ScienceAsia 30 (2004): 171-181

New species of algae *Actinastrum lagerheim* and *Closterium nitzsch* ex Ralfs from Middle Miocene Sediments of Chiang Muan basin, Phayao, Thailand, with tropical pollen composition

Wickanet Songtham,[a,b,*] Benjavun Ratanasthien[a] and Dallas C Mildenhall[c]

[a] Department of Geological Sciences, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand.
[B] Bureau of Geological Survey, Department of Mineral Resources, Rama VI Road, Ratchathevee, Bangkok 10400, Thailand.
[C] Institute of Geological and Nuclear Sciences, P.O. Box 30-368, Lower Hutt, New Zealand.

[*] Corresponding author, E-mail: wickanet@dmr.go.th

Received 23 May 2003
Accepted 24 Dec 2003

ABSTRACT: Two forms of algae were described including *Actinastrum bansaense* n. sp. and *Closterium thailandicum* n. sp. They occurred abundantly in some sedimentary horizons of Middle Miocene age from Chiang Muan basin. Abundant occurrence of the two algal species with some rare forms of algae *Botryococcus* and *Striatriletes susannae* aquatic fern spores reveals that the Chiang Muan basin formation occurred in a freshwater depositional environment. Abundant spores of *Crassoretitriletes vanraadshoovenii* (*Lygodium microphyllum*-type) were also recovered with common Dipterocarpaceae, *Lagerstroemia*, *Ilexpollenites*, *Myrtaceidites*, and Combretaceae with rare forms of *Florschuetzia*, *Homonoia*, *Calophyllum*, *Striatriletes susannae*, *Botryococcus* and Mimosaceae. There are abundant *Laevigatosporites haardtii* fern spores in some horizons with various forms of as yet unidentified tricolporate and tricolpate pollen. Three acme palynological zones were established and used for describing variation in paleoenvironment through time of sedimentation. The sporomorphs representing tropical palynofloras derived from tropical monsoon forests, accumulated mainly in lacustrine depositional environments. Origins and distributions of the families Dipterocarpaceae and Myrtaceae are discussed and criticised and new criteria elucidating their paleophytogeographic histories in relation to northern Thailand are proposed.

KEYWORDS: new species, freshwater algae, palynology, Middle Miocene, northern Thailand.

INTRODUCTION

The history of vegetation change in northern Thailand has been mainly based on palynological and paleobotanical studies.[1-10] Major climatic fluctuations are recorded by major vegetation changes from Oligocene through Miocene time.[6,9,10] Northern Thailand is considered in a tropical region. Tropical monsoon forests mainly occupy lowland areas with some warm temperate forests on mountainous areas recognisable as successive overlapping altitudinal ranges of various plant species. However, both latitudinal and altitudinal geographic settings control the occurrence and distribution of tropical forests and warm temperate plant species. The first indication that northern Thailand used to have a warm temperate climate was determined on the basis of macrofloral remains – leaves, catkins, cones, and scales – found in assumed Paleogene sediments from the Li Basin.[1-3] Thereafter, several palynological studies confirmed this.[4-10] On the basis of both palynology and vertebrate palaeontology it was determined that tropical forests also occurred in northern Thailand at least as early as late Early Miocene. These types of fossil material, pollen, spore and vertebrate remain, are reliable and provide acceptable clues to the understanding of plant and animal communities within particular depositional environments.

Chiang Muan basin is a Cenozoic basin (Fig 1) in Chiang Muan District of Phayao Province. It has a north-south elongated shape and is located between 100° 10' and 100° 25' east longitude and 18° 45' and 19° 05' north latitude (Fig 2). The basin contains Middle Miocene sediments overlain by Quaternary deposits.[12] The basin is bounded by Pre-Tertiary rocks including Jurassic sandstone, siltstone, shale, and redbed formations with some Triassic clastic rocks exposed in the south. There are some Jurassic rhyolite, tuffaceous

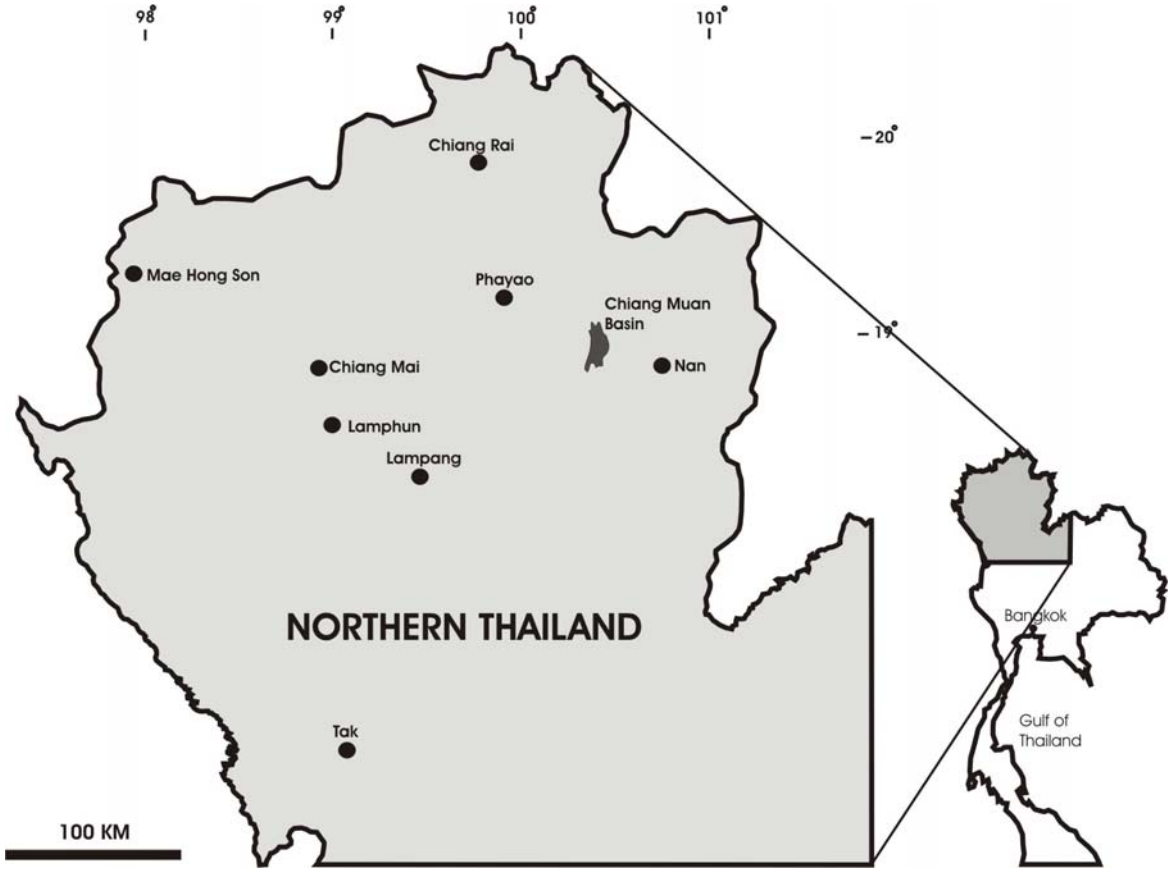

Fig 1. Map of northern Thailand showing location of Chiang Muan basin.

shale, and sandstone outcrops along the western flank of the basin (Fig 2).

