การจำลองสภาพภูมิอากาศบรรพกาลด้วยหลักฐานทางฟอสซิลละอองเรณู จากช่วงปลายสมัยโอลิโกซีนถึงช่วงต้นสมัยไมโอซีน แอ่งย่อยบ้านป่าคา แอ่งลี้ จังหวัดลำพูน

A Palaeo–climate Reconstruction of the Late Oligocene to Early Miocene Palynoflora from Ban Pa Kha Subbasin, Li basin, Lamphun Province

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บทคัดย่อ

การวิจัยนี้มีวัตถุประสงค์เพื่อจำลองสภาพภูมิอากาศบรรพกาล ด้วยหลักฐานทางฟอสซิลสปอร์และละอองเรณู จากช่วงปลายสมัยโอลิโกซีนถึงช่วงต้นสมัยไมโอซีน แอ่งย่อยบ้านป่าคา แอ่งลี้ จังหวัดลำพูน โดยทำการเก็บตะกอนจากชั้นส่วนคั่นชั้นแร่ของแอ่งย่อย จากนั้นทำการสกัดฟอสซิลสปอร์และละอองเรณูด้วยกรดไฮโดรคลอริก กรดไฮโดรฟลูออริก อะซีโตไลซีส และซิงค์ โบรไมด์ และทำการศึกษาด้วยกล้องจุลทรรศน์แบบใช้แสงและกล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด นอกจากนี้ทำการนับและจัดจำแนกเป็นจำนวนทั้งสิ้น 1,587 เม็ด ผลการศึกษาพบฟอสซิลสปอร์และละอองเรณูจำนวน 43 ชนิด ซึ่งเป็นเรณูของพืชที่สามารถพบได้ใน (1) เขตอบอุ่น (2) เขตกึ่งเขตร้อน และ (3) เขตร้อน นอกจากนี้พบว่ามีละอองเรณูของ *Alnus* และ *Quercus* เป็นจำนวนมากในตะกอน จากการวิเคราะห์ฟอสซิลสปอร์และละอองเรณู โดยใช้ระบบจำแนกสภาพภูมิอากาศของ Köppen จึงสรุปได้ว่าสภาพภูมิอากาศของบริเวณแอ่งย่อยบ้านป่าคาระหว่างช่วงเวลาดังกล่าว มีความเป็นไปได้ว่าจะมีสภาพเป็นกึ่งเขตร้อน

คำสำคัญ แอ่งย่อยบ้านป่าคา ฟอสซิลละอองเรณู จังหวัดลำพูน สภาพภูมิอากาศในบรรพกาล เรณูวิทยา

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Abstract

The objective of this research was to reconstruct palaeo–climate of the late Oligocene to early Miocene of Northern Thailand using fossil spores and pollen retrieved from Ban Pa Kha subbasin, Li basin, Lamphun Province. Fossil spores and pollen were extracted from sediments taken from the interburden layer of the subbasin using hydrochloric acid, hydrofluoric acid, acetolysis, and zinc bromide, and then examined with both LM and SEM. A total of 1,587 spores and pollen grains were counted and identified. The results showed that 43 spore and pollen species belonging to plants which are (1) temperate, (2) subtropical, and (3) tropical elements were observed. *Alnus* and *Quercus* pollen were found in very high numbers. Based on Köppen signatures of their modern analogues, subtropical climate seems likely for this region at that time.

Keywords: Ban Pa Kha Subbasin, Fossil pollen, Lamphun Province, Palaeo–climate, Palynology

Introduction

In Northern Thailand, 42 sedimentary deposits have been recognized. Many basins are identified as Tertiary deposits, including Fang, Mae Chaem, Mae Moh, Mae Lai, Mae Teep, Mae Than, Chiang Mai, Chiang Muan, Pong, Phrae, and Li basins (Morley & Racey, 2011). Li basin is located in Lamphun Province, corresponding to the Oligocene to Miocene (Songtham et al., 2003; Morley & Racey, 2011). This basin can be geomorphologically divided into four subbasins, i.e., Ban Pu, Ban Pa Kha, Na Sai, and Mae Long (Sawangchote et al., 2009; 2010). Palynofloras from the late Oligocene to early Miocene suggest warm temperate environments, while those from the Middle Miocene indicate tropical settings (Songtham et al., 2003; Sepulchre et al., 2010).

