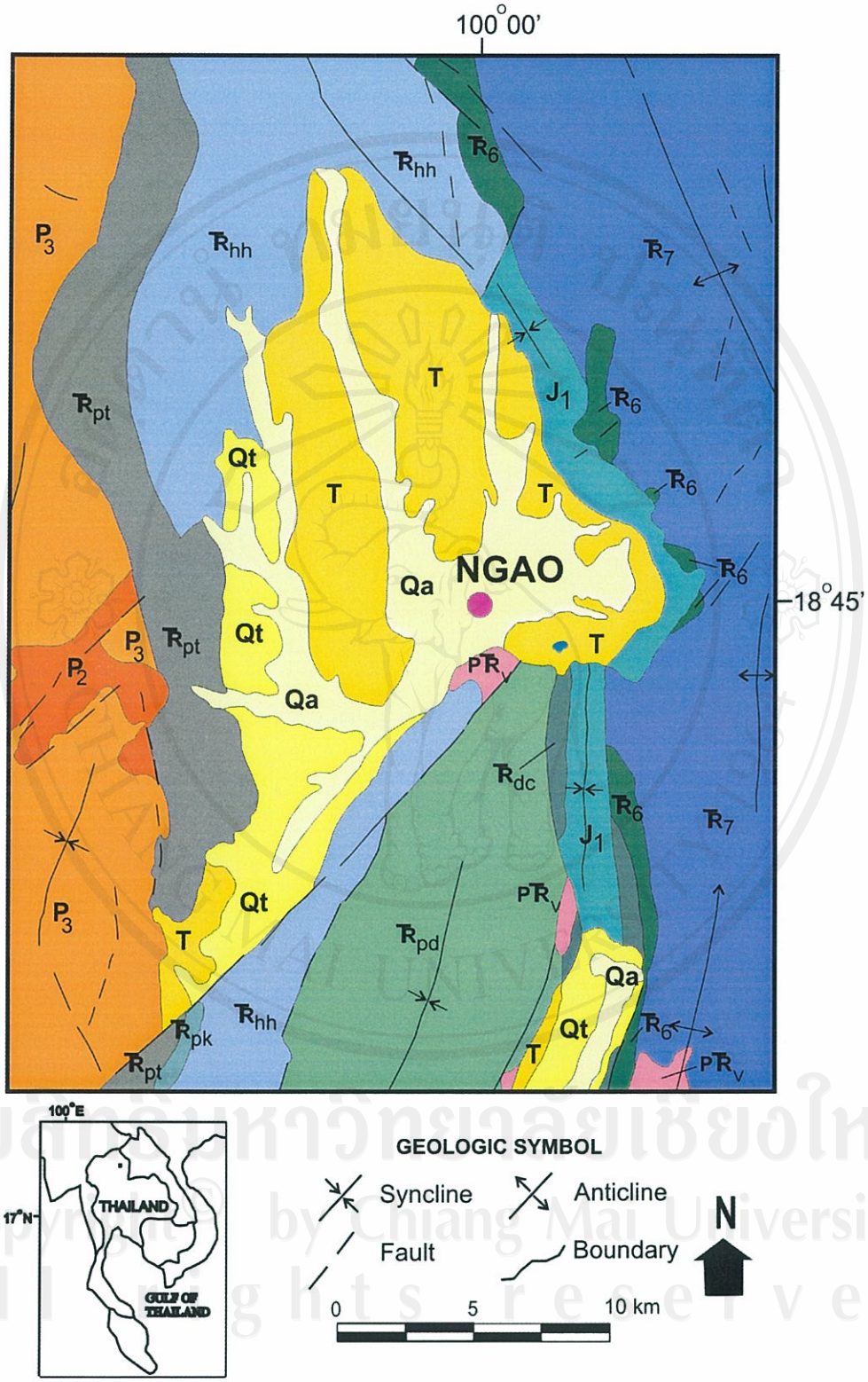


Figure 2.15 Geological map of the Ngao basin (modified from Charoenprawat and others, 1994a).