Tertiary sediments consist of a series of claystone, sandstone, ligneous claystone, and coal layers with common vertebrate and plant remains. Abundant gastropod molluscs occur in some horizons, as seen in Chiang Muan coal mine in Ban Sa, in the northwest of the basin. The formation includes coal measures exploited for a cement factory in Saraburi Province. Various forms of vertebrate remains have been reported, including primate, proboscidean, rhinoceros, pig, barking deer, deer, bovid, bird, reptile, and many indeterminate forms.[11] Presence of a new primate species, *Lufengpithecus chiangmuanensis*, was claimed as an ancestral orangutan ape.[12] Age of the sediments is thought to be late Middle Miocene, between 13.5 and 10 Ma yrs, on the basis of magnetic polarity changes.[12]

We present evidence for tropical late Middle Miocene palynological assemblages in Chiang Muan basin and establish three new palynological acme zones to help elucidate changes in the depositional environment. Two new species of freshwater algae are described. Some ideas on floristic development of the late Middle Miocene forests are also presented.

Materials and Methods

Twenty-four coal and sedimentary samples were collected from outcrops in the Chiang Muan coal mine. About 5 grams of each sample was first soaked with 48% HF to digest minerals under heating on the hotplate for 30 minutes. The residues (also coal samples) were treated with 2 ml concentrated HNO_3 with a few droplets of saturated sodium chlorate solution, $NaClO_3$, 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 microns fractions. The 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 examined under an SEM (Model JSM-5410) at the National Science and Technology Development Agency (NSTDA) in Pathumthani. The laboratory work was carried out at the Palynology

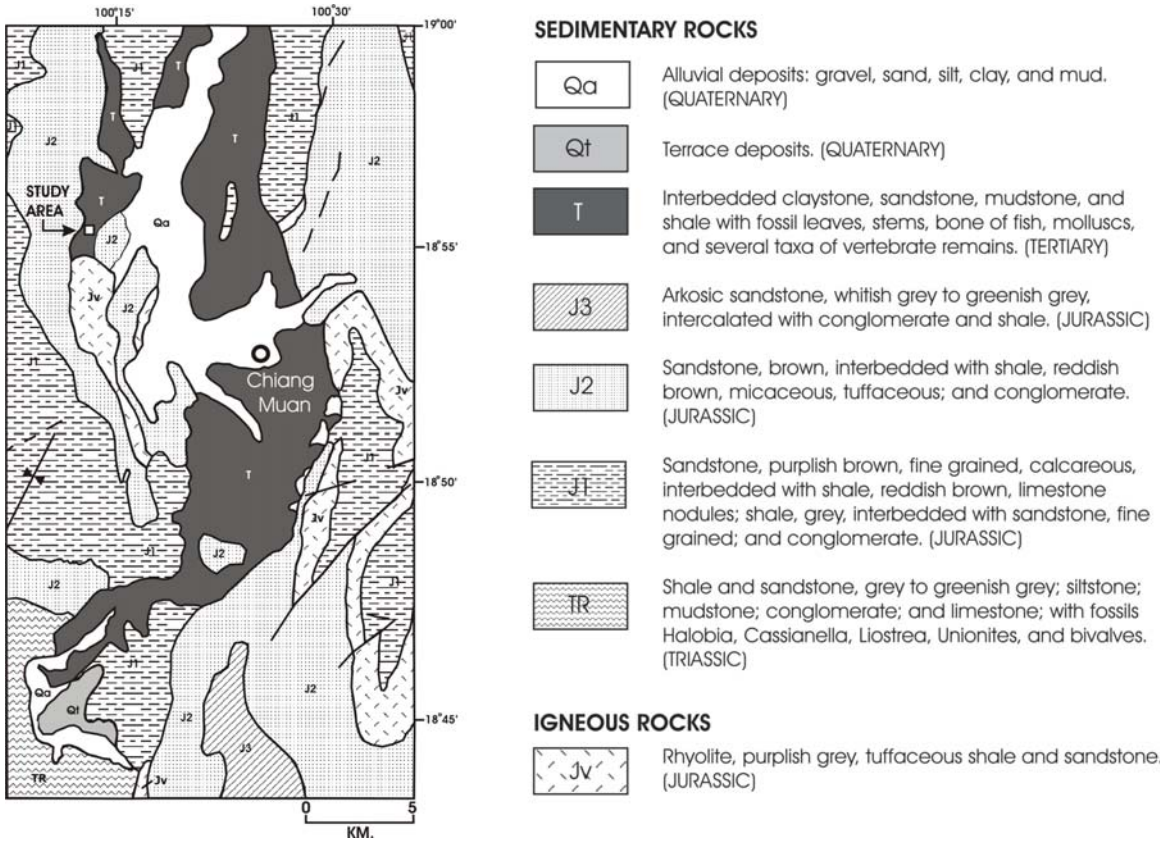

Fig 2. Geological map of Chiang Muan basin.[44]

Laboratory of the Department of Mineral Resources in Bangkok.

Systematic Palynology

The systematic section of the paper involves description of some important freshwater palynomorphs including *Actinastrum bansaense* n. sp., *Closterium thailandicum* n. sp., which occur abundantly in some samples. It also includes discussion on *Crassoretitriletes vanraadshoovenii* Germeraad, Hopping, and Muller. Other forms of palynomorph will not be described but will be cited in the text and some are illustrated. Please refer to diagramme in Fig 3, locations of the sample collected and pollen counts are shown in Table 1.

Colonial green algae

Order: CHLOROCOCCALES
Family: SCENEDESMACEAE

Some authors place *Actinastrum* into a separate family, Coelastraceae, with close affinities to *Scenedesmus*.[13-15]

Genus ***Actinastrum*** Lagerheim, 1882

Actinastrum bansaense Songtham, Ratanasthien, and Mildenhall, n. sp.
Plate 1, figs 1-2

Etymology: Name of a village, Ban Sa, where the fossils were first found.
Holotype: slide no. CM-37a; co-ordinates N19/3 (England reference).
Paratype: slide no. CM-37a; co-ordinates N20/3, S21/3 (England reference).

