CHAPTER 1

INTRODUCTION

1.1 General introduction

Fossil fuel is a general term for any hydrocarbon that may be used for fuel, including petroleum, natural gas, oil shale, and coal. Fossil fuels in northern Thailand are mainly coal with minor petroleum and oil shale. Coals are originated from peat deposited in swamps, both autochthonous and allochthonous deposits. The autochthonous coal deposits are common in the northern Thailand.

In Thailand, there are more than seventy Cenozoic basins (Figure 1.1) scattered throughout both onshore and offshore area. Most basins originated during the Early Tertiary as a result of extensional rifting related to the collision between Indian plate and Asian plate (Tapponnier and others, 1986). Those basins are characterized by N-S trending half- grabens and grabens, filled with sediments. The sedimentary sequences can be divided into syn-rift and post-rift sequences. Rifting of the onshore basins continued through to the Pliocene whereas rifting of the offshore basins was ended in Early Miocene. The rifting provided accommodation space for extensive lacustrine deposits (Sethakul, 1984; Pradidtan, 1989).

In northern Thailand, there are more than forty basins which rich in coal and oil shale deposits (Figure 1.2). Large deposits of oil shale have been found in the Mae Sot basin. Large lignite deposits have been found in the Mae Moh and Li basins.

Coal seams were deposited in two different environments. First, thin coal seams were deposited in the back-swamps of fluviatile environment as indicated by the

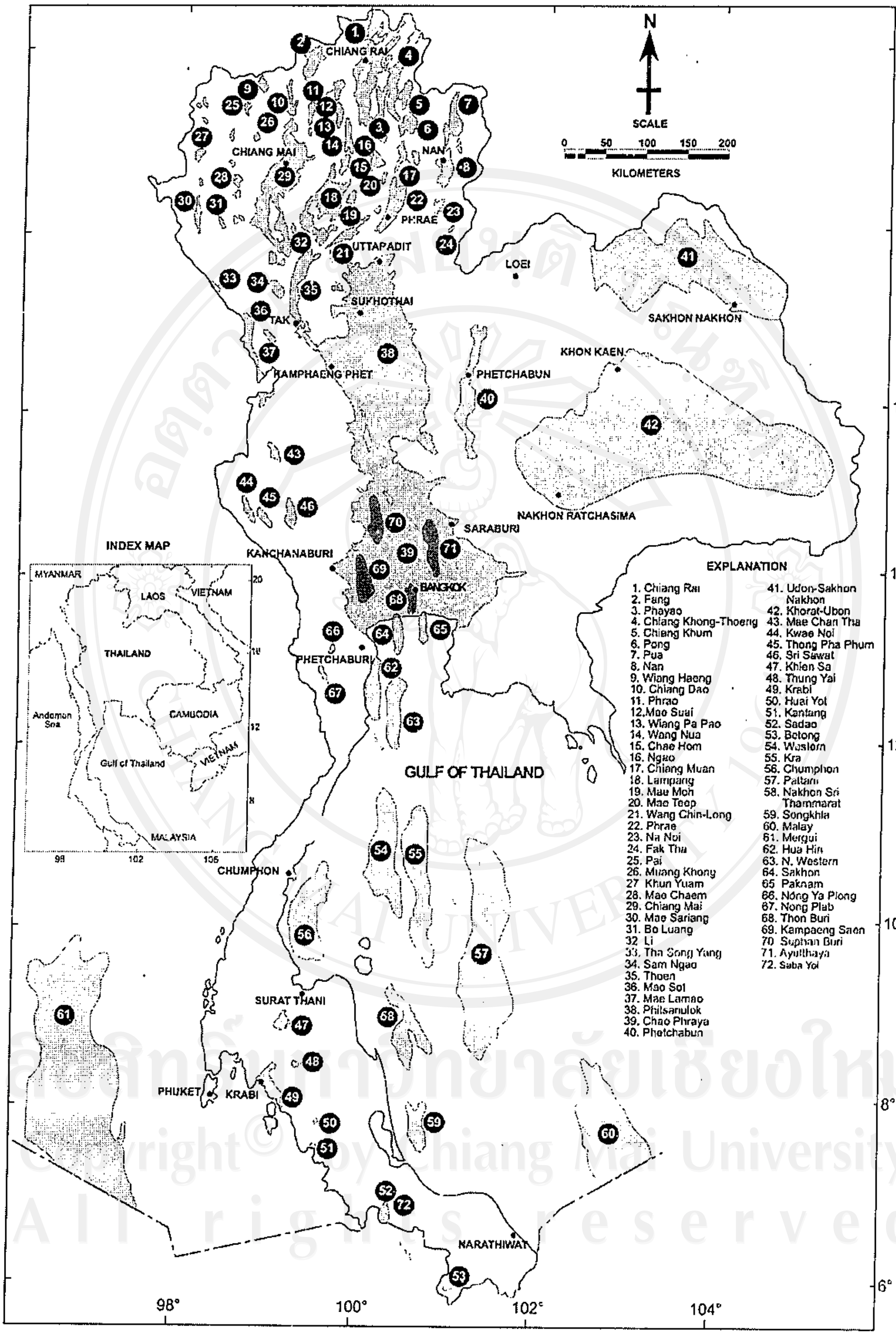

Figure 1.1 Map showing the distribution of the Cenozoic basin of Thailand (modified from Chaodumrong and others, 1983; Chinbunchorn and others, 1989; and Uttamo, 2000)

