THE PALEOVEGETATION AND ENVIRONMENTAL RECONSTRUCTION DURING THE QUATERNARY OF THE KHORAT PLATEAU BASED ON THE PALYNOLOGICAL RECORD

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พืชพรรณโบราณ และการฟื้นฟูสภาพแวดล้อมในช่วงปลายยุคควอเทอร์นารี ในพื้นที่ราบสูงโคราช ของประเทศไทยจากหลักฐานเรณูวิทยา

นายเฟิงชุน หยาง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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THE PALEOVEGETATION AND ENVIRONMENTAL RECONSTRUCTION DURING THE QUATERNARY OF THE KHORAT PLATEAU IN THAILAND BASED ON THE PALYNOLOGICAL RECORD

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เฟิงชุน หยาง : พืชพรรณโบราณและการจำลองสภาพแวดล้อมในช่วงปลายยุคควอเทอร์นารี ในพื้นที่ราบสูงโคราชของประเทศไทย จากหลักฐานเรณูวิทยา (THE PALEOVEGETATION AND ENVIRONMENTAL RECONSTRUCTION DURING THE QUATERNARY OF THE KHORAT PLATEAU IN THAILAND BASED ON THE PALYNOLOGICAL RECORD) อาจารย์ที่ปรึกษา : อาจารย์ ดร.พอล เจ โกรดิ, 237 หน้า.

ที่ราบสูงโคราชตั้งอยู่บริเวณศูนย์กลางของคาบสมุทรอินโดจีน เป็นที่ราบที่มีระดับค่อนข้างสูง พรรณไม้ท้องถิ่นที่พบมีความเกี่ยวข้องอย่างใกล้ชิดกับพรรณไม้ทางตอนเหนือของเขตอินโด-หิมาลัย-จีน และบริเวณมาเลเซียตอนใต้ ที่ราบสูงนี้เป็นสะพานสำคัญที่เชื่อมสิ่งมีชีวิตระหว่างสองดินแดน แต่ยังไม่ทราบสาเหตุที่ชัดเจนว่าการเปลี่ยนแปลงของโลกและสภาพภูมิอากาศมีผลกระทบต่อที่ราบสูงโคราชอย่างไร จึงได้ทำการศึกษาละอองเรณูวิทยาจากตะพักแม่น้ำโบราณของบ่อทรายท่าช้าง ในตำบลท่าช้าง อำเภอเฉลิมพระเกียรติ จังหวัดนครราชสีมา จากผลการวิเคราะห์ด้านลำดับชั้นหินและตะกอนวิทยา ในช่วงความลึก 14 เมตร พบว่าสามารถจำแนกลำดับชั้นตะกอนจากชั้นล่างถึงชั้นบนได้สามกลุ่ม คือ 1) ชั้นตะกอนของพื้นที่แอ่งน้ำท่วมและทะเลสาบน้ำตื้น 2) ชั้นตะกอนของพื้นที่ร่องลำน้ำ และ 3) ชั้นตะกอนของพื้นที่ดอนหรือตะพักที่มีทางน้ำเก่า พบซากดึกดำบรรพ์ละอองเรณูจำนวนมากจากชั้นตะกอนในบ่อทราย และสามารถจำแนกเรณูสัณฐานได้ประมาณ 100 แบบ ส่วนใหญ่พบในระยะที่เกิดร่องแม่น้ำมูลโบราณ โดยมีทั้งพืชพรรณในป่าและทุ่งสะวันนา รวมทั้งพบพืชในป่าชายเลน เช่น *Acrostichum, Barringtonia, Ceratopteris, Nypa, Oncosperma* และวงศ์ Rhizophoraceae ภายในช่วงตะกอนชั้นที่ 11 10B และ 10A ซึ่งทั้ง 3 ชั้นดังกล่าวพบละอองเรณูของพืชพรรณป่าผลัดใบและป่าผลัดใบผสม ในช่วงอายุตั้งแต่ 52,296 ± 6,800 ปีก่อนปัจจุบัน ถึง 28,150 ± 7,860 ปีก่อนปัจจุบัน นอกจากนี้ยังพบพรรณพืชของระดับพื้นที่ที่ค่อนข้างสูงจากระดับน้ำทะเล คือ พรรณพืชสะวันนาในเขตอบอุ่นและกึ่งร้อนที่พบแพร่หลายในช่วงสมัยที่อากาศเย็นกว่าในช่วงชั้นตะกอน 16A (172,739 ± 22,400 ปีก่อนปัจจุบัน) ชั้นตะกอน 13B (88,661 ± 10,600 ปีก่อนปัจจุบัน) และชั้นตะกอน 9B (27,332 ± 3,000 ปีก่อนปัจจุบัน) ทั้ง 3 ช่วงเวลาดังกล่าวนี้ สอดคล้องกับช่วงอากาศหนาวเย็นของยุคน้ำแข็ง แสดงถึงลมหนาวจากมรสุมฤดูหนาวมีอิทธิพลต่อที่ราบสูงโคราชแม้ว่าดินแดนนี้จะอยู่ไกลจากพืชน้ำแข็งที่ปกคลุมในยุคน้ำแข็ง ละอองเรณูของพืชจำนวนสนที่พบน่าจะถูกพัดพามาจากทางเหนือโดยลม แต่ไม่ได้อยู่ในที่ราบสูงโคราชมาก่อน

งานวิจัยนี้เป็นผลการศึกษาจากตะกอนแม่น้ำมูลโบราณในที่ราบสูงโคราชเท่านั้น ควรมีการศึกษาหลักฐานเพิ่มเติมจากฟอสซิลขนาดใหญ่และเหตุการณ์ผลกระทบจากการเปลี่ยนแปลงของเปลือกโลกในพื้นที่บริเวณดังกล่าวรวมทั้งการเปลี่ยนแปลงรูปแบบของมรสุม

สาขาวิชาชีววิทยา

ปีการศึกษา 2557

ลายมือชื่อนักศึกษา__________

ลายมือชื่ออาจารย์ที่ปรึกษา__________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม__________

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FENGCHUN YANG : THE PALEOVEGETATION AND ENVIRONMENTAL RECONSTRUCTION DURING THE QUATERNARY OF THE KHORAT PLATEAU IN THAILAND BASED ON THE PALYNOLOGICAL RECORD. THESIS ADVISOR : PAUL J. GROTE, Ph.D. 237 PP.

PALYNOLOGY/ VEGETATION/ ENVIRONMENT/ QUATERNARY/ KHORAT PLATEAU

The Khorat Plateau is located at the center of mainland Southeast Asia. It is a relatively high altitude tableland. The local flora is closely related to the Indo-Himalayan-Chinese region in the north and the Malesian region in the south. This plateau is an important bridge connecting the biotas of the two large regions. However, it is still unclear how the Khorat Plateau has been affected by global changes including climate change. An exposed sand pit along the ancient fluvial terrace at the village Ban Som, Tha Chang Subdistrict, Chaloem Phra Kiat District, Nakhon Ratchasima Province, Thailand was selected for palynological research. A 14 m depth exposed section was analysed based on the nnnstratigraphy and sedimentology. According to the results, three different stratigraphic groups were classified from the bottom to the upper layers, shallow lake and flood basin, developed river channel, and dry land with an abandoned river terrace. Abundant pollen grains were discovered from the sediments, from which approximately 100 fossil palynomorphs were recognized and classified. Most of the pollen grains were concentrated in the channel river stage. The main paleovegetation varied from forest to the savannah. Mangrove

components such as *Acrostichum*, *Barringtonia*, *Ceratopteris, Nypa*, *Oncosperma*, and Rhizophoraceae were recognized in a continuous deposit in layers 11, 10B, and 10A. These three layers contained pollen indicating deciduous and mixed forest in the ages from 52,296 ± 6,800 yr BP to 28,150 ± 7,860 yr BP. A period with a relatively high sea level was suggested. Temperate and subtropical savannahs were prevalent in cooler periods 16A (172,739 ± 22,400 yr BP), 13B (88,661 ± 10,600 yr BP), and 9B (27,332 ± 3,000 yr BP). These three periods corresponded well with cold events occurring elsewhere. The cold winter monsoon had influenced the Khorat Plateau even though it was far from the ice sheets present during glacial periods. The pollen grains of conifers were not regarded as local deposits, but were probably transported from the north by wind.

This research focused on the palynological deposits of the ancient Mun River terrace in the Khorat Plateau. Future research is recommended on megafossils as well as on tectonic effects on the region and changes in the monsoonal patterns.

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CHAPTER I

INTRODUCTION

1.1 General introduction

Climate change is an important topic; most people want to know what the real cause of increasing global warmth is. Endless debates are focused on natural climate change and greenhouse gas produced by industry. Some scientists insist it is the result of climate change commonly seen in the earth history related to the solar activity, which is known as Milankovitch cycles (Lang, 2005; Weng, 2005; Schwander, 2007; Paluš and Novotná, 2009; Scafetta, 2012). Tectonic movement is also accompanied by significant climate change in geological time; the daily movement of tectonic plates is not easy to see but it really happens (Boyer *et al*., 2005; Poutanen and Ivins, 2010; Toker *et al*., 2012). The opposite opinion insists that industry development, especially fossil fuel consumption and automobile industry, are responsible for the frequent extreme weather catastrophes (Priambodo and Kumar, 2001; Hove *et al*., 2002; Rehan and Nehdi, 2005).

Although it is difficult to give a final conclusion for this debate, pieces of evidence in many research areas are coming out day by day. We should think about them rationally if we want to get at the truth about the climate change in the past time.

Formally, vegetation is an indicator of climate, for different groups of plants are sensitive to the temperature, moisture, sunshine, etc. The change of vegetation implies synchronized environment shifting. Vegetation on the earth changed many times over the past geological history and could be preserved in many forms. It is the best way to know the natural history in the past. Because of the synchronism between organisms and their living world, it is worthwhile to find the vegetation and its interactions in the physical environment. Megafossils, such as petrified trunks, fossilized leaves, fruits, and their impressions, even carbonized wood, are always accepted in paleovegetation reconstruction; animal fossils, such as foot prints, bones, teeth, skulls, eggs, and even their coprolites, are also important references to interpret the vegetation which supports them, and also explain the weather and environment in which they lived. However, megafossils in sediments are not always well preserved. Soft tissue like flowers are also rarely found in the sediment, the same as many herbaceous species. Furthermore, many megafossil samples are not found in the original deposition, and sometimes they are found in reverse deposition, irregular distortion, or mixed layers (Lowe and Walker, 1997). In order to get over such a difficulty, microfossils like pollen and spores are required. Sediments with continuous deposition with small particles are good at preserving small sized organisms and providing more information beyond megafossils. To a certain degree, microfossils such as pollen and spores represent local vegetation, including forest structure and species composition; it is an efficient proxy for studying vegetation in the past. Pollen analysis is an important and popular way to classify the plant species which have occurred and flourished on the earth. By this type of analysis, vegetation and the related environment have been studied around the world with various records discovered from lakes, ponds, peat, and other depositional environments.

1.1.1 Pollen analysis and paleoenvironment reconstruction

Pollen is the microgametophyte or microspore formed in the microsporangia. In palynology research, the word palynomorph includes pollen and spore grains of gymnosperms, angiosperms, pteridophytes, lycophytes, bryophytes, algae and fungi. Sometimes the tiny fragments or single cellular algae and fungi are also included. The size of most pollen grains ranges from 5 - 200 μm in diameter (Wang, 1983). The pollen wall consists of exine and intine (Figure 1.1). Exine is a resistant and waxy coat of sporopollenin; it is the main structure preserved in the form of fossil. Intine is the inner layer consisting of cellulose and cannot be fossilized (Faegri and Iversen, 1989; Punt *et al.*, 2004). Exine is characterized by a variety of morphological and structural features. The morphological characters of pollen such as size and shape, germinal apertures, and the structure and surface sculpture of exine can be used for taxonomic identification. The exine is variously sculptured, often bearing spines or warts. The sculptural characters are often of value for identification at different levels, family, genus, or species. Various terms are developed based on the pollen and spore subjects. Usually, single pollen grains are found in the plants, but in some groups the pollen forms tetrads or pollinia.

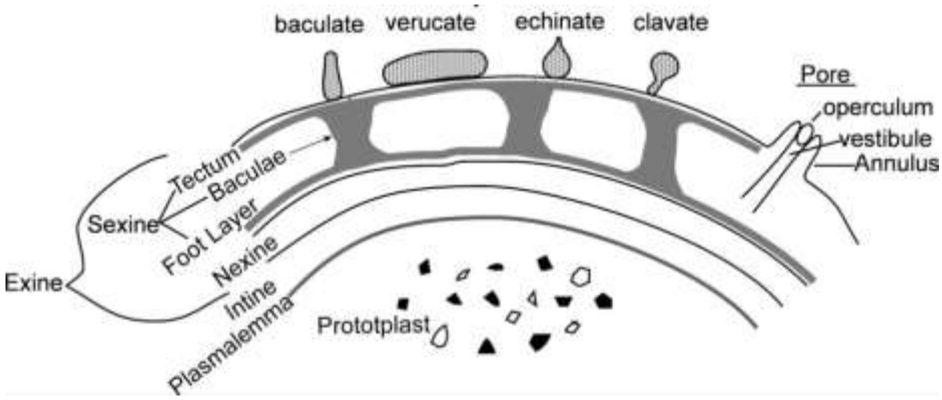


Figure 1.1 Structure of pollen (http://www-ist.massey.ac.nz/pollen/Palynology.htm).

Many studies have shown that the dispersal of pollen and spores is not far from the parent plants. The distribution map looks like a circle around the point of origin. Pollen grain collected from the ground surface presents a dramatic decline from the parent tree to the outside (Wang, 1983; Caroline and Patrica, 2001; Pluess *et al*., 2009) (Figure 1.2). For this reason, pollen sediments *in situ* are a reflection of local plant species.

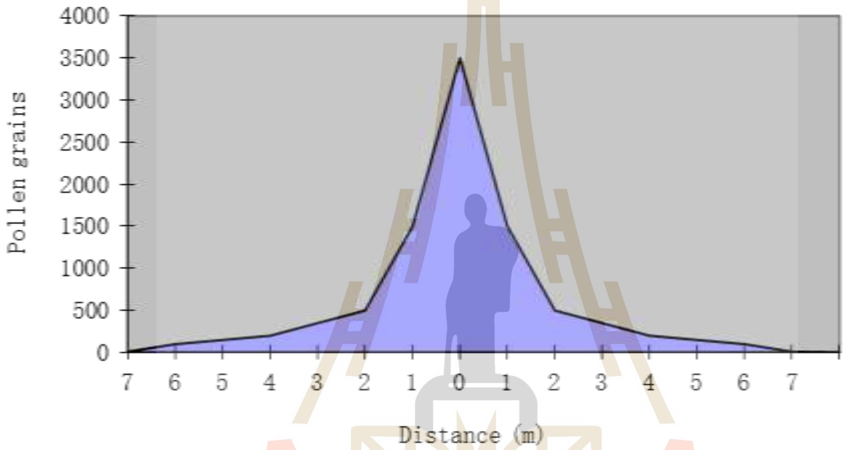


Figure 1.2 Dispersal of pollen (Modified from Wang, 1983).

Pollen analysis was born in 1916 as a technique for species identification and paleovegetation reconstruction. The original meaning of palynology is about fossil pollen analysis in geology. The pollen morphology is stable for a long-term, even millions of years. Modernity of fossil pollen on different levels (families, genera, even species) is the fundamental assumption of palynology. Recognized pollen and pollen assemblages were used to rebuild the plant community, and then rebuild the paleoenvironment and climate. After 1944, the research object covered not only pollen, but also other resistant microfossils, such as diatoms, dinoflagellates, cryptogam spores, small animal remains, etc. (Faegri and Iversen, 1989). Optimal environments for fossil preservation are lakes, bogs, swamps, brackish water estuaries, and ocean basins. Organisms living near aquatic habitats are more frequently presented than terrestrial organisms. In palynology research, the taphonomic processes that influence the fossil assemblages should be considered, including the pollen processes such as production, dispersal, transportation, deposition, preservation, and sampling techniques (Lowe and Walker, 1997). Some fossil samples may be removed from their original place and redeposited in a new locality. So, we have to keep in mind that the plant remains found in a particular formation may or may not give a representative picture of the vegetation at that time. Modern vegetation analog approaches are important to reconstruct the past vegetation (Lowe and Walker, 1997).

1.1.2 The Quaternary Period and related climate events

The Quaternary is the most recent geological period from 2.6 million years before present (Ma BP) to present, including the Pleistocene (2.6 - 0.01 Ma BP) and the Holocene (0.01 Ma BP - present). The environment changed a lot in the Quaternary, including the crustal movement, lifting of Himalaya, transgression and regression of the sea water, and glacial and interglacial periods. There are several records of these alternating periods in the Pleistocene, closely related to the earth's environmental and vegetation change [Table 1.1]. Furthermore, there were some other records, such as the Bolling-Allerod warm phase 14.7 - 12.5 ka BP (Dykoski *et al*., 2005), Younger Dryas (12.8 - 11.5 ka BP) (Muscheler *et al*., 2008), and Little Ice Age (1.35 - 1.85 ka AD) (Solomon *et al*., 2007). Fluctuations of repeated warm and cold episodes occurred over a long time period. All biological organisms on the earth are affected by climate change in many ways, such by as glaciation and deglaciation, drought and flooding, and also including sea level rise and fall. Living organisms are forced to evolve in the changing environment (Lowe and Walker, 1997).

Table 1.1 Some identified glacial periods in the Quaternary period.

	Glacial 1	Glacial 2	Glacial 3	Glacial 4
Alps	Günz (676-621ka) (Lisiecki and Raymo, 2005)	Mindel (478-424 ka) (Lisiecki and Raymo, 2005)	Riss (350-130 ka) (Lisiecki and Raymo, 2005)	Würm (26.5-19 ka) (Clark *et al.*, 2009)
North Europe		Elsterian (before 478 ka, Ehlers *et al.*, 2011)	Saalian (350-130 ka) (Lisiecki and Raymo, 2005)	Weichselian (25-13 ka) (Lokrantz and Sohlenius, 2006)
British Isles	Beestonian (before 866 ka) (Lisiecki and Raymo, 2005)	Anglian (478-424 ka) (McMillan, 2005).	Wolstonian (350-130 ka) (Richmond and Fullerton,1986; Lisiecki and Raymo, 2005)	Devensian (118-10 ka) (Delaney, 2003)
North America		Kansan (400 ka, Roy *et al.*, 2004)	Illinoian (191-130 ka) (Willman and Frye, 1970)	Wisconsin (85-11 ka) (Aber, 1991; Harris *et al.*, 1997)
China	Poyang (676-621 ka) (Li, 1947)	Taku (478-424 ka) (Li, 1947)	Lushan (350-130 ka) (Li, 1947)	Tali (26.5-19 ka) (Li, 1947)

1.1.3 Paleoenvironmental reconstruction in and around the Khorat Plateau

Although some research about pollen from the Quaternary of the Khorat Plateau has been carried out preliminarily, evidence provides some information but still not enough; the paleoenvironment during the Quaternary in this region is still poorly known. A lithostratigraphical column of a sand pit in Tha Chang Subdistrict, Chaloem Phra Kiat District, Nakhon Ratchasima Province, Thailand was constructed from a 25.4 m soil profile (Bunchalee, 2005). According to the pollen data, twenty-nine pteridophytes, four gymnosperms, and twenty-one angiosperms were recognized. Three deposition units are divided in the research area, floodplain, channel, and flood basin. The age from lithostratigraphy and palynostratigraphy researches indicates a Pliocene/Pleistocene period. A 6.18 m core which consisted of pollen and phytoliths was researched in Lake Kumphawapi, Udon Thani of Thailand (Kealhofer and Penny, 1998). The pollen data suggest human-environment interaction from the Early Holocene to present. Extracted pollen indicates a distinctive change from arid land to herbaceous swamp and then swamps forest communities in the Late Pleistocene. Another sediment core was extracted from approximately the center of a small peat swamp, depth to 230 cm, Nong Pa Kho, Udon Thani, Thailand (Penny, 2001). Radiocarbon dating indicates that the age maximum is 40,000 yr BP. Palynological analysis reveals stable vegetation during the glacial age; most pollen related plants are tolerant to a cool and dry environment. *Pinus* and *Quercus* are dominant taxa because of their anemophily and the extreme abundance of pollen produced; they were popularly accepted as indicators of a temperate climate in the Late Pleistocene except for a few tropical species such as *Pinus merkusii*, *Quercus* *kerii* and *Q. lineata*. A rapid vegetation shift is found at the Pleistocene/Holocene boundary; tropical and sub-tropical broad-leaf taxa developed after the increasing of temperature and precipitation. A paleoenvironment project aiming to retrieve empirical data on sediments of archaeological records in monsoonal Asia was carried out in different places of Thailand, including three cores from Nong Thale Song Hong (the south), Kwan Phayao (the north), and Nong Han Kumphawapi (the northeast) (White *et al*., 2004). The three cores show a similar trend from the Last Glacial Maximum to the Late Holocene, although a little diversity still exists due to the influence of topography, latitude, and elevation. In this research, anthropogenic impact on environment is considered important in vegetation changes, not only a single chronological or land use scenario. The authors suggest paying more attention to the multiple reasons and their interaction which affect the sub-regional vegetation, such as climate variability, monsoon system developing, and human activities. Another core from Nong Han Kumphawapi sediment was analyzed (Wohlfarth *et al*., 2012). Geochemical variables (TOC, C/N, $\delta^{13}C$) and diatom assemblages are considered to be the parameters to reconstruct regional climate and environment during the Holocene. The multi-proxy study shows that Kumphawapi paleorecords have a close relationship with moisture, and the moisture closely relates to the Asian summer monsoon. Stronger summer monsoons have influenced the Khorat Plateau and changed the vegetation phases several times (Wohlfarth *et al*., 2012).

Other pollen sediment researches about paleoenvironment reconstruction near or around the Khorat Plateau are also valuable. There were two fluvial cores extracted from the river delta of Tonkin Gulf, Vietnam. Palynological records reveal a significant change of paleomonsoon and paleoenvironment during the border of the Late Pleistocene and Holocene (Li, 2010). There are five major taxon groups (conifers, broad leaf and sclerophyll trees, herbs, fungi and algae) well-represented in the two cores. The data indicate three short periods of strengthened winter monsoons and cold currents at 6.0, 2.7, and 0.2 ka BP, while two summer monsoons and warm currents centered at 7.5 and 3.4 ka BP. Some other sediment cores were also analyzed in Tonle Sap, Cambodia, the biggest lake at the lower region of the Mekong River (Penny, 2006). Biostratigraphic and sedimentological data derived indicate that the lake was more stable than present from 7,000 yr BP to 5,500 yr BP and strongly influenced by saline tidal water. The sea level was higher than nowadays by about 2.5m (Nguyen *et al*., 2000). As a result of monsoon variability and sea-level fluctuations during the Holocene, there was a littoral swamp forest community in the catchment area, which is different from modern vegetation. Interestingly, a sedimentological and palynological study of three sediment cores from the north part of the Mekong River Delta was also reported (Proske *et al*., 2011). The research focused on the regional environment evolution referenced from the mid-Holocene sea level. The sediment core shows a progression of tidal flat, local adjacent mangroves, and floodplain with local swamp species. Another research in Bangkok with a similar result was carried out in the Senanivate housing area from deposits that seem to extend to the Late Quaternary (Somboon, 1988). Grass pollen dominates the apparent Late Quaternary samples; it is interpreted as freshwater vegetation followed by an increase of brackish water and mangrove swamp pollen.

Research in Kanchanaburi, western Thailand, suggests very similar vegetation to the present day in 4,500 yr BP, which comprises dry evergreen to deciduous forest, swamp and aquatic areas (Hutangkura, 2000). The pollen from Doi

Inthanon intramontane peat bog, northern Thailand, indicates that this area has been a typical upper montane rain forest since 4,300 yr BP. However, the fluctuation in Rosaceae, *Engelhardia, Agapetes, Vaccinium* and *Rhododendron* suggests a dynamic change in the Holocene (Poungtabtim, 1998). A sediment core was retrieved from Songkhla province, southern Thailand; samples dated as far back as 33,880 yr BP (Rugmai, 2006). There are 31 families of plants including ferns, gymnosperms, and angiosperms, which mainly comprise mangrove species. The palynoflora is similar to the extant flora and indicates that the shoreline changed from the Late Pleistocene to present. From another study, the sea level in the Holocene, Malay Archipelago, was reported as being higher than at present (Morley and Flenley, 1987). Pollen data from Sichuan, Southwest China suggest a colder and drier environment before 10,000 yr BP (Jarvis, 1993). Supporting research from lake sediments at Dianchi, Southwest China, also indicates a cool and dry climate before 9,500 yr BP and a warm and humid time after that, with plenty of precipitation (Sun *et al*., 1986). *Pinus* dominated the hill slopes with deciduous and evergreen forests and *Tsuga* in valley heads. This means a cooler summer and a little colder winter with low drought risk. A report of the Younger Dryas age (12,800-11,500 yr BP) from the loess plateau of Central China is interpreted as an interval of warm and wet summer climate resulting from the enhanced southwest monsoon activity (An *et al*., 1993). Another review paper concludes the evidences for the Younger Dryas climatic event from mainland and island Southeast Asia; it suggests a detectable climatic event with finer resolution pollen analysis at the time of the Younger Dryas (Maloney, 1995). The data from Sumatra, west Java, and New Guinea suggest a cool climate in the Late Pleistocene glacial maximum (Morley and Flenley, 1987). Another pollen record from Cambodia shows that the last glaciation ends at around 8,500 yr BP, about 1,000 years later than in Southwest China. Summer monsoon intensity increased between 8,400-5,300 yr BP, similar to most other sites in the Asian monsoon region. After that, a secondary forest developed and expanded into the dense semi-evergreen forests, suggesting a drier climate with frequent fire disturbance (Maxwell, 2001).

According to the pollen evidence and various conclusions mentioned above, scientists have different ideas about the exact time sequences and related climates. Although divergence still exists, we also can get a general outline about the paleoenvironment in Southeast Asia, especially in the Indochina peninsula region. For example, an open savannah forest, rich in grass and sparse tree environment, may have extended rapidly at the shift of Late Pleistocene/Holocene, perhaps forming a "savanna corridor" from Thailand to the Malay Peninsula. This opinion is also supported by some Asian herbivorous animal fossils discovered in Java (Medway, 1972).

1.2 Research objectives

(A) To produce a palynoflora and reconstruct the paleovegetation and paleoenvironment during the Late Quaternary along the ancient Mun River in the Khorat Plateau.

(B) To analyze the interactions between paleovegetation and environment and classify vegetation types by characteristic species or species assemblages which dominated in their period but faded or disappeared at other times.

1.3 Research hypotheses

According to the preliminary sedimentary researches in Khorat Plateau and surrounding area, the paleovegetation and paleoclimate kept changing in the past. Some evidence discovered in the past seemed insufficient to explain certain cases, such as how the Asia monsoon worked in winter and summer, the frequency of the climate events, and the co-relationship between terrestrial vegetation and current weather. Also, some pollen records were interpreted incorrectly; some groups were interpreted arbitrarily and used to indicate a certain environment, because there were various habitats for different species in one taxon. In conclusion, much more data with correct recognition and classification are required. Also, some representative pollen records are also expected to be discovered.

(1) Regionally, there was a tremendous difference as a result of the global climate impact, hundreds to thousands years' time lag is normally seen in different areas. It is expected that distinct pollen records (representative pollen) within given stages of this research will be found, the turnover point between climate events by local extinction and new colonization will be identified.

(2) The local flora of Khorat Plateau can be influenced by the surrounding biotas. Long distance dispersal of seeds changes local vegetation, while some pollen and spores change palynofacies in sediments. Pollen and spores with small size, low weight, and distinct sculptures can be transported a long way by wind, rain or even be carried by the jet stream, then fall down and deposit at a new place.

1.4 Scope and limitations

1.4.1 Research scope

This research is focused on the Khorat Plateau. The main sampling points are the sand pits along the old Mun River. The candidate area is Ban Som in Thachang, Nakhon Ratchiasima, Thailand, and new sand pits discovered nearby also investigated. The reference samples were collected from the representative vegetation types, the surface soil samples were collected and analyzed

1.4.2 Research limitations

Including the preliminary study and field sampling, which had been carried out since September 2012, this work was finished in 2014, about 27 months in total. The main tasks were fossil pollen extraction, modern pollen preparation, microscopic observation and data analysis.

1.5 Expected results

(1) A palynoflora during the Late Quaternary period.

(2) Restored paleovegetation and paleoenvironment.

(3) An interaction within the paleovegetation, paleoenvironment and global change.

1.6 The significance of this study and objectives

Compared to megafossils (animals, petrified woods, and fruits), pollen grains and their assemblages are micro products of environments; they are also the representatives of the local environment of the past. According to the pollen records, we can figure out what species had ever inhabited or flourished in this area or nearby, because the amount of pollen groups means the same amount of plant species, which also means the paleovegetation. Furthermore, different pollen components mean varied ratios; their elements are the response of local environment and climate. Different plants prefer different habitats, such as dipterocarps growing well in tropical zones but ginkgos preferring temperate zones. *Asplenium* prefers high moisture in heavy shade, but *Lygodium* grows well in arid areas with more sunshine. Representative species are good symbols to tell their living condition. Species assemblages provide information on the community, and the community in turn provides information on the local environment.

In the past decades, the attempts of paleoenvironment and vegetation reconstruction in the Late Quaternary of the Khorat Plateau have yielded various results (Bunchalee, 2005; Kealhofer and Penny, 1998; Penny *et al.*, 1996; Penny, 2001; White *et al*., 2004; Wohlfarth *et al*., 2012). Many works focus on megafossils of animals and plants as they are everywhere in this area, and they are efficient and useful. However, there are still some problems. Many megafossil samples are found by random, or second hand collection, the original deposition of which is usually unknown or destroyed; disturbed and mixed layers are commonly seen in field investigations. It is always a big problem to fix the *ex situ* megafossils to the exact geological age. But the same problem does not exist in pollen research. Pollen samples are usually collected from continuous deposition relative to megafossils; detailed sedimentary and distinctive layers are easy to identify. Compared to megafossils, pollen sample collection can be carried out depending on the deposition conditions. A high resolution with small time scale (maybe centuries) usually tells more information in detail although it means more lab work and data analysis.

River sediments are valuable for environmental analysis and offer the opportunity to reconstruct climatic variability and hydrodynamics over long time-scales. In this case, the pollen grains were collected and extracted from alluvial sediments, the geological age presumably from the Pleistocene to recent days, including some notable climate events such as the Last Glacial Maximum, the Bolling-Allerod warm phase, Younger Dryas, etc. Pollen characters and related information are analyzed in this research. It is expected to provide more complete information about the paleovegetation and paleoenvironment, and it can also be applied to the Indochina peninsula.

In the preliminary study, various pollen and spores were found in different sediments. The exposed section in Tha Chang Subdistrict, Chaloem Phra Kiat District, Nakhon Ratchasima, revealed a potential pollen deposition in the Quaternary. However, more field investigation and lab work are necessary in the same area in order to complete the whole geological succession.

CHAPTER II

GEOLOGICAL AND VEGETATIONAL BACKGROUND

2.1 Geology, topography, and vegetation of the Khorat Plateau

Geology: Southeast Asia lies on the southeast margin of the Eurasian plate where the Indian-Australian plate is converging beneath as a subduction zone. It is regarded as a part of the extension terrain resulting from the southeast direction tectonic extrusion caused by the Indian-Eurasian plate collision since Middle Eocene. Southeast Asia consists of two geographic regions, mainland and island. The Indochina Peninsula is the mainland connected with the Eurasian plate while the other islands or archipelago are scattered in the West Pacific Ocean (Tapponnier *et al*., 1982). As part of the Indochina terrane, the Khorat Plateau has been continuously uplifted for a long period throughout the Late Cenozoic. A volcanic eruption had affected the marginal Pacific tectonic domain; lavas erupted as scattered spots in the direction from east to west along the south margin of the Khorat Plateau. These volcanic rocks resemble those of southern China, differentiated by fractional crystallization without assimilation of crustal rocks (Faure, 2001). These geological activities created various landforms such as mountain ranges, tableland, cuesta, and peneplains. Himalayan orogenies, commenced during the Paleogene, also contributed to the geographical change; collision between the Indian subcontinent and Eurasian continent remarkably changed the landforms (Tapponnier *et al*., 1982). The Khorat Plateau is a relatively high altitude tableland in the central part of the Indochina

Peninsula with a cuesta slope formed at the southwest margin. In the plateau, the rocks are old in the southwest but younger to the northeast. The oldest rocks are limestone, shale, and slate with an age of Permian (299 - 252 Ma BP). Neogene (23.0 - 2.6 Ma BP) and Quaternary (2.6 Ma BP - present) sediments are unconsolidated, especially gravel terrace deposits, with the Yasothon soil series at the upper set (Loffler and Kubiniok, 1991; Songtham, 2012). The plateau is made up mainly of sandstone and shale. The sedimentary rocks in the southern part of the plateau near Surin, Si Sa Ket, and Buriram are interbedded with and intruded by basalt flows and dikes. Deposits of fluvial silt, clay, sand, and gravel of Quaternary age occur throughout the area beneath flood plains, stream channels, and terraces originated from sandstone, claystone or granitic rock (Bunchalee, 2005). The Khorat Plateau has usually been divided into three structural features: the Phu Phan range of hills, created by a series of gentle folds in rocks of Triassic age, the Sakon Nakhon basin (the north part of the Khorat Plateau) and the Khorat basin (the south part of the Khorat Plateau), depressions formed on opposite sides of the range (Lamoreaux *et al*., 1954).

Topography: The Khorat Plateau is located in the center of the Indochina Peninsula (Loffler and Kubiniok, 1996), characterized by a relatively high altitude, rolling surface and undulating terrains with approximately 170,000 km^2 (Parry, 1996). The Mekong River flows past in the north and east, and the region is sheltered by the Phanom Dong Rak Mountain range in the south, and Petchabun and Dong Phayayen mountain ranges in the west. Elevation ranges from 130 m to approximately 1,326 m above sea level (asl) with a platform around 238 m in high mountainous surroundings (Heine, 2007; WCPS, 2011) [Figure 2.1]. The central parts are plains and small hills.

Ground water in northeastern Thailand is derived almost or wholly from rains during the wet season, May to October. The Mun and Chi rivers and their tributaries are the main water resources through this area. The Mun River is one of the large tributaries of the Mekong, flowing from Khon Buri district, Nakhon Ratchasima, and diverting to the east in Chaloem Phra Kiat district, Nakhon Ratchasima, finally draining into the Mekong River in Khong Chiam, Ubon Ratchathani. It is 641 km long before joining the Mekong River. The elevation is 530 m at the head in Thap Lan and 95 m at the mouth (Department of Water Resources of Thailand, 2014; Pollution Control Department, Ministry of Science, Technology and Environment, Thailand, 2005) [Figure 2.2]. Flood gauge records in recent years indicate the Mun River flooded frequently (Hydrology and Water Management Center for Lower Northeastern Region, Thailand, 2014).

Climate: The Khorat Plateau is in the tropical zone with a terrestrial monsoonal climate based on the critical alternation of wet and dry seasons. The meteorological data between the year 1951 and 2011 showed an annual relative humidity of 80%, and an annual mean temperature of 23.9 - 28.5 ˚C (18.3 ˚C in winter, 35.0 ˚C in summer, and 27.7 ˚C in rainy season) (Climatological Center, Meteorological Development Bureau, Meteorological Department, 2012, 2013a, 2013b). The seasons are divided as follows: the summer season lasts from March to May with an average of 35.0 ˚C with precipitation below 71.9 mm; the rainy season is between May and October with an average temperature of 27.7 ˚C with a high precipitation of about 1,085.8 mm. The winter season lasts from October to February with an average of 18.3 ˚C, with a high precipitation of about 214.2 mm (Climatological Center, Meteorological Development Bureau, Meteorological Department, 2012, 2013a, 2013b).

Figure 2.1 Location and topography of the Khorat Plateau (Heine, 2007).

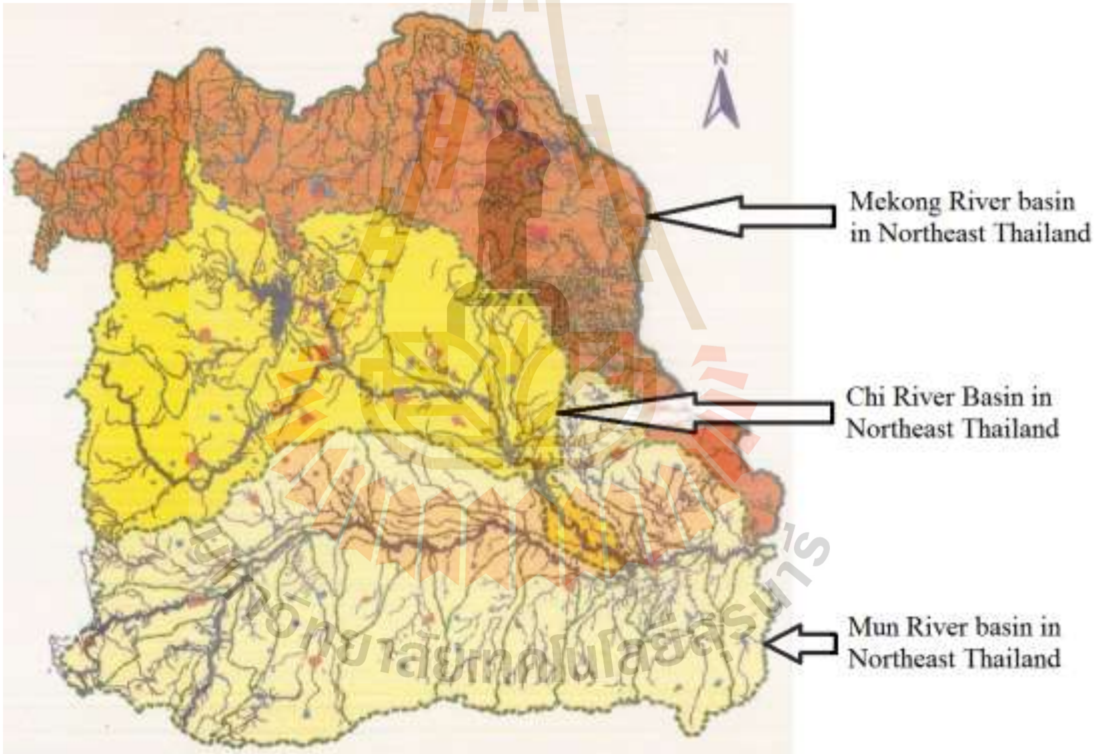


Figure 2.2 Flood basin of the Mun, Chi, and Mekong River in the Khorat Plateau (Pollution Control Department, Ministry of Science, Technology and Environment, Thailand, 2005).

Vegetation: The Khorat Plateau lies in two major bioregions of Asia, the Indo-Himalayan-Chinese region in the north (including eastern Himalaya, Myanmar, south China, and Indochina) and the Malaysian region in the south. The local biodiversity is influenced by its neighbors. According to the classification of terrestrial ecoregions and related forest types of the "World Wild Fund for Nature" (WWF, 2013), there are several defined forest types in and around the Khorat Plateau (Table 2.1).

The vegetation around the research area was destroyed by farming, digging of sands and road construction. Rice fields, eucalyptus forest, and degenerated forests with abundant herbs occupied most of the area. However, according to a field survey (Bunchalee, 2005) covering an area two kilometers wide along both sides of the river at geographical coordinates of 15° 00' - 15° 03' N and 102° 15' - 102° 19' E, total numbers of 212 species in 167 genera and 76 families were identified. The most common species are *Setaria*, *Dipterocarpus*, *Tamarindus indica* (exotic), *Lantana camara* (exotic), *Chromolaena odoratum* (exotic), *Peltophorum pterocarpum*, *Delonix regia* (exotic), and some Labiatae species. Gymnosperms and ferns are absent. In this study, a field survey was carried out on January 13, 2015 in the dry dipterocarp and mixed deciduous forest near the Nakhon Ratchasima Airport and also along the modern Mun River. However, around 24 families and 39 species were identified with 7 species exotic. Poaceae, Fabaceae and Dipterocarpaceae were the dominant families and were also wind pollinated (Appendix A).

Table 2.1 Ecoregion and forest types in and around the Khorat Plateau.

Ecoregion	**Forest type**	**Location**	**Characters**
Tropical and Subtropical Moist Broadleaf Forests ecoregions	Cardamom Mountains Moist Forests	Cambodia and Thailand	*Hopea pierrei*, *H. odorata*, *Anisoptera costata*, *A. glabra*, *Dipterocarpus costatus*, *Shorea hypochra*, *Caryota urens*, and *Oncosperma tigillarium*
	Peninsular Malaysian Lowland and Montane Forest	Malaysia, Singapore, and Thailand	About 8,000 plant species with 6,000 different trees. Montane rainforests, unique limestone forests, and pristine lowland dipterocarp forest.
Tropical and Subtropical Moist Broadleaf Forests ecoregions	Annamite Range Moist Forests	Cambodia, Laos, and Vietnam	Dominated by Myrtaceae, Fagaceae, Elaeocarpaceae, and Lauraceae, high endemism.
	Southeast China-Hainan Moist Forests	Southeastern China, Vietnam	*Ginkgo biloba*, *Metasequoia glyptostroboides*, and *Bambusa arunidinacea.*

Table 2.1 (Continued) Ecoregion and forest types in and around the Khorat Plateau.

Ecoregion	**Forest type**	**Location**	**Characters**
Tropical and Subtropical Moist Broadleaf Forests ecoregions	Northern Indochina Subtropical Moist Forests	Southern China, northern Laos, Myanmar, Thailand, and Vietnam	Monsoon forests, including drought-deciduous savanna woodlands to montane evergreen forests, seasonally humid, evergreen-broadleaved forest.
Tropical and Subtropical Dry Broadleaf Forests ecoregions	Chhota-Nagpur Dry Forests	Eastern India	*Tectona*, *Shorea*, *Anogeissus latifolia*, *Terminalia alata*, *Phoenix robusta*, and *Cycas beddomei*.
	Indochina Dry Forests (the sampling site)	Cambodia, Laos, Thailand, and Vietnam	Dry evergreen and dry forests adapted to distinct dry season and torrential rainy season.
Tropical and Subtropical Grasslands, Savannas and Shrubland ecoregions	Terai-Duar Savannas and Grasslands	Bangladesh, Bhutan, India, and Nepal	The tallest grasses, *Saccharum* and elephant grass, over seven meters, grow annually.

Table 2.1 (Continued) Ecoregion and forest types in and around the Khorat Plateau

Ecoregion	Forest type	Location	Characters
Temperate Broadleaf and Mixed Forests eco regions	Eastern Himalayan Broadleaf & Conifers	Bhutan, China, India, Myanmar, Nepal	High proportion of endemic species, *Cymbidium*, *Paphiopedilum*, *Acer*.
Temperate Coniferous Forests ecoregions	Hengduan shan Coniferous Forests	China	Glaciation refuge of endemic and relict species. Subtropical evergreen broadleaf to conifer forests. *Metasequoia*, *Taxus*, and *Cryptomeria*.
Mangrove ecoregions	Greater Sundas Mangroves	Indonesia, Malaysia, and Brunei	Mangroves, waterlogged, salty soils of sheltered tropical and subtropical shores
	Sundarbans Mangroves	Bangladesh and eastern India	

2.2 Fossil records discovered from the Khorat Plateau

The Khorat Plateau contains unconsolidated sediments in different types and provenances. There was a successive geological age decline from the outermost regions to the center, from Permian to Quaternary. Numerous vertebrate, invertebrate, and plant fossils and their impressions were found in this area. Most fossil samples were from fluvial deposits along the Mun and Chi River or their tributaries. However, there was still no precise dating because of the difficulty in dating unconsolidated and frequently reversing stratigraphic columns and mixed layers that always occurred in fluvial taphonomy. Anyway, there has been some valuable work already: (1) Numerous fossil animals have been discovered in well preserved sequences, such as *Gomphotherium*, *Elephas*, spotted hyenas, chital deer, orangutan, hipparion horses, rhinoceroses, hippopotamuses, crocodiles, Indian gharials, turtles, soft-shelled turtles, fishes, mollusks, stegodon, and bovines, although most of the vertebrates were incomplete specimens. The fossil fragments are varied, including skulls, jaws, teeth, bones, and antlers collected from the Quaternary gravelly sand layers in 4-5 meters depth in the channels and flood plain (Hanta *et al.*, 2008). (2) Abundant fossil woods supposedly Pliocene-Pleistocene have been found in river terraces. Some specimens were described and identified such as *Albizia lebbeck*, *Aquilaria sp.*, Anacardiaceae, *Azadirachta* sp., *Homalium tomentosum*, *Canarium* sp., *Careya sphaerica*, *Combretum* sp., *Dipterocarpoxylon sarapeense*, *Millettia leucantha*, *Mangiferoxylon* sp., *Terminalia paracoriaceum*, *Wrightia arborea* and Palmae. Most taxa were similar to the modern samples and represented dry evergreen broadleaf to mixed deciduous forests (Benyasuta, 2003; Boonchai, 2008). (3) Reported fossil fruits here were also in good condition. Some of them were *Ziziphus khoksungensis*, *Dipterocarpus costatus*, *Melia azedarach*, and *Dracontomelon dao* (Grote, 2007). (4) Some tubers identified were similar to *Cyperus* or *Bolboschoenus* (Grote, 2007). A tektite layer discovered in Southeast Asia indicated that a controversial comet or meteorite impact occurred around 0.69-0.80 Ma. Some tektite fragments were discovered in the sand pit around Ban Som, which was commonly accepted as a symbol of chronology (Charusiri *et al*., 2002; Duangkrayom *et al*., 2014; Haines *et al*., 2004; Koeberl *et al*., 1997; Langbroek, 2014; Songtham *et al*., 2012; Wang and Bae, 2014).

Interpreted information from discovered fossils is presented as follows:

(1) The vegetation at the time of deposition is similar to the African continent. The spotted hyenas are found in Africa today, but they may have inhabited the Khorat Plateau during the Late Cenozoic and later became extinct at the end of the Late Pleistocene (WCPS, 2011). Today a similar species of striped hyena is found in India (WWF, 2013). *Elephas*, rhinoceroses and hippopotamuses are still active in Africa today.

(2) It is supposedly tropical mixed deciduous and dry evergreen forests (Boonchai, 2008). Most fossil wood species belong to dicotyledons and palms, and the taxonomic composition strongly suggests that they are either Neogene or Quaternary floras and not older than Neogene because of the presence of dipterocarpaceous woods (Dutta *et al.*, 2011; Muller, 1981).

(3) The mammal fossils from the Khorat Plateau are key evidences for the faunal elements of Indochinese and Sundaic zoological provinces in the Middle/Late Pleistocene. The mammal species are similar to those occurring at present days; their appearances were thought to be an indication of a hub station of quadrupeds on the migration to the south through the Indochina Peninsula, whereas the Javanese fauna

(isolated by the sea) are mainly composed of endemic forms. There was a dramatic climatic change during the Pleistocene, and the northern faunas were forced to migrate to the south. There is a zoological boundary located in the Kra Isthmus in south Thailand, although it is supposed to have been located more southward than the current location. The well-known evidence is the fossil of *Elephas namadicus* discovered in Malesia (Tougard, 2001). Therefore, the Indochina Peninsula, including the Khorat Plateau, should be part of the great dispersal corridor in the past time (mostly during cooler periods).

CHAPTER III

MATERIALS AND METHODS

3.1 Field work

3.1.1 Location and field survey

The study area is beside the ancient Mun River channel, Ban Som (15° 2' 5.89" N, 102° 17' 20.56" E, altitude 164 m), Tha Chang Subdistrict, Chaloem Phra Kiat District, Nakhon Ratchasima Province, Thailand. It is located in the center of the Khorat Plateau [Figure 3.1]. The Quaternary deposition is composed of flood plain, fluvial, and oxbow lake sediments. Redeposits are commonly seen because of seasonal monsoon precipitation and also because of the river migrating.

Figure 3.1 Topography of the rivers in the Khorat Plateau, and the sampling site (Ban Som) (modified from Google Earth, 2015).

The deposits of the sampling area are composed of Quaternary sediments, unconsolidated conglomerate, such as gravel, cobble, sands, and soil; and semi-consolidated conglomerate in the lower layer, such as siltstone, claystone and sandstone (Boonchai *et al.*, 2012; Lamoreaux *et al.*, 1954; Songtham *et al.*, 2012) (Figure 3.2). Abundant megafossils and organic layers have been explored along the ancient channels with the age from Middle Miocene to Late Pleistocene (Grote, 2007; Boonchai, 2008; Songtham *et al.*, 2012). The active river channel is about 0.3 km from the sampling site with plenty of riverine vegetation (Figure 3.3).

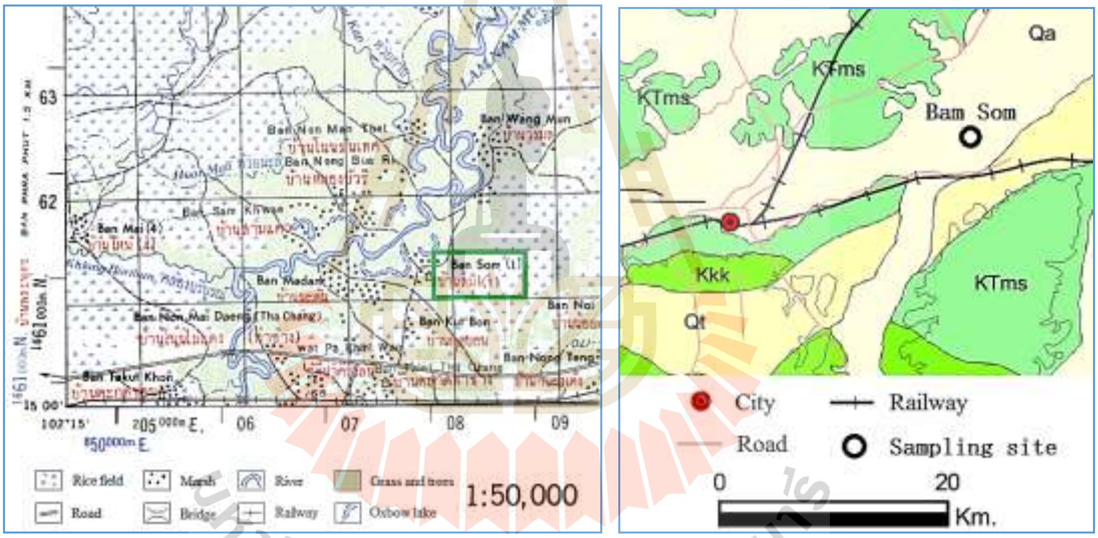


Figure 3.2 Topography and stratigraphy of the sampling site (Pollution Control Department, Ministry of Science, Technology and Environment, Thailand, 2005). Kkk: Cretaceous siltstone, sandstone, reddish brown and red, calcareous; claystone and conglomerate with calcrete along horizons. KT_{ms}: Cretaceous siltstone, reddish brown, red; claystone and sandstone, intercalated with rock salt, potash, gypsum and anhydrite. Q_a: Quaternary alluvial deposits: gravel, sand, silt and clay; deposited in the channel, river bank and flood plain. Q_t: Quaternary alluvial terrace deposits: gravel, sand, silt, clay and laterite.

Modern Mun River, bar deposit

Modern Mun River, vegetation

Rice field near the river

Degraded vegetation

Albizia lebbekkoides

Typha angustifolia

Figure 3.3 Vegetation along the Mun River in Tha chang Subdistrict.

3.1.2 Outcrop section sampling

A 14 meter thick outcrop section from the explored sand pit was checked several times. Eleven samples were collected and analyzed preliminarily. There were distinctive differences in the layers indicating identifiable deposits. Numerous pollen grains were discovered in some layers, suggesting that the ancient river sediment here is valuable for paleoenvironment reconstruction by the way of palynology. Formal sampling was carried out after the preliminary work [Figure 3.4 - 3.5]. Sampling methods followed Erdtman (1969), Faegri and Iversen (1989), and Wang (1983). The surface soil was scraped off for the potential contamination from modern pollen grains. Referring to the fluvial condition and the thickness of each layer, an average interval of 50 cm was adapted in the sampling. More samples would be collected and marked as a new layer if the intervals covered more than one distinct layer, while the continued and homogeneous layers with the same texture would be considered as one layer. Furthermore, in order to keep continuous information, at least one sample was collected in each layer. More samples are suggested in the thick and dark layer.

Figure 3.4 Explored sandpit, showing the sampling place.

Figure 3.5 Explored sandpit, showing the outcrop section and the deposits.

3.1.3 Modern pollen reference preparation

The extant pollen and spores are used to infer the ancient taxa. There were 57 herbarium pollen samples collected from the Forest Herbarium (BKF) and Bangkok Herbarium (BK) [Figure 3.6]. In addition, 33 samples were collected in the field, identified by experienced taxonomists and were prepared as voucher specimens at the same time (Figure 3.7).

Figure 3.6 Herbarium samples.

