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Oligocene-Miocene Climatic Changes in Northern Thailand Resulting from Extrusion Tectonics of Southeast Asian Landmass

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ABSTRACT: Palynological research has been carried out on some Tertiary basins of northern Thailand including Mae Moh, Li, Na Hong, Mae Lamao, and Chiang Muan basins. Two main palynological assemblages are recognised, namely warm temperate and tropical. Warm temperate elements include common to abundant pollen of conifers such as *Pinus*, *Picea*, *Tsuga*, *Taxodium*, and *Sequoia* with rare occurrences of Podocarpaceae. Angiosperm pollen includes *Alnus*, *Betula*, *Carya*, *Engelhardia*, *Fagus*, *Ilex*, *Juglans*, *Liquidambar*, *Lonicera*, *Pterocarya*, and *Quercus*. These warm temperate elements are Oligocene to Early Miocene in age and resemble present pollen from trees growing in temperate, high latitude, northern hemisphere climates. Tropical elements include *Calophyllum* cf. *C. inophyllum*, *Crudia*, Dipterocarpaceae, *Lagerstroemia*, and *Radermachera*. These tropical pollen assemblages are of Middle Miocene and probably also Early Miocene age. These two assemblages, at two stratigraphic positions, suggest that climate in Thailand changed from temperate to tropical during Oligocene to Miocene time. The climatic change is postulated to have been caused by the southward to southeastward movement of the Southeast Asian landmass resulting from extrusion tectonics induced by the collision between the Indian and Eurasian continents beginning about 40 to 50 Ma years ago. The movement of the Southeast Asian landmass from temperate latitude to tropical latitude eventually led to the change of the vegetational patterns from temperate to tropical forests.

KEYWORDS: palynology, climate changes, extrusion tectonics.

INTRODUCTION

This paper is a progress report evaluating the occurrence of warm temperate and tropical floral elements in Tertiary deposits of northern Thailand. The presence of both warm temperate and tropical pollen in distinctly different stratigraphic positions strongly points to a climate change during the depositional period of these basins. These climatic changes clearly demonstrate that Thailand was in a warm temperate climate regime prior to a recent tropical climate condition that probably began in the Early to Middle Miocene.

The first report on floral remains was presented by a Japanese palaeobotanist who studied warm temperate macrofloral remains from the Li basin of Lamphun province.[1,2] Two decades later, this was confirmed by the occurrence of warm temperate elements from the Li basin (Ban Pu coal field) on the basis of palynology.[3-5] There was also record of temperate pollen from the Nong Ya Plong basin of Petchaburi province in central Thailand.[5] In addition, warm temperate palynological elements from the Na Hong basin in Chiang Mai province were recovered.[6] Most recently, there was report of warm temperate pollen assemblage from the same sedimentary sequences in Ban Pa Kha coal field.[7] These studies identified warm temperate assemblages dominated by conifers *Glyptostrobus*, *Picea*, *Pinus*, *Sequoia*, and *Taxodium* together with angiosperms *Alnus*, *Carya*, *Engelhardia*, *Fagus*, *Ilex*, *Juglans*, *Quercus*, and *Liquidambar*. These temperate elements dominate without tropical elements, or occasionally with small proportions of tropical pollen. Possibly, these floral assemblages, at most, represent a subtropical environment in the northern hemisphere, but not fully tropical as found today in northern Thailand and in tropical countries elsewhere. The occurrence of abundant warm temperate elements in the Tertiary sediments of northern Thailand is strong evidence for claiming that northern Thailand used to be occupied by a warm temperate climate during the Oligocene to Early Miocene periods.

Tropical palynological elements were also reported.[4,5] Tropical pollen is difficult to identify, even to a generic level. Their overall morphologies from genus to genus and species to species vary only slightly. Many sporomorphs are described and named in form genera and form species without reference to their botanical affinities. In particular, the tricolpate and tricolporate forms are usually named as Triporites and Tricolporites with the prefix terms indicating the surface ornamentation, for example, *Striatricolporites*, *Psilatricolpites*, *Baculatricolpites*, and so forth.

To improve sporomorph recognition of tropical pollen, we applied scanning electron microscopy (SEM) to investigate morphologies of both fossil and recent pollen. We selected the Li basin as a case study locality for developing the concept of climatic change history since the basin contains both temperate and tropical elements. The eastern part (Ban Pu and Ban Pa Kha coal fields) is dominated by Oligocene to Early Miocene warm temperate floral assemblages.[1-5,7] The western and southern parts (Mae Long sub-basin and Na Sai coal fields) are dominated by Middle Miocene tropical faunas.[8-13] Furthermore, the relative stratigraphic positions of the fossil assemblage-bearing formations have been proven by drilling.[14]

This paper discusses the occurrence of warm temperate and tropical floral assemblages, and proposes a cause of the climate changes during their deposition.

Materials and Methods

Fossil pollen specimens examined in this study were obtained from Tertiary fluvial-lacustrine sediments and coals from Ban Pa Kha and Na Sai coal fields together with samples from a small outcrop along an intermittent stream close to Mae Long reservoir, Mae Long sub-basin, in Lamphun province of northern Thailand (Figs 1, 2, 3). The sediments were first soaked with 48% HF to digest minerals under heating on the hotplate for 30 minutes. Thereafter, the residues (also coal samples) were then reacted with 2 ml concentrated HNO_3 with a few droplets of saturated potassium chlorate solution, $KClO_3$, to oxidise for 5 minutes at room temperature. After washing the residues with distilled water, 10% KOH solution was added then washed with distilled water. After that the residues were sieved to obtain 11 to 133 micron residues. The residues including sporomorphs were then permanently mounted with Eukit mounting media for light microscopic work. For SEM work, the sporomorphs were coated with a 30 nanometres layer of gold then run under SEM (Model JEOL JSM-5410) at the National Science and Technology Development Agency (NSTDA) in Pathumthani. The laboratory work was carried out at the Palynology Laboratory of the Department of Mineral Resources in Bangkok.

