THE PALEOENVIRONMENT AND VEGETATION CHANGE DURING THE LATE QUATERNARY PERIOD OF SOUTHERN THAILAND FROM THE PALYNOLOGICAL RECORD

Wipanu Rugmai

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การศึกษาสภาพแวดล้อมบรรพกาลและการเปลี่ยนแปลงพืชพรรณในช่วงปลายยุคควอเทอร์นารี ในพื้นที่ภาคใต้ของประเทศไทย จากหลักฐานทางเรณูวิทยา

นางวิภานุ รักใหม่

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

Thesis Examining Committee

____

(Asst. Prof. Dr. Nathawut Thanee)

Chairperson

____

(Dr. Paul J. Grote)

Member (Thesis Advisor)

____

(Prof. Dr. David K. Ferguson)

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ตะกอนดินตัวอย่างจากหลุมขุดเจาะสองหลุม ที่อำเภอสิงหนคร จังหวัดสงขลา ตรวจหาอายุแล้วพบว่าเป็นตะกอนดินยุคไพลสโตซีน โดยมีอายุตั้งแต่ก่อน 33,880 ± 280 ปี จนมาถึงปัจจุบัน ตะกอนดินดังกล่าวได้นำมาสกัดหาละอองเรณู โดยใช้วิธีอซิโตไลซิส หลังจากนั้นได้นำมาศึกษาภายใต้กล้องจุลทรรศน์แบบใช้แสง และกล้องจุลทรรศน์อิเลคตรอนแบบส่องกราด เพื่อใช้สังเกตลักษณะทางกายภาพ พร้อมทั้งการถ่ายรูป ส่วนการจำแนกชนิดละอองเรณูนั้น ใช้การเทียบเคียงจากกุญแจและคู่มือการจำแนกชนิด และการเปรียบเทียบกับชุดละอองเรณูพืชปัจจุบันที่ได้จัดทำขึ้น ละอองเรณูที่พบนั้นสามารถจำแนกได้เป็นสามกลุ่มใหญ่คือ เฟิร์น พืชเมล็ดเปลือย และพืชมีดอก หลังจากนั้นได้จัดทำแผนผังละอองเรณูขึ้น เพื่ออธิบายถึงสังคมพืชในอดีต ซึ่งพบว่า มีสังคมป่าชายเลน ป่าหลังป่าชายเลน ป่าชายหาด ป่าที่ราบต่ำ ปรากฏอยู่ในพื้นที่มาตั้งแต่ช่วงปลายยุคไพลสโตซีน ลำดับชั้นดินตะกอนได้ถูกจัดแบ่งเป็นโซนการเปลี่ยนแปลงพืชพรรณโดยใช้ลักษณะการเปลี่ยนแปลงของสัดส่วนของละอองเรณูพืชป่าชายเลน และละอองเรณูพืชกลุ่มอื่น นอกจากนี้ การมีละอองเรณูพืชป่าชายเลนปรากฏยังบ่งชี้ถึงการเปลี่ยนแปลงตำแหน่งของฝั่งทะเลได้ด้วย

สาขาวิชาชีววิทยา　　　　ลายมือชื่อนักศึกษา_______________

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WIPANU RUGMAI : THE PALEOENVIRONMENT AND VEGETATION CHANGE DURING THE LATE QUATERNARY PERIOD OF SOUTHERN THAILAND FROM THE PALYNOLOGICAL RECORD.
THESIS ADVISOR : PAUL J. GROTE, Ph.D. 175 PP.

PALYNOLOGY/POLLEN/VEGETATION CHANGE/ PALEOENVIRONMENT/ SEA LEVEL/LATE QUATERNARY/LATE PLEISTOCENE/ SONGKHLA LAKE

Sediment samples were collected from two sediment cores retrieved from Singha Nakhon district in Songkhla province, southern Thailand. Sediment samples were dated and the age of the cores was found to be from the Late Pleistocene (before 33,870 ± 280 BP) until the present day. Pollen was extracted from the sediment using the standard acetolysis method. A compound microscope and scanning electron microscope were used for morphological observations and taking photographs of the fossil palynomorphs. Identification, conducted using keys and modern pollen reference collections, indicated origin from ferns, gymnosperms, and angiosperms. Plant communities were explained by pollen diagram interpretation. It was found that mangrove, back mangrove, beach, and lowland forest were already established in the area in the Late Pleistocene. The layers were divided into zones based on changes in relative proportions of mangrove and other taxa. Presence of mangrove pollen can be used to indicate shoreline position.

School of Biology	Student's Signature____________________
Academic Year 2006	Advisor's Signature____________________
	Co-advisor's Signature_________________
	Co-advisor's Signature_________________

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Wipanu Rugmai

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CHAPTER I

INTRODUCTION

Climate change and global warming problems have been discussed for decades. Causes, effects, and solutions of these problems have been investigated on a large scale. Human activities are thought to be a major source of the problems because of production of greenhouse gases, deforestation, and burning from vehicles and industry, for example. The consequences are threatening and dangerous, resulting in droughts, diseases, floods, and even ecosystem degradation or loss.

However, Earth’s climate itself has changed over its long history. Temperatures have at times warmed, causing the rising of sea levels. Sometimes, the climate has become extremely warm, but this phenomenon occurred slowly over thousands of years. Alternately, cold periods have also occurred, resulting in glaciations and sea level regression. Ecosystems have consequently changed over the long Earth history. These changes have left evidence in geological traces, including animal and plant fossils. Knowledge from these clues will lead to proper preparation to confront and solve the problems eventually.

This study proposes ‘palynology’ as an indicator to understand interactions between climate changes and ecosystem responses.

1.1 Palynology

Palynology is a term used for the study of pollen, spores, and other resistant microfossils, such as diatoms, dinoflagellates, cryptogamous spores, small animal remains, etc. (Hyde and Williams, 1944). Before that, the term **pollen analysis** was used for the technique of reconstructing former vegetation by means of the pollen grains it produced. This technique was at first limited to studies of Late Quaternary vegetation in lake and bog deposits. Today, it is also used in pre-Quaternary beds and studies of a wide range of deposits (marine, lacustrine, and terrestrial sediments, loose and consolidated). The term pollen analysis is reserved for the original concept of analysis of fossil pollen in a geological context (Faegri and Iversen, 1989). The term palynology covers a wider meaning than pollen analysis and will be used in this study.

1.2 Basic principles of palynology

Pollen refers to the microspore or microgametophyte formed in the microsporangia of seed-producing plants. Most pollen grains are extremely small in the order of 10-100 μm in diameter (Faegri and Iversen, 1989). A typical pollen wall consists of three elements: perine, exine, and intine. The perine is the outer layer, which is not always resistant to acetolysis treatment. The exine is the middle layer that consists of a resistant and waxy coat of material called sporopollenin, which can be preserved in fossil form. The intine is the inner layer that consists of cellulose, which does not fossilize (Faegri and Iversen, 1989; Punt, Blackmore, Nilsson, and Thomas, 2004). The exine is characterized by a variety of morphological and structural features. The morphological characters of pollen, such as overall size and shape, the number and distribution of germinal apertures, and also the structure and sculpturing of the perine and exine layers, can be used for taxonomic identification.

Spores, which are always included in palynomorph studies, are the reproductive units representing the gametophyte stage of lower plants (cryptogams), such as ferns (Pteridophyta) and mosses (Bryophyta), as well as algae and fungi.

Pollen grains contain the dispersed male gametophyte generation of the angiosperm or gymnosperm. Spores are also the dispersal phase of the cryptogams. When a pollen grain arrives at the stigma (or micropyle) of a plant of the same species, germination can occur with subsequent fertilization of an egg. On the other hand, a cryptogam spore simply requires to reach a site suitable for its germination, and a gametophyte plant can establish and grow (Moore et al., 1991).

Pollen grains and spores are frequently dispersed in very large numbers, which maximizes the opportunities for successful pollination or gametophyte growth. Large amounts of them therefore accumulate on the ground surface or in water. Some may subsequently become fossilized in the sediments. Pollen grains and spores are dispersed in different ways (Fig. 1.1). Spores are usually dispersed by wind, while pollen grains can also be dispersed by water, insects, birds, or mammals.

Taxa with wind-borne pollen, termed anemophilous, generally produce a greater number of grains than entomophilous taxa, which produce pollen transported by insects. Wind dispersed pollen is normally small, with a smooth surface, and low specific gravity. These features help facilitate the dispersion. In the pollen of some gymnosperm taxa, air bladders or sacs have evolved not only as a means of reaching the pollen chamber, but to enable pollen to remain air-borne for a long time and a long distance (Lowe and Walker, 1997). Entomophilous grains have evolved hardy, armored surfaces, which often have prominent spines and are coated with a sticky material (pollenkitt). These features enable them to adhere to one another and to the animal vectors (Lowe and Walker, 1997). Because the entomophilous species usually produce much fewer pollen grains than anemophilous species, their pollen is likely less well represented in the fossil record than the anemophilous pollen.

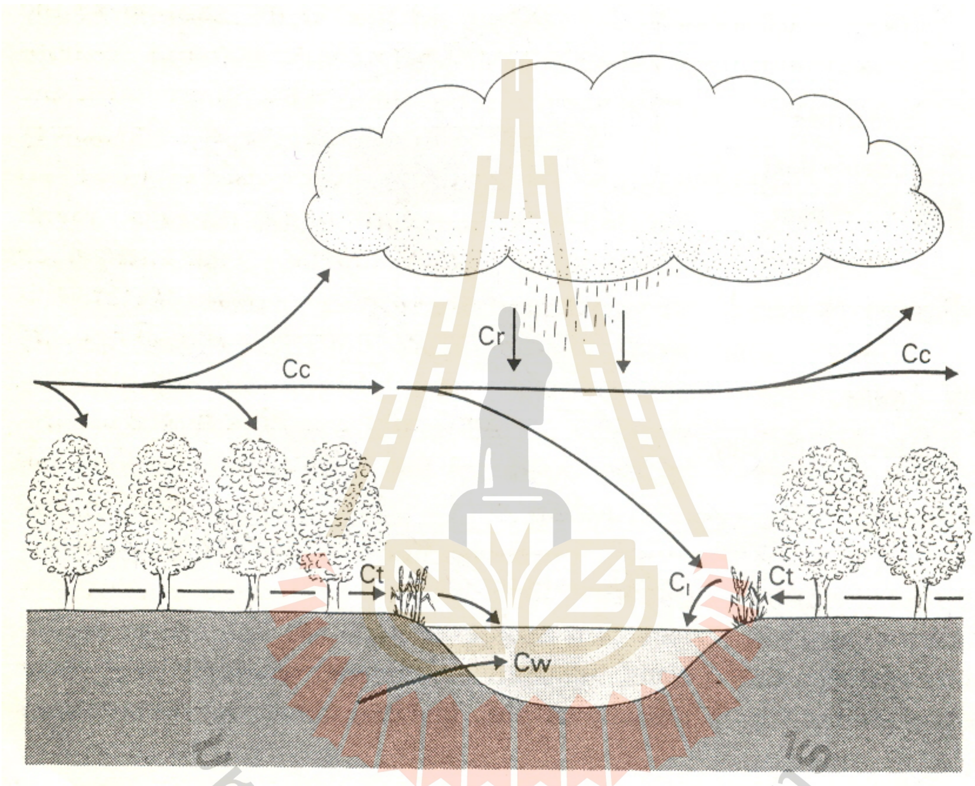


Fig. 1.1 The illustration shows the various sources of pollen in a small lake or mire within a wooded landscape (after Moore et al., 1991, p.12). Cc = canopy component; Cl = local component; Cr = rain component; Ct = trunk space component; Cw = secondary component, transported by water.

Moreover, suitable conditions are needed for pollen to become fossilized. Optimal environments for fossil preservation can occur in freshwater lakes, bogs, swamps, brackish water estuaries, and ocean basins. Organisms living near aquatic habitats are more frequently represented in the macrofossil record than organisms from purely terrestrial habitats (hinterland). The fossil record of pollen grains and spores is exceptional in that they consistently represent plant taxa from both terrestrial and aquatic ecosystems (Delcourt and Delcourt, 1991).

The interpretation of past vegetation by pollen analysis must, however, take the taphonomic processes that influence the fossil assemblages into consideration (Lowe and Walker, 1997). These involve processes of pollen production, pollen dispersal and transportation, pollen deposition, pollen preservation, and sampling techniques. Pollen shed from parent plants may or may not be preserved to become fossil remains, depending on the conditions in each process. Some fossils may subsequently be removed from their initial place of deposition and redeposited in a new locality. Thus, 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 the time (Ferguson, 1993; Ferguson et al., 1996). The modern pollen assemblages collected from waterlogged locations can be used as a modern vegetation analog. This approach will give a reasonable degree of confidence to reconstruct former vegetation (Lowe and Walker, 1997).

1.3 Thailand and paleoenvironmental reconstruction

Plate tectonic theory places Thailand in the middle of the mainland of southeast Asia. The collision of the Indian plate with Asia in the Middle Eocene and the compression from the south and the east caused by the Pacific and Australian plates during the Neogene led to partial connections between Australia, Eurasia, and the Pacific. At that time there were good opportunities for dispersal, intermixing, and unique development of the floras in this region (Morley, 2000).

At present, the area of Thailand experiences a monsoon climate and lies between two major biogeographical regions, the Indo-Himalayan-Chinese region (including eastern Himalaya, Myanmar, south China, Indo-China) and the Malesian region. It has become a crossroad of the two major floristic elements (Pooma, 2003). This is one reason why Thailand has a high diversity of plants.

The southern part of Thailand is covered by mangrove and beach forests along the east and west coasts with scattered patches of freshwater swamp forests. Importantly, it is the only part of Thailand that is (or was) covered by large areas of tropical lowland evergreen rainforest. This makes southern Thailand an interesting area for studies of environmental and vegetational changes through time.

There is no indication that, during the Pleistocene epoch, long known as the Ice Age, any mainland mountain in Southeast Asia (even Doi Inthanon, which is the highest mountain in Thailand) was glaciated. However, Mt. Kinabalu, Sabah, in east Malaysia on the island of Borneo and minor areas of the Aceh Mountains in North Sumatra were glaciated (Maloney, 1995). Moreover, there are some studies (Woodruff, 2003; Meijaard, 2003; Van der Kaars and Dam, 1995) suggesting the expansion of dry climates in Southeast Asia during the Pleistocene. The pollen evidence indicated that the Malesian rain forest pollen was pushed further south, whereas savanna vegetation was present forming the ‘savanna corridor’ from Thailand into the Malay Peninsula. This may have allowed the migration of savanna plants and animals across the area at that time (Medway, 1972; Morley and Flenley, 1987; Morley, 2000). Furthermore, during the glacial phases, when a great deal of water was locked away in the 3-4 km thick polar ice caps, the sea level was about 125 m lower than today resulting in the present Gulf of Thailand becoming dry (Morley, 2000). The above studies show that the vegetation in this area has been sensitive to the climatic changes.

There is very fragmented and discontinuous information about vegetation and climatic changes during the Late Quaternary of SE Asia. Most of the studies are restricted to the time of the Pleistocene / Holocene boundary (Maloney, 1992;1995, Maxwell, 2001, White et al., 2004, Yulianto et al., 2004, Horton et al., 2005, Li et al., 2006). More evidence prior to that time is needed to make the retrospective pictures clearer and more continuous, especially evidence from areas in Thailand.

Important questions, such as how long ago vegetation types were established, how they changed, and under what conditions, need to be investigated. To understand how Thailand’s vegetation was established and changed, information concerning the changes in geology, environment, fauna, and flora is needed both from within Thailand and on a regional scale, i.e., Southeast Asia.

Pollen data starting from the Late Pleistocene, before the Last Glacial Maximum (LGM), in peninsular Thailand will be investigated in this study. This research is expected to provide more complete information on the paleovegetation and paleoenvironment of Thailand and SE Asia.

1.4 Objectives

The main objective of this study is to investigate the pollen assemblages from the Late Pleistocene and Holocene of southern Thailand in three aspects as follows:

1. To identify the fossil pollen and spore assemblages from the late Quaternary of southern Thailand using morphological analysis and comparison with modern pollen.
2. To investigate the quantitative changes of some selected fossil pollen and spore types and create pollen diagrams, which can lead to reconstruction of plant community change.
3. To reconstruct the paleovegetation and paleoenvironment during the late Quaternary of southern Thailand and their relation to the larger scale of Southeast Asia.

As a strong proxy, palynomorph assemblages will indicate the environments and climates in which the plants had been living and also their changes. For the study site near the shore as in this study, the sea level changes will also be interpreted by the changes of mangrove pollen assemblages. Since my approach is multi-disciplinary, geological, botanical, ecological, and anthropological knowledge are needed to complete the past reconstruction.

1.5 Synopsis

The thesis comprises six chapters:

Chapter I presents a general introduction to palynology and its basic principles, which are pollen production, dispersion, deposition, preservation, and interpretation. The geological history of Southeast Asia and Thailand is summarized, and the importance of further investigation of the vegetation of this area using palynology as a proxy is indicated. A brief summary of the following chapters is also given in this part.

Chapter II contains a review of the Quaternary to the present day of Thailand, in relation to the regional scale of Southeast Asia, involving aspects of geology, vegetation, faunal, and climate changes, and fluctuation of sea level. Previous publications relevant to this study are reviewed and discussed in this chapter.

Chapter III includes the materials and methods used in the study. It is separated into three parts: field work, laboratory work, and data analysis. For a clearer understanding, the necessary terminology is provided in this chapter.

Chapter IV describes the identification of individual palynomorphs in terms of morphology, shape, size, surface sculpture, and other important or specific features. Light and scanning electron microscopic photographs are prepared from both fossil pollen grains and modern pollen grains of possible living relatives in order to increase the accuracy of the identifications.

Chapter V presents the pollen diagrams with descriptions of the pollen zones and pollen assemblage change. The habitats and ecology of the living taxa that are considered to represent the nearest living relatives (NLR) to the fossil taxa are described providing information for environment interpretation. The environmental interpretation is described in terms of vegetation and climate changes. Climate and sea level are discussed relating to reconstructed vegetation.

Chapter VI presents conclusions and comment and suggestions for future research.

Plates of other palynomorphs and indeterminate spores and pollen, data on pollen counting, and list of herbarium specimens collected are provided in the appendices.

CHAPTER II

GEOLOGICAL AND VEGETATIONAL BACKGROUND

2.1 Introduction

Plate tectonic theory positions Thailand in the middle of the mainland of the Southeast Asia region. This region experienced intensive tectonic activity during the Tertiary, starting with Tertiary volcanism, and the collision of India with Asia, resulting in extrusion of Indochina to the southeast (Songtham, 2003). Following with the fracturing in Late Eocene – Early Oligocene, much of the Sunda region was broken into horsts and grabens or half graben topography while extensive regions underwent subsidence. During the Neogene, the region was compressed from the south and east by the combined forces of the approaching Pacific and Australian plates, which were drifting west and north, respectively (Morley and Flenley, 1987; Morley, 2000).