Lagerstroemia speciosa

Hibiscus mutabilis

Dipterocarpus retusus

Murdannia keisak

Elaeis guineensis

Rubus alceifolius

Paspalum dilatatum

Senna alata

Polygonum thunbergii

Chromolaena odorata

Lithocarpus trachycarpus

Radermachera ignea

Figure 3.7 Fresh samples.

3.2 Laboratory work

3.2.1 Fossil pollen extraction

The extraction of fossil pollen followed the methods of Erdtman (1969), Faegri and Iversen (1989), with some improvements (Rugmai, 2006; Li, 2007). High concentration acid and alkaline solution were applied to remove calcium carbonate, organic detritus, and silica. A pre-customized fine mesh cloth (diameter 0.006-0.010 mm) was used to remove resistant impurities. To accelerate the progress, the samples were stirred at 900 rpm (Big squid, IKA, Thailand) and centrifuged at 2,500 rpm (Labofuge 400R, Heraues, Germany). In the preliminary test, the extracted samples after stirring and centrifuging were compared with the traditional methods, and the modified technique was proved efficient without any negative results (such as extrusion and grain lose) (Figure 3.8).

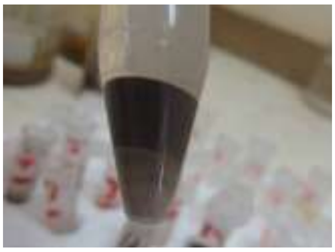
Fume hood

Magnetic stirrer

Centrifuge

Samples

Stratification



Check at microscope

Figure 3.8 Fossil pollen extraction.

The main procedures are listed as follows (Figure 3.9):

1. Surface cleaning of all samples by razor blade or knife. Samples were placed into polypropylene beakers, about 10 g for each.

2. More than 50 ml hydrochloric acid (HCl, 10%) was added for removing calcium carbonate. The mixture was left overnight until particles dissolved and the HCl was decanted. Samples were washed with plenty of deionized water and left for more than 4 hours. Such a rinsing was repeated three times.

3. More than 50 ml sodium hydroxide solution (NaOH, 10%) was added to removed humus or organic matters. This solution was left overnight until humus was dissolved and NaOH was decanted. Plenty of distilled water was added to wash the solution, and the samples were then left for more than 4 hours. Such a rinsing was repeated three times.

4. To remove some resistant calcium carbonate, step 2 was repeated with a high concentration of hydrochloric acid (HCl, 36%).

5. More than 50 ml hydrofluoric acid (HF, 40%) was added to remove silicates (slowly and carefully at this stage). This solution was left overnight until silicates were dissolved and HF was decanted. Plenty of distilled water was added to wash the solution, and then the samples were left for more than 4 hours. Such a rinsing was repeated three times.

6. To get pollen residues without too much water, the final solution in the deionized water was sieved through a pre-customized fine mesh cloth (mesh diameter is about 10 μm to filter water and collect most kinds of pollen grains). The mesh cloth was supported in a bowl or beaker. All the solution in the deionized water was drained

through the mesh cloth; residues were absorbed on the mesh cloth by a Pasteur pipette, and then put into a vial tube (5 ml volume).

7. The tubes filled with rough pollen solutions were centrifuged at 2,500 rpm for 3 minutes. The upper part was poured out slowly. Two ml of glycerin were added into the vial tube to keep the pollen grain residues at the bottom.

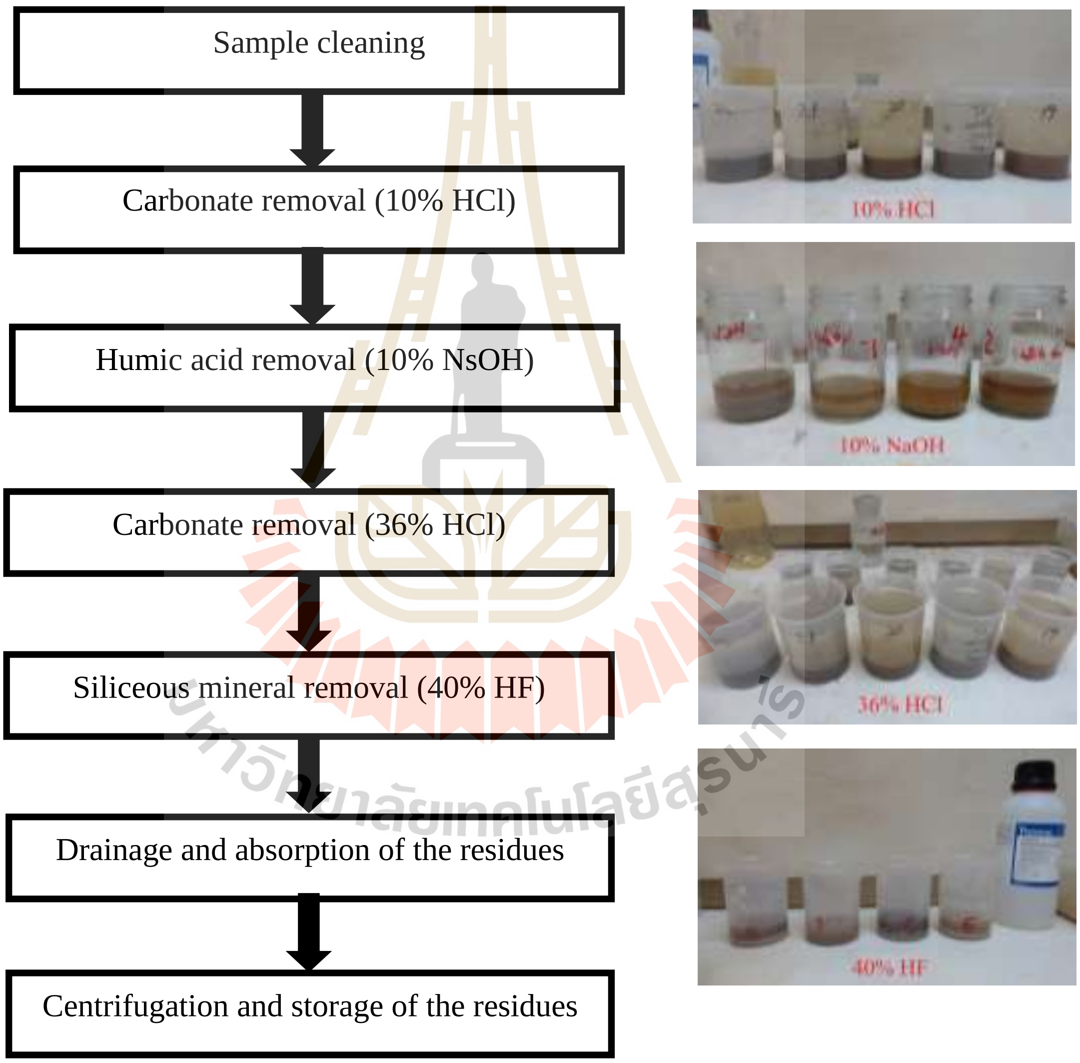


Figure 3.9 The procedure of fossil pollen extraction (1. All the steps should be carried out in the fume hood. 2. All proceedings related with alkaline and acid solution were followed by repeated washing with plenty of deionized water).

8. A little drop of pollen residue was put on the microscope slides, mixed with a drop of glycerin jelly (gelatin: glycerin: distilled water = 20: 70: 10), and then covered.

3.2.2 Modern pollen preparation

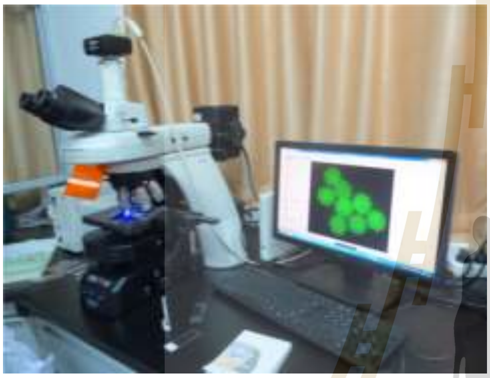
Acetolysis with acetic anhydride $(CH_3CO)_2O$ was popularly used to digest the organic matters in the pollen grains (Dixit and Bera, 2013; Erdtman, 1969; Kennedy *et al*., 2005; Mao *et al*., 2012; Paudayal and Gautam, 2012). Because of the dangerousness of acetolysis, other methods were also considered. Some pollen grains composed of very thin exine and thick intine were also digested by alcohol (Saensouk *et al*., 2009). A neutralizing method with weak alkaline solution was also mentioned as having the same function to produce clean and transparent pollen grains (Song, 1965). Anthers were picked out and put in 10% KOH or NaOH, followed by a few minutes shaking or stirring to break the anther wall and digest the contents in pollen grains. The solutions were diluted with plenty of water, and the pollen grains were washed three times or more after 10 - 30 minutes. The broken anther wall and other plant tissues were removed by a tweezer, and then centrifuged. The residues were kept in small vial tubes with glycerin.

3.3 Microscopic analysis

3.3.1 Light microscopy (LM)

Light microscopy (LM) was used for morphological observation, statistical counting, and photographing. Three hundred pollen grains and spores including algae and fungi were counted in each sample (Faegri and Iversen, 1989; Moore and Webb, 1978; Li *et al*., 2007; Rugmai, 2006). Pollen identification and counting were carried at 10x40 magnifications (Ni-E, Nikon, Japan) while detailed photographs of selected fossil and reference grains were taken at 10x63 (Axio Imager A2, Zeiss, Germany). A single pollen grain of each type was picked out by a hair needle (Zetter, 1989) under inverted microscope (CKX 41, Olympus, Japan), then photographed and documented (Figure 3.10).

Stereo microscope



Microscope station

Inverted microscope

Pollen grain slides (sigle grain)

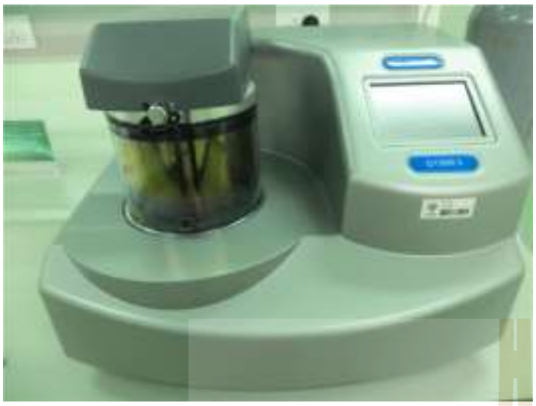
Figure 3.10 Light microscopes and slides.

3.3.2 Scanning electron microscopy (SEM)

Scanning electron microscope (SEM) analysis was critical for detailed morphological observation and photographing. The same single pollen grain documented under light microscope was used for SEM. A little absolute alcohol was dropped on metal stub, and then the pollen grain was placed in the alcohol before it evaporated by a hair needle. Each stub can be divided to 12-16 small zones on which to put different pollen grains. Gold coating was carried out to reduce negative charge on the surface of samples before SEM observation. It was carried out after the evaporation of alcohol on stubs. Gold was used as the conductive medium in the sputter coater (Q150R, Quorum Technologies Ltd., UK; JFC 1100E, JEOL, Japan). The optimal current strength is 10 mA, coating time is 10 minutes. To get the best observation, fresh coating is necessary according to our experience. Coated samples should be put in the vacuum chamber as soon as possible after coating and the old samples should be coated again if exposed to the air more than 30 minutes (Figure 3.11).

The stub was observed and photographed at high resolution (× 1,000 - 12,000) with a 3D view on SEM (EVO LS10, Zeiss, Germany; JSM-6010LV, JEOL, Japan). Some small grains (moss and fungi spores) requiring high magnification were observed with an ultra-high resolution (× 20,000) field emission SEM (JSM -7800F, JEOL, Japan) (Figure 3.11). Beam current voltage was ranged from 5 to 15 kV depending on the pollen types and coating quality. Generally, the low voltage (5 kV) was accepted in the case when the pollen grain had a heavy shadow under SEM, while high voltage (15 kV) was used to get a high resolution image.

Ion sputtering instrument



Ion sputtering instrument

SEM

SEM

Ultra-high resolution field emission SEM

Gold coated stubs

Figure 3.11 Scanning electron microscopy.

3.4 Data analysis

3.4.1 Age dating

The published age dating records at the same place based on tektites indicated 0.69-0.80 Ma (Charusiri *et al*., 2002). Although the tektite layer is just several centimeters thick and deposited at different depths in the Khorat Plateau, the age data were similar to each other (Izett and Obradovich, 1992; Kunz *et al*., 1995). The sampling layers in this study are 14 m, a few meters' gap from the known tektite age. Theoretically, they should be younger than the tektite layer. The dating methods were different depending on the materials. Carbonized wood was sent for C^{14} dating (scintillation counting) (following Arnold, and Libby, 1949) while the clay and silt were sent for thermoluminescence dating. The samples for thermoluminescence dating were collected in a deep hole and packaged in dark bags (following Keizars *et al*., 2008) (Figure 3.12).

Figure 3.12 Carbonized wood and thermoluminescence sampling.

3.4.2 Reconstruction methods

(A) The modern analog technique (Jackson and Williams, 2004). This is the way of a "modern analogue" to find the similarity between the fossil pollen samples and the modern ones, and then obtaining average climate associations in the sediment.

(B) Characteristic components or endemic species approach (Faegri and Iversen, 1989; Li *et al*., 2006). This method is based on the most characteristic groups or endemic species which grow in unique habitats. These species are normally found in a narrow temperature range or only survive in an exclusive habitat, such as brackish water or open forest, and they are considered to be the best environment indicators.

(C) Coexistence Approach (Utescher and Mosbrugger, 1997). The coexistence approach is a quantitative method for terrestrial palaeoclimate reconstruction. It is based on the assumption that fossil plant taxa and their nearest living relatives have similar climatic requirements.

3.4.3 Pollen diagram

A pollen diagram is usually helpful for plant community and ecological interpretations. They enable a qualitative and quantitative representation of the plants occurring in the pollen assemblages. The matrix pollen data in this research were analyzed quantitatively and presented in this way. Extracted pollen grains were counted in each layer and presented in the form of pollen diagrams by the computer software TILIA and TILIA*GRAPH (Grimm, 2011). The pollen and spore percentage was plotted against its stratigraphic depth. The vertical axis (Y) represents depths and ages while the horizontal axis (Y) represents pollen abundance in each layer. Different kinds of plants were placed in different groups based on their environmental requirements. Some other information (e.g. sedimentology, chronology, megafossil, etc.) were used for calibration. The size measurements of pollen and spore grains were carried out by Image J (Rasband, 2014).

CHAPTER IV

RESULTS OF GEOLOGICAL STUDY

4.1 Lithology, sedimentology, and stratigraphy

The river basin is mainly composed of basalt and quartzite bedrock, comprising mainly gravels and sands, which are the major deposit facies. The lithology and sedimentology were analyzed and described according to bed thickness, grain size, sphericity, and sorted level, etc. The description followed Ingram (1954), Munsell soil color charts (Munsell Color Company, 1988), Nichols (2009), and Udden (1914) (Table 4.1). The stratigraphy was analyzed and described in a column based on the components, structures, depositions, etc. (Figure 4.1). The sediment structures were documented by photographs and sketches (Figure 4.2). Sedimentary facies were the results of external processes, fluvial erosion, rock collisions, chemical interaction, wind, precipitation, etc. All the particles in the samples, organic and inorganic, were the indicators of the deposit profiles. Different sedimentary facies indicate potential pollen assemblages. However, dark layers are believed hopeful to find pollen grains (Erdtman, 1969; Faegri and Iversen, 1989; Wang, 1983).

To compare with the research in the past carried out at the same place (Figure 4.2), the stratigraphic profile was described from the top to the bottom. Three groups were divided as follow:

Group 1 (layers 1-7): 3.1 m thick, massive clay and sand group with homogenous texture, obscure layer borders. It is a vertical accretion in floodplain with reddish yellow, pink, to pinkish white. It can be divided into 2 subgroups.

Subgroup 1.1 (layers 1 and 2): 1.2 m thick. The main component is light gray clay (HUE 5YR 7/1), $\Phi < 0.004$ mm, well rounded and very well sorted.

Subgroup 1.2 (layers 3-6): 1.9 m thick. The main component is fine and coarse sand, white (layer 3, HUE 5YR 8/1), very pale brown (layer 4, HUE 10YR 7/4), dark yellowish (layer 5, HUE 10YR 4/6, and layer 6, HUE 10YR 3/4). 0.25 mm $\leq \Phi \leq$ 2.0 mm, most layers were rounded and very well sorted.

Group 2 (layers 7-14): 3.9 m thick, it was formed by repeated channel deposition, marked by sharp, erosional and irregular contact hiatus, complex structures. The main sediment components were clay, sand, granule, and pebble. The particles vary from clay to cobbles. The dominant structures in the bed were cross bedding, while the gravel bed was structureless. It indicated an alternation of a river with high and low flow in the lateral accretion. Logs and wood fragments were embedded in the clay bed. It can be divided into 8 sub-groups based on the components and distinct boundaries.

Subgroup 2.1 (layers 7, 8A, 8B and 9A): 1.15 m thick. The main components were fine sand at the top and massive pebble, granule, mixed coarse and medium sand at the bottom, yellowish brown (layer 7, HUE 10YR 5/4), rounded and very well sorted, $\Phi < 0.25$ mm. Dark yellowish brown HUE 10YR 4/6 to gray HUE 10YR 5/1, sub rounded, very poorly sorted unconsolidated conglomerate, composed of clay and rock fragments, 0.25 mm $< \Phi <$ 4.0 mm.

Subgroup 2.2 (layer 9B, 10A): 0.65 m thick. The main components at the top were massive clay and fine sand, mixed with mud nodules, very dark gray HUE 10YR 3/1, rounded, very well sorted, composed of quartz and clay, $\Phi < 0.063$ mm. The main components at the bottom were well stratified granule and pebble, dark yellowish brown HUE 10YR 4/6, sub angular, moderately sorted, composed of quartz and rock fragments, Φ >2.0 mm.

Subgroup 2.3 (layers 10B, 11, and 12): 1.10 m thick. The main components at the top were clay and silt, gray to dark gray HUE 10YR 6/1 ~ HUE 10YR 3/1, sub angular to well rounded, very well sorted, composed of mud, 0.004 mm< Φ < 0.063 mm. A large carbonized wood log was discovered. The main components at the bottom were pebble and medium sand, light brownish gray HUE 10YR 6/2, sub rounded and well sorted, composed of quartz and rock fragments, Φ > 0.5 mm.

Subgroup 2.4 (layer 13A, 13B and 14): 1.00 m thick. The main sediment components at the top was clay, dark gray HUE 10YR 5/1, sub angular, very poorly sorted, composed of clay and gravels, particle size various. The main sediment components at the bottom were cobble, pebble, granule, and coarse sand, mixed with mud nodules, dark yellowish brown to gray HUE 10YR 6/1~ HUE 10YR 4/4, rounded, poorly sorted to moderately sorted, composed of quartz, clay and rock fragments, particle size various.

Horizontal beds were developed in the top layers such as 7, 9B, 11, and 13A; they indicated a low energy river at weak run-off, while rounded and well sorted pebbles and granules were developed in bottom layers such as 8A, 8B, 9A, 10A, 10B, 12, 13B, and 14. It was typical river evolution process with the deposit materials various from large to small.

Group 3 (layers 15-23): 4.5 m thick. This is a massive deposition with homogenous components interbedded by two layers of clay, reddish yellow, gray, white, and reddish brown. It is a vertical accretion composed of 3 sub layers.

Subgroup 3.1 (layers 15-17): 1.5 m thick. The main sediment components are medium and coarse sand, brown (layer 15, HUE 10YR 6/3), grayish brown (layer 16B and layer17, HUE 10YR 5/2), and very pale brown (layer 15, HUE 10YR 7/4), interbedded continuous parallel laminations (~ 2 cm thick) and mud nodules (in layer 16A, HUE 10YR 3/1). Well stratified. Particles are rounded and very well sorted. Fossil pollen grains were present in the interbed (16A), $0.004\text{mm} < \Phi < 2.0$ mm.

Subgroup 3.2 (layers 18 and 19): 0.75 m thick. The main component is massive gray clay, HUE 10YR 6/1, well rounded, very well sorted, composed of clay.

$\Phi < 0.004$ mm.

Subgroup 3.3 (layers 20-23): 2.25 m thick. The accretion of this group is normal graded bedding of stratified fine sand, silt, and clay from the bottom to the top, respectively. The main sediment components are fine sand, silt, and clay, gray (layers 20, 21, and 22, HUE 10YR 6/1) and pale brown (layer 23, HUE 10YR 6/3). (Silt: light gray HUE 10YR 7/1, well rounded, very well sorted, composed of quartz; clay: very dark gray HUE 10YR 3/1. $\Phi < 0.25$ mm.

Table 4.1 The Udden–Wentworth grain-size scale (Nichols, 2009).

mm	Name		
	Boulders	Gravel	Conglomerate
256			
128			
64	Cobbles		
32			
16			
8	Pebbles		
4			
	Granules		
2			
	Very coarse sand	Sand	Sandstone
1			
	Coarse sand		
0.5			
	Medium sand		
0.25			
	Fine sand		
0.125			
	Very fine sand		
0.063			
	Coarse silt	Mud	Mudrock
0.031			
	Medium silt		
0.0156			
	Fine silt		
0.0078			
	Very fine silt		
0.0039			
	Clay		

A general glossary of geological are listed as below:

Basin: An area in which sediments accumulate.

Cretaceous: In geological time, the last period of the Mesozoic Era, preceded by the Jurassic Period and followed by the Tertiary Period; it extended from 145 million years to 66 million years before present (Cohen *et al*., 2013).

Deposit: Consolidated or unconsolidated material that has accumulated by a natural process or agent.

Φ: Diameter.

Fluvial Deposit: A sedimentary deposit of material transported by or suspended in a river.

Floodplain: The relatively smooth valley floors adjacent to and formed by the rivers which are subject to overflow.

Glacial: Pertaining to an interval of geologic time which was marked by an equatorward advance of ice during an ice age.

Glaciation: Alteration of any part of the earth's surface by passage of a glacier, chiefly by glacial erosion or deposition.

Holocene: An epoch of the Quaternary Period from the end of the Pleistocene, around 11,700 years ago, to the present (Cohen *et al*., 2013), known as Postglacial.

HUE 5YR 8/1: Chromatographic value.

Lamination: A small scale sequence of fine layers.

Lateral accretion: The digging away of material at the outer bank of a meandering stream and the simultaneous building up to the water level by deposition of material brought there by pushing and rolling along the stream bottom.

Lithology: The physical character of a rock as determined by eye or with a low-power magnifier, and based on color, structures, mineralogical components, and grain size.

Mud: The mixture of silt and clay.

Permian: The last period of geologic time in the Paleozoic era, from 298.9 ± 0.15 to 252.17 ± 0.06 million years ago (Cohen *et al*., 2013).

Pleistocene: The older of the two epochs of the Quaternary Period, spanning about 2.58 million to 11,700 years ago (Cohen *et al*., 2013). It represents the interval of geological time (and rocks accumulated during that time) extending from the end of the Pliocene Epoch (and the end of the Tertiary Period) to the start of the Holocene Epoch. It is commonly characterized as an epoch when the earth entered its most recent phase of widespread glaciation.

Quaternary: The second period of the Cenozoic geologic era, following the Tertiary, and including the last 2.58 million years (Cohen *et al*., 2013).

Sediment: A mass of organic or inorganic solid fragmented material, or the solid fragment itself, that comes from weathering of rock and is carried by, suspended in, or dropped by air, water, or ice; or a mass that is accumulated by any other natural agent and that forms in layers on the earth's surface such as sand, gravel, silt, mud, fill, or loess.

Sedimentary facies: The physical, chemical, and biological aspects of a sedimentary bed and the lateral change within sequences of beds of the same geological age.

Sedimentology: The description, classification, origin, and interpretation of sediments and sedimentary rock.

Sorted level: Concentration of particles of similar size.

Sphericity: Roundness, the degree of abrasion of sedimentary particles; expressed as the radius of the average radius of curvature of the edges or corners to the radius of curvature of the maximum inscribed sphere.

Stratigraphy: The form, arrangement, geographic distribution, chronologic succession, classification, correlation, and mutual relationships of rock strata, especially sedimentary.

Texture: The physical nature of the soil according to composition and particle size, or the physical appearance or character of a rock; applied to the megascopic or microscopic surface features of a homogeneous rock or mineral aggregate, such as grain size, shape, and arrangement.

4.2 Chronology

Most layers with pollen reported were sent for age dating and the results were listed as below (Figure 4.3). The carbonized wood was tested by the way of carbon 14 (C14) at the Thailand Institute of Nuclear Technology, Ongkarak, Nakhon Nayok, Thailand while the clay samples were tested by thermoluminescence (TL) at Department of Earth Sciences, Kasetsart University, Bangkok, Thailand. The TL data indicated Late Pleistocene sedimentation, ranging from 172,739 ± 22,400 yr BP in layer 16A to 27,332 ± 3,000 yr BP in layer 9B. The C14 data indicated an age of 28, 150 ± 7,860 yr BP in the layers 10B and 11. The C14 data did not vary so far from the TL result (33,611 ± 4,000 yr BP in layer 10B and 48,022 ± 6,200 yr BP in layer 11). Generally, the date results were stable decreasing from the bottom to the top except layer 10A (52,296 ± 6,800 yr BP). It was reasonable although the age of layer 10A seemed to deviate from the time scale. Some reworking could have happened in the geological time, such as a river bank collapse leading to a repeat deposition which is very common. The layers were correlated with the published glacial periods (Table 4.2).

Table 4.2 The correlation between the dated layers and the glacial events.

Layer	**Climate and glacial events**
9B (27,332 ± 3,000 yr BP)	Hulu cave stalagmites - Cold stage (Yuan *et al.*, 2004); Würm (26.5-19 ka) (Clark *et al.*, 2009)
10A (52,296 ± 6,800 yr BP)	Dongge and Hulu cave stalagmites - Warm stage (Yuan *et al.*, 2004)
10B (TL: 33,611 ± 4,000 yr BP; C14: 28150 ± 7860 yr BP)	Hulu cave stalagmites - Warm stage (Yuan *et al.*, 2004)
11 (48,022 ± 6,200 yr BP)	Dongge and Hulu cave stalagmites - Warm stage (Yuan *et al.*, 2004)
13A (51,682 ± 6,700 yr BP)	Dongge and Hulu cave stalagmites - Warm stage (Yuan *et al.*, 2004)
13B (88,661 ± 10,600 yr BP)	Dongge Cave stalagmites - Cold stage (Yuan *et al.*, 2004)
16A (172,739 ± 22,400 yr BP)	Dongge Cave stalagmites - Cold stage (Yuan *et al.*, 2004); Riss (350-130 ka) (Lisiecki and Raymo, 2005)

There was a tektite layer found in the sediments of Southeast Asia that indicated a controversial comet collision occurring around 0.69-0.80 Ma (Charusiri *et al.*, 2002; Duangkrayom *et al.*, 2014; Haines *et al.*, 2004; Koeberl *et al.*, 1997; Langbroek, 2014;

Songtham *et al*., 2012; Wang and Bae, 2014). It was not discovered in this research although it was reported in different depths around the Khorat Plateau (Charusiri *et al*., 2002; Haines *et al*., 2004; Satarugsa *et al*., 2005; Sato, 2002; Songtham *et al*., 2012). However, the general sediment profiles matched well with another research although the description on the top layer was different (Figure 4.4). It was regarded as dry land in this research but regarded as flood plain by Bunchalee (2005).

4.3 Discussion

River deposits include suspended and bed load. The coarsest material is carried in the deep parts of the channel, while the fine bedload is carried in shallow parts, and deposited at different velocities. River systems deposit sediments within channels or their tributaries in the basin. These depositions can be the indicator of tectonic activity and paleoclimate. A river change from sandy anabranching to braid was recorded by the fluvial deposits in eastern Germany which indicated a strong cooling event at 40 ka (Kasse *et al*., 2003). Channel changes in Pleistocene–Holocene deglaciation were reported with high runoffs and sediment loads in the Nile, Amazon, and Niger ricers (Thomas, 1998). The change from dry to wet climate between 9,000 and 1,200 yr BP resulted in high discharges and accompanying land sliding and changes in slope hydrology and processes.

The river sedimentary facies are determined by the resource of detritus and the flow current variations. The size changes of clasts are helpful in the reconstruction of paleogeography and paleoenvironment (Nichols, 2009). Fluvial stratigraphic analysis includes sedimentary texture and organic activity. The fluvial deposition was not immutable; for a meandering river, it is usually narrow channeled and braided in the upper parts. Oppositely, floodplain facies are developed in the lower part.

Group 1: Dry land deposition

Water flow is normally confined to channels. The overbank area or floodplain receives water only when the river is flooded. The channel and overbank settings comprise the fluvial environment. The channel-fill successions are fining up and consisted of stacks of cross stratified conglomerate with fine detritus at the top and coarse detritus at the bottom. However, a depositional bar with fine sands or silts on the top was usually considered the end of a deposit progress; they are formed and cannot move anymore. The thickness of the succession usually represents the depth of the original channel. Braid plains are characterized by small size of deposits and found in areas where the river channel shifted frequently. Bedload of clasts such as coarse sands or gravels in the channel give the river a braided form at low flow (Nichols, 2009; Perry and Taylor, 2007; Xia, 1995). Lateral channel migration was the result of continuous channel-fill and braided deposits (Nichols, 2009). This migration was related to a wet climate or sparse vegetation.

In group 1, there were clay and sand deposits, few organic particles, thick deposition without distinct structure such as ripple and lamination. It was the end of the channel-fill succession; the lifted river bed was much higher than ground plane; physically, the input water volume exceeded what the channel can accept (Ouchi, 2015). The over bank flow occurred frequently and the river channel shifted to a new place, the old one was abandoned. Another possibility is that the river disappeared completely at that period. The landform at this stage should be covered by flood plain first and then became a dry land. Wind erosion played the main role of landform change. Vegetation was difficult to develop at this place because of the poor water supply, and longtime dry periods were also not good for the preservation of pollen grains. This stage was located above the layer 9B (dated during the Last Glacial Maximum), there was no evidence indicated a rework process. Therefore, the Group I was at least started from the Last Glacial Maximum and influenced by global temperature decline, and the sea level retreat about 120 m lower than present (Sun *et al*., 2006; Sun and Li, 1999; Sun *et al*., 2000; Wang, 1978; Zhang and Long, 2007, 2008). The continental shelf was exposed to the air and covered by extensive grassland. Winter monsoon was prevalent at this period and a lot of small soil particles were carried from the north and then deposited in the south (Zhou *et al*., 2014). There was a typical long range transportation recorded at 21 March 2010, a strong Asian dust storm affected large areas from the Gobi Desert to the West Pacific, including Taiwan and Hong Kong, and was also observed in the northern South China Sea (Wang *et al*., 2011).

Group 2: Channel river deposition

A high proportion of coarse sands, granules, and pebbles usually indicated a rolling and saltation procession along the channel. The deposits tend to be large size at the bottom and smaller upwards. Sediment stratifications are recognizable; it means a river with water flowing close to or at the level of the bank is at high flow stage or bank-full flow (Nichols, 2009; Xia, 1995). Excessive detritus and discharge accelerate the aggradation, boosting up the riverbed, which resulted in depositional bars, and then a braided river system. In group 2, layers 8, 9, 10, and 11 were clay, medium sands, and mixed rare granules at the top, while layers 12, 13, and 14 were pebbles or even larger deposits at the bottom. It was obviously a deposition of channeled river. The clay layer and granule layer were alternated in the deposits. Interbedded mud nodules were intermittent accumulation discovered in the intervals. Organic sediments were much more than other groups. Normally, there was distinct "pebble – granule – sand/clay" cycle in the formation of a river although some deposits are absent in the deposit series. At least 4 cycles were recognized in this group, which indicated the ancient Mun River developed at the same place with a stable a river bank, the riverbed was elevated step by step, but the channel did not move so far. It also indicated a relative stable landform in this plateau. Developed tributaries were developed at this stage and can support a high biodiversity. Vegetation should flourish and protect the surface soil at the same time. However, there was very little research mentioning the landform change in the Khorat Plateau. Rainfall erosion was not frequent at this stage while fluvial erosion was the key role. According to the research, the fluvial deposition represented well the riverine vegetation (Wang, 1983; Wu *et al*., 2012; Zhang *et al*., 2012).

Group 3: Shallow lake and flood basin

The river would flood if the supplied water in the channel exceeds the volume that can be contained. According to the opinion of Nichols (2009), the suspended load would flow out of the river channel and deposit as a thin sheet in the forms of ripples or parallel laminations in the flood basin deposition. According to the stratigraphic profile, rippled sands indicated a shallow lake deposition and flood basin. The main characters were very thin beds and sheets of sediment graded from sand to mud plane, parallel lamination (~ 2 cm thick). The temporary shallow lakes should scatter in the flood plain by repeat water drain and fill. The landform was frequently eroded by rainfall and fast water flow; vegetation was very difficult to generate at this stage except some aquatic and ephemeral plants.

4.4 Conclusion

According to the lithostratigraphical study of the ancient fluvial terrace, three different evolved stages were classified. The evolution of the Mun River was constructed respectively based on the evidence of sedimentary components, structures, grain size, etc. Rainfall was thought important to the vegetation and landform development, weathering, river regimen, coastal features and vegetation (Verstappen, 1980). This result was similar to Bunchalee (2005) and Sato (2002):

Group 1: Abandoned river terrace, dry land deposition, dominated by thick and structureless clay and silt deposits, rare organic materials.

Group 2: Developed river channel, channel river and bank full deposits, dominated by alternating sediments of pebble, gravel, sand/clay. Interbedded with mud nodules and lignified wood logs.

Group 3: Shallow lake and flood basin, dominated by sand and silt parallel lamination.

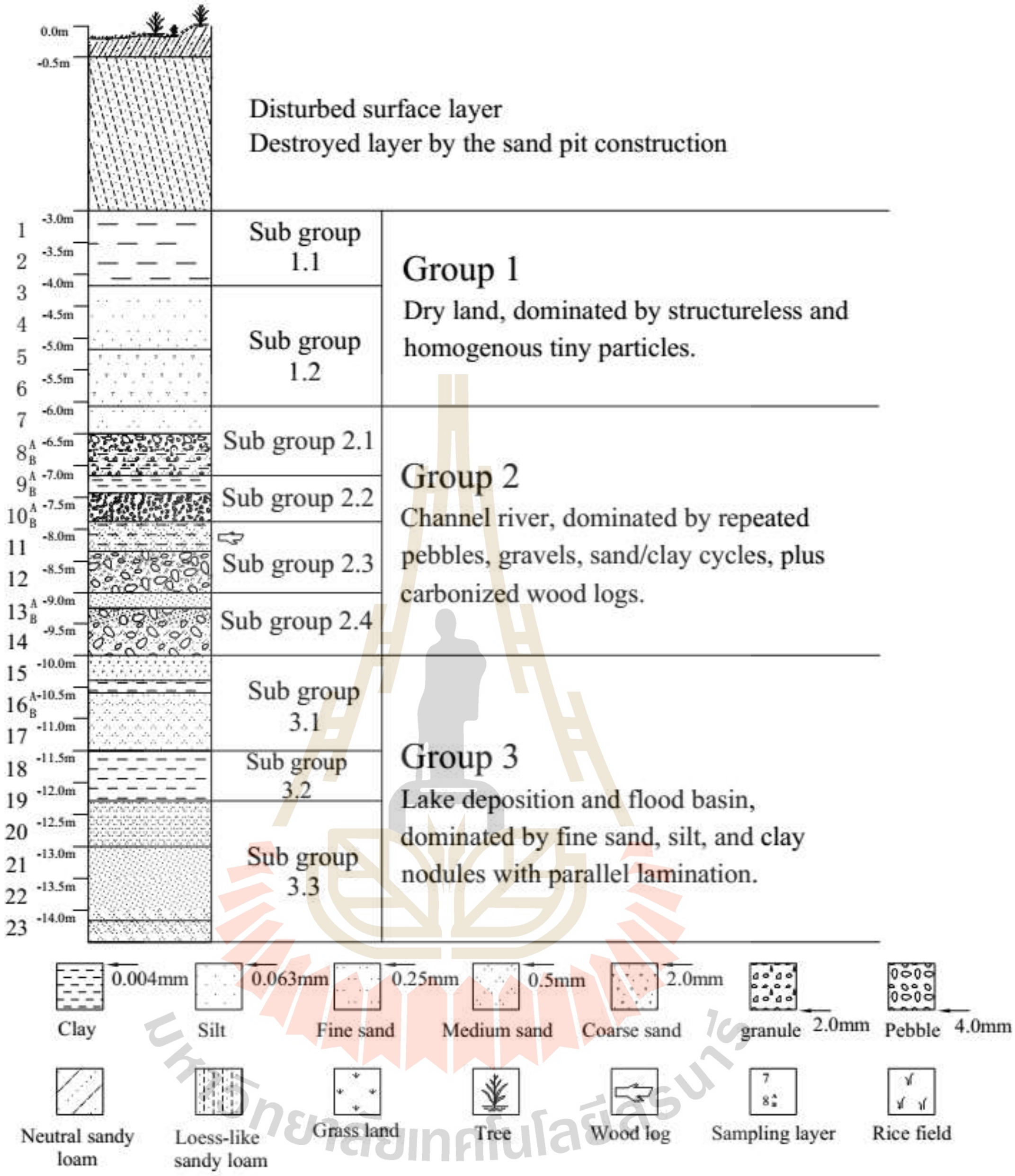


Figure 4.1 Stratigraphic profile of the sampling site.

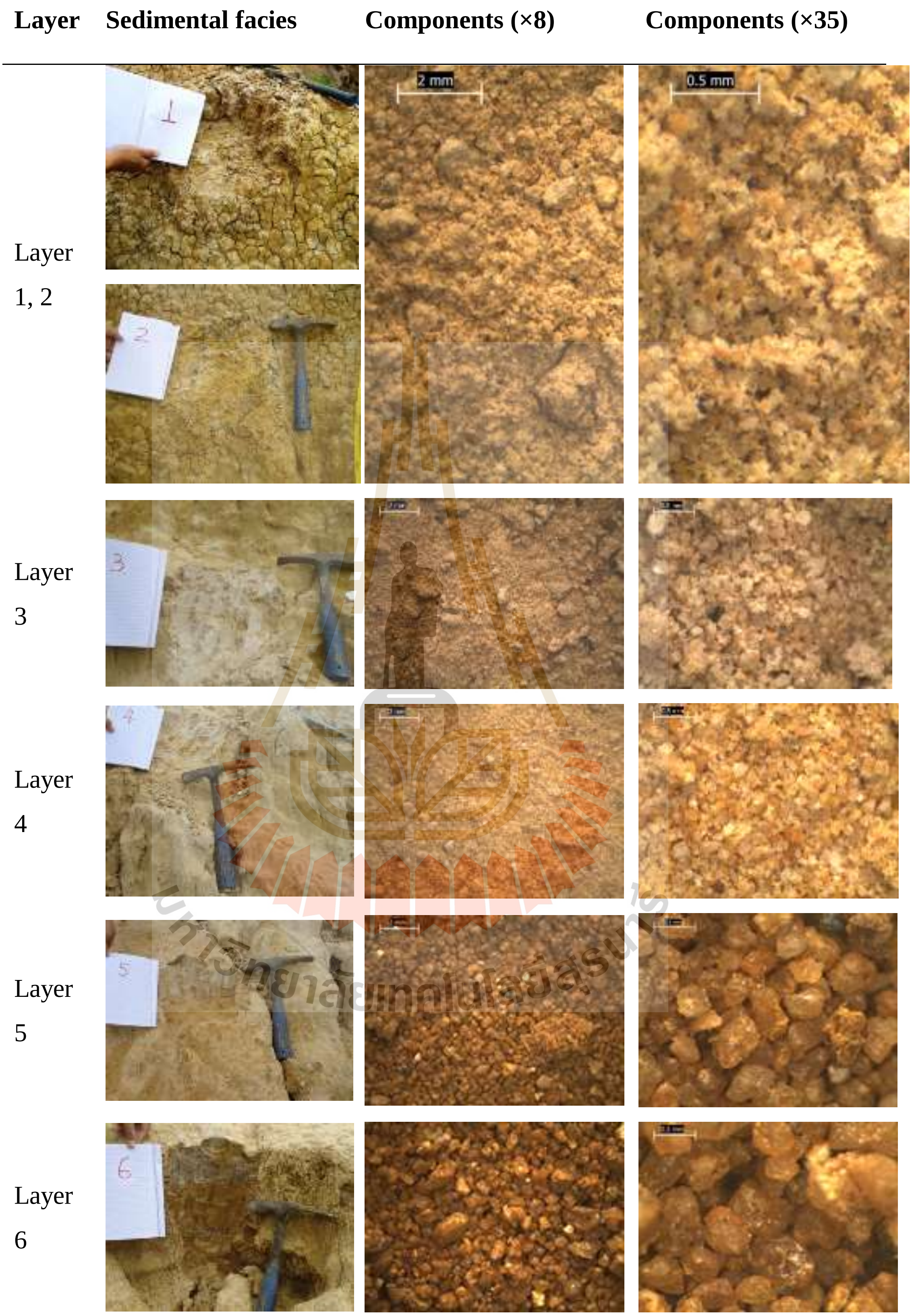


Figure 4.2 The sedimental structures and the major components of each layer.

Layer	Sedimental facies	Components (×8)	Components (×35)
Layer 7			
Layer 8A			
Layer 8B			
Layer 9A			
Layer 9B			
Layer 10A			

Figure 4.2 (Continued) The sediment structures and major components of each layer.

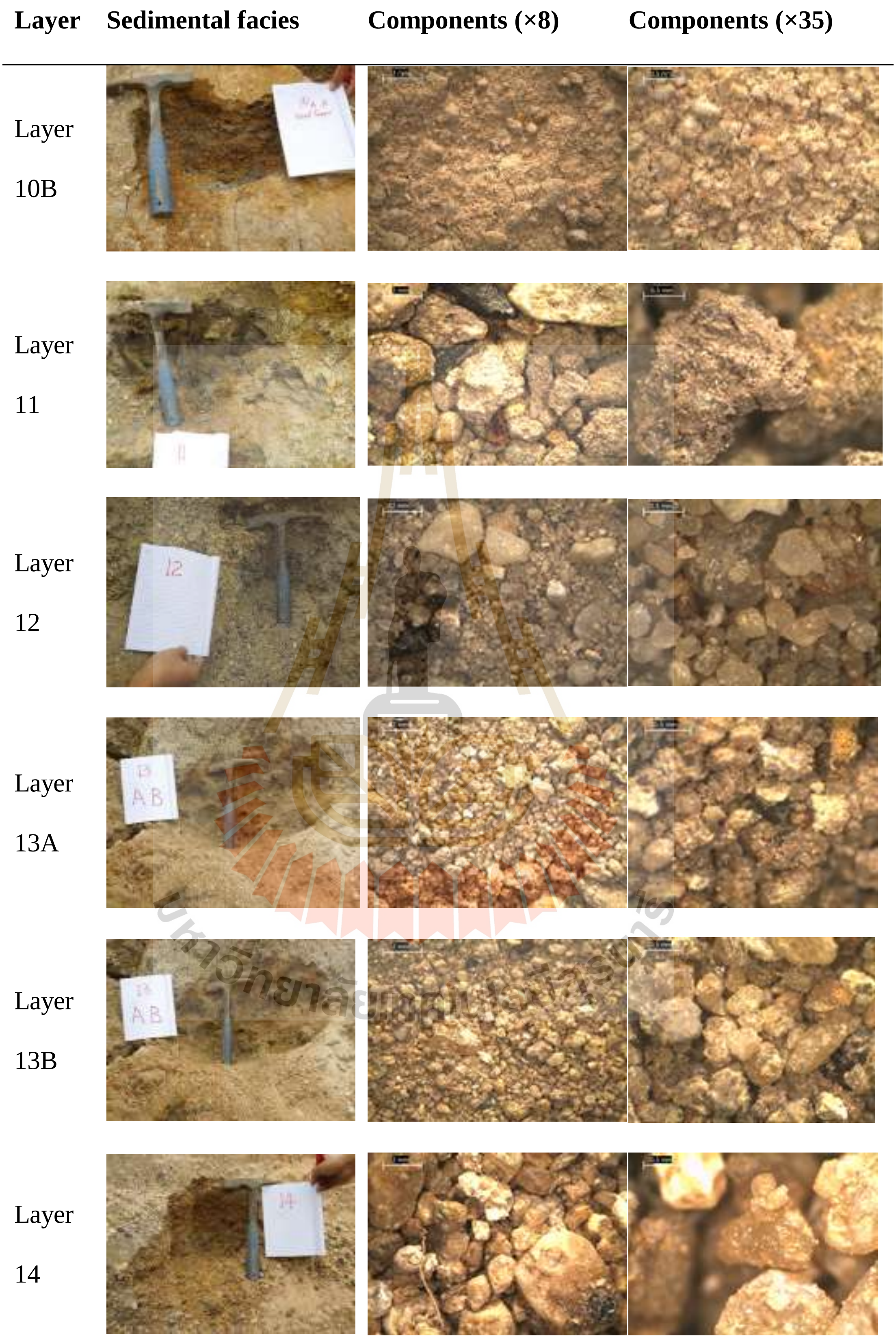


Figure 4.2 (Continued) The sediment structures and major components of each layer.

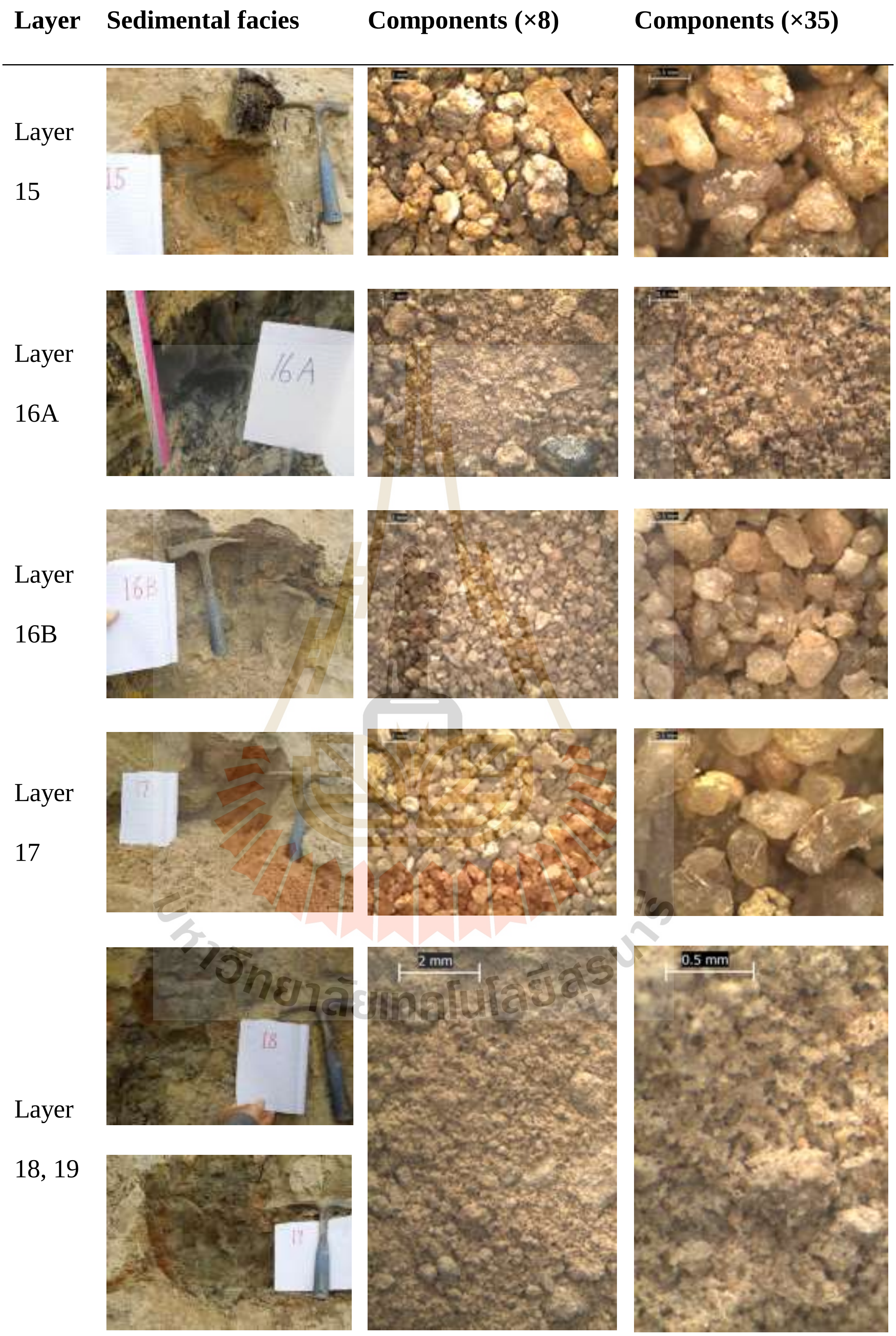


Figure 4.2 (Continued) The sediment structures and major components of each layer.

Layer	Sedimental facies	Components (×8)	Components (×35)
Layer 20			
Layer 21			
Layer 22			
Layer 23			

Figure 4.2 (Continued) The sediment structures and major components of each layer.

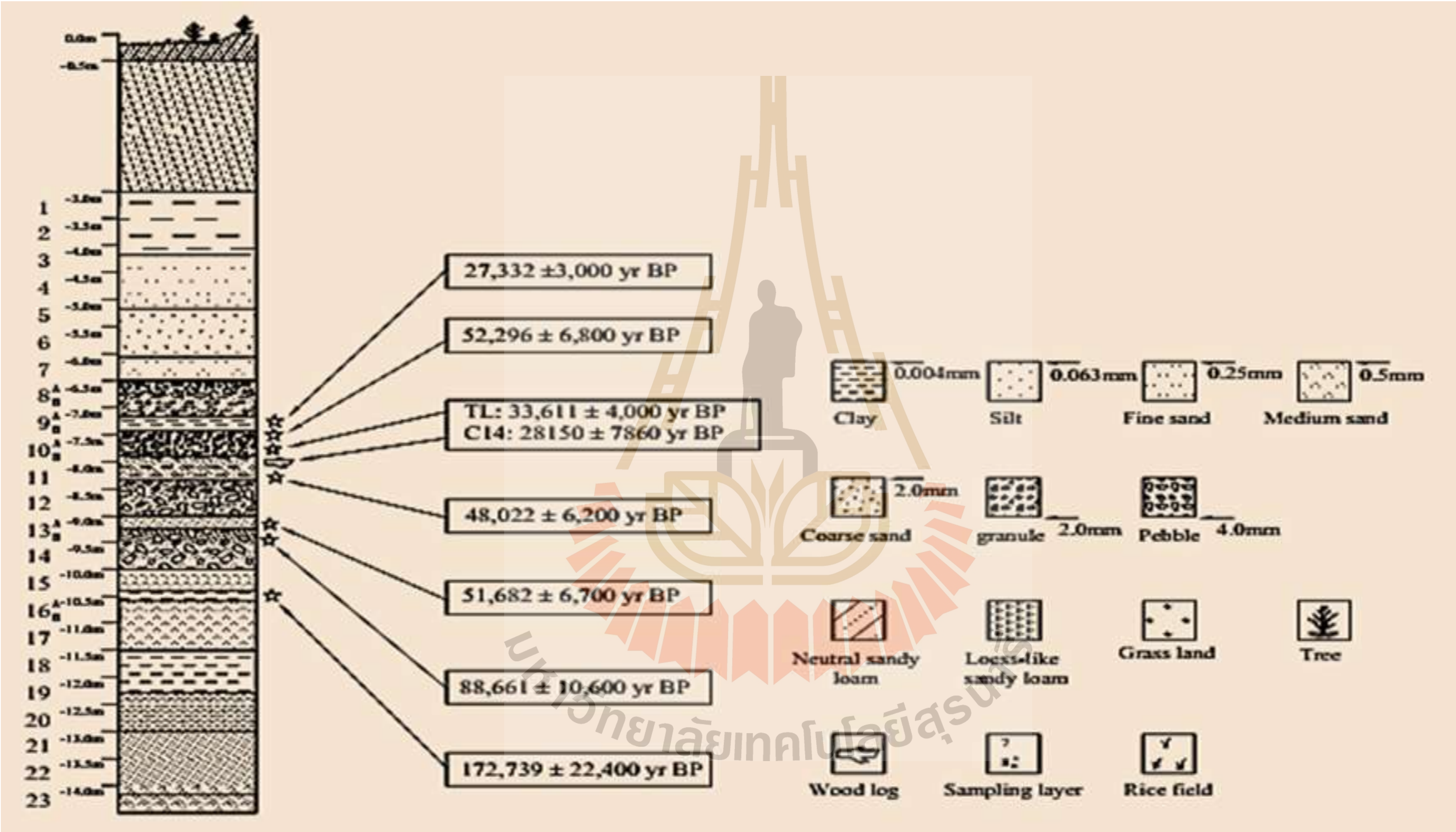


Figure 4.3 Chronology.