Geology

The Li Basin is located about 80 kilometres south of Lamphun Province (Fig 1). It extends some 55 kilometres in north-south direction, narrow in the north and widening toward the south to some 20 kilometres. The basin is bounded by Ordovician massive and laminated limestone and shale (Thung Song Group), Silurian-Devonian quartzite, quartz-schist, and phyllite (Don Chai Group), with some Carboniferous conglomerate, sandstone and shale, and Triassic diorite in the southern part (Fig 2). Gravity investigation indicates that the Li basin comprises a series of N-S trending horst and graben system derived from normal faulting. The western boundary of the basin is bounded by a set of large displacement normal faults showing a very steep basement profile. A large N-S trending horst plunging to the south can be traced continuously from a basement ridge near the northern margin closing to the western side of Ban Pu and Ban Hong coal deposits. The horst extends through the central part of the basin and ended at the southern margin in area closing to the western side of Na Sai coal deposit. This basement horst separates the Li basin into two sub-basins, the Western and Eastern sub-basins.[15] The basin is considered to be a rift basin formed under approximately east-west extension with at least five episodes of predominantly NNW-SSE to NE-SW oriented compression interrupted the extensional development of the basin. The compression was probably related to the extrusion tectonic of the Himalayan orogeny.[16,17]

The Tertiary deposits in the basin has been named “Li Group” comprising two formations, namely the Paleogene Li Formation and the Neogene Mae Moh Formation.[14] In this study, the two formations are renamed for practical reasons on the basis of the International Stratigraphic Guide. The reason is because the “Li Group” should not contain the “Li Formation” and the word “Mae Moh” is derived from the Mae Moh Basin in Lampang Province.[18] This renaming is an attempt to avoid confusion in using the geographic names. The underlaying Li Formation is changed to Ban Pa Kha Formation. The overlaying Mae Moh Formation is changed to Mae Long Formation (Fig 3).[19]

The Ban Pa Kha Formation is mainly exposed in some coal mines in the eastern part of the basin including Ban Pu, Ban Hong, Ban Na Klang, Mae Long Bok, and Ban Pa Kha coal fields (Figs 2, 4). This forma

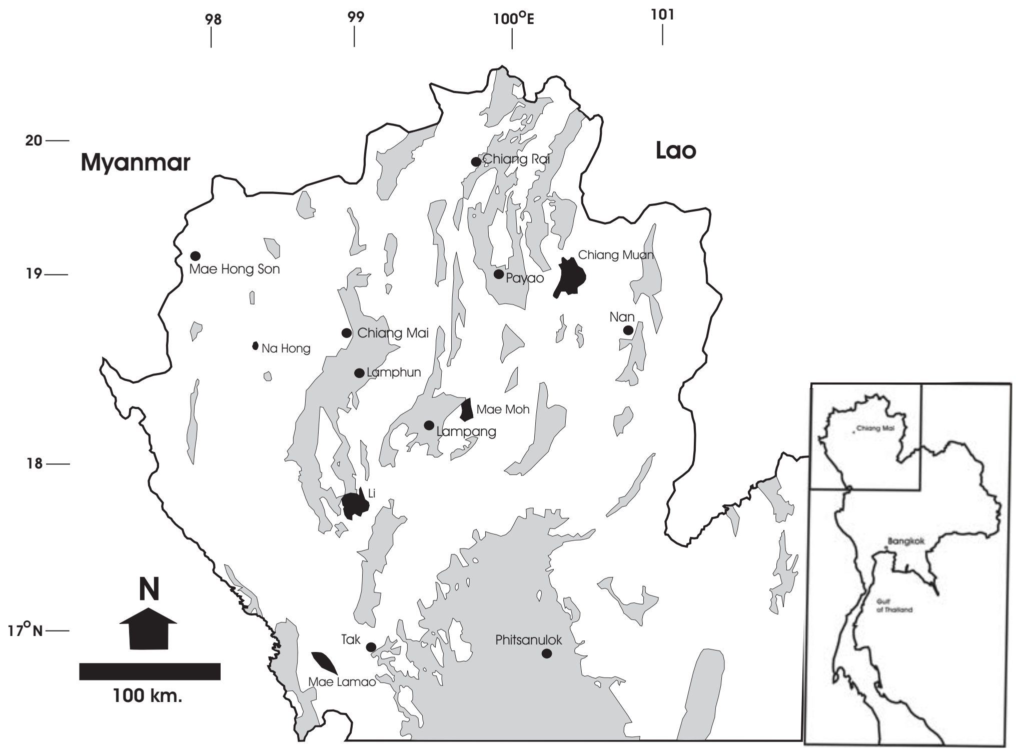

Fig 1. Map showing Cenozoic basins in northern Thailand and location of five basins in this research.