Description: The species is characterised by a shuttle-like or cigar-like cell body. It is swollen in the middle portion and tapers to both sides with blunt ends. The cell length between both ends ranges from 20 to 37 μm; the cell width in the middle portion of the cell body ranges between 7 to 13μm. Surface ornamentation is smooth. Twenty specimens were measured.

Remarks: The fossil form is comparable in its general morphology to the extant freshwater green alga *Actinastrum*, family Scenedesmaceae[16]. However, when compared with *Actinastrum gracillimum* Smith and

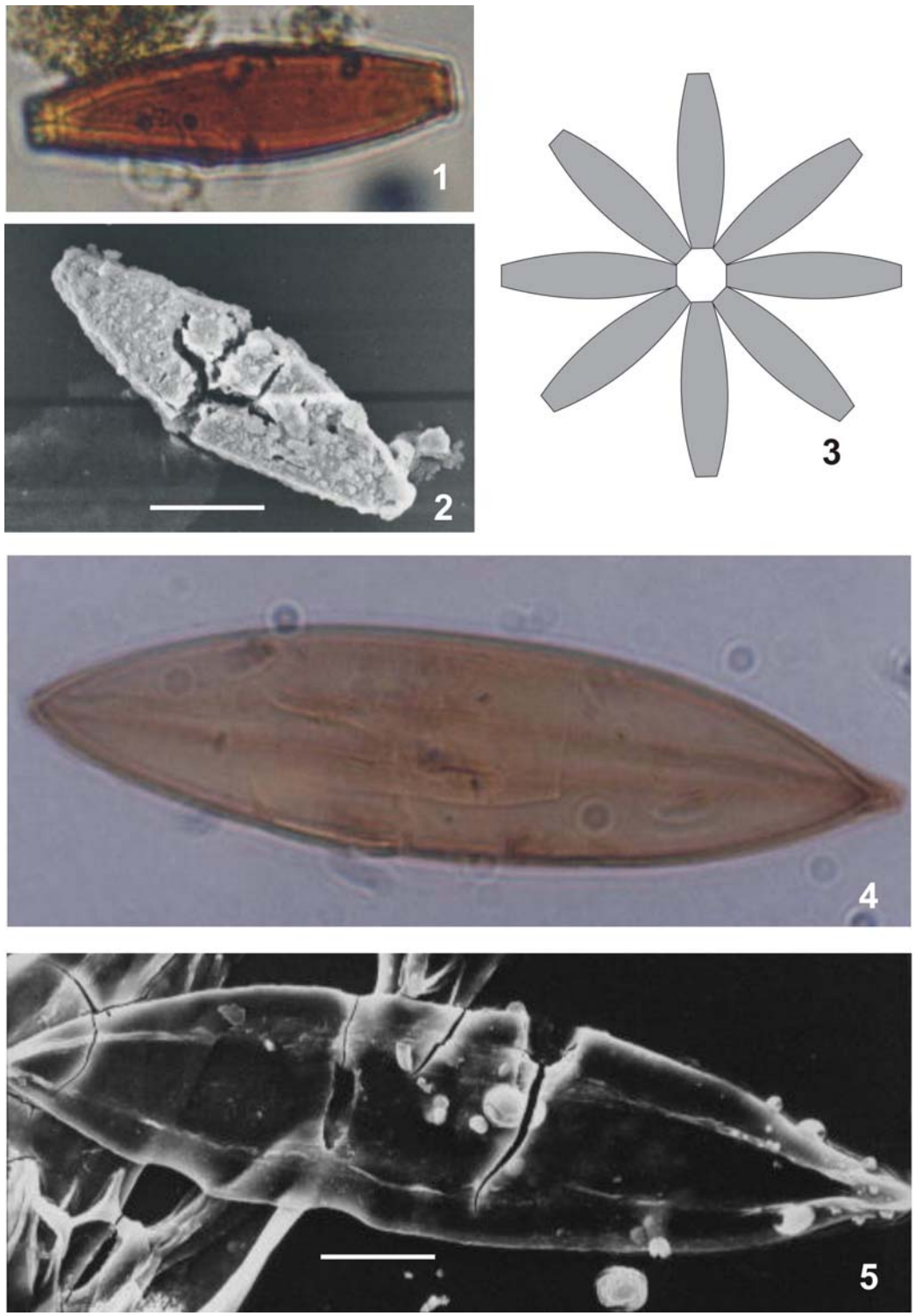

PLATE 1: All at same scale (bar = 10 mm.).
1. *Actinastrum bansaense* Songtham, Ratanasthien, and Mildenhall, n. sp., LM.
2. *Actinastrum bansaense* Songtham, Ratanasthien, and Mildenhall, n. sp., SEM.
3. Reconstructed *Actinastrum* colony, 8 cells in star-like form, two dimension cell arrangement.
4. *Closterium thailandicum* Songtham, Ratanasthien, and Mildenhall, n. sp., LM.
5. *Closterium thailandicum* Songtham, Ratanasthien, and Mildenhall, n. sp., SEM.

Table 1. Percentages of each sporomorph taxon counted from 24 sedimentary samples.

Sample No.	*Striatriletes susannae*	*Closterium thailandicum*	*Botryococcus*	*Laevigatosporites haardtii*	*Homonoia*	*Calophyllum*	*Ilexpollenites*	*Myrtaceidites*	*Hopea*	*Florschuetzia*	Combretaceae	*Crassoretitriletes vanraadshoovenii*	*Actinastrum hansaense*	Indeterminant sporomorphs	Total percentage	Number of count
CM-69													92.0	8.0	100	200
CM-66													96.0	4.0	100	200
CM-65													95.5	4.5	100	200
CM-63													95.0	5.0	100	200
CM-60													90.5	9.5	100	200
CM-49													87.0	13.0	100	200
CM-42													89.5	10.5	100	200
CM-39													98.5	1.5	100	200
CM-37													97.0	3.0	100	200
CM-31													98.5	1.5	100	200
CM-25													99.5	0.5	100	200
CM-21													97.5	2.5	100	200
CM-17													96.5	3.5	100	200
U1-6-B1												100			100	200
U1-4-B1					5.4							20		74.6	100	56
U2-9				100											100	200
U2-8						7.3					4.9			87.8	100	41
U2-4				23										77.0	100	125
U2-2							15		10			9		66.0	100	78
LM-A-6				57			8.9			1.8				32.3	100	56
LM-A-4			6.3				17							76.7	100	48
LM-A-3			7.5	16	0.5	2.5		9.5						64.0	100	200
LM-A-1		100													100	200
LS-B-1	8.3													91.7	100	36

Actinastrum hantzschii Lagerheim, the fossil forms have a greater size in both middle portion and the length between both ends than the extant forms. *Actinastrum* is a colonial green alga comprising a fixed number of cells (4, 8, 16, 32 or more). The cells in the colony are arranged into 2 to 3 dimensions by adjoining one end of each cell together at a center point while the another end of each cell points outwards forming a star-like (Plate 1, fig 3), circular or spherical colony (coenobium). However, we have never seen any fossil colonial forms because they were probably disarticulated forming individual cells during diagenesis and sample treatment.