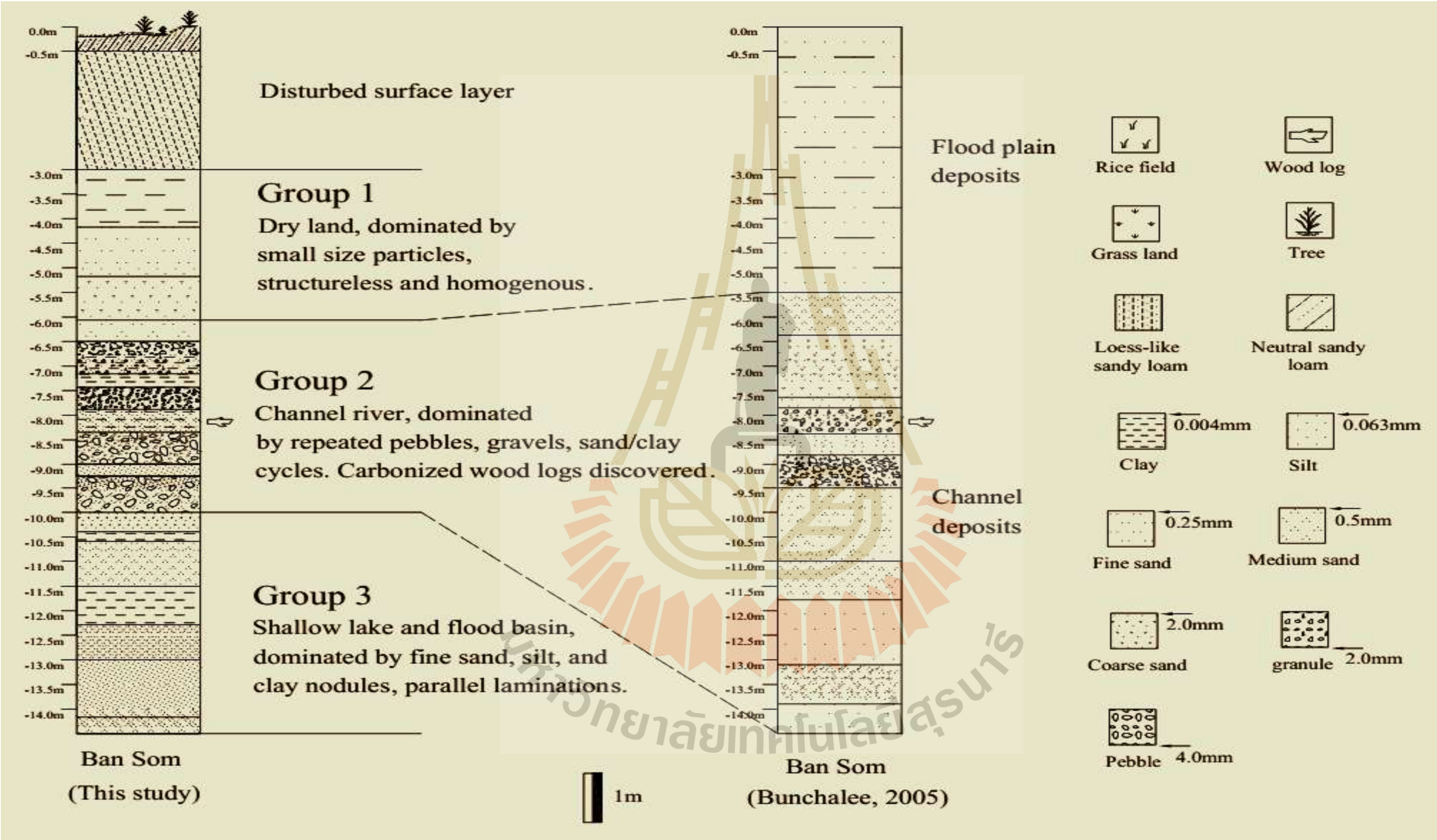


Figure 4.4 Lithostratigraphic correlations in different studies.

CHAPTER V

IDENTIFICATION AND DESCRIPTION OF PALYNOMORPHS

Fossil palynomorphs, especially from the Quaternary sediments, are usually compared to the same living species or their relatives. The morphology of pollen grains were almost similar at a high taxonomic level; normally, there is little difference in the same genus (e.g. *Pinus*, *Lagerstromia*, *Quercus*, etc.), and some taxa were even homogeneous at the family level, such as Asteraceae, Poaceae, and Chenopodiaceae. However, there are still some taxa that can be recognized to species level in cases where they are strongly heterogeneous (e.g. bryophyte, *Lagerstroemia*, Lygodium, etc.). Pollen grains from a small family or genus are easily distinguished. It is better of a precise identification as much as it can be. However, it is more valuable if some representative or endemic species are recognized; they can present a convincible paleoenvironment relatively. Sometimes, combined pollen groups were accepted for the interpretation of the environment reconstruction. Anyway, a difficulty that cannot be avoided is the absence of well-identified modern pollen database, which is necessary and important for comparison and identification of fossil palynomorphs.

The description of palynomorphs is based on the grain shape, size, aperture, sculpture, etc. Normally they are categorized to five groups: fungi, bryophyte, pteridophyte, gymnosperm, and angiosperm. Pollen descriptions are alphabetically arranged and the terms follow Faegri and Iversen (1989), Hoen (2007), Hesse *et al*. (2009), and Punt *et al.* (2007). The scientific name of pteridophytes, gymnosperms, and angiosperms follow Wu and Raven (2013), and the bryophytes follow Zhang and Wu (2004) while fungi follow Webster and Weber (2007).

Terminology of pollen grains

Pollen unit

Tetrad: A unit of four pollen grains.

Polyad: A unit of more than four united pollen grains.

Shape

Oblate: The polar axis is shorter than the equatorial axis.

Prolate: The polar axis is longer than the equatorial axis.

Spheroidal: The polar axis is equal to the equatorial axis.

Irregular: Not the shape mentioned above.

Apertural condition

Catalept: A thin area located at the proximal pole which displays as an aperture.

Colpate: Elongate apertures situate at the equator or spread over the pollen grain.

Colporate: Apertures composed of colpus and porus.

Leptoma: A thin area located at the distal pole which displays as an aperture.

Porate: Circular or elliptic apertures situate at the equator or spread over the pollen grain.

Poroid: Circular or elliptic aperture areas with indistinct margin.

Sulcate: An elongate aperture situates at the distal pole.

Ulcerate: A single rounded aperture situates at the distal pole.

Ornamentation

Baculate: Rod like, free standing exine elements, more than 1 µm in length and without pointed top.

Clavate: Club-shaped elements of the ektexine, higher than 1 µm.

Echinate: Spines longer than 1 µm.

Fossulate: Elongated irregular grooves.

Foveolate: rounded or nearly rounded depressions or lumina.

Gemmate: Globular exine elements, larger than 1 µm, and constricted at the base.

Granulate: Globular elements smaller than 1 µm.

Microechinate: Spines shorter than 1 µm.

Microreticulate: Reticulate exine with lumina smaller than 1 µm.

Perforate: Exine with rounded or elongated tectal perforations, less than 1 µm.

Psilate: Smooth surface.

Reticulate: Network like pattern of lumina wider than 1 µm.

Reticulate-heterobrochate: Reticulate exine with lumina of different sizes.

Reticulate-homobrochate: Reticulate exine with lumina of the same size.

Reticulo-cristate: Reticulate exine formed by rows of pila.

Regulate: Elongate exine elements longer than 1 µm and irregular arranged.

Striate: Parallel arranged exine elements separated by grooves.

Striato-reticulate: Parallel arranged muri connected by short lines in a lower level.

Verrucate: Wart-like exine elements never constricted at the base.

5.1 Bryophytes

Most bryophyte spores are distinct in species, and it is easy to identify, there were 5 families, 5 genera, and 10 taxa recognized in this study.

Bartramiaceae: 10 genera, distribute in warm and temperate mountain zone.

***Bartramia*:** 72 species, world widely, usually tufted or pulvinate.

Bartramia ithyphylla Plate 1, Figures 1-3

Shape:	Spheroidal or prolate	Size:	48-49 μm
Aperture:	Concave catalept	Sculpture:	Big verrucate, wart-like 5-6 μm

---

***Bartramia* sp1.** Plate 1, Figures 4-6

Shape:	Spheroidal or prolate	Size:	28-30 μm
Aperture:	Concave catalept	Sculpture:	Big verrucate, wart-like 1-3 μm

---

***Bartramia* sp2.** Plate 1, Figures 7-9

Shape:	Spheroidal	Size:	22-26 μm
Aperture:	Concave catalept	Sculpture:	Big verrucate, wart-like 2-3 μm

---

Funariaceae : 16 genera world widely distributed, grow on the ground.

Physcomitrium : 68 species in the world, normally found in the forest.

Physcomitrium repandum Plate 2, Figures 1-3

Shape:	Spheroidal	Size:	16 μm
Aperture:	Catalept	Sculpture:	Baculate

***Physcomitrium* sp.** Plate 2, Figures 7-9

Shape:	Spheroidal	Size:	26 μm
Aperture:	Catalept	Sculpture:	Baculate

Sematophyllaceae: 35 genera, commonly seen in tropic and subtropic zone.

***Giraldiella*:** 1 species, grow in mountain forest trunks and rotten wood.

Giraldiella levieri Plate 3, Figures 1-3

Shape:	Spheroidal	Size:	15-17 μm
Aperture:	Unknown	Sculpture:	Clavate

Splachnaceae: 8 genera in the world, grow on the excrement of animals.

***Tayloria*:** 40 species in the world.

***Tayloria* sp.** Plate 3, Figures 7-9

Shape:	Prolate	Size:	33×27 μm
Aperture:	Perforate	Sculpture:	Foveolate

Trachypodaceae: 6 genera distribute in tropical and subtropical area.

***Trachypodopsis*:** 6 species in hot and humid mountain area.

***Trachypodopsis* sp1.** Plate 4, Figures 1-3

Shape:	Spheroidal or nearly	Size:	36-38 μm
Aperture:	Catalept	Sculpture:	Clavate and striate intertwined

***Trachypodopsis* sp2.** Plate 4, Figures 4-6

Shape:	Spheroidal or nearly	Size:	26-33 μm
Aperture:	Catalept	Sculpture:	Clavate and striate intertwined

***Trachypodopsis* sp3.** Plate 4, Figures 7-9

Shape:	Spheroidal or nearly	Size:	22-30 μm
Aperture:	Catalept	Sculpture:	Clavate and striate intertwined

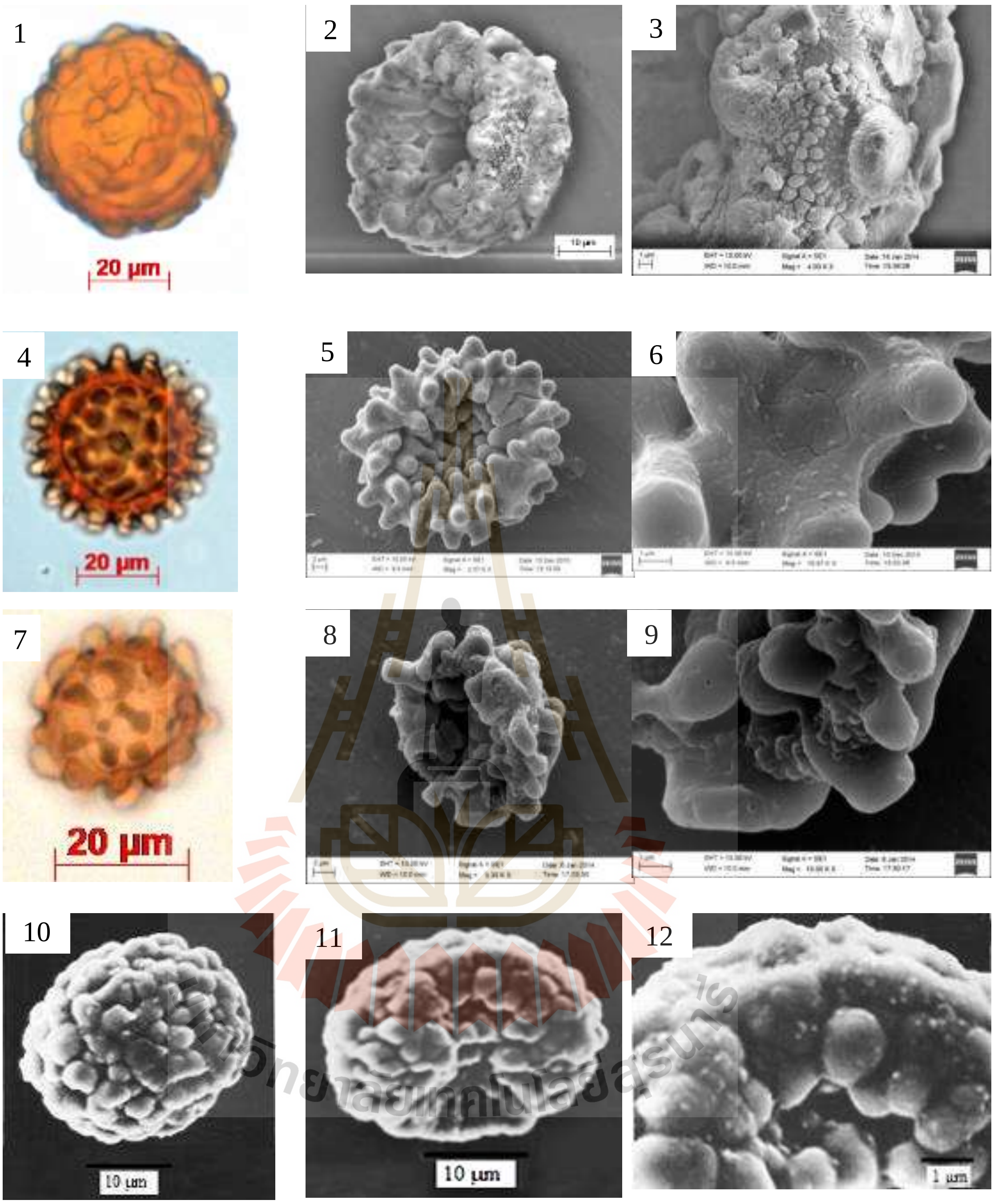


Plate 1 Bartramiaceae

Figure 1-3 *Bartramia ithyphylla* (LM, SEM, and SEM close-up)

Figure 4-6 *Bartramia* sp1. (LM, SEM, and SEM close-up)

Figure 7-9 *Bartramia* sp2. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Bartramia ithyphylla*
(SEM, and SEM close-up, Pei *et al*., 2006)

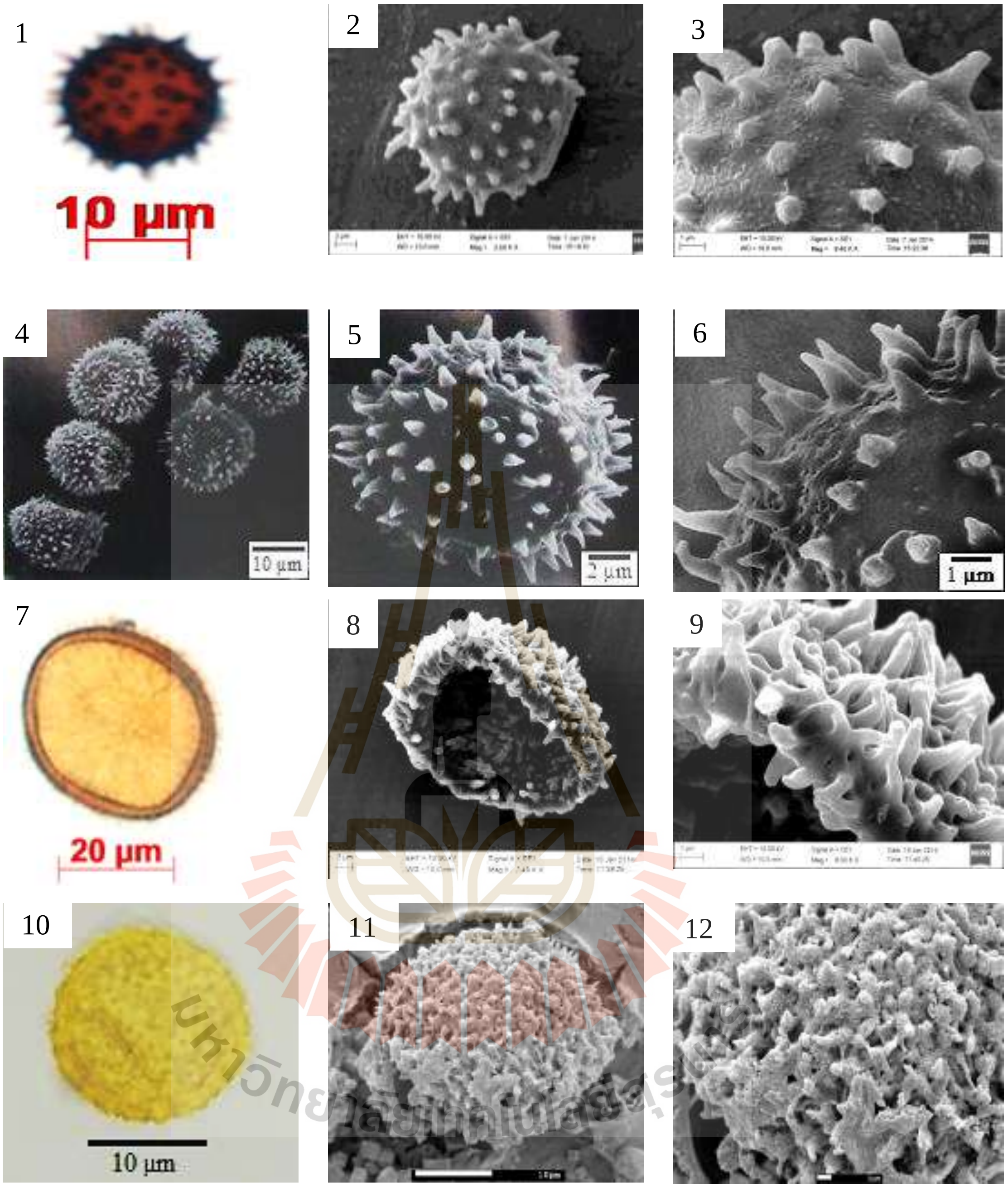


Plate 2 Funariaceae

Figure 1-3 *Physcomitrium repandum* (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Physcomitrium repandum* (SEM, and SEM close-up, Zhang and Wu, 2004)

Figure 7-9 *Physcomitrium* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Physcomitrium pyriforme* (LM, SEM, and SEM close-up)

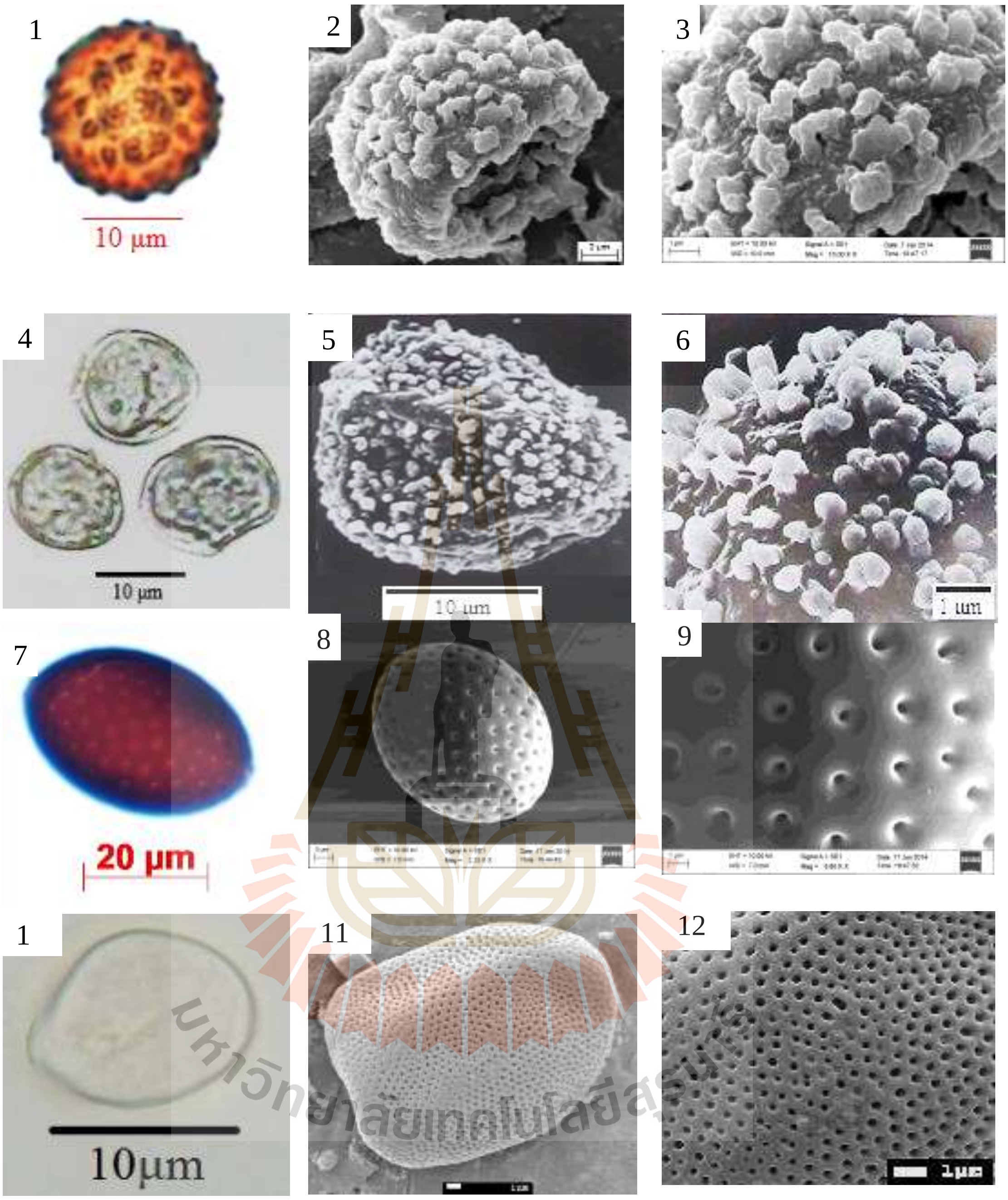


Plate 3 Sematophyllaceae and Splachnaceae

Figure 1-3 *Giraldiella* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Giraldiella levieri* (SEM and SEM close-up, Zhang and Wu, 2004)

Figure 7-9 *Tayloria* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Tayloria indica* (LM, SEM, and SEM close-up)

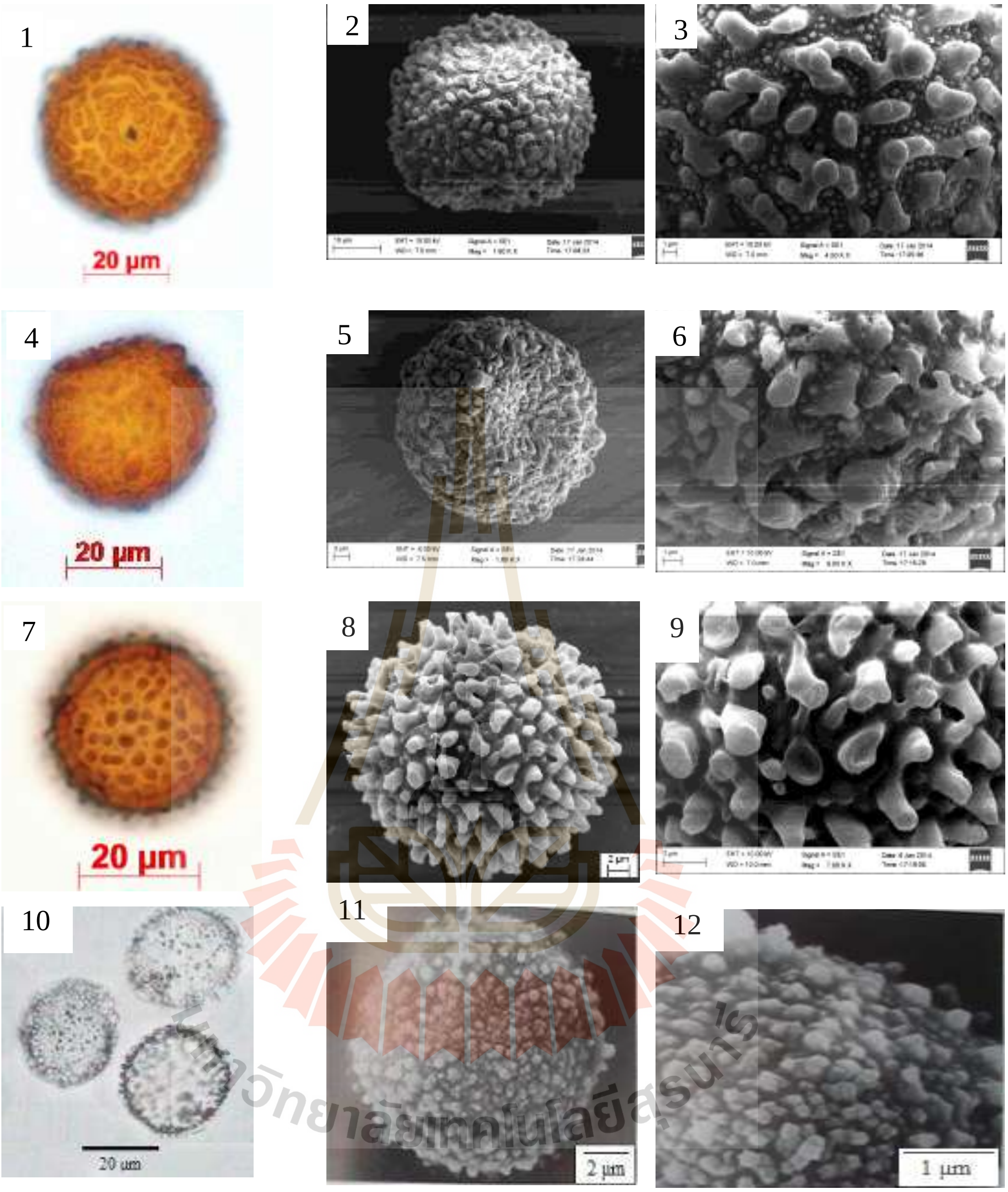


Plate 4 Trachypodaceae

Figure 1-3 *Trachypodopsis* sp1. (LM, SEM, and SEM close-up)

Figure 4-6 *Trachypodopsis* sp2. (LM, SEM, and SEM close-up)

Figure 7-9 *Trachypodopsis* sp3. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Trachypodopsis auriculata* (LM, SEM, and SEM close-up, Zhang and Wu, 2004)

5.2 Pteridophytes

There were 7 families, 11 genera, and 14 taxa recognized in this study.

Cibotiaceae: One genus and about 11 species: east and southeast Asia, Central America, Pacific islands (Hawaii) (Zhang and Nishida, 2013). One species in Thailand (Tagawa, and Iwatsuki, 1979).

Cibotium barometz Plate 5, Figures 1-3

Shape:	Triangular, tetrahedral	Size:	45-50 µm
Aperture:	Trilete	Sculpture:	Psilate

Dryopteridaceae: About 25 genera and 2,100 species, nearly cosmopolitan, but highest diversity found in east Asia (Dryopteris, Polystichum) and the New World (Ctenitis, Elaphoglossum) (Zhang, Wu, Xiang, *et al*., 2013).

***Lastreopsis*:** About 35 species: pantropical, extending into south temperate regions.

***Lastreopsis* sp.** Plate 5, Figures 7-9

Shape:	Prolate, subtriangular	Size:	35×50 µm
Aperture:	monolete	Sculpture:	Psilate

Davalliaceae: Five genera (one according to Nooteboom) and ca. 35 species: mostly in tropical and subtropical Asia, a few species extending to Africa, one species in northwest Africa, southwest Europe, and Macaronesia **(**Xing *et al*., 2013). Five genera in Thailand (Tagawa and Iwatsuki, 1985)**.**

***Davallia*:** About 40 species: from Atlantic Ocean islands through Africa and south Asia to Malaysia, Japan, northeast Australia, and Pacific islands (Xing *et al*., 2013). Six species in Thailand (Tagawa and Iwatsuki, 1985).

***Davallia* sp1.** Plate 6, Figures 1-3

Shape:	Oblate	Size:	46×32 μm
Aperture:	Monolete, laesura 17 μm	Sculpture:	Large verrucae, shallow, psilate surface

***Davallia* sp2.** Plate 6, Figures 4-6

Shape:	Oblate	Size:	46×36 μm
Aperture:	Monolete, laesura 21 μm	Sculpture:	Large verrucae, psilate surface

***Davallia* sp3.** Plate 6, Figures 7-9

Shape:	Oblate	Size:	50×31 μm
Aperture:	Monolete, laesura 15 μm	Sculpture:	Large verrucae, psilate surface

Lygodiaceae: One genus and ca. 26 species: pantropical, extending northward to south Korea, Japan, and North America and southward to south Africa and New Zealand (Zhang and Hanks, 2013).

Lygodium: 7 species in Thailand (Tagawa and Iwatsuki, 1979).

***Lygodium* sp1**. Plate 7, Figures 1-3

Shape:	Triangle	Size:	63 μm
Aperture:	Trilete	Sculpture:	Verrucae

***Lygodium* sp2.** Plate 7, Figures 4-6

Shape:	Triangle	Size:	60 μm
Aperture:	Trilete	Sculpture:	Psilate

Ophioglossaceae: Four (nine) genera and ca. 80 species: nearly worldwide (Zhang, Liu, and Sahashi, 2013

Ophioglossum**:** About 28 species, mainly in the). north hemisphere (Zhang, Liu, and Sahashi, 2013). Four species in Thailand (Tagawa and Iwatsuki, 1979).

***Ophioglossum* sp.** Plate 8, Figures 1-3

Shape:	Spheriodal, oblate	Size:	31-32 µm
Aperture:	Trilete	Sculpture:	Reticulate-cistate

Polypodiaceae: More than 50 genera and ca. 1,200 species, pantropical, a few temperate (Zhang, Lu, Lin, *et al*., 2013). Twenty genera in Thailand (Tagawa, and Iwatsuki, 1989).

Aglaomorpha**:** About 31 species: restricted to tropical Asia, from Himalaya to Taiwan, most abundantly in Malesia**.** One species in Thailand (Tagawa and Iwatsuki, 1989).

***Aglaomorpha* sp.** Plate 9, Figures 1-3

Shape:	Prolate	Size:	29×19 µm
Aperture:	Monolete, laesura 20 µm	Sculpture:	Psilate

Polypodium**:** About ten species, throughout the north temperate zone, ranging from temperate Europe and North Asia to North America. Eight species in Thailand (Tagawa and Iwatsuki, 1989).

***Polypodium* sp.** Plate 9, Figures 7-9

Shape:	Prolate	Size:	42×23 µm
Aperture:	Monolete, laesura 16 µm	Sculpture:	Psilate

Pteridaceae: About 50 genera and 950 species, subcosmopolitan, but most numerous in tropics and arid regions (Zhang, Liao, Ding, *et al*., 2013). Three genera in Thailand (Tagawa and Iwatsuki, 1985).

Acrostichum**:** 3 species, pantropical. Two species in Thailand (Tagawa and Iwatsuki, 1985)**.**

***Acrostichum* sp.** Plate 10, Figures 1-3

Shape:	Triangle, oblate	Size:	40 µm
Aperture:	Trilete, laesura arms almost equal to the radius	Sculpture:	Psilate

---

Ceratopteris**:** 4 to 7 species, tropics and subtropics. One species in Thailand (Tagawa and Iwatsuki, 1985).

***Ceratopteris* sp.** Plate 10, Figures 7-9

Shape:	Oblate	Size:	54×102 µm
Aperture:	Monolete, laesura 18 µm	Sculpture:	Striate

Pteris**:** About 250 species, distributed in tropical and subtropical areas, southward to New Zealand, Australia, and south Africa, north to Japan and North America. Twenty nine species in Thailand (Tagawa and Iwatsuki, 1985).

***Pteris* sp.** Plate 11, Figures 1-3

Shape:	Triangular, tetrahedral	Size:	41 µm
Aperture:	Trilete, laesura arms almost equal to the radius	Sculpture:	Baculate with lateral ridge

---

Taenitis: About 15 species, from Sri Lanka and south India to south China, through Malaysia and Indonesia to north Queensland and Fiji. One species in Thailand (Tagawa and Iwatsuki, 1985).

***Taenitis* SP.** Plate 11, Figures 7-9

Shape:	Triangle, oblate	Size:	42-47 µm
Aperture:	Trilete, with skirt margin	Sculpture:	Clavate with lateral ridge

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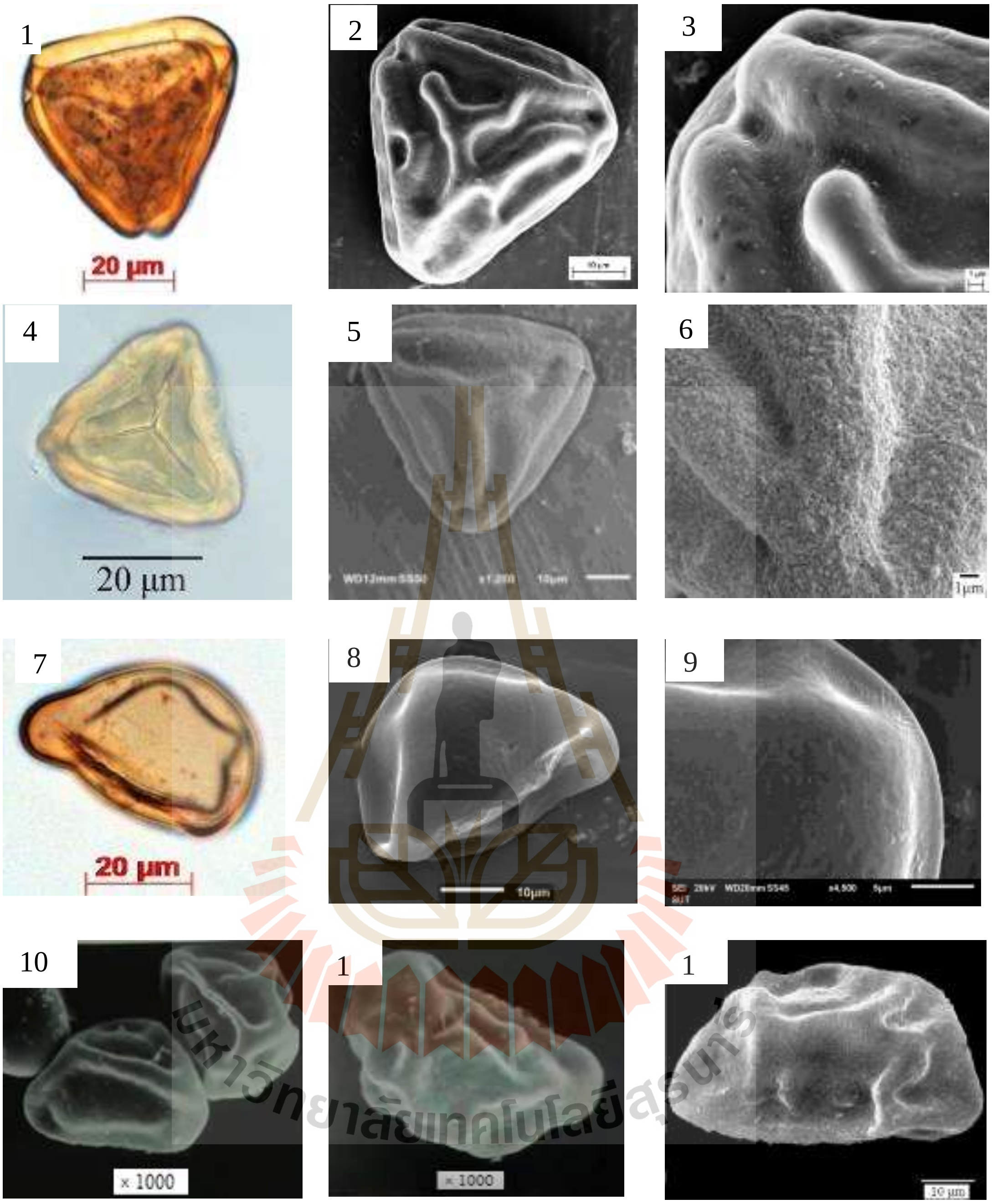

Plate 5 Cibotiaceae and Dryopteridaceae

Figure 1-3 *Cibotium* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Cibotium barometz* (LM and SEM)

Figure 7-9 *Lithostegia* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Lithostegia foeniculacea* (SEM, Lu *et al*., 2007; Tryon and Lugardon, 1990)

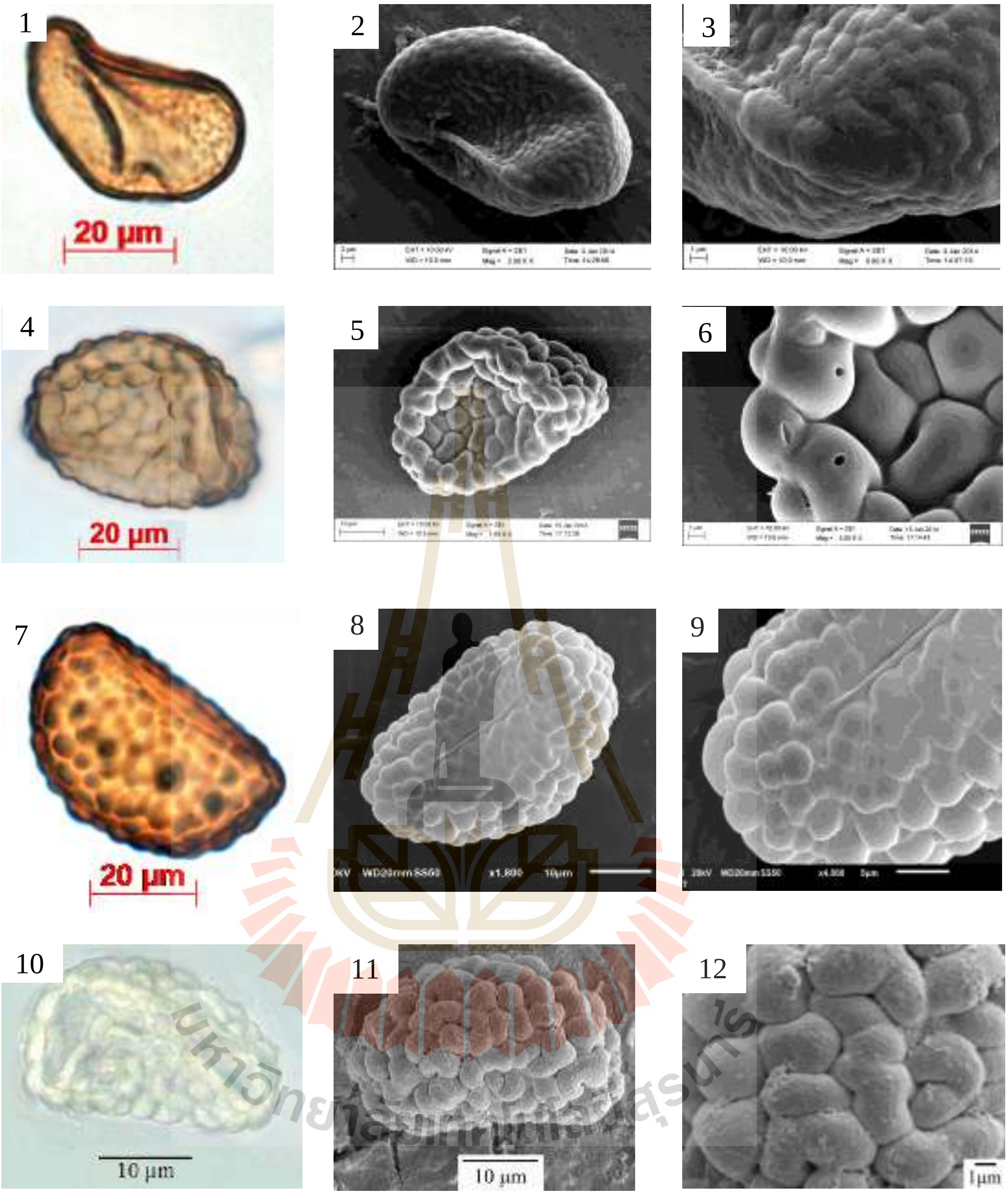

Plate 6 Davalliaceae

Figure 1-3 *Davallia* sp1. (LM, SEM, and SEM close-up)

Figure 4-6 *Davallia* sp2. (LM, SEM, and SEM close-up)

Figue 7-9 *Davallia* sp3. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Davallia repens* (LM, SEM, and SEM close-up)

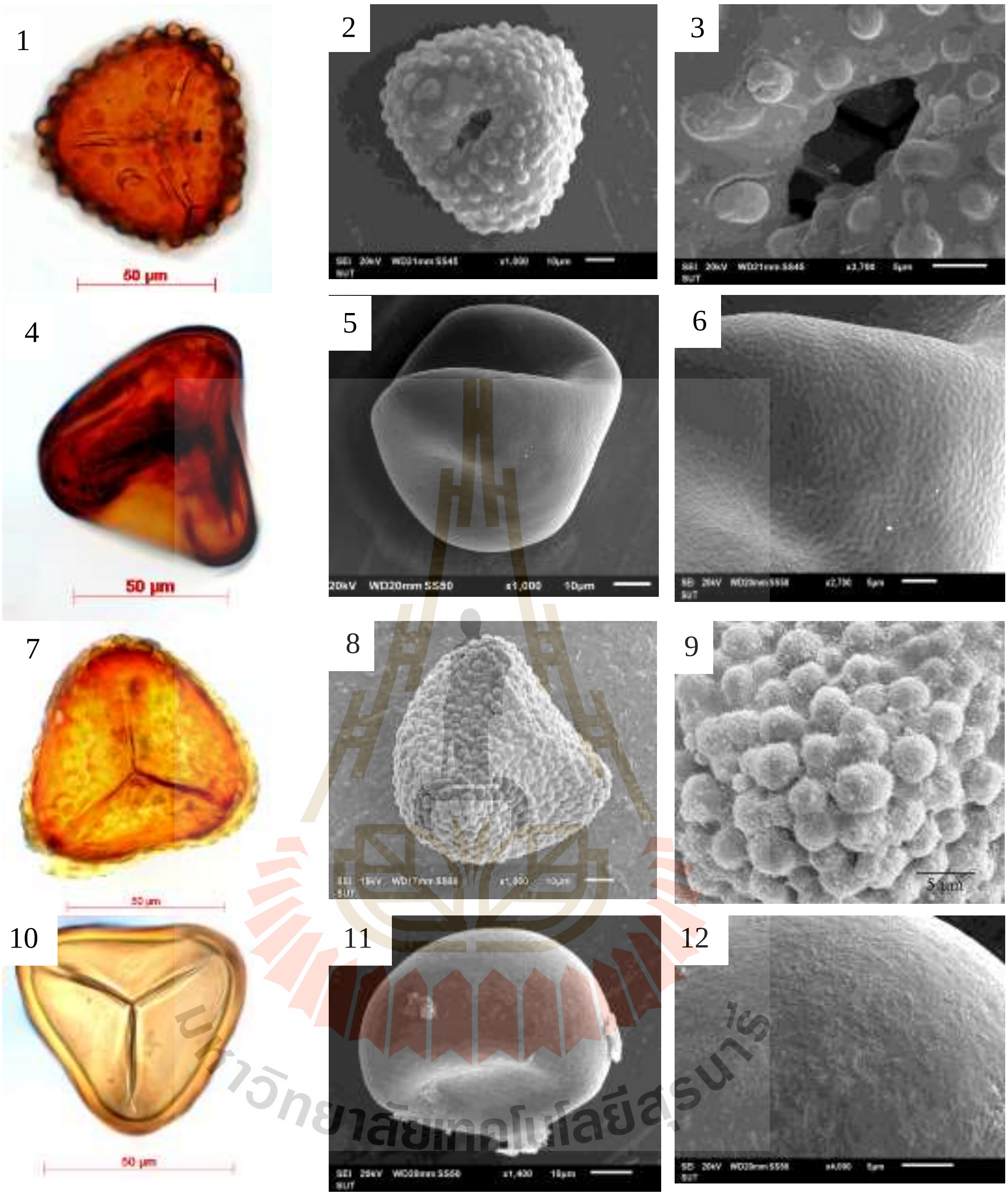

Plate 7 Lygodiaceae

Figure 1-3 *Lygodium* sp1. (LM, SEM, and SEM close-up)

Figure 4-6 *Lygodium* sp2. (LM, SEM, and SEM close-up)

Figure 7-9 Modern reference *Lygodium flexuosum* (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Lygodium polystachyum* (LM, SEM, and SEM close-up)

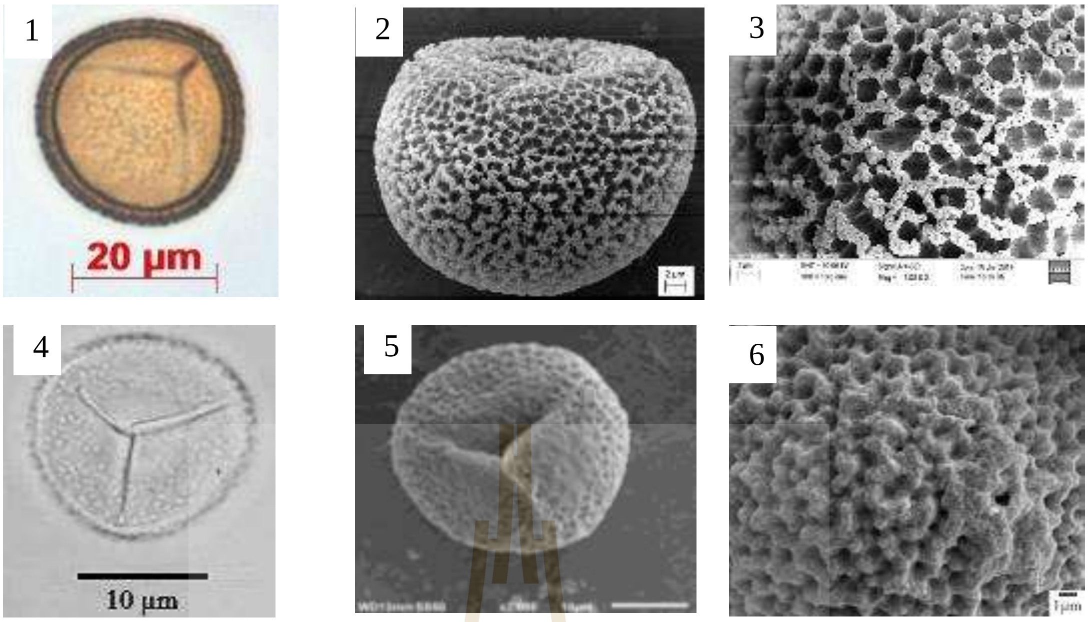

Plate 8 Ophioglossaceae

Figure 1-3 *Ophioglossum* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Ophioglossum* sp.
(LM, SEM, and SEM close-up)

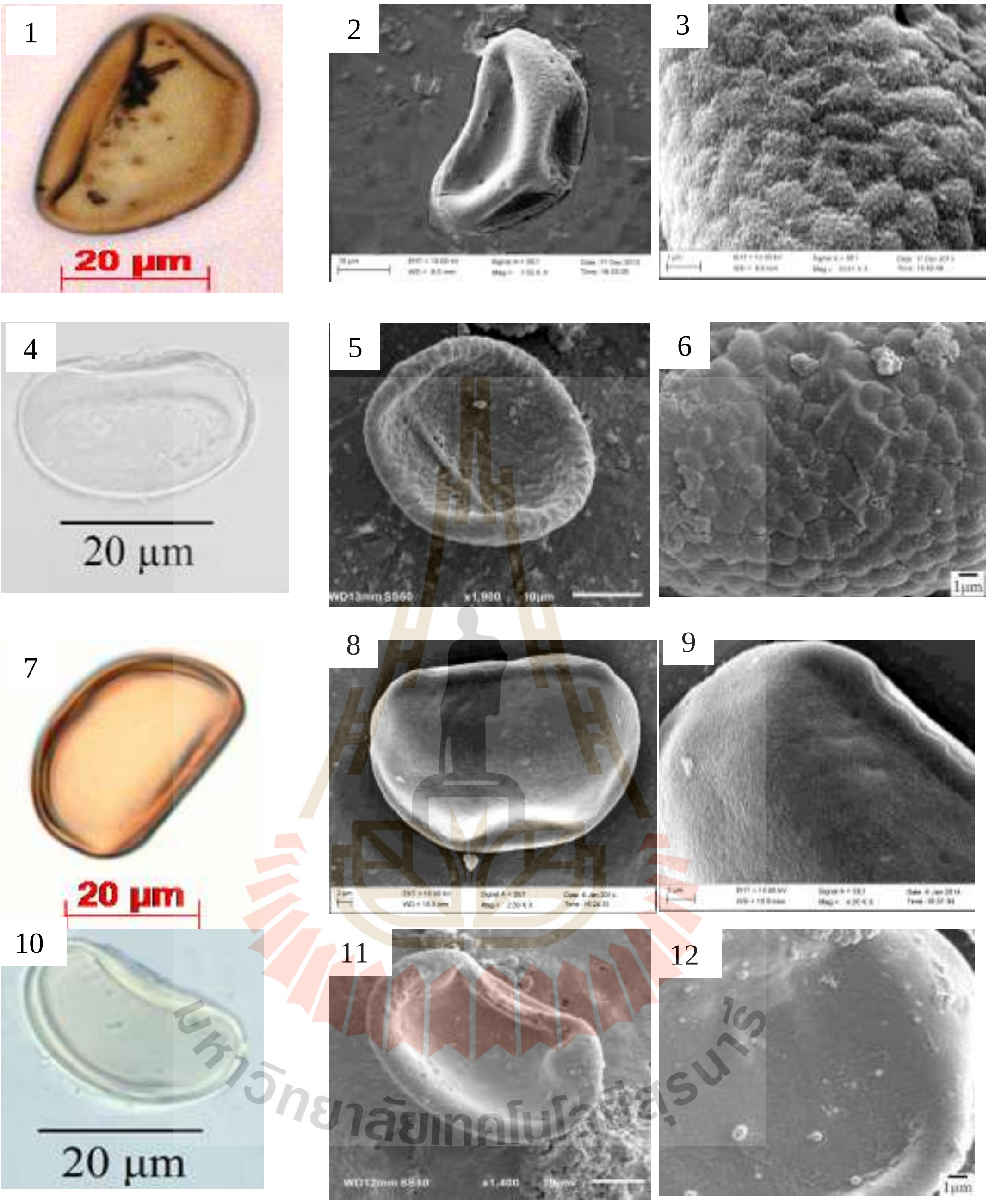

Plate 9 Polypodiaceae

Figure 1-3 *Aglaomorpha* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Aglaomorpha acuminata* (LM, SEM, and SEM close-up)

Figure 7-9 *Polypodium* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Polypodium hastatum* (LM, SEM, and SEM close-up)

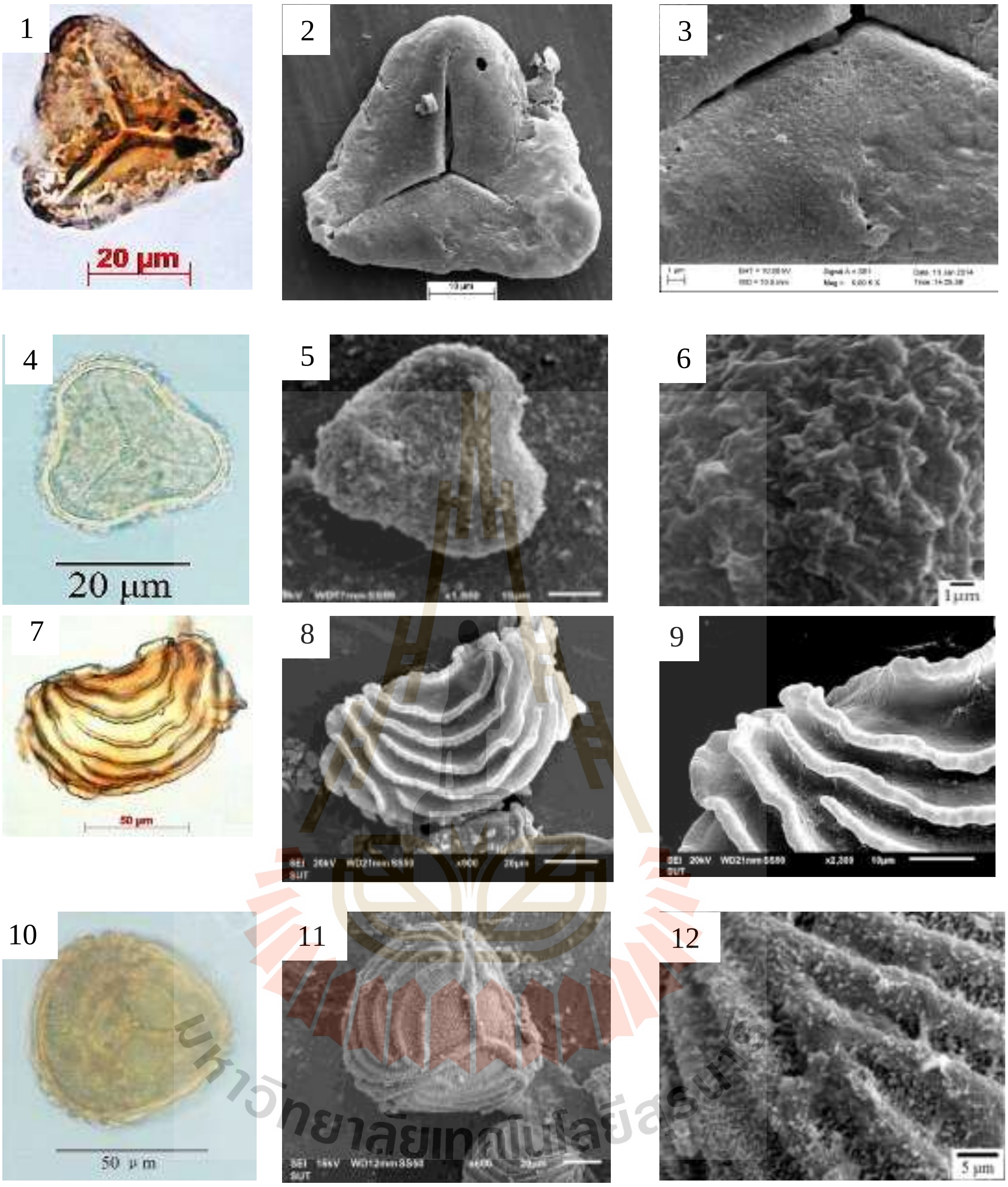

Plate 10 Pteridaceae

Figure 1-3 *Acrostichum* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Acrostichum aureum* (LM, SEM, and SEM close-up)

Figure 7-9 *Ceratopteris* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Ceratopteris thalictroides* (LM, SEM, and SEM close-up)

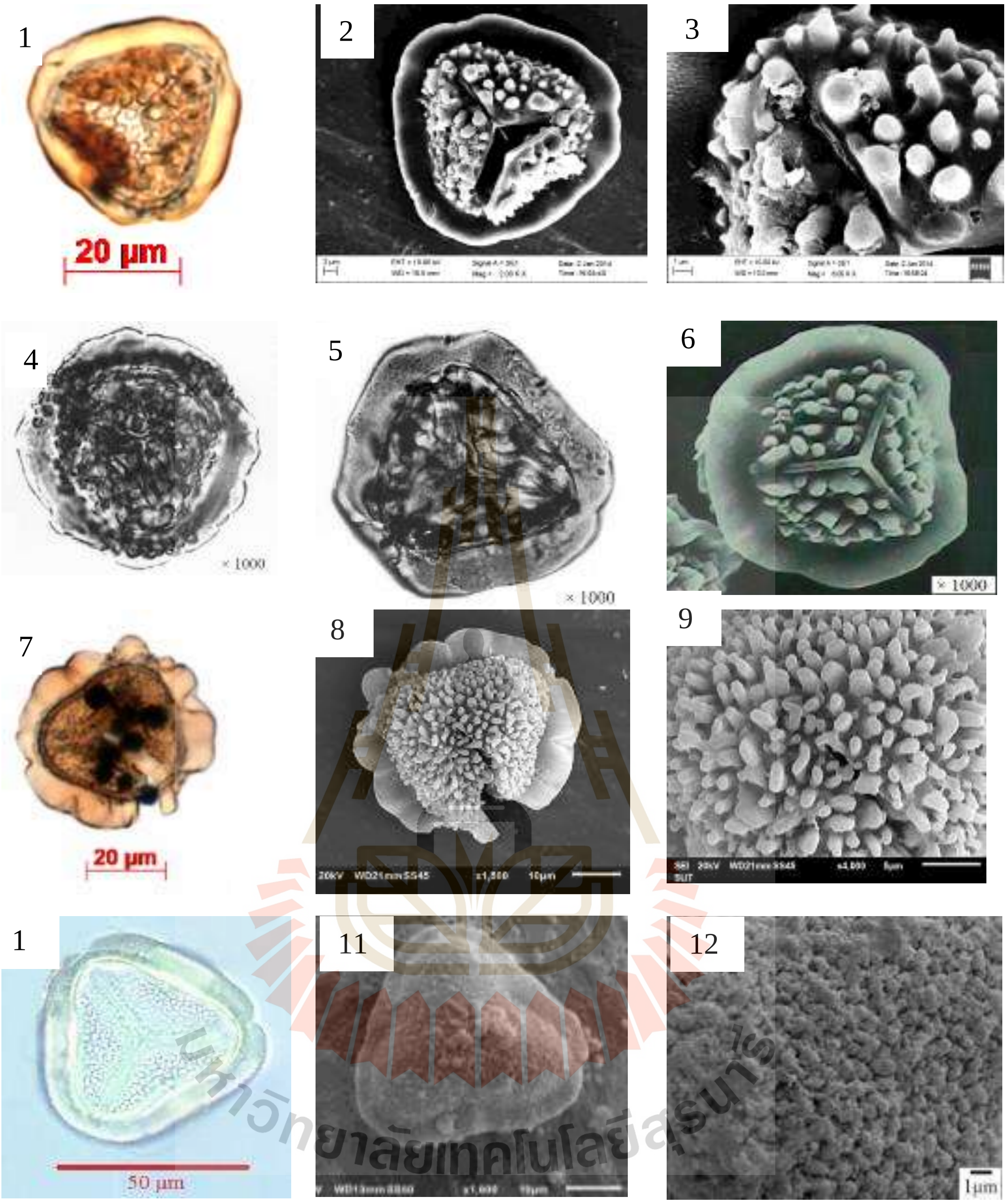

Plate 11 Pteridaceae

Figure 1-3	*Pteris* sp. (LM, SEM, and SEM close-up)
Figure 4-6	Modern reference *Pteris grandifolia* (LM, Roubik, 2003; SEM, Tryon and Lugardon, 1990)
Figure 7-9	*Taenitis* sp. (LM, SEM, and SEM close-up)
Figure 10-12	Modern reference *Taenitis blechnoides* (LM, SEM, and SEM close-up)

5.3 Gymnosperms

There were 1 families, 3 genera, and 5 taxa recognized in this study.