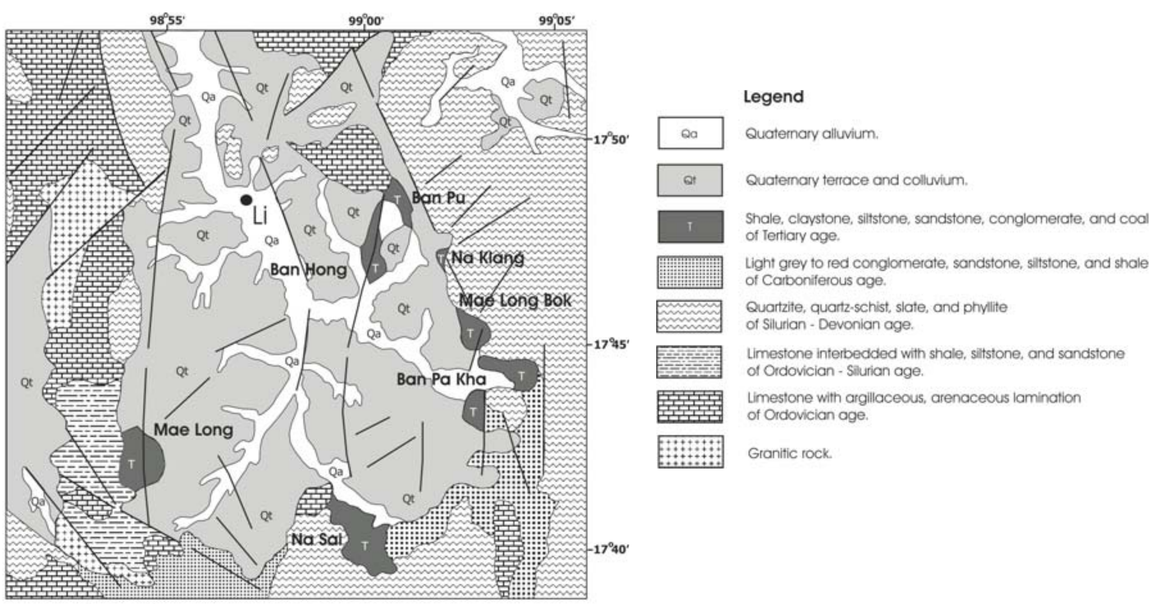

Fig 2. Map showing geological features in the Li basin and vicinity areas.[15]

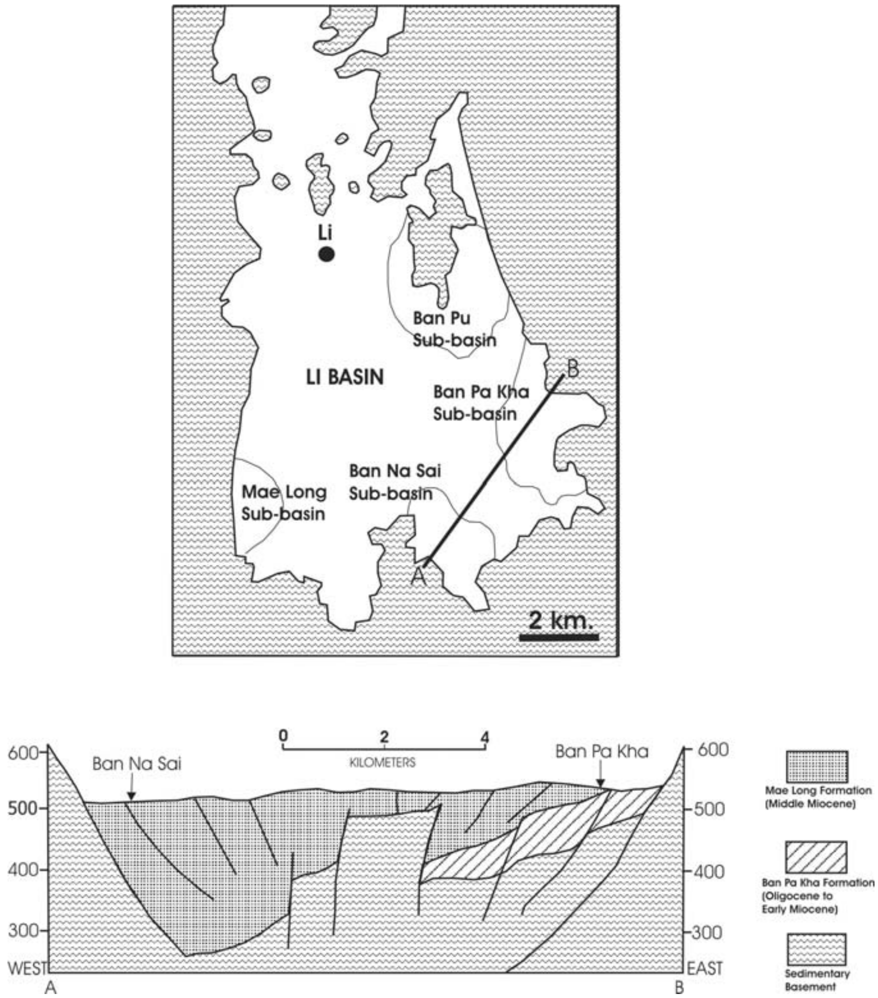

Fig 3. Map of Li basin containing four sub-basins and geological cross section via Ban Na Sai and Ban Pa Kha showing Ban Pa Kha and Mae Long Formations.[14]

tion consists of both fluvial and lacustrine sediments that include sanstone, claystone, oil, shale and coal.[15,20,21] Stratigraphic successions from Ban Pa Kha, Ban Na Klang, and Ban Pu are correlatable by green sand/sandstone horizons as a key marker corresponding to the concentration of some significant elements derived from basic igneous rocks.[22] Elementary analyses of the coal were reported from Ban Pu, Ban Hong, and Ban Pa Kha, showing ash contents of 2.80, 2.92, and 4.27%, respectively.[23] There are numerous reports on the occurrence of fossil floras including leaves, cones, scales, and sporomorphs, strongly suggesting warm temperate floras belonging to Oligocene to Early Miocene age.[1-5,7] No indicative vertebrate remains have been reported from this formation.

