CHAPTER 5

RESULTS

This chapter describes the results of this research. It contains the results of each basin including the Li, Chiang Muan, Mae Moh, Mae Lamao, and Na Hong basins respectively. The descriptions mainly focus on the palynological facts with some previous work from other fields for stratigraphic correlation purpose.

5.1 LI BASIN

Fossil sporomorphs from the Li basin were recovered from two formations, the Ban Pa Kha Formation and Mae Long Formation. The Ban Pa Kha Formation is characterized by a warm temperate palynological assemblage but the Mae Long Formation is a tropical pollen-bearing formation. The Ban Pa Kha Formation is distributed in the eastern part of the basin and the Mae Long Formation is in the southern and western parts. The Ban Pa Kha Formation can be observed in the Ban Pa Kha coalfield as the type section, Ban Pu coalfield, and Na Klang coalfield. The Mae Long Formation is generally distributed in the southern and western parts of the basin like the Na Sai coalfield and Mae Long locality.

5.1.1 Ban Pa Kha coalfield

The type section of the Ban Pa Kha Formation is in Ban Pa Kha coalfield. Ninety-three samples were collected and yielded sporomorphs in different proportions across the stratigraphic succession (Table 5-1). The formation mainly contains warm temperate sporomorphs such as *Inaperturopollenites dubius*, *Pinuspollenites*, *Piceaepollenites*, *Tsugaepollenites igniculus*, *Alnipollenites verus*, *Momipites coryloides*, *Juglanspollenites*

Table 5-1 Sporomorph taxa appearance in percentage from samples collected from Ban Pa Kha Formation.

SAMPLE NO.	*Pinuspollenites*	*Piceaepollenites*	*Tsugaepollenites igniculus*	*Inaperturopollenites dubius*	*Alnipollenites verus*	*Faguspollenites*	*Juglanspollenites verus*	*Liquidambarpollenites stigmosus*	*Caryapollenites simplex*	*Laevigatosporites haarditii*	*Polypodiaceoisporites retirugatus*	*Momipites coryloides*	*Quercoidites*	*Ilexpollenites*	*Ulmipollenites*	*Polypodiisporites* spp.	*Salixipollenites*	*Closterium*	*Pediastrum*	*Actinastrum*	*Botryococcus*	*Scyphiphora*	*Pterocaryapollenites stellatus*	*Podocarpidites*	*Sporotrapoidites*	*Lagerstroemia*	*Alangiopollis*	*Striatriletes susannae*	*Perfotricolpites digitatus*	INDET	Total percent	Number of count	REMARKS
OU-26	0.4				0.8	0.8		0.8	0.1	64	0.1	0.1	0.1		0.1	5.3						11	0.1						0.1	16	100	718	
OU-25										59																				41	100	232	
OU-24																															0		
OU-23																															0		
OU-22																															0		
OU-21																															0		
OU-20																															0		
OU-19																															0		
OU-18																															0		
OU-17	7.6			0.5		8.1				21																				63	100	211	
OU-16																															0		
OU-15										5.5																		0.9		94	100	109	
OU-14																															0		
OU-13																															0		
OU-12																															0		
OU-11																															0		
OU-10																															0		
OU-9																															0		
OU-8																															0		
OU-7																															0		
OU-6																															0		
OU-5																															0		
OU-4																															0		
OU-3																															0		
OU-2	3.7	1.9																												94	100	54	

Table 5-1 Continue.

SAMPLE NO.	*Pinuspollenites*	*Piceaepollenites*	*Tsugaepollenites igniculus*	*Inaperturopollenites dubius*	*Alnipollenites verus*	*Faguspollenites*	*Juglanspollenites verus*	*Liquidambarpollenites stigmosus*	*Caryapollenites simplex*	*Laevigatosporites haardtii*	*Polypodiacoisporites retirugatus*	*Momipites coryloides*	*Quercoidites*	*Ilexpollenites*	*Ulmipollenites*	*Polypodiisporites spp.*	*Salixipollenites*	*Closterium*	*Pediastrum*	*Actinastrum*	*Botryococcus*	*Scyphiphora*	*Pterocaryapollenites stellatus*	*Podocarpidites*	*Sporotrapoidites*	*Lagerstroemia*	*Alangiopollis*	*Striatrietes susannae*	*Perfotricolpites digitatus*	INDET	Total percent	Number of count	REMARKS
OU-1			3.8		1.9		44			0.6						0.6														49	100	160	
OB-17																															0		
OB-16																															0		
OB-15																															0		
OB-14																															0		
OB-13						2.4										2.4														95	100	42	
OB-12												2.7														2.7	2.7			92	100	37	
OB-11																															0		
OB-10																															0		
OB-9																															0		
OB-8													7.7																		0		
OB-7	9.8	6.1	2.4							1.2	2.4		6.1			1.2														92	100	65	
OB-6																									4.2					71	100	82	
OB-5										3.7																				96	100	24	
OB-4																														96	100	27	
OB-3	5.1	2.6								2.6																					0		
OB-2																														90	100	39	
OB-1	5.8	0.2	2.5		5.3	11	0.2	1.5	0.2	5.7		0.2	2.3			21	9					31	0.3	0.2						0		
U-29																			60	30	10								4	100	600	
U-28																			80	15	5									100	*	
U-27																			80		20									100	*	
U-26																			95	3	2									100	*	
U-25																		20	80											100	*	
U-24																														100	*	
U-23																														0		
																														0		

Table 5-1 Continue.

SAMPLE NO.	*Pinuspollenites*	*Piceaepollenites*	*Tsugaepollenites igniculus*	*Inaperturopollenites dubius*	*Alnipollenites verus*	*Faguspollenites*	*Juglanspollenites verus*	*Liquidambarpollenites stigmosus*	*Caryapollenites simplex*	*Laevigatosporites haardtii*	*Polypodiaceoisporites retirugatus*	*Momipites coryloides*	*Quercoidites*	*Ilexpollenites*	*Ulmipollenites*	*Polypodiisporites* spp.	*Salixipollenites*	*Closterium*	*Pediastrum*	*Actinastrum*	*Botryococcus*	*Scyphiphora*	*Pterocaryapollenites stellatus*	*Podocarpidites*	*Sporotrapoidites*	*Lagerstroemia*	*Alangiopollis*	*Striatriletes susannae*	*Perfotricolpites digitatus*	INDET	Total percent	Number of count	REMARKS
U-22												6.3																		94	100	32	
U-21																															0		
U-20																															0		
U-19												4.3																		96	100	46	
U-18					0.7					0.3		67	1			1.7														29	100	288	
U-17	2.9											21		1.5		1.5														74	100	68	
U-16																															0		
U-15	3.7	0.2	0.6	0.2	2.9			0.2	0.2	2.9	4.3	59	7.8	4.7	0.2	3.1	0.2													10	100	487	
U-14	0.7	6.4	0.7	9	3				0.4	0.7	0.4	64	14			1.1															100	267	
U-13	1.3				62		0.2	0.6		0.6	0.4	14	12			0.6														8	100	535	
U-12	0.2		0.2		89			0.6	0.2	0.2	0.6	0.9	6		0.2															1.9	100	530	
U-11	5.7	0.6		0.3	75			0.3	0.3	2.6	1.7	1.4	3.2	0.3		2.3														6.6	100	349	
U-10																															0		
U-9																															0		
U-8					2.4							0.8	59																	38	100	125	
U-7	2.1	5.3	4.3	7.4	1.1					1.1	1.1	1.1				1.1														76	100	94	
U-6	38	0.4		6.9	30		0.2	0.8		2.9	0.2	3.3	6.9			6.9														3.1	100	518	
U-5																															0		
U-4																															0		
U-3	62	3.3	12	0.2	2.4		0.9	1.8	0.2	1.8		2	0.9	8.3	0.2	1.1														3.1	100	456	
U-2	1.8				50																									48	100	56	
U-1	2.9				2.9			2.9				2.9																		88	100	34	
IB-9	9.5				4.8							4.8																		81	100	21	
IB-8	9.1																													91	100	44	
IB-7	2.5																													98	100	40	

Table 5-1 Continue.