The Ban Pa Kha subbasin is located in the eastern part of the Li basin, consisting of four units, the lower coal seam, interburden, upper coal seam, and overburden (Songtham et al., 2003). The sedimentary formations contained lacustrine deposits, including coals, oil shales, and marls, lying upon coarse fan sediments (Songtham et al., 2003; Sawangchote et al., 2009; Morley & Racey, 2011). Palynomorph fossils were mainly recovered from the interburden layer. The age of this subbasin is the late Oligocene to early Miocene (Songtham et al., 2003; Morley & Racey, 2011). The Ban Pa Kha subbasin also provided valuable fossil evidence indicating changes in palaeo–vegetation in Northern Thailand caused by the Oligocene–Miocene climatic shift due to Southeast Asia landmass movement, as well as the monsoon linked to Himalayan–Tibetan Plateau uplift (Morley, 1998; Songtham et al., 2003; Sepulchre et al., 2010).

Based on the macrofossil evidence found in the Ban Pa Kha subbasin, mixed evergreen–deciduous, swamp, and riverine communities were suggested (Nichols & Uttamo, 2005; Sawangchote et al., 2009; 2010; Grote, 2015). The late Oligocene to early Miocene palynofloras from Ban Pa Kha subbasin were also examined by Ratanasthien (1984) and Songtham et al. (2003; 2005). A total of 29 sporomorph species were observed and characterized by the diverse spectrum of warm temperate pollen assemblages. However, in our preliminary study, approximately 40 fossil sporomorph taxa were recognized from this subbasin. Therefore, it would be possible that the number of pollen species recovered from Ban Pa Kha subbasin shown in previous studies was underestimated, possibly due to a classical technique used. In addition, pollen analysis (pollen counting) was not employed by those studies. Such low taxonomic resolution of palynological record, as well as the lack of a quantitative analysis, can lead to misinterpretation of palaeo–climates and environments. As shown in many studies (Grimmson et al., 2011a; b; 2015; 2016; 2020), by combining LM and SEM, fossil spores and pollen were identified more accurately. A light microscope (LM) appears to provide details of shape, aperture, and exine thickening, while fine characteristics of exine ornamentation can be obtained using a scanning electron microscope (SEM) (Ferguson et al., 2007). A pollen counting is one of the most important methods for estimating pollen assemblages produced by plants presenting in the past. Therefore, retrieved fossil spores and pollen of theirs would provide us images of palaeo–environments where they occupied.

Even though there are a number of studies on spore and pollen fossils from the Mid–Tertiary in Northern Thailand, attention has only been paid to the indicative sporomorphs of climate change, while some other palynomorph taxa have been underestimated due to techniques used. The present study is aimed to re-examine fossil spores and pollen from Ban Pa Kha subbasin, Li basin, Lamphun Province, using a combined LM and SEM analysis together with a pollen counting technique to obtain a higher degree of quantitative compositional fidelity for more accurate interpretation of palaeo–climate of Northern Thailand during the late Oligocene to early Miocene.

Objective

1. To reconstruct the palaeo–climate of the late Oligocene to early Miocene of Northern Thailand using fossil spores and pollen recovered from the interburden layer of Ban Pa Kha subbasin, Li basin, Lamphun Province

Research Methodology

This study is the experimental research. ***Sampling site.*** — The late Oligocene to early Miocene sediment samples (sample number SUT 809, 893, and 1386) were collected from lacustrine deposits in the interburden layer of Ban Pa Kha subbasin in Northern Thailand (Figure. 1). The stratigraphy of the subbasin was examined by Songtham et al. (2003) and Sawangchote et al. (2009; 2010). ***Spore and pollen extraction.*** — Each sample was scraped with a paper cutting blade on the surface and rinsed with distilled water to remove modern spores and pollen possibly contaminating fossil samples. All samples were ground, put into a glass