The Mae Long Formation was first named and described in 1990.[19] It is characterised by thin laminated sediments or the so-called “Paper-Shale” lying on top of mudstone and coal seam (Fig 5). The type section at Mae Long Reservoir extends to Na Sai coal field and this can be divided into coal-bearing and paper-shale bearing parts. Elementary analysis of the coal was reported from Na Sai, with ash content being 42.57%.[23] Numerous vertebrate remains were reported from both Mae Long and Na Sai localities including fish, bird, snake, turtle, otter, rodent, pig, elephant, rhino and deer, suggesting Middle Miocene and perhaps including upper Early Miocene tropical faunas.[8-13]

Palynological Evidence

Palynological identification in this study are identified as temperate and tropical, to represent forms of the fossil sporomorphs. This application has been kept in the relative sense regarding the sporomorphs as temperate and tropical groups. The two distinctive characteristics of the fossil pollen are recognisable on the

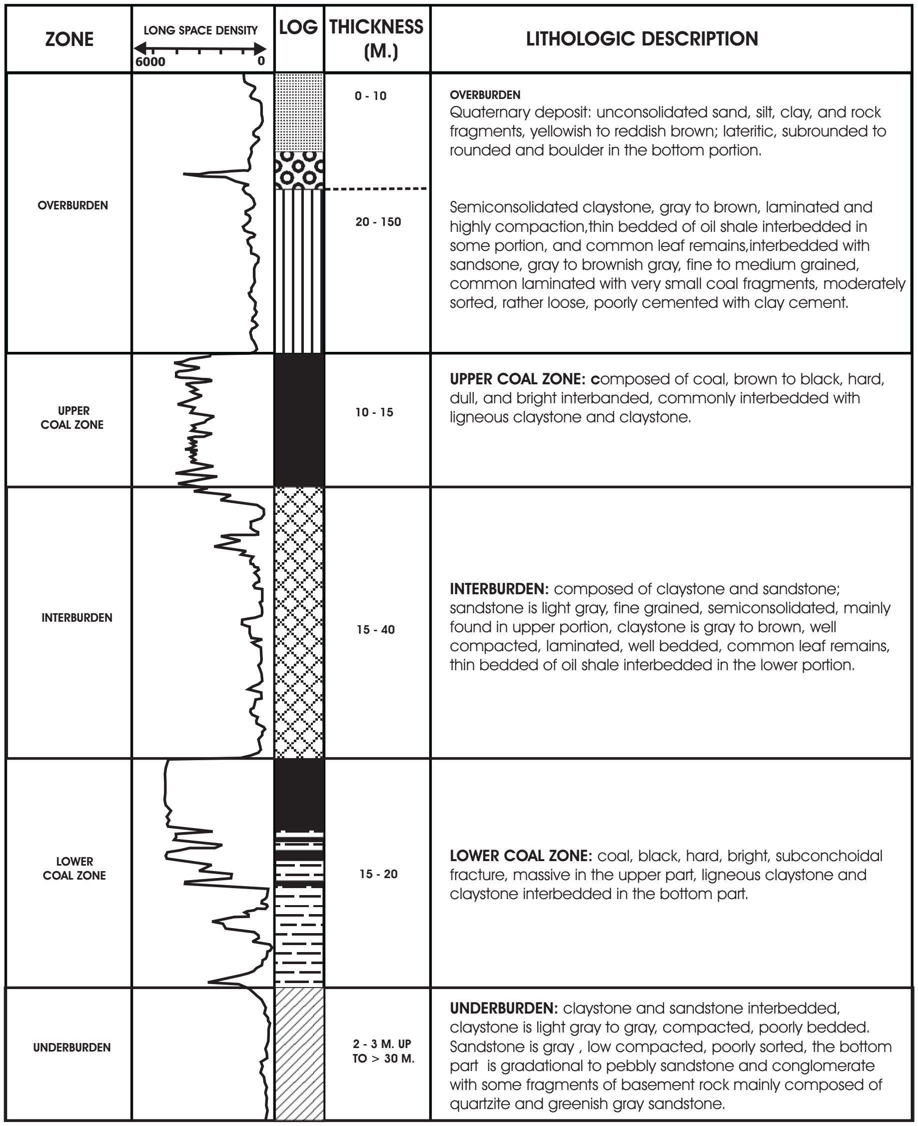

Fig 4. Schematic stratigraphy of Ban Pa Kha Formation at Ban Pa Kha Coalfield.[21]

basis of comparison between the fossil and recent pollen. One is attributable to temperate pollen and another one is tropical pollen. This is to use the fossils as representatives in reconstructing the plant communities in the past and understanding the climate change history during the basin formation. Some of common to abundant sporomorphs are illustrated on Table 1 and are described below and some important forms are shown in Plate I.

Temperate Elements

Piceaepollenites Potonié is a bisaccate pollen, comparable to extant conifer *Picea* pollen of the family Pinaceae. The *Picea* today occurs throughout the northern hemisphere in the temperate region. It is now extinct in Thailand.

Pinuspollenites Raatz is a bisaccate pollen, attributable to extant conifer pollen *Pinus* of the family Pinaceae. These *Pinus* are in the northern hemisphere, occurring mainly in northern temperate regions, extending from America and eastern Asia to the seasonal tropics. There are two native species , *Pinus merkusii* and *Pinus kesiya*, that still survive in the mountainous areas of northern, northeastern, and western Thailand.[24] These two species are considered to be a remnant of the temperate climate *Pinus* that used to occupy the regions.

Taxodiaceaepollenites Kremp ex Potonié is characterized by a spheroidal shape with thin exine which normally appears in flat grain and broken. The form is

Table 1. Warm temperate and tropical pollen from Ban Pa Kha and Mae Long Formations.