This tectonic history has had an influence on the geology and vegetation of this region. Vegetation in this area experienced eastern tropical dispersal and intermixing resulting in the unique characteristic of tropical floral diversity. The scattered landmasses as many isolated islands surrounded by the sea allowed the rapid proliferation of endemic floras. It is stated that the monsoon forest was widespread in this region during the Oligocene and Early Miocene. Then, the dipterocarp-dominated rain forest replaced the monsoon forest during the Miocene (Morley, 2000). The rain forest has been present in this area ever since.

Morley (2000) mentioned three reasons for the richness of the SE Asian rain forest. Firstly, it is a result of the mixing between Eocene SE Asian floras with Indian floras, which comprised both the endemic Indian floras and the African Cretaceous floras brought with the Indian plate. Secondly, the above mixing of floras was combined with the results of the collision of the Australian and Sunda plates at the end of the Oligocene. This allowed dispersal of Gondwanan floras into SE Asia. The southern conifers, such as *Agathis*, *Podocarpus*, and *Phyllocladus*, dispersed to SE Asia through this pathway. Thirdly, the continuous continental connection of E Asia across latitudinal climate zones from the equator to 60^{o} N allowed the Northern Hemisphere elements to survive and diversify in this area (Morley, 2000).

In the Quaternary, besides the plate tectonic effects, vegetation in this region experienced extreme fluctuations of climate. During the glacial periods, this area experienced dry climates which were more widespread than during previous periods (Morley, 2000). This has influenced the floristic distribution present today.

This chapter reviews the evolution of geology, climate, and vegetation in the Quaternary which will be necessary background information for this study. Finally, the study area is focused on in detail and discussed in relation to the regional scale of Southeast Asia.

2.2 Quaternary geology and geomorphology

According to Sinsakul et al. (2002), Quaternary geologic sequences of Thailand cover one-third of the total area. They are mainly semiconsolidated and unconsolidated sediments and include some crystalline and lithified volcanic rocks such as basalt. Quaternary sediments are of both marine and non-marine origin and are usually found in the lowland areas, intermontane basins, broad valleys, plateaus, and coastal zones.

2.2.1 Tectonic movement

As stated above, plate tectonic activity has affected the geology and vegetation of this region. Although Thailand was considered to be a stable landmass, compared to adjacent regions in Southeast Asia, throughout the Cenozoic era the collision of the Indian and Eurasian continental plates resulted in tectonic deformation with faulting, crustal uplift and subsidence. The strike-slip motion of the faults resulted in the clockwise rotation of continental blocks in Southeast Asia (Dheeradilok, 1995).

In southern Thailand, there are two main faults: the Ranong and Klong Marui, which are oriented in a NNE-SSW direction (Fig. 2.1). The occurrence of shallow intrusive geyserite rocks on the western coast is related to crustal movement along these faults (Raksaskulwong et al., 1989). The uplift of the western coast resulted in the emergence of the thick Tertiary coal beds and associated freshwater fossil gasteropods and bivalves (Dheeradilok, 1995). The tectonic changes are thought to have affected the Quaternary climate, fluvial and coastal processes, and also Holocene sea level fluctuation.

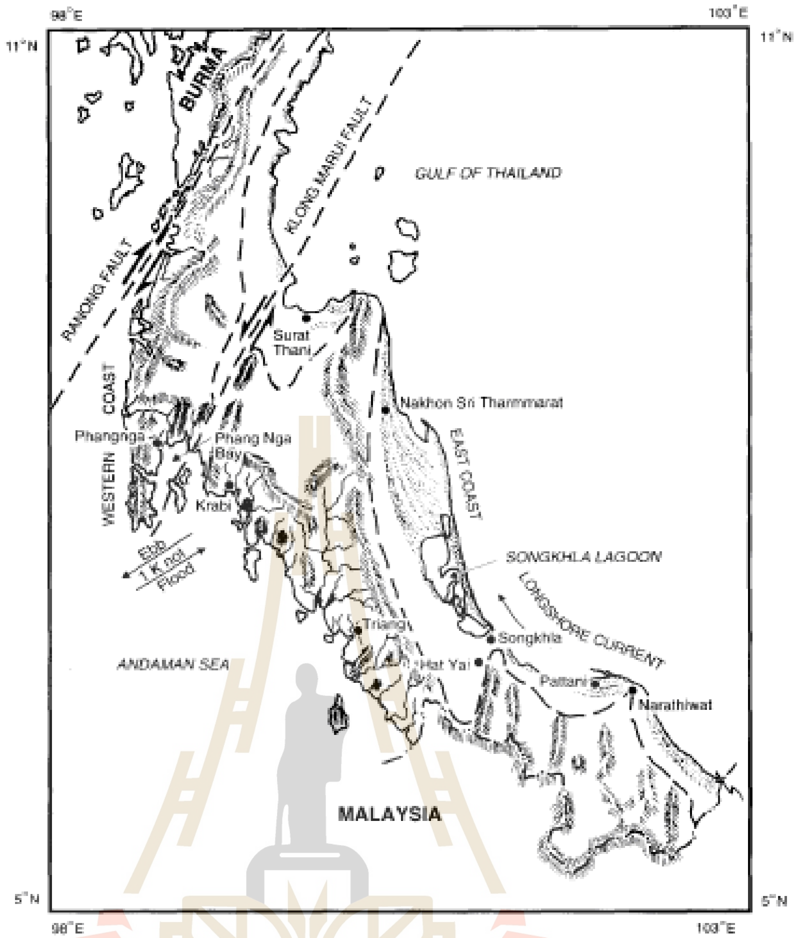


Fig. 2.1 Geomorphology of southern Thailand, after Dheeradilok, 1995

2.2.2 Geomorphic features and stratigraphic sequences of southern Thailand

2.2.2.1 Geomorphic features

Southern Thailand or the southern Thai peninsula consists of a mountain range running down the middle, which slopes downward to the coastal plains on both sides of the peninsula. The peninsula lies between the Gulf of Thailand, which is part of the South China Sea, and the Andaman Sea.

On the east coast of the southern Thai peninsula, geomorphic features are characterized by a broad coastal plain with sand bars, beach ridges, and cheniers occurring in Nakhon Sri Thammarat, Songkhla, Pattani, and Narathiwat provinces. Tidal flats are present surrounding Songkhla Lake, and sand spits are also common along the coast. Prodelta deposition is found at the mouth of the Tapi River in Surat Thani province (Fig. 2.1) (Dheeradilok, 1995). These features are present in Holocene river deposit sediments, which resulted from erosion in the western upland area. Furthermore, sand has been carried into the area by first southerly and later northerly-directed long shore currents (Dheeradilok, 1995).

2.2.2.2 Stratigraphic sequences

Sawata et al. (1982) mentioned that Quaternary sedimentary sequences are over 200 m thick on the eastern coast of the southern Thai peninsula. The deposits are mainly sand, clay, and gravel layers of Pleistocene colluvial and alluvial origin occurring along the base of the mountains as undulating terrain and on coastal cliffs. The short period of late Pleistocene marine transgression was also recorded as a shelly bed (30,950 ± 620 yr. BP) found under stiff clay along the coast of Songkhla (Tiyapairach, 1999).

The colluvial and alluvial Pleistocene deposits may be results of the long period of weathering and erosion alternating with fluvial transportation during that time. Several lateritic, stiff clay layers can be found in this sequence and are believed to be an effect of the Pleistocene climatic change (Dheeradilok, 1995; Sinsakul et al., 2002). The weathering features are thought to have occurred during the late Pleistocene warming climate, which is generally accepted to have begun after 18,000 yr BP. That was a time period of regional climatic fluctuation, affecting the depositional rate in many countries along the Pacific Ocean. This phenomenon was also responsible for the lateritic zone deposition (Dheeradilok, 1995).

Along the east coast, soft, marine Holocene clay overlies a stiff Pleistocene clay formation. There is a mark of the Pleistocene-Holocene boundary which was left by the abrupt change. It is related to the rapid shortening of river channels imposed by rising sea level in the Holocene and the subsequent marine regression. Because of the higher sea level, the Holocene sequences are mainly marine in origin. The sequences are classified into two main groups based on the geomorphologic evidence, namely, tidal flats and beach sand. The ^{14}C dating of peat and shell fragments in tidal flat sediments of the marine clay deposit indicates 9,000 yrs BP to the present day, depending on the depth of the sedimentary sequence. The beach sands have been accumulating since 6,000 yrs BP until just a hundred years ago (Dheeradilok, 1995). These clastic sediments usually overlie the tidal flat sediments (Dheeradilok, 1995; Sinsakul et al., 2002).

2.2.3 Geology of the study site

The study site is located at Ban Bo So, Singha Nakhon district, Songkla province, at latitude 7° 16′ N. and longitude 100° 30′ E or grid reference 666300806400. The surface is approximately 8 m above mean sea level, about 2 km to the west of the present shoreline of the Gulf of Thailand, and about 8 km from the east shore of Songkhla Lake (Fig. 2.2). The coring site is characterized as having narrow composite sand ridges, which are parallel to the present shore line in the NW-SE direction. The coastal plain behind the sand ridges is flat and wide and occupied by paddy fields and marshland (Tiyapairach, 1999).

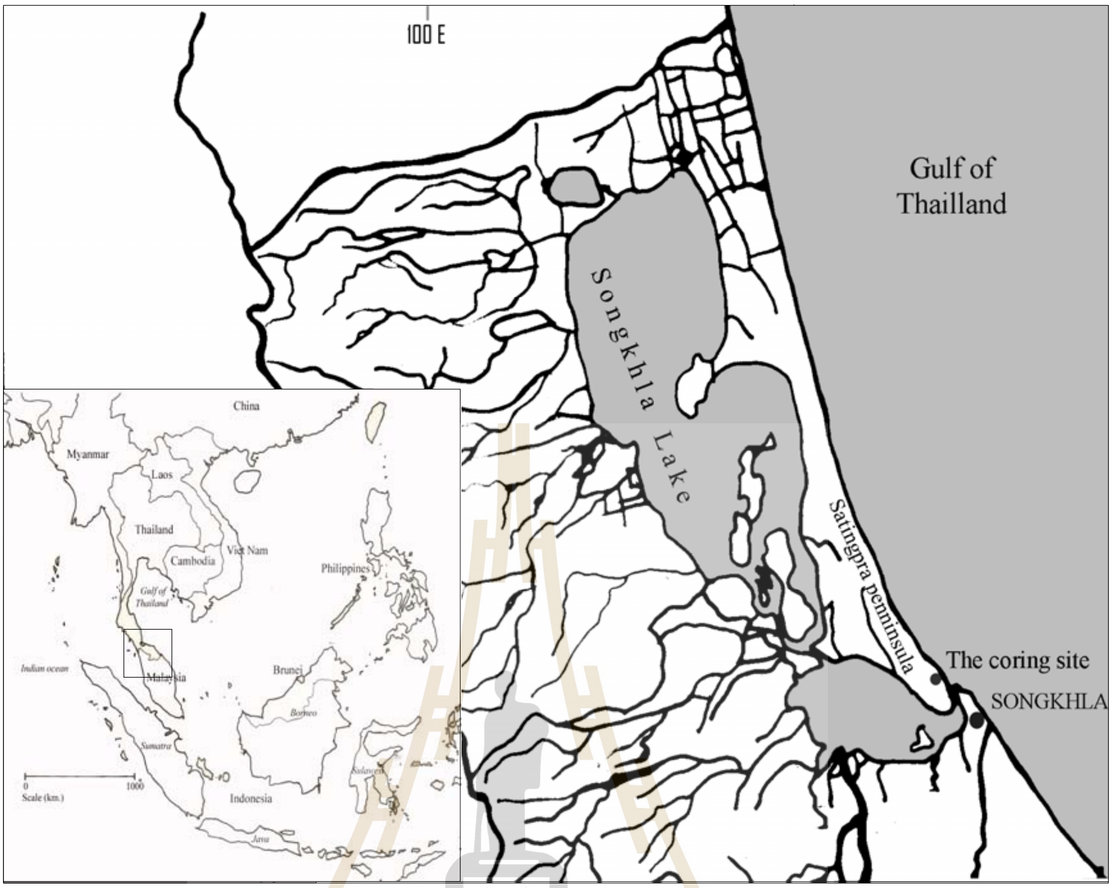


Fig. 2.2 Map of the study site at Ban Boh So, Singhanakhon district, Songkhla province

Information on the geology and stratigraphy of the study site has been documented by Chaimanee et al. (1984) and Tiyapairach (1999) using lithology and depositional environment as classification factors. Coastal lithofacies were divided into five units, which are beach sand deposit, runnel silty clay deposit, tidal flat clay deposit, lake swamp clay deposit, and marine clay deposit Tiyapairach (1999) (Fig. 2.3).

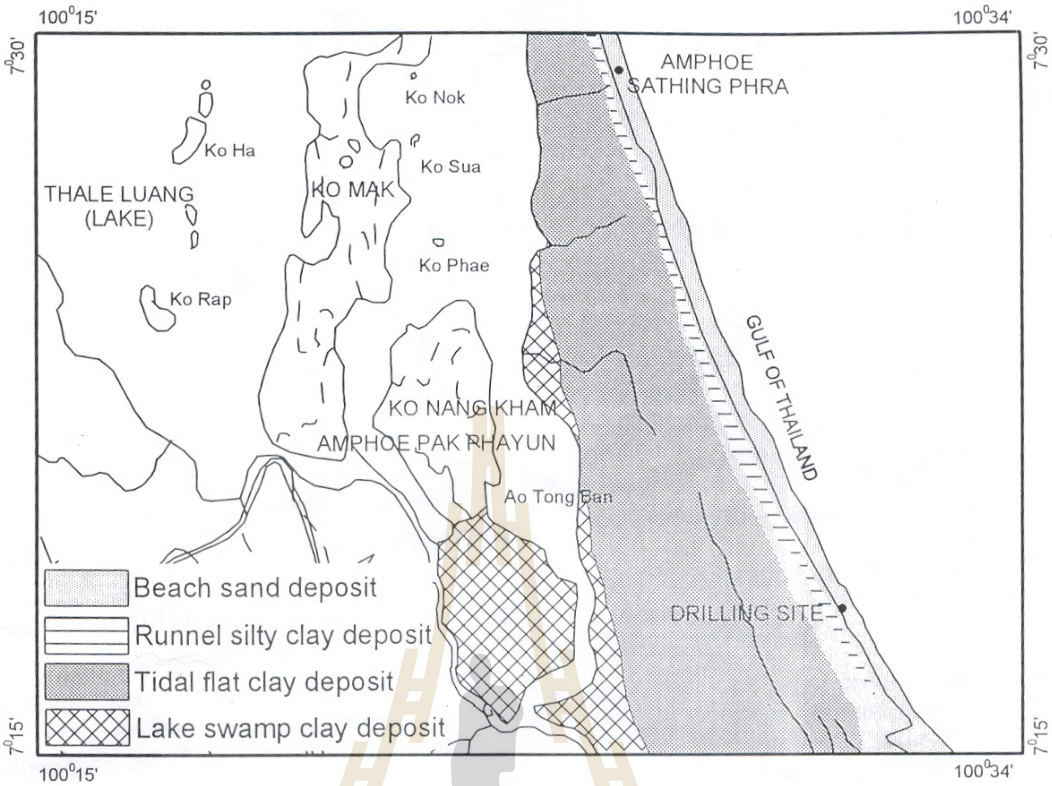


Fig. 2.3 The coastal zone geology of the study site (after Chaimanee et al., 1984, in Tiyapairach, 1999)

The beach sand deposit is a long linear ridge parallel to the shore line. This unit is over 4 m thick and overlying the marine clay unit. The runnel silty clay deposit is present between old beach ridges. It varies from 2.1 to 3.1 m in thickness and also overlies the marine clay unit. The tidal flat clay deposit is situated behind the beach. This deposit extends to the lake in the west. The thickness of this unit varies from 1- 4 m from west to east. The lake swamp clay deposit is located in wet lowland or swampy areas of Songkhla Lake, which are occupied by aquatic plants. Lithological characters vary from peat layers to peaty clay to clay, and plant remains are abundant. This unit is 1.3 to 3.8 m thick. The marine clay deposit is not exposed, but rather is covered by younger sediments at 2 - 3 m under the ground surface. The thickness of this unit varies from 0.3 m to more than 8 m.

As part of the Khlong Siam Project of the Geological Mapping Section, borehole no. 2-1 was retrieved in September, 1998. The sediment coring was conducted in the beach sand deposit, located about 2 km to the west of the present shoreline of the Gulf of Thailand and about 8 km from the east shore of Songkhla Lake (Fig. 2.3), at the position mentioned above.

The sediment core SE2-1 was classified into ten layers and described by Tiyapairach (1999) as follows (Fig. 2.4):

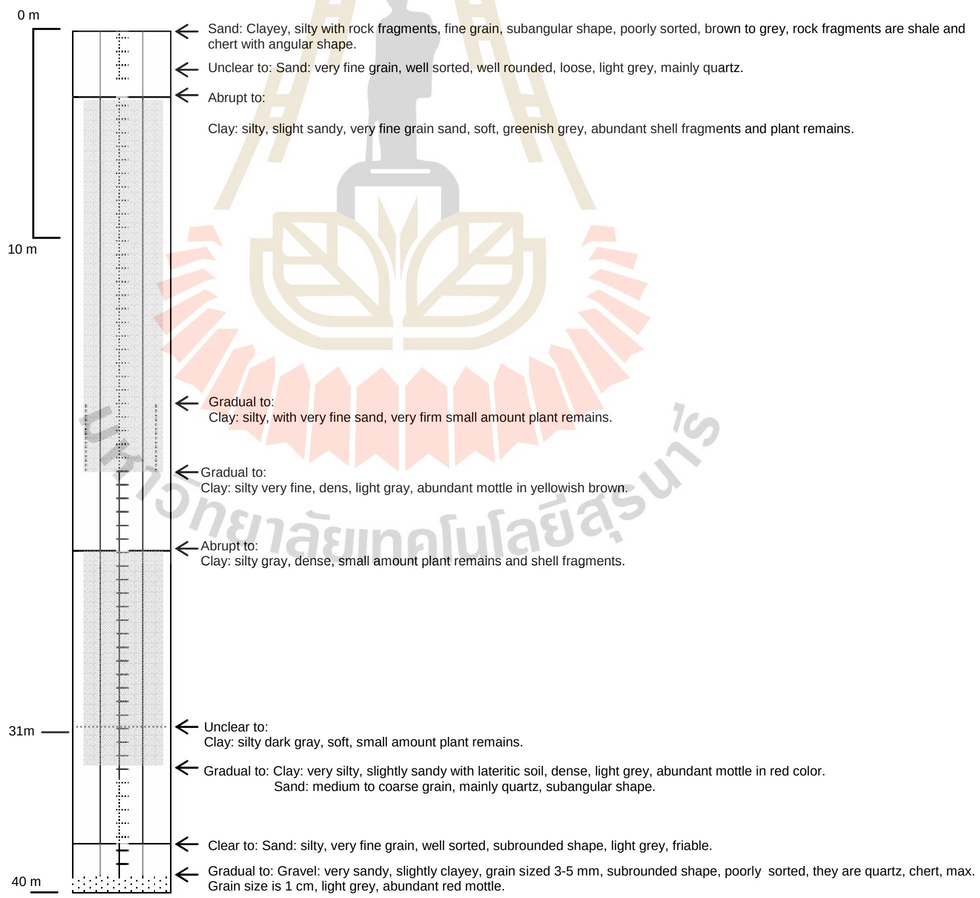


Fig. 2.4 The stratigraphic column of the core SE2-1 (after Tiyapairach, 1999)

Tiyapairach (1999) indicated that the 9 m-thick sediments (depth between 25 - 34 m) in the lower marine clay layer suggested a near shore or tidal flat environment. It meant that there had been a sea transgression in this area at that time. This assumption was investigated and will be described in the following chapters.