SAMPLE NO.	*Pinuspollenites*	*Piceaepollenites*	*Tsugaepollenites igniculus*	*Inaperturopollenites dubius*	*Alnipollenites verus*	*Faguspollenites*	*Juglanspollenites verus*	*Liquidambarpollenites stigmosus*	*Caryapollenites simplex*	*Laevigatosporites haarditi*	*Polypodiaceoisporites retirugatus*	*Momipites coryloides*	*Quercoidites*	*Ilexpollenites*	*Ulmipollenites*	*Polypodiisporites* spp.	*Salixipollenites*	*Closterium*	*Pediastrum*	*Actinastrum*	*Botryococcus*	*Scyphiphora*	*Pterocaryapollenites stellatus*	*Podocarpidites*	*Sporotrapoidites*	*Lagerstroemia*	*Alangiopollis*	*Striatriletes susannae*	*Perfotricolpites digitatus*	INDET	Total percent	Number of count	REMARKS
IB-6	8.7	0.9	0.9	0.9			0.9	3.7	0.5	3.7	0.9	6.4	0.9		0.5	0.5														71	100	219	
IB-5	3.6																													96	100	28	
IB-4	5.3																													95	100	19	
IB-3	3.6		3.6																											93	100	28	
IB-2	7.8			2				2				2																		86	100	51	
IB-1	56																													44	100	68	
LM-3	2.7		2.7		5.4																									89	100	37	
LM-2	62																													38	100	29	
LM-1	5.9		7.8		2																									84	100	51	
LS-9	38	0.5	3	7.8	1.9					3.8		13	2.4			8.9														21	100	372	
LS-8	11			6.5								3.2	1.6																	77	100	62	
LS-7	58				0.8			0.8	0.8	2.3	0.8																			37	100	128	
LS-6	4.3																													96	100	23	
LS-5	62		6.1	1			1																							30	100	98	
LS-4	52																													48	100	341	
LS-3	3.2			6.3	1.6	1.6																								87	100	63	
LS-2	8.7	5.1	5.1		20		0.7			8.7	1.4					1.4														49	100	277	
LS-1																															0		

Remark: Percentage occurrence of algae *Actinastrum*, *Botryococcus*, *Closterium*, and *Pediastrum* derived from estimation under the light microscope.

verus, *Liquidambarpollenites stigmosus*, *Ulmipollenites*, *Loniceraepollenites*, *Caryapollenites simplex*, *Quercoidites*, *Faguspollenites*, and *Ilexpollenites*. Various forms of fern spores are rare to common. There are abundant occurrences of the algae *Pediastrum* in the uppermost part of the upper coal seam. Changes in the vegetational pattern in this formation will be described zone by zone from the lower to the upper zones (Figure 5-1) as follows:

1. *Pinuspollenites* Zone: This zone covers the entire lower coal seam and a lower part of the interburden unit. *Pinuspollenites* dominates the zone up to 52 to 62 percent in some horizons. *Tsugaepollenites igniculus* and *Inaperturopollenites dubius* are common, though in some parts of the zone *Momipites coryloides* and *Alnipollenites verus* are also rare to common. There are rare to very rare occurrences of *Caryapollenites simplex*, *Juglanspollenites verus*, *Liquidambarpollenites stigmosus*, *Piceaepollenites*, *Quercoidites*, *Faguspollenites*, *Loniceraepollenites*, and some forms of monolete and trilete spores, *Laevigatosporites haardtii*, *Polypodiisporites* spp., and *Polypodiaceoisporites retirugatus*.

This zone mainly has coniferous pollen *Pinuspollenites*, *Tsugaepollenites igniculus*, and *Inaperturopollenites dubius*, together with rare occurrences of *Piceaepollenites*. The Taxodiaceae (*Inaperturopollenites dubius*) indicate swamp but the rest are dry terrain vegetational elements. It is probably understandable that the Taxodiaceae swamp was the depositional environment and *Pinuspollenites*, *Tsugaepollenites igniculus*, and *Piceaepollenites* were introduced as *ex situ* elements. The sedimentary sequence in this zone is an intercalation between tree trunk coal beds and sandy claystone layers representing a fluvial system with probable alternations of catastrophic events. The

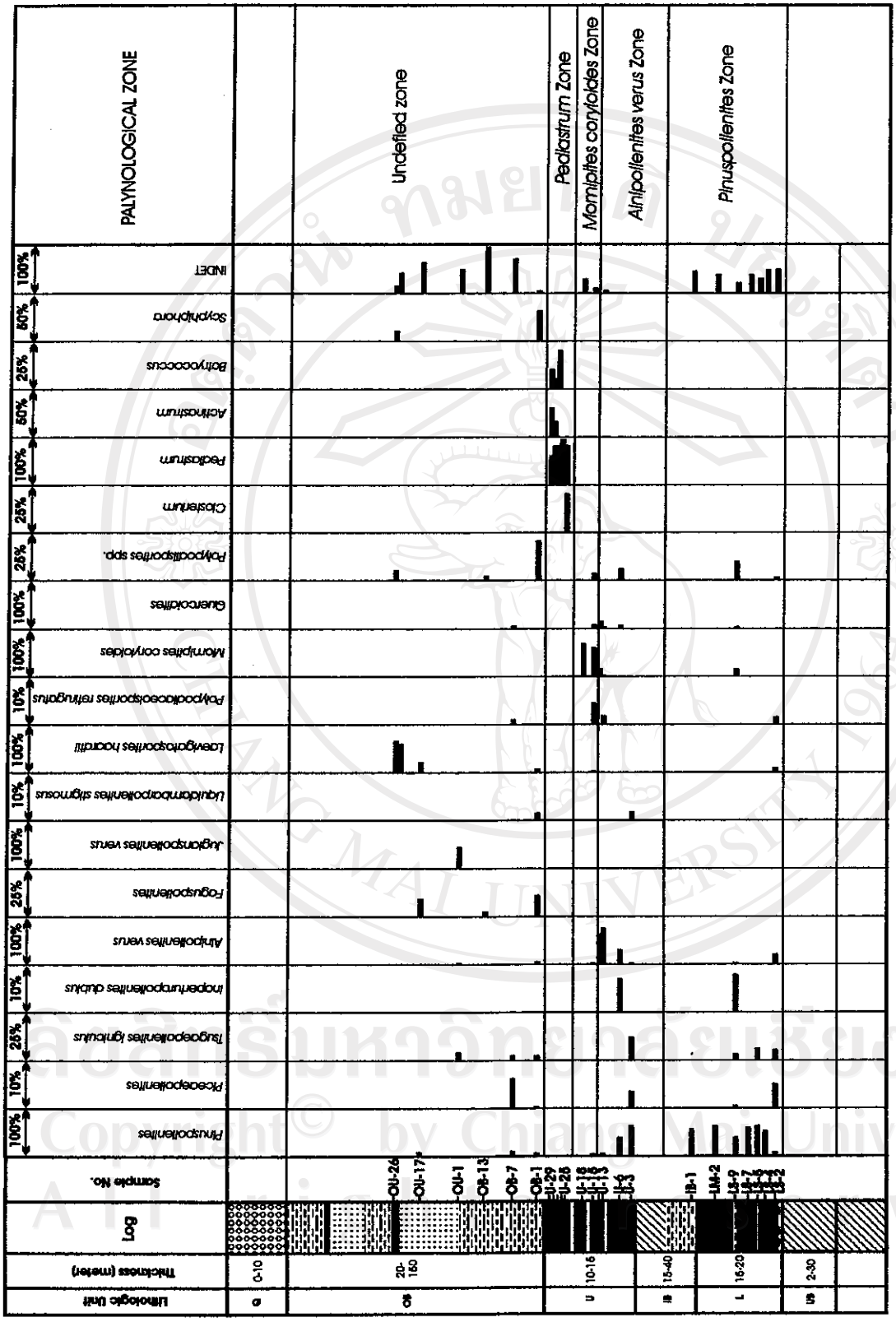

Figure 5-1 Pollen diagram showing plots of pollen occurrence in percentage against lithostratigraphic units and palynological zones of Ban Pa Kha coalfield.

climate during the deposition of this sequence was warm temperate and there were plant communities comparable to those in the temperate zone of the northern hemisphere today.

2. *Alnipollenites verus* Zone: This zone covers just the lowermost part of the upper coal zone (U-unit). *Alnipollenites verus* dominates the zone, being from 50 percent to 89 percent of the forms in some samples, and is well preserved and easy to recognize. Other common to very rare taxa include *Pinuspollenites*, *Momipites coryloides*, *Juglanspollenites verus*, *Inaperturopollenites dubius*, *Quercoidites*, *Tsugaepollenites igniculus*, *Liquidambarpollenites stigmosus*, *Caryapollenites simplex*, *Piceaepollenites*, and *Ulmipollenites*. Fern spores of *Polypodiisporites* spp., *Polypodiaceoisporites retirugatus*, and *Laevigatosporites haardtii* are also rare to very rare.

Coniferous taxa are much less prevalent in this zone. The occurrence of *Pinuspollenites* has declined dramatically from the 52-62 percent in the *Pinuspollenites* Zone. The taxon has 38 to 62 percent occurrence at the bottom of this zone and this occurrence decreases to less than 6 percent at the top of the zone. *Tsugaepollenites igniculus* decreases from 4.3 to 12 percent to be 0.2 to 0.7 percent at the top and *Piceaepollenites* is rare to very rare. The temperate taxa in the underlying *Pinuspollenites* Zone have been replaced by mesothermal taxa, such as *Ilexpollenites*, *Quercoidites*, and, particularly, by *Alnipollenites verus*. *Alnipollenites verus* suddenly increases from about less than 5 percent in the *Pinuspollenites* Zone to 50 percent and, in one sample (U-12), to nearly 90 percent in this zone. Lithologically, this zone is mainly coal with oil shale and claystone in the middle part. This zone is interpreted as lacustrine and swamp deposits with fluvial deposits in the middle part, and the climate was warm temperate.

3. *Momipites coryloides* Zone: This zone occurs in the middle part of the upper coal zone. *Momipites coryloides* dominates this zone, forming from 59 percent to 67 percent of the forms. This zone dominantly contains *Momipites coryloides* with sparse occurrence of pollen of which dominated in the previous zones.

The depositional environment of the *Momipites coryloides* Zone was a coal swamp that had a different plant community from that in the two underlying zones. The occurrence of *Alnipollenites verus* is greatly reduced, having been replaced by *Momipites coryloides*. *Momipites coryloides* dominates the pollen profile and *Quercoidites* pollen is common in the bottom of the zone. Conifer pollen is sparse. The climate was warmer and wetter than during deposition of the previous two zones.