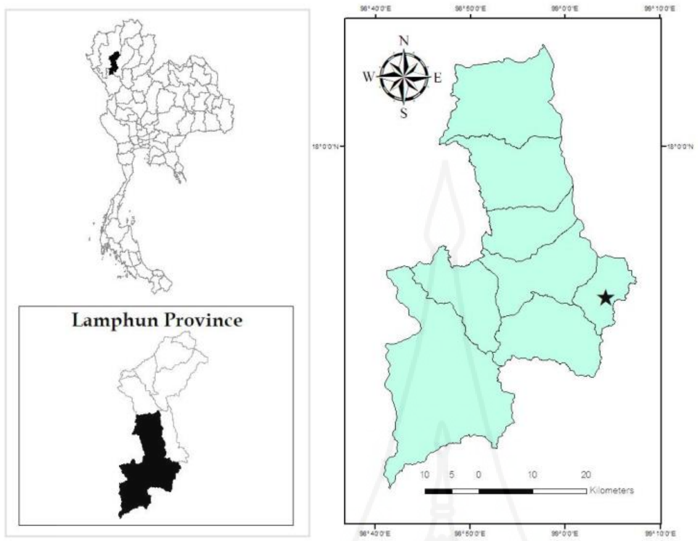

Figure 1. The geographical map showing the location of Ban Pa Kha subbasin (asterisk), Li basin, Li District (highlighted in blue colour), Lamphun Province

beaker, and boiled with 150 ml of 37% hydrochloric acid (HCl) for five to ten minutes to dissolve calcium carbonate ($CaCO_3$). After removing the HCl, the remaining sediment was transferred into a five-liter plastic jar and combined with 48% hydrofluoric acid (HF) to dissolve silica for three to seven days. The plastic jar was then filled with water. The liquid was decanted, and the remaining substance was moved to plastic tube, to which 37% HCl was added. This mixture was boiled for five to ten minutes and washed with distilled water. The remaining sediment was then treated with 99.8% glacial acetic acid, centrifuged, and decanted. The remaining sediment was chlorinated, acetolysed, and washed with distilled water (Erdtman, 1960). The palynomorphs were separated from inorganic matter using heavy liquid separation (zinc bromide). The final organic material was mixed with pure glycerol and smeared onto a slide. ***Palynomorph analysis.*** — Fossil spores and pollen were sorted, picked, and photographed with both LM (BX43, Olympus) and SEM (FEI Quanta 400) using the single grain technique (Zetter, 1989) until it was ensured that all fossil spore and pollen taxa were obtained. The observed fossil sporomorphs were identified by comparison with illustrations and descriptions of pollen and spores in the literature (Grímsson et al. 2011a; 2011b; 2015; 2016, 2020). At least 500 spores and pollen were counted and identified per each sample. The palynomorph percentage was then calculated. The palaeo–climate of the study site was reconstructed using the Köppen signatures (climate–vegetation types) described by Denk et al. (2013) and Grimmson et al. (2016; 2020).

Results

A total of 43 spore and pollen species belonging to 3 pteridophytes, 6 gymnosperms, and 34 angiosperms were observed using both LM and SEM (Table 1, Figure 2 and 3). Based on the main climatic preferences of potential modern analogues (Köppen signatures) of the fossils from the interburden layer of Ban Pa Kha subbasin, fossil palynomorph assemblages can be divided into three main groups, including (1) nemoral (temperate), (2) meridio–nemoral and semihumid–meridional (subtropical), and (3) tropical and tropical–meridional (tropical) elements (a summary of the climatic niche occupied by modern plants related to recovered fossil spores and pollen provided in Grimmson et al. (2016; 2020) (supplementary materials) and the ClimGrim database). The temperate elements consisted of pollen from *Alnus*, *Corylus*, Juglandaceae (*Pterocarya* or *Juglans*), *Pinus* subg. *Pinus*, *Quercus* Group Ilex, *Tsuga*, *Salix*, and *Ulmus*, whereas the subtropical components comprised of *Abies*, *Diospyros*, Hamamelidaceae (*Distylium* or *Parrotia*), *Ilex*, *Liquidambar*, Myricaceae (*Myrica* or *Morella*), *Pinus* subg. *Strobus*, *Quercus* Group Quercus, *Rehderodrendon*, *Styrax*, and *Viburnum*. Tropical elements composed of *Adinandra*, Araliaceae (*Aralia*, *Polyscias*, or *Schefflera*), Castaneoideae (*Castanopsis* or *Lithocarpus*), Cupressaceae (*Taiwania*, *Taxodium*, or *Sequiea*), *Ligustrum*, Sapotaceae, and *Symplocos*.