There are only two published reports on fossil forms of *Actinastrum*, both from Early Triassic rocks, from Germany[17] and Western Australia.[14] The later report was later re-illustrated.[15]

Occurrence: Abundant in some horizons from Oligocene to Miocene sediments of northern Thailand. This includes the entire overburden unit (OB unit) of Chiang Muan coalfield in this study, *Pediastrum* Zone of Ban Pa Kha coalfield (Li basin), and Mae Lamao basin.

Green algae
Order: DESMIDIALES
Family: DESMIDIACEAE
Genus: ***Closterium*** Nitzsch ex Ralfs (1848)

Remarks: Many species of *Closterium* are found in most parts of the world or cosmopolitan. All species in this genus are solitary with elongate-cylindric and curved (at least at the ends). A few species have elongate-fusiform straight cells. Cells gradually narrow toward both apices that may be acutely pointed, rounded, or truncate. Cell wall may be smooth, have fine longitudinal striae, or have coarse costae.

Closterium thailandicum Songtham, Ratanasthien, and Mildenhall, n. sp.
Plate 1, figs 4-5

Etymology: named after Thailand, where the fossils were first found.

Holotype: slide no. LM-A-1a; co-ordinates F23/3 (England reference).
Paratypes: slide no. LM-A-1a; co-ordinates G19 and D15/4 (England reference).

Description: The species is characterised by a single, long, straight cell. The cell wall is thin with a smooth surface and some longitudinal lines. The cell is usually flattened forming a long, frond-like shape tapering at both ends. Both ends have sharply acute to small, rounded points. Width of the middle portion of the cell ranges from 10 to 26 μm and length between both ends ranges between 43 to 91 μm. The ratio between the width of the middle portion and the length between both ends is about 1: 4.5. Twenty specimens were measured.

Comparison: The cell of extant species of *Closterium* are generally of crescentic shape. Only a few species of the subgenus *Closterium* (*Holopenium*) have straight cells,

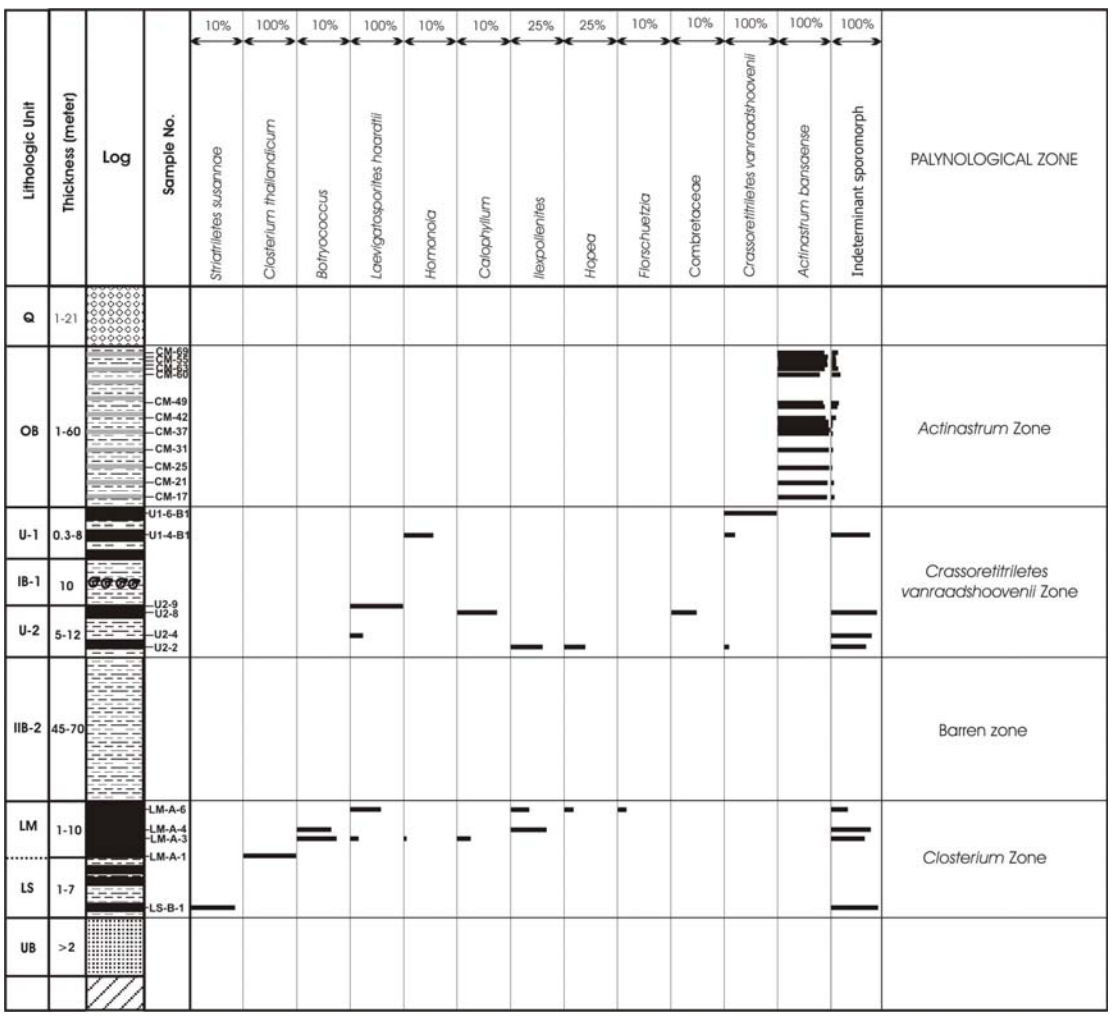

Fig 3. Pollen diagram showing plots of pollen occurrence in percentage against lithostratigraphic units and palynological acme zones of Chiang Muan coalfield.