Pinaceae: 10 to 11 genera and about 235 species, north hemisphere (Fu *et al*., 1999).

***Abies*:** About 50 species, Asia, Europe, North America, grows at elevations of 2000-3000 (3700) m.

***Abies* sp.** Plate 12, Figures 1-3

Shape:	Bisaccate, oblate	Size:	Corpus 36×22 µm; Sacci 40×24 µm
Aperture:	Leptoma	Sculpture:	Psilate

Pinus: About 110 species, north Africa, Asia, Europe, And North America.

***Pinus* sp.** Plate 12, Figures 7-9

Shape:	Bisaccate, oblate	Size:	Corpus 31×28 µm; Sacci 22×32 µm
Aperture:	Leptoma	Sculpture:	Corpus microverrucate, sacci faintly microverrucate with perforations (Rugmai, 2006)

***Pseudolarix*:** 1 species, native in China, along the Changjiang River.

Pseudolarix amabilis Plate 13, Figures 1-3

Shape:	Bisaccate, oblate	Size:	Corpus 40×32 µm; Sacci 22×20 µm
Aperture:	Leptoma	Sculpture:	Corpus and sacci both rugulate

Pinaceae indeterminate 1 Plate 13, Figures 7-9

Shape:	Bisaccate, oblate	Size:	Corpus 56×16 µm; Sacci 50×22 µm
Aperture:	Leptoma	Sculpture:	psilate

Pinaceae indeterminate 2 Plate 13, Figures 10-12

Shape:	Bisaccate, oblate	Size:	Corpus 36×18 µm; Sacci 16×10 µm
Aperture:	Leptoma	Sculpture:	Corpus and sacci both rugulate

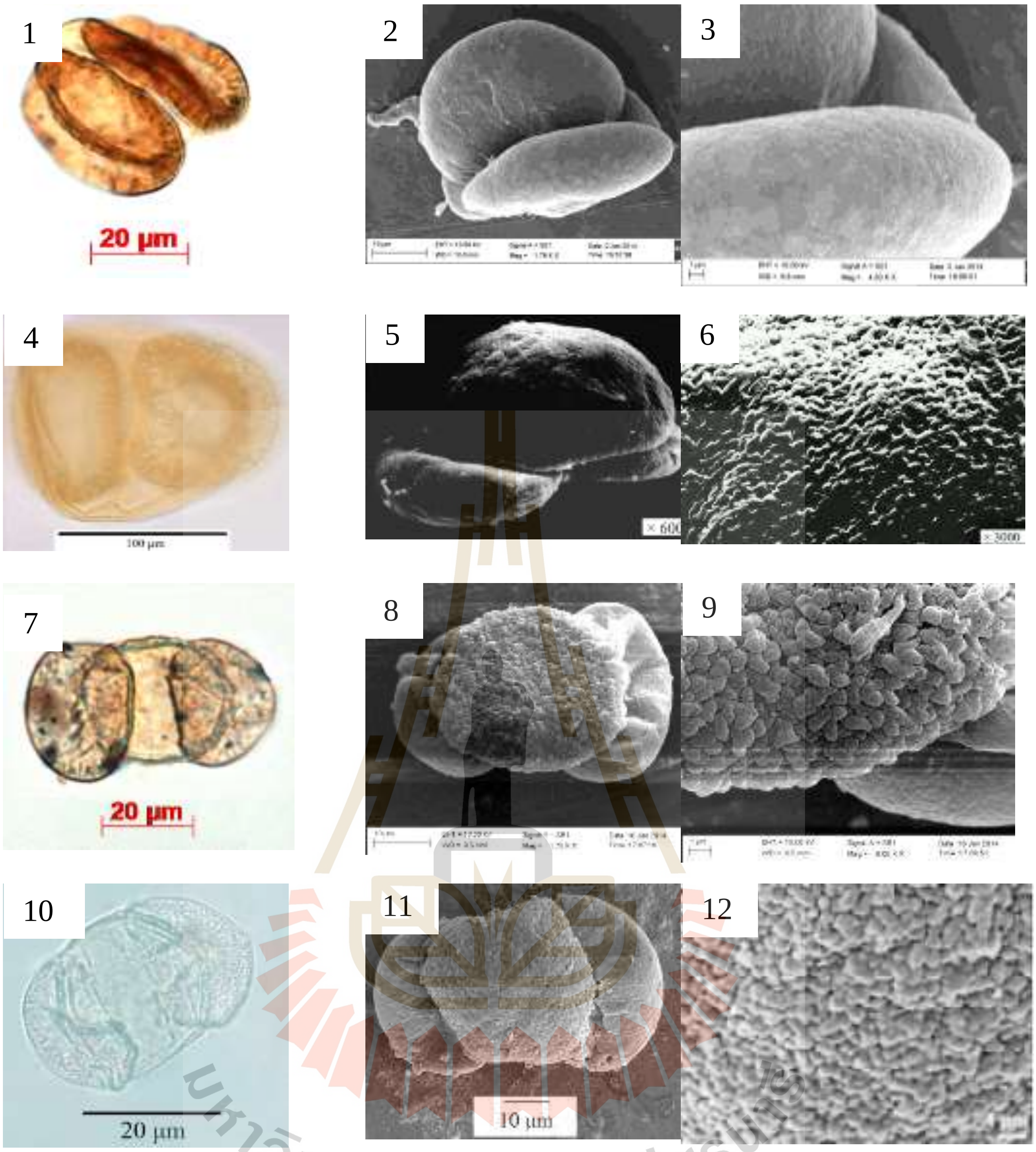

Plate 12 Pinaceae

Figure 1-3 *Abies* sp. (LM, SEM, and SEM close-up, airbag)

Figure 4-6 Modern reference *Abies amabilis* and *Abies ernestii* (LM, APSA, 2014; SEM and SEM close-up, air bag, Li *et al*., 2008)

Figure 7-9 *Pinus* sp. (LM, SEM, and SEM close-up, body)

Figure 10-12 Modern reference *Pinus contorta* (LM, SEM, and SEM close-up, body)

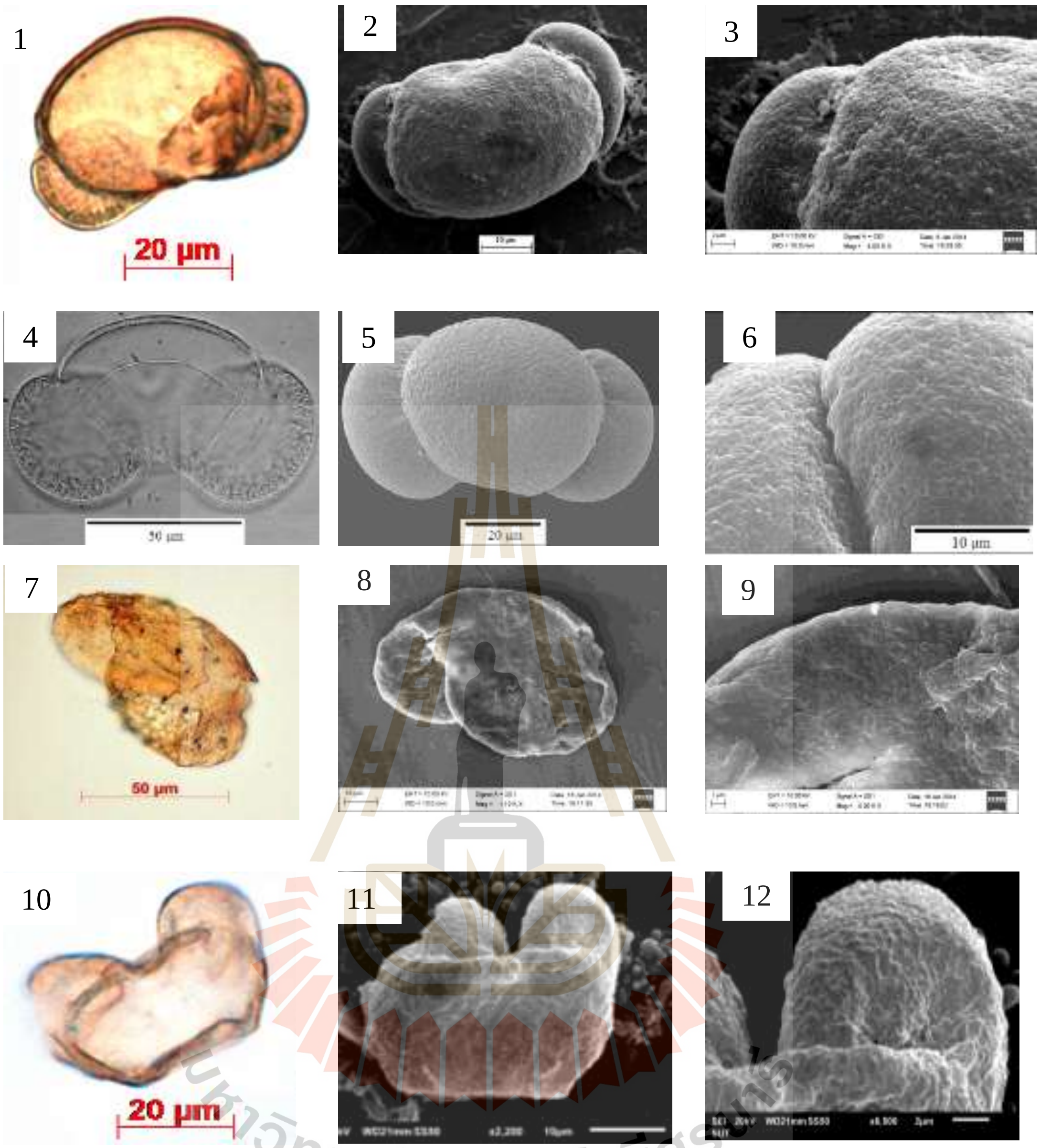

Plate 13 Pinaceae

Figure 1-3 *Pseudolarix amabilis* (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Pseudolarix amabilis*
(LM, SEM, and SEM close-up, Zanni and Ravazzi, 2007)

Figure 7-9 Pinaceae indeterminate 1 (LM, SEM, and SEM close-up)

Figure 10-12 Pinaceae indeterminate 2 (LM, SEM, and SEM close-up)

5.4 Angiosperms

There were 28 families, 38 genera, and 59 taxa recognized in this study.

Acanthaceae: About 220 genera and ca. 4,000 species, pantropical and subtropical, with a few species in temperate regions (Deng *et al*., 2011)

***Hygrophila*:** 100 species, widely distributed in tropical and subtropical regions.

***Hygrophila* sp.** Plate 14, Figures 1-3

Shape:	Spheroidal	Size:	28×22 µm
Aperture:	Stephanocolporate	Sculpture:	Striate-reticulate

***Stenandrium*:** About 140 species, tropical regions worldwide

Stenandrium dulce Plate 14, Figures 7-9

Shape:	Spheroidal	Size:	34 µm
Aperture:	Inaperturate	Sculpture:	Gemmate

***Ruellia*:** About 250 species, tropical to temperate regions worldwide.

***Ruellia* sp1.** Plate 15, Figures 1-3

Shape:	oblate	Size:	28-38 µm
Aperture:	Leptoma	Sculpture:	Reticulate-heterobrochate

***Ruellia* sp2.** Plate 15, Figures 4-6

Shape:	oblate	Size:	32-34 µm
Aperture:	Leptoma	Sculpture:	Reticulate-heterobrochate

***Ruellia* sp3.** Plate 15, Figures 7-9

Shape:	oblate	Size:	34-36 µm
Aperture:	Leptoma	Sculpture:	Reticulate-heterobrochate

Adoxaceae: 4 genera and 220 species, mainly in the north hemisphere (Hong *et al*., 2011).

***Viburnum*:** About 200 species: mostly in temperate and subtropical regions of Asia and South America.

***Viburnum* sp1.** Plate 16, Figures 1-3

Shape:	Oblate	Size:	28-36 µm
Aperture:	Tricolporate	Sculpture:	Reticulo-cristate

***Viburnum* sp2.** Plate 16, Figures 4-6

Shape:	Oblate	Size:	18-26 µm
Aperture:	Tricolporate	Sculpture:	Reticulo-cristate

Araliaceae: About 50 genera and 1350 species, tropical and subtropical regions of both hemispheres, much less in temperate areas (Xiang and Lowry, 2007).

***Schefflera*:** Nearly 1100 specie, distributed in tropics and subtropics of both hemispheres.

***Schefflera* sp.** Plate 17, Figures 1-3

Shape:	Oblate	Size:	20×17 µm
Aperture:	Tricolporate	Sculpture:	Perforate

Arecaceae: Nearly 183 genera and 2,450 species in tropical and subtropical areas in Africa, the Americas, Asia, Madagascar, and the Pacific (Pei *et al*., 2010).

Nypa: One species distribute from Sri Lanka through Southeast Asia to Japan (Ryukyu Islands), the Pacific islands (Solomon Islands), and reaching Australia**.**

***Nypa* SP.** Plate 17, Figures 1-3

Shape:	Spheroidal	Size:	28 µm
Aperture:	Tricolporate	Sculpture:	Spinulate

Asteraceae: Between 1,600 and 1,700 genera and ca. 24,000 species: cosmopolitan (except Antarctica) (Shi *et al*., 2011).

***Pluchea*:** About 80 species, Africa, southeast Asia, Australia, Caribbean, North and South America, Pacific islands.

***Pluchea* SP.** Plate 18, Figures 7-9

Shape:	Spheroidal	Size:	28 µm
Aperture:	Tricolporate	Sculpture:	Spinulate

Asteraceae indeterminate 1 Plate 18, Figures 1-3

Shape:	Spheroidal	Size:	24 µm
Aperture:	Tricolporate	Sculpture:	Reticulate-spinulate

Asteraceae indeterminate 2 Plate 18, Figures 4-6

Shape:	Spheroidal	Size:	24 µm
Aperture:	Tricolporate	Sculpture:	Spinulate

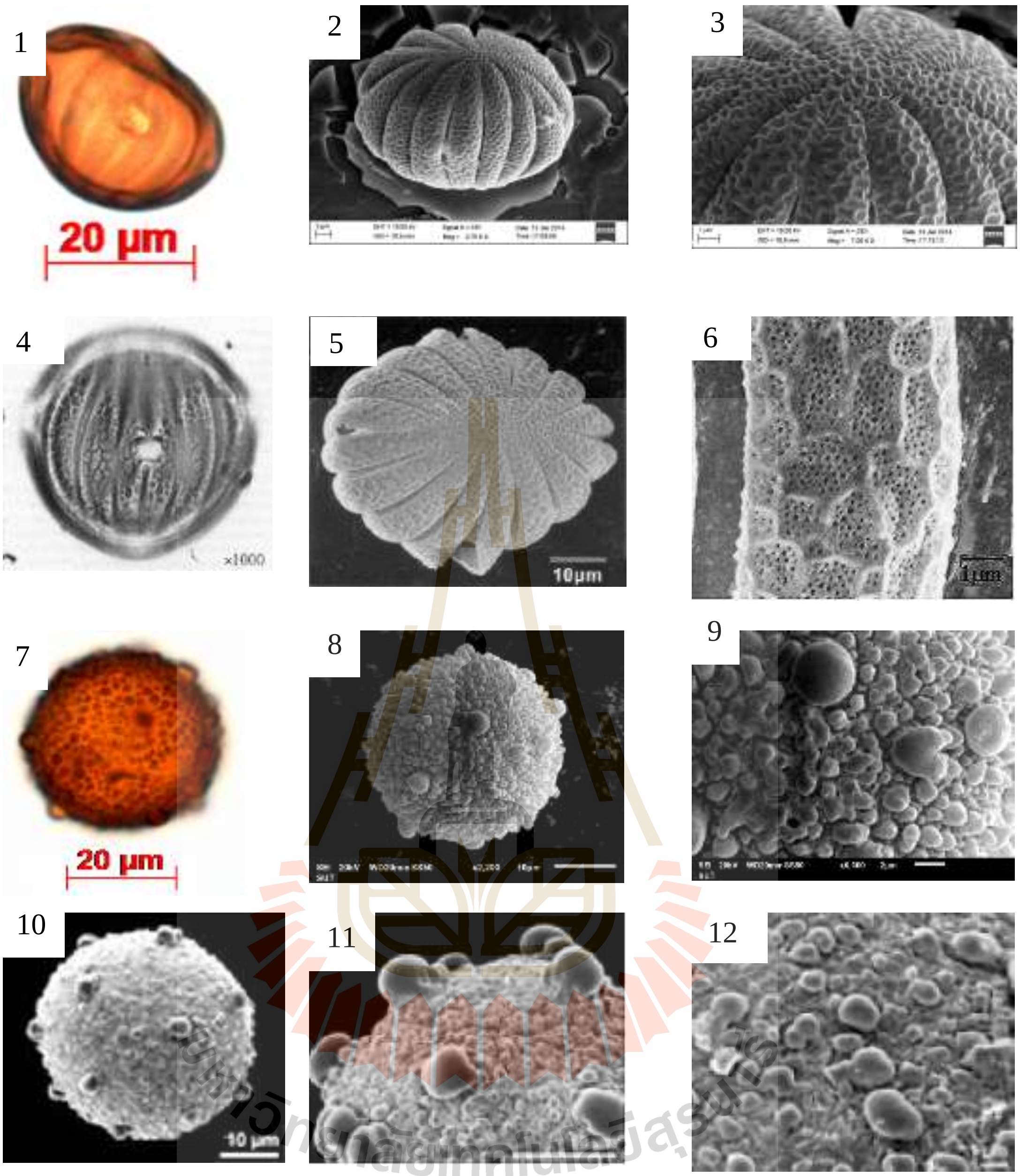

Plate 14 Acanthaceae

Figure 1-3 *Hygrophila* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Hygrophila auriculata* (LM, SEM, and SEM close-up, Furness, 2013)

Figure 7-9 *Stenandrium dulce* (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Stenandrium dulce* (SEM, and SEM close-up Paldat, 2014)

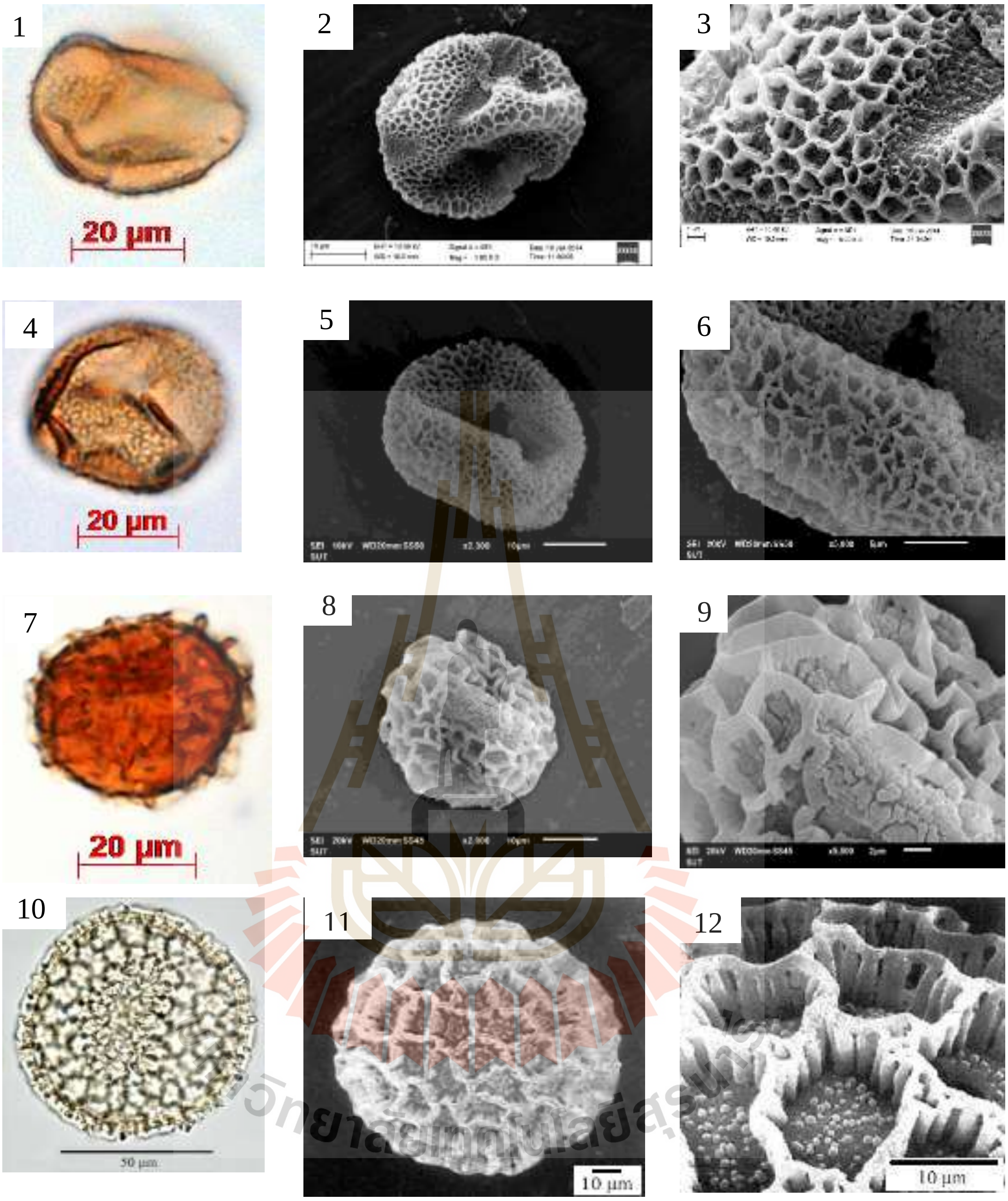

Plate 15 Acanthaceae

Figure 1-3 *Ruellia* sp1. (LM, SEM, and SEM close-up)

Figure 4-6 *Ruellia* sp2. (LM, SEM, and SEM close-up)

Figure 7-9 *Ruellia* sp3. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Ruellia tuberosa* and *R. genduana* (LM, APSA, 2014; SEM and SEM close-up, Furness and Grant, 2009)

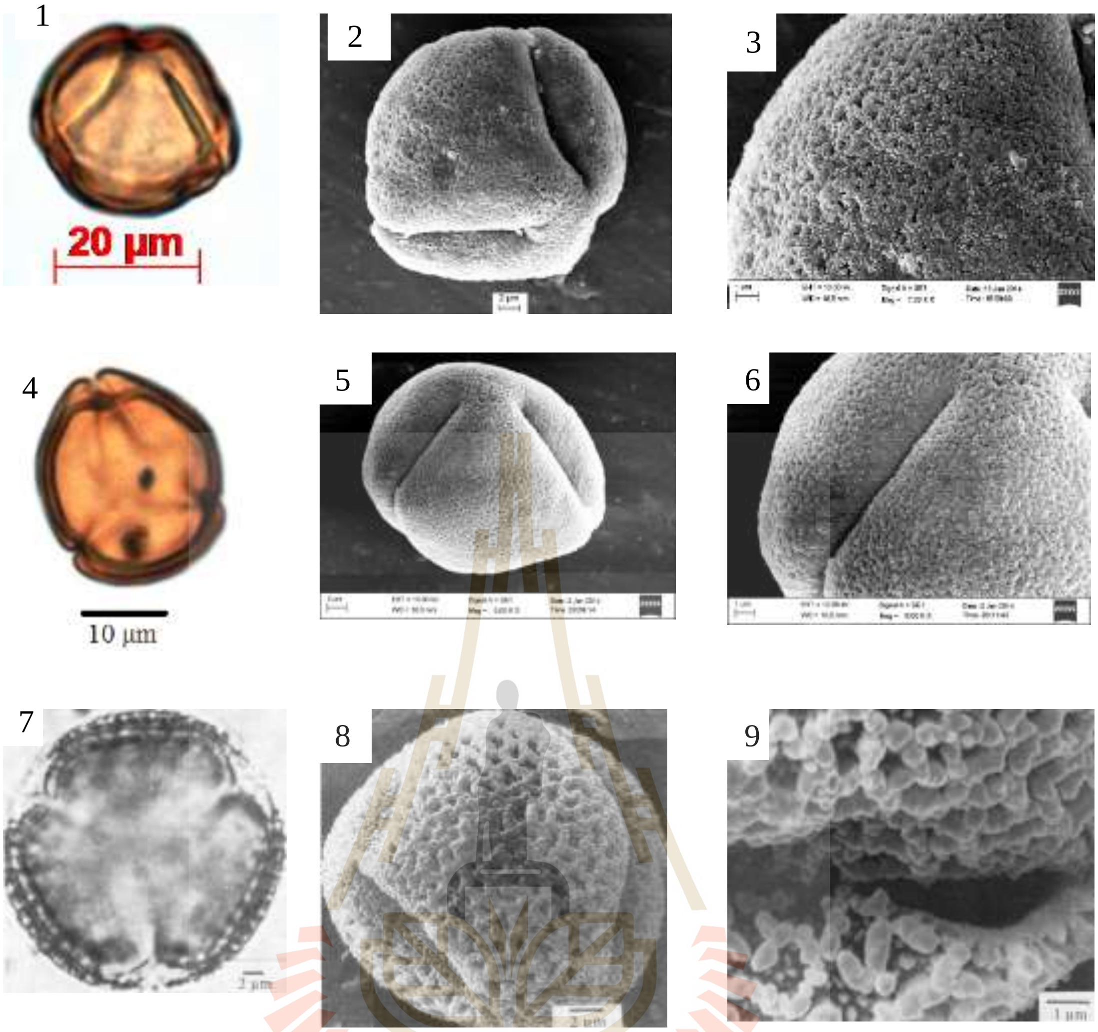

Plate 16 Adoxaceae

Figure 1-3 *Viburnum* sp1. (LM, SEM, and SEM close-up)

Figure 4-6 *Viburnum* sp2. (LM, SEM, and SEM close-up)

Figure 7-9 Modern reference *Viburnum Lantana*

(LM, APSA, 2014; SEM and SEM close-up, Maciejewska, 1997)

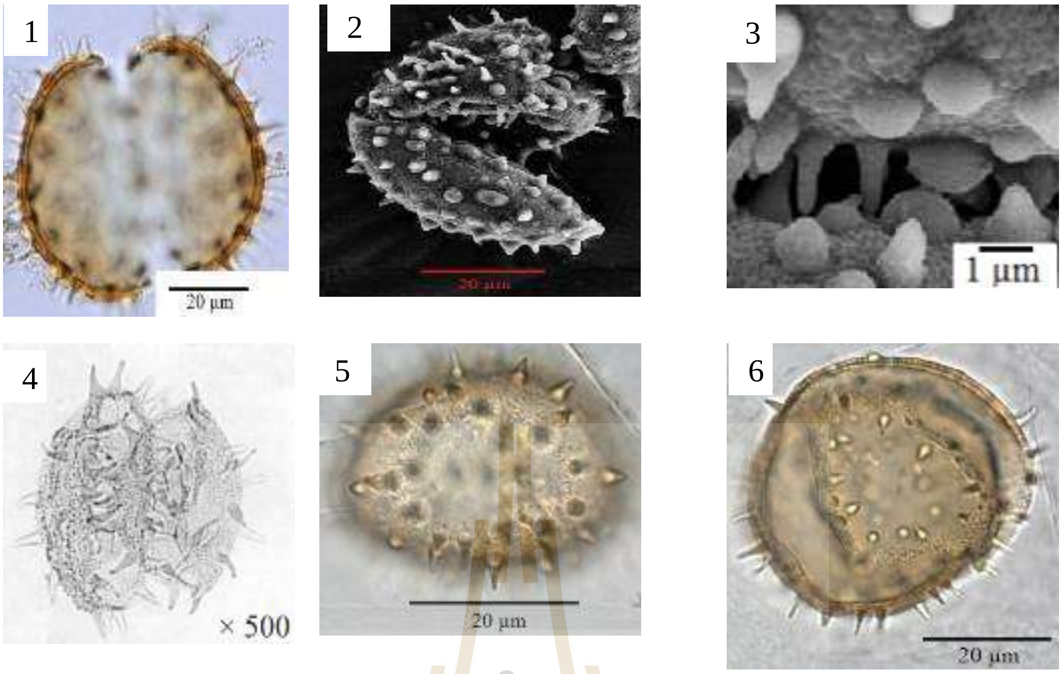

Plate 17 Arecaceae

Figure 1-3 *Nypa fruticans*

(LM, SEM, and SEM close-up, Mao *et al*., 2012)

Figure 4-6 Modern reference *Nypa fruticans*

(LM, Gee, 2001; APSA, 2014)

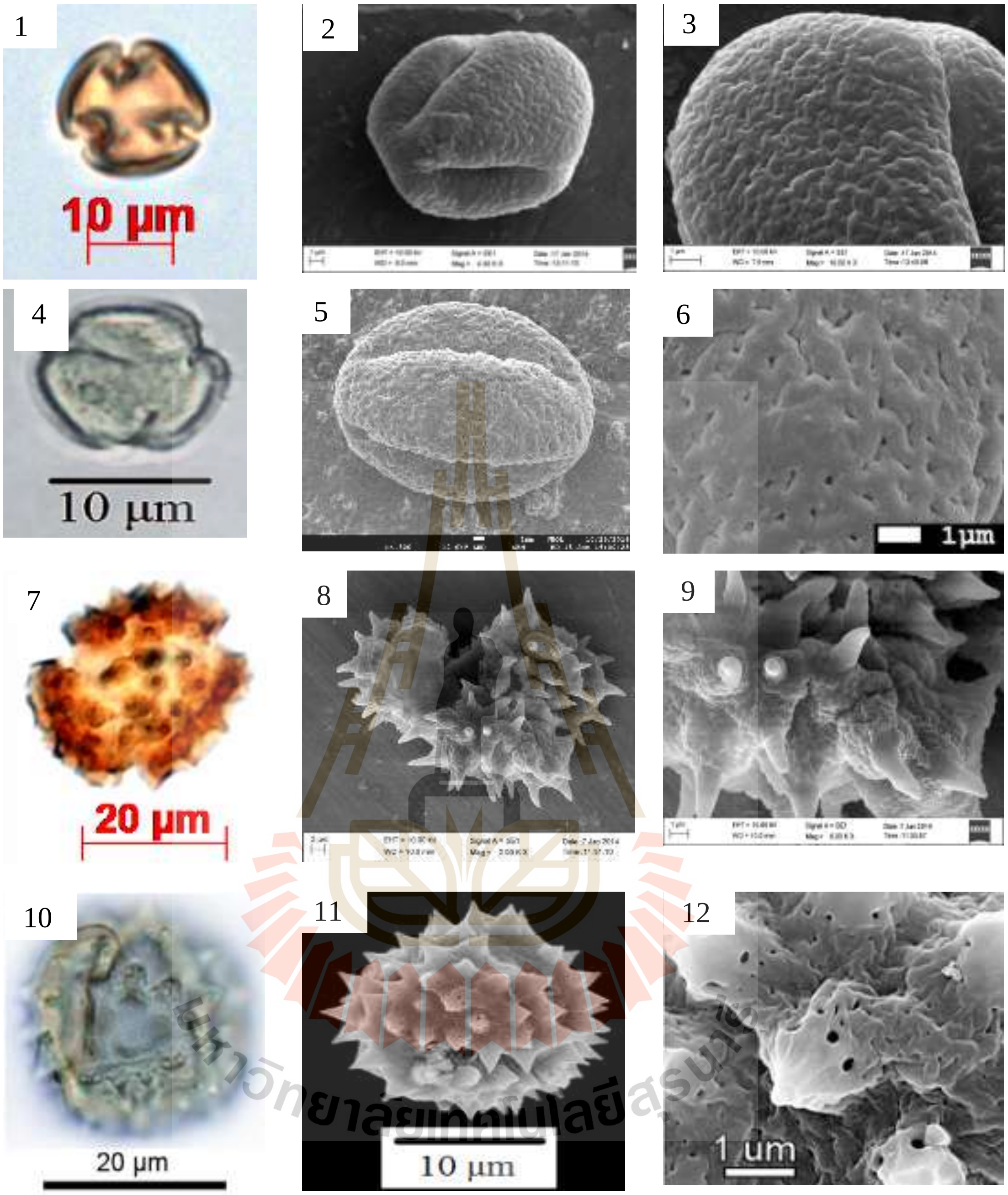

Plate 18 Araliaceae and Asteraceae

Figure 1-3 *Schefflera* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Schefflera subintegra* (LM, SEM, and SEM close-up)

Figure 7-9 *Pluchea* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Pluchea indica* (LM, SEM, and SEM close-up, Mao *et al*., 2012)

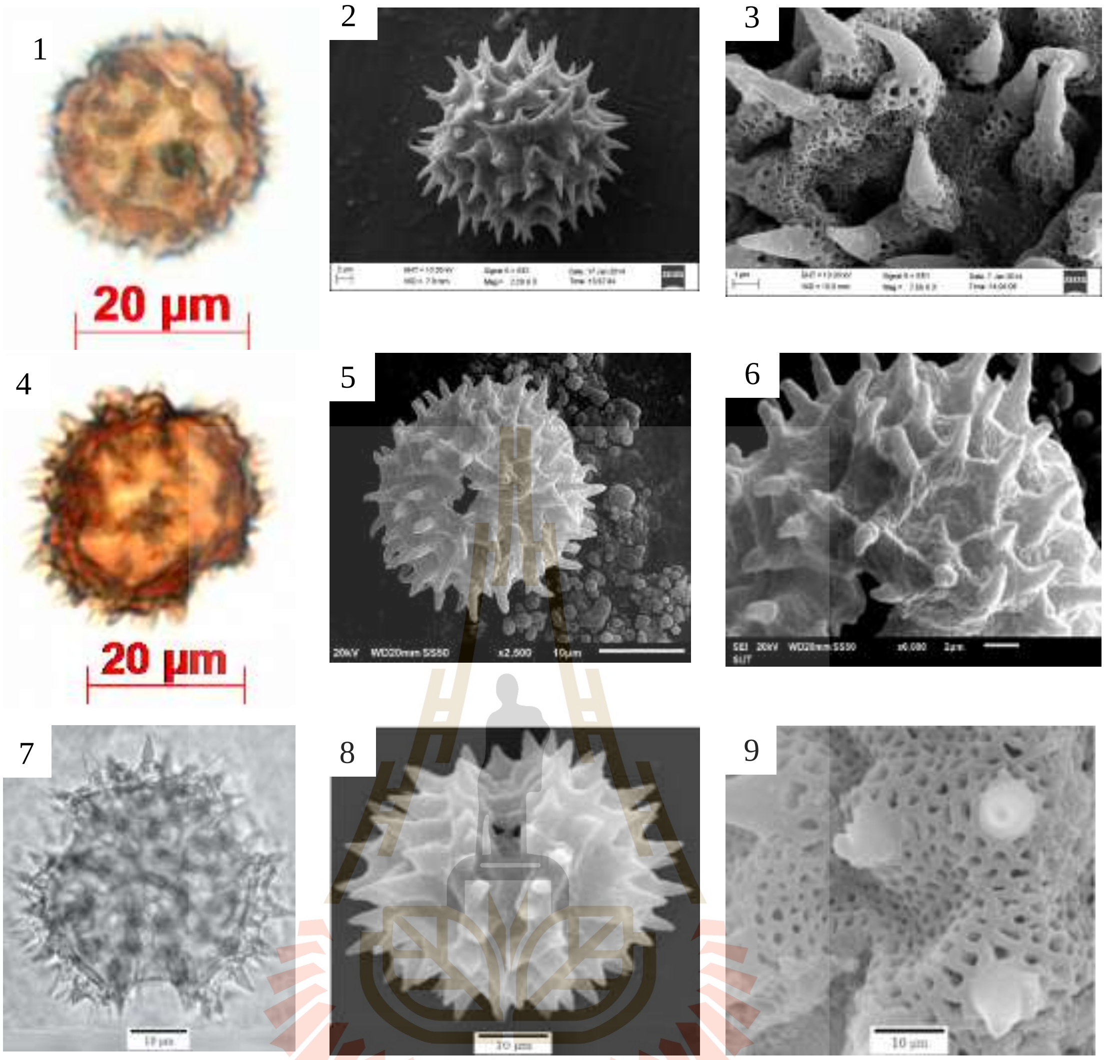

Plate 19 Asteraceae

Figure 1-3 Asteraceae indeterminate 1 (LM, SEM, and SEM close-up)

Figure 4-6 Asteraceae indeterminate 2 (LM, SEM, and SEM close-up)

Figure 7-9 Modern reference *Eremanthus capitatus* (LM, SEM, and SEM close-up, Loeuille *et al*., 2012)

Bignoniaceae: About 116-120 genera and 650-750 species, mostly in tropical and subtropical regions (Zhang and Santisuk, 1998).

***Radermachera*:** About 16 species, distribute in tropical Asia

***Radermachera* sp.** Plate 19, Figures 1-3

Shape:	Prolate	Size:	55×20 µm
Aperture:	Tricolporate	Sculpture:	Reticulate

***Nyctocalos*:** About 5 species in Cambodia, China, northeast India, Indonesia, Malaysia, Myanmar, Philippines, Thailand

***Nyctocalos* sp.** Plate 19, Figures 7-9

Shape:	Prolate	Size:	61×32 µm.
Aperture:	Tricolporate	Sculpture:	Reticulate

Chenopodiaceae: Probably about 100 genera and 1400 species (depending on taxonomic opinions), mainly in arid areas, deserts, and coastal and saline habitats of north and south Africa, Asia, Australia, Europe, and North and South America (Zhu, *et al.*, 2003).

***Chenopodium*:** About 170 species, abundant in temperate and subtropical zones.

***Chenopodium* sp.** Plate 12, Figures 1-3

Shape:	Spheroidal	Size:	24-26 µm
Aperture:	Panporate with few spinules around the pore	Sculpture:	Microechinate, perforate

Suaeda**:** 100 species, Asia, Europe, North America, and seashores worldwide.

***Suaeda* sp.** Plate 12, Figures 7-9

Shape:	Spheroidal	Size:	16-20 μm
Aperture:	Panporate with few spinules on the pore membrane	Sculpture:	Microechinate, perforate

---

Combretaceae: About 20 genera and ca. 500 species, widespread in tropics and subtropics (Chen and Turland, 2007).

Lumnitzera**:** 2 species, Bangladesh, Cambodia, China, India, Indonesia, Japan (Ryukyu Islands), south Korea, Malaysia, New Guinea, Philippines, Singapore, Sri Lanka, Thailand, Vietnam; east Africa (including Madagascar), north Australia, Pacific islands.

***Lumnitzera* sp.** Plate 21, Figures 1-3

Shape:	Prolate, stephano-lobed in polar view	Size:	16×12 μm
Aperture:	Colporate	Sculpture:	Perforate

Terminalia**:** About 150 species, tropics of Africa, America, and Asia, extending to south Africa, Australia, and Pacific islands.

***Terminalia* sp.** Plate 21, Figures 7-9

Shape:	Prolate, six-lobed in polar view	Size:	26×18 μm
Aperture:	Colporate	Sculpture:	Perforate

Commelinaceae: About 40 genera and 650 species, mainly in tropical regions, fewer species in subtropical and temperate regions (Hong and De Filipps, 2000).

Commelinaceae indeterminate 1 Plate 16, Figures 1-3

Shape:	Prolate	Size:	40×15 µm
Aperture:	Sulcate	Sculpture:	Psilate

Commelinaceae indeterminate 2 Plate 16, Figures 7-9

Shape:	Prolate	Size:	40×24 µm
Aperture:	Sulcate	Sculpture:	Perforate

Euphorbiaceae: About 300 genera and 5000 species, widespread throughout the world, primarily in the tropics and subtropics, more poorly represented in temperate regions (Chayamarit and Welzen, 2014)).