The 1,587 spores and pollen grains in total were counted and classified. *Quercus* pollen were found in high numbers, 78.54% (SUT 809) and 68.95% (SUT 893), while high numbers of *Alnus* pollen were observed in the sample No. SUT 1386 (61.76%). *Pinus* pollen was found in low numbers, from between 5.00 to 13.00%. Sporomorphs from other plant species were found at less than 5.00% from all sediment samples (Table 1).

Table 1. Percentages of palynomorphs recovered from each study site and numbers of the observed spore and pollen taxa

Palynomorph taxa	SUT 809	SUT 893	SUT 1386	Number of morphotaxa
Polypodiaceae	0.61	0.00	1.15	3
Cupressaceae gen. et spec. indet.	0.81	0.88	2.49	1
Abies sp.	0.61	1.58	0.57	1
Pinus sp.	6.48	12.98	4.97	2
Tsuga sp.	1.01	2.63	0.00	2
Liquidambar sp.	1.62	4.04	0.19	1
Viburnum sp.	0.20	0.18	4.21	1

Ilex sp.	0.20	0.35	0.76	1
Araliaceae gen. et spec. indet.	0.81	0.00	0.38	1
Alnus sp.	0.81	1.58	61.76	4
Betula sp.	0.00	0.18	0.00	1
Corylus sp.	1.01	0.00	0.00	1
Diospyros sp.	0.00	0.70	0.00	1
Adinandra sp.	0.00	0.18	0.38	1
Castaneoideae gen. et spec. indet.	0.20	0.35	0.76	2
Quercus sp.	78.54	68.95	15.49	7
Rehderodendron sp.	1.82	0.53	0.57	1
Styrax sp.	0.61	0.70	0.00	1
Hamamelidaceae gen. et spec. indet.	0.20	0.35	0.38	1
Ligustrum sp.	0.00	0.00	0.38	1
Juglandaceae gen. et spec. indet.	0.81	1.05	1.15	2
Myricaceae gen. et spec. indet.	1.82	0.53	2.87	1
Poaceae gen. et spec. indet.	1.01	1.05	0.00	1
Salix sp.	0.40	0.35	1.15	1
Sapotaceae gen. et spec. indet.	0.00	0.18	0.00	1
Symplocos sp.	0.20	0.35	0.38	1
Ulmus sp.	0.00	0.35	0.00	1
Indetermined taxon 1	0.20	0.00	0.00	1
Total	**100.00**	**100.00**	**100.00**	**43**