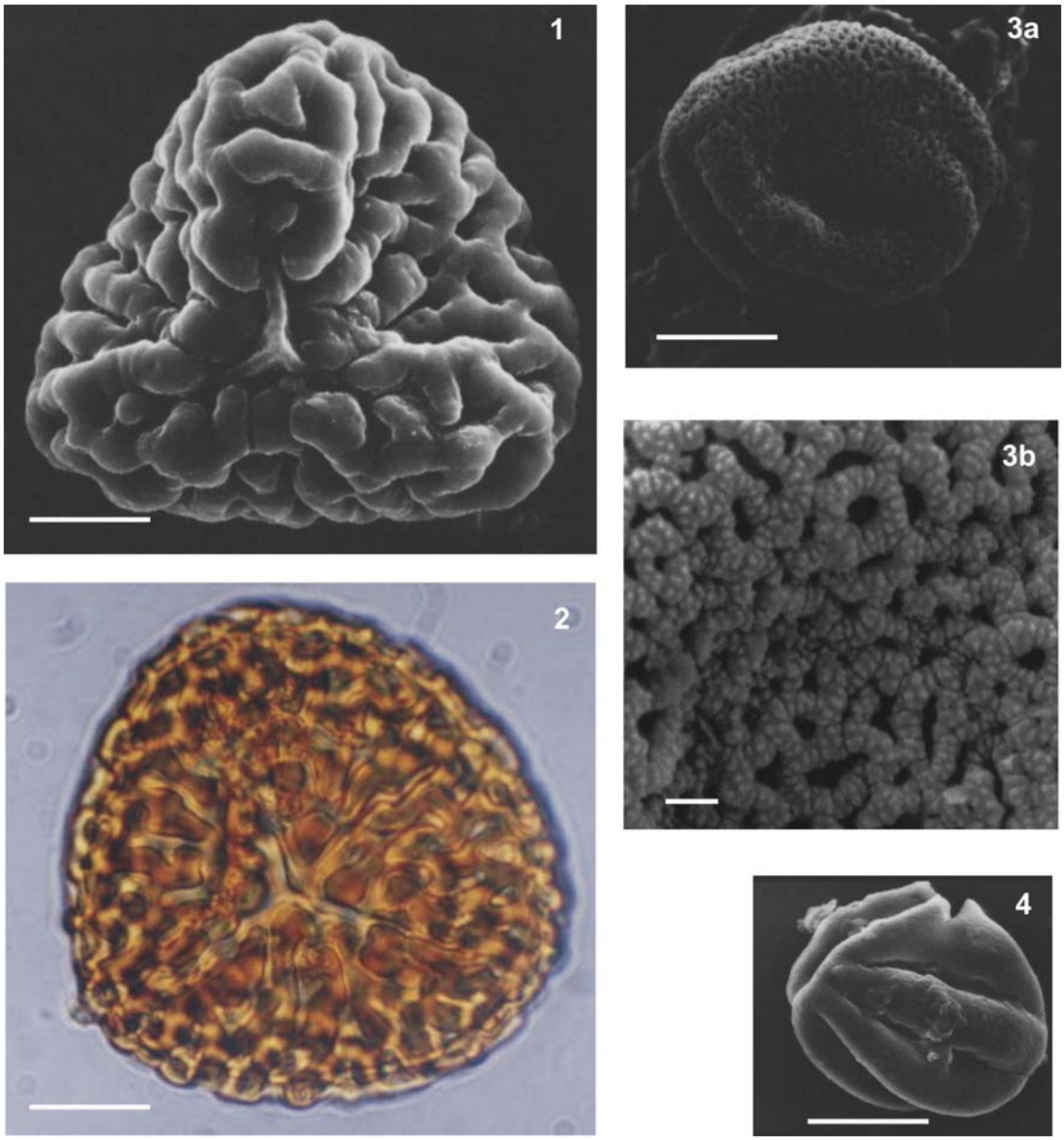

PLATE 2: All at same scale (bar = 10 μm.) except 3b (scale bar = 1 μm.).
1. *Crassoretitriletes vanraadshoovenii* Germeraad, Hopping, and Muller, SEM.
2. *Crassoretitriletes vanraadshoovenii* Germeraad, Hopping, and Muller, LM.
3. *Hopea* sp., tricolpate form with reticulate sculpture.
4. Combretaceae, tricolporate form with pseudocolpi.

including *Closterium libellula* (Focke) and *Penium navicula* (Lütkemüller). These two modern forms are much bigger than fossil *Closterium thailandicum*.

Remarks: So far, there are no reports of fossil *Closterium* from sediments, except for zygospores of *Closterium idiosporum* West and West from Holocene sediments in the Netherlands.[18] *Closterium* is a green alga belonging to the family Desmidiaceae occurring in freshwater environments.

Occurrence: They are abundant in the lower coal unit (LS and LM coal units) of Chiang Muan coalfield. One sample (LM-A-1) contains nearly 100% *Closterium thailandicum*.

Pteridophytic spores
Trilete spores
Genus ***Crassoretitriletes*** Germeraad, Hopping, and Muller (1968)

Crassoretitriletes vanraadshoovenii Germeraad, Hopping, and Muller (1968)
Plate 2, figs 1-2

Description: These spores from Chiang Muan coalfield are spherical to slightly triangular in polar view. They have broadly convex sides, with a trilete mark on the proximal surface clearly observable in polar view. The surface sculpturing is entirely coarsely reticulate with wide undulating muri, about 3 to 5 μm wide, covering the whole grain on both distal and proximal sides. The lumina of the reticulum are 2 to 5 μm wide. Exine thickness is indistinct. The grains range from 52 to 74 μm and average about 62 μm, based on 20 measured grains.

Remarks: The above characteristics well match the descriptions of *Crassoretitriletes vanraadshoovenii* reported from Borneo, Nigeria and South America[19] and from Thailand.[5] However, first designation[19] describes the size as ranging between 58 and 101 μm, while the forms from Thailand[5] describes the size as ranging from 62 to 90 μm. *Crassoretitriletes vanraadshoovenii* is comparable to the extant spores of *Lygodium microphyllum* (Cav.) of the family Lygodiaceae.[19,20] *L. microphyllum* is a climbing fern, common in humid marsh and swamp forests in open to semi-open forests in tropical to subtropical areas of West Africa, Australia, and Indo-Malesia, but absent today from South America.