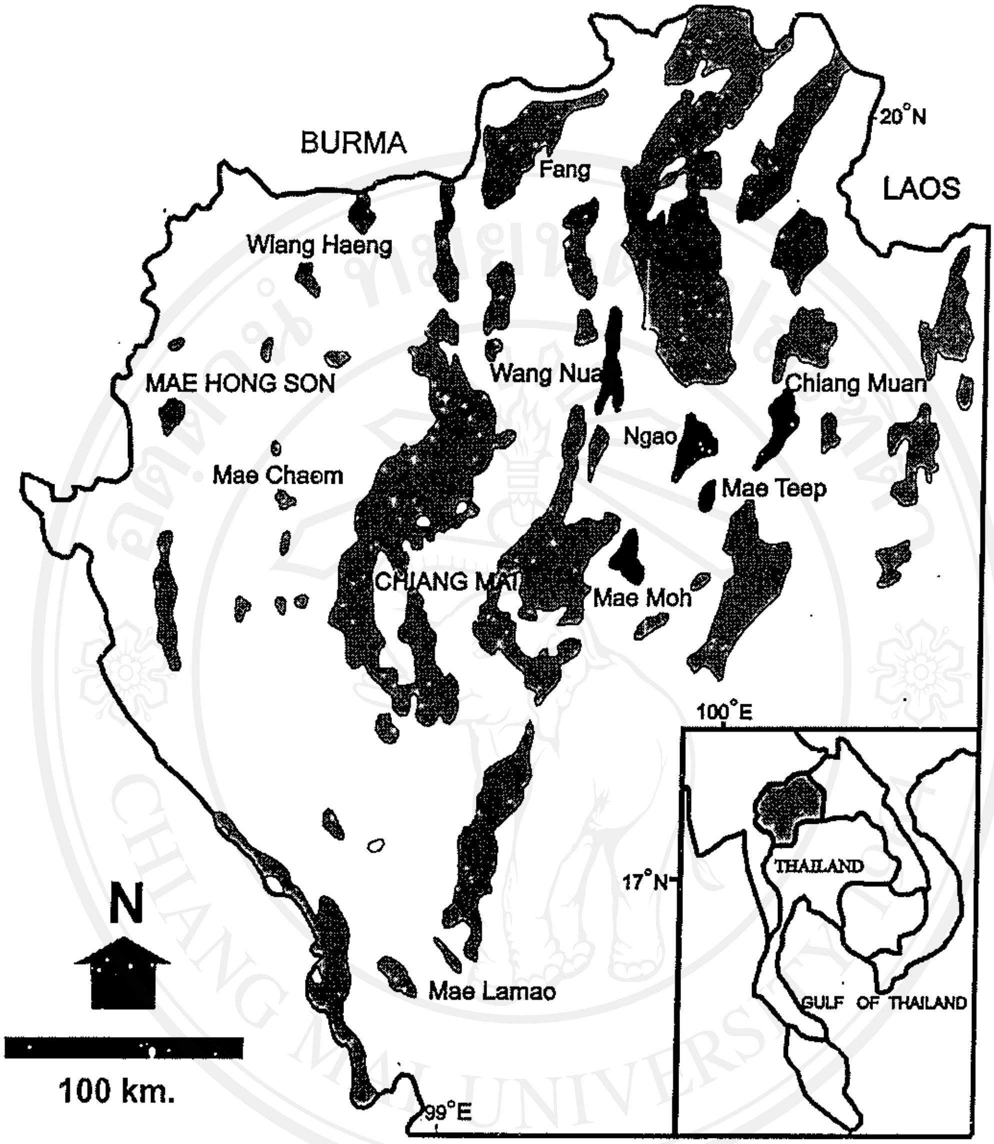

Figure 1.2 Cenozoic basins in northern Thailand (modified from Ratanasthien, 1990; Uttamo, 2000; Uttamo and others, 2003).

coarsening upward cycle capped by sheet-like coal seams. Second, the thicker coal seams were deposited in the peat swamp resulted from the sitting up processes of paleolake as indicated by tabular geometry of coal seams overlying the lacustrine facies (Khantaprab, 1985).

There are three depositional environments preserved in coal-bearing sequences of northern Thailand. The lacustrine environment is typical for the Mae Moh and Na Sai basins. The intermontane-forest is typical for the Ban Pu and Mae Tun basins. The mixed-forest swamp and lacustrine environment is typical for the Ban Pa Kha and Mae Teep basins (Ratanasthien and Ruangvatanasirikul, 1984).

Gibling and Ratanasthien (1980) recognized 3 groups of northern Thailand coals that according to their suitability for production and use as follows:

i. High quality coals. They are dark brown to black color, and show fine banding of vitrian and attrital coal. They are hard, with conchoidal to subconchoidal fracture, and are resistant during long-distance transportation. Heating values are high (8,395-12,810 Btu/lb). They are in Mae Tha, Mae Teep, Ban Pa Kha (Li), Ban Wiang Haeng, and Ban Huay Dua basins (western and eastern basins).

ii. Intermediate quality coals. They are the same as Group I, but they are moderately hard and show splintery fractures. Heating values are (9,180-15,309 Btu/lb). On storage under cover for more than about six months, they slack into fragments and eventually powder, and develop white crystals between the coal layers. They are in Mae Chaem, Tha Song Yang and Mae Ramat (western basins), and Jae Hom basins (eastern basins).

iii. Low quality coal. They are brown to brownish-black color, and tend to contain much attrital coal. They are brittle with splintery fracture, and are not resistant during long-distance transportation. Heating values are low (4523-10,612 Btu/lb). On storage under cover, they slack rapidly into fragments and develop white crystals between the coal layers. They show spontaneous combustion on storage. They are in Jae Hom, Wang Nua, Ngao, and Mae Moh basins (all in the east).