2.3 Climate

Thailand has a monsoon climate characterized by a seasonal reversal of the atmospheric pattern. There are two major types of monsoon influencing this area: the southwest and the northeast monsoon.

The southwest monsoonal wind, which blows from the Indian Ocean, affects areas of Thailand during mid-May to October. The airstreams pick up moisture while they cross the seas, resulting in heavy rainfall in Thailand, especially in the coastal areas.

The northeast monsoonal wind begins after the southwest monsoon influence. It affects areas of Thailand from mid-October to February. The source is in the high atmospheric pressure areas of the Northern Hemisphere in Mongolia and China. The airstreams bring cold and arid conditions to the Central, North, and Northeast regions of Thailand. On the other hand, this monsoonal wind picks up humidity while blowing across the Gulf of Thailand. This causes the east coast of southern Thailand to experience high rainfall.

Beside the monsoonal winds, tropical cyclones also influence this area. They form over the South China Sea and sometimes move landward to Thailand. They affect the southern region with heavy rainfall, flooding, landslides, and coastal erosion.

The effect of the winds mentioned above is that the south of Thailand has high rainfall all year round except for a few months in the summer. The significantly different climate compared to elsewhere in Thailand is reflected in the different vegetation types found in the area.

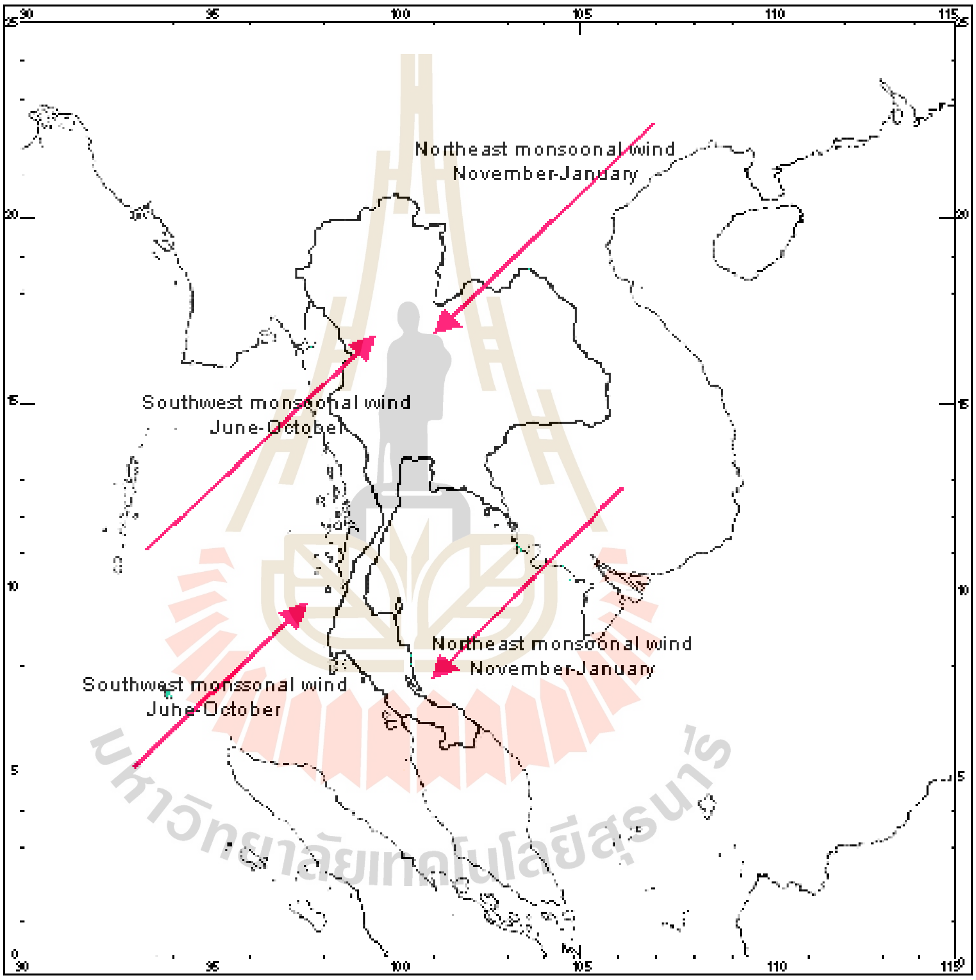


Fig. 2.5 Map of monsoonal wind directions, modified from the Thai Meteorological Department, http://www.tmd.go.th/info/.

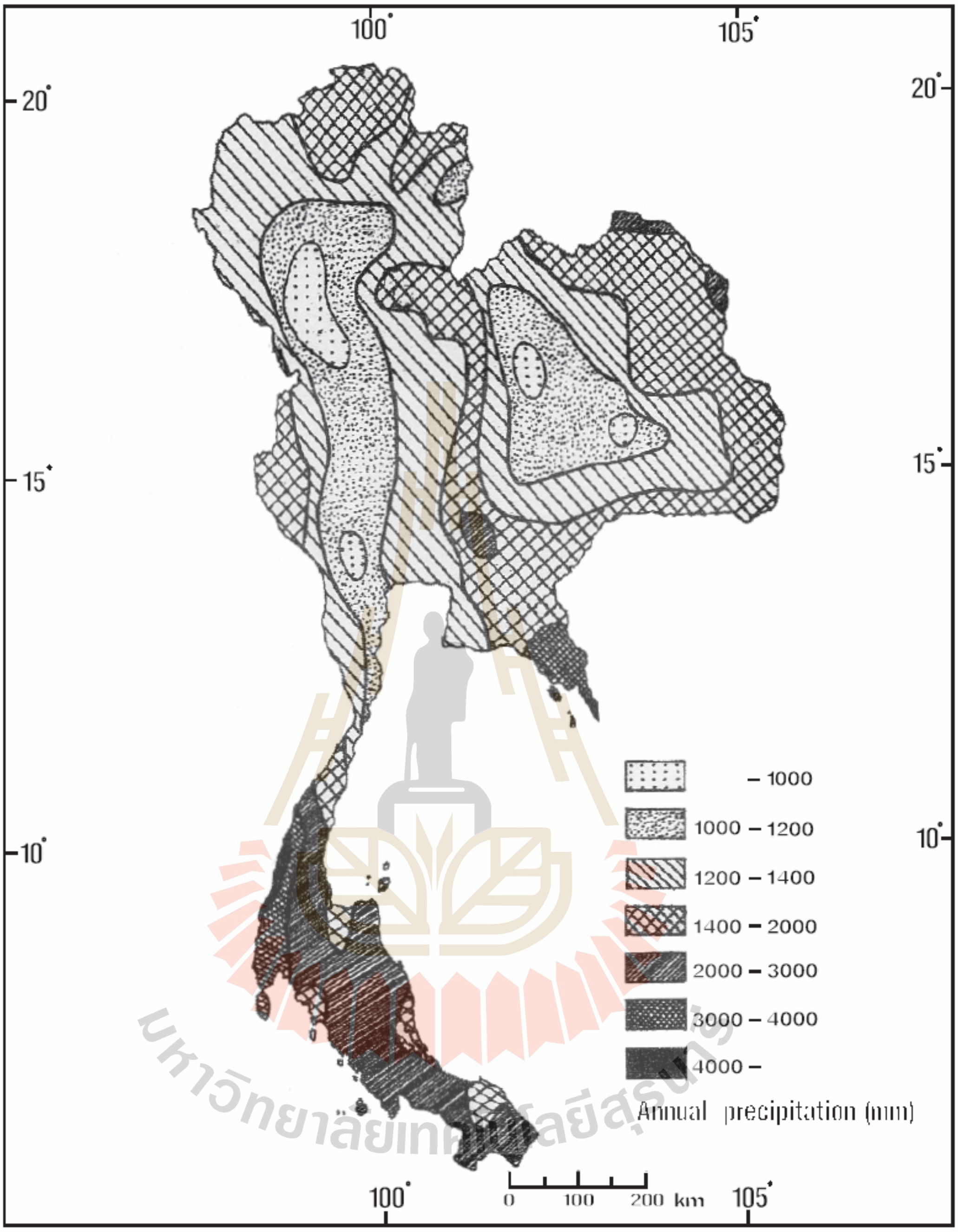


Fig. 2.6 Map of annual precipitation zones, after Santisuk, 2006

2.4 Vegetation

2.4.1 Present vegetation in Thailand

Santisuk (2006) has classified floristic types of Thailand using 1) climatic, 2) edaphic, 3) elevational, and 4) biotic factors.

Forests in Thailand comprise two main types: evergreen and deciduous forests. The evergreen forests are separated into 14 minor types of forest: tropical rain forest, seasonal rain forest, lower montane rain forest, lower montane oak forest, lower montane pine-oak forest, lower montane coniferous forest, lower montane scrub forest, cloud forest, upper montane scrub, montane peat bog, mangrove forest, peat swamp forest, fresh water swamp forest, and strand vegetation. The deciduous forests are separated into three minor types: mixed deciduous forest, dry dipterocarp forest, and pine-deciduous dipterocarp forest.

Distribution of floristic types is due to the four major factors mentioned above, but the elevations and moisture gradients are particularly important. The diagram of forest types in Thailand (Fig. 2.7) displays the pattern of distribution as related to the latter two factors.

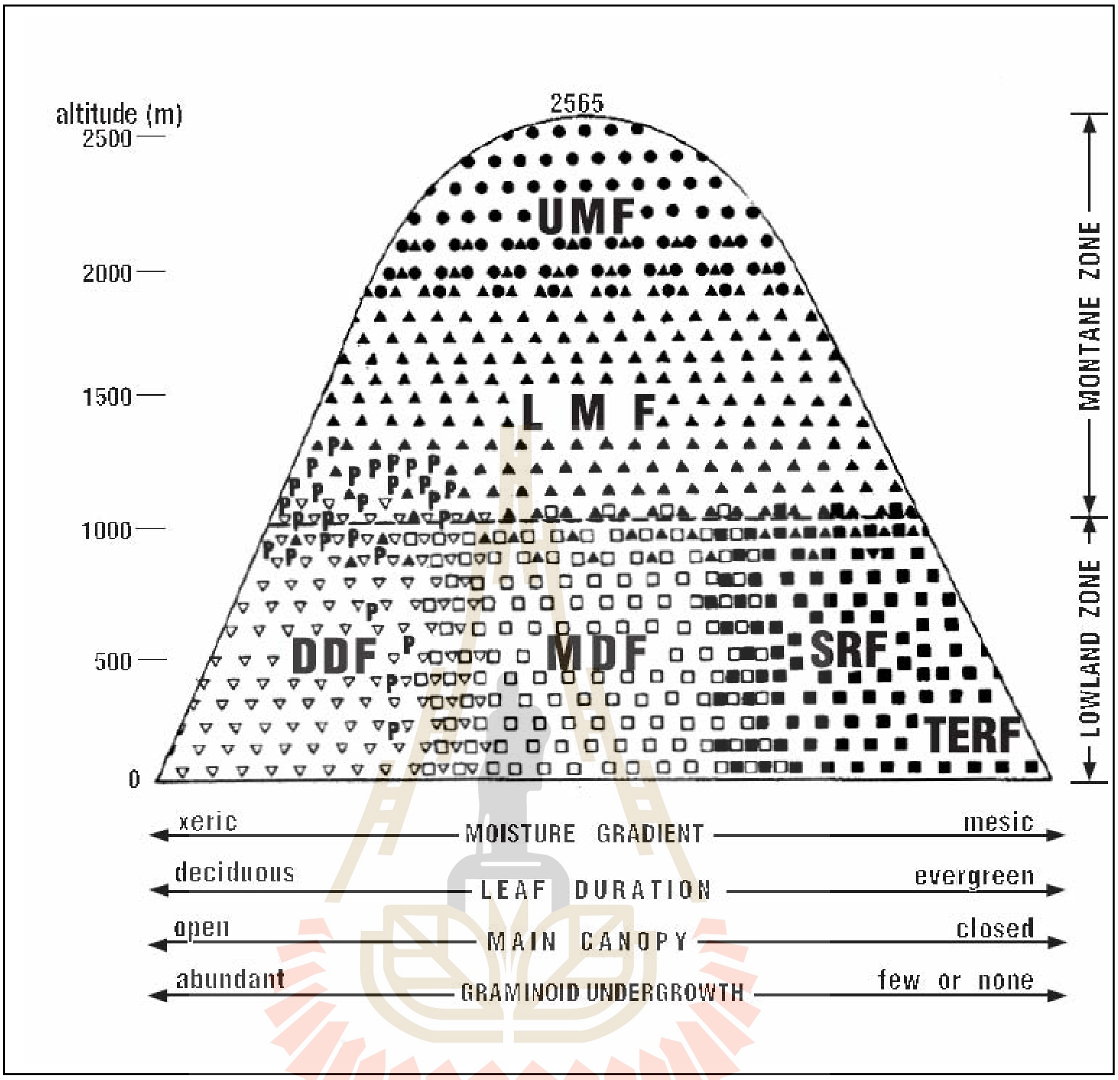


Fig. 2.7 Diagram showing the distribution of forest types in Thailand with respect to elevation and moisture gradients (after Santisuk, 2006). TERF = tropical evergreen rain forest, SRF = seasonal rain forest, MDF = mixed deciduous forest, DDF = dry dipterocarp forest, LMF = lower montane forest, UMF = upper montane forest, P = pines.

Before major human disturbance, most of the area in the South was originally covered by tropical rain forest because of high rainfall and high soil humidity of the areas. These forests have high species diversity and are dense with a multilayer of tree crowns. Tree crown strata are not clearly classified because they are composed of a diversity of trees in which each mature individual reaches a different height. The plant characters frequently found are buttresses and entire margined leaves with drip tips. Lianas and epiphytes are common. The composition of trees at the family level is remarkably similar to that of other rain forests elsewhere in the world, with representatives of Leguminosae, Annonaceae, Moraceae, Rubiaceae, Euphorbiaceae, Sapindaceae, Apocynaceae, Burseraceae, and Guttiferae. The different characters compared to other regions are the dominance of Dipterocarpaceae and the significantly high diversity of Myrtaceae (Santisuk, 2006). Dominant species in the forest are shown in Table 2.1.

Table 2.1 The dominant species in tropical rain forests of Southern Thailand (Santisuk, 2006).

Family	Species
Dipterocarpaceae	*Dipterocarpus kerrii, D. grandiflorus, D. gracilis, D. chartaceus, D. dyeri, D. hasseltii, Anisoptera curtisii, Neobalanocarpus sp., Cotylelobium sp., Parashorea stellata, Hopea odorata, H. pedicellata, H. sangai, H. latifolia, Shorea glauca, S. laevis, S. faguetiana, S. gratissima, S. hypochra, S. curtisii, S. dasyphylla, S. leprosula, S. macroptera, S. parvifolia, S. singkawang, Vatica lowii, V. odorata*.

Table 2.1 (Continued)

Family	Species
Leguminosae	
Mimosoideae	*Parkia speciosa, P. timoriana, Callerya atropurpurea, Archidendron jiringa,*
Caesalpinioideae	*Cynometra malaccensis, C. ramiflora, Koompassia excelsa, K. malaccensis, Intsia palembanica, Dialium indum, D. platysepalum, Saraca thaipingensis, Sindora echinocalyx.*
Meliaceae	*Aglaia* spp., *Dysoxylum* spp., *Chisocheton* spp.
Lythraceae	*Lagerstroemia speciosa*
Moraceae	*Antiaris toxicaria, Artocarpus dadah, A. elasticus, A. rigidus*
Apocynaceae	*Dyera costulata, Alstonia macrophylla, A. scholaris*
Bombacaceae	*Durio lowianus, D. griffithii, Neesia altissima*
Anacardiaceae	*Semecarpus curtisii, Swintonia floribunda, Parishia insignis, Pentaspadon velutinus, Dracontomelon dao*
Sterculiaceae	*Scaphium linearicarpum, S. scaphigerum*
Myrtaceae	*Syzygium* spp.
Annonaceae	*Goniothalamus* spp., *Polyalthia* spp., *Pseuduvaria* spp.

The presence of palms is also an important characteristic of this forest type. The commonly found species of Arecaceae are *Borassodendron machadonis, Johannesteijsmannia altifrons, Orania sylvicola, Oncosperma horrida, Licuala* *elegans, L. distans, Arenga westerhoutii, Livistona speciosa, Caryota* spp., *Calamus* spp., *Daemonorops* spp., *and Korthalsia* spp. (Santisuk, 2006).

The lower montane rain forest covers some high areas, which are 1000 - 1900 m above mean sea level, such as on the mountains in Nakhon Si Thammarat province. This forest is as dense as the tropical rain forest in the lowland, but is different in its floristic composition. The flora is composed of temperate and montane species which prefer a rather cool climate all year round. Plants of Fagaceae and the conifer family, Podocarpaceae, are commonly found in this forest.

Peat swamp forest or coastal peat swamp forest is distributed in areas which are low, close to the sea, and always flooded with fresh water. The vegetation is significantly distinct with the adaptations of pneumatophores, buttresses, and stilt roots. The typical species are *Calophyllum teysmannii*, *Blumeodendron kurzii*, *Eleiodoxa conferta*, and *Neesia malayana*.

The mangrove forest is normally dominated by plants belonging to the family Rhizophoraceae. Mangrove communities usually occupy the mud flat areas along the seashores. They are frequently found at river mouths or estuaries. The amount of salinity which the different mangrove species can withstand affects their distribution. Frequency of marine inundation and mud flat types also influence the habitats of mangrove species.

Santisuk (1983) subdivided mangrove vegetation into two types. Firstly, true mangrove or swampy mangrove forest is found along the border of the sea and in lagoons, extending as far as the river mouths where the water is still saline. These mangrove plants grow in swampy soils, which are covered by the sea during high tides. Secondly, the back mangrove or tidal mangrove forests are communities reached by the sea water only at very high tide, exceptional tides, or during cyclones. They consist of other species, which tend to occur in more inland areas, such as freshwater swamps, peat swamps, salt flats, and on dry land forest. Such plants associated with mangroves are classified as part of the back mangroves.

Strand vegetation is found along the seashores growing on sandy or rocky strand. This plant community grows along the narrow littoral marine zones or on isolated patches. Morley (2000) recognizes two main plant associations in strand vegetation, i.e., herbaceous communities and beach forest.

Herbaceous communities are often dominated by grasses, especially *Spinifex littoreus*, and *Ipomoea pes-caprae* (Convolvulaceae). Sometimes shrubs, such as *Scaevola frutescens* (Goodeniaceae), are included. They directly border the sea on unstable sands above the effects of tides (supralittoral zone).