Occurrence: Abundant fossils were recovered from the U-1 and U-2 units of the late Middle Miocene Chiang Muan coalfield. They were previously reported from Mae Tip basin in Lampang Province.[5] The species has been widely reported from Late Eocene sediments to the present day from Australia, China, South America, India, and South East Asia. They were reported from the late Early Miocene of South America and Early Miocene to Recent of Borneo and Nigeria.[19] In Australia the species first appears in the late Eocene and dies out in the late Miocene[21] although they were previously reported from the Pleistocene of Tasmania, southern Australia considerable as recycled specimens.[20] In addition, they were also reported from Eocene to Early Miocene and Oligocene sediments of India.[22-25]

PALYNOSTRATIGRAPHY

Most palynofloras from Chiang Muan sediments contained identifiable tropical elements and abundant freshwater green algae. Three palynological acme zones are defined - *Closterium thailandicum* Acme Zone, *Crassoretitriletes vanraadshoovenii* Acme Zone, and *Actinastrum bansaense* Acme Zone - from the base to the top (Fig 3).

1. *Closterium thailandicum* Acme Zone, new zone

This zone covers the whole part of the lower coal zone. It is dominated by the freshwater alga *Closterium thailandicum*. Some coenobia of the colonial chlorophycean alga *Botryococcus* and fossil spores *Striatriletes susannae* (van der Hammen), related to the extant aquatic fern *Ceratopteris thalictoides* (L.), family Parkeriaceae, also occur. These freshwater elements occur in association with several forms of pollen from predominantly tropical plants, including *Calophyllum*, Combretaceae, *Florschuetzia*, *Homonoia*, *Ilexpollenites*, *Lagerstroemia*, and Mimosaceae. This zone reflects a freshwater depositional environment surrounded by tropical rainforests. The climate was tropical.

The forms of *Ilexpollenites*, *Homonoia,* and *Florschuetzia* represent taxa occurring near swamps and rivers at the present day. *Ilexpollenites* (*Ilex*-type) is a fossil pollen grain from a plant genus typically common in swampy environments. The fossil *Homonoia* pollen matches well pollen from the extant species *Homonoia riparia* Lour., family Euphorbiaceae, a species of shrub growing along streams or riversides in Thailand. *Florschuetzia* (Sonneratiaceae-type) has a pollen morphology close to sonneratiaceous pollen forms from plants living in coastal mangrove as well as terrestrial environments. There is today only one species of Sonneratiaceae in northern Thailand, namely *Duabanga grandiflora* (DC.), occurring well inland,[26] in the moist areas. Even though the fossil *Florschuetzia* pollen does not match well the pollen of *Duabanga grandiflora* or *Sonneratia*, they may be best regarded as representing an early stage in the phylogenetic evolution of *Duabanga grandiflora* pollen. The fossil *Florschuetzia* pollen type cannot be from *Sonneratia*, a mangrove taxon, because it occurred in a distinctly freshwater palynological assemblage.

2. *Crassoretitriletes vanraadshoovenii* Acme Zone, new zone

This zone covers the upper coal zone including the units U1, U2, and IB-1. The zone is dominated by *Crassoretitriletes vanraadshoovenii*, the ancestral spores of the extant fern *Lygodium microphyllum* Link., with several forms of tropical pollen. These include cf. *Bauhinia*, *Calophyllum*, Combretaceae, *Homonoia*, *Hopea*, *Ilexpollenites*, *Lagerstroemia*, *Myrtaceidites* (Myrtaceae), cf. *Shorea* with abundant *Laevigatosporites haardtii* R. Pot. et Venitz spores, of uncertain, but probably mixed botanical affinity, in some horizons.

This zone reflects a moist environment probably along marginal areas of the Chiang Muan Miocene lake. The pollen and spore assemblages from this zone come from tropical rainforests. Climate during deposition was tropical.

3. *Actinastrum bansaense* Acme Zone, new zone

This zone covers the total thickness of the overburden unit (OB unit). It contains almost entirely cells from the freshwater alga *Actinastrum bansaense*. Pollen and spores are absent but some indeterminate fungal spores are present. This zone is interpreted as an ancient freshwater lake. The abundant occurrence of freshwater algae probably resulted from algal bloom events during sedimentation of the overburden, but why spores and pollen are not preserved is not known unless they were differentially oxidized out of the sediment or completely overwhelmed by the abundance of algal material.

All three palynological zones of the Chiang Muan Formation provide evidence of tropical climate during sedimentation. The vegetation around the Chiang Muan Miocene lake during basin formation was comprised of tropical rainforests. The age of the sedimentary sequence is between 13.5 and 10 Ma yrs (late Middle Miocene). [12]

Discussion

Chiang Muan sediments yielded some distinctive sporomorph forms representing tropical megathermal floras dominated by members of the family Dipterocarpaceae. The origin and distribution through time of this family has often been debated. Dipterocarps today have their greatest diversity in Southeast Asian rain forests. They also occur in some parts of India and Sri Lanka. Two genera, *Marquesia* and *Monotes*, occur in tropical Africa,[27,28] and one genus, *Pakaramaea*, occurs in northern South America.[29] This was maintained that the family did not originate in Southeast Asia, but in either South America or Africa and that their descendants have not substantially changed their paleoecological preferences.[29] However, a new revision was recently made placing African and American dipterocarps into a new family, Monotaceae, comprising two subfamilies Monotoideae (*Monotes* and *Marquesia*) and Pakaramaeoideae (*Pakaramaea*). Therefore, dipterocarps (*senso stricto*) today survive just in the western region of Wallace's line including western Indonesia, the Melasian archipelagoes, Southeast Asian mainland, India and Sri Lanka. *Monotes* is characterised by endoapertures meanwhile Dipterocarpaceae is tricolpate. On the basis of aperture characteristics, it is believed that Dipterocarpaceae is more primitive than the Monotoideae. Dipterocarps were clearly extensively represented in the monsoon forests of the Sunda region during the Late Oligocene and Early Miocene.[29] Meanwhile, dipterocarps first appeared in India during Neogene[30-34] and without any record of dipterocarps from the Paleogene of India.[35] Thus it is possible that the family originated in Southeast Asia and later expanded to India via Thailand and Myanmar sometime in the Early Miocene which was previously proposed.[35] The occurrence of dipterocarpaceous pollen, *Hopea* and cf. *Shorea*, from the Middle Miocene Chiang Muan sediments reveals that the dipterocarp vegetation developed under a tropical monsoon climate.