Nowadays, coal is mainly burned in large combustion units, principally for electricity generation and industrial plants. The use of coal and its waste cause a hazardous impact environment and human health. Most hazards are due to the quality of coal, especially those high in sulfur and nitrogen contents (Rubin, 1991). The amount of sulfur and nitrogen oxides depends on the chemical balance of the initial contents in coal (Ratanasthien and others, 1995). The quality of coal depends on the controlling factors either inside or outside basins.

The controlling factors inside the basins can be divided into three catagories; the evolutionary development of flora, palaeogeography, and tectonic activities (Stach and others, 1982). The flora's evolution and the palaeogeography are responsible for development of thick peat deposits. The types of plant are important factors for coal quality (Francis, 1960). The warmer and wetter the climate, the more luxuriant is the flora and the more dominant forest swamps over reed and moss swamp. A tropical swamp will renew itself in 7-9 years and during this time trees can grow to heights of 30 m. In contrast, the trees of the Alnus-swamp forest of temperate zones will only grow to heights of 5-6 m. in the same period of time. Northern Thailand coals made up of temperate climate plants (Endo, 1964, 1966; Yabe, 2002; Songtham, 2003).

Tectonic activities affected the basins would be the best if the abrupt subsidence occur to oil-bearing formations. Alternatively slow subsidence would be the best for those good coal quality deposits (Ratanasthien and Kandharosa, 1986).

Volcanic activities are the most important outside basins controlling factors. The evidences of volcanic activities are recognized in two ways. Firstly by the presence of associated lava within the basin as found in exploratory wells in many areas, both oil and coal exploration. The other evidence as indicated by series of volcanic Ash (Tonstein) or diatomaceous bed was found in Mae Moh Mine in Lampang and Na Sai Mine in Li basin (Ratanasthien, 1994).

High sulphur content of coals, especially those in form of framboidal pyrite, indicate marine influence. But reports on paleontological evidences of fauna and flora, gastropods, bivalves, fishes, insects, carnivora, plant remains, trace fossils, etc. in northern Thailand Tertiary basins indicated non-marine origin (Khantaprab, 1985). This contradiction from the basis of sulphur contents and paleontological evidence await for detailed study of sulphur sources. Therefore this study of depositional environment of coal deposit in northern Thailand is necessary to solve this problem.

1.2 Objective

The objective of this research was to use geochemical techniques to determine sedimentary source, depositional processes, and changes in depositional environments of Tertiary rocks in the Mae Moh coal field, Chiang Muan coal field, Mae Teep coal field, Ngao coal field, and Wang Nua coal field (Figure 1.2).

1.3 Scope, planning, and methodology

1.3.1 Review previous work

1.3.2 Collection of sedimentary rock and coal samples from the Mae Moh mine face, Chiang Muan mine face, Mae Teep mine face, Ngao pit, and Wang Nua pit.

1.3.3 Sample preparation for geochemical analyses

1.3.4 Proximate and ultimate analyses to determine chemical composition and coal quality

1.3.5 Study of minerals and elements of sedimentary rocks and coal samples using X-ray diffractometry technique, X-ray fluorescence spectrometry, and induced couple plasma to define the chemical composition of fly ash coal, sediment sources, processes of deposition, and depositional environments

1.3.6 Study stable isotope of δ^{34} sulfur, δ^{18} oxygen, and δ^{13} carbon to define the source of sulfur and depositional environment

1.3.7 Making polished sections of coal samples and studying coal petrography to determine coal macerals

1.3.8 Data compilation and analysis to construct the pattern of depositional environments of the Mae Moh coal field

1.3.9 Discussion and conclusion

1.4 Education advantages

1. This research will indicate the changes of depositional environments in the Mae Moh coal field, Chiang Muan coal field, Mae Teep coal field, Ngao coal field, and Wang Nua coal field in northern Thailand.

2. The geochemical data of the Mae Moh coal field, Chiang Muan coal field, Mae Teep coal field, Ngao coal field, and Wang Nua coal field from this study may be used for comparison and correlation with surrounding Tertiary coal fields.

3. The data can be used for an appropriate exploration and exploitation methods of coal deposits.

1.5 Previous works

1.5.1 Structural geology and tectonic setting

Tertiary deformation of the SE Asia has been accepted as the result of the collision of the Indian against Eurasian plates by many researchers (Tapponnier and others, 1982, 1986; Daly and others, 1991; Dewey and others, 1989; Rangin and others, 1990; Lee and Lawver 1995; Hall 1996, 1997, 2002; Packham 1996; and Matthews and others, 1997). The propagation extrusion model (Tapponnier and others, 1982) that has a free boundary to the south and east is widely accepted by many workers (Figure 1.3). However, there are other plate margins to consider.