4. *Pediastrum* Zone: The taxa in this zone are almost completely dominated by the freshwater green alga *Pediastrum*. The *Pediastrum* Zone covers the upper part of the upper coal zone. Several forms of *Pediastrum* occur. The *Pediastrum simplex* is more abundant than other forms. *Botryococcus*, another kind of freshwater green alga, is rare to common. Pollen and spores are very rare and most of them are enveloped by *Pediastrum* coenobia and are impossible to identify. The uppermost part of the zone is dominated by *Pediastrum* with different rare to common forms identifiable as freshwater green algae *Actinastrum* and *Closterium*. Occurrence of *Pediastrum*, *Botryococcus*, *Actinastrum*, and *Closterium* in this zone clearly suggests that deposition occurred in a lacustrine environment.

From the *Pediastrum* Zone onward, the samples are dominated by tricolporate and tricolpate pollen forms. Coniferous pollen has nearly disappeared. However, the warm temperate elements are still in very rare to common, like *Piceaepollenites*,

Pinuspollenites, *Podocarpidites*, *Tsugaepollenites igniculus*, *Alnipollenites verus*, *Faguspollenites*, *Quercoidites*, *Juglanspollenites verus*, *Momipites coryloides*, *Salixipollenites*, *Pterocaryapollenites stellatus*, and *Liquidambarpollenites stigmosus*. Eventhough, nearly all of the dominant constituents, are still not identified but few of them are recognizable as tropical to sub-tropical elements such as *Lagerstroemia*, *Perfotricolpites digitatus*, *Striatriletes susannae*, and cf. *Scyphiphora* with abundant *Laevigatosporites haardtii* and various fern spores in the uppermost thin coal layer. This palynological assemblage needs further identification to understand the true nature of the depositional environment in this zone. However, just using the identifiable sporomorphs, this zone is dominated by warm temperate elements with very rare tropical sporomorphs. The climate was probably becoming warmer and warmer with time.

The warm temperate palynological assemblages conform well with the works of Endo (1964, 1966) and Yabe (2002), who reported warm temperate macrofloras. Eventhough the macrofloral and palynofloral assemblages are not exactly the same, they do indicate the same paleophytogeography. This is discussed in more details in Chapter 6.

5.1.2 Na Sai coalfield and Mae Long locality

Na Sai coalfield was a small coal mine with only a thin sedimentary section that could be observed during the time of sampling. The samples are generally unproductive but most recoverable sporomorphs are tropical elements and usually more than 50 percents are indeterminant forms (Table 5-2, Figure 5-2). The pollen composition include rare to common *Striatricolpites catatumbus*, *Lagerstroemia*, *Calophyllum*, *Dipterocarpaceae*, and *Abelmoschus*. These tropical sporomorphs conform well to

Figure 5-2 Sporomorph taxa appearance in percentage from samples collected from Na Sai coalfield.

SAMPLE NO.	*Striatricolpites catatumbus*	*Laevigatosporites haardtii*	*Polypodiisporites spp.*	*Polypodiaceoisporites retirugatus*	*Pinuspollenites*	*Abelmoschus*	*Calophyllum*	Dipterocarpaceae	*Lagerstroemia*	*Botryococcus*	*Pediastrum*	INDET-6	INDET-8	INDET-9	INDET-11	Other INDET	Total percentage	Number of count	REMARKS
NS-12		27							12							62	100	26	
NS-11	4.8	16	3.7	0.5	9.6				2.7							63	100	187	
NS-10									18							82	100	44	
NS-9	4.5	26	14	0.5	1				3.5							52	100	200	
NS-8					12				4.9							83	100	41	
NS-7																	0		
NS-6																	0		
NS-5	1	8.4	5.9	2.4	4.2		2.4		6.3	2.1			4.2			63	100	287	
NS-4							2.3		5.5	1.6	2.3	0.8	1.6			86	100	128	
NS-3		19	13	6.3					4.8					4.8	3.2	49	100	63	
NS-2	3.3	5.6	8.4	0.9	7	3.7	9.8	2.8	10	15	0.9	0.5	1.4	2.8		22	94	215	
NS-1	18	28	26	4.1								4.1	4.1	4.9		11	100	122	

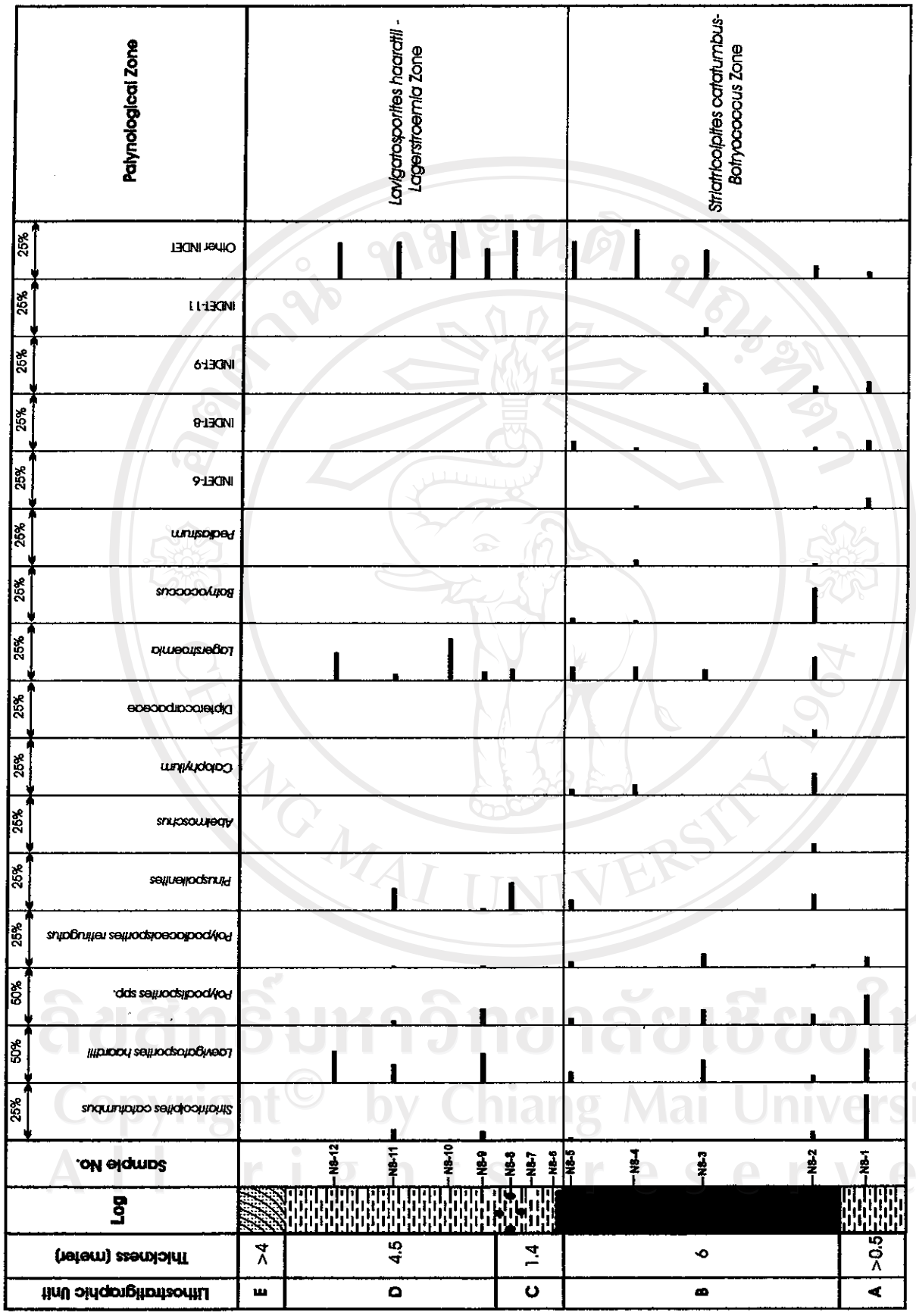

Figure 5-2 Pollen diagram showing plots of pollen occurrence in percentage against lithostratigraphic units and palynological zones of Na Sai coalfield.

records of various kinds of tropical fauna from the same locality. Rare to common occurrences of *Botryococcus* and *Pediastrum* strongly suggest that the depositional environment was lacustrine.

There are many records of tropical faunas from sediments around the spillway of Mae Long Reservoir. But the reservoir has been flooded all year round even during the summer and it was impossible to collect samples. Another locality occurs further beyond the reservoir, about one kilometer away. A Tertiary outcrop in an intermittent stream exposes both claystone and coal and a diatomite layer. Eventhough the samples are generally unproductive but some sporomorphs were recovered. Most of them are not known warm temperate pollen types and a form is identifiable as *Homonoia*, a tropical pollen. This form of *Homonoia* is quite similar to the extant pollen of *Homonoia riparia*, a common taxon growing well along the streams in tropical areas and also in northern Thailand today.

The occurrences of tropical sporomorphs in Na Sai coalfield and Mae Long confirm that the Mae Long Formation is a tropical formation as previously recognized by its faunal assemblage. The age of Na Sai and Mae Long is late Early Miocene on the basis of vertebrate remains including *Antemus thailandicus*, *Spanocricetodon khani*, *Kanisamus benjavuni*, and *Diatomys liensis* (Mein and others, 1990; Cheneval and others, 1991; Tassy and others, 1992).