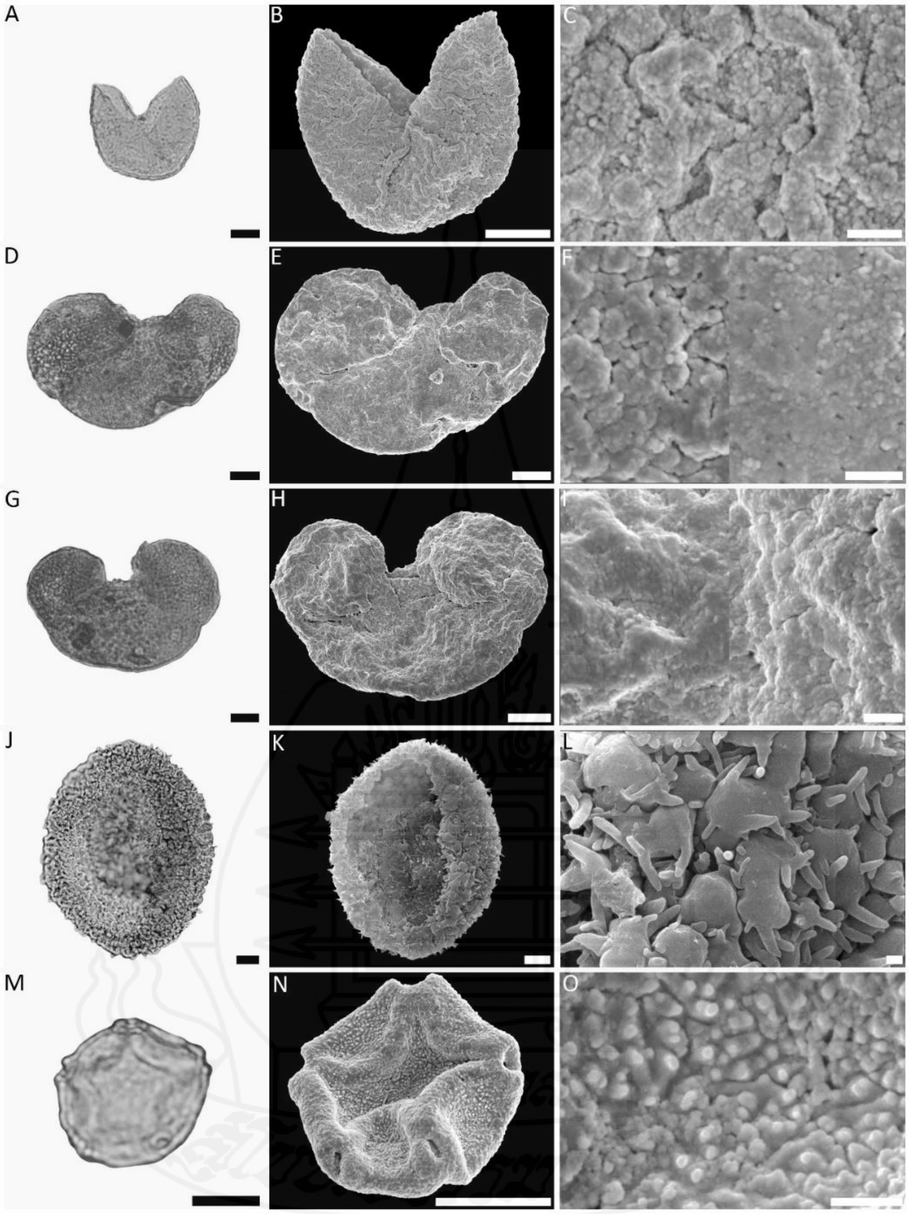

Figure 2. Light microscopy (A, D, G, J, M) and scanning electron microscopy (B, C, E, F, H, I, K, L, N, O) micrographs of dispersed fossil pollen. A–C. Cupressaceae gen. et spec. indet. (*Taiwania*, *Taxodium*, vel *Sequiea*). D–F. *Pinus* subgenus *Pinus* sp. G–I. *Pinus* subgenus *Strobus* sp. J–L. *Tsuga* sp. M–O. *Alnus* sp.