The experiments with plasticine of Tapponnier and others (1982) are shown in Figure 1.4. They saw many similarities between the results of their experiment to the geology of the SE Asia (Figure 1.3). For instance, they proposed that the F2 fault in

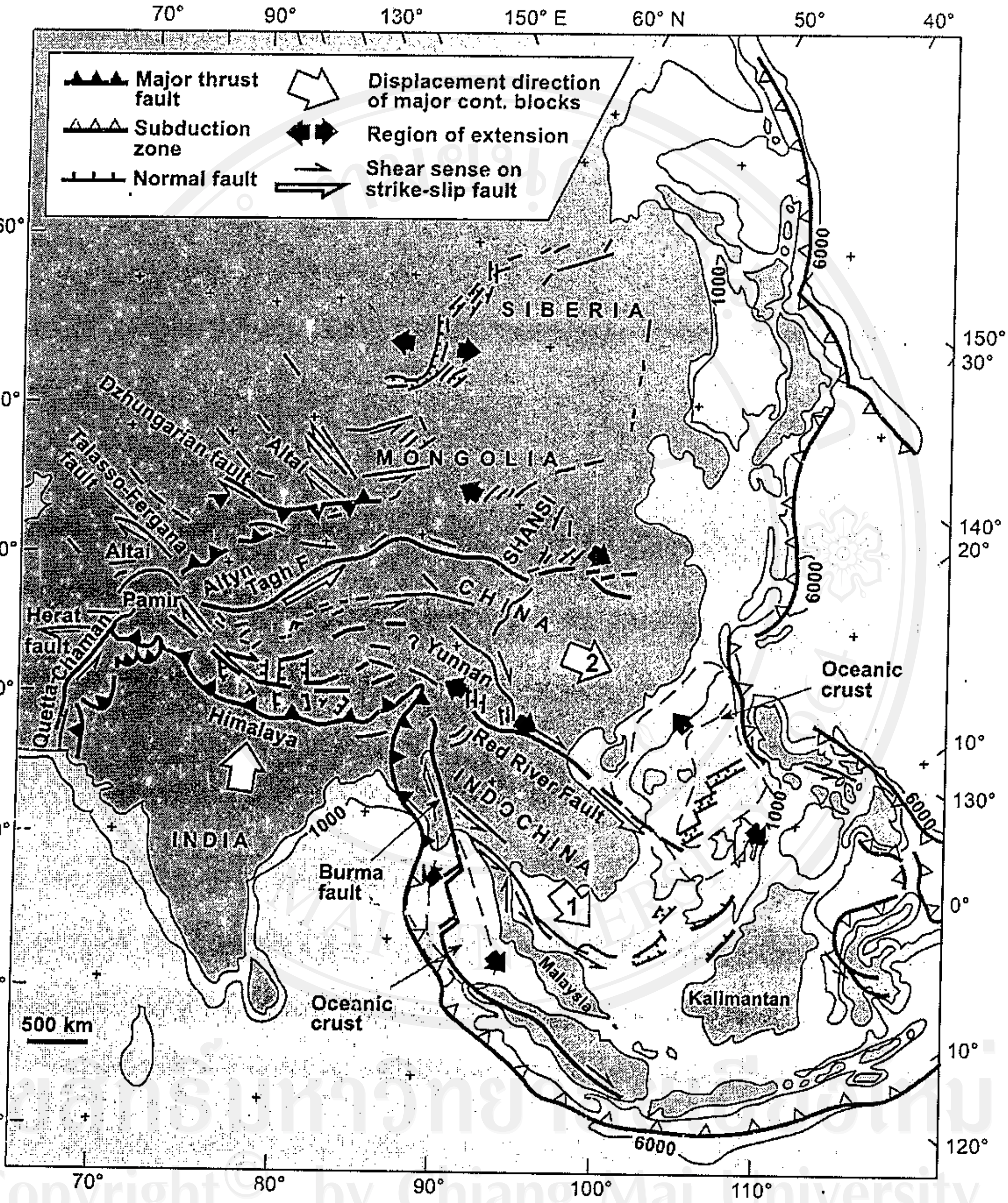

Figure 1.3 Tectonic map of central-east Asia illustrating 'Extrusion' model and its relationship with Cenozoic structures in the region. Number in white arrow indicate the relative order in which certain continental block were extruded toward the southeast (modified from Tapponnier and others, 1982).

the experiment corresponds to the Altyn Tagh Fault and F1 corresponds to the Red River Fault. The tectonics of eastern Asia would thus reflect the succession in time of two major phases of the continental extrusion. The gap between block 2 and block 1 (which are compared to the southern China and the Indochina respectively; Figure 1.4), would be analogous to the South China Sea whereas the gap A (between the rigid block and block 1) corresponds to the Andaman Sea. The principal tectonic units are shown in the Figure 1.3. According to Molnar and Tapponnier (1975), the Himalayan Thrust fold belt was placed in between the conjugate faults of the sinistral Quetta Chaman Fault in the west and the dextral Sittang Fault (Sagiang) in the east. These strike-slip faults mark the margins of the Indian indenter which has been driven northward into the Eurasian plate. The action forced the N-S thrusting in the Himalayas (Molnar and Tapponnier, 1975; Ni and York, 1978).

A large number of NE-SW sinistral strike-slip faults and NW-SE dextral displacements can be observed (Ni and York, 1978). It also induced the Tibetian Plateau and developed various N-S trending basins since the Late Cenozoic (Molnar and Tapponnier, 1975; Ni and York, 1978). The outcome of N-S shortening by the penetration of the Indian Plate into the Eurasian Plate yielded the E-W lateral flow of crustal materials from Tibet and South China which moved eastward away from the path of India (Molnar and Tapponnier, 1975). Molnar and Deng (1984) proposed that at least half of the present day northward convergence between India and Asia is accommodated by crustal thickening, from their studies of the seismic deformation in Central Asia.