5.2 CHIANG MUAN BASIN

Eighty-two samples were collected from Chiang Muan basin. The palynological assemblages indicate with a high degree of confidence that they are tropical elements

(Table 5-3). On the basis of palynological assemblages, the stratigraphic sequence is classifiable into three palynological zones namely, *Closterium* Zone, *Crassoretitriletes vanraadshoovenii* Zone, and *Actinastrum* Zone (Figure 5-3) as follows:

1. *Closterium* Zone: This zone covers the whole part of the lower coal zone. The zone is dominated by alga *Closterium*. *Botryococcus* is also common with rare *Striatriletes susannae*. *Closterium* and *Botryococcus* are freshwater algae and *Striatriletes susannae* is a freshwater fern. The occurrence of these three aquatic elements suggests that deposition occurred in a freshwater environment. The palynological assemblage of the zone includes *Calophyllum*, *Combretum*, *Florschuetzia*, *Homonoia*, *Ilexpollenites*, and *Striatriletes susannae* as persistent elements suggesting that the climate during deposition was tropical.

2. *Crassoretitriletes vanraadshoovenii* Zone: This zone covers the upper coal zone including U-1, U-2, and IB-1 units. *Crassoretitriletes vanraadshoovenii* dominates the zone with *Calophyllum*, *Combretum*, *Homonoia*, *Hopea*, *Ilexpollenites*, with common to abundant *Laevigatosporites haardtii* spores. The spores of *Crassoretitriletes vanraadshoovenii* is from *Lygodium microphyllum*. *Lygodium* is a climbing fern growing in tropical to subtropical areas particularly in the tropical monsoon regions. However, the pollen composition suggests a pure tropical climate according to the occurrence of *Hopea*, a genus of the big tropical tree family, Dipterocarpaceae.

3. *Actinastrum* Zone: This zone covers the whole sequence of the overburden unit. It is completely composed of the freshwater algae *Actinastrum*. Pollen and spores are absent but some indeterminant fungal spores are present. This zone is interpretable as

Table 5-3 Sporomorph taxa appearance in percentage from samples collected from Chiang Muan coalfield.

SAMPLE NO.	*Striatriletes susannae*	*Closterium*	*Botryococcus*	*Laevigatosporites haardtii*	*Homonoia*	*Calophyllum*	*Ilexpollenites*	*Hopea*	*Florschuetzia*	*Combretum*	*Crassoretitriletes vanraadshooveniI*	*Actinastrum*	INDET-22	INDET-27	INDET-31	Other INDET	Total percentage	Number of count	REMARKS
CM-69												100					100	200	
CM-68																	0		
CM-67																	0		
CM-66												100					100	200	
CM-65												100					100	200	
CM-64												100					100	200	
CM-63												100					100	200	
CM-62																	0		
CM-61																	0		
CM-60												100					100	200	
CM-59																	0		
CM-58																	0		
CM-57																	0		
CM-56																	0		
CM-55																	0		
CM-54																	0		
CM-53																	0		
CM-52																	0		
CM-51																	0		
CM-50																	0		
CM-49												100					100	200	
CM-48																	0		
CM-47												100					100	200	
CM-46																	0		
CM-45																	0		
CM-44																	0		
CM-43																	0		
CM-42												100					100	200	
CM-41												100					100	200	
CM-40																	0		
CM-39												100					100	200	
CM-38												100					100	200	
CM-37												100					100	200	
CM-36																	0		
CM-35																	0		
CM-34																	0		
CM-33																	0		
CM-32																	0		
CM-31												100					100	200	
CM-30																	0		
CM-29																	0		
CM-28																	0		
CM-27																	0		
CM-26																	0		
CM-25												100					100	200	
CM-24																	0		
CM-23																	0		
CM-22																	0		

Table 5-3 Continue.

SAMPLE NO.	*Striatriletes susannae*	*Closterium*	*Botryococcus*	*Laevigatosporites haardtii*	*Homonoia*	*Caliophyllum*	*Ilexpollenites*	*Hopea*	*Florschuetzia*	*Combretum*	*Crassoretitriletes vanraadshooveniI*	*Actinastrum*	INDET-22	INDET-27	INDET-31	Other INDET	Total percentage	Number of count	REMARKS
CM-21												100					100	200	
CM-20																	0		
CM-19																	0		
CM-18																	0		
CM-17												100					100	200	
U1-6-B1											100						100	200	
U1-5-B1																	0		
U1-4-B1					5.4						20					75	100	56	
U1-3-B1																	0		
U1-2-B1																	0		
U1-1-B1																	0		
IB-3																	0		
IB-2																	0		
IB-1																	0		
U2-9				100													100	200	
U2-8						7.3				4.9						88	100	41	
U2-7																	0		
U2-6																	0		
U2-5																	0		
U2-4				23												77	100	125	
U2-3																	0		
U2-2							15	10			9		2.6		1.3	62	100	78	
U2-1																	0		
LM-B-1																	0		
LM-A-6				57			8.9		1.8							32	100	56	
LM-A-5																	0		
LM-A-4			6.3				17							23		54	100	48	
LM-A-3			7.5	16	0.5	2.5								14		61	100	200	
LM-A-2																	0		
LM-A-1		100															100	200	
LS-B-4																	0		
LS-B-3																	0		
LS-B-2																	0		
LS-B-1	8.3															92	100	36	

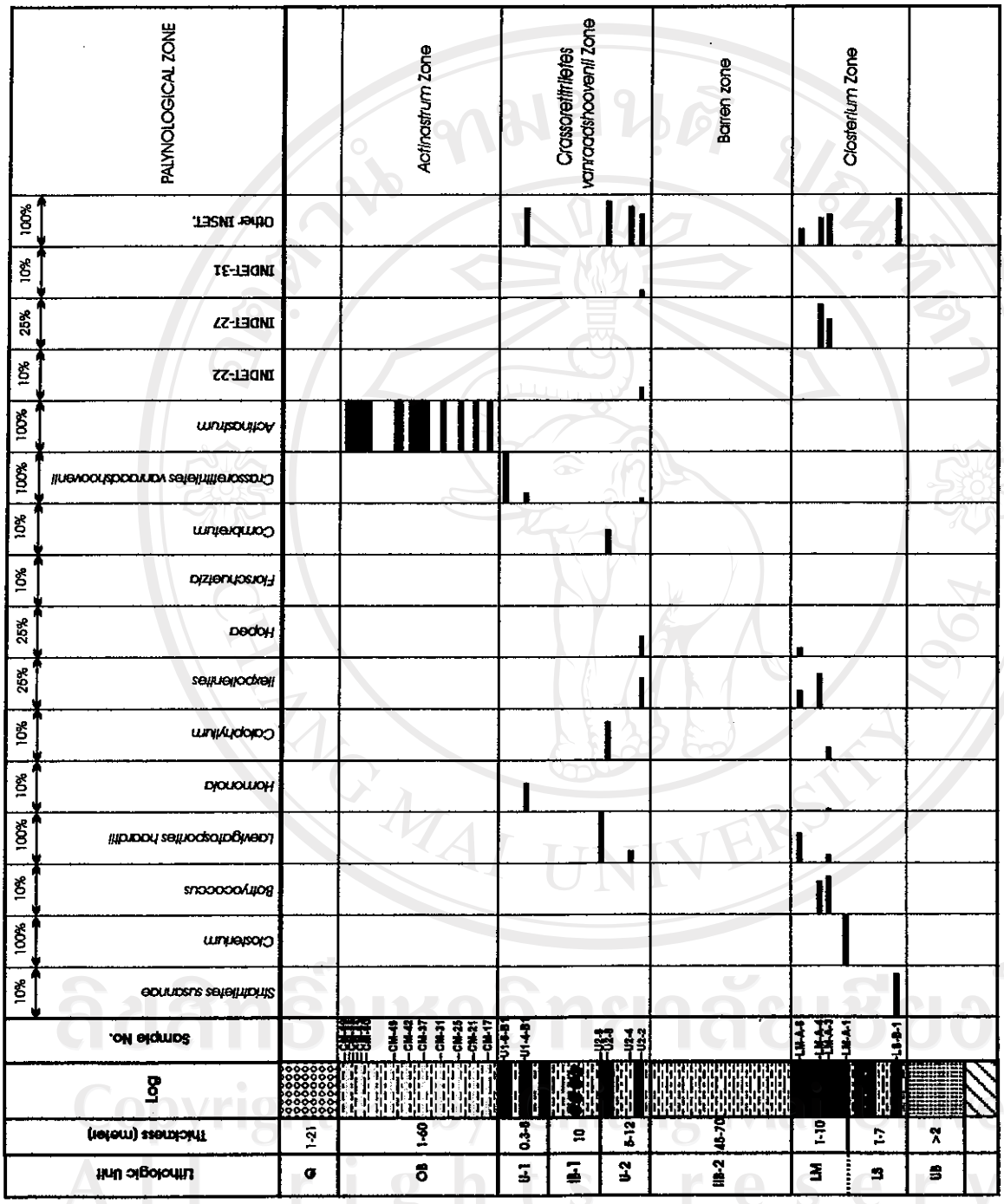

Figure 5-3 Pollen diagram showing plots of pollen occurrence in percentage against lithostratigraphic units and palynological zones of Chiang Muan coalfield.

evidence of an ancient freshwater lake. The abundant occurrence of freshwater algae probably resulted from algal bloom events during sedimentation of this zone.