Explanation

Qa	Alluvial deposits: gravel, sand, silt, clay, and mud.
Qt	Terrace deposit: gravel, sand, silt, clay, and lateritic soil.
T	Interbedded claystone, sandstone, mudstone, diatomite, and shale with fossil leaves, stem, bone of fish and *Viviparus* sp.
J1	Sandstone, purplish brown, fine-grained, calcareous, interbedded with shale, reddish brown, limestone nodules; shale, gray, intercalated with sandstone, fine-grained; and conglomerate.
$\bar{T}R_7$	Shale and sandstone, gray to greenish gray; siltstone; mudstone; conglomerate; and limestone; with fossil *Halobia* sp., *Cassianella* sp., *Liostrea* sp., *Unionites* sp., and bivalves.
$\bar{T}R_6$	Limestone, gray, massive to bedded; shale and sandstone, gray to greenish gray; with *Costatoria* sp., and brachiopods.
$\bar{T}R_{hh}$	Silicified mudstone, gray to black, light brown to yellowish brown; intercalated with sandstone, light gray to dark gray, fine grained; tuffaceous sandstone, gray to browish gray, fine to medium grained, intercalated with shale, gray to dark gray; shale and siltstone, gray to greenish gray, with fossil *Halobia* sp., *Posidonia* sp.,and *Paratrachycerus* sp.
$\bar{T}R_{pk}$	Limestone, thin-bedded to massive, oolith, oncolith, fossiliferous; interbedded with shale, sandstone and mudstone, with fossils of *Daonella* sp., Crinoid stem, bivalves, coral, and algae.
$\bar{T}R_{pt}$	Interbedded black shale, tuff and sandstone; 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 fossil *Claraia* sp., *Costatoria* sp., and other bivalves.
P3	Interbedded black shale, gray sandstone, dark gray mudstone and gray limestone with chert nodules; intercalated with fossiliferous limestone and mudstone.
P2	Massive limestone, shale, calcareous shale and sandstone with fossil corals and crinoid stems.
$P\bar{T}R_V$	Volcanic rocks: rhyolite, andesite, flow and dike; agglomerate; volcanic conglomerate; rhyolitic tuff and andesitic tuff.

Figure 2.15 continued.