Beach forests have more consolidated substrate than that of herbaceous communities. They usually comprise a narrow strip of trees. They are generally characterized floristically by *Barringtonia asiatica* (Lecythidaceae), *Calophyllum inophyllum* (Guttiferae), *Terminalia catappa* (Combretaceae), *Thespesia populnea* and *Hibiscus tiliaceus* (Malvaceae), and *Pandanus tectorius* (Pandanaceae). A single species, *Casuarina equisetifolia* (Casuarinaceae), is widespread in occurrence, especially on the accreting sandy coasts (Morley, 2000; Santisuk, 2006).

2.4.2 Vegetational history of SE Asia

According to Audley-Charles (1987), there is evidence that parts of Burma (Myanmar), the Thai-Malay Peninsula, and Sumatra were separate islands above water during the early Tertiary (ca. 40 million years BP). At that time, the islands were in the equatorial zone and generally experienced high temperatures, allowing the inference to be made that tropical forests existed in Southeast Asia. However, there is no direct evidence available. During the late Tertiary (ca. 20 million years BP), the evidence showed that seasonal and everwet rain forests were present, extending from Indochina to Borneo (Muller, 1972; Morley and Flenley, 1987). During the middle - late Miocene, the areas occupied by the tropical rain forest reached as far north as southern China and southern Japan (Song et al., 1984; Tsuda et al., 1984) and westward to northern India (Mathur, 1984).

There is no clear evidence yet of the presence of glaciers in this region during the Pleistocene but worldwide glaciation did have a major impact on the climate and vegetation, with a decrease in the temperature and ocean volume, causing cold/dry climates and sea level regression. The large sea level regressions during the middle Pleistocene and the LGM reached 160 m and 125 m below present mean sea level, respectively. This must have caused a decrease in evaporation and moisture content of the monsoonal winds (Heaney, 1991).

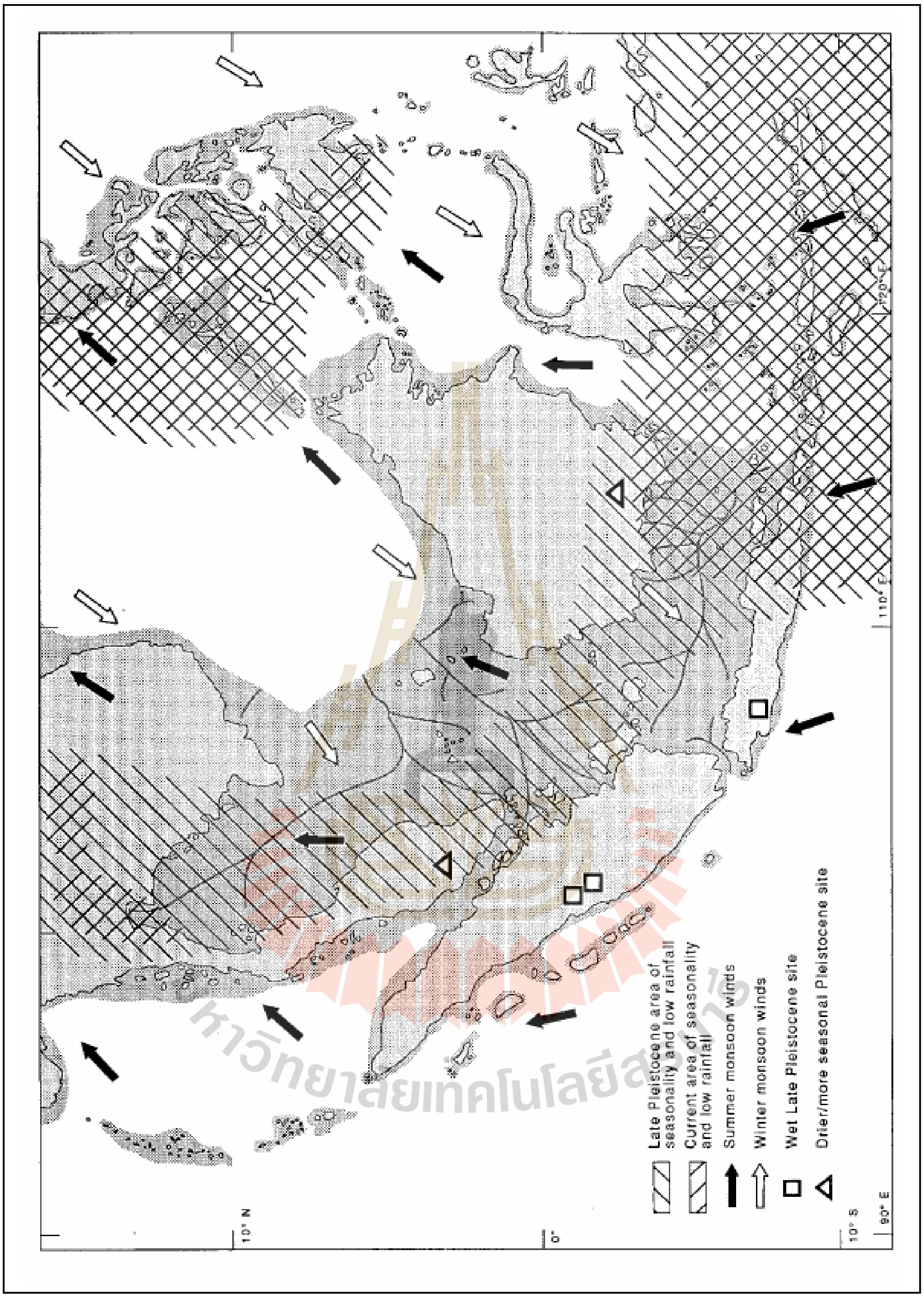


Fig. 2.8 Map of Southeast Asia showing current and late Pleistocene land areas, current and hypothetical late Pleistocene seasonality and low rainfall distribution areas, winter and summer monsoon winds, and palynological study sites (after Heaney, 1991).

The low humidity and rainfall at that time in Southeast Asia are suggested by evidence of expansion of dry climate and seasonality during the LGM (around 18,000 ^{14}C BP) in Kelung valley, Malaysia. Pollen samples contain an abundance of *Pinus*, Gramineae, and Compositae suggesting a *Pinus* savanna, which is similar to a present day type found only in Thailand. Furthermore, the presence of *Dacrydium* pollen, which is typical of a seasonal riparian setting in Indochina, supported the idea of increase of seasonality. Data from Sumatra, west Java, and New Guinea also suggested cooler climates (Morley and Flenley, 1987; Morley, 2000).

According to the pollen evidence above, the open savanna extended rapidly at that time, perhaps forming a ‘savanna corridor’ from Thailand into the Malay Peninsula. This allowed migration of ‘savanna’ plants and animals across the areas. This suggestion was supported by the discovery of Asian herbivorous mammal fossils in Java (Medway, 1972).

On the other hand, the drier climates probably reduced the areas of rain forest. This is indicated by an absence of Malesian rain forest pollen types in Malaysia. It suggests that the rain forest migrated further south (Morley, 2000). This agrees with the statement of Meijaard (2003) that open vegetation types have covered many areas, including the Thai-Malay Peninsula, during the LGM.

However, the rain forests persisted in several areas such as west Sumatra, northwest Borneo, the Malacca Straits, and around Palawan. The survival of rain forests during glacial times in the Quaternary indicates the long term continuity of moist climates within the equatorial zone in this area. This evidence is interpreted as one of the major factors for the rich centers of endemism and species richness in SE Asia (Morley, 2000).

The drier conditions persisted at the boundary of the Pleistocene/Holocene. A pollen record from New Guinea indicates the expansion of lower montane oak forest before 10,000 BP followed by grasslands and woodlands before 9,500 BP. This was followed by an increase in pteridophyte spores, which suggested an increase in precipitation (Van der Kaars, 1990, cited in Maloney, 1995).

The increase in precipitation after the Pleistocene-Holocene boundary is supported by data from northeast Thailand indicating a rapid increase of tropical and subtropical broad-leaved taxa (Penny, 2001). In addition, the pollen record from Cambodia shows that after the late glacial conditions ended around 8,500 BP, the summer monsoon intensity increased over the period 8,400-5,300 BP, which agrees with the evidence from most other sites in the Asian monsoon region (Maxwell, 2001).

Palynological evidence from Bo Phloi Basin, western Thailand, at approximately 4,500 BP, shows similarity of vegetation to that of today, comprising dry evergreen to deciduous forest, swamps, and aquatic areas (Hutangkura, 2000).

Evidence of the secondary forest expansion and frequent fire disturbance in Cambodia (Maxwell, 2001), as well as the presence of *Polygonum* and grass pollen in the peat bog of Doi Inthanon, northern Thailand (Poungtabtim, 1998), may be due to deforestation for settlement and farming.

CHAPTER III

MATERIALS AND METHODS

Methodology in this study was divided into 5 parts which are field work, laboratory work, microscopic work, chronology, and data analysis as the relationship shown in the diagram below (Fig. 3.1).

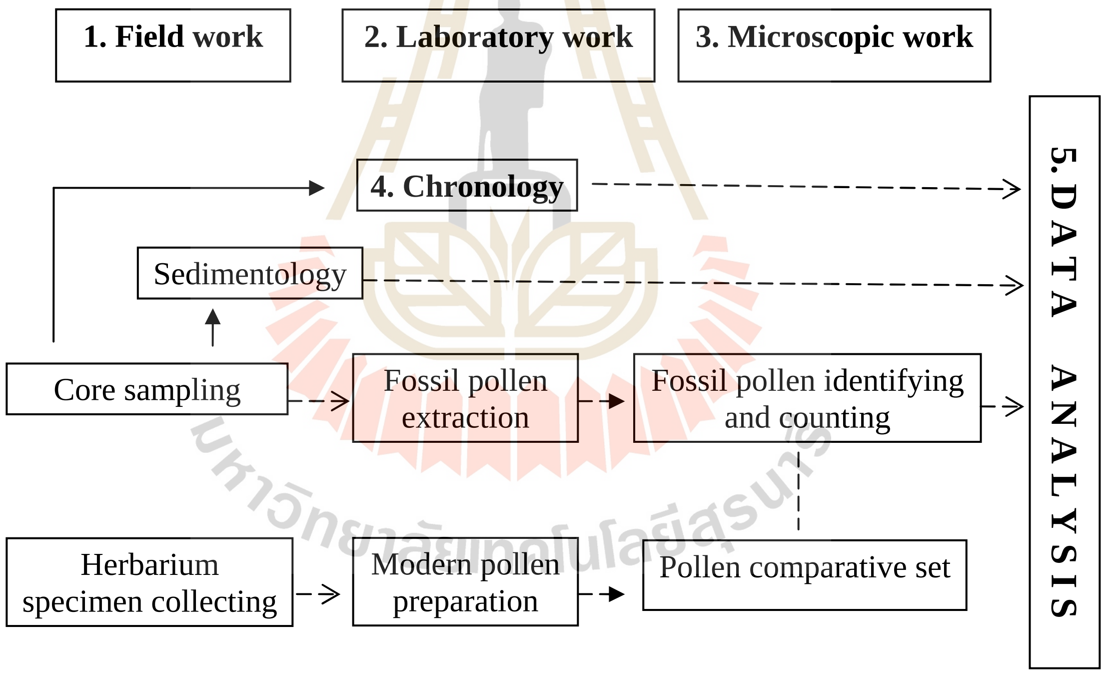


Fig. 3.1 Diagram showing methodological processes in this study

3.1 Field work

The Songkhla Lake Basin, in southern Thailand (Fig. 3.2), was selected to be the study area for field work. The basin is located on the east coast of peninsular Thailand and covers areas of Songkhla province and some parts of Phatthalung and Nakhon Si Thammarat provinces. There are depositions of marine and fresh water sediments, which are characterized by coastal plain with sandbars, beach ridges and also a tidal flat with a large lagoon (Dheeradilok, 1995).

3.1.1 Core sampling

In September, 1998, the 40 m long sediment core from borehole no. SE2-1 of the Khlong Siam Project of the Mineral Resources Department was analyzed in a preliminary fashion. It was taken from Ban Bo So, Singha Nakhon district, Songkhla province, at 7° 16' N latitude, 100° 30' E. longitude, grid reference 666300806400 about 2 km to the west of the present shoreline and 8 km to the east of Songkhla Lake (Tiyapairach, 1999).

After investigation, it was discovered that the pollen occurrence in sediment core no. SE2-1 was not continuous. Some layers were barren. It was therefore considered worthwhile to take a second core. In April 2006, this core, no. SUT-1, was retrieved close to the site of the first core, at grid reference 666466806304. The site is in a small paddy field near an orchard and houses. The first attempt to take a core using a hand auger was unsuccessful because water in the sediment made it difficult to pull the auger up. A core was eventually retrieved successfully by using a piston corer (Fig. 3.3). In this way 8 m of sediment was extracted.

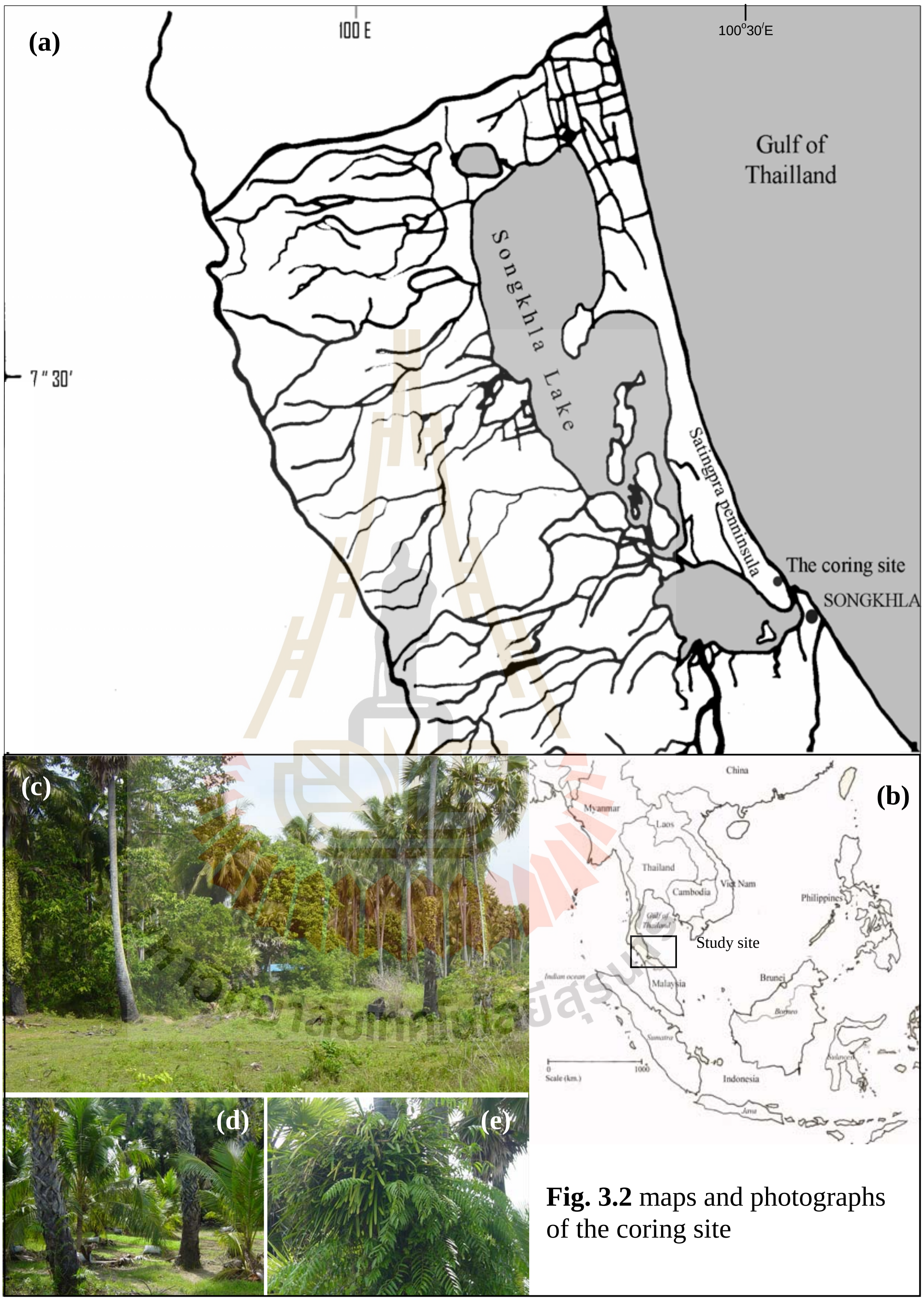


Fig. 3.2 maps and photographs of the coring site

(a) map showing the coring site in Songkhla Lake basin,
(b) map showing the coring site in southeast Asia region,
(c) an abandoned paddy field in the coring site
(d) an orchard with coconuts, palms, and vegetables planted around the coring site
(e) *Stenochlaena palustris* growing on a palm trunk, common around the site

Fig. 3.3 Photographs of core sampling for core no. SUT-1: (a) coring by hand auger; (b) coring by piston corer. (photographed by Pikun Sittiprasertkun)

3.1.2 Sedimentological study

Knowledge of the sedimentology of the study area is useful for understanding the environment at the time of deposition, which is necessary for the interpretation of the floristic assemblages. The sediment cores were analyzed and described based on color, grain size, sedimentary component, and texture. The sediment structures were documented in the stratigraphic column by taking photographs and making sketches. For the sediment core structures that had already been studied, the information was used and cited in this study.

3.1.3 Herbarium specimens

Comparative material is essential for accurate pollen identification. Approximately 1,000 pollen samples were collected from well-identified herbarium specimens. These were mainly requested from the herbaria of the Forest Herbarium (BKF), Prince of Songkla University, and Suranaree University of Technology.

Additional modern pollen was collected from well-identified trees in botanical gardens or under the supervision of botanists and prepared as voucher specimens. The list and details of modern pollen collection are presented in Appendix A.

3.2 Laboratory work

3.2.1 Fossil pollen extraction

Sediment samples with fossil palynomorphs were treated by techniques modified and simplified from those of many authors (Faegri and Iversen, 1989; Paudayal, 2002; Songtham, 2000; Zetter, personal communication, 2003). These are divided into seven steps as follows:

3.2.1.1 Sample cleaning

The surface of the samples was cleaned to eliminate weathered or contaminated material. If the sample was hard, then it was necessary to grind the sediment using a mortar and pestle.

3.2.1.2 Carbonate content removal

Each sample was checked for the presence of calcium carbonate with a drop of dilute hydrochloric acid (HCl). If bubbles appeared, it meant that this sample contained calcium carbonate. To remove it, samples were boiled in conc. HCl for a few minutes. The sediment was then allowed to settle to the bottom and any excess HCl decanted.

3.2.1.3 Siliceous matter removal

The residue sample was transferred to a 250 ml polypropylene (PP) beaker. Some 37% hydrofluoric acid (HF) was poured in and stirred with a polypropylene (PP) stirring rod. The sample was left for ca. 2-3 days or more and stirred occasionally. The sample was then transferred into a large PP beaker or bucket containing 2-3 liters of water. The sample was allowed to completely settle to the bottom. The residue was obtained after the liquid was decanted.

The residue was transferred to a 250 ml glass beaker and boiled in conc. HCl to prevent the formation of fluorite crystals. It was left until it had settled to the bottom. Then the remaining HCl solution was decanted. The residue was transferred to a hardened glass test tube and washed with water three times, each time centrifuging at 1,500 rpm.