The three palynological zones of the Chiang Muan Formation persistently suggested that the climate during sedimentation was tropical. The forests around Chiang Muan basin during basin formation were tropical rainforests. The age of the sedimentary sequence is between 13.5 and 10 million years derived from paleomagnetic studies (Suganuma and others, 2002; Chaimanee and others, 2003; Benammi and others, 2003).

5.3 MAE MOH BASIN

The samples from Mae Moh coalfield were collected from outcrops in the coal pit. Eventhough the sedimentary sequence of the basin is remarkably thick it is exposed just from the Q lignite zone onward because the sequence from the Q lignite zone downward is not excavated for coal. Thus, this palynological study did not cover the entire sequence or represents the whole period of deposition. However, a palynological research reported by Watanasak (1988) is added to complete the sequence (Figure 5-4; Table 5-4). This combination provides a good picture of the changes in pollen composition across the whole stratigraphic sequence.

Watanasak (1988) began sampling at the base of the Na Khaem Formation. The formation starts with the occurrence of warm temperate pollen assemblages and gradually changes upward to more tropical ones. This suggests that the underlying Huai King Formation is also a warm temperate pollen-bearing zone.

The samples from the Q lignite, K lignite, J lignite, and I lignite zones were successively collected but just few samples of them were productive in sporomorphs.

Table 5-4 Sporomorph taxa appearance in percentage from samples collected from Mae Moh coalfield.

SAMPLE NO.	*Pinuspollenites*	*Cyperaceaepollenites*	*Lagerstroemia*	*Quercoidites*	*Laevigatosporites haarditi*	*Polypodiaceoisporites retirugatus*	*Homonoia*	*Ilexpollenites*	*Polypodiisporites* spp.	*Calophyllum*	Dipterocarpaceae	*Spondias*	*Closterium*	INDET-57	Other INDET	Total percentage	Number of count	REMARKS
Im-20																0		
Im-19																0		
Im-18																0		
Im-17																0		
Im-16																0		
Im-15																0		
Im-14																0		
Im-13																0		
Im-12																0		
Im-11																0		
Im-10																0		
Im-9																0		
Im-8																0		
Im-7																0		
Im-6																0		
Im-5																0		
Im-4																0		
Im-3																0		
Im-2														100		100	200	
Im-1																0		
Jm-14																0		
Jm-13																0		
Jm-12																0		
Jm-11																0		
Jm-10																0		
Jm-9																0		
Jm-8																0		
Jm-7																0		
Jm-6																0		
Jm-5													100			100	200	
Jm-4																0		
Jm-3																0		
Jm-2					100											100	200	
Jm-1																0		
Km-11																0		
Km-10																0		
Km-9																0		
Km-8																0		
Km-7	1.1		3.4		18		8	6.9	4.6			2.3			55	100	87	
Km-6					100											100	200	
Km-5																0		
Km-4	2.7	13	2	6.1	7.5	2			18	3.4	2.7				43	100	147	
Km-3																0		
Km-2																0		
Km-1																0		
IB-5																0		
IB-4																0		
IB-3																0		
IB-2																0		

Table 5-4 Continue.

SAMPLE NO.	*Pinuspollenites*	*Cyperaceaepollenites*	*Lagerstroemia*	*Quercoidites*	*Laevigatosporites haardtii*	*Polypodiaceolsporites retirugatus*	*Homonoia*	*Ilexpollenites*	*Polypodiisporites* spp.	*Calophyllum*	*Dipterocarpaceae*	*Spondias*	*Closterium*	INDET-57	Other INDET	Total percentage	Number of count	REMARKS
IB-1																0		
Qm-9	4.7	10	14		6.2			3.9		0.8					60	100	129	
Qm-8																0		
Qm-7																0		
Qm-6																0		
Qm-5			3.4	19		2.1	1.4	10	7.6						56	100	145	
Qm-4																0		
Qm-3																0		
Qm-2	3.6	15	1.8	11	4.1	0.6									63	100	169	
Qm-1																0		
UB-1																0		

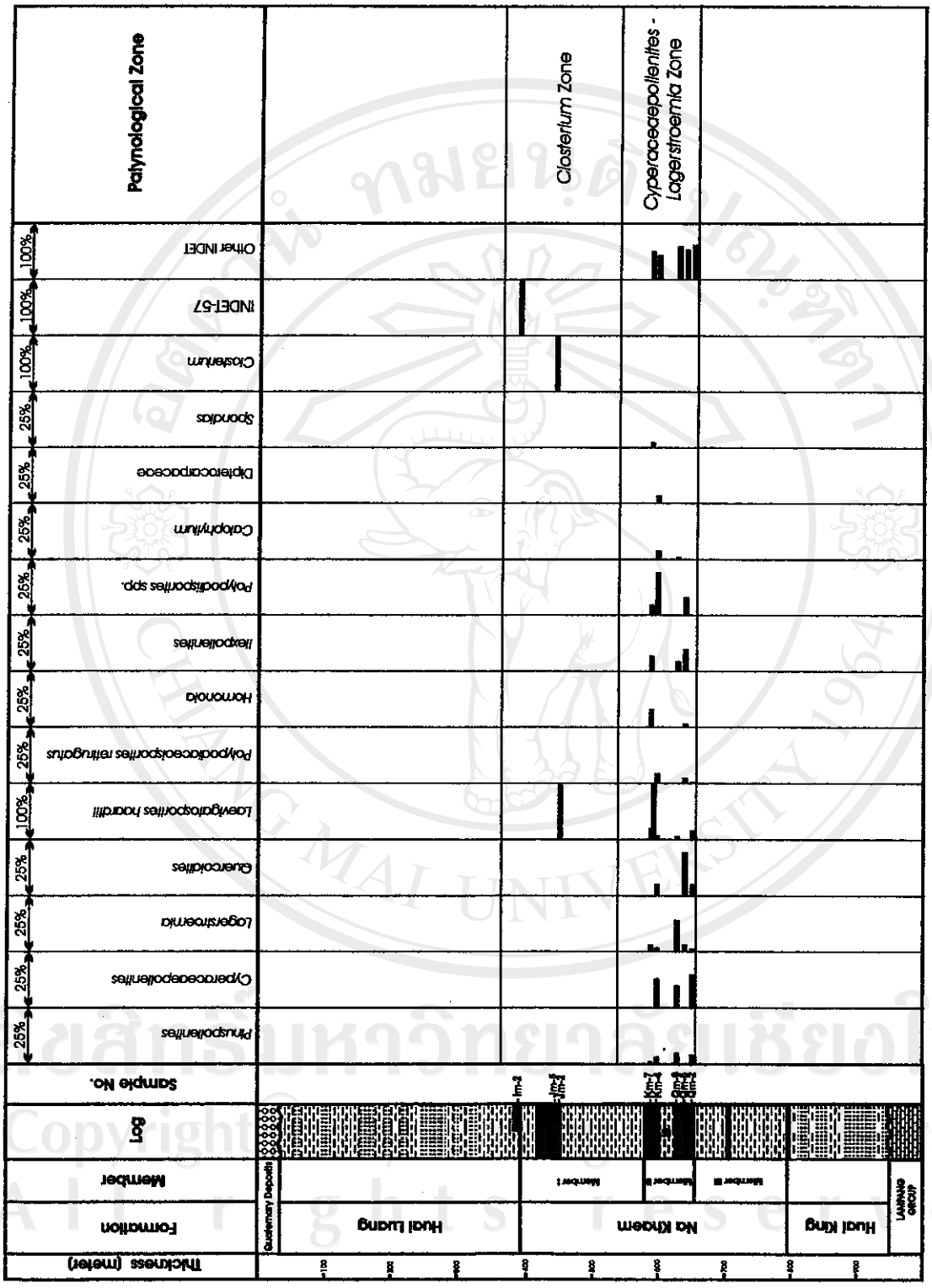

Figure 5-4 Pollen diagram showing pollen occurrence in percentage against lithostratigraphic units and palynological zones of Mae Moh coalfield.

Some samples yielded abundant but low diversified fern and fungal spores probably representing local *in situ* deposits, including some samples from every coal zone. Generally, tropical sporomorphs dominated the zones with some sporadic occurrences of warm temperate elements.

The Q lignite zone is dominated by *Cyperaceaepollenites* and fern spores with rare to common *Calophyllum*, *Homonoia*, *Lagerstroemia*, *Quercoidites*, *Ilexpollenites*, and *Pinuspollenites*. The common occurrence of *Cyperaceaepollenites* (*Cyperus*-type) strongly suggests that the sedimentation of this zone occurred in a freshwater swamp environment. The climate during deposition was tropical but the basin was probably surrounded by high mountain ranges on which mountainous vegetation produced some pollen like *Quercoidites* and *Pinuspollenites*, the same as is typically characteristic of the present forest types in northern Thailand.

The K lignite zone is dominated by fern spores of *Laevigatosporites haardtii*. The palynological assemblage in this zone is not much different from the Q lignite zone but the tropical sporomorphs were prominent. Occurrence of *Cyperaceaepollenites* is common in one sample (Km-4). The composition includes rare *Lagerstroemia*, *Hopea* or *Shorea* (dipterocarpaceous pollen), *Ilexpollenites*, *Calophyllum*, *Quercoidites*, *Spondias*, and *Pinuspollenites*. The common occurrence of *Cyperaceaepollenites* suggests that the sedimentation of this zone occurred in a freshwater environment under a tropical climate.