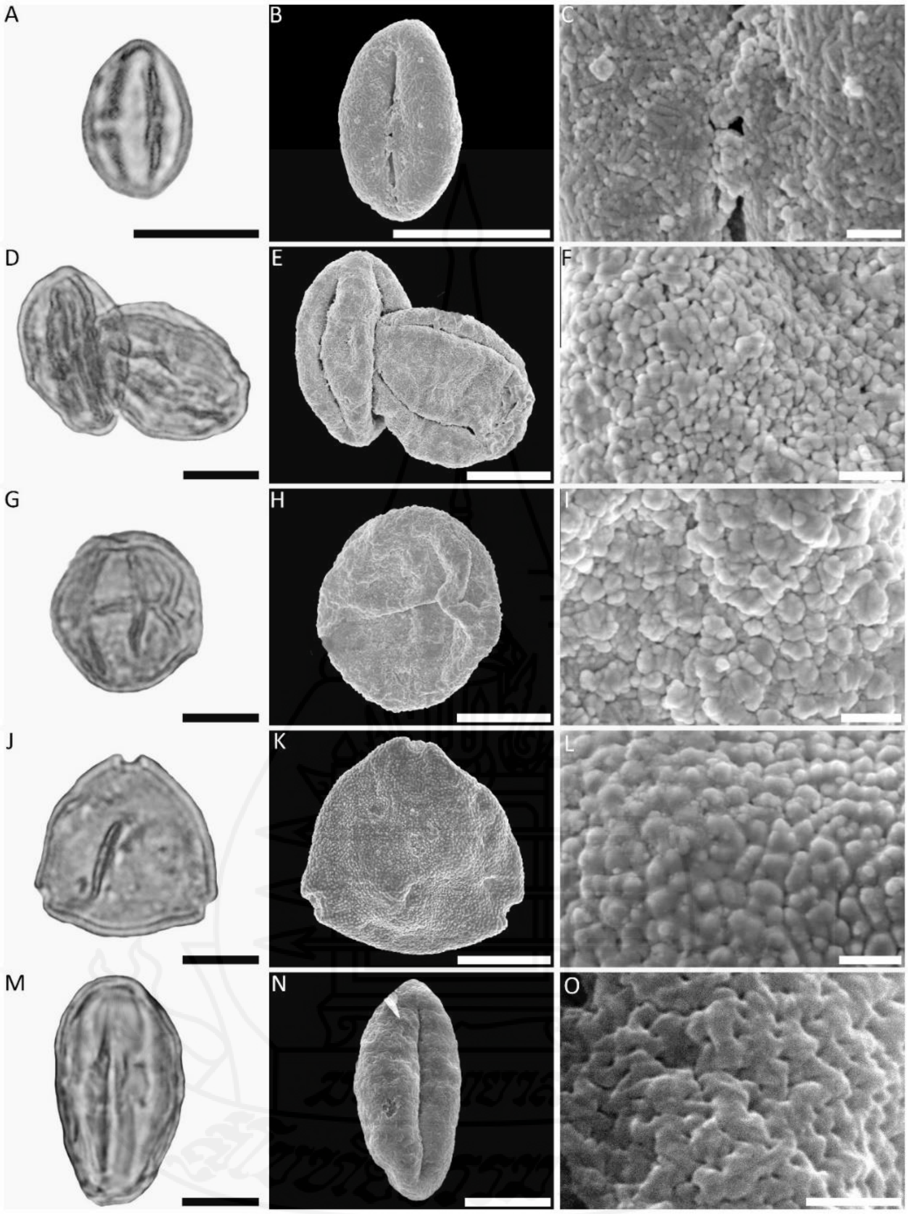

Figure 3. Light microscopy (A, D, G, J, M) and scanning electron microscopy (B, C, E, F, H, I, K, L, N, O) micrographs of dispersed fossil pollen. A–C. Castaneoideae gen. et spec. indet. (*Castanopsis* vel *Lithocarpus*). D–F. *Quercus* Group Ilex sp. G–I. *Quercus* Group Quercus sp. J–L. Myricaceae gen. et spec. indet. (*Morella* vel *Myrica*). M–O. *Rehderodendron* sp.

Discussion

Most of the fossil spores and pollen found in this present study represent palynomorphs that were commonly observed in the late Oligocene to early Miocene reported in previous studies (Ratanasthien, 1984; Songtham et al., 2003; 2005), including pollen from *Alnus*, Cupressaceae, *Ilex*, Juglandaceae, *Liquidambar*, Myricaceae, *Pinus*, *Quercus*, *Salix*, *Tsuga*, and *Ulmus*. On the other hand, there are a number of fossil pollen species that have never been found before from Ban Pa Kha subbasin, e.g., *Abies*, *Adinandra*, Araliaceae, Castaneoideae (*Castanopsis* or *Lithocarpus*), *Corylus*, *Diospyros*, Hamamelidaceae, *Ligustrum*, *Rehderodrendon*, Sapotaceae, *Styrax*, *Symplocos*, and *Viburnum*. Moreover, some pollen types that could be assigned into only one genus can be divided into subgenera or morphotaxa; for example, *Pinus* sp. can be separated into *Pinus* subgenus *Pinus* sp. and *Pinus* subgenus *Strobus* sp., and *Quercus* sp. can be classified into 7 morphotaxa. Since the single grain technique invented by Zetter (1989) was employed in this present study, a higher taxonomic resolution of fossil palynomorphs was obtained. As this technique allows spores or pollen grains to be manipulated into various positions under LM, their significant characters can be investigated and photographed. Moreover, the same grains of those examined spores or pollen can be transferred onto a stub and analyzed with SEM. The increase in numbers of fossil sporomorph taxa due to the single grain technique was also reported by Grimmson et al. (2011a; b; 2015; 2016; 2020). This permits more accurate interpretation of fossil records.