	Warm temperate pollen															Tropical pollen				
	Piceaepollenites	*Pinuspollenites*	*Tsugaepollenites igniculus*	*Taxodiaceaepollenites*	*Alnipollenites verus*	*Caryapollenites simplex*	*Faguspollenites*	*Ilexpollenites iliacus*	*Juglanspollenites*	*Liquidambarpollenites stigmosus*	*Loniceraepollenites*	*Momipites coryloides*	*Pterocaryapollenites*	*Quercoidites*	*Ulmipollenites*	*Calophyllum cf. C. inophyllum*	*Crudia*	*Dipterocarpaceae*	*Lagerstroemia*	*Radermachera*
Mae Long Formation (Middle Miocene)																X	X	X	X	X
Ban Pa Kha Formation (Oligocene-Early Miocene)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					

Table 2. Elementary analysis of Tertiary Thai coals.[23]

Coal deposit location	Floras and Faunas	Weight percent of elementary analysis					
		Ash free basis					Ash
		H	C	N	O	S	
1. Na Sai, Li, Lamphun	Tropical	5.90	55.81	1.81	33.65	0.99	42.57
4. Na Hong (seam K), Chiang Mai	Warm temperate	5.13	61.13	0.51	32.63	0.43	0.68
5. Na Hong (seam B), Chiang Mai	Warm temperate	4.31	55.97	0.58	38.43	0.64	0.96
6. Ban Pu, Li, Lamphun	Warm temperate	4.11	49.57	0.25	44.56	1.15	2.80
7. Ban Hong, Li, Lamphun	Warm temperate	4.81	57.94	0.31	36.34	0.53	2.92
8. Ban Pa Kha, Li, Lamphun	Warm temperate	4.98	62.13	0.62	32.05	0.52	4.27
9. Nong Ya Plong, Petchaburi	Warm temperate	4.65	69.12	0.84	23.02	0.93	3.87

comparable to the extant conifer family Taxodiaceae including various genera viz. *Taxodium*, *Sequoia*, *Metasequoia*, *Sequoiadendron*, and *Cryptomeria*. They were widespread throughout the world in Pliocene times but are now restricted to the Sierra Nevada of California. There are reports about the occurrence of Dawn Redwood *Metasequoia* from Central China.

Tsugaepollenites igniculus Potonié is a monosaccate pollen with saucer-like form comparable to modern pollen of the conifer *Tsuga* of the family Pinaceae. The extant *Tsuga* occurs in the temperate regions of North America and eastern Asia. It is now extinct in Thailand.

Alnipollenites verus Potonié is a unique pollen and is easy to recognize. It is a polyporate pollen normally having five vestibulate pores but there are also four and six pores with arci connecting between the nearby pores. Its morphologic pattern is very similar to extant pollen of the genus *Alnus* of the family Betulaceae. The *Alnus* pollen come from deciduous trees and shrubs that are predominantly natives of the north-