3.2.1.4 Humic acid removal

The sample was treated with a mixed solution of 1) 3 ml of saturated solution of sodium chlorate ($NaClO_3$), 2) 1.5 ml of glacial acetic acid, and 3) a few drops of conc. HCl. The sample in the test tube was placed in a hotwater bath for 5 minutes and stirred occasionally to prevent the boiling mixture from overflowing. The mixture was allowed to cool and then centrifuged at 2,000 rpm for 30 seconds. The excess liquid was decanted. The sample was washed with water and centrifuged 3 times. The sample was then washed with acetic acid twice to remove the water prior to the acetolysis step.

3.2.1.5 Cellulose removal

The acetolysis solution was prepared by mixing 9 parts of acetic anhydride with 1 part of conc. sulfuric acid (H_2SO_4). This solution is very corrosive and explosive if it comes into contact with water, so this step should be done with care. The sample was treated with acetolysis solution. The sample tube was placed in a water bath for 5 minutes. The solution turned brown during this treatment. The sample tube was taken out of the water bath and allowed to cool before centrifuging at

2,000 rpm for 1 minute and decanting the liquid. The residue was washed once with glacial acetic acid followed by three times with water.

3.2.1.6 Organic-inorganic matter separation

In cases where the mineral substance cannot be removed, a gravity separation technique can be carried out using a heavy liquid such as zinc bromide.

About 2 ml of zinc bromide ($ZnBr_2$) was added to the test tube containing the residue and mixed with the residue. Then some water was added carefully to the tube with the help of a glass rod to prevent these two liquids from mixing together. The tube was then centrifuged at 3,000 rpm for 1 minute. The organic suspension layer appeared at the boundary between the heavy liquid and water. The organic suspension was then transferred carefully to another test tube. The mineral particles and liquid were left behind. The organic part was cleaned with water and centrifuged twice. The residue was transferred to a vial with some glycerine added for storage. It was then ready to be prepared for light microscopic and scanning electron microscopic study.

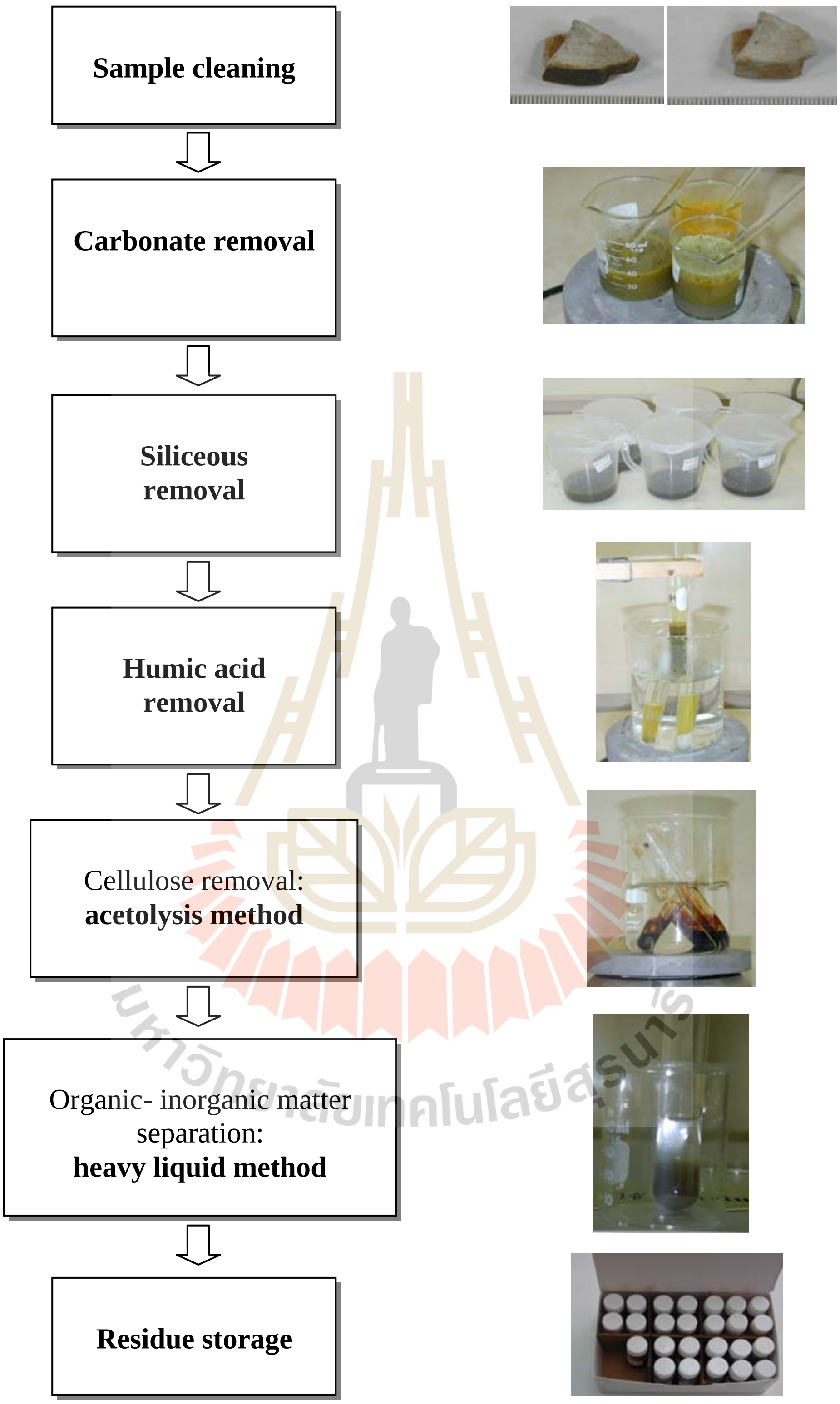


Fig. 3.4 Flow chart and pictures of fossil pollen extraction procedures

3.2.2 Modern pollen reference preparation

Well-identified herbarium material was used in this step. An anther was removed carefully with clean forceps and placed on a slide. Then the acetolysis solution was gently dropped onto it. A hair needle, as created by Zetter (1989), together with a normal needle were used to release pollen from their anther into the solution. The glass slide was heated over a spirit lamp for a short time to remove the cell contents inside the pollen wall. The liquid then turned brown. The pollen exine was stained a light yellow-brown color by the acetolysis solution mixture, so additional staining was not needed. The pollen grains were transferred by the hair needle to a drop of glycerine on another slide. These slides were ready for light microscopic and scanning electron microscopic study.

3.2.3 Other microfossil observation

Other microfossils, such as diatoms, dinoflagellate cysts, small animal remains, etc., from each sediment layer were observed and noted during the procedures.

3.3 Microscopic analysis

Two types of microscopes were used in modern and fossil pollen study as follows:

3.3.1 Light microscopy (LM)

A drop of organic residue from fossil pollen extraction was prepared on a glass slide. The liquid was uniformly distributed on the glass slide using the hair needle. The pollen was examined under a compound light microscope using 10x, 20x, and 40x objectives and 10x eye piece for morphological observation, statistical counting, and taking photographs.

At least 400 palynomorphs were counted for each sample. The sample slide was moved from left to right during identification and counting. The data was documented on a counting form. In some samples, which were not rich in pollen, more than one slide had to be prepared to obtain 400 grains of pollen. If only a few pollen grains were present, they were identified and noted as present, without any calculation of the percentage.

The pollen grains that were particularly interesting were moved to the edge of the glycerine for easy removal. These were then transferred to a fresh drop of glycerine on another slide using a hair needle. The photographs of the interesting pollen were taken under a light microscope using a 40x objective. A digital camera (CoolPix 950) was attached to the light microscope and used for taking photographs. During the photography, the hair needle was used to rotate the pollen grains into the desired position, e.g., polar or equatorial views.

The LM photographs of modern pollen were taken using the same procedures as for fossil pollen mentioned above.

3.3.2 Scanning electron microscopy (SEM)

After the LM investigation and photography, the same grain of pollen was prepared for scanning electron microscopic investigation. The pollen grain was moved to the edge of the glycerine and transferred to a SEM stub with the help of a hair needle. A drop of absolute ethanol was applied to the surface of the SEM stub just prior to the addition of the pollen grain. In order to be sure of success, these steps were carried out under a stereomicroscope. Any glycerine and water remaining on the pollen grain surface was removed by the absolute ethanol before it evaporated. The stub then was left to dry under an infrared lamp for 15 minutes. The stub with its clean, dry pollen was then placed in a Sputter Coater (JEOL/ JFC 1100E) for gold coating for four minutes.

After this the pollen on the SEM stub was ready for investigation with a scanning electron microscope (JEOL 6400) at 10 kV at different magnifications and orientations. SEM photographs were taken showing the pollen grain in overall morphology and the details of its sculpture.

3.4 Chronology

The age of samples in each sediment core was investigated by the Carbon-14 radiocarbon dating method. Four pieces of organic sediment were chosen from the stratigraphic sediment cores, at layers containing significant changes in sedimentological features and pollen assemblages.

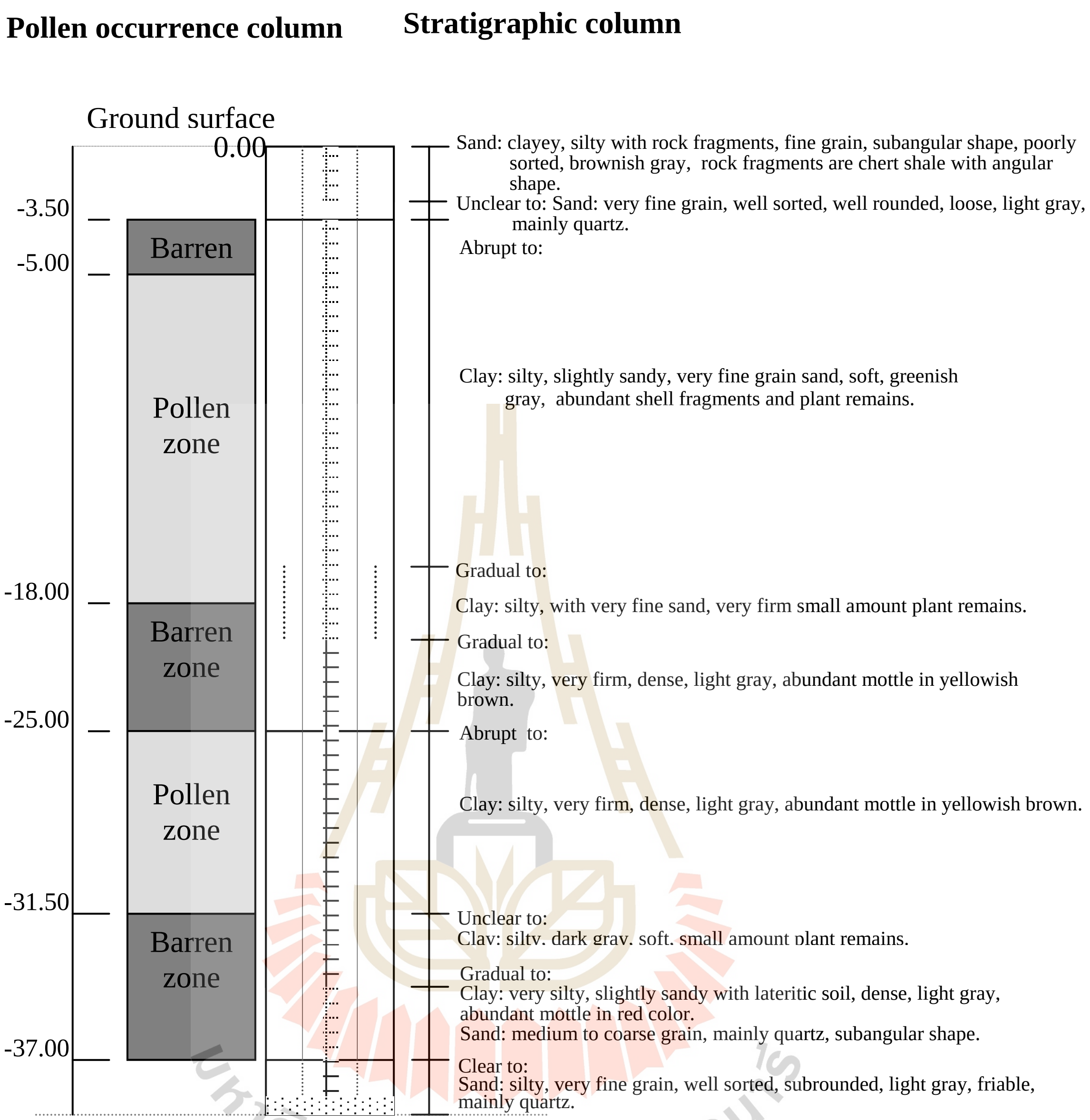


Fig. 3.5 Core no. SE 2-1: stratigraphy (modified from Tiyapairach, 1999) and pollen occurrence column

Sediment samples from core number SE2-1 were taken at depths of 7.5, 17.5, and 24.5 m for chronology analysis. These sediment layers were characterized by significant changes in the pollen assemblages. Another sediment sample for chronology analysis was taken from 7.5 m depth in the core no. SUT-1.

3.5 Data analysis and pollen diagrams

The investigation of Quaternary vegetation in this study highlighted two aspects: taxonomy and ecology.

In taxonomic analysis, fossil palynomorphs were identified to the species level. If this proved impossible, the next level such as genus or family was identified. These taxa from the late Quaternary can be compared to the same or closely related taxa at the present day in order to predict the past environment by the Nearest Living Relative method.

In ecological analysis, quantitative pollen data were needed for interpretation. The pollen grains were counted in each stratigraphic layer and presented in the form of pollen diagrams, using the computer software, TILIA (version 1.07) and TILIA-GRAPH (version 1.16). The percentage of each spore and pollen type was plotted against its stratigraphic depth. These pollen diagrams were interpreted in terms of plant composition, vegetation, and tentative climatic and environmental changes.

Information on sedimentological, chronological, and other microfossil studies were used for the interpretation of the environment at the time of deposition.

3.6 Terminology

The following terms are mainly from the Glossary of Pollen and Spore Terminology, Punt et al., 2004 [on-line] http://www.bio.uu.nl/~palaeo/glossary/glos-int.htm), Thanikaimoni (1987), and Faegri and Iversen (1989).

Aperture: a specialized region of the sporoderm, that is thinner than the remainder of the sporoderm and generally differs in ornamentation and/or in structure. Apertures are described as simple if they are present in only one wall layer or compound if they affect more than one layer of the wall. Various types of apertures are recognized on the basis of their shape (colpus, laesura, porus, sulcus, ulcus), position (ana-, cata-, zona-, zono-), or fusion (syn-). In living pollen grains or spores, the apertures usually function as sites of germination. They may also provide routes for transfer of water and other substances.

Colporus (adj. colporate): meridional composite aperture having an elongated ectoaperture (colpus) and an endo-aperture (os).

Colpus (adj. colpate): meridional simple aperture having length/ breadth ratio > 2.

Columellae (adj. columellate): infratectal columnar elements of the sexine.

Costa colpi: costal thickening accompanying colpus.

Costa equatorialis: girdle like costal thickening at the equator.

Costa pori: costal thickening accompanying the pore or os.

Costa: thickening of the nexine bordering the apertures.

Echinate (adj.) (sing. echina, pl. echinae): describing pollen and spores with an ornamentation comprising spines longer than 1µm. Comment: (Echinate should only be used in the adjectival form.) recommended the term spinose, but in his usage spines were defined as longer than 3µm and smaller features as spinules (adj. spinulose).

Ectexine: outer layer of the exine staining red with fuchsin B and differing from the endexine by electron density as seen in TEM.

Ectoaperture: the thinning or opening in the ectexine/sexine.

Endexine: inner layer of exine that appears faintly pink after staining with fuchsin B and differing from the ectexine by electron density as seen in TEM.

Endoaperture: thinning or opening in the endexine/nexine, also known as os.

Endosculpture: sculpture of the inner surface of the nexine or endexine.

Equatorial axis: the greatest axis, perpendicular to the polar axis, except when the pollen is constricted at the equator. When the equatorial contour is elliptic or rectangular, two equatorial axes E^1 and E^2 are measured.

Equatorial view: the view of a pollen grain or spore where the equatorial plane is directed towards the observer.

Exine: external wall of pollen containing sporopollenin.

Fastigium (pl. fastigia): cavity in a colporate grain caused by a separation or discontinuity of nexine and accompanied by a dome shaped sexine in the area of the endoaperture.

Fossula (adj. fossulate): ± elongated irregular depressions.

Foveola (adj. foveolate): ± circular depressions.

Heteropolar: pollen grain with asymmetrical distal and proximal parts.

Infratectum: situated under the tectum.

Intine: part of the pollen wall between the exine and the cytoplasm. It lacks sporopollenin and does not resist acetolysis.

Isopolar: pollen grain with ± symmetrical distal and proximal parts.

Lumina: meshes of the reticulum.

Meridional: surface features perpendicular to the equatorial plane.

Nexine: inner exine representing either sole (foot layer), endexine, or both.

Operculum: thickened exine covering the aperture, often becoming detached after acetolysis.

Os (pl. ora; adj. orate): nexinal or endexinal part of the composite aperture; also known as endoaperture.

Palynology: the study of pollen and spores and of other biological materials that can be studied by means of palynological techniques.

Palynomorphs: a general term for all entities found in palynological preparations. In addition to pollen grains and spores, the term encompasses acritarchs, dinoflagellates and scolecodonts, but not other microfossils, such as diatoms, that are dissolved by hydrofluoric acid.

Pilum (pl. pila, adj. pilate): sculptural element consisting of a ± swollen apex and a rod-like neck.

Polar axis: line between the proximal and distal poles.

Polar view: a view of a pollen grain or spore in which the polar axis is directed towards the observer.

Poles: the two extremities of the axis oriented towards the center of the tetrad at the time of pollen (and spore) development.

Porus or pore (adj. porate): simple aperture with length/ breadth ratio < 2. The pores are equatorial in position. When they are distributed over the entire surface of the pollen grain, the latter is described as periporate.

Pseudocolpus: symmetrically distributed, elongated exinal thinning or opening resembling the colpus but not associated with an underlying intinal thickening.

Reticulum (adj. reticulate): network with walls (muri) encircling the lumina.

Rugulae (adj. rugulate): irregularly elongated sculptural elements.

Scabrae (adj. scabrate): sculptural elements of < 1 µm dimension.

Sculpturing: the surface relief, or topography, of a pollen grain or spore.

Sexine: outer, sculptured layer of the exine, which lies above the nexine.

Sporomorph: a general term for pollen and spores.

Vermiculate (adj.): a general descriptive term used to describe winding features.

Comment: vermiculate has been used to describe depressions (fossulae). Others use the term for raised structures (muri) in rugulate pollen and spores.

Verruca (pl. verrucae, adj. verrucate): a wart-like sexine element, more than 1μm wide, that is broader than it is high and is not constricted at the base. Example: *Plantago* (Plantaginaceae)

CHAPTER IV

IDENTIFICATION AND DESCRIPTION OF PALYNOMORPHS

4.1 Introduction

This chapter includes the description of palynomorphs in this study. They are categorized into three groups: pteridophytic spores, gymnospermic pollen, and angiospermic pollen. In each group, descriptions are alphabetically arranged under the scientific name. Palynomorphs are described based on characteristics of shape, size, aperture arrangement, and sculpture of the exine. Photographs of algae, fungi, and other palynomorphs are presented in Appendix B.