***Croton*:** More than 800 species, tropics and subtropics of the world, most numerous in the neotropics.

***Croton* sp.** Plate 23, Figures 1-3

Shape:	Spheriodal	Size:	51 µm
Aperture:	Inaperated	Sculpture:	Reticulo-cristate, croton pattern

***Mallotus*:** About 150 species, tropical and subtropical regions in Asia, a few species in Africa and Australia.

***Mallotus* sp.** Plate 23, Figures 7-9

Shape:	Oblate	Size:	32×16 µm
Aperture:	Tricolpate	Sculpture:	Perforate with free echinate

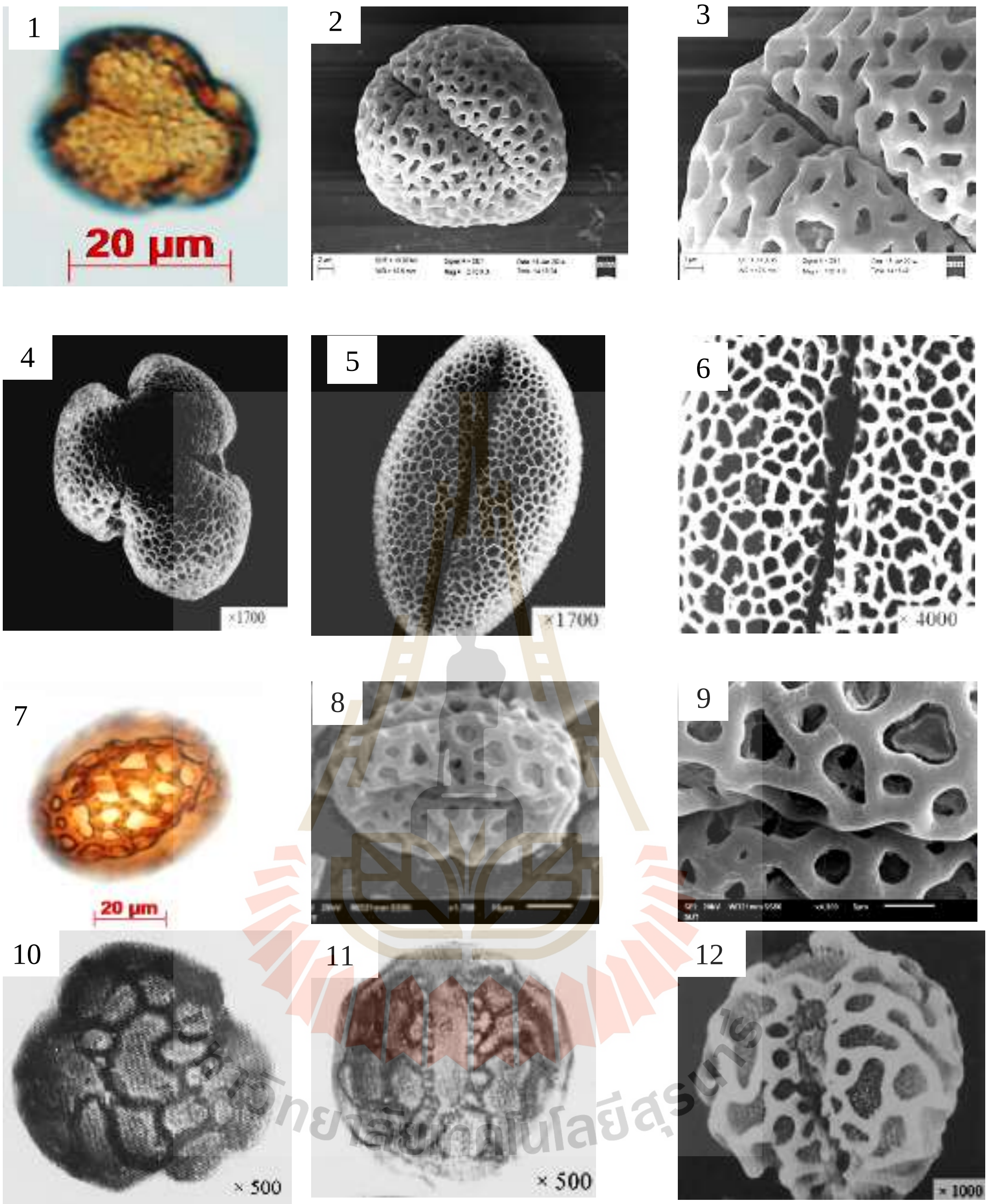

Plate 20 Bignoniaceae

Figure 1-3 *Radermachera* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Radermachera sinica* (SEM, and SEM close-up, Li *et al*., 2008)

Figure 7-9 *Nyctocalos* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Nyctocalos shanica* (LM and SEM, Wei *et al*., 2001)

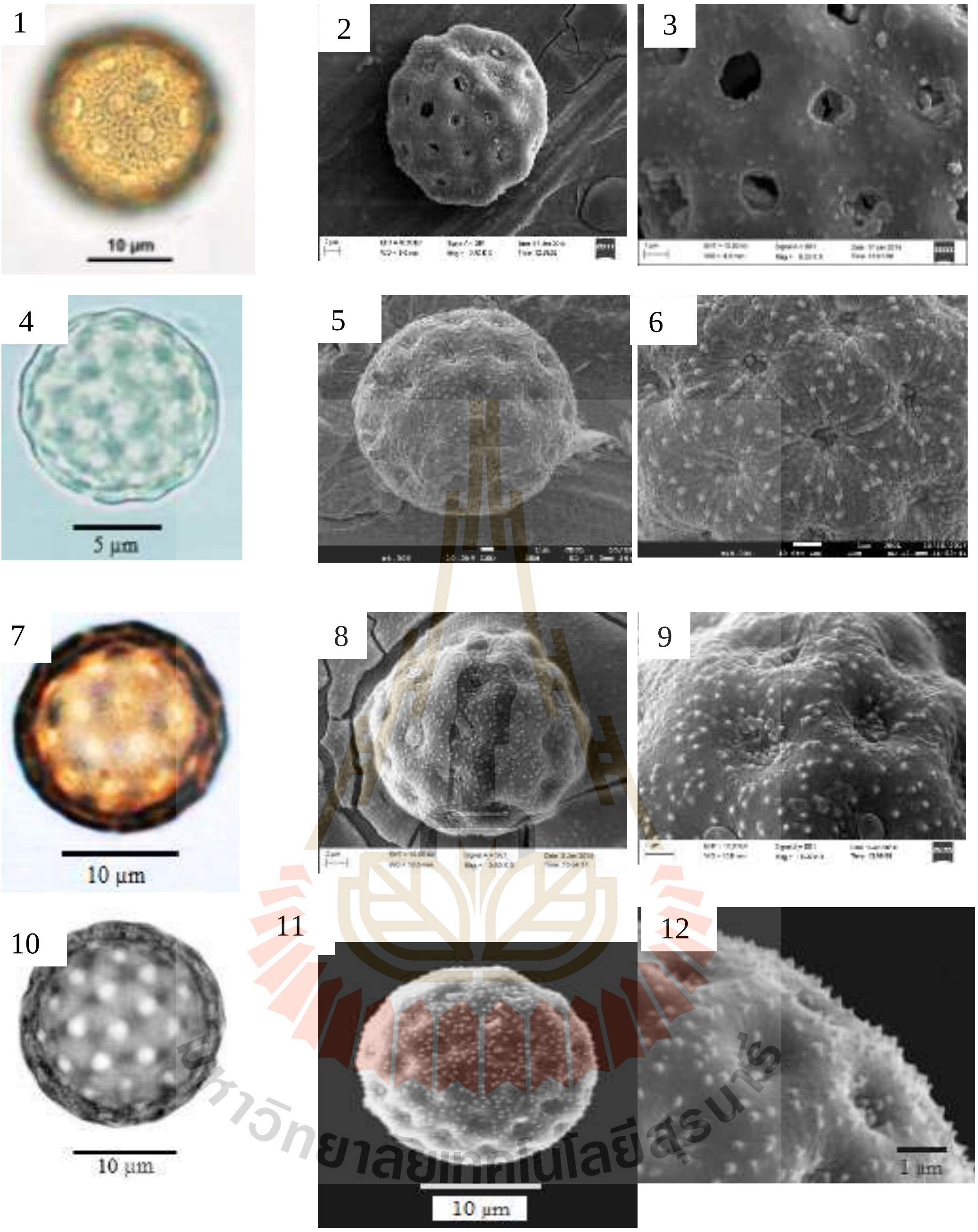

Plate 21 Chenopodiaceae

Figure 1-3 *Chenopodium* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Chenopodium* sp.
(LM, SEM, and SEM close-up)

Figure 7-9 *Suaeda maritima* (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Suaeda maritime*
(LM, SEM, and SEM close-up, Dehghani and Akhani, 2014)

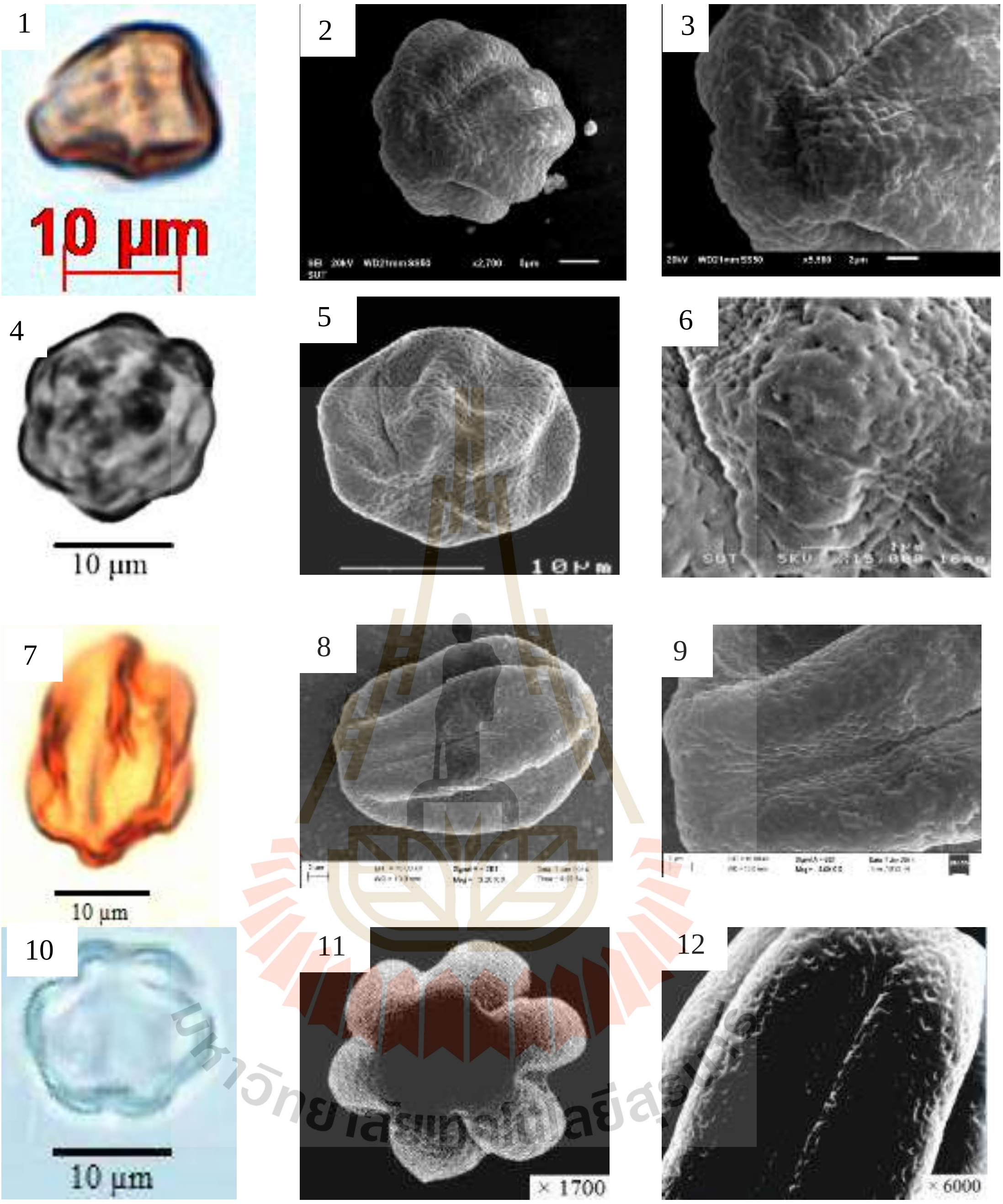

Plate 22 Combretaceae

Figure 1-3 *Lumnitzera* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Lumnitzera racemosa* (LM, SEM, and SEM close-up, Rugmai, 2006)

Figure 7-9 *Terminalia* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Terminalia catappa* (LM, SEM, and SEM close-up, Li *et al*., 2008)

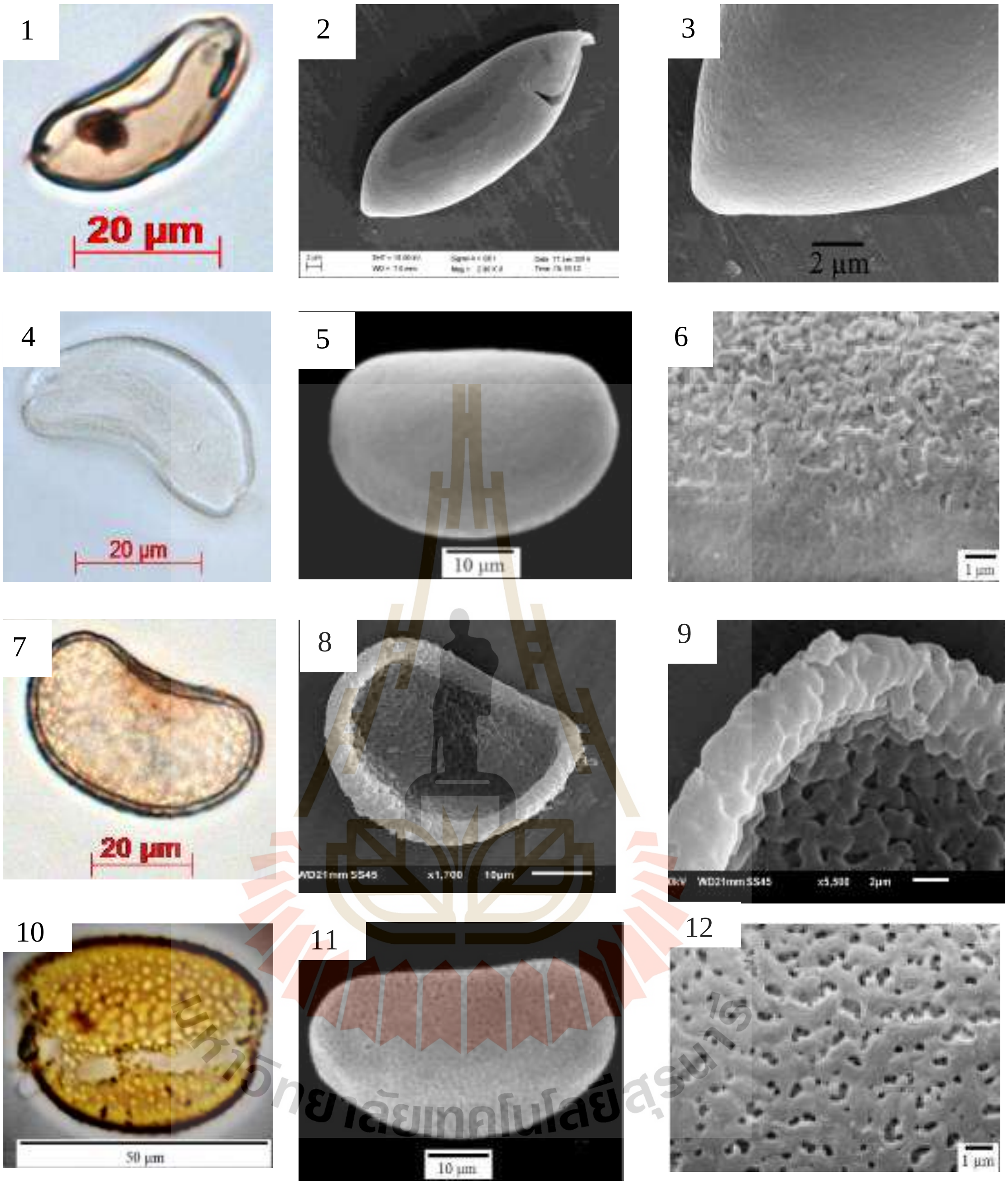

Plate 23 Commelinaceae

Figure 1-3 Commelinaceae indeterminate 1 (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Cochliostema odoratissimum* (LM, SEM and SEM close-up, Paldat, 2014)

Figure 7-9 Commelinaceae indeterminate 2 (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Commelina cyanea* (LM, SEM and SEM close-up, APSA, 2014; Paldat, 2014)

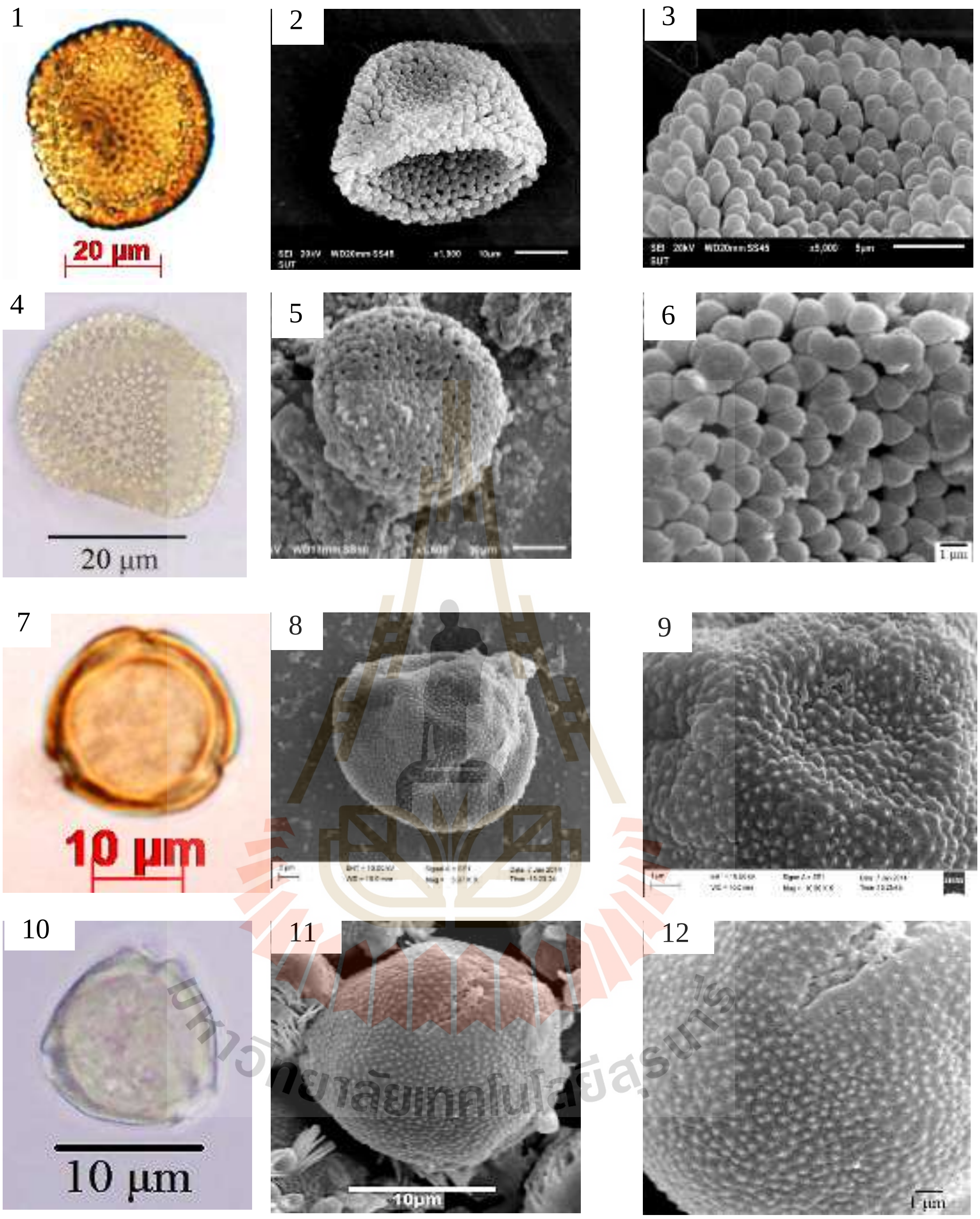

Plate 24 Euphorbiaceae

Figure 1-3 *Croton* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Croton oblongifolium* (LM and SEM)

Figure 7-9 *Mallotus* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Mallotos paniculatus* (LM, SEM, and SEM close-up)

Fabaceae: About 650 genera and ca. 18,000 species: distributed worldwide, woody genera mostly in the S Hemisphere and the tropics, herbaceous genera mostly in temperate regions, very numerous in Mediterranean-climate areas (Li *et al*., 2010).

***Acacia*:** 7000 species, Africa, America, Asia, and Australia

***Acacia* sp.** Plate 24, Figures 1-3

Shape:	Polyad	Size:	24-56 µm
Aperture:	Ulcerate	Sculpture:	Psilate

***Albizia*:** 120-140 species, tropical to warm regions of the world**.**

***Albizia* sp.** Plate 24, Figures 7-9

Shape:	Polyad	Size:	25-60 µm
Aperture:	Ulcerate	Sculpture:	Psilate

***Caesalpinia*:** About 100 species, pantropical.

***Caesalpinia* sp.** Plate 25, Figures 1-3

Shape:	Oblate	Size:	28-30 µm
Aperture:	Tricolporate	Sculpture:	Reticulate

***Senna*:** About 260 species, pantropical regions.

***Senna* sp.** Plate 25, Figures 7-9

Shape:	Oblate	Size:	17-19 µm
Aperture:	Tricolporate	Sculpture:	Rugulate

Fagaceae: 7-12 genera and 900-1000 species: worldwide except for tropical and south Africa (Huang *et al*., 1999).

***Castanopsis*:** About 120 species, tropical and subtropical Asia.

***Castanopsis* sp1.** Plate 26, Figures 1-3

Shape:	Prolate	Size:	32×18 µm
Aperture:	Tricolporate	Sculpture:	Perforate with micro rugulate

***Castanopsis* sp2.** Plate 26, Figures 4-6

Shape:	Prolate	Size:	28×22 µm
Aperture:	Tricolporate	Sculpture:	Perforate with micro rugulate

***Castanopsis* sp3.** Plate 26, Figures 7-9

Shape:	Oblate	Size:	25×19 µm
Aperture:	Tricolporate	Sculpture:	Perforate with micro rugulate

***Quercus*:** About 300 species, north Africa, Asia, Europe, North America, South America (Colombia).

***Quercus* sp1.** Plate 27, Figures 1-3

Shape:	Prolate	Size:	27×14 µm
Aperture:	Tricolporate	Sculpture:	Rodlike-clavate

***Quercus* sp2.** Plate 27, Figures 4-6

Shape:	Prolate	Size:	18×16 µm
Aperture:	Tricolporate	Sculpture:	Rodlike-clavate

***Quercus* sp3.** Plate 27, Figures 7-9

Shape:	Prolate	Size:	16×14 µm
Aperture:	Tricolporate	Sculpture:	Rodlike-clavate

***Quercus* sp4.** Plate 28, Figures 1-3

Shape:	Prolate	Size:	30×21μm
Aperture:	Tricolporate	Sculpture:	Fossulate

***Quercus* sp5.** Plate 28, Figures 4-6

Shape:	Prolate	Size:	14×10 μm
Aperture:	Tricolporate	Sculpture:	Fossulate

***Quercus* sp6.** Plate 28, Figures 7-9

Shape:	Prolate	Size:	30×20 μm
Aperture:	Tricolporate	Sculpture:	Fossulate

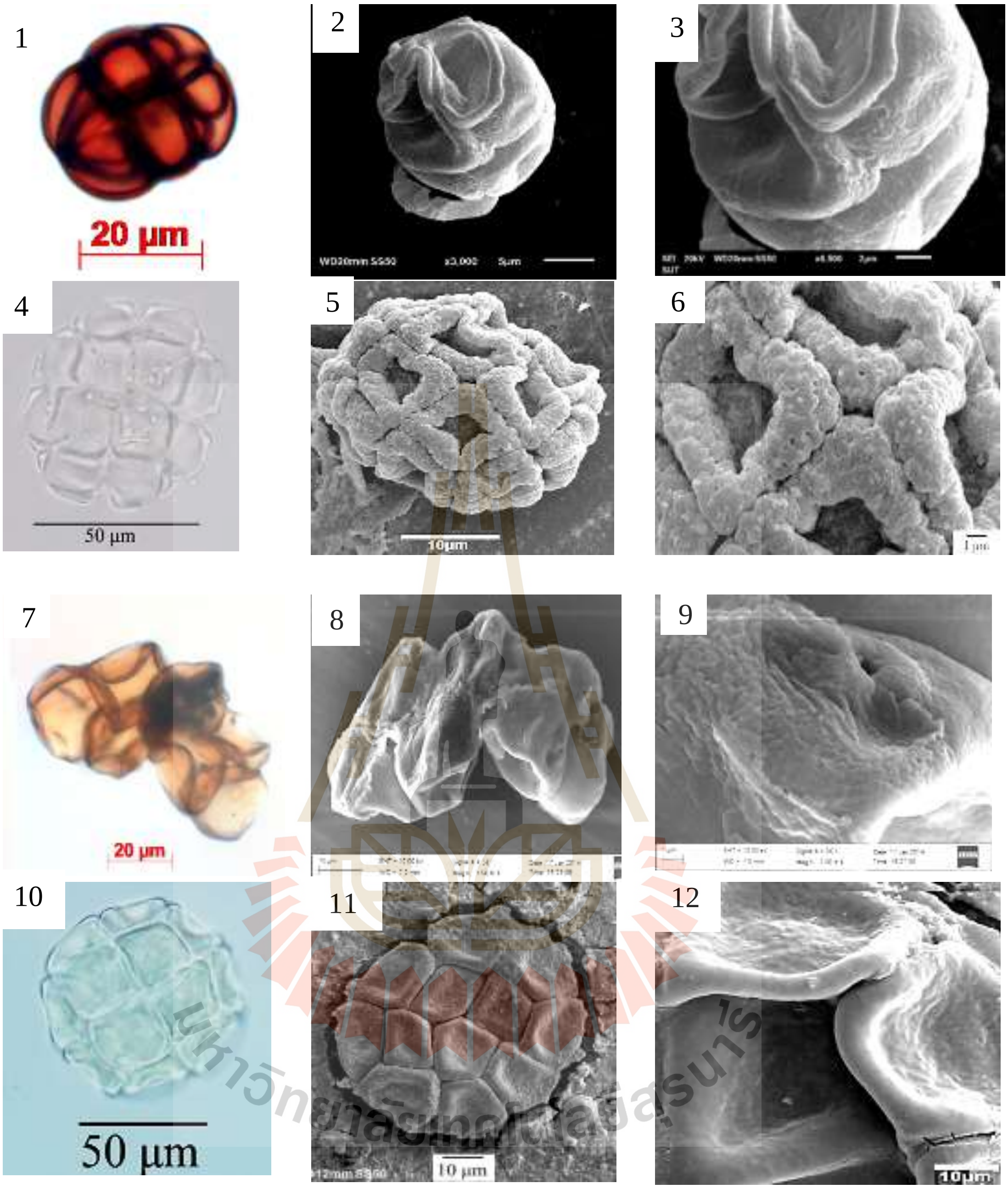

Plate 25 Fabaceae

Figure 1-3 *Acacia* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Acacia harmandiana* (SEM, and SEM close-up)

Figure 7-9 *Albizia* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Albizia lebbeck* (LM, SEM, and SEM close-up)

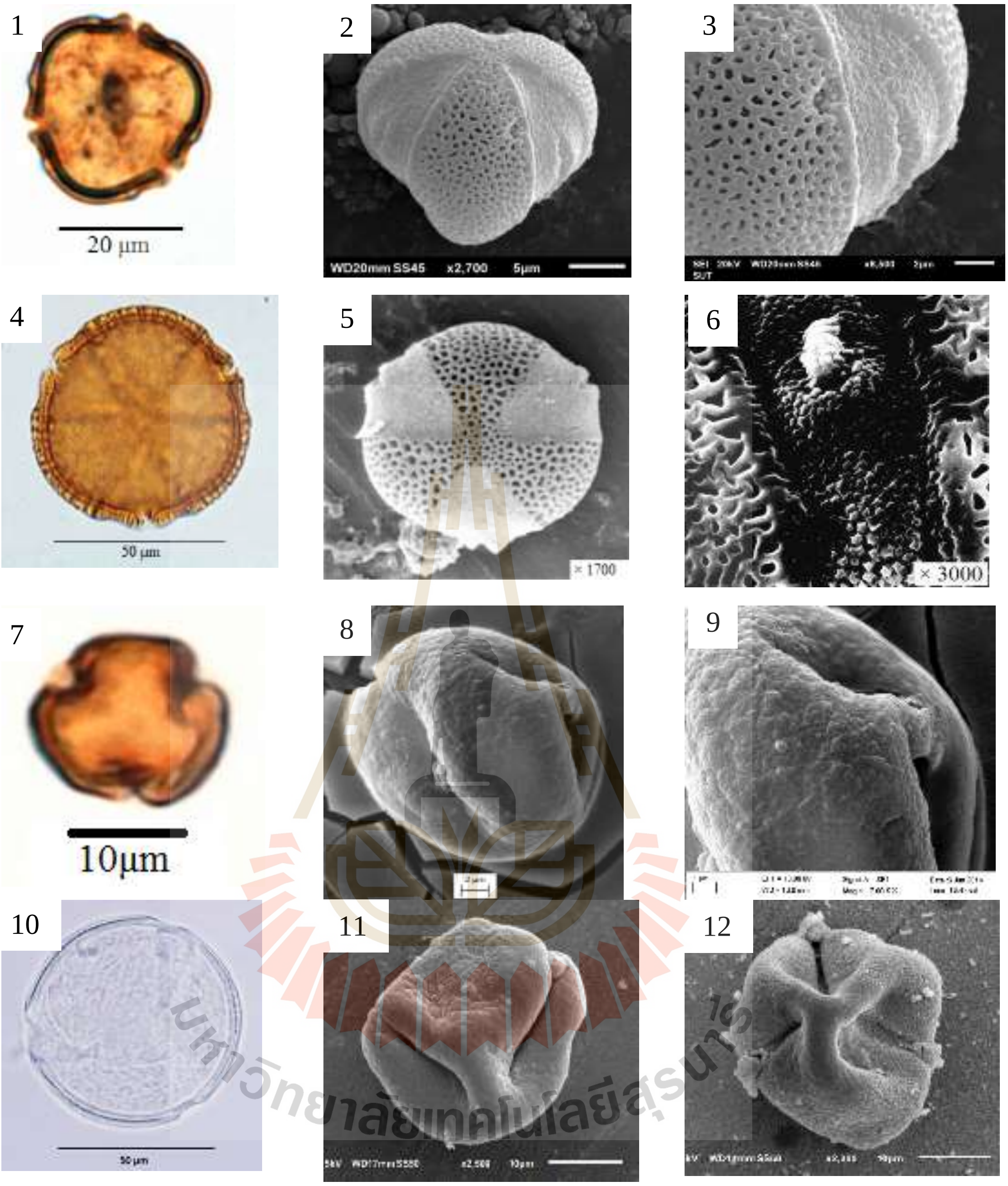

Plate 26 Fabaceae

Figure 1-3 *Caesalpinia* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Caesalpinia echinata* and C. *sappan* (LM and SEM, Corrêa, *et al*., 2003; SEM close-up, Li *et al*., 2008)

Figure 7-9 *Senna* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Senna garretiana* (LM and SEM)

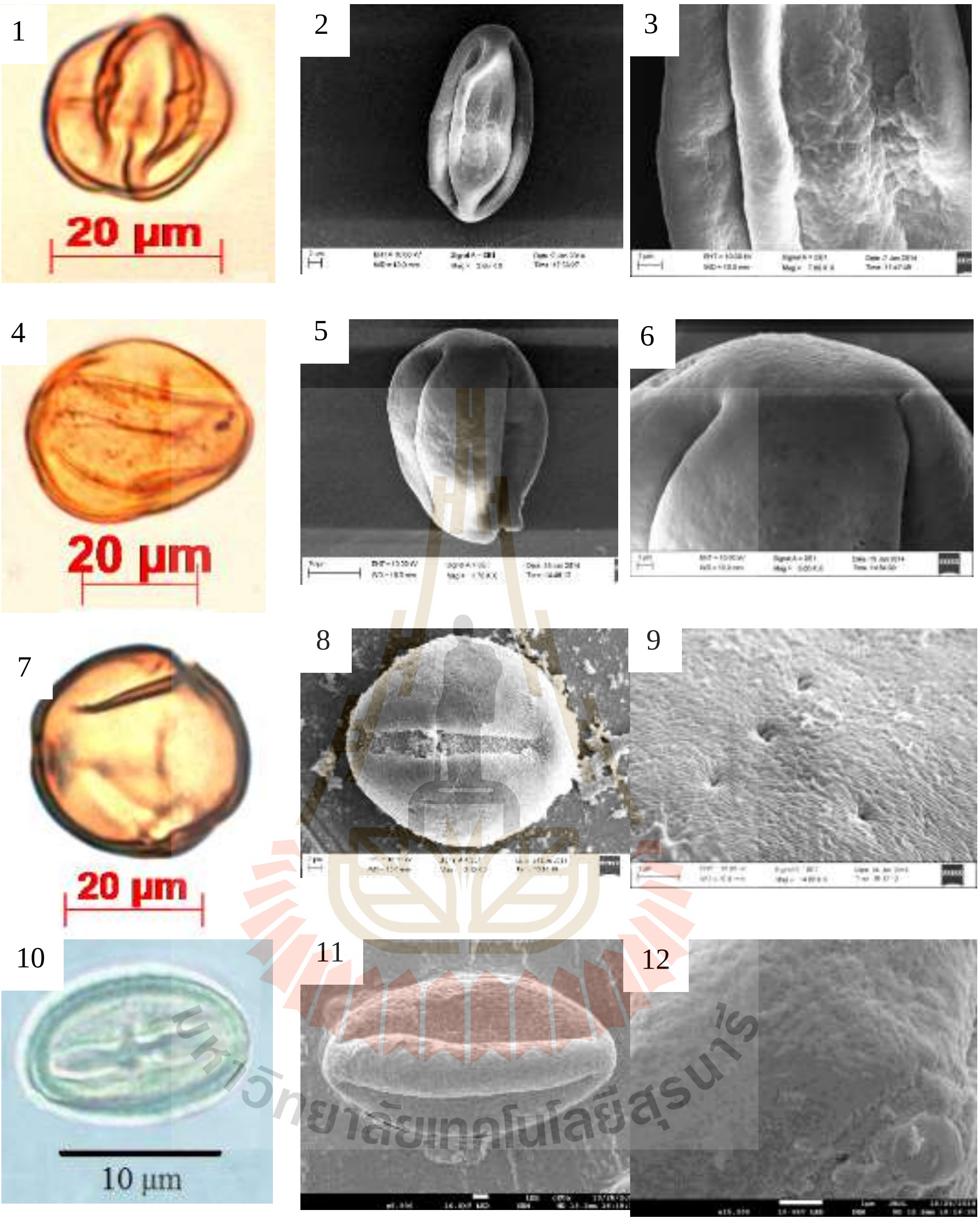

Plate 27 Fagaceae

Figure 1-3 *Castanopsis* sp 1. (LM, SEM, and SEM close-up)

Figure 4-6 *Castanopsis* sp 2. (LM, SEM, and SEM close-up)

Figure 7-9 *Castanopsis* sp 3. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Castanopsis armata* (LM, SEM, and SEM close-up)

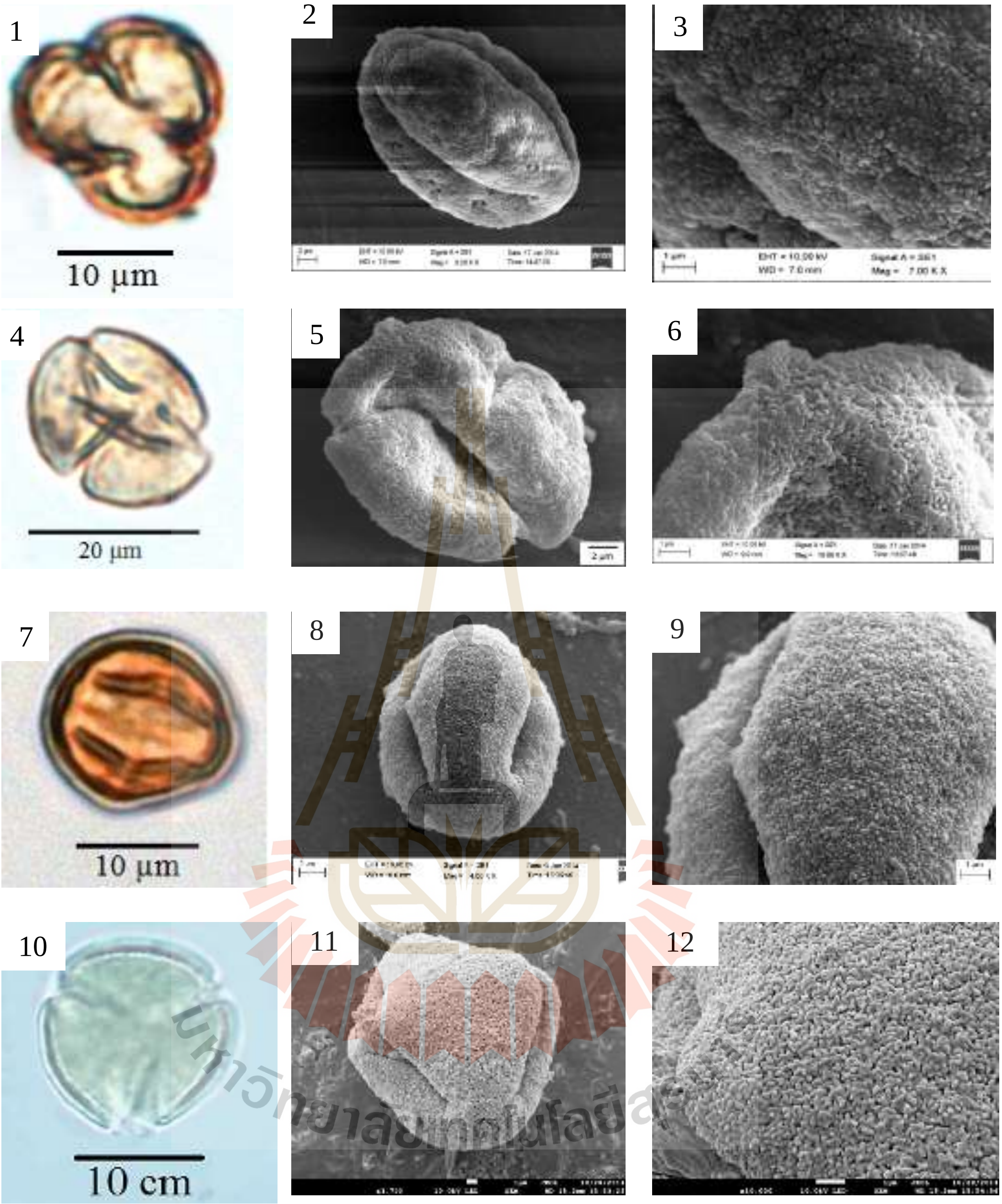

Plate 28 Fagaceae

Figure 1-3 *Quercus* sp 1. (LM, SEM, and SEM close-up)

Figure 4-6 *Quercus* sp 2. (LM, SEM, and SEM close-up)

Figure 7-9 *Quercus* sp 3. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Quercus mespilifolioides* (LM, SEM, and SEM close-up)

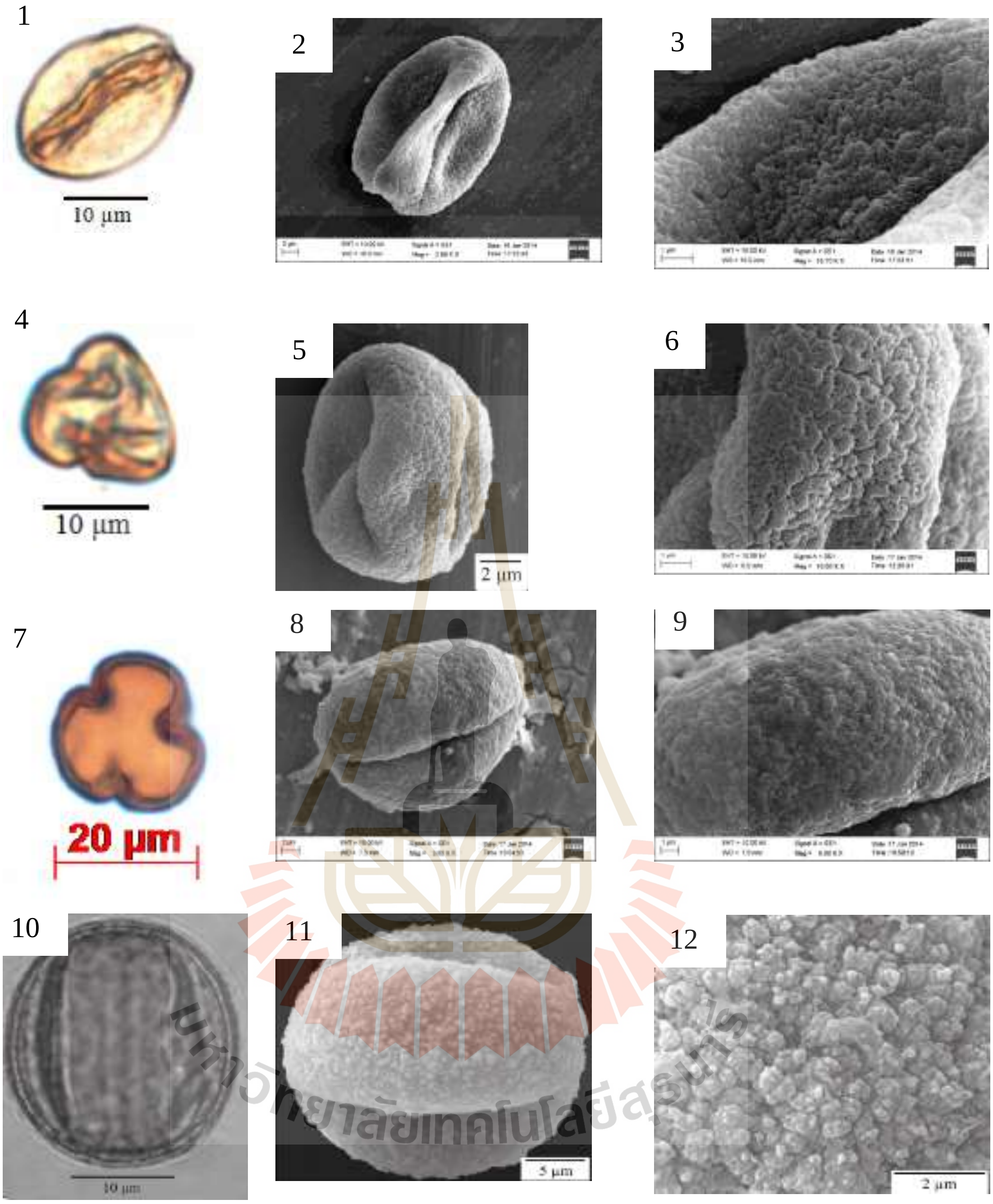

Plate 29 Fagaceae

Figure 1-3 *Quercus* sp 4. (LM, SEM, and SEM close-up)

Figure 4-6 *Quercus* sp 5. (LM, SEM, and SEM close-up)

Figure 7-9 *Quercus* sp 6. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Quercus infectoria* subsp. *boissieri* (LM, SEM, and SEM close-up, Panahi *et al*., 2012)

Gesneriaceae: About 133 genera and 3000 species, Africa, Central and South America, east and south Asia, south Europe, Oceania (Wang *et al*., 1998).

***Primulina*:** 1 species, endemic to China.

***Primulina* sp.** Plate 28, Figures 7-9

Shape: Oblate   Size: 18 µm

Aperture: Monocolporate   Sculpture: Perforate

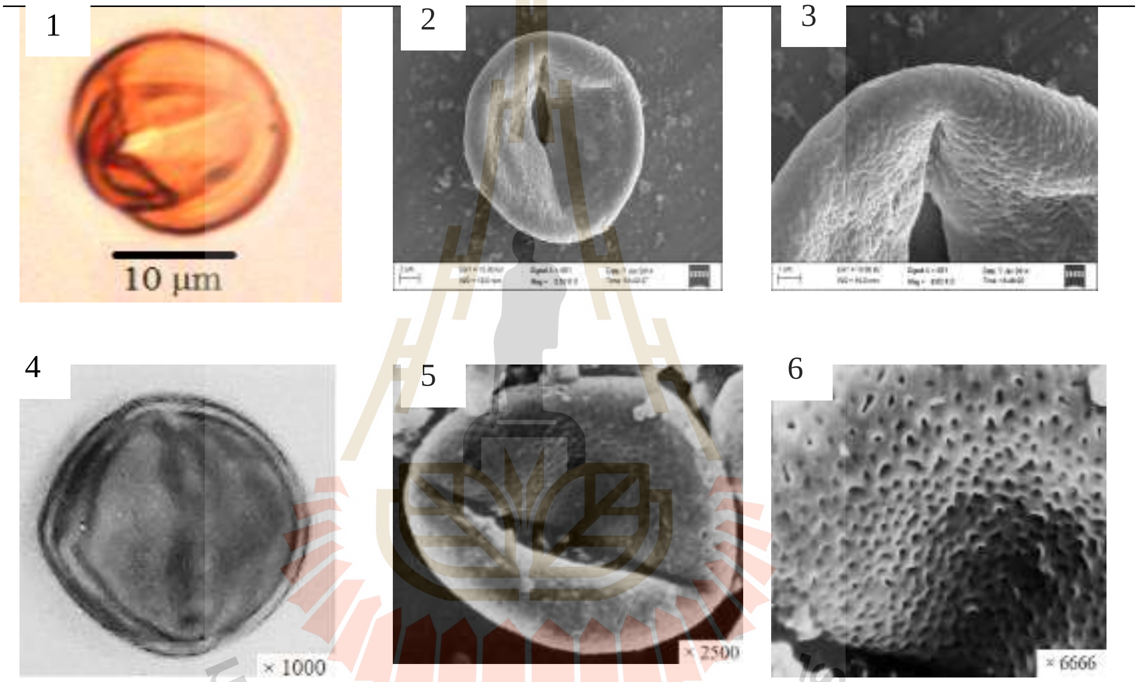

Plate 30 Gesneriaceae

Figure 1-3 *Primulina tabacum* (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Primulina tabacum*

(LM, SEM, and SEM close-up, Wang *et al*., 1995)

Lecythidaceae: About 20 genera and 450 species, tropical regions of Africa, Asia, Australia, some Pacific islands, and South America (Qin and Prance, 2007).

Barringtonia**:** About 56 species, East Africa to Australia, mainly in Asia**.**

Barringtonia acutangula**:** Coastal wetland. Plate 30, Figures 1-3

Shape:	Prolate	Size:	28×18 µm
Aperture:	Syntricolpate	Sculpture:	Polar area smooth, large reticulate to perforate (~3 µm lumen wide) along colpi becoming gradually smaller in the mesocolpium, colpus margin smooth. Distinct colpate margin

Barringtonia racemosa**:** Seashores, along tidal rivers, estuaries. Plate 30, Figures 7-9

Shape:	Prolate	Size:	26×17 µm
Aperture:	Syntricolpate	Sculpture:	Polar area smooth, large reticulate to perforate (~3 µm lumen wide) along colpi becoming gradually smaller in the mesocolpium, colpus margin smooth. Distinct colpate margin

Lythraceae: About 31 genera and 625-650 species, widespread in tropical regions, less common in temperate regions (Qin *et al*., 2007).

Lagerstroemia**:** About 55 species, tropical and subtropical Asia to Australia, north to Japan.

***Lagerstroemia* sp1.** Plate 31, Figures 1-3

Shape:	Oblate	Size:	25×23 µm
Aperture:	Tricolporate	Sculpture:	Fossulate

***Lagerstroemia* sp2.** Plate 31, Figures 4-6

Shape:	Oblate	Size:	27×24 µm
Aperture:	Tricolporate	Sculpture:	Fossulate

Lagerstroemia subcostata Plate 32, Figures 1-3

Shape:	Oblate	Size:	31×22 µm
Aperture:	Tricolporate with pseudocolpi formed as shallow grooves, clip longer than pseudocolpi	Sculpture:	Fossulate

***Woodfordia*:** 2 species, one in Africa and the Arabian Peninsula, one in Southeast Asia including China.

Woodfordia fruticosa Plate 32, Figures 7-9

Shape:	Prolate	Size:	36×22 µm
Aperture:	Tricolporate	Sculpture:	Psilate

Malvaceae (*sensu stricto*)**:** About 100 genera and ca. 1000 species, tropical and temperate regions of north and south hemisphere (Tang *et al*., 2007).

Malvaceae indeterminate 1 Plate 33, Figures 1-3

Shape:	Spheroidal	Size:	61-72 µm
Aperture:	Porate	Sculpture:	Echinate and reticulate

Malvaceae indeterminate 2 Plate 33, Figures 4-6

Shape:	Spheroidal	Size:	51-62 µm
Aperture:	Porate	Sculpture:	Echinate

Malvaceae indeterminate 3 Plate 33, Figures 7-9

Shape:	Spheroidal	Size:	51-58 µm
Aperture:	Porate	Sculpture:	Echinate

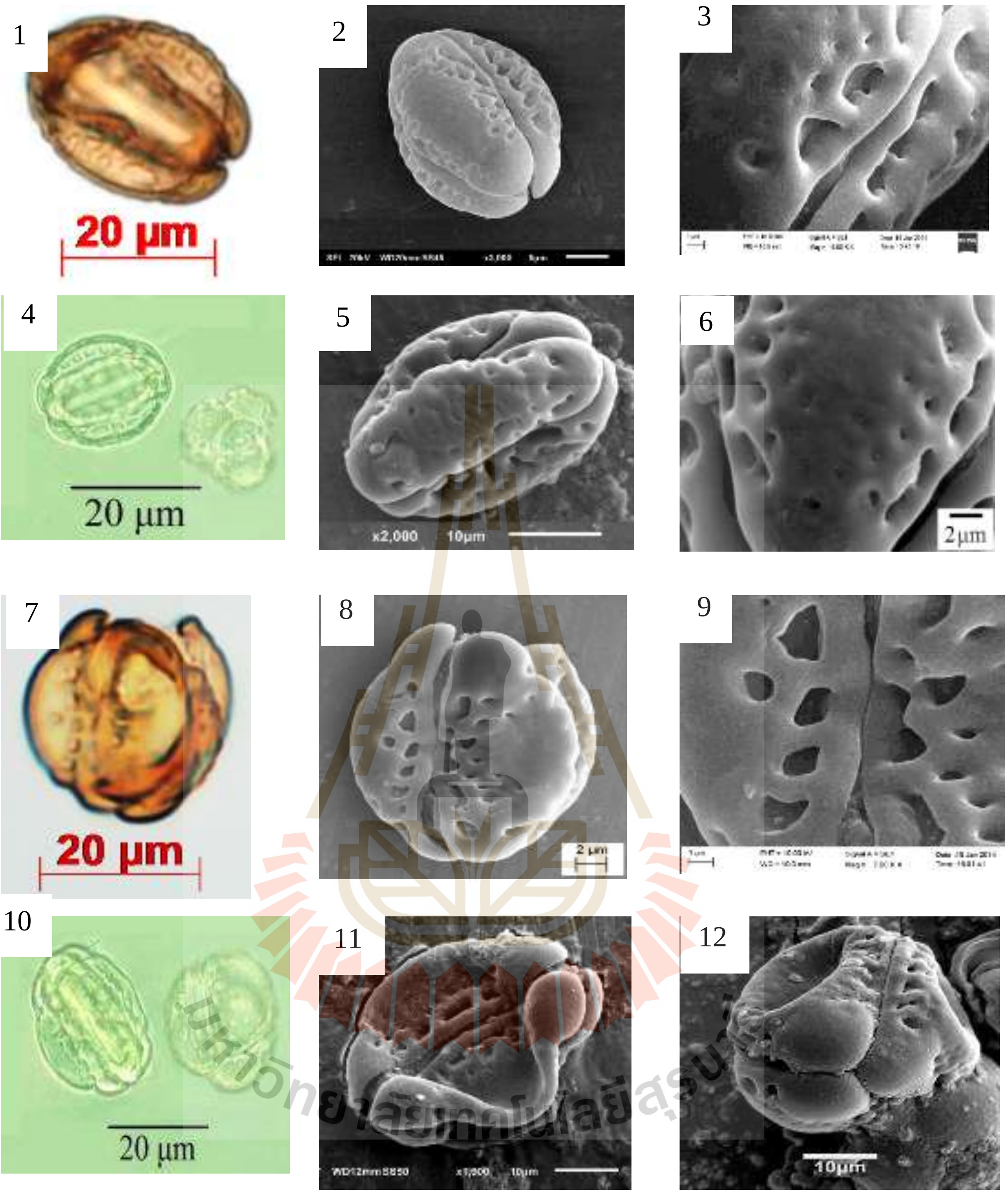

Plate 31 Lecythidaceae

Figure 1-3 *Barringtonia actangula* (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Barringtonia actangula* (LM, SEM, and SEM close-up)

Figure 7-9 *Barringtonia racemosa* (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Barringtonia racemosa* (SEM, and SEM close-up)

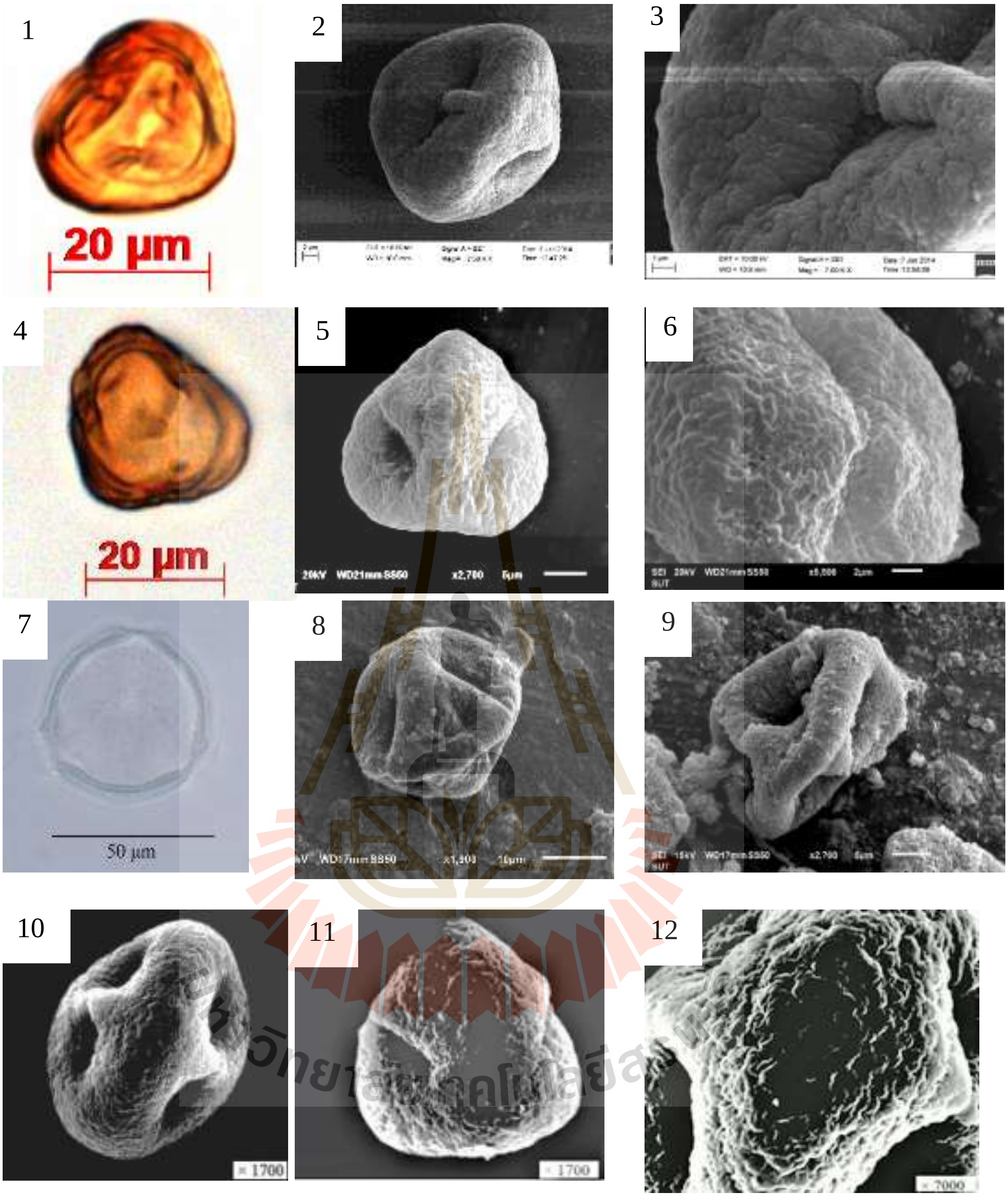

Plate 32 Lythraceae

Figure 1-3 *Lagerstroemia* sp1. (LM, SEM, and SEM close-up)

Figure 4-6 *Lagerstroemia* sp2. (LM, SEM, and SEM close-up)

Figure 7-9 Modern reference *Lagerstroemia racemosa* (LM and SEM)

Figure 10-12 Modern reference *Lagerstroemia balansae* (SEM and SEM close-up, Li *et al*., 2008)

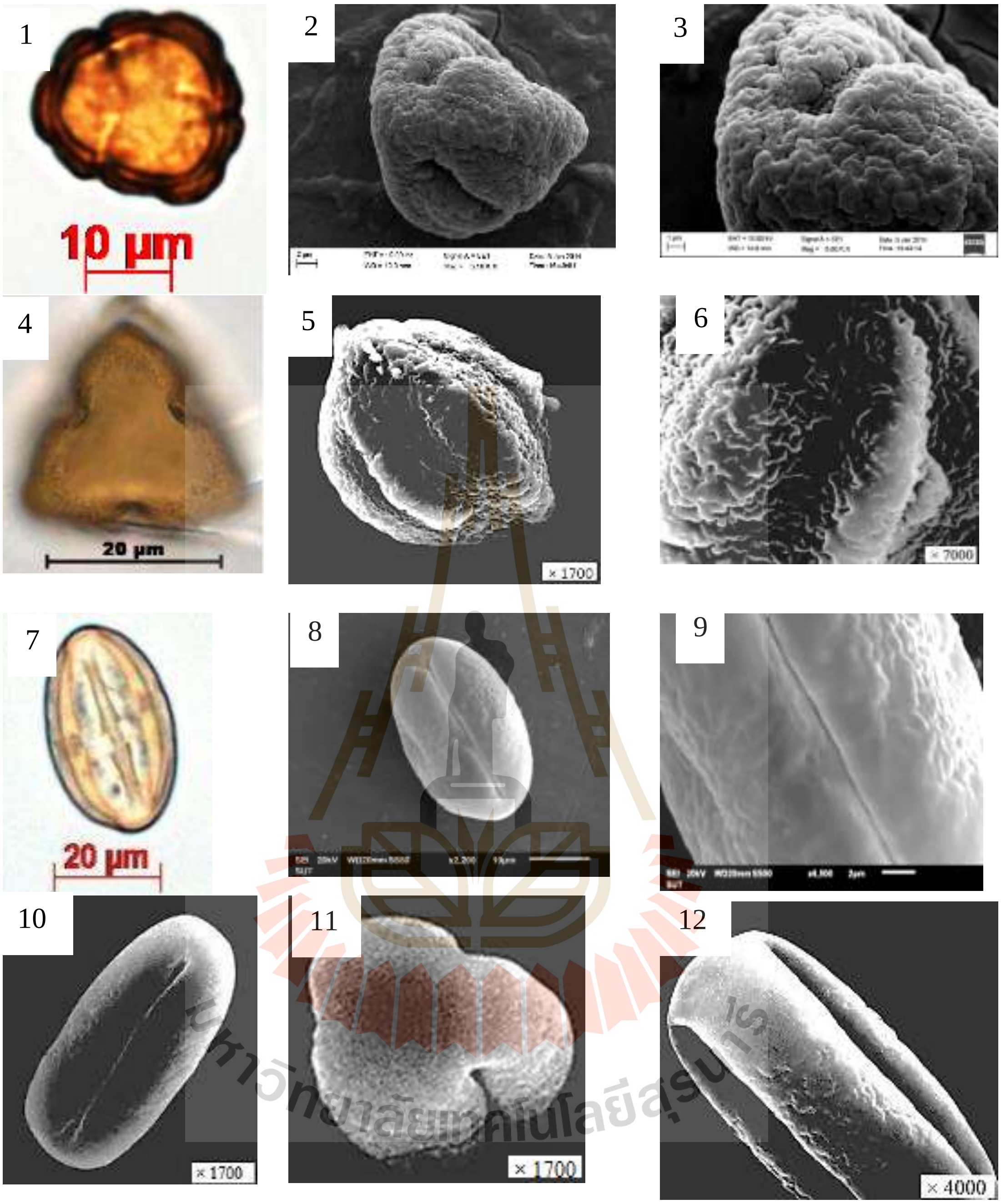

Plate 33 Lythraceae

Figure 1-3	*Lagerstroemia subcostata* (LM, SEM, and SEM close-up)
Figure 4-6	Modern reference *Lagerstroemia subcostata* (LM, APSA, 2014; SEM and SEM close-up, Li *et al*., 2008)
Figure 7-9	*Woodfordia fruticosa* (LM, SEM, and SEM close-up)
Figure 10-12	Modern reference *Woodfordia fruticosa* (SEM, and SEM close-up, Li *et al*., 2008)

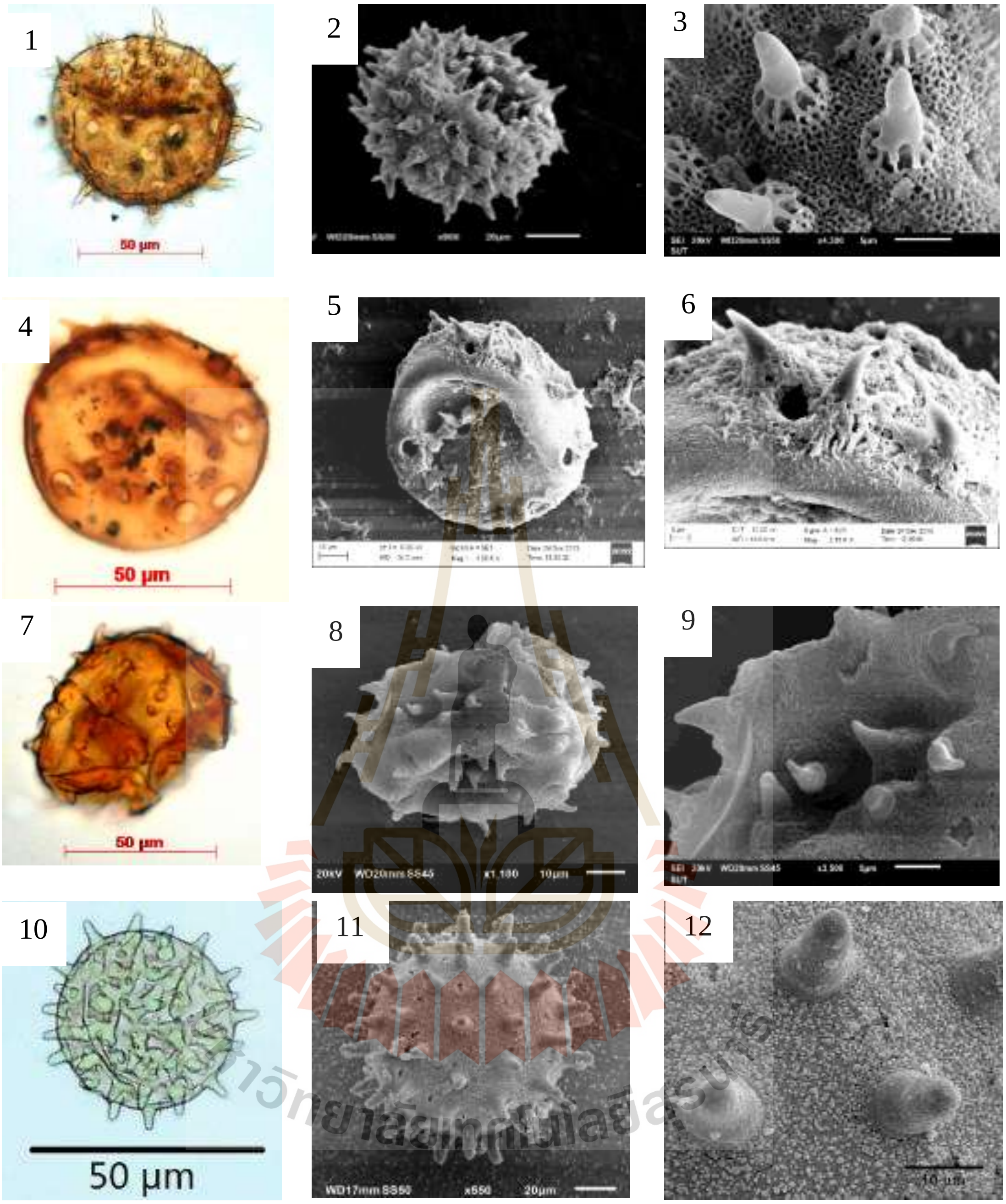

Plate 34 Malvaceae (*sensu stricto*)

Figure 1-3 Malvaceae indeterminate 1 (LM, SEM, and SEM close-up)

Figure 4-6 Malvaceae indeterminate 2 (LM, SEM, and SEM close-up)

Figure 7-9 Malvaceae indeterminate 3 (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Hibiscus rosa-sinensis* (LM, SEM, and SEM close-up)

Meliaceae: About 50 genera and 650 species, tropical, subtropical, and occasionally warm temperate regions of both hemispheres (Peng *et al*., 2008)

***Melia*:** 3 species, south tropical Africa, tropical to temperate Asia.

***Melia* sp.** Plate 34, Figures 1-3

Shape:	Prolate	Size:	21×16 µm
Aperture:	Tetracolporate	Sculpture:	Perforate

Moraceae: Between 37 and 43 genera and 1100–1400 species, widespread in tropical and subtropical areas, less common in temperate areas (Wu, Zhou, and Gilbert, 2003).