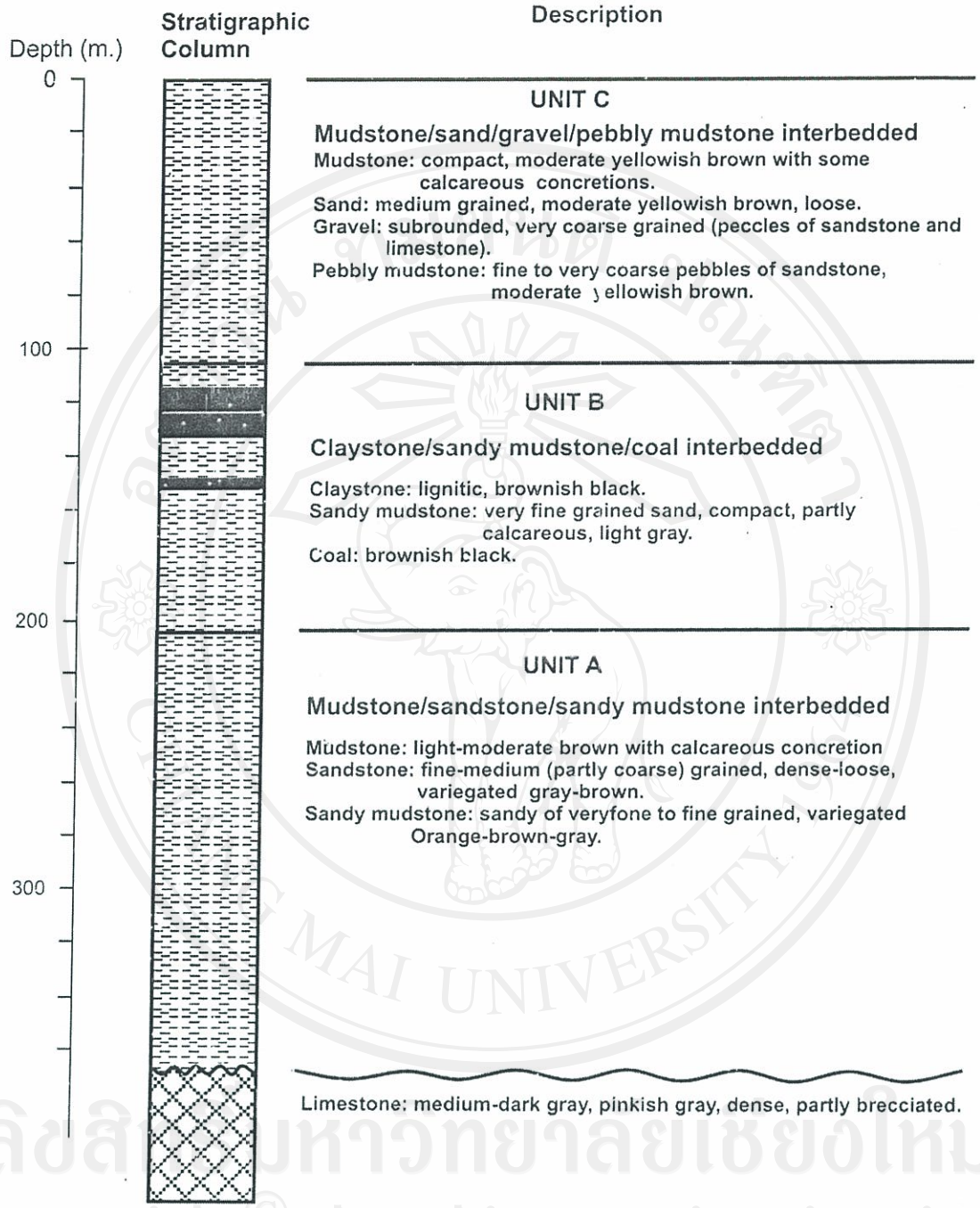


Figure 2.16 Stratigraphic column of Ngao coal field. (modified from Water Resource Engineer (Ltd.) company, 1998)

2.3.5. Wang Nua coal field

Wang Nua basin is in Wang Nua District, Lampang Province, in northern Thailand. The basin is approximately 100 kilometers north of Lampang Province and 730 kilometers north of Bangkok. This basin covers an area of 332 square kilometers at 19° 06' 16" north latitude and 99° 35' 47" east longitude. The Wang Nua basin has an elongate shape, trend north-south, and parallels flanking mountains. The coal quality is lignite A-B to sub-bituminous A-C (Department of Mineral Resources, 1989). The geological reserve is approximately 9 million ton.

2.3.5.1 Geologic setting of the Wang Nua basin

The rocks that flank the Wang Nua basin are sedimentary rocks and Metamorphic rocks of Silurian to Triassic and Cretaceous granite (Department of Mineral Resources, 1989). The Silurian-Devonian rocks are quartzite and schist that found in the west of the basin. The Carboniferous rocks are chert interbedded with mudstone and shale also found in the west of the basin. The limestone and shale of Permian is in the west and east of the basin. The Triassic rocks occur surrounding the basin especially in east and south of the basin, which consist of limestone, shale, and sandstone. The granite of Cretaceous found in east of the basin. The Tertiary rocks consist of conglomerate, sandstone, siltstone, mudstone, shale, and lignite. Quaternary fluvial deposits form a thin veneer cover throughout the basin (Figure 2.17).