The descriptive terms applied originate from the term used by Faegri and Iversen (1989), Punt et al. (2004), and Thanikaimoni (1987). The fossil palynomorphs's scientific names used herein follow the name of the recent plants which have a botanical affinity to the fossil palynomorphs.

An attempt was made to identify the fossil palynomorphs to the species level. However, many palynomorphs were identified just to the generic or even the family levels. The difficulty arises from the lack of a well-identified Recent pollen data bank. An adequate pollen literature, LM slides, and SEM photographs of the Recent pollen proved to be very important for comparison and identification of fossil palynomorphs.

Photographs of identified fossil palynomorphs are provided in this chapter. Some unidentified palynomorphs are also illustrated in the Appendices 2-3 for the purpose of investigation in the future.

4.2 Pteridophytes and other non-seed plants

Pteridophyta

Blechnaceae: 7 genera/ more than 200 species in the world (Stevens, 2001)

5 species have been collected in Thailand (The Forest Herbarium, 2007)

Stenochlaena palustris (Burm.f.) Bedd.

Plate I, Figs. 1-3

Shape: Ellipsoidal, plano-convex in equatorial view, convex distal outline, straight or slightly concave proximal outline.

Size: 38 x 22 µm.

Aperture: Monolete.

Exospore: Exine 2-3 µm, verrucate sculpture, wart-like verrucae with irregular height and distribution.

This spore has wart-like verrucae as a distinctive character. Spore shape is not easy to recognize because it is always folded. However, the distorted shape can be another characteristic feature of this spore.

Cyatheaceae: 5 genera/ 600 species in the world (Stevens, 2001)

1 genera/ 7 species have been recorded in Thailand (The Forest Herbarium, 2007)

Cyatheaceae gen. indet. 1

Plate I, Figs. 4-6

Shape: Subtriangular, apices rounded, proximal pole flat, distal pole hemispherical.

Size: 47 µm.

Aperture: Trilete, laesura arms straight with lip-like margo.

Sculpture: Psilate.

Cyatheaceae gen. indet. 2

Plate I, Figs. 7-9

Shape: Subtriangular, apices rounded, proximal pole conical, distal pole hemispherical.

Size: 33 µm.

Aperture: Trilete, laesura arms straight with lip-like margo.

Sculpture: Psilate to micrograngulate.

Cyathea is the only genus of Cyatheaceae in Thailand today. Spores are similar in shapes and sizes. Laesura with lip-like or flange-like margo is a distinctive character. *Cyathea* sp. 1 and 2 are similar in shape and sculpture, but they were separated by the different sizes. However, the size of a spore fossil might be affected by various influences during the time of deposition. Chemical treatment during spore extraction processes also influenced their size. This means size may not be used as a strict criterion in the identification processes. So, *Cyathea* sp. 1 and 2 may or may not be the same species.

Davalliaceae: 4-5 genera/ 65 species in the world (Stevens, 2001)

5 genera/ 19 species have been recorded in Thailand (The Forest Herbarium, 2007)

***Davallia* sp. 1**

Plate I, Figs. 10-12

Shape: Ellipsoidal, bilaterally symmetrical, oblong-elliptic in polar view, plano-convex in equatorial view, bean shaped.

Size: 33 μm long, 23 μm wide.

Aperture: Monolete, laesura 17 μm long.

Sculpture: Large verrucae to areolate with psilate or occasionally microgranulate surface.

***Davallia* sp. 2**

Plate I, Figs. 13-15

Shape: Ellipsoidal, bilaterally symmetrical, oblong-elliptic in polar view, plano-convex in equatorial view.

Size: 43 μm long, 27 μm wide.

Aperture: Monolete, laesura 21 μm long.

Sculpture: Exine thinner than that of *Davallia* sp. 1, large verrucate or rugulate with psilate surface, occasionally microgranules present.

Gleicheniaceae: 6 genera/ 125 species in the world (Stevens, 2001)

2 genera/ 8 species in Thailand (The Forest Herbarium, 2007)

***Dicranopteris* sp.**

Plate II, Figs. 4-6

Shape: Trilobate, proximal pole flat, distal pole hemispherical.

Size: 38 μm.

Aperture: Trilete. Laesura arms simple, straight, length equal to the radius.

Sculpture: Psilate.

Gleicheniaceae gen. indet.

Plate II, Figs. 1-3

Shape: Sub-triangular with prolonged angles, apex rounded.

Size: 38-39 μm.

Aperture: Trilete, straight, almost equal to the radius.

Sculpture: Exine 2 μm, psilate to microrugulate.

Polypodiaceae: 56 genera/ 1200 species in the world (Stevens, 2001)

***Polypodium* sp. 1**

Plate II, Figs. 10-12

Shape: Elliptical.

Size: 33-34 μm.

Aperture: Monolete.

Sculpture: Exine 2-3 μm, verrucate sculpture, verrucae larger than 2 μm forming a net-like pattern.

***Polypodium* sp. 2**

Plate II, Figs. 13-15

Shape: Spheroidal to elliptical.

Size: 20 µm long, 15 µm wide in proximal view.

Aperture: Monolete, laesura 5.5 µm long.

Sculpture: Verrucate.

Pteridaceae: 50 genera/ 950 species in the world (Stevens, 2001)

3 genera/ 32 species in Thailand (The Forest Herbarium, 2007)

***Pteris* sp. 1**

Plate III, Figs. 7-9

Shape: Subtriangular.

Size: 27 µm.

Aperture: Trilete, laesura arms almost equal to the radius.

Sculpture: tuberculate, tubercles of different shapes and sizes, surface microscabrate, microgranulate between tubercles.

***Pteris* sp. 2**

Plate III, Figs. 10-12

Shape: Subcircular.

Size: 21 µm.

Aperture: Trilete, laesura arms almost equal to the radius.

Sculpture: tuberculate, tubercles of different shapes and sizes, microscabrate, microgranulate between tubercles.

Pteridaceae gen. indet. 1

Plate III, Figs. 1-3

Shape: Sub-triangular, apex rounded, annulate equatorial ridge (~5 µm wide).

Size: 32 µm.

Aperture: Trilete.

Sculpture: verrucate with granules in the grooves, microgranulate on the equatorial ridge surface.

Pteridaceae gen. indet. 2

Plate III, Figs. 4-6

Shape: Sub-triangular, apex rounded, annulotrilete equatorial ridge.

Size: 26 µm.

Aperture: Trilete.

Sculpture: Vermiculate, irregular sizes and orientation, scabrate surface, equatorial ridge with microscabrate surface.

Family Pteridaceae is classified by the trilete aperture (monolete only in *Cheilanthes hirsuta*) and rounded triangular to subtriangular shape. The presence of an equatorial ridge is characteristic for some species of the genus *Pteris*. The sculpture consists of various patterns of tuberculate, reticulate, regulate, or convolute ornamentation (Huang, 1981).

Schizaeaceae: 2 genera/ 30 species in the world (Stevens, 2001)

2 genera/ 9 species in Thailand (The Forest Herbarium, 2007)

***Anemia* sp.**

Plate III, Figs. 13-15

Shape: Subtriangular

Size: 27 µm

Aperture: Trilete**,** laesura arms almost equal the radius

Sculpture: Clavate, irregular, long (> 1 μm), clavae fused at the base

Lycopodiophyta

Lycopodiaceae: 1 genus/ 9 species in Thailand (The Forest Herbarium, 2007)

Lycopodium cernuum L.

Plate II, Figs. 7-9

Shape: Sub-circular.

Size: ca. 26 µm.

Aperture: Trilete, lip-like margo.

Sculpture: Slightly rugulate, rugulae look like meandering ridges, occasional microgranules present.

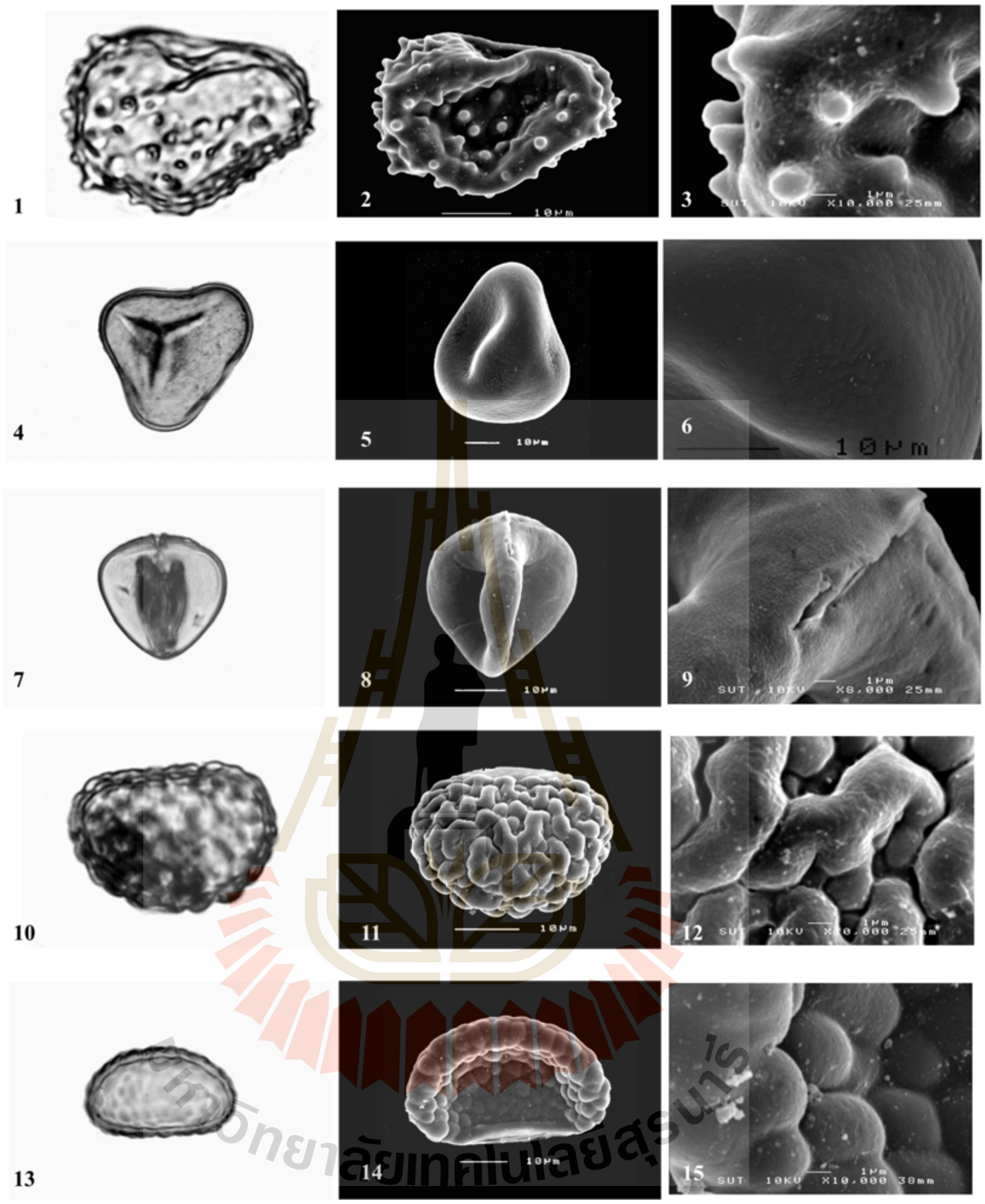


Plate I Figs. 1-3. *Stenochlaena palustris* (Burm.f.) Bedd. (LM, SEM, and SEM close-up)

Figs. 4-6. Cyatheaceae gen. indet. 1 (LM, SEM, and SEM close-up)

Figs. 7-9. Cyatheaceae gen. indet. 2 (LM, SEM, and SEM close-up)

Figs. 10-12. *Davallia* sp. 1 (LM, SEM, and SEM close-up)

Figs. 13-15. *Davallia* sp. 2 (LM, SEM, and SEM close-up)

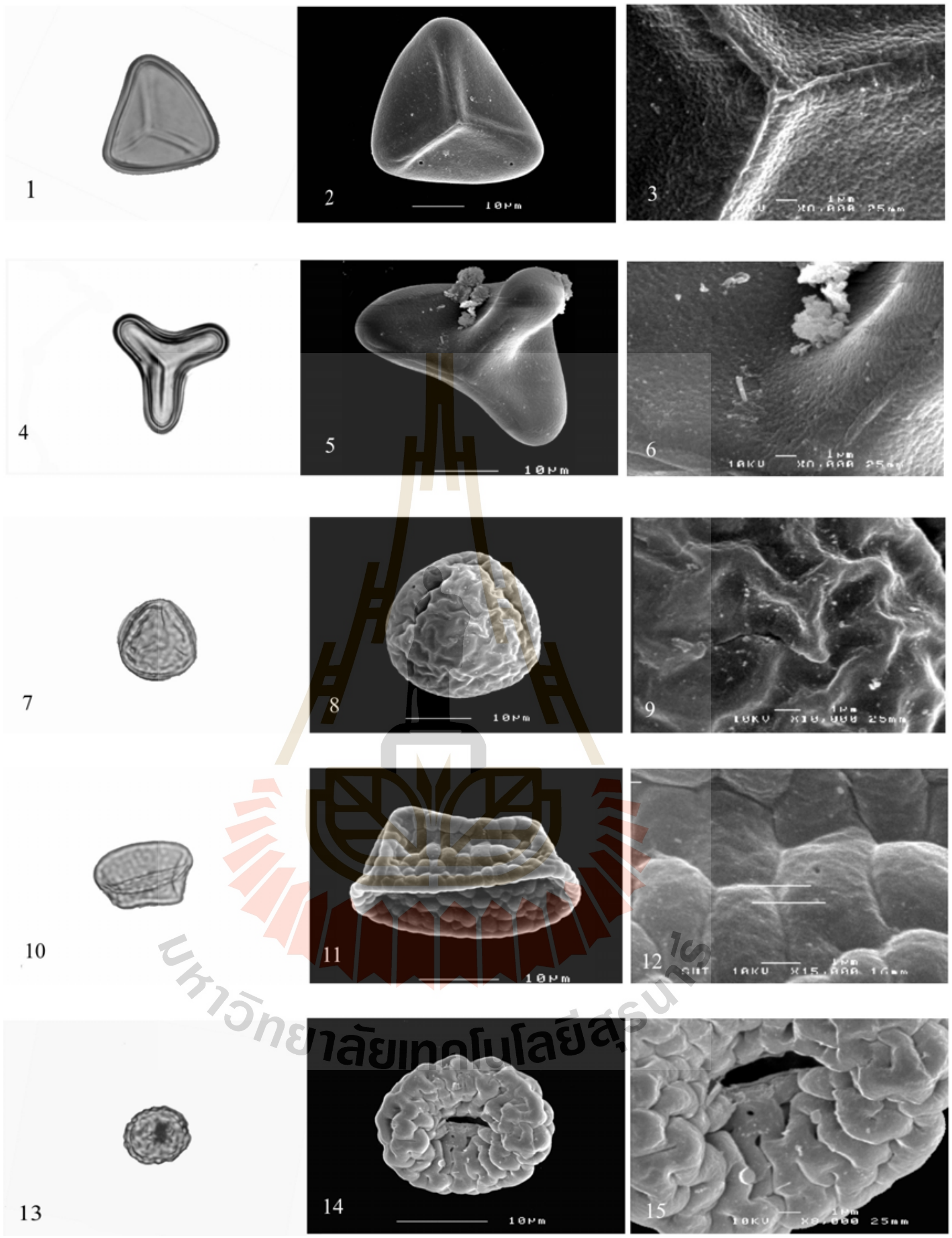


PLATE II Figs. 1-3. Gleicheniaceae gen. indet. (LM, SEM, and SEM close-up)
Figs. 4-6. *Dicranopteris* sp. (LM, SEM, and SEM close-up)
Figs. 7-9. *Lycopodium cernuum* L. (LM, SEM, and SEM close-up)
Figs. 10-12. *Polypodium* sp. 1 (LM, SEM, and SEM close-up)
Figs. 13-15. *Polypodium* sp. 2 (LM, SEM, and SEM close-up)

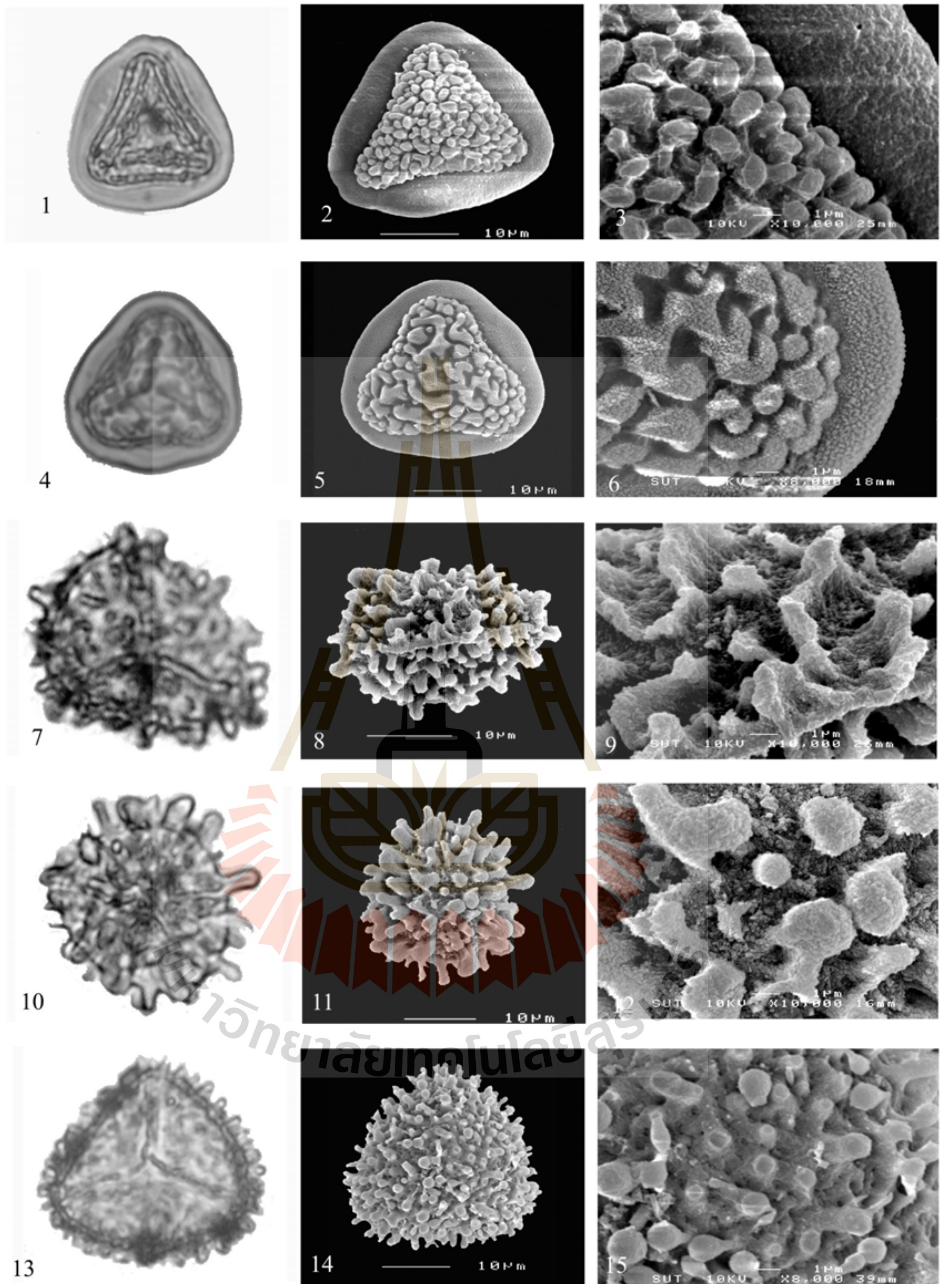


PLATE III Figs. 1-3. Pteridaceae gen. indet. 1 (LM, SEM, and SEM close-up)

Figs. 4-6. Pteridaceae gen. indet. 2 (LM, SEM, and SEM close-up)

Figs. 7-9. *Pteris* sp. 1 (LM, SEM, and SEM close-up)

Figs. 10-12. *Pteris* sp. 2 (LM, SEM, and SEM close-up)

Figs. 13-15. *Anemia* sp. (LM, SEM, and SEM close-up)

4.3 Gymnosperms

Pinaceae: 11 genera/ 210 species in the world (Stevens, 2001)

***Pinus* sp.**

Plate IV, Figs. 1-3

Shape: Bisaccate.