Myrtaceidites is also an important fossil sporomorph with a distinctive morphology found primarily in the family Myrtaceae, making it easy to tracing the family's origin and distribution through time. Abundant fossil Myrtaceae pollen were previously reported from Chiang Muan sediments, which they related to *Syzygium*, and claimed that the dominance of this pollen type and the swampy environment indicated a dispersal corridor to Africa.[12] Myrtaceae is a family of trees and shrubs found in the tropics, subtropics, Polynesia, and temperate Australia and New Zealand comprising 140 genera and 3000 species and including the well known gum tree, eucalyptus. *Syzygium* is native to Australia, New Zealand and elsewhere, as well as Southeast Asia including Thailand. There are many native species of *Syzygium* reported from northern Thailand[26] including the Chiang Muan area. Accordingly, there is no reason to regard these *Syzygium*-like sporomorphs from Chiang Muan sediments as indicating an African connection. In addition, most myrtaceous pollen from Tertiary sediments have been identified only at the family level and assigned the fossil form generic name *Myrtaceidites*, and it appears impossible to accurately determine botanical affinity to the generic level in many cases.[36] Use of the scanning electron microscope to accurately identify the botanical affinity of myrtaceous fossil pollen is possible in some cases and probably impossible in others where the pollen morphology of the family is so conservative and the pollen grains so small. Some species of *Syzygium* are distinctive in that this pollen type often has a more triangular appearance in polar view with more acute angles and an ectexinous polar island

reduced to scabrae and granules[36,37] [as *Eugenia*] than other myrtaceous grains.

It is not known when Myrtaceae first appeared in Thailand but it is at least Early Miocene.[6] The first appearance of Myrtaceae pollen types in Australia and New Zealand in the Paleocene[38-40] probably represents its worldwide first appearance. Therefore, the presence of this Gondwanan family in northern Thailand in the Miocene may relate to the tectonic movement of the Indian subcontinent. India used to be a part of Gondwana, together with Australia, and broke up when it moved northward acting as a Noah's ark[29] carrying the southern fauna and flora, including the Myrtaceae, northward. India collided and welded onto South Asia during the Eocene forming the massive Himalayan Ranges and Tibetan Plateau. The Gondwanan flora then entered the Eurasian supercontinent and subsequently migrated southeastward to occupy the Southeast Asia region.

A Middle Miocene marine incursion into the Chiang Muan area may have occurred.[41] This conclusion came from sulfur isotope values from the upper coal seam unit, which is remarkably high in sulfur. On the other hand, palynological results from the same unit yielded no closely related sporomorphs representing marginal marine environments. The unit contains abundant *in situ* fern spores of *Crassoretitriletes vanraadshoovenii* and *Laevigatosporites haardtii* with other sporomorphs representing inland environments, without any trace of marginal marine pollen evidence. The lack of palynological evidence for a marine incursion needs corroboration by further geochemical, sedimentological and other studies to see if the high sulfur content could have been caused by conditions other than a marine incursion. From a palynological point of view, absence of mangrove pollen does not mean no marine incursion occurred if the Chiang Muan basin was occupied by a temperate climate. However, the Chiang Muan sediments yielded sporomorphs clearly representing an inland tropical, monsoon vegetation and if there was a marine incursion then the sediments should have contained significant numbers of mangrove pollen.

However, if a marine interval is shown to be present by further sedimentological and geochemical studies then more detailed investigations of the palynology are required to find the coastal taxa associated with the transgression and more detailed oxygen isotope and magnetostratigraphic studies to accurately date the timing of the transgression.

Acknowledgements

We appreciate the sponsorship of Royal Golden Jubilee Ph.D. Programme, The Thailand Research Fund for financial support for this research. We thank the Department of Mineral Resources, Chiang Mai University, and Institute of Geological and Nuclear Sciences, New Zealand in providing financial, logistical, and equipment support. We thank all the staff of Chiang Muan Mine Company who warmly welcomed us and permitted us to collect samples in the mine. Special thanks also to Mr. Nikorn Wongchai and his family for hospitably providing us with many things.

References

1. Endo S (1963) Some older Tertiary plants from northern Thailand. *Japanese J Geol Geog* **34**(2-4), 177-80.
2. Endo S (1964) Some older Tertiary plants from northern Thailand. In*: Geoloogy and Palaeontology of Southeast Asia, Vol. 1* (Edited by Kobayashi T), pp 113-7. The University of Tokyo Press.
3. Endo S (1966) A supplementary note on the Paleogene Li flora in northern Thailand. In: *Geoloogy and Palaeontology of Southeast Asia, Vol.* 3 (Edited by Kobayashi T and Toriyama R), pp 165-9. The University of Tokyo Press.
4. Ratanasthien B (1984) *Spore and pollen dating of some Tertiary coal and oil deposits in northern Thailand*. Proceedings of Conference on Application of Geology and the National Development. Bangkok: Chulalongkorn University, 273-80.
5. Meesuk J (1986) *Geology of the Tertiary coal basins of Thailand*. Unpublished MSc. thesis, Birmingham, University of Aston, England, 331 p.
6. Watanasak M (1988) *Mid-Tertiary palynology of onshore and offshore Thailand*. PhD. thesis, Adelaide, University of Adelaide, Australia, 207 p.
7. Songtham W, Ratanasthien B, Mildenhall DC, Singharajwarapan S and Kandharosa W (2001) Palynological zonation and their paleovegetations of Ban Pa Kha coal mine, Li basin, Changwat Lamphun. *Paper presented at Geological Survey Division Annual Academic Meeting, Department of Mineral Resources, Bangkok*: 1-11.
8. Songtham W, Ratanasthien B, Watanasak M and Mildenhall DC (2000) Temperate palynological elements from Na Hong basin, northern Thailand. *Mahidol J* **7**, 121-6.
9. Songtham W, Ratanasthien B, Mildenhall DC, Singharajwarapan S and Kandharosa W (2003) Oligocene-Miocene climatic changes in northern Thailand resulting from extrusion tectonics of Southeast Asian landmass. In: *Proceedings of the 8th International Congress on Pacific Neogene Stratigraphy: Pacific Neogene Paleoenvironments and their evolution* (Edited by Ratanasthien B, Rieb SL and Chantraprasert S), pp 248-64. Chiang Mai University, Thailand.
10. Songtham W (2003) *Stratigraphic correlation of Tertiary basins in northern Thailand using algae, pollen and spores*. Unpublished PhD. Thesis, Chiang Mai University, Thailand, 280 p.
11. Nakaya H, Saegusa H, Kunimatsu Y and Ratanasthien B (2002) Miocene mammalian faunas of northern Thailand and their geological age. *Primate Res* **18**, 131-41.
12. Chaimanee Y, Jolly D, Benammi M, Tafforeau P, Duzer D, Moussa I and Jaeger JJ (2003) A Middle Miocene hominoid from Thailand and orangutan origins. *Nature* **422**, 61-5.
13. Komarek J and Fott B (1983) Chlorophyceae (Grünalgen). Ordnung: Chlorococcales. Systematik und Biologie. In: Das Phytoplankton des Süsswassers, 7, 1. Die Binnengewässer, 16. E. Schweizerbart'sche Verlagsbuchhandlungen, Stuttgart,