***Artocarpus*:** 4 species, East Asia, Pacific Islands.

***Artocarpus* sp.** Plate 27, Figures 7-9

Shape:	Spheroidal	Size:	17 µm
Aperture:	Diporate (Li *et al*., 2008)	Sculpture:	Microechinate

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Oleaceae: About 28 genera and over 400 species, tropical, subtropical, and temperate regions of world, but mainly in Asia (Chang *et al*., 2005).

***Syringa*:** About 20 species, Afghanistan, India, Japan, Kashmir, Korea, Nepal, Pakistan, Sikkim; southwest Asia, southeast Europe**.**

***Syringa* sp.** Plate 35, Figures 1-3

Shape:	Spheroidal	Size:	17 µm
Aperture:	Tricolporate	Sculpture:	Reticulate

Poaceae: About 700 genera and 11,000 species, widely distributed in all regions of the world (Chen *et al*., 2006).

Poaceae indeterminate 1 Plate 35, Figures 7-9

Shape:	Spheroidal	Size:	23-32 μm
Aperture:	Monoporate, annulate	Sculpture:	Fossulate with microgranulate

---

Rhizophoraceae: About 17 genera and 120 species, tropics and subtropics **(**Qin and Boufford, 2007).

Rhizophoraceae indeterminate Plate 36, Figures 1-3

Shape:	Oblate	Size:	32-36 μm
Aperture:	Tricolporate	Sculpture:	Striato-reticulate

Rosaceae: Between 95 and 125 genera and 2825-3500 species: cosmopolitan, mostly in N temperate zone (Gu *et al*., 2003).

Prunus**:** About 30 species: Asia, Europe, And North America.

***Prunus* sp.** Plate 36, Figures 7-9

Shape:	Oblate	Size:	28 μm
Aperture:	Tricolporate	Sculpture:	Rugulate

Rubiaceae: About 660 genera and 11,150 species: cosmopolitan family, with most genera and species in humid tropical regions (Chen *et al*., 2013).

Canthium**:** About 30 species: tropical and subtropical Africa and Asia.

***Canthium* sp.** Plate 37, Figures 1-3

Shape:	Oblate	Size:	39-41 μm
Aperture:	Triporate	Sculpture:	perforate

Rutaceae: About 155 genera and ca. 1600 species, nearly cosmopolitan but mainly tropical and subtropical (Zhang *et al*., 2008).

Acronychia**:** About 48 species, south and southeast Asia, Australia, southwest Pacific islands.

***Acronychia* sp.** Plate 37, Figures 7-9

Shape:	Prolate	Size:	16×12 µm
Aperture:	Tricolporate	Sculpture:	Striato-reticulate

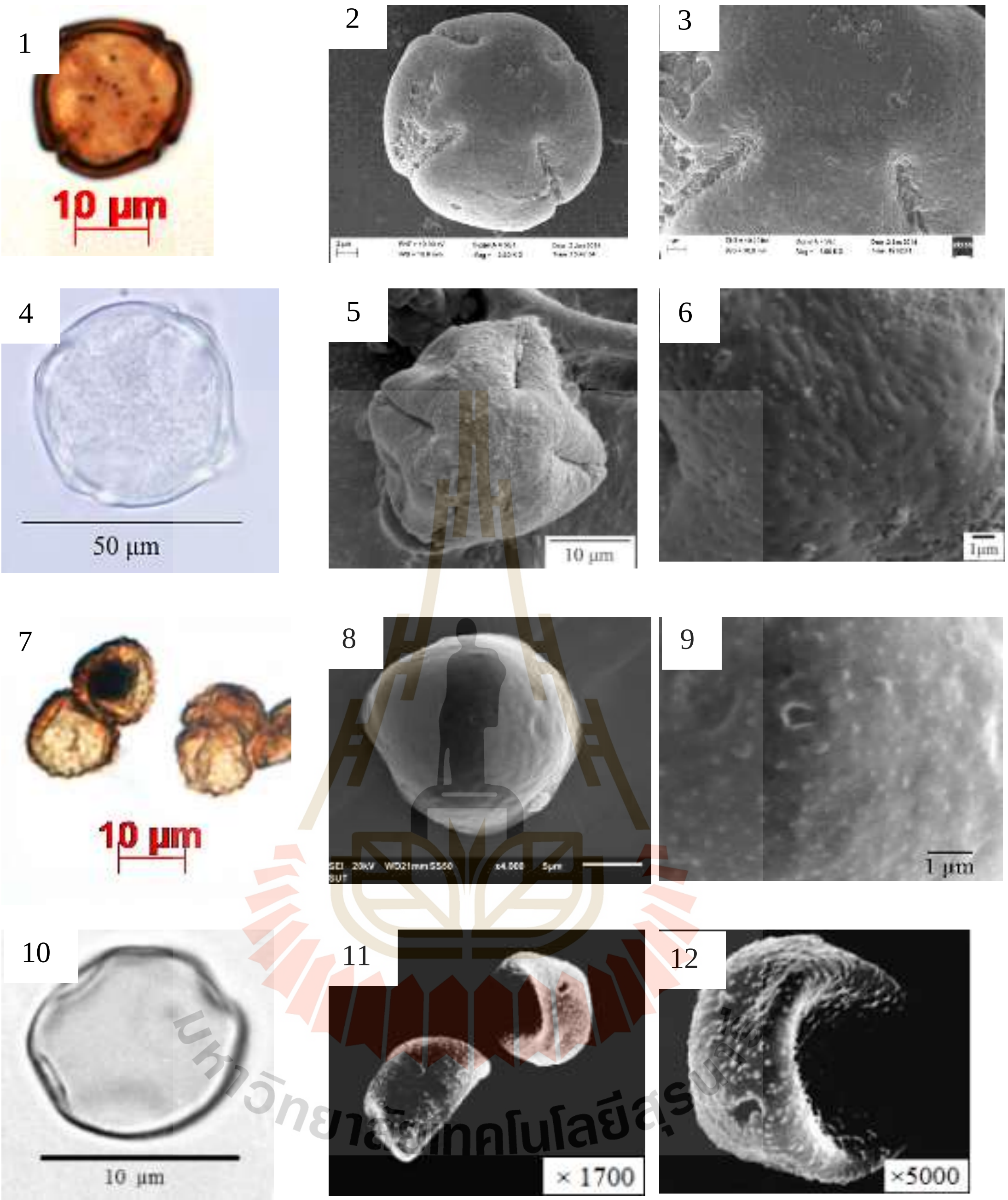

Plate 35 Meliaceae and Moraceae

Figure 1-3 *Melia* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Melia azedarach* (LM, SEM, and SEM close-up)

Figure 7-9 *Artocarpus* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Artocarpus heterophyllus* (LM, Martin, 1969; SEM, Li *et al*., 2008)

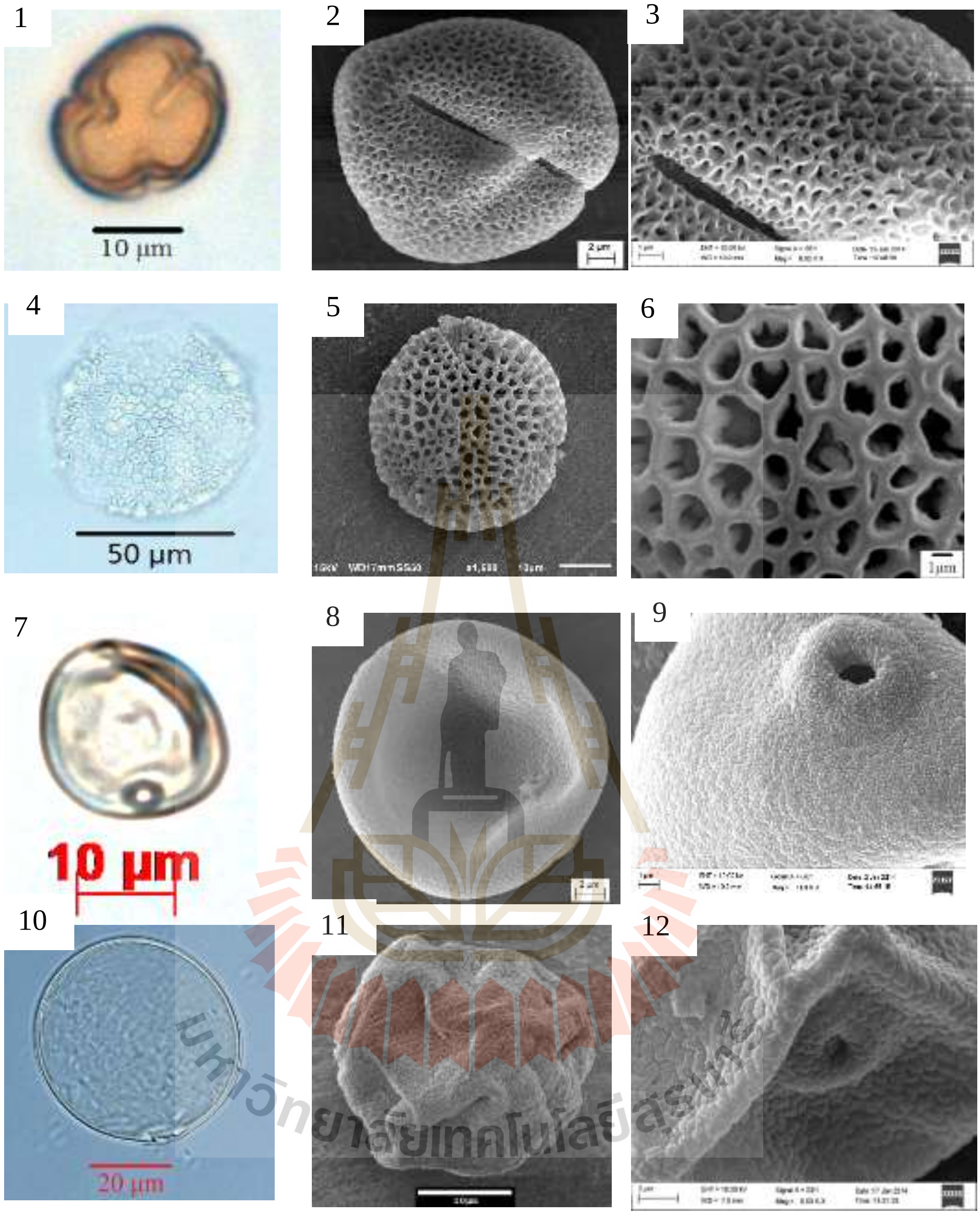

Plate 36 Oleaceae and Poaceae

Figure 1-3 *Syringa* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Syringa microphylla* (LM, SEM and SEM close-up)

Figure 7-9 Poaceae indeterminate (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Bambusa* sp. (LM, SEM, and SEM close-up)

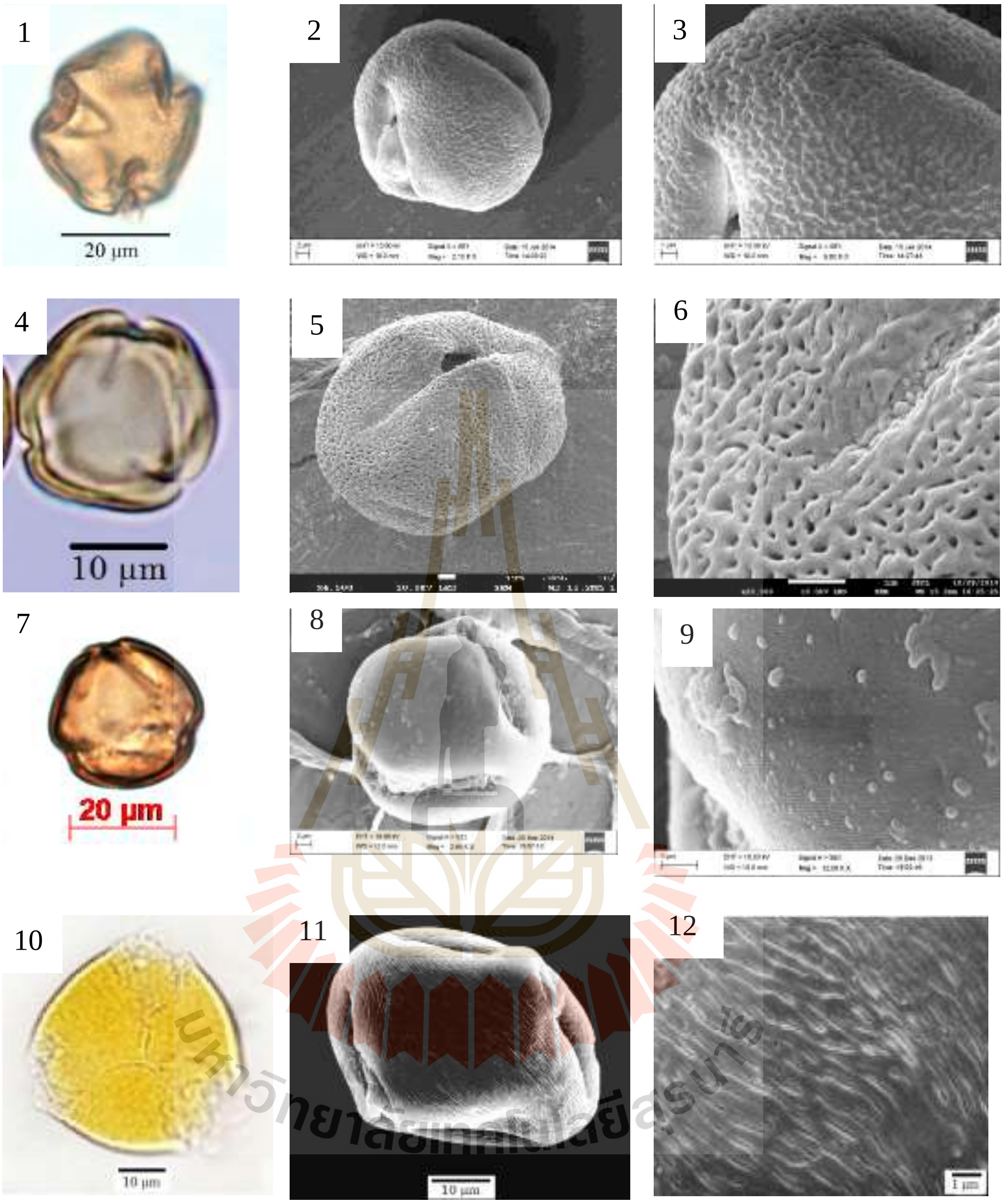

Plate 37 Rhizophoraceae and Rosaceae

Figure 1-3 Rhizophoraceae indeterminate (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Rhizophora apiculata* (LM, SEM and SEM close-up)

Figure 7-9 *Prunus* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Prunus tenella* (LM, APSA, 2014; SEM and SEM close-up, Paldat, 2014)

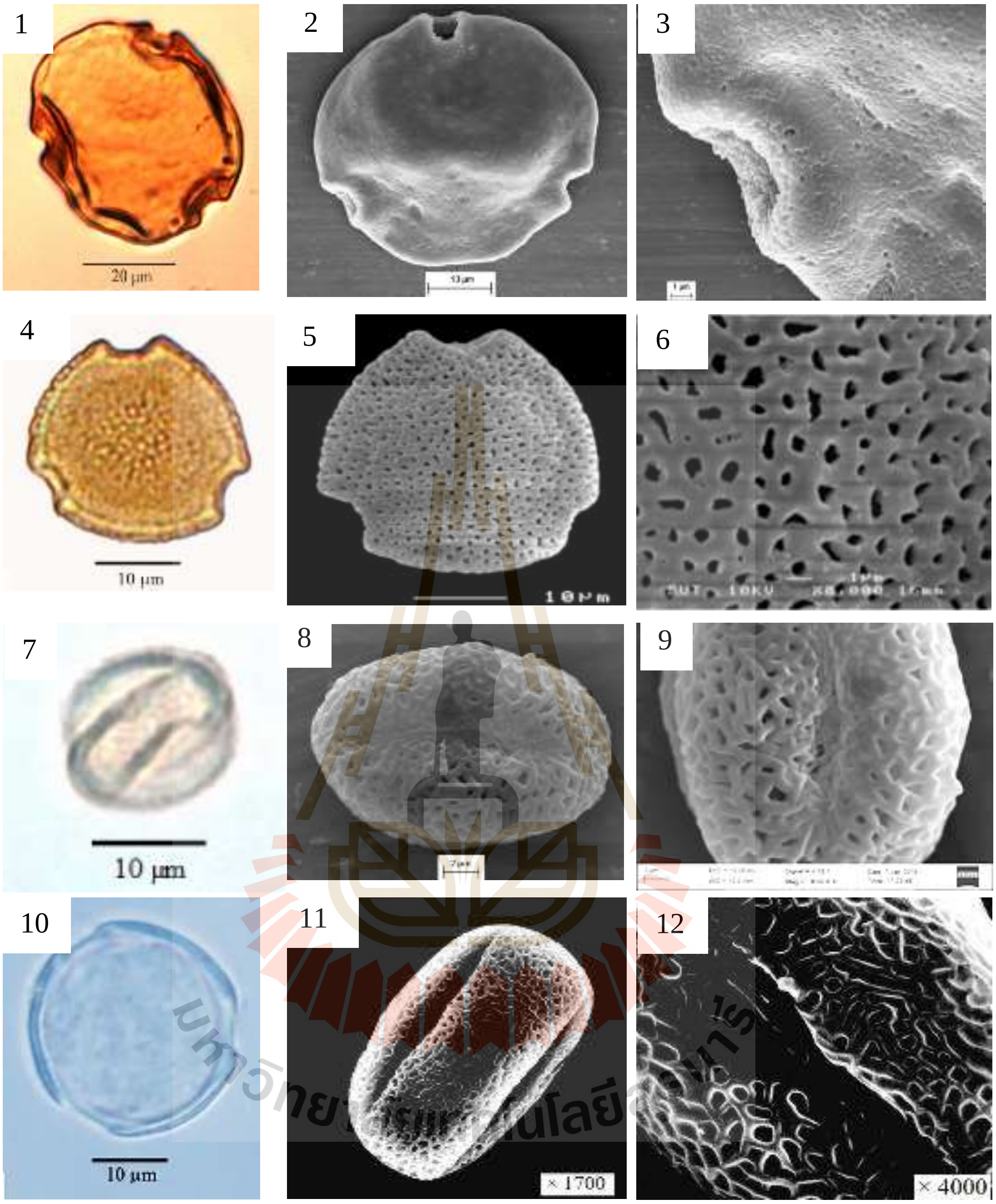

Plate 38 Rubiaceae and Rutaceae

Figure 1-3 *Canthium* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Canthium glabrum* (LM; SEM and SEM close-up, Rugmai, 2006)

Figure 7-9 *Acronychia* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Acronychia pedunculata* (LM; SEM and SEM close-up, Li *et al*., 2008)

Sterculiaceae: About 68 genera and ca. 1100 species: tropics and subtropics of both hemispheres, a few in temperate regions (Tang *et al*., 2007).

***Pterospermum*:** Between 18 and 40 species: tropical and subtropical Asia.

***Pterospermum* sp.** Plate 38, Figures 1-3

Shape:	Spheridol	Size:	30 µm
Aperture:	Triporate	Sculpture:	Baculate

Symplocaceae: 1 genus and 200 species: widely distributed in tropics and subtropics of Asia, Australia, and America (Wu and Nooteboom, 2005).

***Symplocos*:** Same to family.

***Symplocos* sp.** Plate 38, Figures 7-9

Shape:	Oblate	Size:	17-21 µm
Aperture:	Triporate	Sculpture:	Fossulate

Theaceae: About 19 genera and 600 species: tropical and subtropical Africa, tropical America, east, south, and southeast Asia, southeast North America, Pacific islands (Min and Bartholomew, 2007).

***Camellia*:** About 120 species: Bhutan, Cambodia, China, northeast India, Indonesia, south Japan, south Korea, Laos, Malaysia, Myanmar, Nepal, Philippines, Thailand, Vietnam.

***Camellia* sp.** Plate 40, Figures 1-3

Shape:	Prolate	Size:	30×16 µm
Aperture:	Tricolporate	Sculpture:	Perforate

Tiliaceae (*sensu stricto*)**:** About 52 genera and ca. 500 species, primarily in tropical and subtropical areas (Tang *et al*., 2007)

***Grewia*:** About 90 species: tropical regions of Old World.

***Grewia* sp.** Plate 39, Figures 1-3

Shape:	Prolate	Size:	23×16 µm
Aperture:	tricolporate	Sculpture:	Microreticulate

Verbenaceae: About 91 genera and ca. 2000 species: primarily tropical and subtropical (Chen and Gilbert, 1994).

***Avicennia*:** About 14 species: maritime in tropics and subtropics of both hemispheres.

***Avicennia* sp.** Plate 41, Figures 1-3

Shape:	Oblate	Size:	20×16 µm
Aperture:	Tricolporate	Sculpture:	Reticulate

***Clerodendrum*:** About 400 species: mostly tropical and subtropical, few in temperate Asia, Africa, and America.

***Clerodendrum* sp.** Plate 41, Figures 7-9

Shape:	Prolate	Size:	30×16 µm
Aperture:	Tricolpate	Sculpture:	Echinate

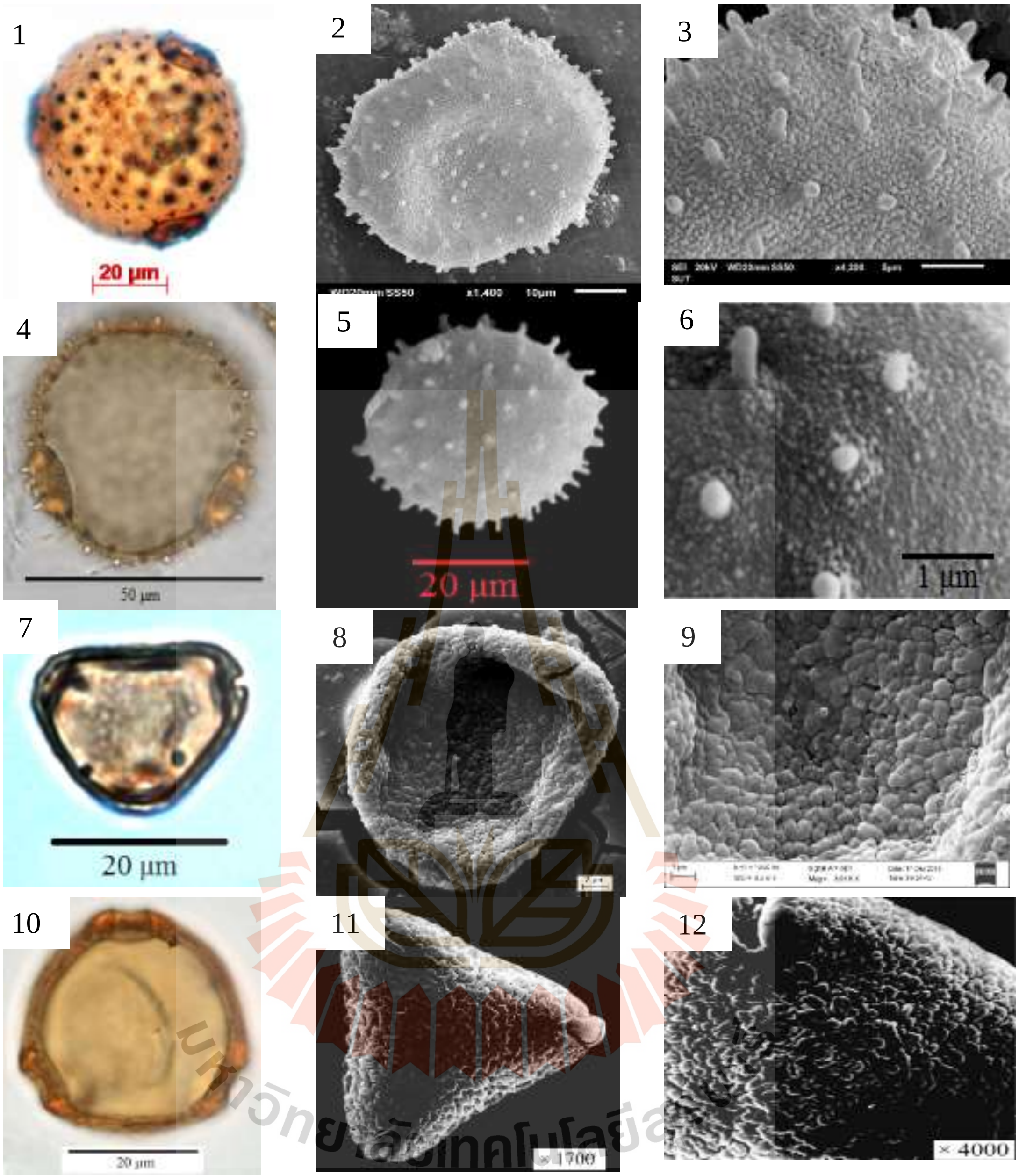

Plate 39 Sterculiaceae and Symplocaceae

Figure 1-3 *Pterospermum* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Pterospermum acerifolium* (LM, APSA, 2014; SEM and SEM close-up, Hamdy and Shamso, 2010)

Figure 7-9 *Symplocos* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Symplocos caudata* (LM, APSA, 2014; SEM and SEM close-up, Li *et al.*, 2008)

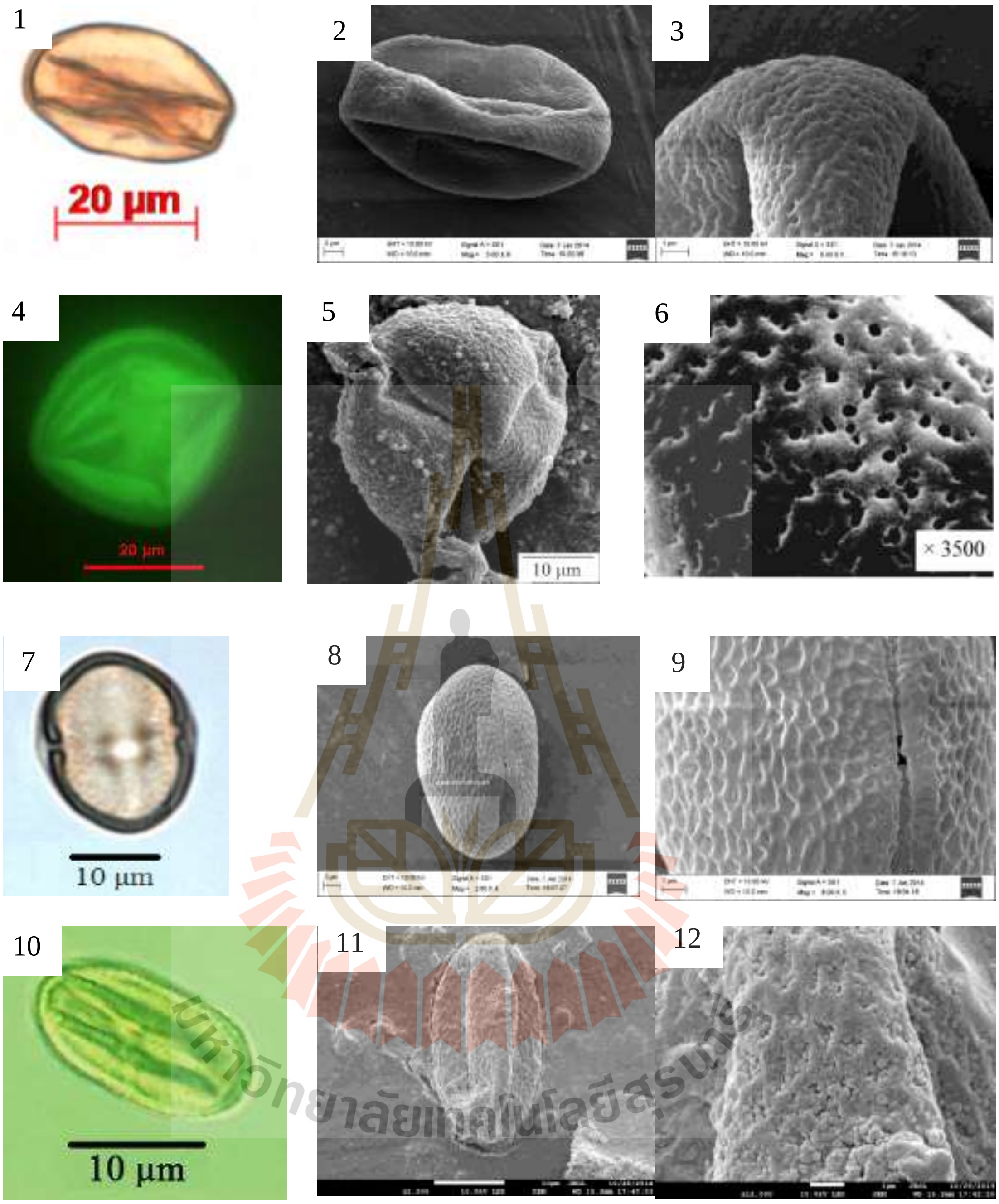

Plate 40 Theaceae and Tiliaceae

Figure 1-3 *Camellia* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Camellia compressa* (LM, SEM, and SEM close-up)

Figure 7-9 *Grewia* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Grewia eriocarpa* (LM, SEM, and SEM close-up)

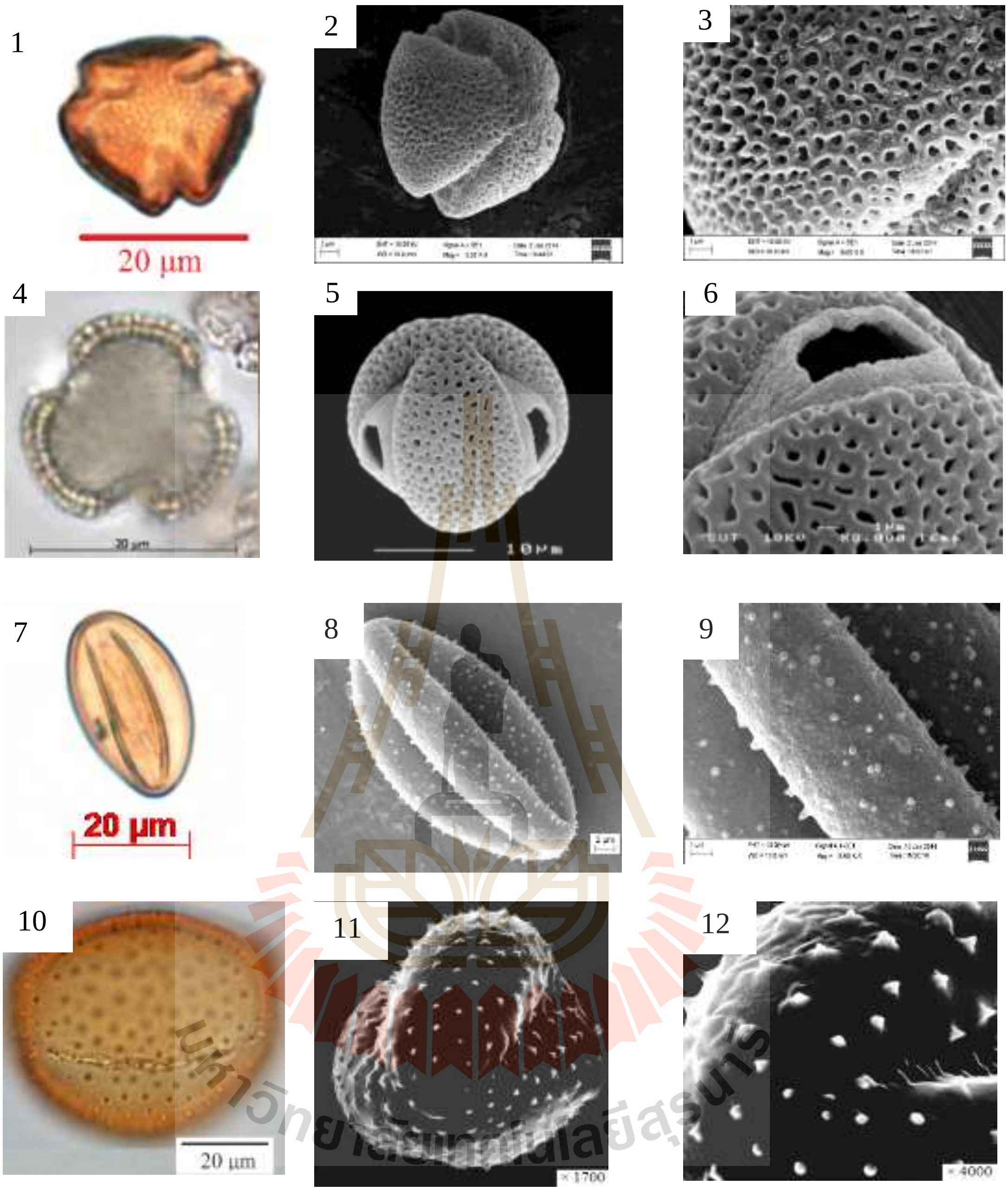

Plate 41 Verbenaceae

Figure 1-3 *Avicennia* sp. (LM, SEM, and SEM close-up)

Figure 4-6 Modern reference *Avicennia marina* and *A. tomentosum* (LM, APSA, 2014; SEM, and SEM close-up, Rugmai, 2006)

Figure 7-9 *Clerodendrum* sp. (LM, SEM, and SEM close-up)

Figure 10-12 Modern reference *Clerodendrum trichotomum* (LM, APSA, 2014; SEM and SEM close-up, Li *et al.*, 2008)

5.5 Fungi

There were 8 fungal spores in 7 genera recognized from the sediments, 2 species were known as parasites in plants or animals (*Leptosphaeria* sp. and *Nigrospora* sp.) (Lumbsch and Huhndorf, 2007; Mason, 1927). Other 6 species were published as fossil genera, *Dictyosporites* sp1., *Dictyosporites* sp2., *Fusiformisporites* sp., *Hilidicellites* sp., *Hypoxylonites* sp., and *Inapertisporites* sp. (Jansonius and Kalgutkar, 2000) (Plate 42 and 43).

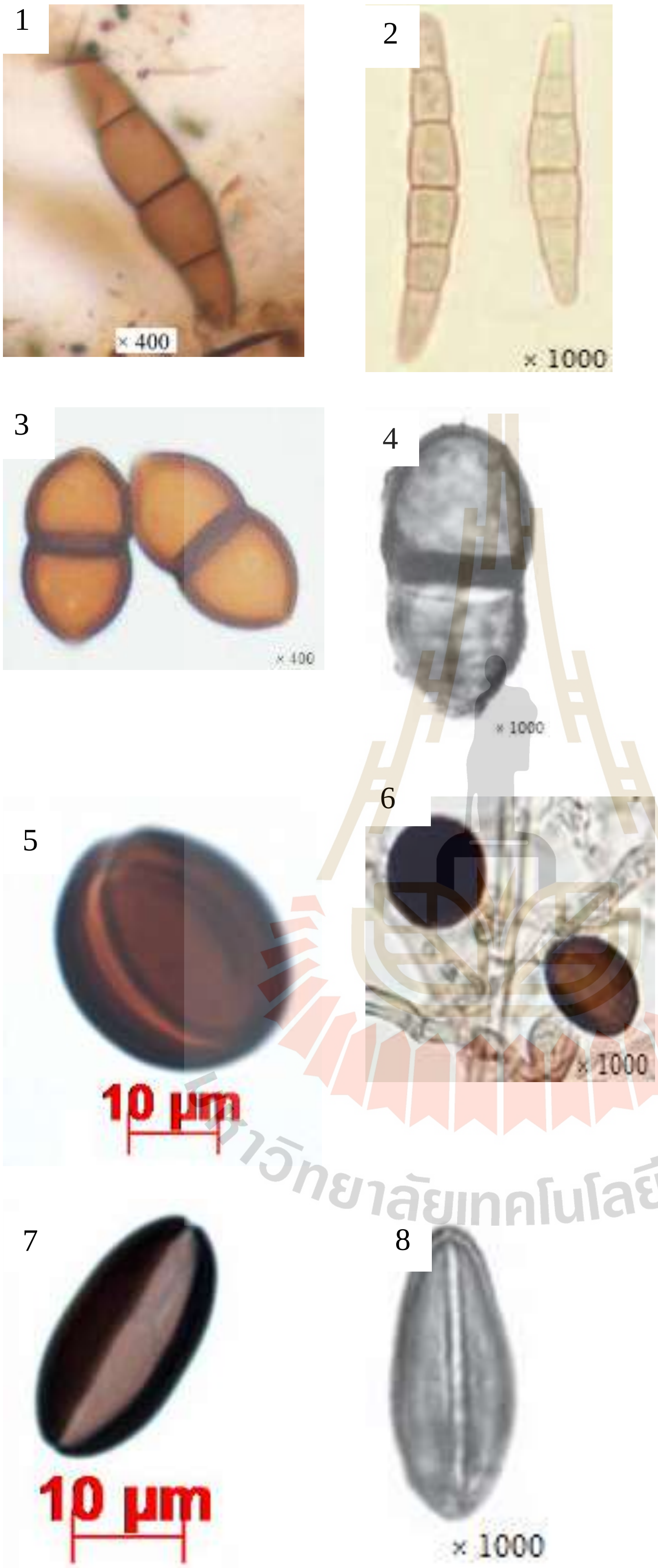

Figure 1 Phylum scomycota *Leptosphaeria* sp.

Figure 2 Reference spores of *Leptosphaeria* sp. (Levetin, 2014)

Figure 3 Phylum Ascomycota *Hilidicellites* sp.

Figure 4 Reference spores of Hilidicellites *teleutosporoides* (Jansonius and Kalgutkar, 2000)

Figure 5 Phylum Ascomycota *Nigrospora* sp.

Figure 6 Reference spores of *Nigrospora* sp. (Levetin, 2014)

Figure 7 Phylum Ascomycota *Hypoxylonites* sp.

Figure 8 Reference spores of *Hypoxylonites xylarioides* (Jansonius and Kalgutkar, 2000)

Plate 42 Fungal spores

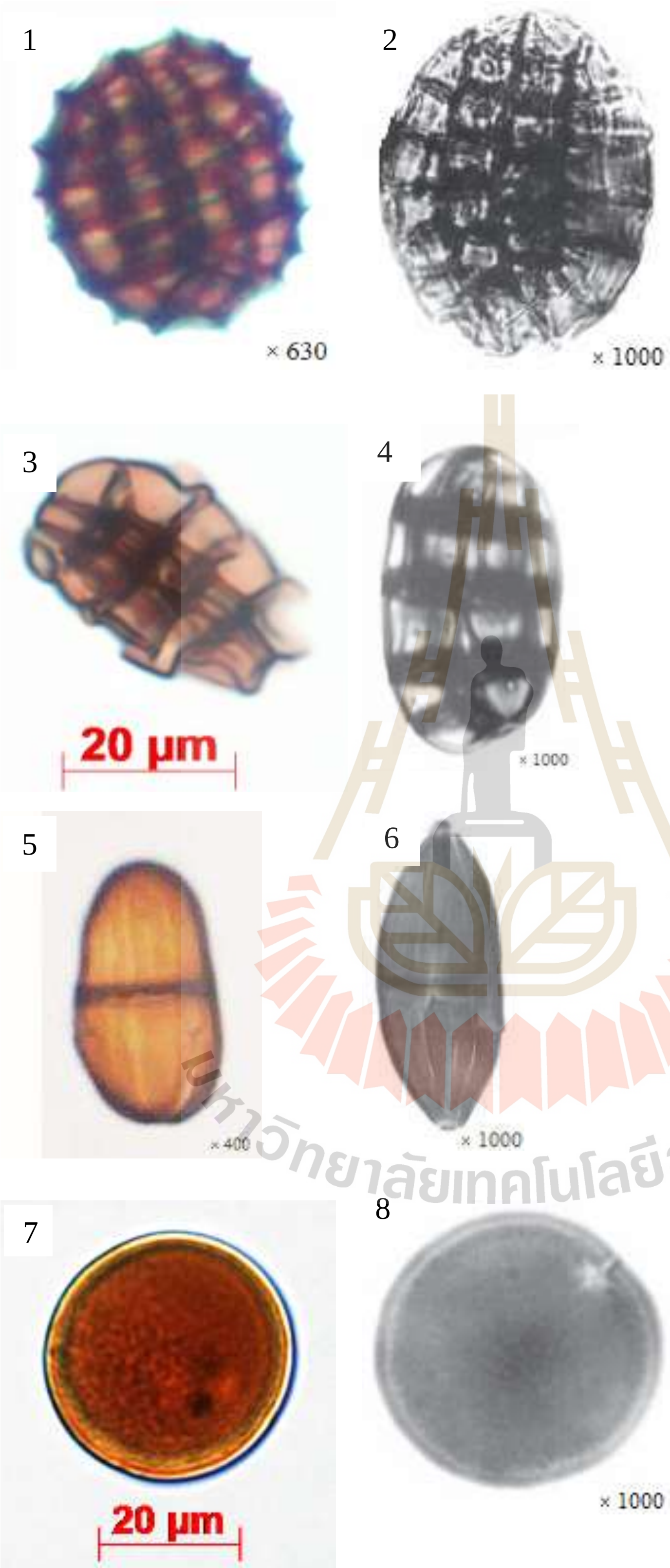

Figure 1 *Dictyosporites* sp1.
Figure 2 Reference spores of *Dictyosporites morularis* (Jansonius and Kalgutkar, 2000)

Figure 3 *Dictyosporites* sp2.
Figure 4 Reference spores of *Dictyosporites ovoideus* (Jansonius and Kalgutkar, 2000)

Figure 5 *Fusiformisporites* sp.
Figure 6 Reference spores of *Fusiformisporites lineatus* (Jansonius and Kalgutkar, 2000)

Figure 7 *Inapertisporites* sp.
Figure 8 Reference spores of *Inapertisporites clarkei* (Jansonius and Kalgutkar, 2000)

Plate 43 Fungal spores

5.6 Unknown taxa

There are more than 34 pollen and spores that are difficult to be identified, including angiosperm 11 taxa, fern 2 taxa, algae 8 taxa, and fungi 13 taxa (Plate 44-51).