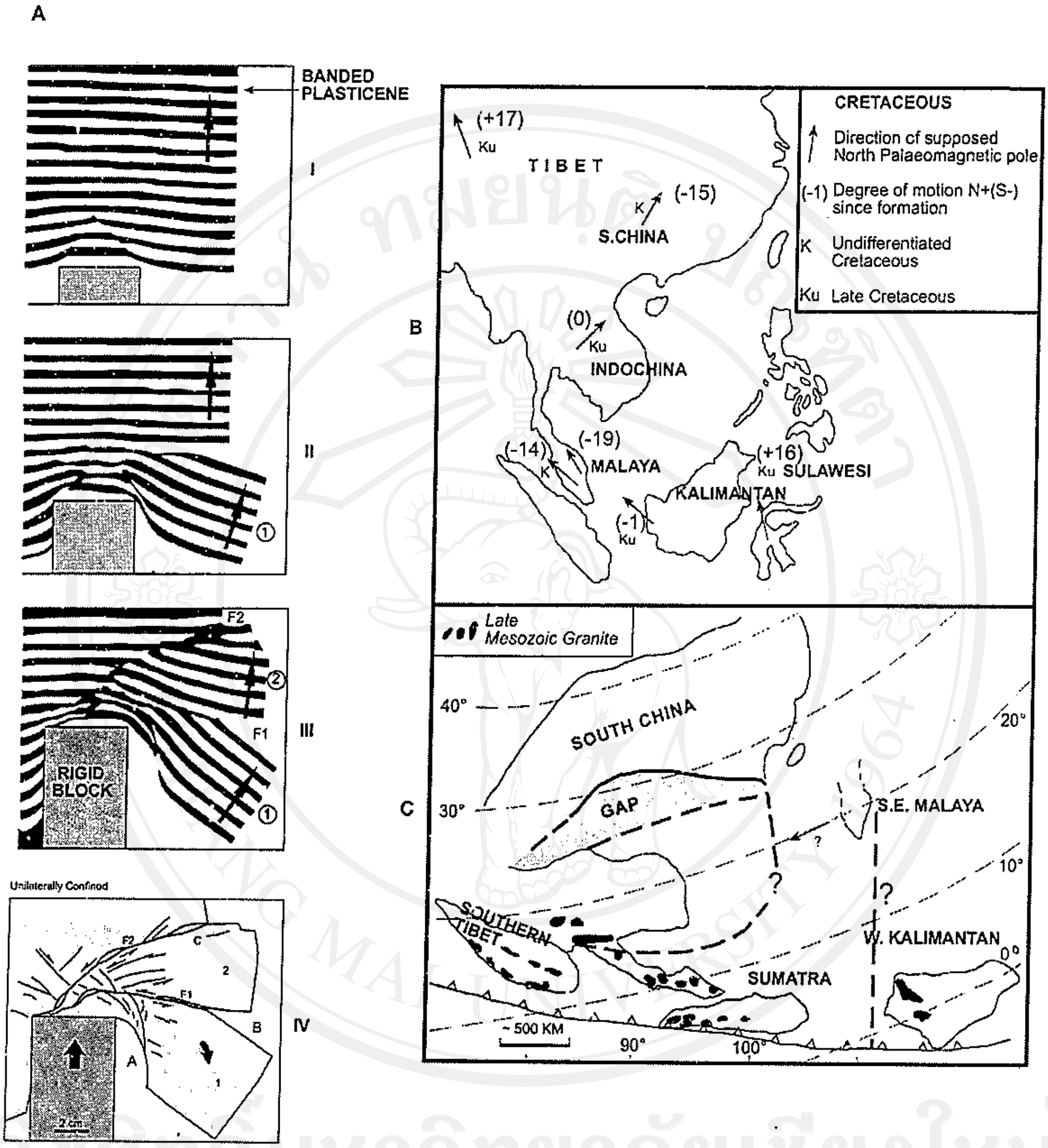

Figure 1.4 (A) Three successive stages (I to III and IV is an interpretation) of extrusional model experiment with plasticine (plain view). Right hand side free is applied. The rigid block is modelled as India. 1 is taken as the Indochina-SE Asian Block, 2 as south China (modified from Tapponnier and others, 1982). F1 is compared to the Red River Fault, F2 to the Altyn-Tagh Fault, A to the Andaman Sea and B to the South China Sea. (B) Cretaceous palaeomagnetic data from SE Asia (modified from Hutchison, 1992). (C) Palaeogeographic reconstruction of SE Asia in the Late Cretaceous before upward moving of India. The gap is the crustal shortened area (modified from Hutchison, 1992).

The soft collision between Indian and Eurasian plates commenced during Late Paleocene to Middle Eocene (~58–44 Ma) whilst hard collision started in the Middle Eocene (Lee and Lawver, 1995). The Cenozoic tectonic evolution of this region can be discussed in four stages, related to the northward movement of the Indian plate relative to the Eurasian plate. The eastern syntaxis, the right corner of the Indian plate (Lacassin and others, 1997), has penetrated through the Eurasian plate and has resulted in changing stress patterns of the region through time. The changing stress fields have controlled the opening of the sedimentary basins in this region and the South China Sea as well as the sense of movement of the major strike-slip faults (Huchon and others, 1994).