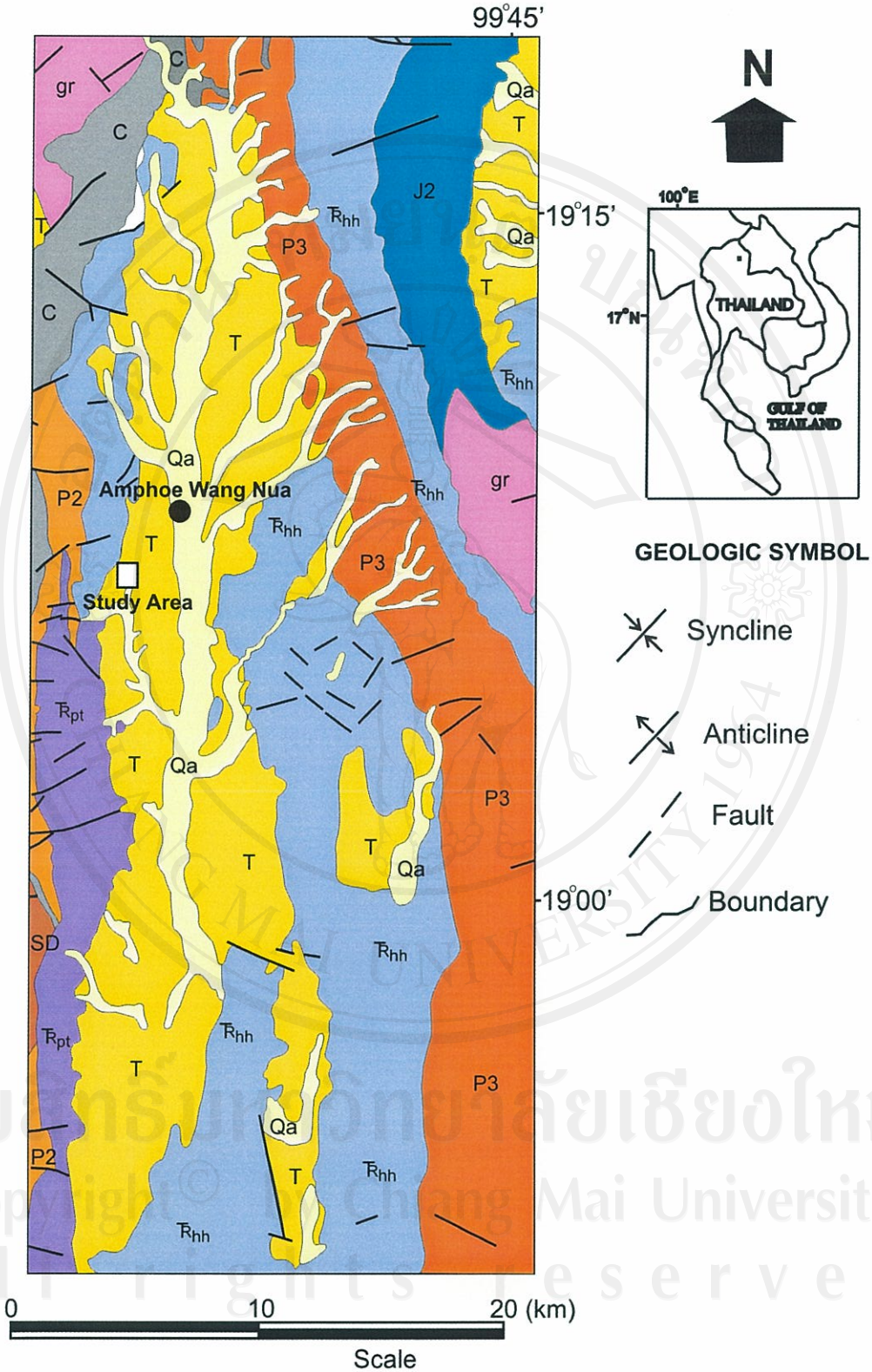


Figure 2.17 Geological map of the Wang Nua basin (modified from Baum and Hahn, 1977; Charoenprawat and others, 1994a, 1994b).

Explanation

Sedimentary Rocks

Qa	Alluvial deposits: gravel, sand, silt, mud, and clay. (Quaternary).
T	Interbedded claystone, sandstone, mudstone, diatomite, and shale, with fossil leaves, stems, fish bones, and *Vivipalus* sp., And several taxa of vertebrate animals.
J2	Sandstone, brown, interbedded with shale, reddish brown, micaceous, tuffaceous; conglomerate.
$\mathrm{T_{Rhh}}$	Silicified mudstone, gray to black, light brown to yellowish brown; intercalated with sandstone, light gray to dark gray, fine grained; tuffaceous sandstone, gray to browish gray, fine to medium grained, intercalated with shale, gray to dark gray; shale and siltstone, gray to greenish gray, with fossil *Halobia* sp., *Posidonia* sp.,and *Paratrachycerus* sp.
$\mathrm{T_{Rpt}}$	Interbedded black shale, tuff and sandstone; 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 fossil *Claraia* sp., *Costatoria* sp., and other bivalves.
P3	Interbedded black shale, gray sandstone, dark gray mudstone and gray limestone with chert nodules; intercalated with fossiliferous limestone and mudstone.
P2	Massive limestone, shale, calcareous shale and sandstone with fossil corals and crinoid stems.
C	Quartzitic and feldspatic sandstone; consisting of graywacke, arkosic, proto-quartzite and orthoquartzite; shale; white-light green to dark brown, medium to thick and well bedded with quartz veinlets.
SD	Phyllite, quartzite, quartzitic sandstone, quartzofeldspatic schist and schist.

Igneous Rocks

gr	Biotite granite, medium to coarse grained, porphyritic; muscovite granite, fine to medium grained; biotite-hornblende-adamellite granite, medium to coarse grained, equigranular to porphyritic and tourmaline muscovite granite, fine grained.

Figure 2.17 continued.

2.3.5.2 Wang Nua stratigraphic succession

Department of Mineral Resources (1989) had studied the geology and coal deposit in Wang Nua basin and divided the Tertiary clastic sequence of Wang Nua basin into 3 units (Figure 2.18).

Unit A is the lower part of the sequence. It consists mainly of gray and greenish gray color sandstone, siltstone, and muddy sandstone for coarse-grained sedimentary rocks. The fine-grained sedimentary rocks consist of reddish brown and purplish red color of sandy mudstone and mudstone. This unit is approximately 65 meters thick.