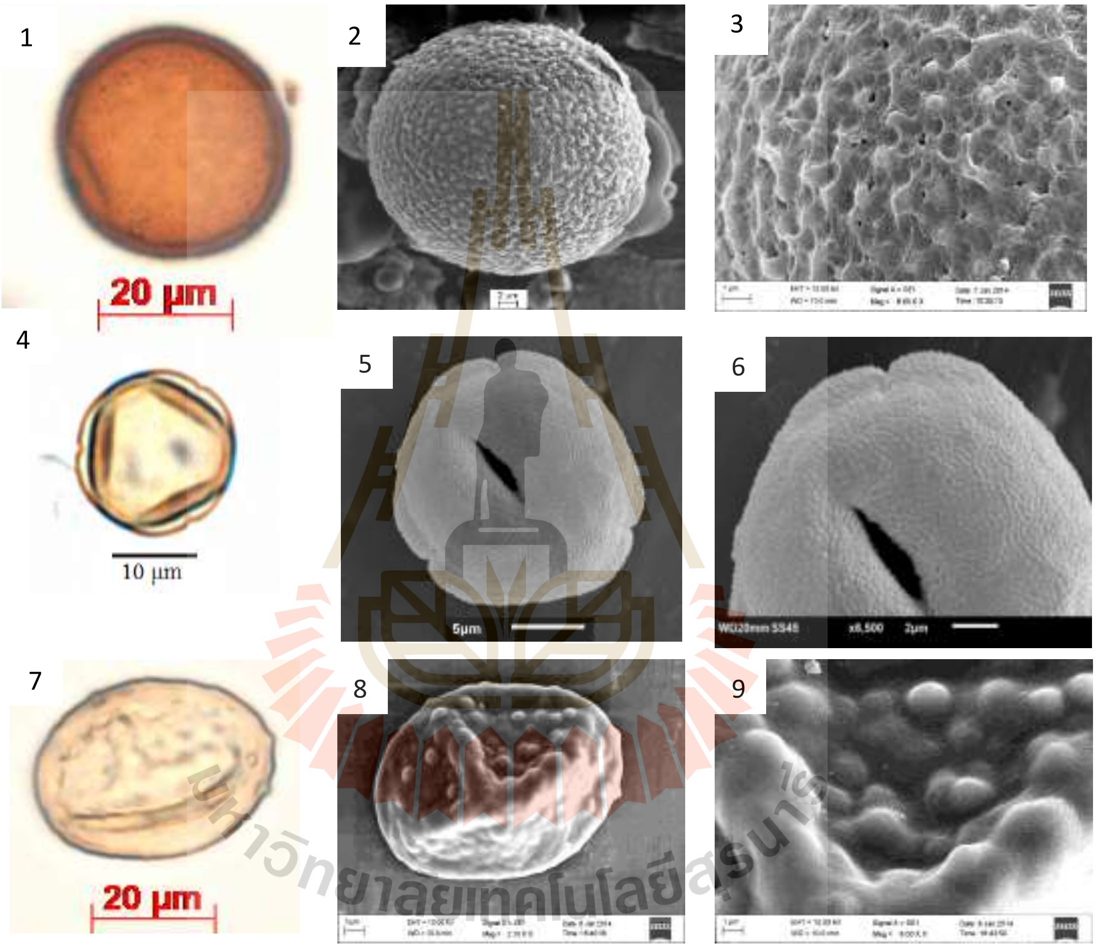

Plate 44 Unknown (Figures 1-3 Angiosperm I; Figures 4-9 Fern)

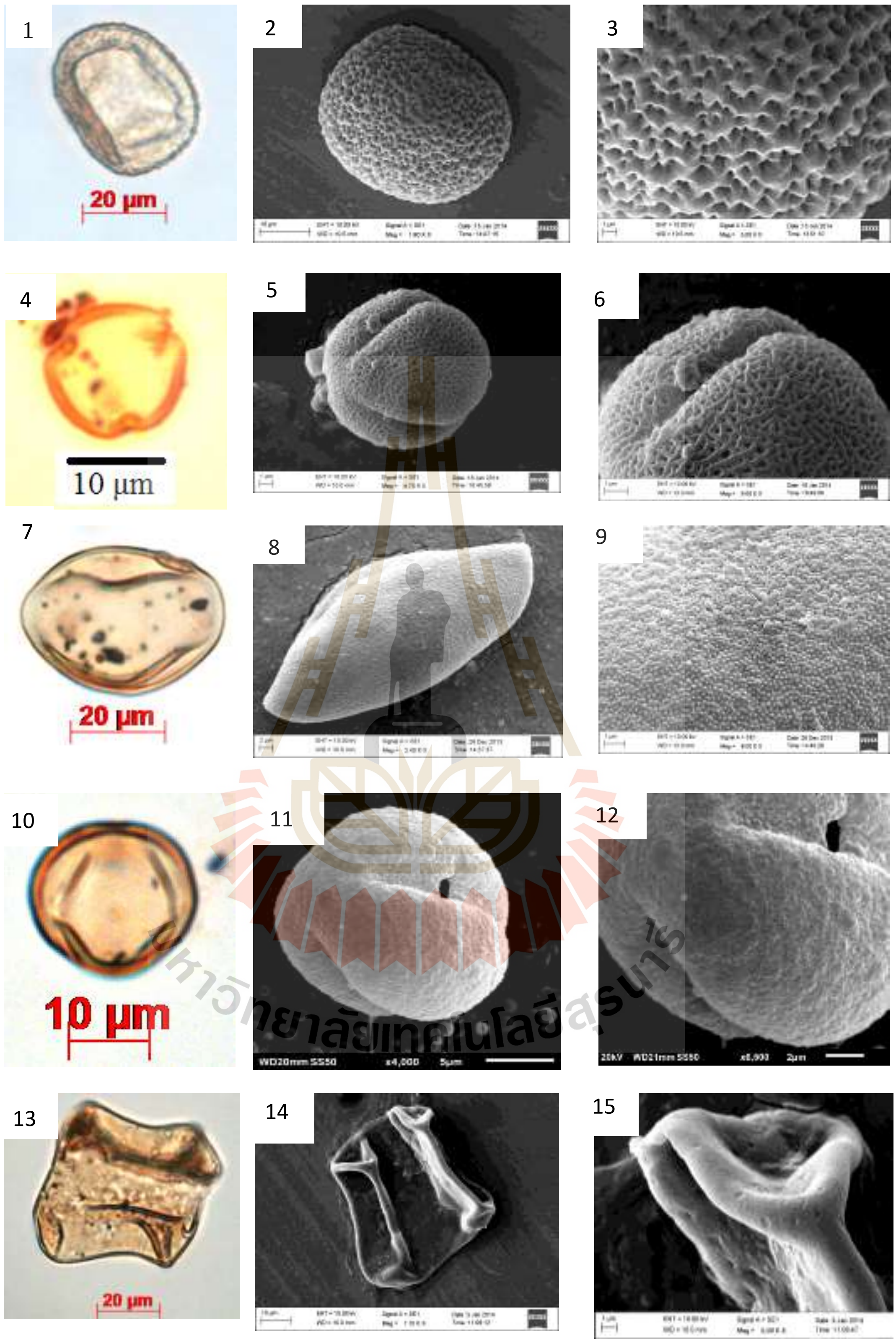

Plate 45 Unknown (Angiosperm II)

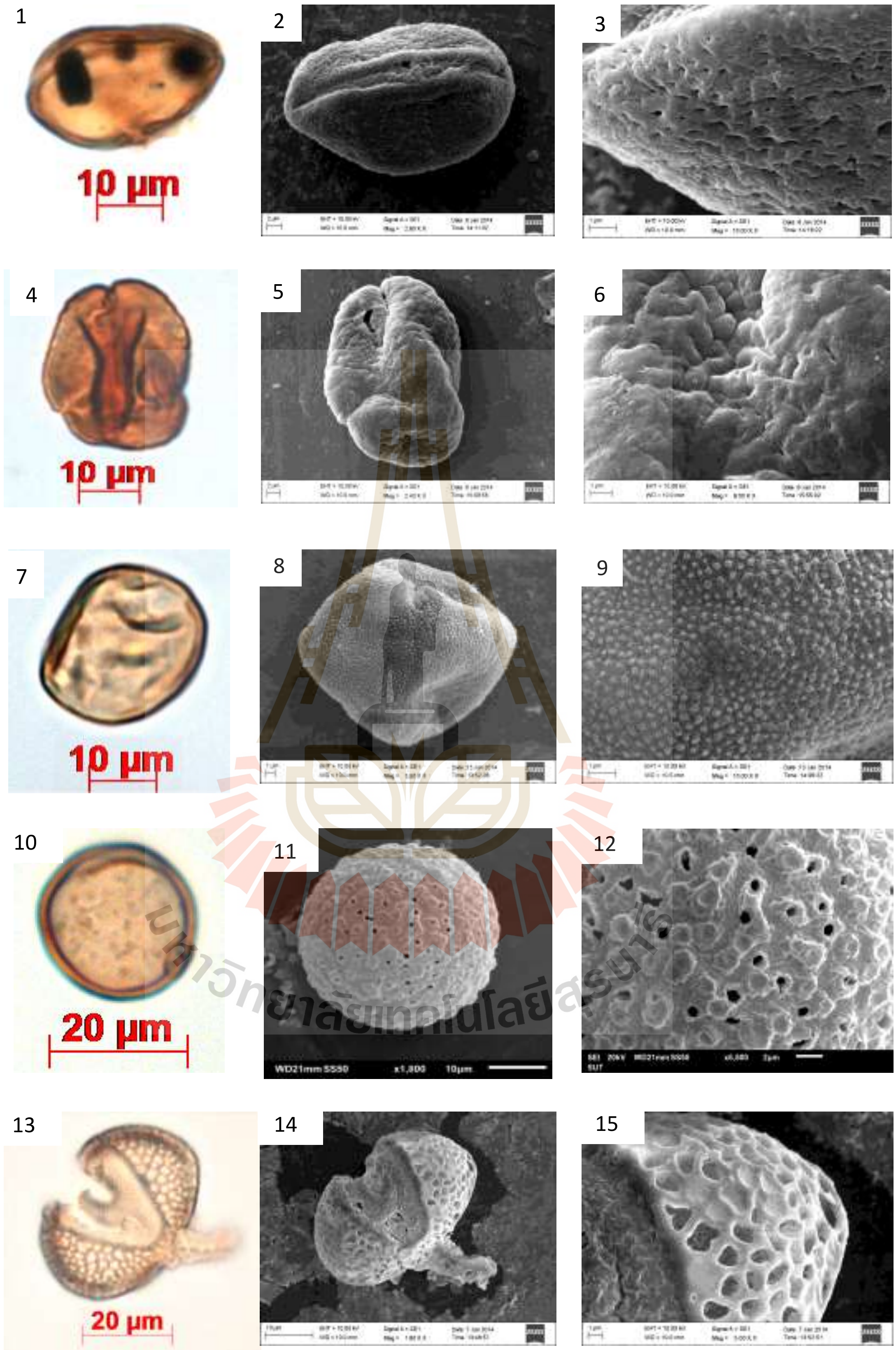

Plate 46 Unknown (Angiosperm III)

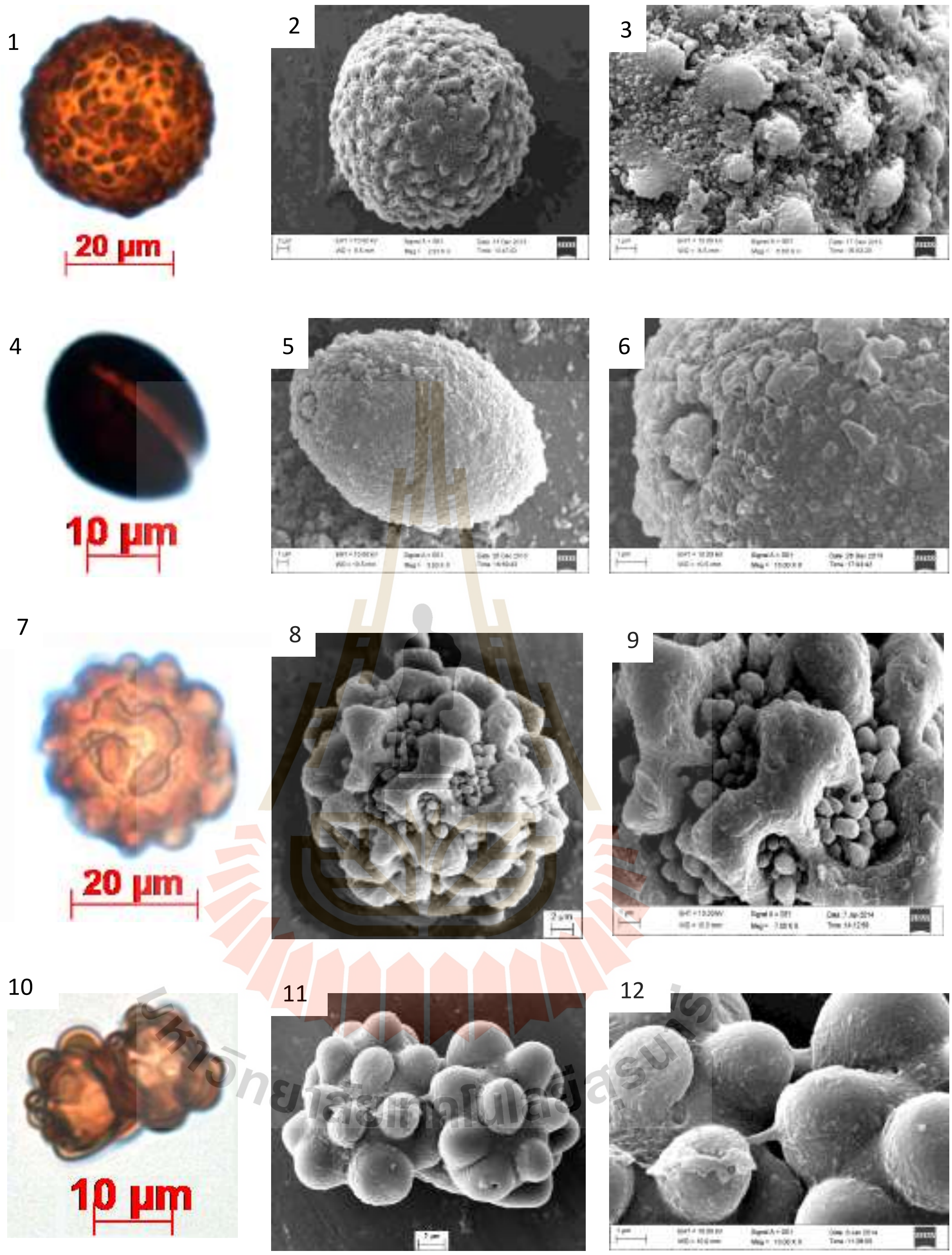

Plate 47 Unknown (Algae I)

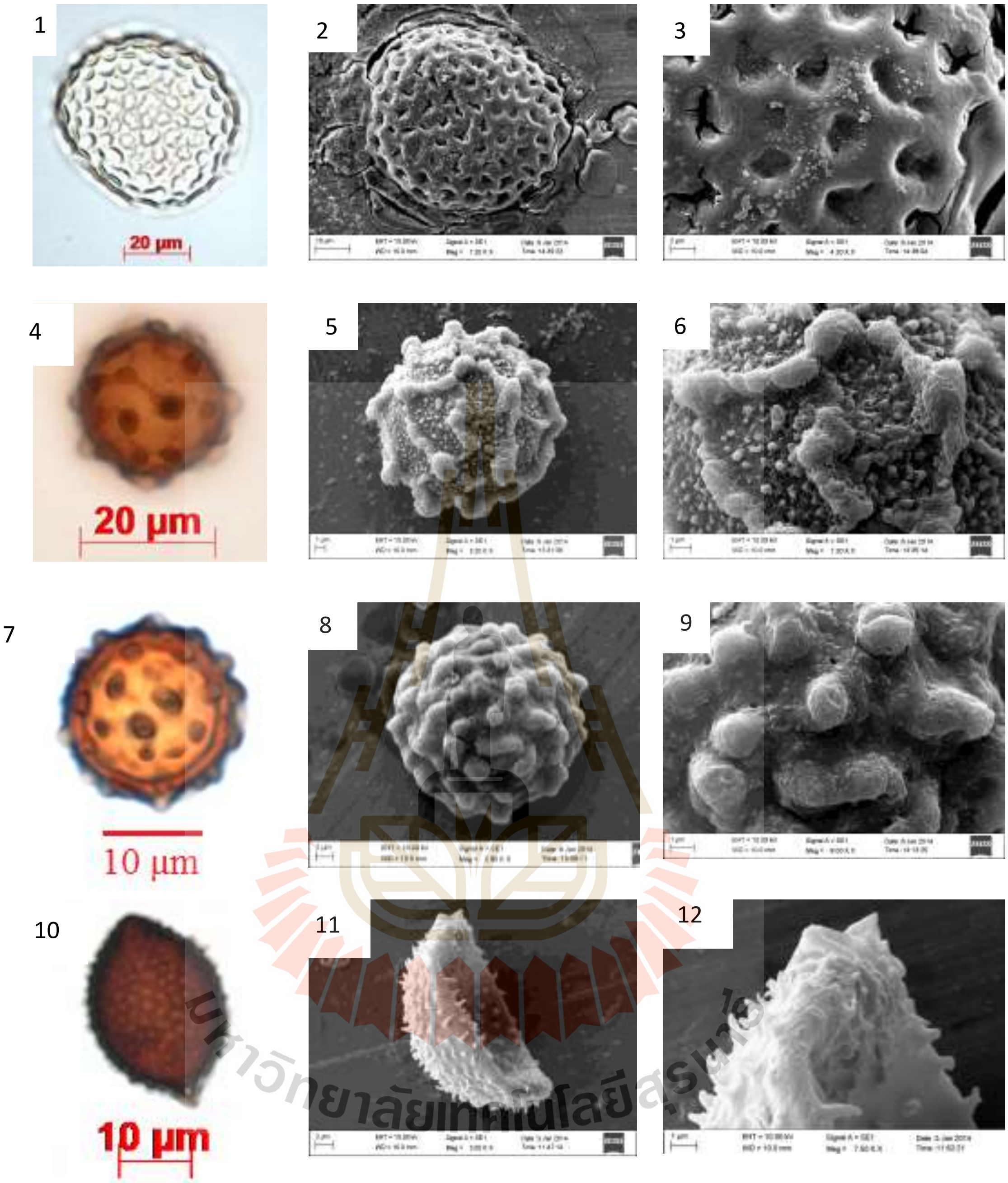

Plate 48 Unknown (Algae II)

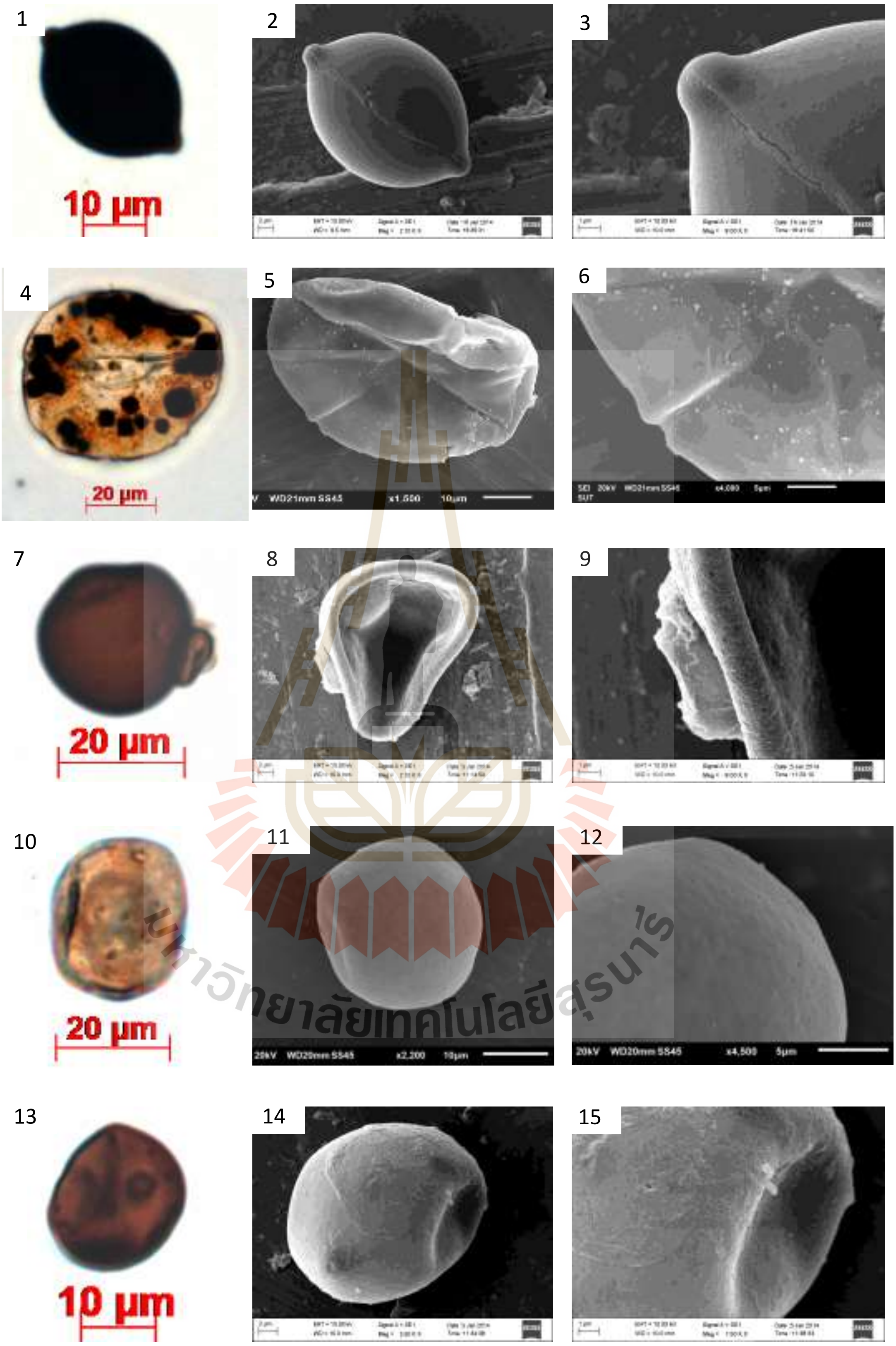

Plate 49 Unknown (Fungi I)

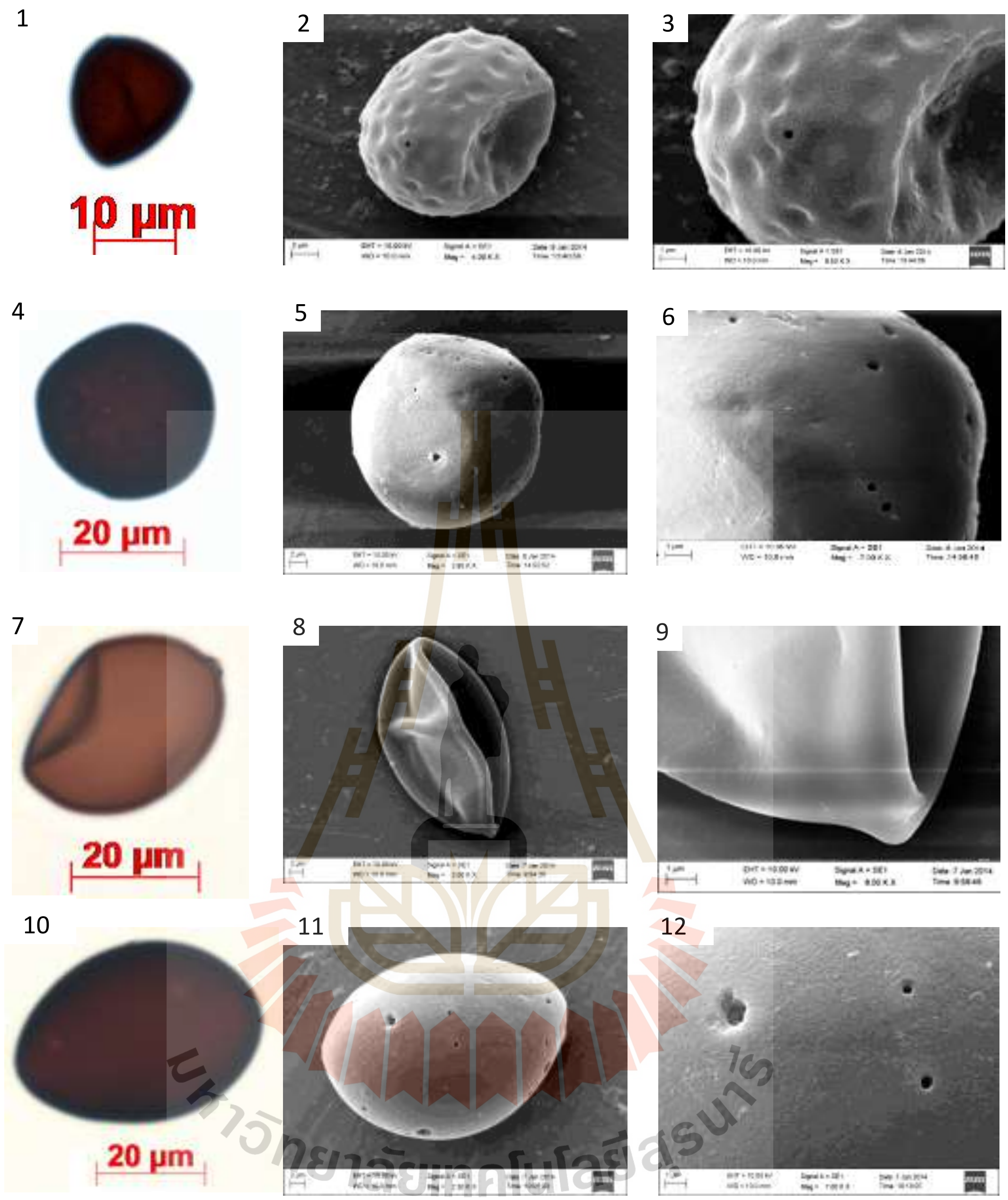

Plate 50 Unknown (Fungi II)

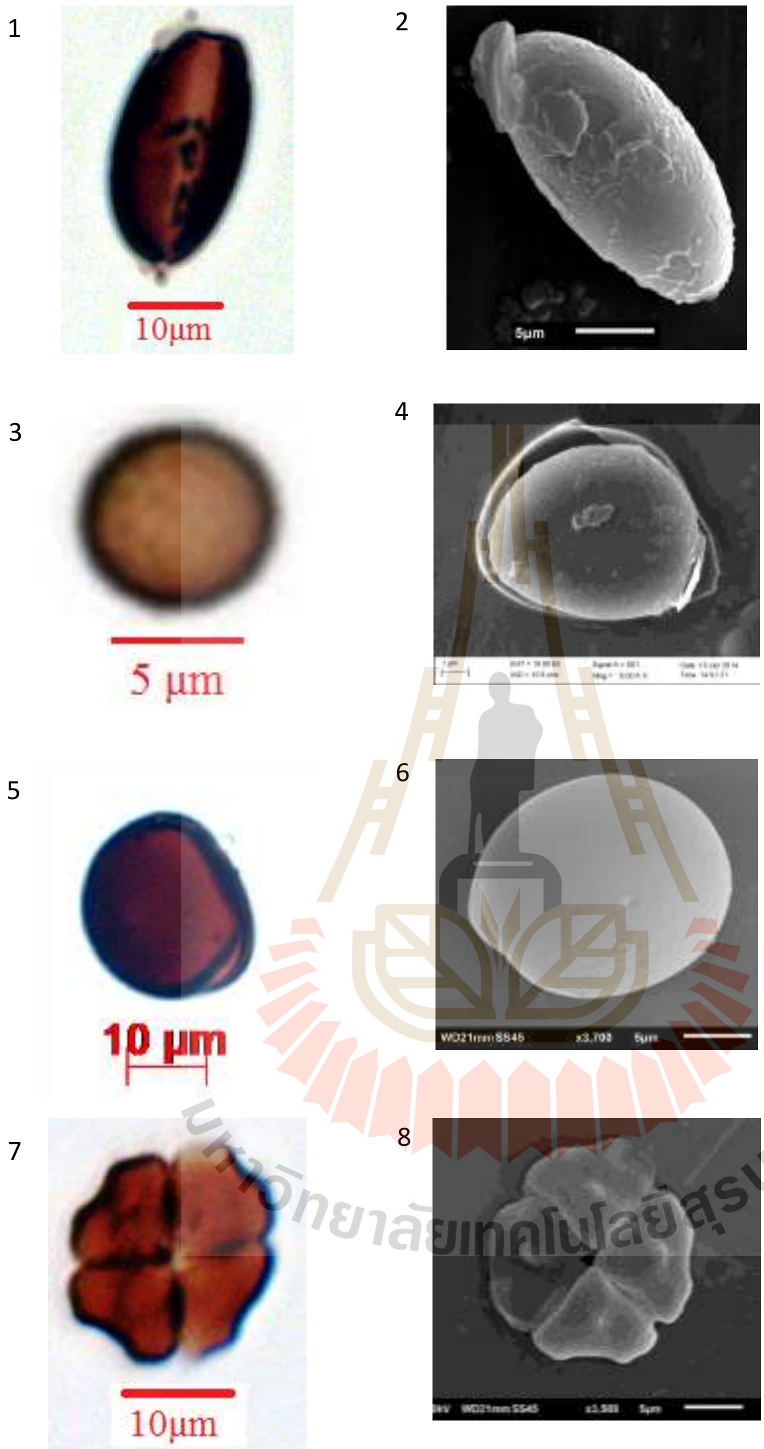

Plate 51 Unknown (Fungi III)

CHAPTER VI

INTERPRETATION OF POLLEN AND POLLEN ASSEMBLAGES

6.1 Pollen diagram and its description

6.1.1 Pollen sum

The pollen sum included all the sedimental micro-organic taxa, including fungi, algae, bryophyte, fern, gymnosperm, and angiosperm. Generally, three hundred grains in each layer were calculated in the pollen diagram, but the taxa with fewer than 3 grains (< 1%) were not calculated in the pollen diagram. The major pollen types were used to reconstruct the vegetation and environment *in situ*. Distinct pollen types or the representative pollen combinations would be used to interpret the climate.

There are more than 96 pollen and spore taxa that were recognized in this study, including 8 fungi, 10 mosses, 14 ferns, 5 gymnosperms, and 59 angiosperms. Some groups with distinct environmental indications were listed below: twelve representative aquatic (mainly aquatic, fresh and brackish) taxa were found: *Acrostichum*, *Barringtonia acutangula*, *Barringtonia racemosa*, *Ceratopteris*, Combretaceae (some), Commelinaceae (some), Cyperaceae (some), *Hygrophila* (some), *Nypa*, *Oncosperma*, Rhizophoraceae (some), and *Typha*. Representative trees/shrubs (most species in the genus are woody) were 22 taxa; they are *Abies*, *Acacia*, *Acronychia*, *Albizia*, *B. acutangula*, *B. racemosa*, *Camellia*, *Canthium*, *Castanopsis, Croton, Lagerstroemia, Mallotus, Melia, Quercus, Pinus, Pseudolarix, Pterospermum, Radermachera, Schefflera, Senna, Terminalia,* and *Viburnum*. Representative herbs were classified in 6 taxa, Asteraceae, *Chenopodiaceae, Lygodium,* Poaceae, *Primulina,* and *Ruellia.*

6.1.2 Zonation of pollen diagram

Zonation in the pollen diagram was used to interpret vegetation change in the geological periods. A zone is a biostratigraphic unit based on the pollen assemblage obtained. It is related to the appearance or disappearance of the taxa in the pollen assemblage, instead of percentages under consideration. However, the zonation results matched well with the geological deposits as independent and equivalent categories. According to the fossil pollen records in layers 9B (-7.25 m to -7.45 m), 10A (-7.45 m to -7.9 m), 10B (-7.9 m to -8.1 m), 11 (-8.1 m to -8.4 m), 13A (-9.0 m to -9.25 m), 13B (-9.25 m to -9.5 m), 16A (-10.4 m to -10.55 m), and 22 (-13.5 m to -14.0 m), the paleovegetation and environment were reconstructed separately layer by layer (Figure 6.1).

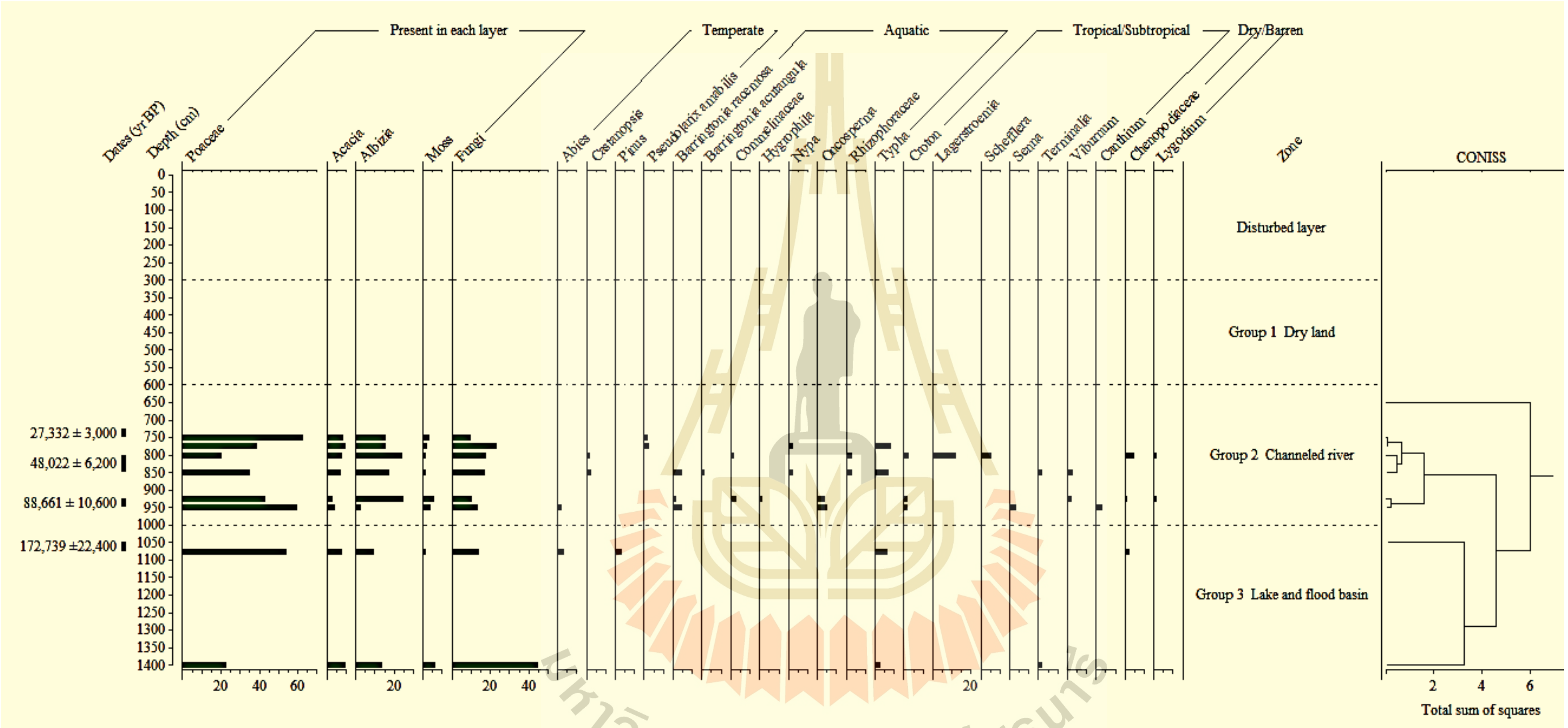

Figure 6.1 Pollen diagram

6.2 Pollen assemblage, vegetation and climate dynamics

The modern analogue technique (Jackson and Williams, 2004) was used to classify the paleovegetation with reference to extant plant communities. Distinct and endemic species approach (Faegri and Iversen, 1989; Kou *et al*., 2006; Li, Yi, and Yao, 2008) was helpful in rebuilding the paleoclimate. The coexistence approach is used to find the joint range of environmental factors (such as temperature and precipitation) in different taxa (Utescher and Mosbrugger, 1997). However, there was not sufficient environmental data available for the coexistence approach, especially for tropical plants.

Layer 22: This layer was classified as belonging to group 3, subgroup 3.3 in the stratigraphic profile, characterized by graded bedding of stratified fine sand, silt, and clay, and displayed a lake deposition and flood basin at this period. The age dating for this layer was absent but we knew it was below the layer 16A which was dated at 172,739 ± 22,400 yr BP. However, reworked sediment was not found; it should be older then the layer 16A. There were 21 pollen types recorded in this layer and 6 types were enough for considering in the diagram. This layer was dominated by legumes, including trees and shrubs (*Acacia* and *Albizia*, 23% together). A high proportion of moss (6%) and *Typha* (3%) indicated a shallow water environment, while a high proportion of fungal spores (44%) indicated a developed organic deposit. There was a relatively low proportion of grass (23%). The forest grew sparsely, composed mainly (by low records) of *Lagerstroemia*, *Mallotus*, *Melia*, *Grewia*, and other species from Malvaceae (*sensu stricto*), and also *Terminalia* (1%). Low pollen records suggested a poor vegetation shrubland with sparse trees.

Most of the plant taxa identified have their extant relatives today with a wide distribution in the tropical or subtropical area. However, they cannot suggest a useful link to the temperature and precipitation in the past because of the absence of the climate data of each tropical and subtropical plant species. It is difficult to get any climate hint in this layer. However, there are still some traces of a general outline of the climate. The fungal spores and hyphae fragments were significantly higher than other taxa. Arbuscular mycorrhizae are the most common fungi group which symbiotic with at least 200,000 plant species in 200 families (Zhang *et al*., 1999). The fungi species diversity and abundance are proved closely related with soil composition and temperature, rich in the tropics and poor in the temperate zone (Zhang *et al*., 1999). Many fungal species were commonly seen in the tropical zone (National Bureau of Statistics of China, 2010). Some research also mentioned that low soil temperature is detrimental to fungal spores because it slows pathogen development and reduces the generation rate (Koike *et al*., 2003). Some samples were collected from different places for comparison (Table 6.1). Generally, the proportion of fungi was higher in tropical zone than subtropical zone or high elevation which snowed in the winter annually. The sample from the shallow deposit of the active Mun River at Tha Chang Subdistrict, Chaloem Phra Kiat District, Nakhon Ratchasima, is 42% fungal spores and hyphae fragments. Another one is from the shallow deposit of the modern Chomphu River in Thung Salaeng Luang National Park, Phitsanulok, with 40% fungal spores and hyphae fragments. The third is from a seasonal intermittent river from a legume forest dominated by *Leucaena* in Suranaree University of Technology, with 40% fungal spores and hyphae fragments. The two layers with relatively low temperature were accompanied by low fungal records.

Table 6.1 Reference sediments and pollen present.

Code	Location	Forest Type	Dominant species	Dominant pollen
R17	Mt. Bama, Yunnan, China	Tropical zone, middle mountain monsoon forest (800 m asl)	*Castanopsis echidnocarp*	*Castanopsis* (61%), moss (6%), fungi (2.6%)
R18	Mt. Ailao, Yunnan, China	Tropical zone, high mountain moist forest (3000 m asl)	*Rhododendron irroratum* and moss	Moss (34%), *Bischofia* (11%), *Davallia* (11%), fungi (4.66%)
R21	Mt. Badagong, Hunan, China	Subtropical zone, middle mountain bamboo forest (800 m asl)	*Phyllostachys viridis*	Fungi (32%), Poaceae (30%)
R22	Mt. Badagong, Hunan, China	Subtropical zone, middle mountain evergreen forest (1200 m asl)	*Fagus lucida*	Fungi (70%), Fagus (12%)
R23	Suranaree University of Technology	Tropical zone, lowland dry deciduous forest (235 m asl)	*Leucaena*, Poaceae	Fungi (40%), *Leucaena* (28%), Poaceae (26%)
R24	Chomphu River in Phitsanulok	Tropical zone, shallow river deposit (96 m asl)	*Phragmites australis* and *Bambusa*	Fungi (40%), Poaceae (23%)
R25	Mun River in Nakhon Ratchasima	Tropical zone, shallow river deposit (165 m asl)	*Bambusa*	Fungi (42%), Poaceae (25%) *Typha* (25%)

Layer 16A (172,739 ± 22,400 yr BP): This layer was classified as belonging to group 3, subgroup 3.1 in the stratigraphic profile, characterized by medium and coarse sand, and displayed a lake deposition and flood basin at this period. The age dating result indicated it was in the glacial age of Asia (Schafer *et al.*, 2002; Yuan *et al.*, 2004). There were 20 pollen types recorded in this layer and 9 types were rich enough for considering in the diagram. It is rich in Poaceae (53%), Pinaceae (*Abies* and *Pinus*, 6% together), legumes (*Acacia* and *Albizia*, 17% together), and Chenopodiaceae (2%), plus moss (1%), fungi (14%), and *Typha* (6%). *Abies, Pinus*, plus Chenopodiaceae were regarded as a typical temperate savannah, characterized by scattered trees and bushes. *Accacia* and *Albizia* were globally distributed even they were considered as the dominant trees in tropical savannah. The co-occurrence of *Pinus*, Poaceae, and Chenopodiaceae represented a cool and dry climate. The limited seasonal rainfall is the main water supply (Anderson *et al.*, 1999; Bird *et al.*, 2005; McPherson, 1997; Solórzano and Felfili, 2008; Sun *et al.*, 2003; Werner *et al.*, 1991; Woodruff and Turner, 2009). *Quercus* (1%) was also found in this layer. Generally, *Quercus* grows in deciduous broad leaf forest while some species grow at an extreme low temperature zone such as -56 °C in Siberia.

According to the researchers (Fu *et al.*, 1999; Sun *et al.*, 2006), *Pinus* which has double vascular bundles in the needles is commonly seen in subtropical and tropical areas, while the single vascular bundle type is found in wet and cold boreal or high altitude (normally > 3000 m, a few species > 1000 m) (Figure 6.2). Many palynology reconstruction works did not classify the double vascular bundles pines and single double vascular bundles pines. Therefore, some reconstructed vegetation seemed not so convincible.

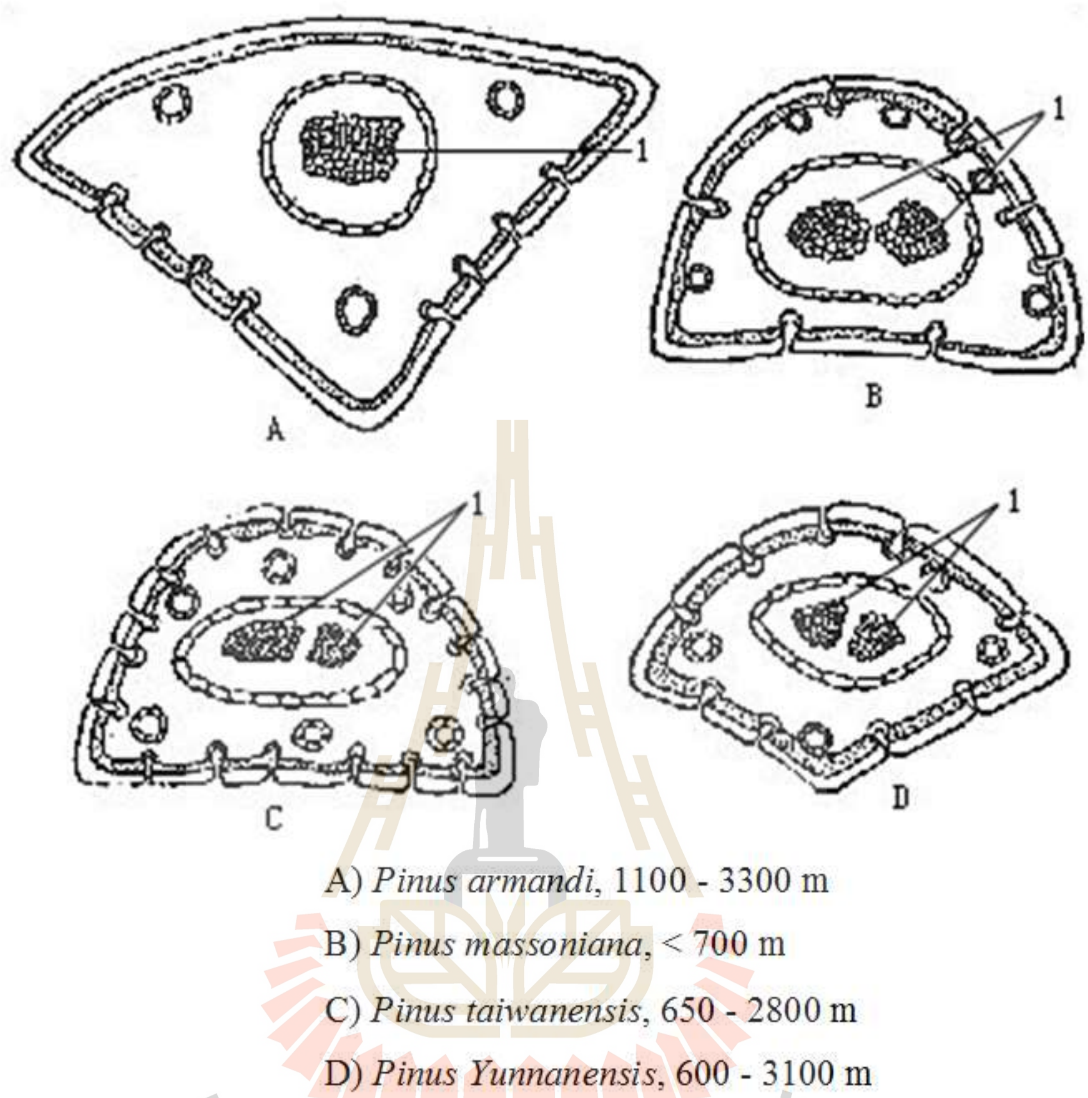

Figure 6.2 Vascular types and altitude limit of *Pinus* (from Fu *et al*., 1999).

The suitable range for *Abies* is 4 - 6 °C (-14 °C in January and 19 °C in July) with a mean precipitation of 200 - 500 mm (Fu *et al*., 1999; Myers and Bormann, 1963; Teskey *et al*., 1984; Zavarin and Snajberk, 1972). *Abies* and *Pinus* share a wide coexistence temperature ranging from 5 °C to 19 °C even they grow at different altitudes (Sun *et al*., 2006). A longer time of dry season dominated the Khorat Plateau during this stage. There was a grass pollen dominated period reported in the South China Sea at the age of 0.14 Ma.

It was a temperate savannah in this layer, with a relatively low temperature, low precipitation, and poor pollen types. According to the nearest glacial in Tibet, there was the most extensive glacial advance around 170 kyr BP (Schafer *et al*., 2002). A dry and cold environment was suggested in this period with strong and dry winter monsoon (Kuhle, 1998, 2001). There are more than 1,000 km from the huge ice gap to the Khorat Plateau. However, the power of the cold winter monsoon influenced the south part of the Asia continent.

Layer 13B (88,661 ± 10,600 yr BP): This layer was classified as belonging to group 2, subgroup 2.4 in the stratigraphic profile, characterized by granule, coarse sand, and mud nodules, and displayed channel deposition. The age dating result indicated it was in the cold stage of Asia (Yuan *et al*., 2004). There were 34 pollen types recorded in this layer and 11 types were enough for considering in the diagram. It was composed of grass (59%), legumes (*Acacia* and *Albizia*, 6% together), *Senna* (3%), *Abies* (2%), moss (3%), fungi (13%), *Oncosperma* (5%), croton (1%), *Canthium* (3%), *Barringtonia racemosa* (5%) The proportion of grass pollen is obviously higher (59%) than others in this layer while the legumes (*Acacia* and *Albizia*) decreased sharply (6% together). Compared to other layers, legumes were relatively low. This decline may be closely related to the temperature and water decline, because most species of these two genera were restricted to tropical to warm-temperate regions (Wu *et al*., 2003). *Croton* (1%) and *Canthium* (3%) also occurred as part of the forest even though they presented at a low proportion. Pollen grains of palm rise up in this layer (*Oncosperma*, 5%). Usually, palm is a unit from which it is difficult to get any environmental information except *Nypa*, because they exhibit an enormous range of habitats, from rainforest to desert, from coastal area to inland.

However, most palms were adapted to sandy soils with high organic content, while a few species grew well in flood plains (Govaerts *et al*., 2004). Therefore, *Oncosperma* in this layer is regarded as a light brackish palm tree with both brackish and wetland representatives and occurs inland behind the mangrove zones (Punwong, 2007; Rugmai, 2006). The palm pollen grains were mixed with *Barringtonia racemosa* (5%) and *Ceratopteris* (few) in this layer, and indicated the existence of a low salinity water condition. Generally, it is a layer rich in grass and accompanied by a few trees growing along the river.

A few pollen grains of *Abies* (2%) were discovered in layer 16A and 13B; it was rare but indicated a cool climate. *Abies* is commonly found in the cool-temperate zone of Asia, Europe, and North America (Fu *et al*., 1999; Myers and Bormann, 1963; Teskey *et al*., 1984; Zavarin and Snajberk, 1972). Fog is considered an important environmental factor for *Abies* to precipitate as fog drips during the growing season (Myers and Bormann, 1963). The high moisture also nourished a high proportion of moss (3%) as symbiotic. The pollen grains of *Abies* can be dispersed by wind and deposited very far from the parent tree; the published record is 300 km (Wang, 1983). Therefore, it is available for the pollen grains of *Abies* to have been transported from some other distant place. There is no extant *Abies* in Thailand, even the mountains with high elevation, such as Khao Lamang in Thap Lan (992 m), Phu Thap Buek (1,794 m), KhaoYai (1,351 m), or even Doi Inthanon (2,565 m) far in the north. The extant closest *Abies* populations are native to Yunnan, Tibet in southwest China, far northeastern India, northern Myanmar, and far northwestern Vietnam. Distribution of *Abies* is from 2,400 m to 4,300 m above the mean sea level. It is too far for the long distance dispersal even though they can be transported by the winter monsoon. The combination of *Abies* and grass were recorded in Yunnan, Southwestern China, which suggested a cool period around the age of 85,000 - 73,400 yr BP (Yang *et al*., 1998). The distribution of *Abies* should have been much southward in the past, at least Doi Inthanon (2,565 m), the highest mountain in Thailand which is 500 km from Khorat Plateau. The mountain area was supposedly covered by *Abies* or single vascular bundle pines while the South China Sea was exposed and dominated by vast grass land. The sea level was reported 120 m lower than at present (Sun *et al*., 2006; Sun and Li, 1999; Sun *et al*., 2000; Zhang and Long, 2007, 2008). Therefore, most pollen grains in these two layers were *in situ* while the *Abies* was exterior.

However, another climate indicator, *Barringtonia racemosa*, was discovered in this layer (5%), a species which presently occurs in the tropical and subtropical zones (McKnight and Hess, 2000). However, the altitude of *B. racemosa* was reported to be 750 m at most (Wu *et al*., 2003). Generally, this is a subtropical savannah at this stage with a high proportion of grass covering the ground.

Layer 13A (51,682 ± 6,700 yr BP): This layer was classified as belonging to group 2, subgroup 2.4 in the stratigraphic profile, characterized by clay, and displayed channel deposition. The age dating result indicated it was in the warm stage of Asia (Yuan *et al*., 2004). There were 30 pollen types recorded in this layer and 13 types were rich enough for calculation. It was composed by grass (43%), legumes *(Acacia* and *Albizia*, 28% together), moss (6%), fungi (10%), *Oncosperma* (4%), Chenopodiaceae (1%), *Croton* (1%), Commelinaceae (3%), *Lygodium* (1%), *Barringtonia racemosa* (1%), *Viburnum* (2%), and *Hygrophila* (1%). Pollen grains of Poaceae (43%), *Acacia* and *Albizia* (28% together) are dominant in the sediment. A high proportion of moss (6%) indicates high moisture while Commelinaceae (3%), *Hygrophila* (1%), and *Oncosperma* (4%) indicated a wet habitat. Additionally, *Croton* (1%), *Lagerstroemia* (few), *Melia* (few) were recorded in this layer with very few records. They composed the forest along with legumes and palms. *Lygodium* and Chenopodiaceae were in low proportion (1%), but they were recognized as colonizers in the open area.

The distinct pollen type was Commelinaceae which indicated a warm temperature (Baike, 2014). *Barringtonia racemosa* was also regarded as another climate indicator, even though it was in low proportion (1%) but indicates a tropical or subtropical climate (McKnight and Hess, 2000). Generally speaking, it is a subtropical mixed forest with developed swamps at this period.

There was a quick shift between the layers 16A, 13B and 13A; the vegetation changed from temperate savannah to subtropical mixed forest with developed swamps. The cold tolerant taxa in layers 16A and 13B were more than in 13A, and a decline of precipitation also occurred as suggested by the plant groups. According to the depositional analysis, layer 16A represented the end of a floodplain stage while layer 13B represented the beginning of a channel stage of the ancient Mun River. The river change was proved to match well the shift of the vegetation.

Layer 11 (48,022 ± 6,200 yr BP) : This layer was classified as belonging to group 2, subgroup 2.3 in the stratigraphic profile, characterized by clay and silt, and indicated channel river depositions. The age dating result indicated it was in the warm stage of Asia (Yuan *et al*., 2004). There were 27 pollen types recorded in this layer and 12 types were rich enough for considering in the diagram. Species were composed mainly by Poaceae (35%), *Acacia* and *Albizia* (24%), moss (1%), fungi (17%), *Typha* (7%), Rhizophoraceae (3%), *Castanopsis* (2%), *Barringtonia* (6%), *Terminalia* (2%), *Nypa* (2%), and *Viburnum* (2%), plus other plants such as *Avicennia* (few), *Lumnitzera* (few). They are commonly recognized as mangrove species. Their co-occurrence is an indication of a river with relatively high salinity.

Typha is widely distributed in the Northern Hemisphere and found in a variety of wetland habitats. They are usually accommodated in fresh water. Research (Beare and Zedler, 1987) mentioned the salinity resistant species *Typha domingensis* in southern California and explained how their seeds and rhizomes survived in hyper saline water. Other studies mentioned that *T. angustifolia* was subdominant in a brackish environment (Gross *et al*., 1993; McGinley *et al*., 2010). However, there were still 7% percent cattail pollen grains discovered in this layer, which indicated a seasonal pond system along the river.

Barringtonia was considered as an environmental indicator in this layer. *B. acutangula* and *B. racemosa* were identified separately and they make up 6% in the diagram. The two species are mostly restricted to inundated plains or swamps, preferring slight salinity with organic clay or loam. They are also found in coastal regions distributed as back mangroves. Some of them are also found at an altitude up to 750 m (DePadua *et al*., 1999). Most of them are distributed in Indochina, southern Thailand, and southern Myanmar to Peninsular Malaysia, Sumatra, Java, and Borneo. The distributions are in the tropical zone (McKnight and Hess, 2000). *Castanopsis* found in this layer was thought of as another distinct component even though it was just 2%. Their extant relatives are distributed in tropical and subtropical Asia at various altitudes (Ding *et al*., 2006; Zhang *et al*., 2005). It is a warm and wet period which can support relatively high biodiversity and productivity.

Layer 10B (TL: 33,611 ± 4,000 yr BP; C14: 28,150 ± 7,860 yr BP): This layer was classified as belonging to group 2, subgroup 2.3 in the stratigraphic profile, characterized by clay and silt, and displayed channel deposition. The age dating result indicated it was in the warm stage of Asia (Yuan *et al*., 2004). There were 25 pollen types recorded in this layer and 13 types were rich enough to put in the diagram. They were Poaceae (20%), *Acacia* and *Albizia* (31%), moss (1%), fungi (18%), *Schefflera* (5%), *Lagerstroemia* (12%), Chenopodiaceae (4%), Rhizophoraceae (3%), *Croton* (2%), *Castanopsis* (2%), Commelinaceae (2%), and *Lygodium* (1%). There is a sharp decrease of grass pollen (20%) in contrast to the rise of other groups such as *Acacia* and *Albizia* (up to 31% together). The legumes are the predominant group in this layer followed by *Lagerstroemia* (12%), Chenopodiaceae (4%) and Rhizophoraceae (3%). There are plenty of arboreal pollen grains recorded (more than 50%) at this stage, including *Acacia*, Araliaceae (5%), *Castanopsis* (2%), *Croton*, *Lagerstroemia*, and *Rhizophora*ceae, accompanied by the aquatic species from Commelinaceae.

There are more than 1,000 species in Chenopodiaceae (*sensu lato*) and they are mainly distributed in halophytic habitats such as arid areas, deserts, and seashore or slightly saline water. The presence of Chenopodiaceae indicated a relatively high saline habitat combined with Rhizophoraceae. *Lygodium* spores in this layer were rich enough for calculation in the diagram. Most *Lygodium* species are heliophytes and usually found growing well in open areas. But there is an exception, *Lygodium microphyllum*; it was recorded growing not only in freshwater wetlands but also estuarine areas, near white mangroves (*Laguncularia racemosa*) and over giant leather fern (*Acrostichum danaeifolium*) (Lockhart, 2007). The occurrence of *Lygodium* is evidence of a more or less barren area along the river. It was a tropical or subtropical deciduous forest in this layer.

Castanopsis was also found in this layer indicating a relatively low temperature (Ding *et al*., 2006; Zhang *et al*., 2005). This opinion was supported by the research in the South China Sea (37,000 - 15,000 yr BP, Sun and Li, 1999) and Xingyun lake in Southwest China (38,000 - 12,000 yr BP, Hodell *et al*., 1999). Commelinaceae distributes in both the Old World tropics and the New World tropics while fewer species are distributed in subtropical and temperate zones.