Longworth-CMPS Engineers (1981) reported the nature of Late Cenozoic faults based on sparse surface exposures, high resolution reflection seismic profiles, and drillholes. This report indicated that in the middle of the area there is a graben that is about 2 kilometers wide. This graben trends about 015 degrees and is bounded on both eastern and western sides by major fault zones. These faults have throws of more than 200 meters along much of their lengths. Evans and Jitapunkul (1989) recognized two phases of deformation. These two phases are the products of strike-slip movements in basement. The first deformation phase was right lateral strike-slip movement along the basin axis. The second deformation phase was left lateral movement. Rui (1998) concluded that the Mae Moh basin is an intermontane basin largely comprised of fluvial, alluvial, and lacustrine sedimentary facies deposited on a pre-Tertiary basement. The basin is one of a series of intermontane basins that developed as intra-cratonic extensional and trans-tensional basins oriented roughly north-south. The extension process that formed these basins and the resulting sedimentation probably started in the Oligocene.

Ratanasthien and Kandharosa (1986) studied the depositional environments of Tertiary coal formations in northern Thailand and concluded that granitic magma intrusion in the Late Cretaceous led to uplift and formed north-south oriented sedimentary basins. The sedimentary rocks that were deposited in these basins were well-sorted and their thickness increased as deposition progressed. Eventually, subsidence ceased and these basins became sites of swamp deposition. These swamp deposits were eventually transformed to coal and petroleum-bearing rocks.

Ratanasthien (1987) recognized four series of faulting system in Mae Moh Mine. The earliest set is the low angle fault ($20-25^0$ dip). The major direction is NNE to SSW. The second set is parallel or nearly parallel to the long axis of basin. The third set is in WNW-ESE direction. The last set, mainly in north by northeast trending is oblique to the second and the third.

1.5.2 Sedimentology

Chaodumrong and Chaimanee (2002) concluded that the depositional environment of Thailand's Tertiary basin can be divided into 3 parts. The lower part and the upper part are dominated in alluvial environments, while lacustrine, fluvio-lacustrine and swamp environments were predominant in the middle part.

Chaodumrong and others (1983) and Chaodumrong (1985) proposed the lithostratigraphy of Tertiary at Mae Moh Mine into three sequences. The lower sequence was given name in Huai King Formation by Corsiri and Crouch (1985). This sequence consists of conglomerate, sandstone, siltstone and claystone. Huai King Formation was deposited in fluvial environment of braided river in the lower part and meandering river with overbank deposit in the upper part of the sequence. The middle sequence is Na Khaem Formation, which consists mainly of mudstone, claystone and coal. This sequence indicates sedimentation under the alternation of fresh-water lake and swamp/marsh of the calcium-rich lacustrine environment. The upper sequence was called Huai Luang Formation, which consists mainly of semiconsolidated and unconsolidated red color of sandstone and claystone. This formation indicates sedimentation in the low energy condition of overbank deposit of the subsiding flood-plain in the lower and upper part of sequence while the middle part indicates fluvial sedimentation of meandering river of relatively higher energy level.

Ratanasthien and others (1997) studied coal petrography in J-, K-, and Q-zone of Na Khaem Formation at Mae Moh basins. In the Q-zone, the sediments are mainly of shallow lacustrine as indicated by alginite, gelinite, and dispersed fusinite. There are lacustrine of high silica and carbonate enrichment at K-zone as indicated by diatom rich and alginite. The tree trunks association to lacustrine or possible the lacustrine dried up to changed to fluvio-forest swamp. Mastodon was found in K-1 zone could indicated the possibility catastrophism and terminated the coal of K- zone. J-zone is mainly of lacustrine environment with close distance volcanic eruption give rise to intraclastic formation of J-4 and J-5. The high sulphur rich zone in J-1 that could be the effect of volcanic eruption and terminated the coal accumulation of Mae Moh basin.

Ratanasthien (1990) reported that the activities recorded in mica during late Early Miocene to early Middle Miocene (ca. 22.4-18.5 Ma by K/Ar) produced series of uplifting and eroding organic sequences, evidenced by mastodon remains in shale layers unconformably overlying the coal bed in Mae Teep coal field. The environment changed to more cooler climate as recorded by temperate flora (Endo, 1964 and 1966) corresponding to the temperate foraminifera. They indicate the region wide cooling, as found in the Andaman and Japan sea in Middle Miocene sediments. Lithological evidences in the sequences show catastropic record of major flooding and volcanic eruption during Middle Miocene.

Uttamo (1998 and 2000) and Uttamo and others (2003) studied the lithofacies of part of the sedimentary sequence in the Mae Moh basin. He concluded that there was a change in the depositional environment of the basin during the Late Miocene. The depositional environment changed from a semi-arid, brackish water flood basin that had small debris flows to a freshwater, lacustrine environment with peat and back swamps and eventually to a flood plain and large braided river environment.

Silaratana and Ratanasthien (2000) concluded that the Chiang Muan lithostratigraphy can be divided into 3 sequences. The lower sequence was deposited in fluvial environment. The lower part of the middle sequence indicates sedimentation under freshwater lake. The middle sequence was deposited under fluvial environment and changed to fresh-water lake of calcium-rich lacustine environment at the upper part of the middle sequence. The upper sequence was deposited in fluvial environment.

1.5.3 Stratigraphy

Brown and others (1953) used the term Mae Sot Series to denote all Tertiary sedimentary rocks of northern Thailand and referred to the Mae Moh lignite.

Gloe (1955) and Sithiprasasna (1959) used the term Mae Moh Tertiary sediments to describe the Tertiary sequence that contained lignite in the Mae Moh basin. Four major lignite beds were recognized and assigned in alphabetical sequence from bottom to top: L shale, L lignite, M shale, M lignite, N shale, N lignite, O shale, O lignite, and P shale (Table 1.1).