Size: 50 μm, corpus 41μm, sacci 19 μm, body much larger than sacci.

Sculpture: Corpus microverrucate, sacci faintly microverrucate with perforations.

Pinus pollen is characterized by the arrangement of corpus and two sacci which are placed symmetrically. Sculpture on distal area ranges from psilate to scabrate, while it is more or less rugulate on the proximal surface (Farjon and Styles, 1997).

Because of the relative uniformity of *Pinus* pollen morphology, they are difficult to classify at the species level. Nowadays, there are 2 species of *Pinus* in Thailand: *P.kesiya* Royle ex Gordon and *P. merkusii* Jungh & de Vriese, both with similar pollen which may or may not exactly match the fossil pollen.

Podocarpaceae: 17 genera/ 125 species in the world (Stevens, 2001)

2 genera/ 7 species in Thailand (The Forest Herbarium, 2007)

***Dacrydium* sp.**

Plate IV, Figs. 7-9

Shape: Bisaccate.

Size: 39 µm.

Sculpture: Corpus microverrucate to finely rugulate, usually fused with each other. Sacci small undulate with perforations.

Podocarpus imbricatus Bl.

Plate IV, Figs. 4-7

Shape: Trisaccate, corpus rounded.

Size: 48 µm, sacci smaller than corpus.

Sculpture: Corpus areolate with microgranules to verrucate at area of attachment to sacci. Sacci verrucate with perforations.

***Podocarpus* sp. 1**

Plate IV, Figs. 10-12

Shape: Bisaccate, sacci constricted at area of attachment to corpus.

Size: 56 µm, corpus 24 µm, sacci 28 µm, sacci much larger than body.

Sculpture: Corpus faintly microverrucate, distinctly verrucate at area of attachment. Sacci psilate to perforate.

***Podocarpus* sp. 2**

Plate IV, Figs. 13-15

Shape: Bisaccate, sacci constricted at the area of attachment to corpus.

Size: 52 µm, corpus 17 µm, sacci 23 µm, sacci much larger than body.

Sculpture: Corpus microverrucate, distinctly verrucate near area of attachment. Sacci psilate to perforate.

Podocarpus sp. 1 and 2 are similar in many characteristics, but species 2 seemed to be smaller in overall size. The microverrucate sculpture on the corpus of species 2 is more apparent than that of species 1.

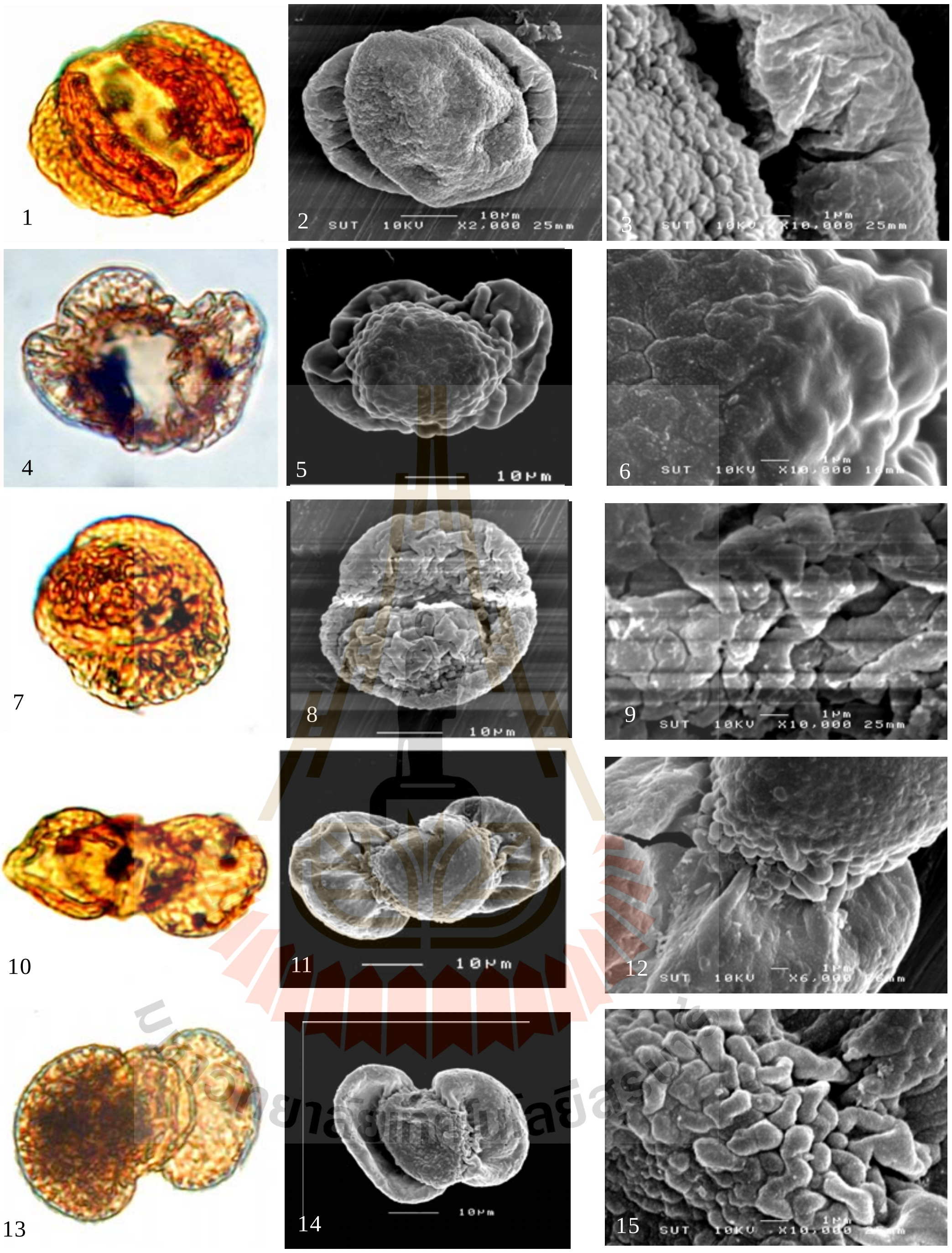


PLATE IV Figs. 1-3. *Pinus* sp. 1 (LM, SEM, and SEM close-up)

Figs. 4-6. *Podocarpus imbricatus* Bl. (LM, SEM, and SEM close-up)

Figs. 7-9. *Dacrydium* sp. (LM, SEM, and SEM close-up)

Figs. 10-12. *Podocarpus* sp. 1 (LM, SEM, and SEM close-up)

Figs. 13-15. *Podocarpus* sp. 2 (LM, SEM, and SEM close-up)

4.4 Angiosperms

Acanthaceae: 229 genera/ 3500 species in the world (Stevens, 2001),

40 genera/ 250 species in Thailand (The Forest Herbarium, 2007)

***Acanthus* sp. 1**

Plate V, Figs. 1-3

Shape: Prolate.

Size: 46 x 24 µm.

Aperture: Tricolpate, colpi long.

Sculpture: Fine reticulate to foveolate.

***Acanthus* sp. 2**

Plate V, Figs. 4-6

Shape: Prolate.

Size: 34 x 19 µm.

Aperture: Tricolpate, colpi long.

Sculpture: Microreticulate to rugulate.

Apart from the size, *Acanthus* species 1 and 2 are similar in shape and aperture. Their sculpture is classified as intermediate between finely reticulate and foveolate, but a little different in detail. They show a general resemblance to *Acanthus ilicifolius* L. (Plate V: Figs. 7-9), but *A. ilicifolius* has a very clear reticulate sculpture with a lumen size of almost 1 µm.

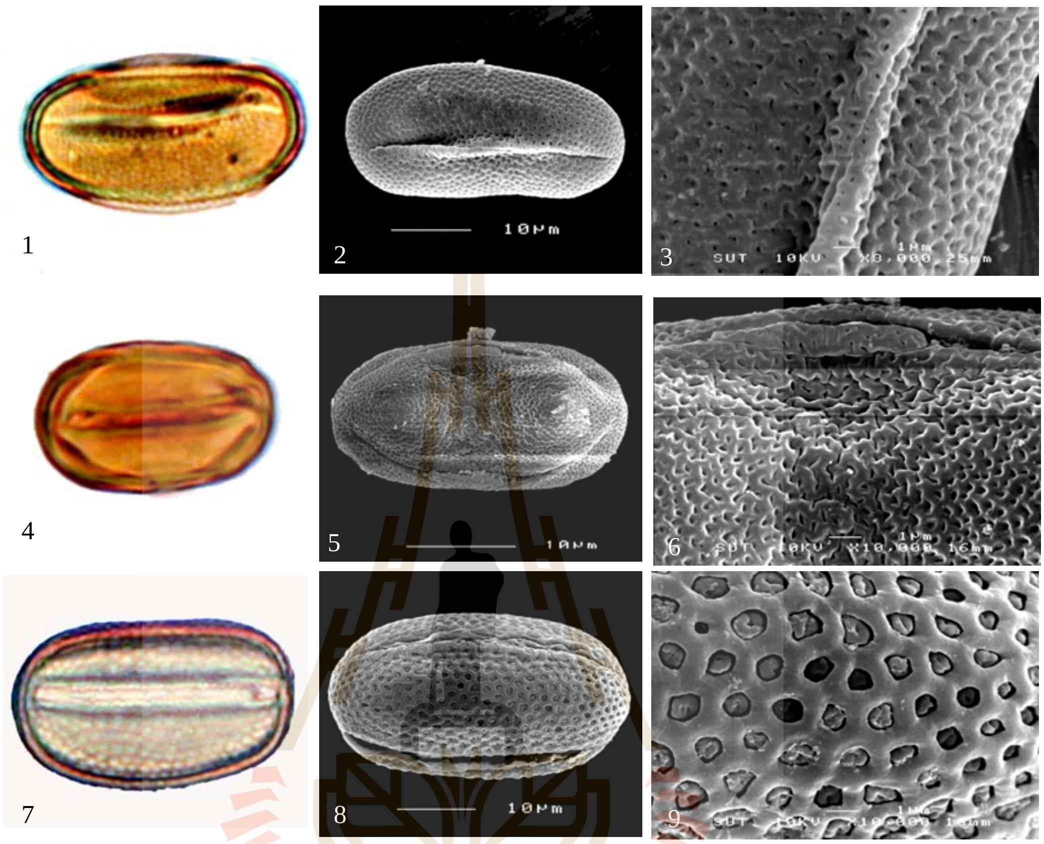


PLATE V Figs. 1-3. *Acanthus* sp. 1 (LM, SEM, SEM close-up)

Figs. 4-6. *Acanthus* sp. 2 (LM, SEM, SEM close-up)

Figs. 7-9. Recent pollen of *Acanthus ilicifolius* L. (LM, SEM, SEM close-up)

Aquifoliaceae: 1 genus/ 405 species in the world (Stevens, 2001)

1 genus/ 5 species in Thailand (The Forest Herbarium, 2007)

***Ilex* sp. 1**

Plate VI, Figs. 1-3

Shape: Subtriangular to spheroidal in polar view.

Size: 17 µm.

Aperture: Tricolporate.

Sculpture: Verrucate, larger verrucae situated on the intercolpium and in the polar area, verrucae gradually smaller to colpi margin, exine thicker in mesocolpium.

Ilex sp. 1 looks very similar to *Ilex cymosa* Bl. (Plate VI: Figs 7-9), but since information available on the variation among modern species was limited, the specimens could only be classified at the generic level.

***Ilex* sp. 2**

Plate VI, Figs. 4-6

Shape: Prolate to subprolate in equatorial view.

Size: 17 x 12 µm.

Aperture: Tricolporate.

Sculpture: Verrucate, clavate, pilate, gemmate, various sizes of element (up to 1 µm), small granules present between coarser elements.

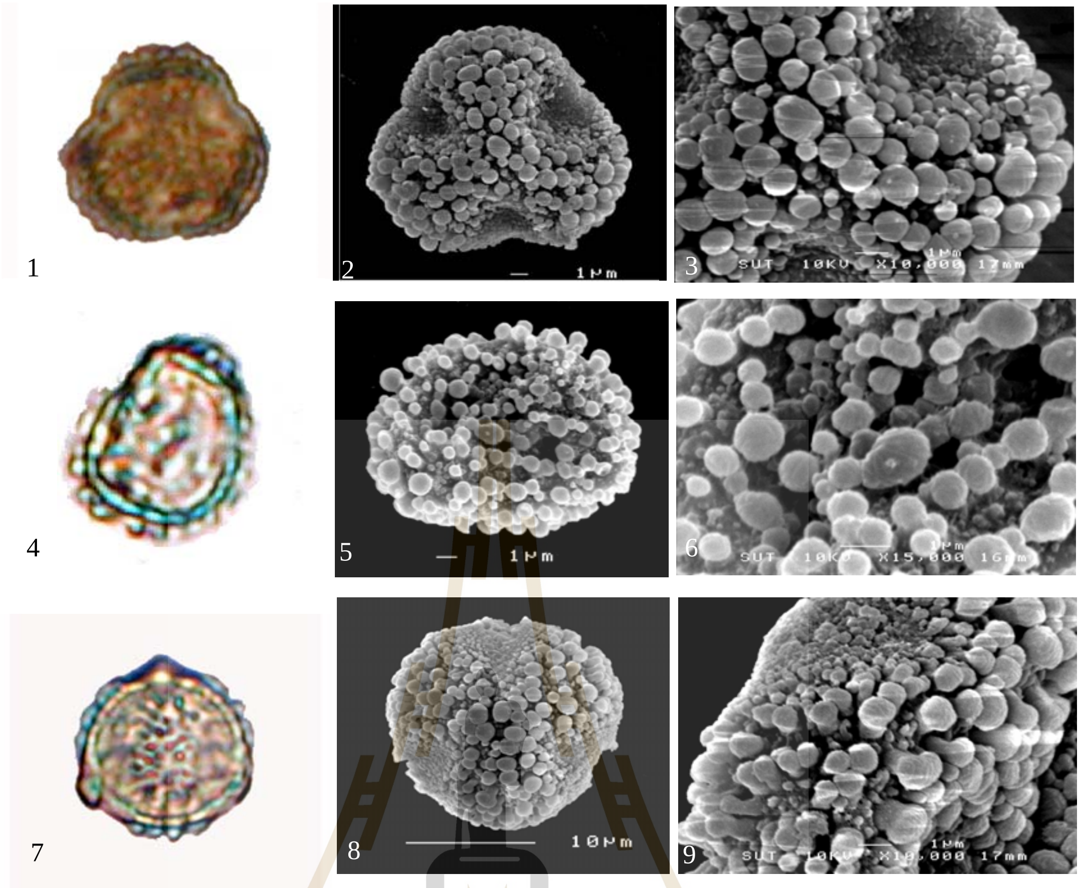


PLATE VI Figs. 1-3. *Ilex* sp. 1 (LM, SEM, and SEM close-up)

Figs. 4-6. *Ilex* sp. 2 (LM, SEM, and SEM close-up)

Figs. 7-10. Recent pollen of *Ilex cymosa* Bl. (LM, SEM, and SEM close-up)

Avicennaceae

***Avicennia* sp. 1**

Plate VII, Figs. 1-3

Shape: Spheroidal – prolate in equatorial view.

Size: 21 µm.

Aperture: Tricolporate; ectoaperture long, ectoaperture wide at the equator, pore oval.

Sculpture: Reticulate.

***Avicennia* sp. 2**

Plate VII, Figs. 4-6

Shape: Prolate in equatorial view.

Size: 23 µm.

Aperture: Tricolporate; ectoaperture long.

Sculpture: Reticulate, thicker muri in mesocolpium area than along aperture margin, small granules around the apertural area.