Layer 10A (52,296 ± 6,800 yr BP): This layer was classified as belonging to group 2, subgroup 2.2 in the stratigraphic profile, characterized by well stratified granule and pebble, displayed channel deposition. The age dating result indicated it was in the warm stage of Asia (Yuan *et al*., 2004). There were 36 pollen types recorded in this layer and 8 types were rich enough for considering in the diagram. They were grass (38%), *Acacia* and *Albizia* (24%), *Pseudolarix amabilis* (2%), moss (2%), fungi (23%), Typha (8%), and Nypa (2%). Poaceae is the dominant taxa up to 41% in total, and then *Acacia* and *Albizia*, approximately 24% together. There are rich aquatic species discovered in this layer, such as *Acrostichum* (few), *Nypa fructicans* (2%), Rhizophoraceae (few), and *Typha* (8%). This combination represents a brackish water environment nearby. *Nypa fruticans* is native to the tropical and subtropical coastline and estuarine areas (Dowe, 2012).

Pseudolarix were found in this layer as a distinct component. Their extant relatives grow well in the subtropical zone, native to eastern China and distributed along the Changjiang River (Fu *et al*., 1999; Fu and Jin, 1991; Ying *et al*., 1993). According to the paleorecords published (Brousse, 1974; LePage and Basinger, 1995;

Erdtman, 1969; Sivak, 1975; Ueno, 1958; Ying *et al*., 1993), they were distributed in a wide range of the Northern Hemisphere during the Cenozoic. The pollen production, aerodynamics and taphonomy of *Pseudolarix* pollen suggest why this species is likely to be well represented in the local pollen diagrams (Zanni and Ravazzi, 2007).

Layer 9B (27,332 ± 3,000 yr BP): This layer was classified as belonging to group 2, subgroup 2.2 in the stratigraphic profile, characterized by clay, and displayed channel deposition. The age dating result indicated it was closed to the Würm glacial (26.5-19.0 ka) (Clark *et al*., 2009), and the cold stage of Asia (Yuan *et al*., 2004). This period was known as the Last Glacial Maximum (LGM), a global cold event. There were 10 pollen types recorded in this layer and 6 types were rich enough for considering in the diagram. They were Poaceae (62%), legumes (*Acacia* and *Albizia*, 23% together), *Pseudolarix amabilis* (2%), moss (3%), and fungi (9%). There was strong representation of Poaceae in this layer with an extremely high proportion. Generally speaking, the grass family is distributed worldwide, including aquatic and terrestrial types. *Acacia*, *Albizia*, and grass are regarded as typical savannah. There are modern analogs in Africa, South American, and some dry and hot valleys in the mountainous area along the upstream of the Changjiang River, Southwestern China (Shen *et al*., 2010; Wu *et al*., 2003; Zhang, Hartley, and Mabberley, 2012). It is obvious that a savannah corridor had existed in the Khorat Plateau; the plateau was covered by high grass and legumes in this period. Some researches mentioned a savannah corridor in the Late Pleistocene Indochina Peninsula based on the fossil mammals (Bird *et al*., 2005). Absence of aquatic and thermal tolerant species demonstrated a dry and cool climate.

The grass pollen was the highest in all the layers; it meant the grassland was prevalent at this age. The same trend was also recorded in the deep sea cores discovered from the South China Sea (about 525 km from the Khorat Plateau) at the age of 24,000 yr BP (He *et al*., 2008). From the Xingyun Lake records based on $CaCO_3$, the period from 41,000 to 12,000 yr BP was also marked as having low temperature and weak summer monsoon (Hodell *et al*., 1999). There is a research in Tam Lod and Ban Rai of Northwest Thailand mentioning strong monsoon and unstable climatic conditions from 33,000 to 20,000 yr BP, followed by peak aridity occurring around 15, 600 BP (Marwick and Gagan, 2011). The continental shelf of the South China Sea was exposed at this period because the sea level was 41 - 120 m below present (Bloom *et al*., 1974; Sun and Li, 1999; Sun *et al*., 2000; Wang, 1978); herbs and montane conifers (*Tsuga, Picea* and *Abies*) suggested that low temperature plant species took over the pollen diagram (Sun and Li, 1999; Sun *et al*., 2000). Paleorecords from continental Southeast Asia provided a synopsis of regional paleoclimate dynamics over the last ~30,000 yr BP. The results suggested that a notable change occurred during the Pleistocene - Holocene Transition. It had been cold and arid for a long time under the impact of a strong winter monsoon. Solar insolation was the dominant control on the climate change (Cook and Jones, 2012).

CHAPTER VII

DISCUSSION

7.1 Vegetation change in the layers

The main vegetation types along the ancient Mun River in the Khorat Plateau were swamp forests and savannahs (Table 7.1). The vegetation shifted in different periods. No one vegetation type was always prevalent, neither forest nor grass land. A mangrove system was developed at some stages. Poor species vegetation was recorded in layer 22 with dominant fungi, cattail, and moss. Temperate savannah was prevalent in the layers 16A (172,739 ± 22,400 yr BP) and 13B (88,661 ± 10,600 yr BP), with a relatively low diversity in layer 16A and higher in 13B. The difference in diversity is likely because of absence of aquatic species. *Barringtonia racemosa*, moss, and *Oncosperma*, plus a few *Ceratopteris* spores were recorded in layer 13B, but none of them can be found in layer 16A. However, based on the geological depositional information, there was a frequently flooded river without a stable river bank in 16A. Oppositely, a developed channel was built up in layer 13B. There is a quick alternation from temperate savannah to subtropical swamp forest in 13B and 13A. After the long cold period in 13A and 16A, the Khorat Plateau went into a warm stage, and the high plant diversity was developed. Tropical forest with developed shrubs and herbs arose since the time of layer 13B.

Table 7.1 General information of the reconstructed environment.

Layer	Age (yr BP)	Taxa	Vegetation	Representative species	River condition based on pollen	River condition based on deposits
22	Unknown	21	Tropical shrubland	Fungi	Flood basin, developed swamps, eutrophic	High flow, flooded
16A	172,739 ± 22,400	20	Temperate savannah	*Abies*, *Pinus*, and *Quercus*	Flood basin, low flow	High flow, flooded
13B	88,661 ± 10,600	34	Subtropical savannah	*Abies*	Channeled river, low flow	Low flow, channeled
13A	51,682 ± 6,700	30	Subtropical mixed forest with developed swamps	*Barringtonia* and Commelinaceae	Channeled river, low flow	Low flow, channeled
11	48,022 ± 6,200	27	Tropical and subtropical deciduous forest	*Barringtonia*	Channeled river, brackish, low flow	Low flow, channeled
10B	33,611 ± 4,000	25	Tropical and subtropical deciduous forest	*Castanopsis* and Commelinaceae	Channeled river, brackish, low flow	Low flow, channeled
10A	52,296 ± 6,800	36	Subtropical forest mixed with developed swamps	*Pseudolarix*	Channeled river, brackish, low flow	Low flow, channeled
9B	27,332 ± 3,000	10	Subtropical savannah	*Pseudolarix*	Channeled river, Low flow	Low flow, channeled

7.2 Diversity various in the layers

According to the pollen types, the paleovegetation varies from layer 22 at the bottom to layer 9B at the upper level. Relatively high diversity occurred in layers 10A (52,296 ± 6,800 yr BP), 10B (33,611 ± 4,000 yr BP), 11 (48,022 ± 6,200 yr BP), 13A (51,682 ± 6,700 yr BP), and 13B (88,661 ± 10,600 yr BP) with more than 25 different pollen types recognized in each. Many of them are related to the aquatic components, such as *Barringtonia*, *Hygrophila*, *Typha* etc. The aquatic components are the evidence of the presence of the ancient river, and the relatively high diversity is closely related to the river development. Referring to the deposits analysis, these layers were deposited in the channel stage with enhanced water flow and wide river basin, and supported a lot of aquatic plants.

The diversity decreased sharply in layers 9B (27,332 ± 3,000 yr BP), 16A (172,739 ± 22,400 yr BP), and 22 (the age is unknown, but it is under the layer 16A) compared to other layers. According to the sedimentology analysis, layer 9B occurred in the channel deposition stage while 16A and 22 occurred in the floodplain stage. There are no aquatic species discovered in layer 9B, which means a dry period and a more or less shrunken river. A flooded plain with rapid water flow also cannot support many plants. Oppositely, based on the sedimentology analysis, the deposits between layers 16A and 22, which are composed of sand and clay, are recognized as frequently flooding with rapid flow and accelerated deposition. Therefore, the two layers which were proved vegetative but low in diversity are thought to be a break in the long term flooding.

However, the diversity change in the layers was closely related to the climate and the river change. Some plant taxa, such as *Acacia*, *Albizia*, and Poaceae were regularly found in all the reported layers; they have a worldwide distribution with extensive climate range. They took over the Khorat Plateau in the past and even at present while other plants are constrained to strict temperature and precipitation ranges. Their appearance and disappearance are closely related to climate change.

Dominant grass was closely related to cold weather with low CO_2 in the ice age. Low CO_2 was a negative impact factor to most C3 plants but did not have any influence on C4 plants (Cerling *et al*., 1997; He *et al*., 2008; He and Wang, 2005; Morgan *et al*., 1994; Pagani *et al*., 1999; Retallack, 2001). Efficient CO_2 absorption and utilization make C4 plants more advantageous in competition with C3 plants during the ice age.

7.3 Discussion about the discovered taxa

Most discovered pollen taxa have their modern relatives extant on the earth today, and some of them were not useful for the paleoclimate or paleoenvironment reconstruction, but some of them were more representative separately or in combination. In some researches, the abundance of the fungal complex of microthyriaceous fruit bodies, hyphae fragments and spores were considered as indicators of higher humidity and heavy precipitation (Kumaran *et al*., 2013; Lezine and Cazet, 2005; Shi *et al*., 2001). Quantitative correlation analysis was prepared by software named Past (Hammer *et al*., 2001).

Spores from ferns, mosses, algae and fungi, were also accepted and calculated for the palynology research and paleoenvironment reconstruction (Almeida-Lenero *et al*., 2005; Dutta *et al*., 2011; Huang *et al*., 2009; Kumaran *et al*., 2013; Li, Zhang, Li, *et al*., 2010). Most of them are from small plants adapted to humid habitats, presenting difficult long distance transportation of spores except for some riverine groups, where they can disperse spores by water flow. However, just as for angiosperm pollen, not all algal and fungal spores can be well preserved. Preservation depends on the thickness and composition of the spore wall. Normally only the thick-wall spores can be preserved well, such as fungal spores of ascomycetes and Dematiaceae (Almeida-Lenero *et al*., 2005).

7.3.1 Fungi

The associations between plants and mycorrhizae are formed with most species of angiosperms, all gymnosperms and pteridophytes, and some bryophytes. Many terrestrial plants are mycorrhizal, including Fabaceae. The legume pollen and fungal spores were discovered in all the layers. The interaction between fungi and legumes created a complex symbiotic community underground. There were more than 12 fungal species in 2 genera (*Glomus* and *Acaulospora*) distributed 0 - 50 cm underground which were correlated with legumes (Daft and El-Giahmi, 1976; Brewin, 1991; Omar and Abd-Alla, 2000; He *et al*., 2008). In a survey carried out in Europe, 76% plants were infected by mycorrhizal fungi (Harley and Harley, 1987). The presence of the fungal spores and hyphae increases the nutrient absorption. Mycorrhizal associations often enhance the longevity of the roots (Isaac, 1992). Eutrophic rivers were usually seen when there was a low flow rate accompanied by the rich input of animal excrement and other organic waste (e.g., litter from trees and grass). The coprophilous fungal spores were used for environmental indicators, such as the characteristic fungi on mammal feces, especially from herbivores (Almeida-Lenero *et al*., 2005; Gill *et al*., 2009). They were found very commonly from the sediments of archaeological sites (Buurman *et al*., 1995; van Geel *et al*., 2003). Davis

(1987) reported the coprophilous fungus *Sporormiella*, which was used to calculate the abundance of large herbivores in North America. However, according to the results in this study, there was not a close relationship between fungi and legumes (Figure 7.1), but what was surprising was the positive relationship between the species diversity and fungal spores (Figure 7.2). The same conclusions were mentioned in other researches (Harley and Harley, 1987; Zhang *et al*., 1999). The richest records of fungal spores were found in the high moisture environment. Layer 10A reached to 23% fungal spores while layer 22 reached 44%. It was a strong evidence of a eutrophic river at that period. The occurrence of fungal spores was considered related to the water level (Almeida-Lenero *et al*., 2005). Layers 10A, 13B, 16A, and 22 were characterized by rich fungal spores indicative of the active decomposition of organic material during low water level and low flow.

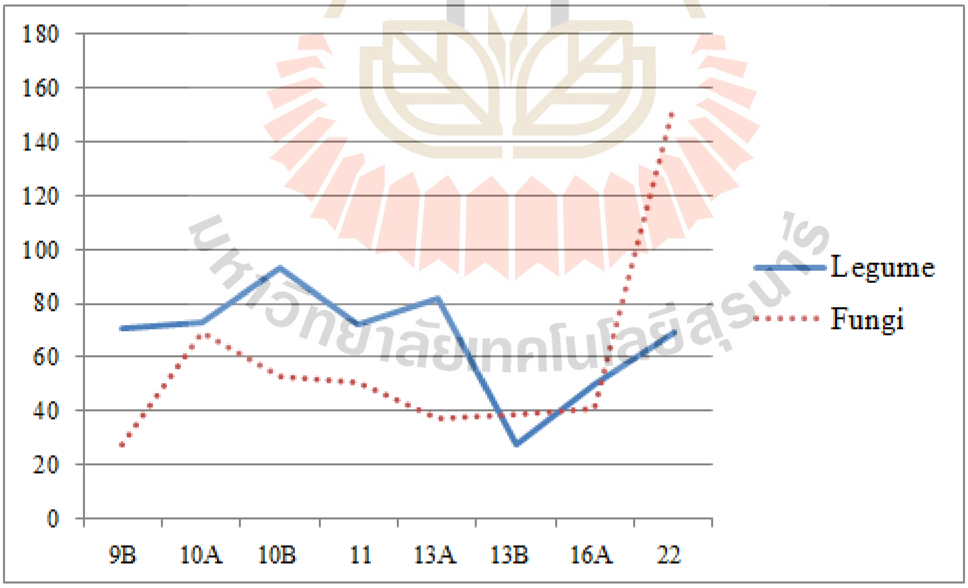

Figure 7.1 Relationship of fungi and legume.

Based on the correlation analysis, there is a weak correlation (r = 0. 774, P = 0.122) between fungi and legume. The Y-axis is the number of pollen and spore grains in the layer, while the X-axis is the layer.

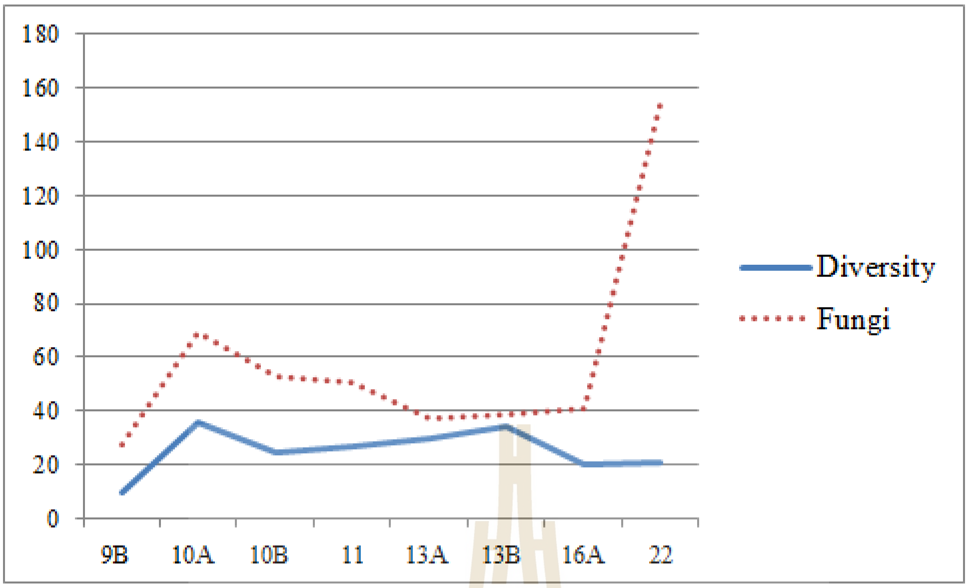

Figure 7.2 Relationship of fungi and diversity in the layers.

The species diversity discovered in all the layers is strongly correlated ($r = 0.983$, $P = 0.008$) with the fungal spores. The Y-axis is the real number of species and fungal spore grains in the layer, while the X-axis is the layer.

7.3.2 Moss

Bryophytes are usually epiphytic, often affected by organic litters. Bryophytes show wider geographic ranges than other terrestrial plants. Some of them even show extremely wide distributions within each major climatic region. Many species are commonly found in the habitat with high moisture, such as foggy mountain, cloud forest, and wetland. They are epiphytic on trees, or grow on soil and rocks. Scott (1988) presented an expansion of bryophyte ranges through vegetative means, given a long period for dispersal. The result showed an outward spreading from the original point to at least 10 km within a million years, although the expansion of a population was just one cm per year. Similarly to other terrestrial plants, many bryophytes prefer the suitable habitat although there is a huge disjunction. According to the opinion of Bates and Farmer (1992), three features accounted for the range of bryophytes spores: small size, vast numbers, and extremely long dispersal time. A peat humification record by stable carbon isotope of a *Sphagnum* peat bog in Germany was used to evaluate the deposit age (Kuhl *et al*., 2010). Moss spores were usually small (around 10 - 30 µm) and colorful (orange or yellow). Many spores were shrunken because of the thin sporoderm, and the ornamentation was sometimes obscure. They were commonly found in the sand pit of Ban Som and dominant in some layers, such as layer 13A (6%) and 22 (6%). It meant a relatively humid environment along the Mun River in the past. They flourished together with aquatic plants, such as *Typha*, *Hygrophila*, and duck weeds.

7.3.3 Pteridophytes

Generally, pteridophytes were not a dominant group in all the layers with few spores recorded, but to some degree, they indicate the regional habitat. They were growing well along the river nowadays. What should be mentioned was the appearance of *Acrostichum* in layer 10A. All species in this genus are known as aquatic, while *A. aureum* and *A. speciosum* were recognized as mangrove (Copeland, 1949; Croft, 1985; Dong and Funston, 2013; Holttum, 1954). However, they were also found in fresh water of Yunnan (Figure 7.3). *Acrostichum* (Figure 7.4) in this layer was an important component which indicates a light brackish environment when combined with *Nypa* and *Rhizophora* (Figures 7.5 and 7.6). *Ceratopteris* was another aquatic fern occurring in layer 13B; it was a representative species of a swamp or low velocity river (Figures 7.7 and 7.8).

Figure 7.3 *Acrostichum aureum* in fresh water. Photographed at Yunnan, China.

Figure 7.4 *Acrostichum aureum* in brackish water. Photographed at Satun, Thailand.

Figure 7.5 *Nypa fruticans* in brackish water. Photographed at Satun, Thailand.

Figure 7.6 *Rhizophora* sp. in estuary water. Photographed at Satun, Thailand.

Figure 7.7 *Ceratopteris thalictroides* in fresh water. Photographed at Yunnan, China.

Figure 7.8 *Ceratopteris thalictroides* in brackish water. Photographed at Hainan, China.

Aglaomorpha, *Davallia*, and *Polypodium* are found in layers 13A, 13B, and 22. They are epiphytic plants with developed rhizomes, attached to trees or rocks; they prefer high moisture and grow well in the forest with heavy canopy. The occurrences of these fern species indicate a relatively high moisture environment or dense canopy in the past (Figures 7.9 and 7.10).

Although most of the pteridophyte spores were too low to be considered, *Lygodium* was still rich enough for calculation in layer 10B, it was about 1%. Usually, *Lygodium* plants are considered as drought-tolerant plants and sometimes pioneer species in barren space of open area. Most *Lygodium* species grow well in the area with poor nutrients. It was not a dominant component in the layer but strongly indicates a dry habitat or open forest in this period (Figures 7.11 and 7.12).

Figure 7.9 Habitat of *Aglaomorpha coronans*. Photographed at KaoYai National Park, Thailand.

Figure 7.10 Habitat of *Davallia denticulata*. Photographed at KaoYai National Park, Thailand.

Figure 7.11 *Lygodium japonicum* in open forest. Photographed at Sakon Nakhon, Thailand.

Figure 7.12 *Lygodium flexuosum* in open forest. Photographed at Kanchanaburi, Thailand.

7.3.4 Conifers

Many gymnosperms are regarded as extra representative in local plant communities because of the high yield of pollen. It means the proportion of pollen grains in the sediment is higher than the real proportion in forest. They are well known for the developed air bag in *Abies*, *Picea*, and *Pinus*, etc. which benefit the distant dispersal and wind pollination. Many conifers (such as *Abies* and *Picea*) are strictly constrained by the environmental factors, some of them distributed only in the temperate zone or at high altitudes. Podocarpaceae mainly grow in the Southern Hemisphere but extend to some montane areas of the Northern Hemisphere (Fu *et al*., 1999). However, conifers were the regular components in the sediments and helpful in paleoenvironment reconstruction as an indicator of low temperature.

7.3.5 *Acacia*, *Pinus*, and Chenopodiaceae

There is still some controversy about the occurrence of some plant groups such as *Acacia, Pinus,* and Chenopodiaceae. *Acacia* was thought traditionally to have originated in Australia and Africa, but the primitive type was proved to have occurred in the dry and hot valley along Jinsha River (the upstream of Changjiang River), southwest China (Ali, 1973; Wu *et al*., 2003). It was not strange to find their pollen grains in the Late Pleistocene in the Khorat Plateau. It was recorded dominant in the layers and composed the main forest.

Pinus is distributed widely throughout the world in cool and dry areas (Eckenwalder, 2009; Fu *et al*., 1999; Penny, 2001; Werner, 1997). Some modern species such as *Pinus merkusii* and *Pinus kesiya* were reported distributed in the Indochina Peninsula, even distributed to Sumatra (Phengklai, 1972; Eckenwalder, 2009). They grow well in the relatively high montane area of the tropic zone, in poor soil and dry area. They are considered to be adapted to arid places and are fire tolerant; sometimes they are pioneer plants in disturbed areas. They strongly indicate a seasonal climate (Penny, 2001). However, it is difficult to say that the fossil *Pinus* pollen is the same as the extant species, but the combination of *Pinus* and Chenopodiaceae (sometimes plus *Artemisia*) was commonly accepted as an indicator of dry and cool climate (Faegri and Iversen, 1989; Kealhofer and Penny, 1998; Penny, 2001; Punt *et al*., 2004; Wang, 1983; Werner, 1997). *Pinus* pollen grains can spread over a wide range with the help of airbags. Sometimes pine pollen grains were discovered in the surface soil samples even though they are no pine trees in the area. This kind of invasion was thought to disturb the pollen diagram. However, pines are useful for the paleoenvironment reconstruction if one pays more attention on their long distance dispersal and disturbance in a local pollen diagram (Faegri and Iversen, 1989; Wang, 1983).

Suaeda maritima is the native species of this genus of Chenopodiaceae in Thailand, growing in saline water and loamy flats behind the mangroves (Santisuk and Larsen, 2000).

7.3.6 Aquatic plants and mangroves

Generally, aquatic plants grow in water or mud, such as rice, sedge, cattail, mangroves, water lily, lotus, etc. Fossil records of aquatic plants present an approach to the ancient river or water environment in the past (Jansonius and Kalgutkar, 2000). Some researchers insist that aquatic plant diversity is closely related to the river dynamics and water quality. Compared to the flooding season, a peaceful river tends to support more riverine species and has a high biomass (Biggs, 1995; Eaton *et al*., 2005; Jafari and Gunale, 2006; Li *et al*., 2012; Raut *et al*., 2010). The lacustrine sediments discovered in a wide range including most parts of South East Asia, West Java and Sumatra, West Malaysia, West Natuna in Indonesia, the Gulf of Thailand, the Nam Con Son and Coo Long basins offshore South Vietnam (Robinson, 1987). Some layers (10A, 10B, 11, and 13A) were proved a wet environment by the aquatic species, although the main components are different. The aquatic species in layer 10A, 10B, and 11 are from a brackish environment, while those in layer 13A are from fresh water.

There are 17 genera in the family Rhizophoraceae (Qin and Boufford, 2007) and 7 genera are distributed in Thailand (Hou, 1988). *Carallia*, *Gynotroches*, and *Pellacalyx* are found in evergreen or mixed forest, or sometimes grow in swamp forests, from the low land up to 1,320 m. However, the pollen of *Carallia* looked different to *Rhizophora*. Ther other two genera were still unknown. Thus taxa were therefore indeterminate to the genus level, but they were still considered as mangrove taxa in this study, because there were some other salt water tolerant species discovered in the same layer, such as *Barringtonia acutangula, B. racemosa, Nypa,* and *Typha*.

According to the mangrove records, layers 11, 10B, and 10A were continuous deposits. It was sure that a relatively high sea level existed at the age from 28,150 ± 7,860 yr BP to 52,296 ± 6,800 yr BP. This period was known as an interglacial before the last glacial age, with different name in other places, such as Tali, Wisconsin, Weichselian, Würm, and Devensian. The sea water rose up and covered vast low lands, and the tide line should be near or not so far from the sampling area of the Mun River. There were some similar wet climates reported around the Khorat Plateau at this stage, which suggested a similar temperature or precipitation at the regional level. Dated organic samples at Tung Kula Ronghai indicated a humid climate around 34,000 yr BP and 20,000 yr BP (Loffler *et al*., 1983). Mega fossils in Konkan of west India indicated prevalence of wet evergreen forest with high precipitation > 3,300 mm at the age of 44,000 yr BP (Kumaran *et al*., 2013). However, there are still some researches based on *Pinus* and *Quercus* which suggest that there was a cool and dry glacial climate around 38,000 yr BP in northeast Thailand (Penny, 2001).

Mangroves are adapted to salt water, occur around tropical or subtropical shorelines with their anemophilous and entomophilous flowers (Mao *et al*., 2006, 2008). They were discovered along the ancient Mun River. Although brackish water was thought important for the establishment of a mangrove system, it was determined mainly by the degrees of tidal inundation (Yakzan *et al*., 2010). According to the mangrove sediment researches (Li, Zhang, Zhang, *et al*., 2008; Punwong, 2007;

Rugmai, 2006), a proportion of more than 40% of the salt tolerant components represented a mangrove system. However, the mangrove components in this study were relatively low, and did not reach 10%. It should not be a local deposit but instead transported from somewhere else. However, it was tough work to explain how mangrove pollen grains occurred in this period, because the altitude of the sampling place is 154 m above the sea level (Figure 7.13). It was a huge barrier for the sea water transgression and also difficult for the dispersal of mangroves.

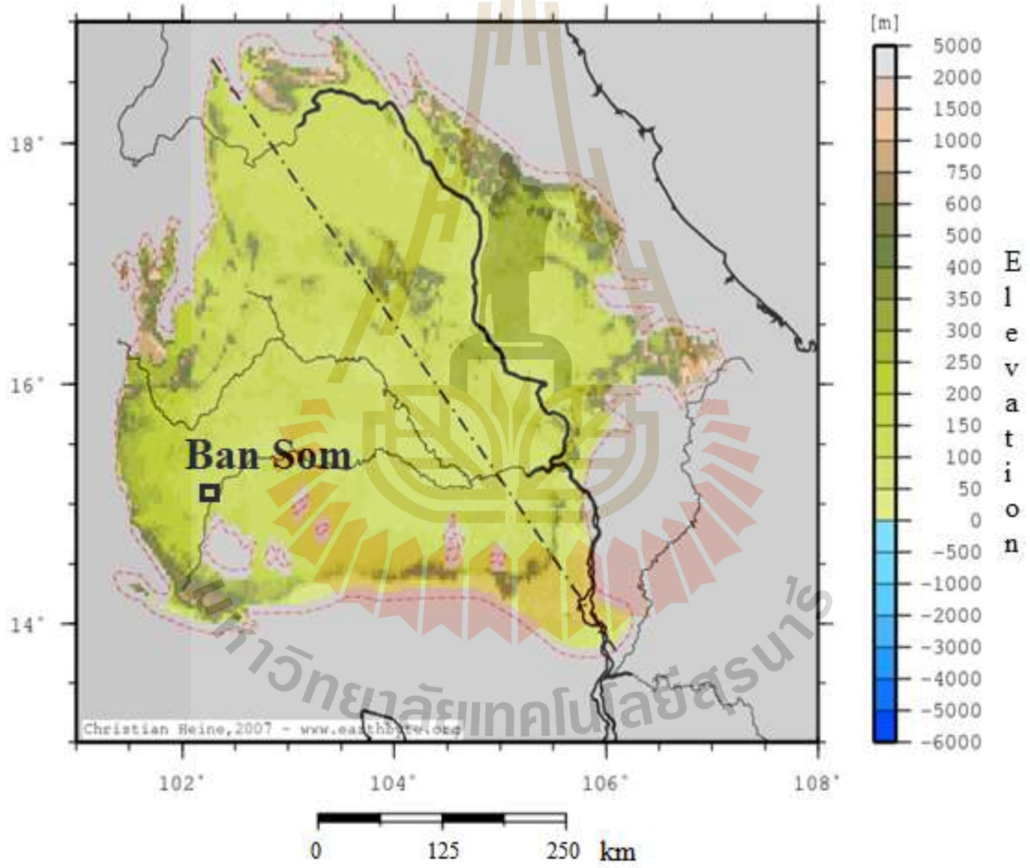

Figure 7.13 The topography of the Khorat Plateau (From Heine, 2007, with the sampling area marked).

Anyway, three hypotheses were suggested for the occurrence of brackish components in this plateau in the past although the evidences are absent:

(1) High temperature in these mangrove reported layers (10A, 10B, and 11) indicated a warm interglacial period and relatively high sea level; the sea water once covered the most part of the Lower Central Plain of Thailand (Paramita, 2007). The sea shore once reached the edge of Khorat Plateau (around 100 km) (Figure 7.14, 7.15). Mangrove grew very close to the head of the ancient Mun River, and the pollen grains transported by the summer monsoon from the ancient Gulf of Thailand. How frequently the sea level had changed and the terrestrial environment had shifted were important. There were several periods of sea level change in the Quaternary, fluctuating below or above the sea line today (Bloom *et al*., 1974; Camoin *et al*., 2001; Hallam and Cohen, 1989; Li *et al*., 2014; Louys, 2007; Wang and Wang, 1980). The high sea level was considered to be a result of temperature change or plate tectonics (Bloom *et al*., 1974; Camoin *et al*., 2001; Hallam and Cohen, 1989; Li *et al*., 2014; Louys, 2007; Verstappen, 1997).

(2) Salt water intruded the Mekong River and influenced its tributaries in the center part of the plateau when the sea level rose; glacial and interglacial events were closely related with the sea level change in the long term (Wang and Wang, 1980). According to the pollen records and age dating results, the layers 10A, 10B, and 11, were indicated by mangroves to be located in the interglacial period. The sea level was at a relatively high level and salt water intrusion is possible.

0 m sea level

60 m sea level

Figure 7.14 Sea level analog in the mainland of Southeast Asia (http://geology.com/ sea-level-rise/).

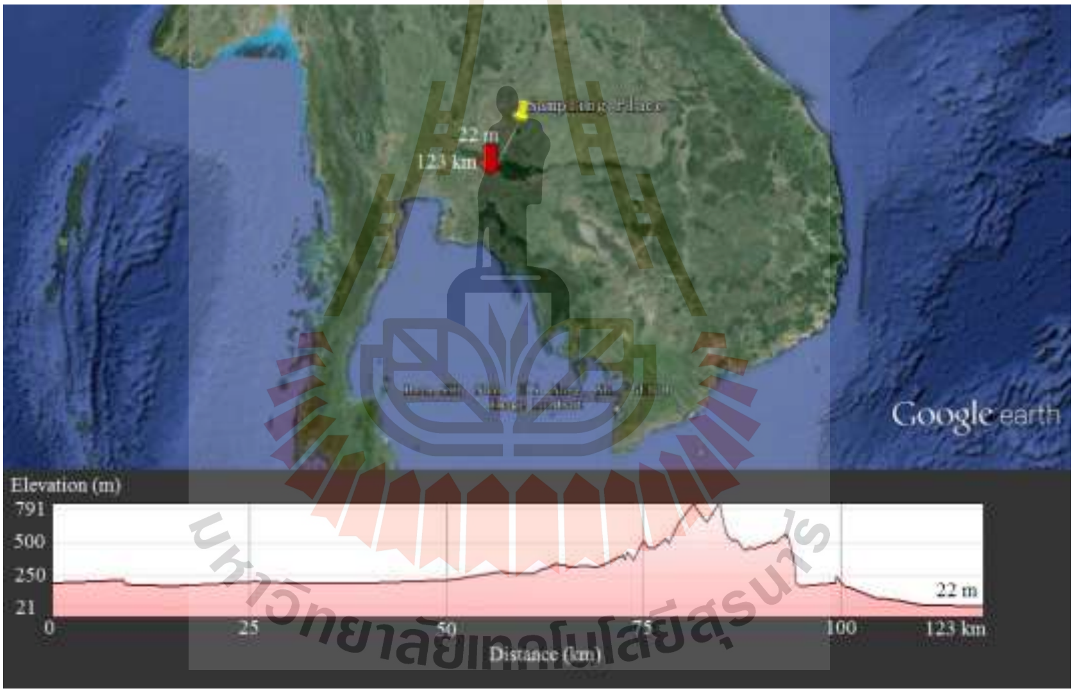

Figure 7.15 Elevation change from the Lower Central Plain to the Khorat Plateau (Google Earth, 2015).

(3) Some researchers mentioned that the lift and decline of the continental shelf in the South China Sea was caused by the tectonic activities that frequently happened in the Late Quaternary (Sun *et al*., 2003; Wang, 1978; Yuan *et al*., 2005). The lift was reported from 60 - 70 m in the continental margin of the South China Sea

to 800 m in Taiwan Island, while a continental decline was recorded from 200 m to 400 m in the North China Plain coast and Yangtze River Delta (Wang, 1978). The sea level increased 100 - 120 m in the South China Sea at the interglacial period of the Late Pleistocene. Furthermore, there was sea water transgression recorded in the Zhujiang River at the age of 20,000 - 30,000 yr BP (Xu *et al*., 1986). The sea level of the Gulf of Thailand had been influenced by the tectonic activities and it is one of the main reasons of the sea level change. There were two identified periods when the Malay Peninsula submerged, sea levels reached 100 m above present from 5 to 4 Ma and 100 - 150 m below present from 20 to 15 Ma (Miller *et al*., 2005; Woodruff, 2003). The Khorat Plateau is not exactly mentioned in the continental shelf lift or decline but the Gulf of Thailand is active tectonically. The vast continental shelf should have been submerged at the Late Pleistocene, the same time with the increasing in the South China Sea, and mangrove vegetation developed in such a brackish environment. Based on this hypothesis, the plateau was at a low elevation because of plate tectonics activities at the age of 52,296 ± 6,800 yr BP to 33,611 ± 4,000 yr BP, and the sea level was high.

However, more evidence is required especially the foraminifera, marine plankton or mollusks in the Quaternary.

7.4 The taphonomy and representatives of pollen components

The taphonomic processes should be considered in the reconstruction for their influence to the fossil assemblages (Lowe and Walker, 1997). This process includes pollen types, quantity, dispersal and transportation methods, deposition, and preservation. The primary pollen which comes out from the parent plants can be blown away and preserved to become fossil remains either way. The environmental condition in this process played a key role. Distant transportation and deposition, or even redeposition in a new locality also should be identified in the field or lab analysis, and then an attempt would be made to find out to what degree the plant remains discovered can represent the real vegetation at that time (Ferguson, 1967; Kou *et al*., 2006; Wang, 1983). However, we collected some modern sediment samples with detailed vegetation information, the extracted pollen assemblages matched well with the ground plant communities (Table 6.1). Therefore, it is convincible to reconstruct paleovegetation and environment.

In the palynology researches, the percentage of some pollen components sometimes cannot represent the real proportion in the plant community. It can be less or more than the true value. The plants which produce a large amount of pollen grains such as *Pinus* and *Betula*, were well known as over-representative (Li *et al*., 2005; Wang, 1983; Wei *et al*., 2009; Zhang and Long, 2007). It is a tough work about how to find the real proportion of an over representative pollen type in the vegetation. Some researches gave a reference proportion of conifers in the vegetation reconstruction *in situ* (Li *et al*., 2005; Wang, 1983). Usually, for the conifers, a percentage more than 50% in local pollen diagram can be accepted as a true value. Lower than 50% was considered not an *in situ* production but exotic. Grass pollen was also commonly seen in this study and dominant in some layers. They are small herbs without pollen air bags. There was research that mentioned a high density of 1,360 pollen grains / cm^2 on the ground, but it decreased dramatically along the distance from the flowering plants, only 3 grains / cm^2 recorded in the distance of 300 m (Li *et al*., 2005; Wang, 1983). However, in concrete analysis of concrete conditions, the river flow is the main transfer media in this study, and then it is the wind. Long distance transportation and exotic accumulation are feasible, and over-representation can happen too. Furthermore, Poaceae species habitats cover aquatic and terrestrial areas, and most of them are also pioneer species of the barren areas. There is no reference value on the over- representation and a value similar to *Pinus* (50%) was accepted.

Abies was regarded as under-representative; the pollen proportion in the sediment is usually lower than the real value (Li *et al.*, 2005; Wang, 1983). This means the real proportion of *Abies* in layer 13B (2%) and layer 16A (3%) should be higher.

External pollen grains are a negative interference in the paleovegetation and paleoenvironment reconstructions. They invade the local pollen flora by long distance dispersal by the means of wind and water. Long distance dispersal results in a deposit far away from the parent tree, and then the pollen grains may accumulate to a high proportion even though they never grow there. It is just a false occurrence in the pollen diagram. However, the occurrence of pine was usually considered to be an indicator of regional cool events without considering the over or under representation. Some other components such as *Artemisia*, *Chenopodium*, and *Suaeda* suggested strong circumstantial evidence in such a climate pattern.

Acacia and *Albizia* were commonly seen in all the pollen layers in this study, and sometimes got a high proportion (totally 31% in layer 10B and 28% in 13A). The two taxa are regularly found in the Khorat Plateau nowadays. Although they were dominant in some layers (31% in layer 10B and 23% in 22A) or sub-dominant in some layers (24% in layer 10A, 11, and 28% in 13A), they still cannot be considered as being over or under representative. There is a secondary succession forest of

Leucaena trees (with a similar pollen dispersal approach with *Albizia*) in Suranaree University of Technology located in the Khorat Plateau. A reference surface soil sample was collected and analyzed. The pollen proportion matches well with the extant community (90% pollen records in the soil and 82% trees in the ground forest).

Pollen grains of *Melia* were also discovered with few grains in layer 13A and 22; the fruit of *Melia azedarach* was identified in the sediment of Pleistocene age at Khoh Sung (about 30 km from this study site). It indicated a low representative of *Melia* in the Khorat Plateau.

7.5 The charcoal layer and wildfire

Charcoals are some kinds of carbon residues. They were usually produced by slow pyrolysis, the heating of wood or other substances in the absence of oxygen. A natural fire of woods, leaves, or other organic matters burns in the presence of oxygen. Long term moderate oxidation processes can proceed in deposits under pressure and heat. This is a geological process and happens in the deep sediments. Charcoals were frequently discovered which indicate natural fire in the past (Ali *et al.*, 2009; Bird *et al*., 2005; Leys *et al*., 2013; Luo *et al*., 2006; Woodruff and Turner, 2009). Fire-history reconstruction was based on the size and number of charcoal fragments. The volume of charcoal particles was suggested as a method of quantifying past charcoal production (Ali *et al*., 2009; Leys *et al*., 2013). A global charcoal database was set for regional fire history reconstructions. This data base focuses on data exploration, hypothesis testing, and evaluation of combined climate–vegetation–fire model simulations (Power *et al*., 2010). A connection between the Late-Glacial history of fire and vegetation suggested a substantial rebuilding of plant communities and an enhanced fire regime (Gill *et al*., 2009). A palynology research focused on the subalpine vegetation of Mt. Wilhelm, Papua New Guinea mentioned how the local fire regime correlated with the vegetation change (Corlett, 1984).

In this study, numerous charcoal fragments, from micrometer (μm) to millimeter (mm) in size were discovered in layers 10A, 13A, and 13B. The layer 13B was reconstructed as a temperate savannah while 10A and 13A were regarded as forest with more trees. They are tiny as the same size as pollen grains, and can be transported by the wind, river, and even rainfall. However, *Acrostichum* (few), *Nypa*, Rhizophoraceae (few), and *Typha* were discovered in 10A, while *Barringtonia*, *Hygrophila*, *Oncosperma*, and high percentage of moss were found in 13A. These plants indicated a vegetative wetland or high moisture environment which is difficult for frequent natural fires. This layer had the richest pollen taxa (36 taxa) which means a highest diversity and rich biomass of ground vegetation. It is correlated with charcoal and biomass to a certain degree but it is too difficult to propose a frequent natural fire at this place. Distant transportation and aggradation of these charcoal fragments were reasonable explanations. Whatever, it is commonly accepted that the combination of Pinaceae and Poaceae indicates a dry and cool environment which facilitate frequently natural fires in the past (Ali *et al*., 2009; Bird *et al*., 2005; Gill *et al*., 2009; Leys *et al*., 2013; Woodruff and Turner, 2009). The charcoal fragments in layer 16A were correlated to *Abies* and high proportion of grass, they agreed with the popularly accepted criteria about the natural fire. The resource is low but it was the evidence of a relatively low temperature and should not be deposited *in situ*; a strong winter monsoon can move them to the Khorat Plateau from the north. Therefore, we regarded that frequent local fire occurred in the layer 13B, around 88,661 ± 10,600 yr

BP. A cold and dry period related with temperature decline facilitated the wild fire and accelerated it. Anyway, natural fire also commonly occurs nowadays in dry dipterocarp forests in the Khorat Plateau (Figures 7.16)

Another opinion mentioned a meteoritic or cometary impact at 0.69 - 0.80 Ma (Charusiri *et al*., 2002; Haines *et al*., 2004; Satarugsa *et al*., 2005; Sato, 2002; Songtham *et al*., 2012). The impact destroyed most of the plants and animals in a short time, and the ash covered the sky for a longtime. However, we did not get any tektite fragments in this layer. Furthermore, the river was also influenced by the wild fire. Destroyed vegetation cannot hold the riverbank strongly; more clasts rushed in to the channel and deposited, accelerating the channel fill succession. Channels were reported to respond to fire-related change by aggradation, braiding, enlarging, and lateral migration, entrenching and narrowing (Laird and Harvey, 1986; Legleiter *et al.*, 2003).

Figure 7.16 Natural fire occurs every year in the Khorat Plateau (Photographed at Sakaerat Biosphere Reserve).

7.6 The wood log layer

There were 2 layers (10B and 11) dominated by semi-carbonized wood logs, the size was from several centimeters to more than 1 m, usually several meters in length. A huge number was present at the depth from -7.75 m to -8.5 m, but absent in other layers. The species name was still unknown, but some trunks were found to have developed buttress base roots and tree rings (Figure 7.17). Buttress was strongly regarded as one of the main characters of tropical arbors influenced by frequent summer monsoon. Some research thought it was convenient for collecting nutrients on the surface soil, and combined an intricate mesh with other trees for supporting each other (Crook *et al*., 1997). Mangrove forest was also dominant with buttresses. Tree rings were commonly seen in the temperate trees. They were also found in some tropical deciduous species (e.g. *Tectona grandis*). The weather (precipitation and temperature), soil pH, plant nutrition, CO_2 concentration, etc. in different years were used in dendroclimatology to infer the past climate variations (James, 2010). The C14 dating is 28,150 ± 7,860 yr BP, while the TL dating is 33,611 ± 4,000 yr BP in layer 10B and 48,022 ± 6,200 yr BP in layer 11. According to the reconstruction, it was tropical and subtropical mangrove forests in these two layers. Pollen records agreed with the characters of the semi-carbonized woods.

It is difficult to explain that a lot of logs had fallen at the same time and were lying randomly. High concentrations of a lot of mega fossils usually indicate natural hazards. However, the logs were not located in the same layer with tektites, and there was no signal of a big fire, so the cometary event was excluded. Even though there is not enough evidence, we still suggest a strong storm should have caused this case.

Figure 7.17 Fossil logs with buttress and tree rings in the layer 10B and 11.

CHAPTER VIII

CONCLUSION

The expected results and hypothesis were realized in this research. A lot of pollen records were discovered in Ban Som along the ancient Mun River. Palynofloras were composed of Fabaceae, Poaceae, Lecythidaceae, Pinaceae, etc.. Paleovegetation and paleoenvironment of the Khorat Plateau were reconstructed based on the representative species, or their assemblages. Paleovegetation shifts following global events were classified in each layer. River evolution, glacial/interglacial, tectonic activity, sea level change, and natural fires were suggested attributed to the various paleovegetations. Temperate and subtropical savannah, tropical and subtropical deciduous forest, tropical shrubland, and subtropical forest mixed with developed swamps were rebuilt based on the palyomorphs and their assemblages. However, there were no records similar to the modern vegetation in the Khorat Plateau. Vegetative deciduous forest and swamp forest flourished in the layers 10A (52,296 ± 6,800 yr BP), 10B (33,611 ± 4,000 yr BP), 11(48,022 ± 6,200 yr BP), and 13A (51,682 ± 6,700 yr BP). The highest diversity occurred in the channel deposits stage and indicated a developed river system and vegetative plants. Dry grass land widely spread in the layer 9B (27,332 ± 3,000 yr BP), 13B (88,661 ± 10,600 yr BP), and 16A (172,739 ± 22,400 yr BP). The brackish components suggested a relatively high sea level at the stage of 33,611 ± 4,000 yr BP to 52,296 ± 6,800 yr BP, and mangrove forest developed at the sea shore located near the edge of the Khorat Plateau. Some hypotheses are suggested associating to this change, such as interglacial, salt water intrusion, and tectonic activities. The chilling periods in the layers 9B, 13B, and 16A agreed with the main glacial events. Cold winter monsoon had been prevalent in the Khorat Plateau even though the main ice gap was far.

The ancient fluvial terrace was classified into three stages from the top to the bottom: dry land, channel river, and lake and flood basin. At least four cycles of "pebble - granule - sand/clay" which related to the river succession were recognized and matched well with the palynoflora records. However, there are still some tough problems not yet resolved:

(1) Himalayan-Tibetan orogeny, significant elevation (3 km) had been created in Tibet (Yin and Harrison, 2000). As the southeast extension of the Himalaya Mountain ranges, the elevation of the Khorat Plateau should be more or less influenced by this collision. Furthermore, the activity of the continental shelf was closely related to the environment change especially the coastal area, the impact in this area is still unknown and more evidences, such as foraminifera, sea plankton or mollusks are required.

(2) More megafossils are required especially in the glacial period. The change of local fauna and flora would suggest the migration of mammals and plants in the Quaternary, and indicate environmental change. The taxonomy of the semi-carbonized logs in the layers 10B and 11 has not progressed.

(3) The Southeast Asia Monsoon dynamics in the past time is not clear; the strength, season, direction etc. are difficult to determine. These factors are closely related with the dispersal of anemophilous pollen grains.

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APPENDICES

APPENDIX A

MODERN VEGETATION INVESTIGATION AROUND THE SAMPLING AREA

Code	Family	Species	Note
1	Annonaceae	*Polyalthia debilis*	
2	Aristolochiaceae	*Aristolochia pothieri*	
3	Asteraceae	*Chromolaena odorata*	exotic
4	Asteraceae	*Ageratum conyzoides*	exotic
5	Bombaceae	*Bombax cambodiense*	
6	Burseraceae		
7	Connaraceae	*Ellipanathus tomentosus*	
8	Cycadaceae	*Cycas siamensis*	
9	Fabaceae	*Acacia catechu*	exotic
10	Fabaceae	*Samanea saman*	Exotic
11	Fabaceae	*Albizia lebbekkoides*	
12	Fabaceae	*Erythrophleum* sp.	
13	Fabaceae	*Mimosa pigra*	exotic
14	Fabaceae	*Sindora siamensis*	

(Conituned.)

Code	Family	Species	Note
15	Fabaceae	*Pterocarpus macrocarpus*	
16	Fabaceae	*Xylia xylocarpa*	
17	Dipterocarpaceae	*Dipterocarpus obtusifolius*	
18	Dipterocarpaceae	*Dipterocarpus tuberculatus*	
19	Dipterocarpaceae	*Shorea obtusa*	
20	Dipterocarpaceae	*Shorea siamensis*	
21	Lygodiaceae	*Lygodium japonicum*	
22	Malvaceae	*Microcos tomentosa*	
23	Malvaceae	*Urina lobata*	
24	Menispermaceae	*Pachygone dasycarpa*	
25	Menispermaceae	*Tinospora crispa*	
26	Melastomataceae	*Memecylon edule*	
27	Moraceae	*Streblus asper*	
28	Ochnaceae	*Ochna integerrima*	
29	Passifloraceae	*Passiflora foetida*	exotic
30	Poaceae	*Bambusa* sp.	
31	Poaceae		
32	Pontederiaceae	*Eichhornia crassipes*	exotic
33	Rubiaceae	*Paederia* sp.	
34	Rubiaceae	*Gardenia sootepensis*	

(Continued.)

Code	Family	Species	Note
35	Phyllanthaceae	*Phyllanthus emblica*	
36	Rhamnaceae	*Ziziphus cambodiana*	
37	Rhamnaceae	*Ziziphus oenoplia*	
38	Rutaceae	*Naringi crenulata*	
39	Salicaceae	*Casearia grewiifolia*	
40	Smilacaceae	*Smilax* sp.	

APPENDIX B

IDENTIFIED PALYNOMORPHS IN THE LAYERS

Species		Layers							
		9B	**10A**	**10B**	**11**	**13A**	**13B**	**16A**	**22**
Present in	Fungi	28	69	53	51	37	39	44	154
each layer	Moss	9	5	3	3	17	10	4	18
	Poaceae	187	122	60	104	129	178	178	50
	Fabaceae - *Acacia* sp.	25	28	22	21	8	11	23	29
	Fabaceae - *Albizia* sp.	46	45	71	51	74	7	27	40
Pteridophytes	Davalliaceae - *Davallia* sp.		3	3			1		
	Lygodiaceae - *Lygodium* sp.			4	1	3	2		

(Continued.)

Species		Layers							
		9B	10A	10B	11	13A	13B	16A	22
Pteridophytes	Ophioglossaceae - *Ophioglossum* sp.		2	2					1
	Polypodiaceae - *Aglaomorpha* sp.					1			
	Polypodiaceae - *Polypodium* sp.	2					1		
	Pteridaceae - *Acrostichum* sp.		1						
	Pteridaceae - *Ceratopteris* sp.					1	1		
	Pteridaceae - *Pteris* sp.		1		1			2	
Temperate	Fagaceae - *Castanopsis* sp.			5	6				
	Fagaceae - *Quercus* sp. (traditionally)				4		2		
	Pinaceae - *Abies* sp.						7	9	1
	Pinaceae - *Pinus* sp.							9	
	Pinaceae - *Pseudolarix* sp.	5						1	

(Continued.)

	Species	Layers							
		9B	10A	10B	11	13A	13B	16A	22
Aquatic	Acanthaceae - *Hygrophila* sp.					3		1	
	Arecaeae - *Nypa* sp.		7		6	5			
	Arecaeae - *Oncosperma* sp.					11	10		2
	Commelinaceae		4	5		8		1	4
	Lecythidaceae – *Barringtonia racemosa*		1		14	4	14		
	Lecythidaceae - *Barringtonia acutangula*				3				
	Rhizophoraceae		1	8	9		1		
	Typhaceae - *Typha* sp.		24		20		1	19	8
	Verbenaceae-*Avicennia*			1	2				
	Combretaceae		3		5				

(Continued.)

	Species	Layers							
		9B	10A	10B	11	13A	13B	16A	22
Terrestrial	Acanthaceae - *Ruellia* sp.			3			3	3	
	Adoxacea - *Viburnum* sp.				7	6			
	Araliaceae - *Schefflera* sp.			15					
	Asteraceae		2	1		1	1		
	Bignoniaceae - *Radermachera* sp.		1		1			5	
	Chenopodiaceae			13	1	3		6	
	Cyperaceae		2				2	1	
	Euphorbiaceae - *Mallotus* sp.			1					1
	Euphorbiaceae - *Croton* sp.		1	6	2	4	4		
	Fabaceae - *Senna* sp.						7		
	Gesneriaceae - *Primulina* sp.						3	1	

(Continued.)

	Species	Layers							
		9B	10A	10B	11	13A	13B	16A	22
Terrestrial	Lythraceae - *Lagerstroemia* sp.		2	35		1			1
	Malvaceae		1				2		1
	Meliaceae - *Melia* sp.					1			1
	Oleaceae - *Syringa* sp.		5				2		
	Rubiaceae - *Canthium* sp.						8		
	Rutaceae - *Acronychia* sp.		1						
	Sterculiaceae - *Pterospermum* sp.			1	1	2			
	Theaceae - *Camellia* sp.		3						
	Tiliaceae - *Grewia* sp.						1		1

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