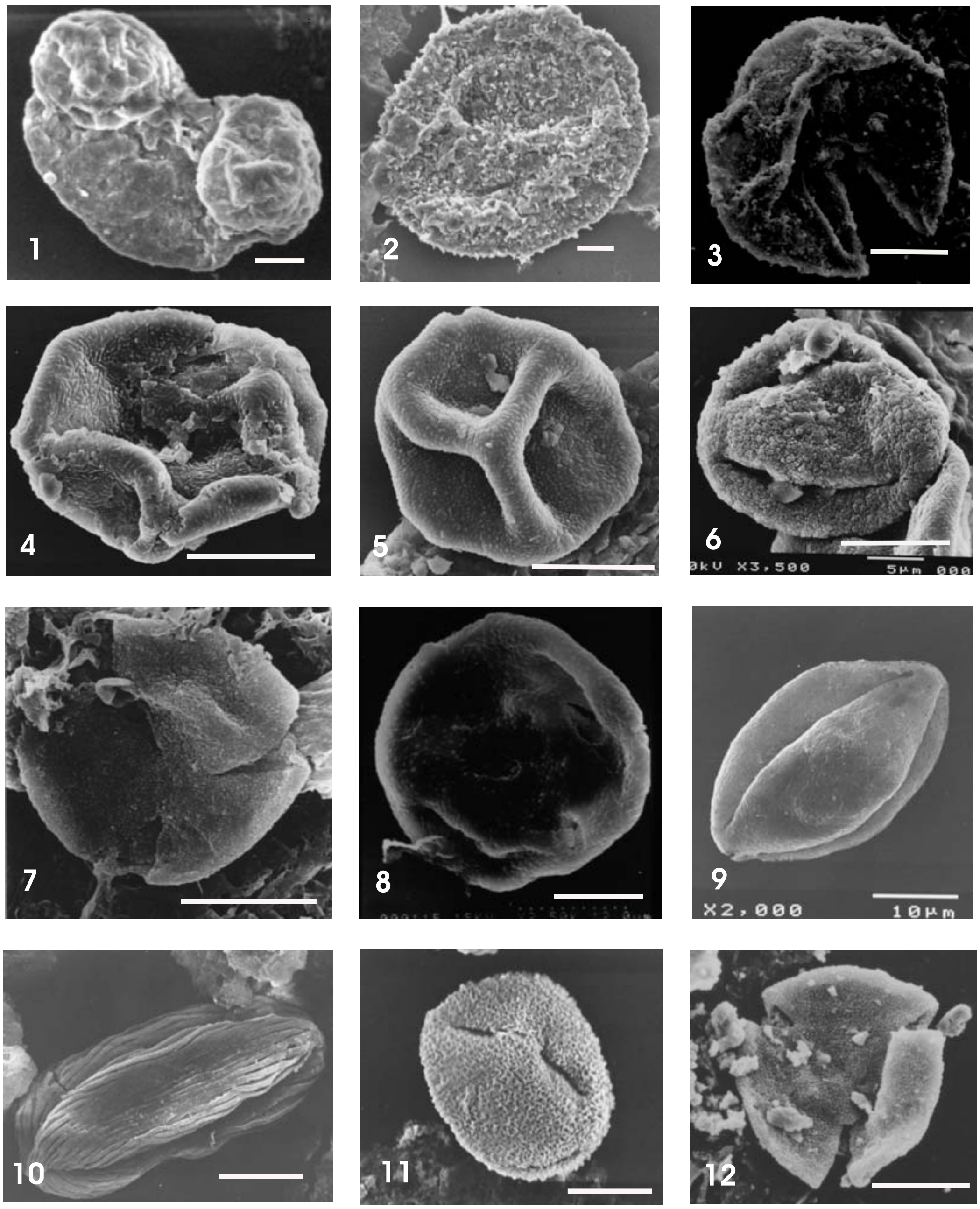

Plate I: figure 1 *Pinuspollenites* sp. from Ban Pa Kha, figure 2 *Tsugaepollenites igniculus* from Ban Pa Kha, figure 3 *Taxodiaceaepollenites* sp. from Ban Pa Kha, figure 4 *Alnipollenites verus* from Ban Pa Kha, figure 5 *Momipites coryloides* from Ban Pa Kha, figure 6 *Quercoidites* sp. from Ban Pa Kha, figure 7 *Faguspollenites* sp. from Ban Pa Kha, figure 8 *Liquidambarpollenites stigmosus* from Ban Pa Kha, figure 9 *Radermachera* sp. from Ban Na Sai, figure 10 *Crudia* sp. from Ban Na Sai, figure 11 *Calophyllum* cf. *C. inophyllum* from Ban Na Sai, figure 12 *Homonoia* sp. from Mae Long. (all scale bars are 10 microns)

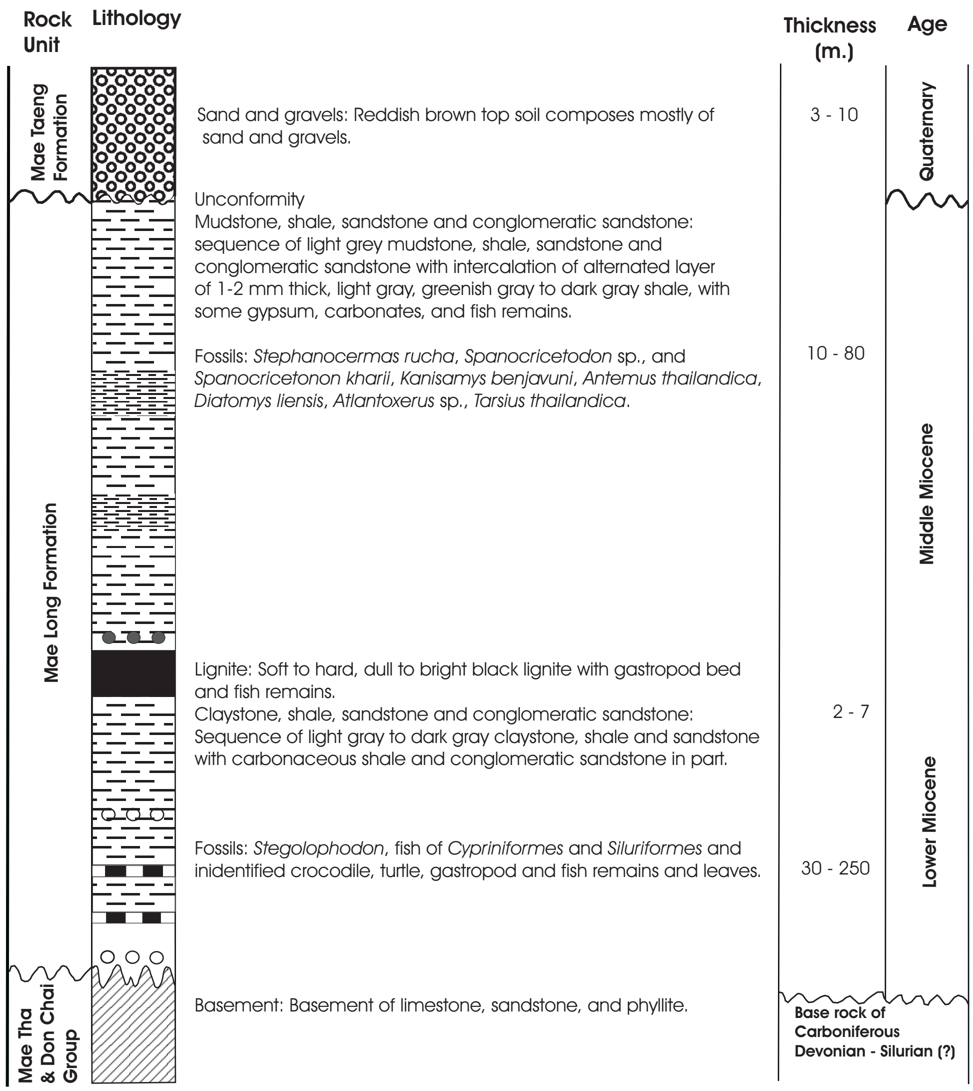

Fig 5. Schematic stratigraphy of Mae Long Formation at Na Sai Coalfield.[19]

ern temperate region. However the genus extends south to the Andes of South America, to Himalayan, and South Europe. The genus is mainly characteristic of cool climates, as well as being moisture loving. A few sporadic trees of *Alnus nepaulensis* have been observed recently along the sandstone cliff of Phu Luang Wildlife Sanctuary in northeastern Thailand.