Gardner (1967) measured and described a type section of the Mae Moh Tertiary rocks using data from outcrops and boreholes. He used the name Mae Moh Formation (formerly spelled Mae Mo Formation) and subdivided the formation using an alphabetical sequence similar to that of Gloe (1955). Gardner recognized nine beds and concealed zones: lower unexposed zone, L claystone bed, L lignite bed, M claystone bed, M lignite bed, N claystone bed, N lignite bed, O claystone bed, O lignite bed, and concealed zone, in ascending order. The thickness of the Mae Moh Formation was estimated to be 937 meters.

Piyasin (1971) used the term Mae Moh Group to denote Tertiary rocks in northern Thailand, deriving the name from the Mae Moh mine site.

Longworth CMPS Engineers (1981) divided and described the stratigraphic sequence within the Mae Moh basin using general terms. From top to bottom, these are: surficial gravel and alluvium, red beds, gray claystone, upper lignite seam K, interburden gray claystone, lower lignite seam Q, and gray claystone. The maximum thickness of the Mae Moh stratigraphic sequence was estimated to be 1,030 meters.

Brown and others (1953)	Gloe (1955)		Gardiner (1967)		Piyasin (1971)	Longworth-CMPS Engineers (1981)		Chaodumrong (1985)		Corsiri and Crouch (1985)		
			Recent sediment							Alluvium		
Mae Sot Series	Mae Moh Tertiary Sedi-Ment		Pleistocene? Sediments		Mae Mo(h) Group	Over-burden	Red Bed	C Formation	C-3	Huai Luang Formation		
									C-2			
		'P' shale	Mae Moh Forma-tion	Concealed					C-1			
		'O' lignite		'O' lignite bed				B Formation	B-6	Na Khaem Forma-tion	I	J zone
		'O' shale		'O' claystone			Gray claystone		B-5			
		'N' lignite		'N' lignite or upper bed		'K' Seam			B-4		II	K zone
		'N' shale		'N' claystone bed		Interburden			B-3			Interburden
		'M' lignite		'M' lignite bed or lower bed		'O' Seam			B-2			Q zone
		'M' shale		'M' claystone bed					B-1		III	
		'L' lignite		'L' lignite		Gray Claystone						R zone
		'L' shale		'L' claystone								
				Unexposed				A Formation	A-2			S zone
										Huai King Formation		

Table 1.1 History of stratigraphic nomenclature applied to the Cenozoic of the Mae Moh basin (modified from Chaodumrong, 1985).

Chaodumrong (1985) recognized that in the code of stratigraphic nomenclature a group is composed of 3 formations. The lower formation, formation A, consists of member A-1 and A-2. The middle formation, formation B, consists of member B-1, B-2, B-3, B-4, B-5, and B-6 from bottom to top respectively. The upper formation, formation C consists of member C-1, C-2, and C-3.

Corsiri and Crouch (1985) established the stratigraphic nomenclature for the Cenozoic of the Mae Moh basin that is in current use. They recognised the Huai King, Na Khaem, and Huai Luang Formations. These correspond to Chaodumrong's formations A, B, and C, respectively. Corsiri and Crouch informally used Roman numerals to label three members of the Na Khaem Formation I, II, and III (from top to bottom). They also retained the K and Q designations of the lignite horizons assigned by Longworth-CMPS Engineers (1981), but identified them as zones. They expanded this nomenclatural system by additionally identifying the lignite J, R, and S zones.

Benammi and others (2002) studied the magnetostratigraphy of Na Khaem Formation of Mae Moh coal field and concluded that the magnetostratigraphic section correlates with geomagnetic porality time scale from the C5ACn chron to C5An.2n chron. This result suggests that the Na Khaem Formation was deposited between 13.5 and 12.1 Ma. The rate of sedimentation is about 17.5 cm/ka, and age of 12.5 and 12.8 Ma can be assigned to the J5 and K1, K2 lignite zones were the mammal remains originate.

Suganuma and others (2002) studied the paleomagnetic of Chiang Muan coal field. The thermal demagnetization of core samples indicates relatively stable remanences from five horizons, three of which are normal polarity and two reversed. Rock magnetic analyses indicate that titanomagnetite is the main magnetic carrier.

The results show a normal-reverse-normal polarity sequence, and correlated it to that from C5A to C5 chrons. This result suggests that the Chiang Muan coal field was deposited 12 Ma to 10 Ma, with a mean sedimentation rate of 4-10 cm/ka. However, Benammi and others (2003) and Chaimanee and others (2003) had also studied the paleomagnetic of Chiang Muan coal field which suggest the age of this coal field are between 13.5 to 12.2 million year.

1.5.4 Paleontology and palynology

Koenigswald (1959) described mastodon molars from the Mae Moh basin as a new species, *Stegolophodon praelatidens*. This species is supposedly more primitive than *S. latidens* from Burma and he referred it to the Lower or Middle Pliocene, which, according to modern usage, would correspond to the Upper Miocene or the Lower Pliocene. Ginsburg (1983) described a new mustelid, *Siamogale thailandica nov. gen, nov. sp.* The type specimen is the lower first molar, which was collected in the Miocene lignite of the Mae Moh Mine. Ginsburg and Tassy (1985) reported mammal remains of mastodon. *Stegolophodon* sp., rhinocerotid, *Rhinocerotini* indet. cf. *Gaindatherium*, and carnivore, *Siamogale thailandica.* They described additional mastodon material though the available material is insufficient to be identified at the species level. *Stegolophodon praelatidens* should thus be considered as a *nomen dubium* and the Mae Moh teeth should be allocated to *Stegolophodon* sp. The rather primitive features of the Mae Moh *Stegolophodon* suggest that it may be Middle Miocene or early Late Miocene in age.