The J lignite and I lignite zones, unfortunately, lack significant identifiable sporomorphs. There are, however, some samples yielding abundant fern spores in both J and I coal zones. The absence of significant sporomorphs is probably a result of the nature of the sediments or the process of sample treatment or both. However, a sample

(Jm-5) yielded abundantly *Closterium*, a freshwater green alga, suggesting deposition occurred in a freshwater swamp environment.

The results of this study and previous work by Watanasak (1988) show that the pollen assemblages change from warm temperate to tropical upwards. The warm temperate part, the lowermost part of the Na Khaem Formation, is considered Oligocene to Early Miocene in age (Watanasak, 1988) relatable to the ages of the Ban Pa Kha, Mae Lamao, and Na Hong sediments. The overlying tropical part, including R, Q, K, J, and I coal zones, is younger than the warm temperate part. It is Early to Middle Miocene in age. The ages of 12.5 and 12.8 million years were proposed for K1, K2, and J5 coal zones, on the basis of magnetostratigraphy (Benammi and others, 2002).

5.4 MAE LAMAO BASIN

During the period of time available to collect samples used in this research the coal mine pit had been abandoned and flooded with water. Only a short sedimentary sequence in the upper portion was studied. It was approximately 20 meters thick (Table 5-5; Figure 5-5). Three palynological zones were classified namely, *Pinuspollenites* Zone, *Alnipollenites verus* Zone, and *Closterium* Zone from the bottom to the top.

1. *Pinuspollenites* Zone: The zone covers unit A, about 10 meters thick. *Pinuspollenites* dominates the zone in common comprising common *Alnipollenites verus*, rare *Faguspollenites*, rare to common *Liquidambarpollenites stigmosus*, common *Quercoidites*, and rare *Sporotrapoidites*. There are also some rare fern spores of *Laevigatosporites haardtii*, *Polypodiaceoisporites retirugatus*, and *Polypodiisporites* spp. The pollen composition belongs to a warm temperate plant community. The occurrence

Table 5-5 Sporomorph taxa appearance in percentage from samples collected from Mae Lamao coalfield.

SAMPLE NO.	*Pinuspollenites*	*Quercoidites*	*Sporotrapoidites*	*Alnipollenites verus*	*Liquidambarpollenites stigmosus*	*Polypodiaceoisporites retirugatus*	*Polypodiisporites* spp.	*Faguspollenites*	*Laevigatosporites haardtii*	*Actinastrum*	*Closterium*	Other INDET	Total percentage	Number of count	REMARKS
MLM-1-15													0	67	
MLM-1-14													0		
MLM-1-13											100		100	200	
MLM-1-12													0		
MLM-1-11										100			100	200	
MLM-1-10										100			100	200	
MLM-1-9											100		100	200	
MLM-1-8										100			100	200	
MLM-1-7										100			100	200	
MLM-1-6	7	21			3.5							68	100	57	
MLM-1-5											100		100	200	
MLM-1-4													0		
MLM-1-3													0		
MLM-1-2													0		
MLM-1-1													0		
MLM-2-5	1	5.1		9.2					26			59	100	98	
MLM-2-4	7.1			20					26			47	100	70	
MLM-2-3	2.1			38								60	100	94	
MLM-2-2	11	3.9		24								62	100	76	
MLM-2-1													0		
MLM-4-11													0		
MLM-4-10		24		16	3.4			5.6	5.6			46	100	89	
MLM-4-9													0		
MLM-4-8													0		
MLM-4-7													0		
MLM-4-6	9.6			30	5.6	2.4	8.8					44	100	125	
MLM-4-5													0		
MLM-4-4													0		
MLM-4-3		24		14								63	100	59	
MLM-4-2			1.8									98	100	56	
MLM-4-1	19	8.1										73	100	62	

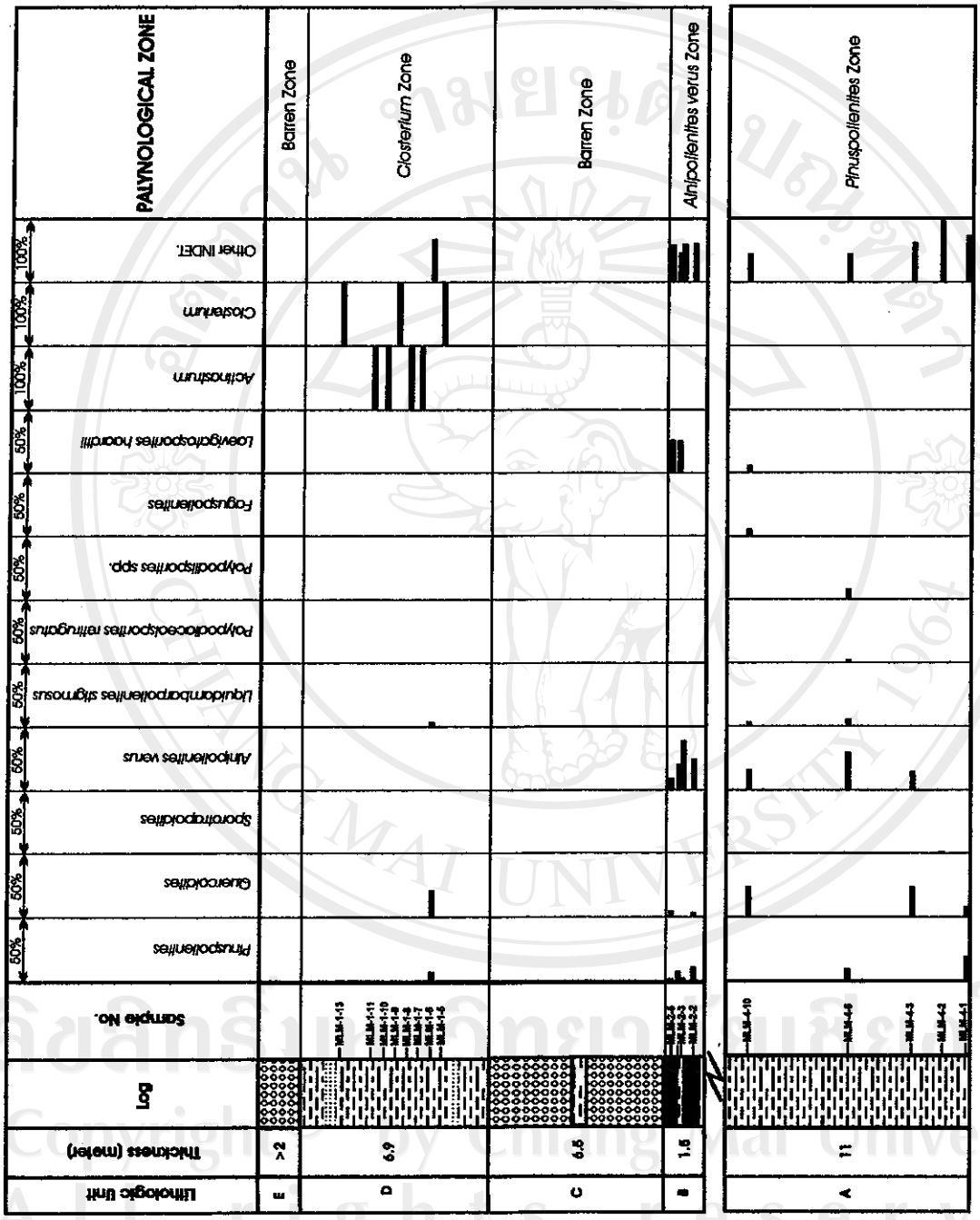

Figure 5-5 Pollen diagram showing plots of pollen occurrence against lithostratigraphic units and palynological zones of Mae Lamao coalfield.

of *Sporotrapoidites* suggests that sedimentation occurred in a freshwater depositional environment.

2. *Alnipollenites verus* Zone: The zone covers unit B, about 1.5 meters thick. It is dominated by 9 to 36 percents *Alnipollenites verus* with rare to common *Pinuspollenites*. *Quercoidites* becomes rare and *Laevigatosporites haardtii* spores are common. The pollen composition is still dominated by warm temperate elements.

3. *Closterium* Zone: This zone covers unit D, the uppermost unit in this study, about 7 meters thick. It contains mostly algae *Closterium* and *Actinastrum* in many samples. One sample contains common *Quercoidites* with rare *Pinuspollenites*, and *Liquidambarpollenites stigmosus*. Despite, the zone yielded somewhat low diversification in taxa, they are warm temperate pollen. The occurrence of *Closterium* and *Actinastrum* strongly suggests that freshwater is the depositional environment.

The Mae Lamao basin formed in a freshwater lake under a warm temperate climate during Oligocene to Early Miocene comparing well with the pollen assemblage of the overburden unit of Ban Pa Kha coalfield. However, there is no evidence to assign the precise age of the formation. Mae Lamao is the same as other warm temperate basins in having no record of vertebrate remains. Remarkably, Mae Lamao coal has high sulfur content but main coal seam was being investigated by drilling during sample collecting.

5.5 NA HONG BASIN

Twenty-one samples were collected from the Na Hong coalfield. The samples yielded warm temperate pollen (Table 5-6). Stratigraphic succession of the Na Hong coalfield is classified into three palynological zones, *Sporotrapoidites* Zone, *Pediastrum-*

Table 5-6 Sporomorph taxa appearance in percentage from samples collected from Na Hong coalfield.