x + 1044 p.
14. Brenner W and Foster CB (1994) Chlorophycean algae from the Triassic of Australia. *Rev Palaeobot Palyno* **80**, 209-34.
15. Batten DJ (1996) Chapter 7: Green algae and blue-green algae, 7C-Colonial Chlorococcales. In: *Palynology: principles and Applications, Vol. 1* (Edited by Jansonius J and McGregor DC), pp 191-203. American Association of Stratigraphic Palynologists Foundation.
16. Wongrat L (2001) *Phytoplankton*. Bangkok, Kasetsart University, 851 p.
17. Ecke HH (1986) *Palynologie des Zechsteins und Unteren Buntsandsteins im Germanischen Becken*. Unpublished PhD thesis, University of Göttingen, Göttingen.
18. Van Geel B, Bohncke SJP and Dee H (1981) A palaeoecological study of an Upper Late Glacial and Holocene sequence from "De Borchert", the Netherlands. *Rev Palaeobot Palyno* **31**, 367-448.
19. Germeraad JH, Hopping CA and Muller J (1968) Palynology of Tertiary sediments from tropical areas. *Rev Palaeobot Palyno* **6**, 189-348.
20. Augustinius PC and Macphail MK (1997) Early Pleistocene stratigraphy and timing of the Bulgobac Glaciation, western Tasmania, Australia. *Palaeogeog Palaeoclimato Palaeoeco* **128**, 253-67.
21. Macphail MK (1999) Palynostratigraphy of the Murray Basin, inland southeastern Australia. *Palyno* **23**, 197-240.
22. Rao MR (1990) Palynological investigation of Arthungal bore-hole, Alleppey District, Kerala. *The Palaeobot* **38**, 243-55.
23. Rao MR (1995) An Early Miocene palynofloral assemblage from Turavur bore-hole, Alleppey District, Kerala – its palaeoecological and stratigraphical significance. *Geophyto* **25**, 155-63.
24. Mandaokar BD (2000) Palynology of coal-bearing sediments of the Tikak Parbat Formation (Oligocene) from Namchik River Section, Changlang District, Arunachal Pradesh, India. *Tert Res* **20**, 37-46.
25. Mandaokar BD (2000) Palynology of the coal-bearing sediments in the Titak Parbat Formation from Jeypore Colliery, Dilli-Jeypore Coalfields, Assam, India. *J Palaeon Soc India* **45**, 173-85.
26. Gardner S, Sidisanthorn P and Anusarnsunthorn V (2000) *A field guide to forest trees of northern Thailand*. Chiang Mai University, 545 p.
27. Bancroft H (1933) A contribution to the geological history of the Dipterocarpaceae. *Geol Foren Stockholm Forhand* **55**: 59-100.
28. Bancroft H (1935) The wood anatomy of representative members of Monotoideae. *American J Bot* **22**, 717-39.
29. Morley RJ (2000) *Origin and evolution of tropical rain forests*. John Wiley and Sons. 362 p.
30. Lakhanpal RN and Guleria JS (1987) Fossil leaves of *Dipterocarpus* from the Lower Siwalik beds near Jawalamukhi, Himachal Pradesh. *The Palaeobot* **35**(3), 258-62.
31. Prasad M and Prakash U (1987) Occurrence of Malayan dipterocarps in the Siwalik sediments of Uttar Pradesh. *Geophyto* **17**(2), 245-55.
32. Antal JS and Awasthi N (1993) Fossil flora from the Himalayan foot-hills of Darjeeling District, West Bengal and its palaeoecological and phytogeographical significance. *The Palaeobot* **42**(1), 14-60.
33. Prasad M (1993) Siwalik (Middle Miocene) woods from the Kalagarh area in the Himalayan foot-hills and their bearing on the palaeoclimate and phytogeography. *Rev Palaeobot Palyno* **76**, 49-82.
34. Prasad M (1994) Siwalik (Middle Miocene) leaf-impressions from the foot-hills of Himalayas, India. *Tert Res* **15**(2), 53-90.
35. Antal JS and Prasad M (1996) Dipterocarpaceous fossil leaves from Ghish River section in Himalayan foot-hills near Oodlabari, Darjeeling District, West Bengal. *The Palaeobot* **43**(3), 73-7.
36. Martin HA (1978) Evolution of the Australian flora and vegetation through the Tertiary: evidence from pollen. *Alcheringa* **2**, 181-202.
37. McIntyre DJ (1963) Pollen morphology of New Zealand species of Myrtaceae. *Transact Roy Soc NZ, Bot*, **2**: 83-107.
38. Stover LE and Partridge AD (1973) Tertiary and Late Cretaceous spores and pollen from the Gippsland Basin, southeaster Australia. *Proc Roy Soc Vict* **85**: 237-86.
39. Mildenhall DC (1980) New Zealand Late Cretaceous and Cenozoic plant biogeography: a contribution. *Palaeogeog Palaeoclimat Palaeoeco* **31**, 197-233.
40. Raine JI (1984) Outlines of a palynological zonation of Cretaceous to Paleogene sediments in West Coast region, South Island, New Zealand. *NZ Geol Surv Rep* **109**, 82 p.
41. Silaratana T, Ratanasthien B, Takayasu K, Asanachinda P, Kandharosa W and Kusakabe M (2003) Sulfur isotope implication of Middle Miocene marine incursion in northern Thailand. In: *Proceedings of the 8th International Congress on Pacific Neogene Stratigraphy: Pacific Neogene Paleoenvironments and their Evolution* (Edited by Ratanasthien B, Rieb SL and Chantraprasert S, pp 356-74. Chiang Mai University, Thailand.
42. Miller KG, Wright JD and Fairbanks RG (1991) Unlocking the Ice House: Oligocene-Miocene oxygen isotopes, eustasy, and margin erosion. *J Geophys Res* **96**, 6829-48.
43. Berggren WA, Kent DV, Swisher CC and Aubry MP (1995) A revised Cenozoic geochronology and chronostratigraphy. In: *Geochronology, time scales and global stratigraphic correlation* (Edited by Berggren WA, Kent DV, Aubry MP and Hardenbol J), pp 129-212. SEPM Special Publication 54.
44. Chareonprawat A, Chuaviroj S, Hinthong C and Chonglakmani C (1995) *Geological map of Thailand, Sheet Lampang (NE 47-7), scale 1: 250,000*. Geological Survey Division, Department of Mineral Resources, Bangkok, Thailand.