Unit B is the middle unit of the sequence. This unit consists mainly of gray, brown, and black color of mudstone, claystone, and coal. The coal occurred in the lower portion of the unit. This unit is approximately 40 meters thick. Fossil in this unit consists of leaf, fish bone, gastropod of *Bellamya* sp., *Margarya* sp., *Brotia* sp., and bivalve of *Hyriopsis* sp. and *Cuneopsis* sp. The name of gastropod and bivalve were identified by Dr. Hiroaki Ugai.

Unit C is the upper unit of Wang Nua sequence, which consists of yellowish brown, brownish red and grayish red color of mudstone, siltstone, sandstone, and conglomerate. This unit is underlying the semiconsolidated to unconsolidated sediments of Quaternary. Unit C is 13 meters thick.

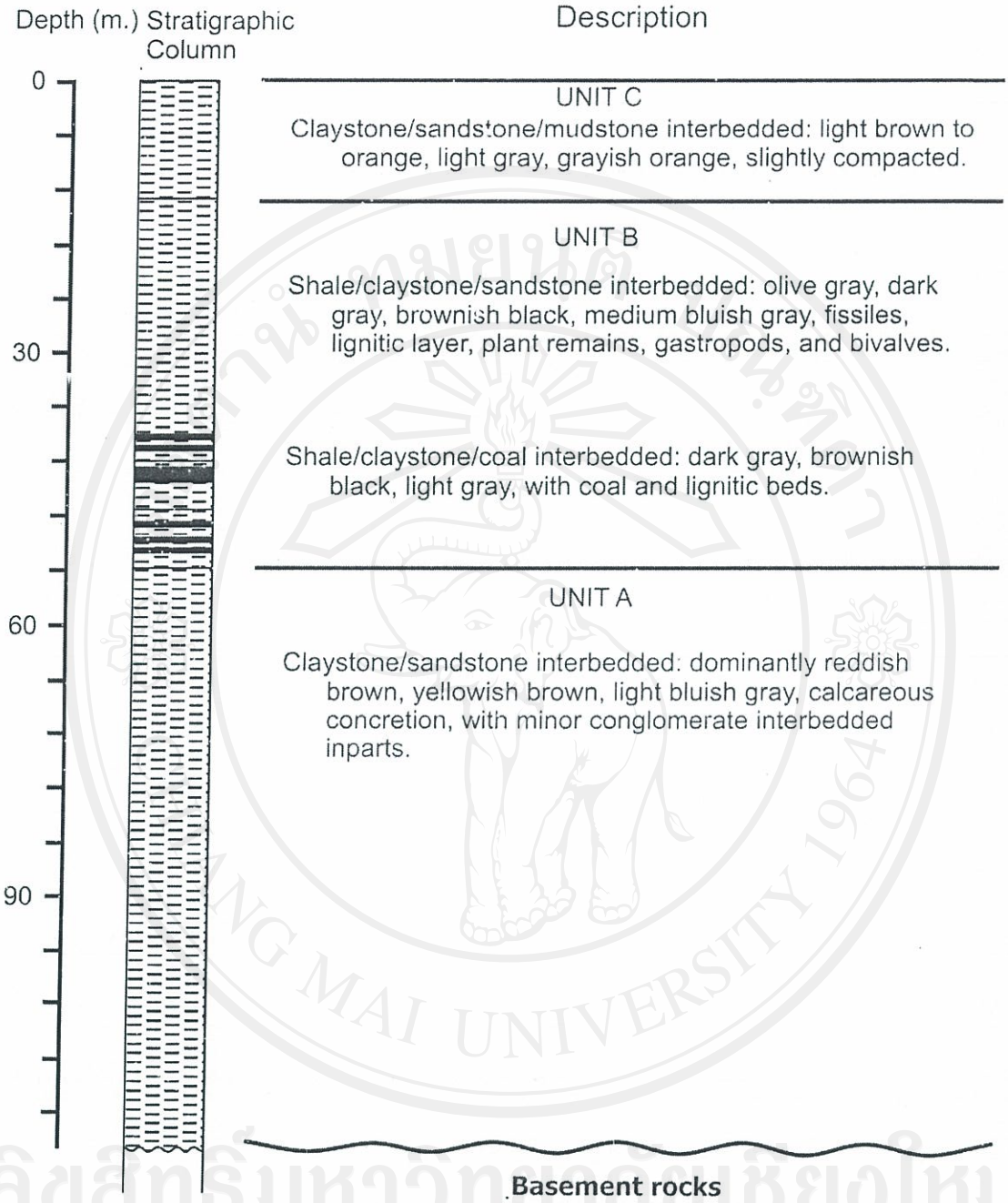


Figure 2.18 Stratigraphic column of Wang Nua coal field (modified from Department of Mineral Resources, 1989).