Tassy and others (1992) described a new finding of a complete third molar (M_3) *Stegolophodon* sp. at Mae Moh basin. Moreover, Ducrocq and others (1995) reported the discovery of additional remains of *Stegolophodon*, juvenile specimens of *Gaindatherium* rhinoceros, and a new form of carnivore and cervid. Kunimatsu and others (2000) found the proximal end of a left ulna that probably belongs to a small carnivore.

Ginsburg and Tassy (1985), Buffetaut and others, (1989), Ducrocq and others (1994) and Ginsburg (1989) addressed the age of the Mae Moh Group and deduced from the evidence of fossil vertebrates that the sequence's age is Miocene. Ginsburg (1989) stated the group's age to be Middle Miocene. Suteethorn and others (1988; 1990) reported that in the northern basins of Li, Mae Moh, Had Pu Dai, Mae Teep and Pong, remains of mammals indicate a Middle Miocene age. Ducrocq and others (1995) concluded from a survey of mammalian fossils that all the Cenozoic continental basins of northern Thailand were created within a time ranging from 16 to 14 million years during the early Middle Miocene.

Gibling and Ratanasthien (1980) found fossil assemblages in mudstone at the Mae Moh mine. A mudstone 6 meters thick contains fish fragments in its lower part and has gastropods and fish and plant fragments in its upper part. This mudstone is overlain by coal. Their study showed a cyclicity of regressive depositional environments, with the depositional environments repeatedly changing from open water to swamps to peat bogs.

Buffetaut and others (1989) reported the discovery of mastodon remains referred to the genus *Stegolophodon* in the Mae Teep basin of northern Thailand. These fossils clearly indicate a Miocene age. They also reported that it is not possible to indicate an accurate age of this mastodon because of the insufficient nature of the remains. However they suggested an approximate age between 18 and 14 million years.

At Chiang Muan coal field, Kunimatsu and others (2000) reported that mine workers found proboscidean remains. Many of bone fragments were discovered in the lignite seams. Kunimatsu and others (2003; 2004) and Nakaya and others (2002; 2003) reported that the Thai-Japan paleontological expedition team discovered large-bodied hominoid fossils, hominoid cheek teeth (the first discovery from the Southeast Asian Miocene), as well as *Propotamochoerus* and/or *Hippopotamodon* and three individuals of the primitive tetralophodont gomphothere. The mammalian fauna from the Chiang Muan mine indicates the latest Middle Miocene age. Moreover, Kunimatsu and others (2004) reported the first Miocene hominoid fossil of the south of the Tropic of Cancer in Eastern Eurasia. Chiang Muan is the southernmost Miocene hominoid site in Eurasia. The Chiang Muan hominoid, cf. *Lufengpithecus chiangmuanensis* sp. (Chaimanee and others, 2003) indicate the latest Middle Miocene age. Pickford and others (2004) concluded that the age of the Chiang Muan homonoid, cf. *Lufengpithecus chiangmuanensis* sp. was originally estimated to be ca 13-13.5 Ma, based on faunal and palaeomagnetic correlation.

Watanasak (1988, 1989) concluded on the basis of pollen and spore content of core samples from a drill hole that the Mae Moh Group ranges in age from the base of the Early Miocene, SIAM-1 spore-pollen zone, to above the Middle Miocene, Siam-II spore-pollen zone. He correlated the lignite-bearing Q and K zones with the post-Siam-II zone, but still referred to them as Middle Miocene. Watanasak (1988) identified the age of the spore pollen zones through the association of microfloral assemblages with foraminifera and coccoliths in marine strata in the Andaman Sea.

Waton (1996) concluded the depositional environments by using palynological study of core samples from PH1 and PH2 drill hole of Phrae basin in northern Thailand. The palynofloras in the samples suggest dates of no older than Miocene, with later Neogene or Pliocene ages likely. The depositional environments represented by the samples from both wells appear to be very similar with a preponderance of continental lacustrine (deep and shallow water/ephemeral?) depositional settings. Tentative evidence from several samples, however, suggest the possibility of slight marine influences on deposition for those samples.

Songtham (2003) has been studied the stratigraphic correlation of Tertiary basins in northern Thailand by using algae, pollen, and spore. The presence of two palynological assemblages suggests that there was climatic change from a warm temperate to a tropical condition during the Oligocene to Miocene. The climate change occurred in the same period of ambient global temperature change. It was a global cooling period during Oligocene to early Early Miocene and changed to a late Early to Middle Miocene climatic optimum. The climatic change was probably also related to the extrusion tectonics of the Southeast Asian landmass. Southeastward movement of the landmass was induced by India-Eurasia collision and the position of the landmass successively changed from a warm temperate latitude to a tropical latitude during the Oligocene to Miocene.

Abundant occurrences of microscopic algae *Actinastrum, Botryococcus, Closterium*, and *Pediastrum* together with some forms of aquatic elements such as *Striatriletes susannae* and *Sporotrapoidites* indicate that sedimentation occurred in a freshwater environment. Reports of mangrove palynofloras and values of sulfur isotope from some horizons indicate that there was a marine incursion in northern Thailand during Miocene climatic optimum.