SAMPLE NO.	*Sporotrapoidites*	*Pediastrum*	*Botryococcus*	*Pinuspollenites*	*Liquidambarpollenites stigmosus*	*Laevigatosporites haardtii*	*Tsugaepollenites igniculus*	*Polypodiisporites* spp.	*Momipites coryloides*	*Retitrecolpites*	*Cupuliferoipollenites pusillus*	*Inaperturopollenites dubius*	*Caryapollenites simplex*	*Juglanspollenites verus*	*Alnipollenites verus*	*Ilexpollenites*	*Piceaepollenites*	*Polypodiaceoisporites retirugatus*	*Gemmetricolporites*	*Sapotaceaepollenites*	*Foveotrietes*	*Rhoipites retiformis*	*Pterocaryapollenites stellatus*	Other trilete spores	Total percentage	Number of count	REMARKS
NH-21				3.1	1.8	1.3			5.8			55			32		0.4	0.4							100	226	
NH-20																									0		
NH-19		R		2.4	0.2	2.1	2		6.9	41	0.5	27	0.2	0.7	10	4.5	1	0.7	0.5	0.2	0.2				100	421	
NH-18																									0		
NH-17																									0		
NH-16																									0		
NH-15																									0		
NH-14		C		6.5	16	26	3.5	1	7.5			25		1	7		5	1							100	200	
NH-13		A		14	16	15	10	4	6.5			7.5		0.5	19	1	6	0.5							100	200	
NH-12																									0		
NH-11				23	17	6	16	6	5						22		4		0.5						100	200	
NH-10	1	C		39	14	3.4	5.8	2.9	3.9			0.5			19	0.5	9.2	0.5							100	207	
NH-9		A		17	15	1.5		1	1.5			1.5	0.5	3.5	48	3	6.5				0.5	0.5			100	199	
NH-8																									0		
NH-7	3.5	A		21	5.5	4.5	3		5			3		0.5	51	0.5	1.5	0.5							100	200	
NH-6																									0		
NH-5		C																							0		
NH-4	0.5	C		21	0.5	15	5.7	10	1.9	0.5		5.2		1.4	28	1	4.8						1	3.3	100	210	
NH-3																											
NH-2		R																							0		
NH-1	92	R		3	2	0.5	1.2	0.5	0.5																100	401	

Remarks: A = abundant, C = common, R = rare occurrence (estimated under the light microscope).

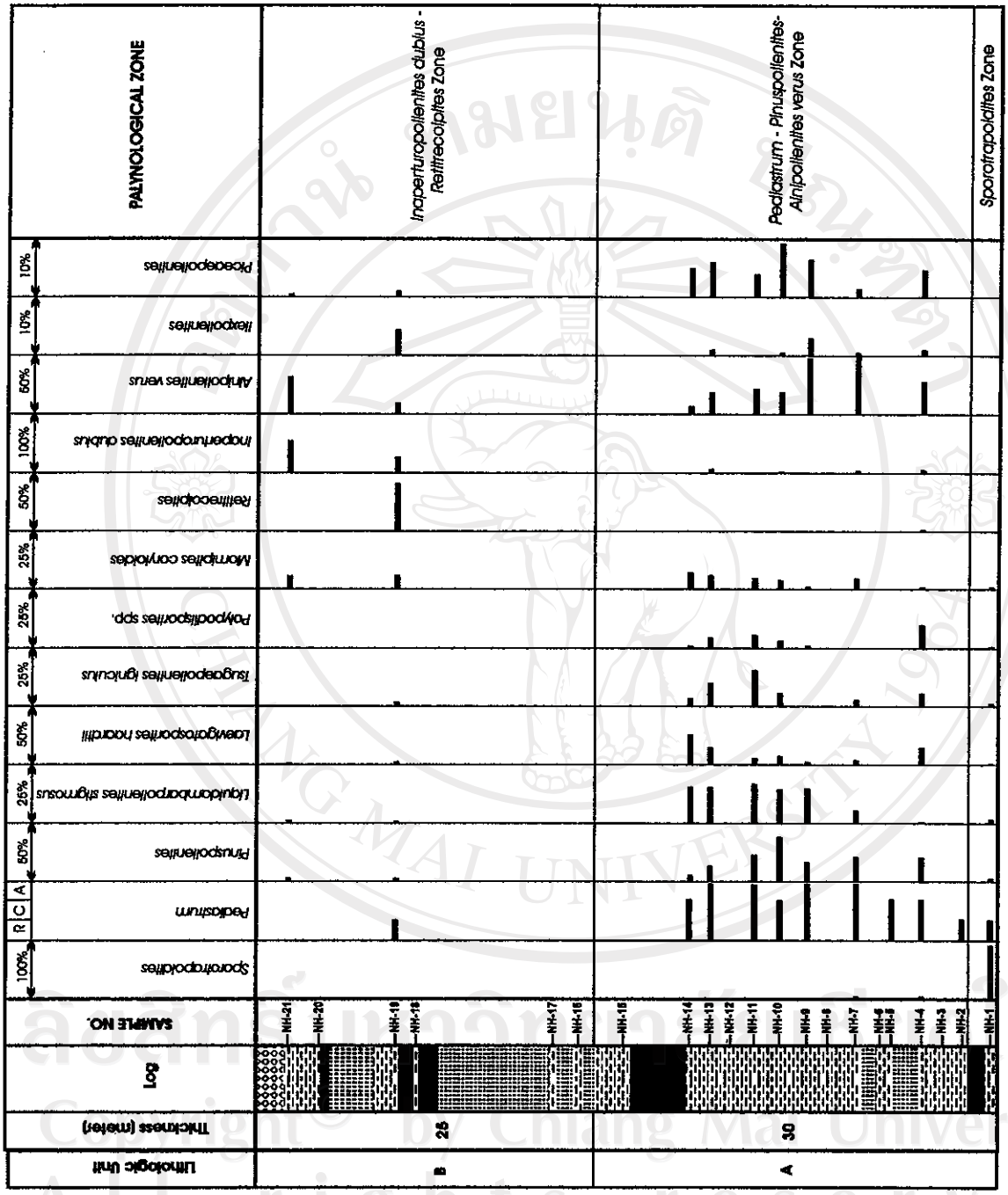

Figure 5-6 Pollen diagram showing plots of pollen occurrence in percentage against lithostratigraphic units and palynological zones of Na Hong. Occurrence of alga *Pediastrum* is estimated in rare (R), common (C), and abundant (A) under the light microscope.

Pinuspollentes-Alnipollenites verus Zone and *Retitrecolpites-Inaperturopollenites dubius* Zone (Figure 5-6).

1. *Sporotrapoidites* Zone: This zone covers the lowermost part of the sequence containing one sample (NH-1). The sample abundantly yielded 92 percents of *Sporotrapoidites* with rare occurrence (0.5 to 3 percents) of some forms of warm temperate pollen including *Pinuspollenites*, *Liquidambarpollenites stigmosus*, *Tsugaepollenites igniculus*, *Momipites coryloides* and spores *Laevigatosporites haardtii* and *Polypodiisporites* spp.

This zone formed in a freshwater environment as the abundant occurrence of *Sporotrapoidites* (*Trapa*-type) under warm temperate climate.

2. *Pediastrum-Pinuspollenites-Alnipollenites verus* Zone: This zone covers the rest of the unit A. It is dominated by *Pediastrum* with some occurrences of *Botryococcus*. *Sporotrapoidites*, *Pediastrum*, and *Botryococcus* are freshwater elements. The zone is interpreted as a freshwater depositional environment. The zone completely contains warm temperate sporomorphs. They include *Inaperturopollenites dubius*, *Piceaepollenites*, *Pinuspollenites*, *Tsugaepollenites igniculus*, *Alnipollenites verus*, *Caryapollenites simplex*, *Ilexpollenites*, *Juglanspollenites verus*, *Liquidambarpollenites stigmosus*, *Momipites coryloides*, *Pterocaryapollenites stellatus*, *Quercoidites*, *Retitrecolpites*, *Rhoipites retiformis*, and some forms of fern spores *Laevigatosporites haardtii*, *Polypodiaceoisporites retirugatus*, and *Polypodiisporites* spp. The climate was warm temperate.

2. *Retitrecolpites-Inaperturopollenites dubius* Zone: This zone covers the whole stratigraphic succession of the unit B. It is dominated by *Inaperturopollenites dubius* and

Retitrecolpites forms. *Pediastrum* has nearly disappeared from this zone. *Sprorotrapoidites* is absolutely absent. The pollen composition is still warm temperate somewhat similar to the assemblage of the previous zone.

The two palynological zones provide information suggesting the basin changed its depositional environment. The sediments of the unit A is dominated by fine-grained sediments such as oil shale and claystone yielding freshwater elements including algae *Pediastrum* and *Botryococcus* and the ancestral form of pollen *Sporotrapoidites*, the *Trapa*-type. The assemblage changes upwards with the near disappearance of freshwater elements. It is interpreted that in the beginning the basin was a lake containing plenty of algae and *Trapa* along the shore, surrounded by a warm temperate forest inland. In the unit B, the environment was changed to a fluvial system, recognized by major coarse-grained sediments, and covered with a warm temperate forest. The warm temperate pollen assemblage suggests the age of the basin as Oligocene to Early Miocene.