Based on Köppen signatures of plant species related to the fossil spores and pollen recovered in this present study (Grimmson et al., 2016; 2020), subtropical climate seems likely for this area during the late Oligocene to early Miocene. It is evident that a number of palynomorph taxa, for which the climatic preference of their analogues is subtropical, were retrieved from the interburden layer of the subbasin. This includes *Quercus* Group Quercus, the pollen of which appeared to be observed in the highest numbers from samples No. SUT 809 and 893. Even though the temperate elements can also occur in recovered palynomorph assemblages, a climate of this region cannot be interpreted as temperate because fossil pollen from *Adinandra* and Castaneoideae (*Castanopsis* or *Lithocarpus*), which are tropical elements that cannot extend to temperate zone, can also be found in the fossil record. However, all observed tropical species can occur in subtropical regions. Conversely, the distributions of *Alnus*, *Corylus*, Juglandaceae (*Pterocarya* or *Juglans*), *Quercus* Group Ilex, *Tsuga*, *Salix*, and *Ulmus*, are restricted in temperate and/or subtropical zones. Due to the modern distribution pattern, they are predominantly thriving in an upper montane zone under subtropical and temperate settings (Fang et al., 1999; Li & Skvortsov, 1999; Fu et al., 2003; Zhang et al., 2003; Farjon, 2010). It is possible that their pollen was transported from an upper montane zone to the subbasin. Moreover, the results from pollen counting showed that *Alnus* and *Quercus*, with temperate and subtropical main climatic preferences, were dominant. This confirms that tropical climate seems unlikely for this part of Thailand at that time. However, according to the previous interpretations on the climatic phenomenon in the northern region of Thailand by Songtham et al. (2003; 2005), it was assumed that the late Oligocene to early Miocene climate of Ban Pa Kha subbasin was warm temperate due to the presence of fossil pollen from *Piceaepollenites*, *Pinuspollenites*, *Tsugaepollenites igniculus*, *Taxodiaceaepollenites*, *Alnipollenites verus*, *Caryapollenites simplex*, *Faguspollenites*, *Ilexpollenites iliacus*, *Juglanspollenites*, *Liquidambarpollenites stigmosus*, *Loniceraepollenites*, *Momipites coryloides*, *Pterocaryapollenites*, *Quercoidites*, and *Ulmipollenites*. Songtham et al. (2005) also proposed that the climate of Northern Thailand was shifted from temperate to tropical in the mid–early Miocene. It was summarized that the temperate elements were found from the late Oligocene to early Miocene of Ban Pu, Ban Pa Kha, Mae Lamao, Mae Tun, Nong Ya Plong, and Na Hong basins, whereas the tropical components were discovered from the middle Miocene of Chiang Muan, Fang, Mae Moh, Mae Long, Mae Sot, and Na Sai basins (Songtham et al., 2003; 2005; Sepulchre et al., 2010). These differences in the interpretation appeared to be caused by the different techniques used for sorting, picking, photographing, and counting fossil spores and pollen, as well as the climate classification system employed to analyze climate–vegetation interaction. It should be noted that this study was based only on three sediment samples. More samples are needed to obtain more accurate interpretations.

Recommendations

Since the Oligocene–Miocene climatic transformation of Northern Thailand is still controversial, our findings appear to be the first evidence suggesting that subtropical climate seems likely for the northern region of Thailand during the late Oligocene to early Miocene, although Grote (2015) concluded a possible temperate or subtropical climate. Therefore, in order to obtain the precise reconstruction, such new evidence should be taken into account when examining the palaeo–climate of this region. For further research, it should also be ensured that appropriate methods for preparing and analyzing fossil spore and pollen samples are used. Also, as fossil palynomorphs can be influenced by various taphonomic factors, for instance pollen production, transportation, and preservation, such variables should be considered when interpreting fossil records.

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