Juglandspollenites verus Raatz is periporate pollen comparable to extant pollen of *Juglans* of the family Juglandaceae. There are twenty-one species occurring mainly in the northern temperate region but extending to the tropics, and are native to Asia and America.

Liquidambarpollenites stigmosus Raatz is a periporate pollen comparable to extant pollen of *Liquidambar* of the family Hamamelidaceae. There are four species of trees and shrubs occurring in the temperate areas of western North America, Asia Minor, and eastern Asia.

Momipites coryloides Wodehouse is triporate pollen. At the polar view, it is characterized by more or less triangular in outline with pore at each apex. This pollen's characteristics are very similar to extant pollen of genus *Corylus* and *Engelhardia*. This form of sporomorph occurs in association with *Alnipollenites verus*. It is therefore thought to be the temperate element.

Apart from the fossil sporomorphs mentioned above, other rare forms that are indications of temperate elements are also found. These rare forms include *Caryapollenites simplex* (*Carya*-type), *Fagus-pollenites* (*Fagus*-type), *Ilexpollenites iliacus* (*Ilex*-type), *Loniceraepollenites* (*Lonicera*-type), *Pterocaryapollenites* (*Pterocarya*-type), *Quercoidites* (*Quercus*-type), and *Ulmipollenites* (*Ulmus*-type) together with several forms of pteridophytic spores like *Laevigatosporites ovatus*, *Polypodiisporites* spp., and *Polypodiaceoisporites retirugatus*.

Tropical Elements

Fossil sporomorphs assigned as tropical elements are identified on the basis of comparison between the fossils and recent species. The names of the fossils used herein informally follow the natural names.

Calophyllum is tricolporate form comparable to recent pollen of *Calophyllum inophyllum* of the family Guttiferae. It is native to central and southern Thailand as well as Southeast Asia region both mainland and archipelago. It normally occurs in the coastal areas in association with *Thespesia populnea* of the family Malvaceae.

Crudia is tricolporate sporomorph with striate surface ornamentation comparable to extant pollen of *Crudia* belonging to the family Caesalpiniaceae. There are fifty-five species of *Crudia* occurring in tropical areas. The recent pollen used for comparison came from *Crudia chrysantha*. The species occurs throughout in Thailand as well as the Southeast Asia region.

Dipterocarpaceae is a big family with pollen having tricolpate form. There are probably eighteen genera and four hundred and fifty species but this may change with future taxonomic work. They predominantly occur in Southeast Asia region but also in India, Sri Lanka, and a genus in Africa in tropical areas. There are reports on the occurrence of a dipterocarpaceous twig from the Eocene London Clay in England.[25,26] This is probably because England during Eocene time was in tropical area as the occurrence of the *Spinizonocolpites* sporomorphs that are comparable to a mangrove palm *Nypa fruticans*.[27]

Lagerstroemia is tricolporate sporomorph with very thick exine. It is comparable to the genus *Lagerstroemia* of the family Lythraceae consisting of fifty-three species native to tropical areas of South Asia and Australia.

Radermacera is sporomorph from Na Sai coal field, having very similar morphology to recent pollen of *Radermachera ignea* of the family Bignoniaceae. The recent species grow in tropical to subtropical regions. It scatters in both evergreen and deciduous forests in northern Thailand, South China (Yunnan), Myanmar, Lao, and northern Vietnam.

Homonoia is tricolporate pollen with finely granulate surface ornamentation. It always occurs close to stream often in large colonies in northern Thailand, Myanmar, and India.

Various forms of sporomorphs from Na Sai and Mae Long localities are still indeterminate. Recent pollen need more study for comparison with the fossil forms.

Freshwater Elements

Pediastrum Meyen is characterised by flat wheel-like coenobium, comparable to extant freshwater multicellular colonial green alga of the family Hydrodictyaceae. The fossil coenobia consist of several different forms that are comparable to extant species like *Pediastrum simplex*, *P. duplex*, *P. boryanum*, and so on. The *Pediastrum simplex* form is dominant. Coal samples from upper part of the upper coal seam from Ban Pa Kha yielded abundantly the *Pediastrum* in association with some *Botryococcus* form. These fossils strongly suggest that sedimentation occurred in a lacustrine environment, e.g. pond, lake, and river.

Botryococcus Kützing is multicellular colony with densely clustered cups. These characteristics are well defined in a form of microscopic freshwater alga *Botryococcus* of the family Botryococcaceae. This form was found in both Ban Pa Kha and Na Sai coalfields.

Magnastriatites grandiosus Dueòas is a trilete spore with striate surface ornamentation, comparable to extant spore of aquatic fern *Ceratopteris thalictoides* of the family Parkeriaceae. This fern occurs in freshwater environment in tropical to sub-tropical areas.

Sporotrapoidites Klaus is a triporate form with three meridional crests connecting from pole to pole forming Y marks clearly visible in polar views. These characteristics are attributable to extant pollen of *Trapa* of the family Trapaceae (Hydrocaryaceae) that occurs in quiet freshwater ponds in both tropical and temperate regions.