5.6 STRATIGRAPHIC CORRELATION AND BASIN DEVELOPMENT

The Tertiary basins in northern Thailand, including the basins in the region of Southeast Asia, were believed to develop as a result of the continent-continent collision between India and Eurasia. The commencement of basin formation has not been clearly understood but it was more or less after the collision event about 40 to 50 Ma, during the Eocene. The existence of the two Tertiary biostratigraphic zones, warm temperate and tropical, gives rise to the understanding that the oldest Tertiary sediments in northern Thailand must be older than MN3 (~19 Ma.) on the basis of vertebrate paleontology from the Na Sai coalfield. Because the underlying stratigraphic zone was deposited under a

warm temperate climate considered to be during Oligocene global cooling period, the age of the zone is, thus, Oligocene to early Early Miocene (Savin and others, 1975; Traverse, 1988; Pocknall, 1989). The Tertiary basins in northern Thailand were, therefore, first developed during the Oligocene under warm temperate climate conditions. The basins containing the warm temperate floras including, Na Hong, Ban Pa Kha, and Mae Lamao localities, have no markers for precise age determination. However, Na Hong, is likely to be the oldest basin and the Mae Lamao and the overburden unit of Ban Pa Kha coalfield are likely to be the youngert in this study. Na Hong sediments contain all warm temperate sporomorphs with abundant *Sporotrapoidites*, probably relatable to Oligocene to Early Miocene sediments from the shelf basin of the East China Sea (Song and others, 1985). The Chinese sediments were dominated by *Quercoidites*, *Retitricolpites*, *Trilobopollis*, Pinaceae, and *Sporotrapoidites*. *Sporotrapoidites* from Na Hong closely resembles the forms reported by Song and others (1985). The *Sporotrapoidites* from the Na Hong and China are likely to be primitive forms compared to the forms reported from Europe (Klaus, 1954; Potonié, 1960; Nagy, 1985; Zetter and Ferguson, 2001). Na Hong basin is, thus, suggested as being the oldest development in this study.

The lower part of Ban Pa Kha, the lower and upper coal zones, also contain predominantly warm temperate sporomorphs somewhat similar to the assemblages from Na Hong. But in Ban Pa Kha, the palynofloral assemblages change upward to the overburden unit with some tropical pollen influx indicating the climate was becoming warmer. Accordingly, the lower and upper coal zones of Ban Pa Kha is equivalent to Na Hong and the overburden unit is younger.

The Mae Lamao sediments also yield warm temperate sporomorphs. The pollen assemblage is inferred to be comparable to the assemblage from the overburden unit of Ban Pa Kha. The lower portion of the Na Khaem Formation including the part of the S coal zone of the Mae Moh Group from Mae Moh basin is equivalent to Mae Lamao and overburden unit of the Ban Pa Kha coalfields. However, the exact stratigraphic positions are not determined but Oligocene to early Early Miocene is suggested as a general age for sediments in this study. A relative stratigraphic arrangement of the warm temperate biostratigraphic zone is now possible in comparison with warm temperate formation of Nong Ya Plong basin in Petchaburi Province (Figure 5-7).

For the tropical biostratigraphic zone, the sediments were dated by vertebrate paleontology and paleomagnetic investigations. On the basis of vertebrate remains, the age of the Mae Long Formation is MN-3 to MN-4 or about the late Early Miocene (see chapter 2). This is regarded as the oldest age of the tropical biostratigraphic zone or probably a little bit older. Paleomagnetic study of the Na Khaem Formation of Mae Moh undertaken from the K-1, K-2, and J-5 lignite zones indicates ages ranging from 12.5 to 12.8 Ma. or part of the Middle Miocene (Benammi and others, 2002). As well as Chiang Muan, the paleomagnetic data suggests the ages of 10 to 13.5 Ma (Suganuma and others, 2002; Chaimanee and others, 2003; Benammi and others, 2003). A schematic diagram showing the age ranges of each locality in comparison with tropical formations of Fang and Mae Sot basins (Watanasak, 1988) is given on Figure 5-7.

Basin development commenced in the western part of northern Thailand and successively extended to the eastern region. Basins in the western region include Na Hong, Mae Lamao, and Nong Ya Plong basins that were probably developed during the

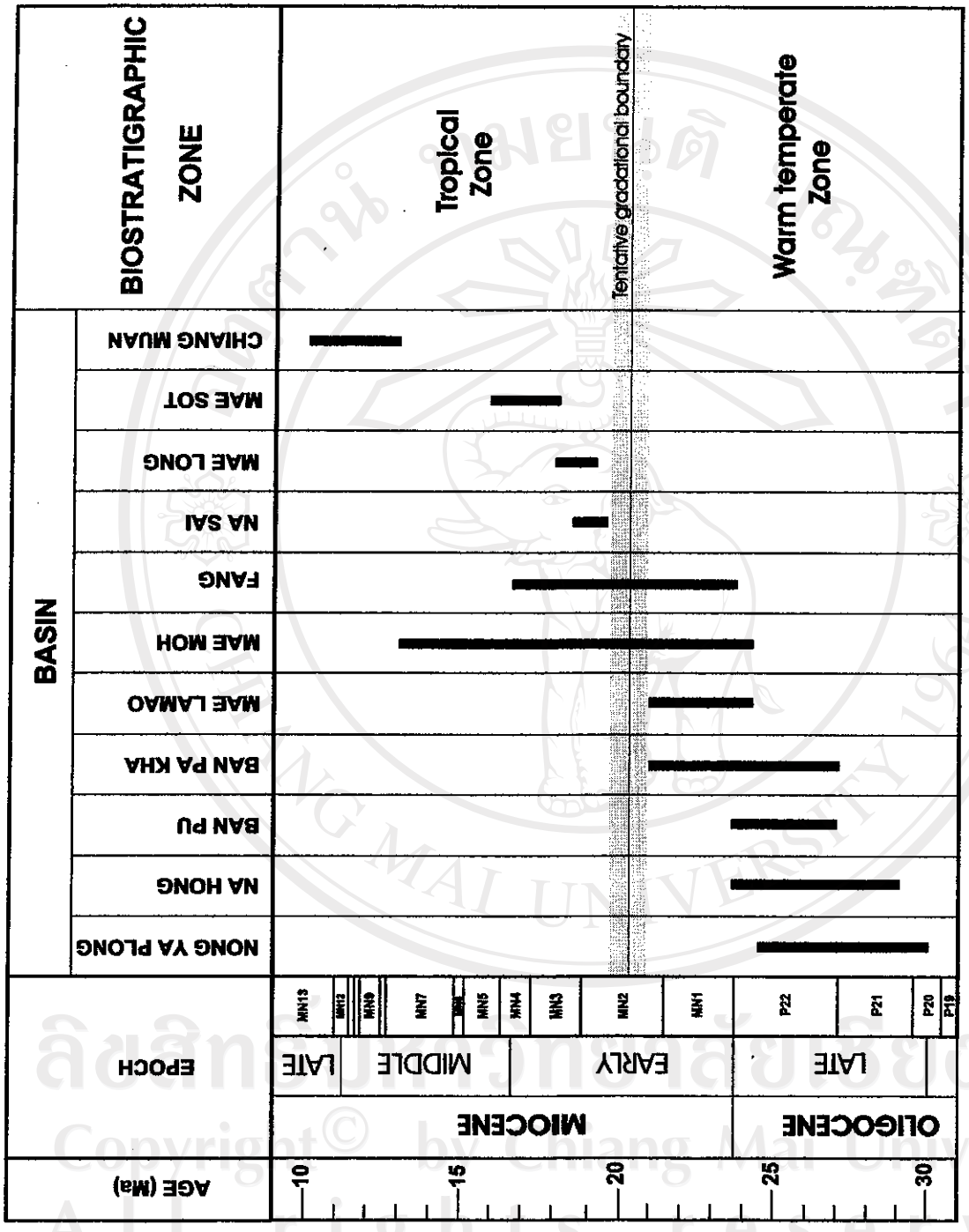

Figure 5-7 Schematic diagram showing geological time range of each basin from this study and from previous works (Watanasak, 1988) with two biostratigraphic zones indicating climatic changes from a warm temperate to a tropical conditions during Oligocene cooling period to Miocene climatic optimum.

Oligocene to early Early Miocene as the earliest episode of basin development in northern Thailand. Subsequently, Li, Mae Moh, and Fang basins, in the central region, were developed during Oligocene to Middle Miocene. Chiang Muan basin, in the eastern region, was developed during late Middle Miocene and is considered to be the youngest development in this study.

All of these basins are characterized by graben and half-graben structure that is controlled by extensional faulting. The basin development was likely caused by extrusion tectonics of the Southeast Asian landmass (Tapponnier and others, 1982; 1986). The southeastward direction movement of the landmass was controlled by two major strike-slip faults, the Red River fault and Wang Chao fault zones. The movement of the landmass set up a series of faults in many episodes of time and at least five episodes (Morley and others, 2000; 2001). This explains the geological cross section of Li basin showing the two formations, Ban Pa Kha Formation and Mae Long Formation (Figure 2-4). The Li basin was first developed in the eastern part forming Ban Pa Kha Formation during Oligocene to early Early Miocene. At that moment, the basin in the southern and western parts were not developed yet and sedimentation did not occur. This is a reason why there is no Ban Pa Kha Formation in the southern and western parts of the Li basin. Subsequently, during Early Miocene the Li basin was extended in approximately east-west direction considerable as rift basin (Morley and others, 2000; 2001) and the basin was developed in the southern and western parts forming Mae Long Formation.