Cause of Climatic Change

The warm temperate and tropical floral elements found in the Tertiary sediments of the Li basin, northern Thailand, are significant evidence of a major climatic change during Oligocene to Miocene. We could not find any published evidence of such a dramatic climate change from countries now situated at the same latitude as Thailand, namely Laos, Vietnam and Myanmar. There is no report on fossil leaves, wood, or sporomorphs from the Oligocene - Miocene sediments of Laos and Vietnam. There are some reports from Myanmar of Neogene tropical wood remains.[28-32] On the other hand, hundreds of reports were from India and Nepal. Fossil leaves, wood, and pollen from Tertiary sediments of the Indian subcontinent are definitely tropical, recovered from Paleocene to Recent deposits.[33-44] This difference in Tertiary floral assemblages between Thailand and India has great significance in plate tectonics. The extrusion tectonic model proposed by Tapponnier and others explains this difference.[45,46]

The Indian subcontinent broke from the southern hemisphere Gondwana supercontinent during the Late Mesozoic, about 132 Ma years ago[47,48] then rapidly moved northward at a rate of about 10 to 18 centimetres a year.[49] Early in the Tertiary period, India passed into the latitudinal range of the tropics[50] colliding with the Eurasian continent around 40 to 50 million years ago[51-53] and that probably explains why the Tertiary sediments in the Indian subcontinent yield only tropical elements.This collision brought the Indian and South Asian/Sundanian floras, which lay in the same climatic zone, into direct contact. The Indian flora seems to have been the more aggressive of the two, with wholesale dispersal into the Southeast Asian region.[54] The India-Eurasia collision set up a series of chain reactions and caused the formation and destruction of sedimentary basins within the region of the collision belt.[50] The rigid indenter India collided with the plastic Eurasia[45] resulting in uplifting of the Hima-

Fig 6. Schematic map of Cenozoic extrusion tectonics and large faults in eastern Asia. Heavy lines are major faults or plate boundaries; thin lines are less important faults. Open barbs indicate subduction; solid barbs indicate intracontinental thrusts. White arrows represent qualitatively major block motions with respect to Siberia (rotation are not represented).[45,46]

layan ranges and the Tibetan plateau, and the formation of a number of large strike slip fault zones.[55] With respect to Thailand and Southeast Asia in general, the nearby Ailao Shan - Red River (ASRR) fault zones which demarcate the South China and Indochina blocks[56,57] is relevant. The Southeast Asian landmass (Sundaland) was confined within two large strike slip fault zones, left lateral ASRR fault zone, extending from Tibet to South China Sea (left lateral in Tertiary but right lateral in Quaternary[46,56]) and right lateral Sagaing fault zone, a N-S trending fault passing through central Myanmar (Fig 6). The force from the India-Eurasia collision induced the extrusion of the Southeast Asian landmass moving southward to southeastward with simultaneous clockwise rotation.[46] The offset between the South China and Indochina blocks, along the Red River fault zone, was estimated to be at least 800 kilometres and probably up to 1000 kilometres.[45] The surface area loss due to the extrusion amounts to about 830,000 km^2 with about 640,000 km^2 and about 190,000 km^2 due to movement along the Ailao Shan – Red River and Wang Chao – Three Pagodas fault zones respectively.[56] The extrusion of the Southeast Asian landmass is postulated to have been from a high latitude to a low latitude position. This mechanism is proposed as the reason for the change in vegetational patterns during the Oligocene to Miocene from a warm temperate to a tropical forest in northern Thailand.

Discussion

Fossil plants are reliable indicators of past climates particularly if related and comparable to modern taxa. This is attributable to the principle that vegetational complexes of the past had environmental requirements that are similar to their modern counterparts except where it can be demonstrated otherwise. Environmental interpretations deduced from individual taxa become more convincing when the floristic complex includes a number of taxa with similar ecological requirements, thereby highlighting a characteristic natural biome.[58] Despite this, there are some reports[59,60] where fossil and modern pollen which have identical morphologies are shown to differ in ecological habitats with time. An individual taxon usually flourishes within a specific ecological tolerance, but through time can change its phytogeographic range without changing its biological characteristics. Nevertheless, for the Tertiary period, we take into account the whole pollen assemblages together with other related components such as leaves, wood, faunas, sedimentological features, and geochemical analyses in determining the palaeoenvironment.

Sporomorphs, used in this study, are a very small part of the total plant and often are conservative in morphology. It is possible that the parent plant can change morphology and ecological tolerances without the associated pollen changing its morphology. As such we have identified sporomorphs to the generic level when compared to recent taxa, on the basis of their morphology. Examination of our pollen assemblages has revealed two distinctive groups when compared to modern plant communities. One assemblage is tropical and the other is warm temperate, and the overlap between these two different ecological assemblages is slight. Warm temperate assemblages have few tropical taxa present, but tropical assemblages can have more temperate taxa present as a result of wind dispersal of pollen from the north and from uplands in the region of the basins of deposition. Because some temperate flowers and cones produce huge quantities of pollen these are often widely dispersed by wind. Conifer pollen like *Pinus* is cosmopolitan in the fossil records. Some species of *Pinus* also grow today in tropical regions in Thailand, Sumatra, and Philippines on mountainous areas.[24] Muller also discussed the occurrence of *Pinus* pollen in recent submarine sediments in the South China Sea.[61] Nevertheless, the tropical assemblages from the Tertiary sediments of northern Thailand contain few temperate sporomorphs and the components of the assemblage are well represented in the same plant communities in the present lowland tropical rainforests of northern Thailand.

Recognition of the temperate and tropical element-bearing formations is probably useful in preliminary evaluating the coal quality. As preliminary assessment, temperate formations seem to yield higher coal quality than those the tropical formations as demonstrate on Table 2. This perhaps results from the original sources, temperate plants are suitable materials for higher lank coalification than the tropical plants. Ash contents of coal from temperate coal formations including Na Hong, Ban Pu, Ban Hong, and Ban Pa Kha are relatively low, ranging from 0.68 to 4.27%. Meanwhile, ash contents from tropical coal formation from Na Sai is relatively high up to 42.57%. However, this observation needs more research to establish the actual relationship between the temperate and tropical formations and the coal qualification.

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