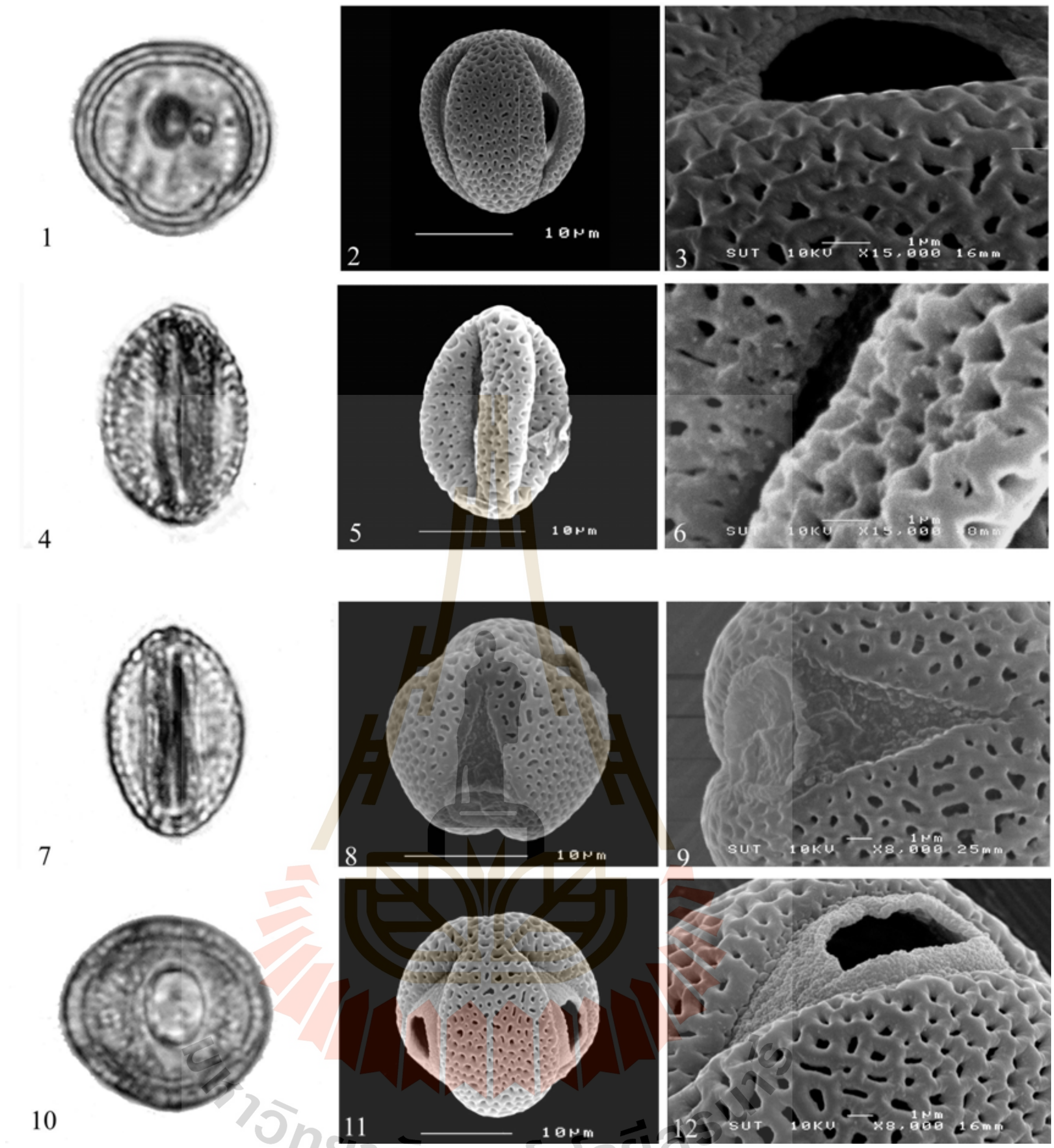


PLATE VII Figs.1-3. *Avicennia* sp. 1 (LM, SEM, and SEM close-up)

Figs.4-6. *Avicennia* sp. 2 (LM, SEM, and SEM close-up)

Figs.7-9. Recent pollen of *Avicennia alba* Bl. (LM, SEM, and SEM close-up)

Figs. 10-12.Recent pollen of *Avicennia tomentosum* Jacq. (LM, SEM, and SEM close-up)

Barringtoniaceae

Barringtonia acutangula (L.) Gaertn.

Plate VIII, Figs. 1-3

Shape: Prolate.

Size: 34 x 24 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.

Modern pollen of *Barringtonia acutangula* (L.) Gaertn. and *Barringtonia macrostachya* Kurz are provided for comparison (Plate VIII, Figs. 4-9). The fossil pollen was classified as *Barringtonia acutangula* (L.) Gaertn. based on the character of the colpus margin ridges. In *B. acutangula* the margin ridge is not obviously present, whereas it is apparently present in the other *Barringtonia* such as in *B. macrostachya*. In *B. macrostachya*, there is an extra groove and ridge parallel to the colpus margin.

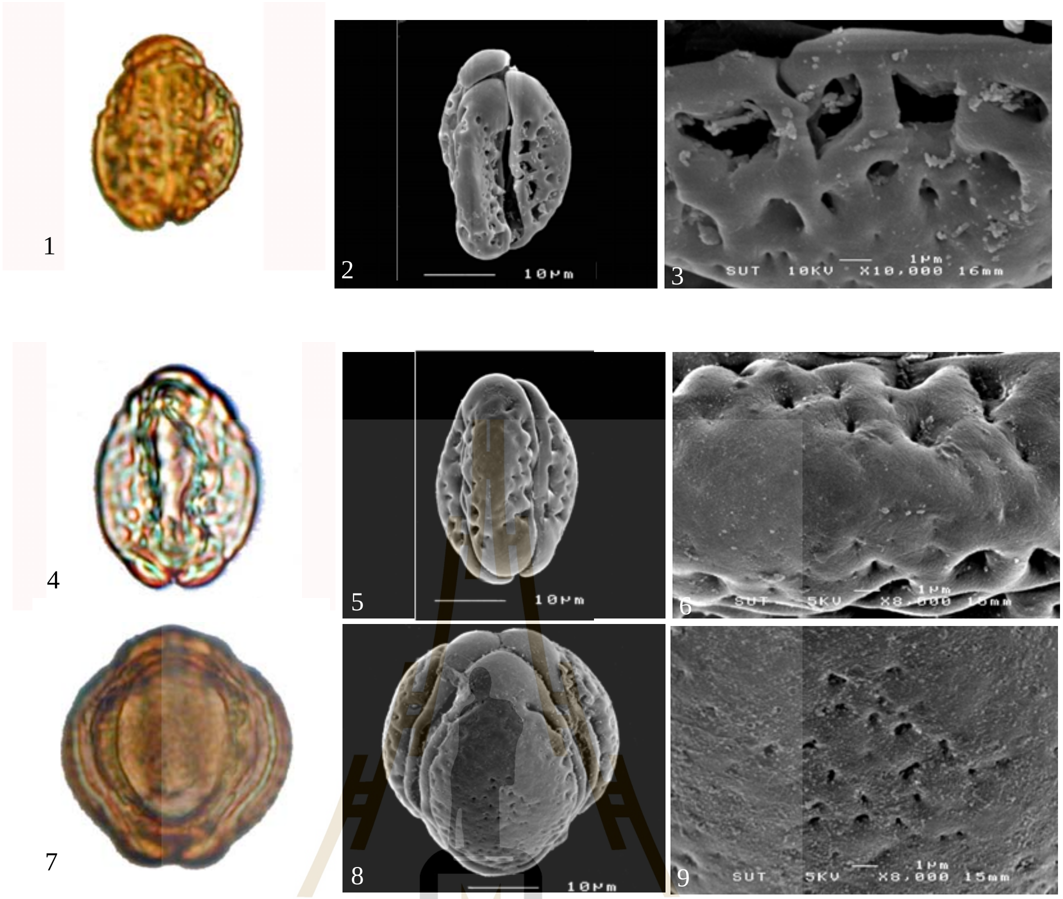


PLATE VIII Figs. 1-3 *Barringtonia acutangula* (L.) Gaertn. (LM, SEM, and SEM close-up

Figs. 4-6 Recent pollen of *Barringtonia acutangula* (L.) Gaertn. (LM, SEM, and SEM close-up)

Figs.7-9 Recent pollen of *Barringtonia macrostachya* Kurz (LM, SEM, and SEM close-up)

Betulaceae: 6 genera/ 110 species in the world (Stevens, 2001)

3 genera/ 4 species in Thailand (The Forest Herbarium, 2007)

***Betula* sp.**

Plate IX, Figs. 1-3

Shape: Subtriangular.

Size: 19 µm.

Aperture: Trizonoporate, pore circular, slightly protruding.

Sculpture: Vermiculate with small spines.

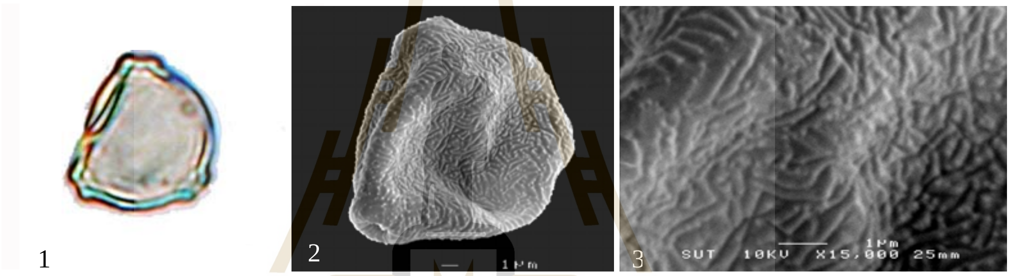


PLATE IX Figs. 1-3. *Betula* sp. (LM, SEM, and SEM close-up)

Casuarinaceae: 4 genera/ 95 species in the world (Stevens, 2001)

1 genus/ 2 species in Thailand (The Forest Herbarium, 2007)

***Casuarina* sp.**

Plate X, Figs. 1-3

Shape: Subtriangular in polar view.

Size: 22 µm.

Aperture: Triporate, angulaperturate, pore circular, slightly protruding, thin pore membrane present.

Sculpture: Microverrucate, surface finely scabrate to microechinate.

Modern pollen of *Casuarina equisetifolius* J.R. & G.Forst. is provided for comparison in Plate X, Figs. 4-6.

Chenopodiaceae: 100 genera/ 1500 species in the world

2 indigenous genera, 2 cultivated genera/ 5 species in Thailand (The Forest Herbarium, 2007)

Suaeda maritima (L.) Dumort.

Plate X, Figs. 7-9

Shape: Spheroidal.

Size: 17 µm.

Aperture: Pantoporate, pores circular, spinules on the pore membrane.

Sculpture: Microverrucate with scattered microspines on surface.

Modern pollen of *Suaeda maritima* (L.) Dumort. is provided for comparison in Plate X, Figs. 10-12. Pollen in this family is usually similar making it difficult to identify.

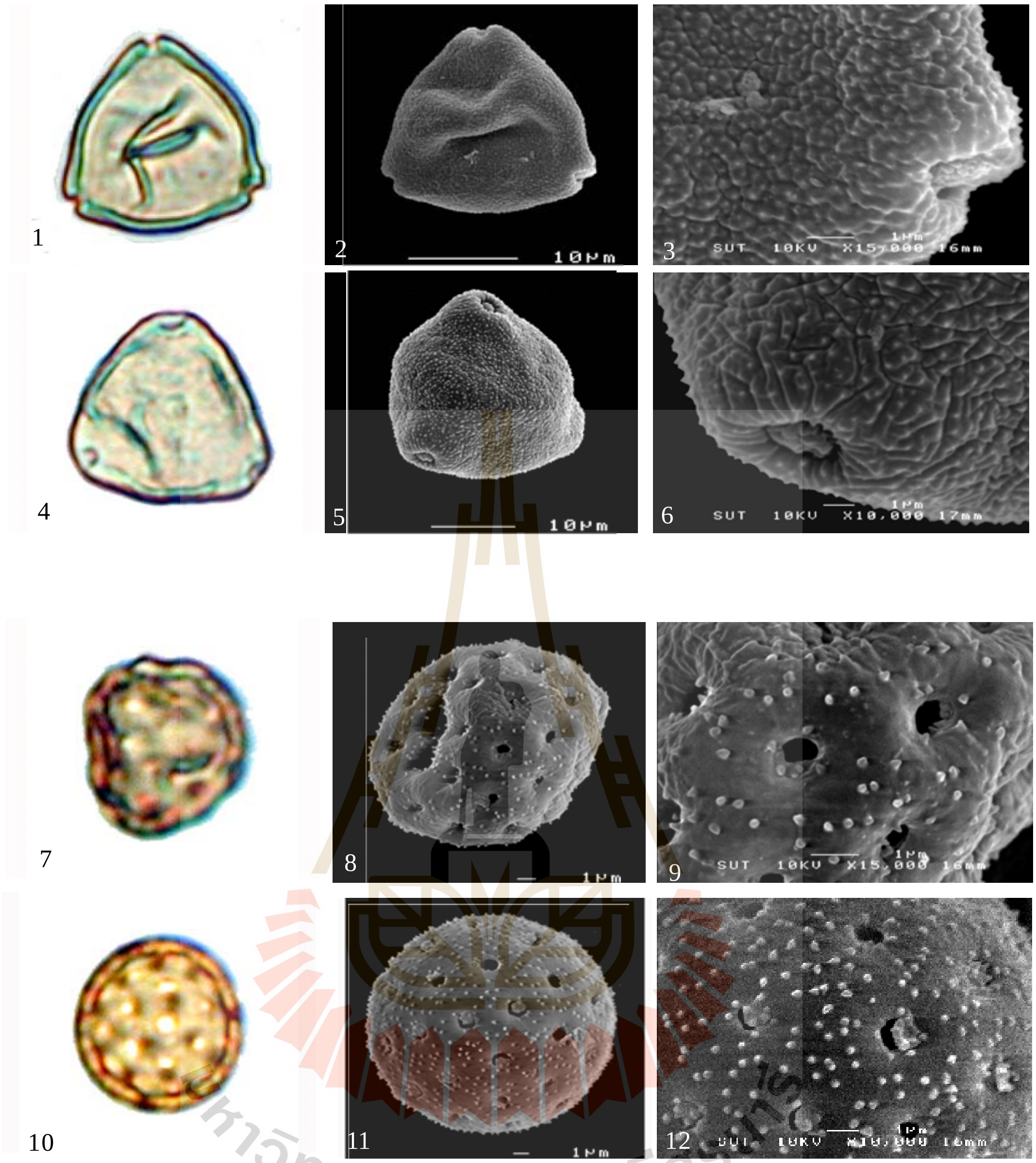


PLATE X Figs. 1-3. *Casuarina* sp. (LM, SEM, and SEM close-up)

Figs. 4-6. Recent pollen of *Casuarina equisetifolius* J.R. & G.Forst. (LM, SEM, and SEMclose-up)

Figs. 7-9. *Suaeda maritima* (L.) Dumort. (LM, SEM, and SEM close-up)

Figs. 10-12. Recent pollen of *Suaeda maritima* (L.) Dumort. (LM, SEM, and SEM close-up)

Combretaceae: 14 genera/ 500 species in the world (Stevens, 2001)

5 genera/ 30 species in Thailand (The Forest Herbarium, 2007)

Combretaceae gen. indet. 1

Plate XI, Figs. 1-3

Shape: Spheroidal, six-lobed in polar view.

Size: 19 µm.

Aperture: Pseudo tricolporate, colpi medium long.

Sculpture: Psilate to faintly rugulate, small granules occasionally present.

Combretaceae gen. indet. 2

Plate XI, Figs. 4-6

Shape: Prolate in equatorial view.

Size: 22 x 12 µm.

Aperture: Pseudotricolporate, colpi long.

Sculpture: Reticulate.

Combretaceae gen. indet. 3

Plate XI, Figs. 7-9

Shape: Prolate in equatorial view.

Size: 26 x 21 µm.

Aperture: Pseudotricolporate, colpi long.

Sculpture: Perforate, small granules occasionally present.

Combretaceae gen. indet. 4

Plate XI, Figs. 10-12

Shape: Spheroidal in polar view.

Size: 18 µm.

Aperture: Pseudotricolporate.

Sculpture: Perforate with microgranules around the apertural area.

Combretaceae gen. indet. 5

Plate XI, Figs. 13-15

Shape: Oblate in equatorial view, six-lobed in polar view.

Size: 19 x 17 µm.

Aperture: Pseudotricolporate, colpi medium long.

Sculpture: Perforate.

Five types of Combretaceae fossil pollen presented above are similar in size and apertural type, i.e., heterocolpate with 3-tricolpi and 3-pseudotricolpi such as found in pollen of Combretaceae. However, colpi lengths and sculpture types varied. Modern pollen of *Lumnitzera coccinea* (Gaudich.) Wight&Arn., *L. littorea* (Jack) Voigt, and *L. racemosa* Willd. are provided for comparison in Plate XII.

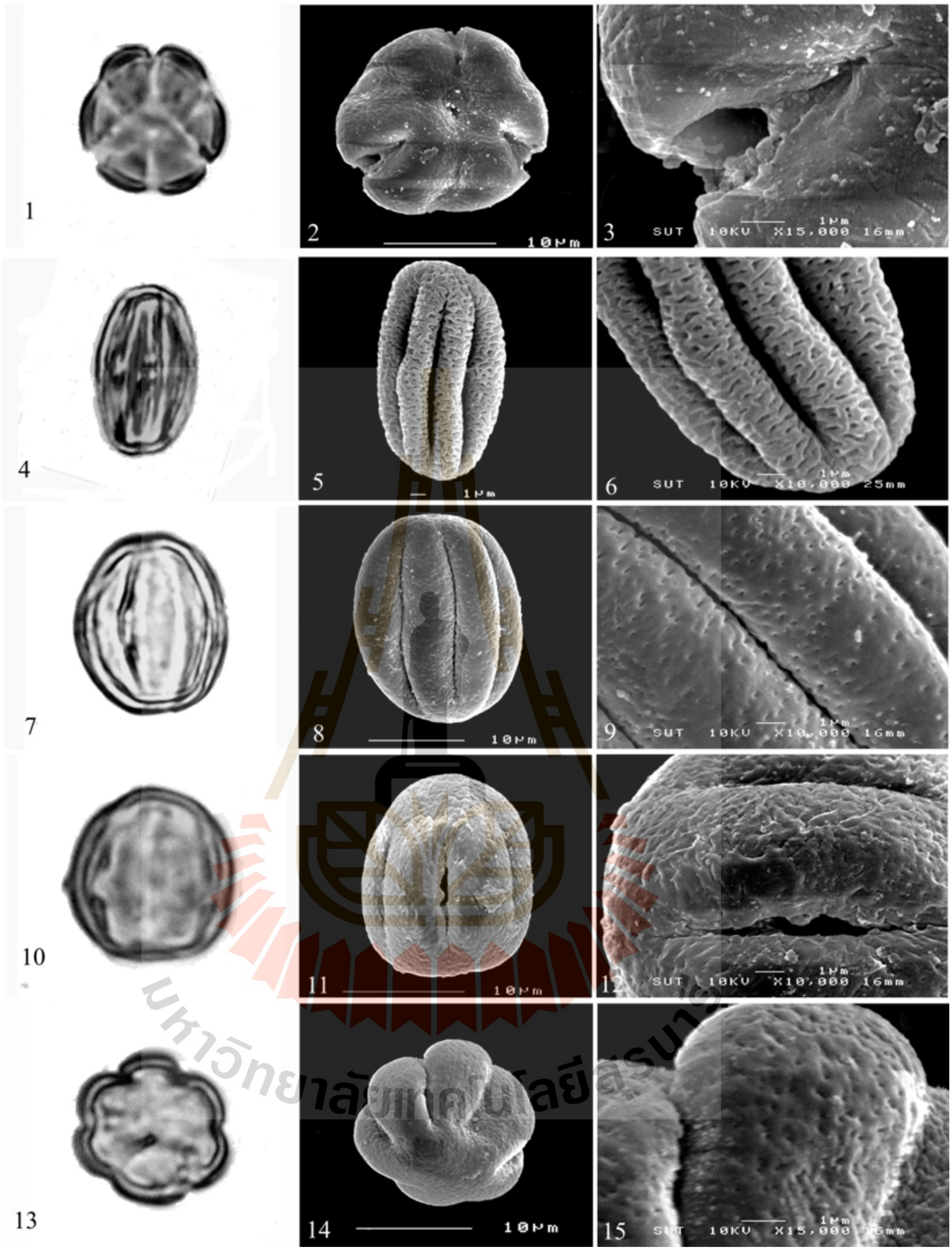


PLATE XI : Figs. 1-3. Combretaceae gen. indet. 1 (LM, SEM, and SEM close-up)

Figs. 4-6. Combretaceae gen. indet. 2 (LM, SEM, and SEM close-up)

Figs. 7-9. Combretaceae gen. indet. 3 (LM, SEM, and SEM close-up)

Figs. 10-12. Combretaceae gen. indet. 4 (LM, SEM, and SEM close-up)

Figs. 13-15. Combretaceae gen. indet. 5 (LM, SEM, and SEM close-up)

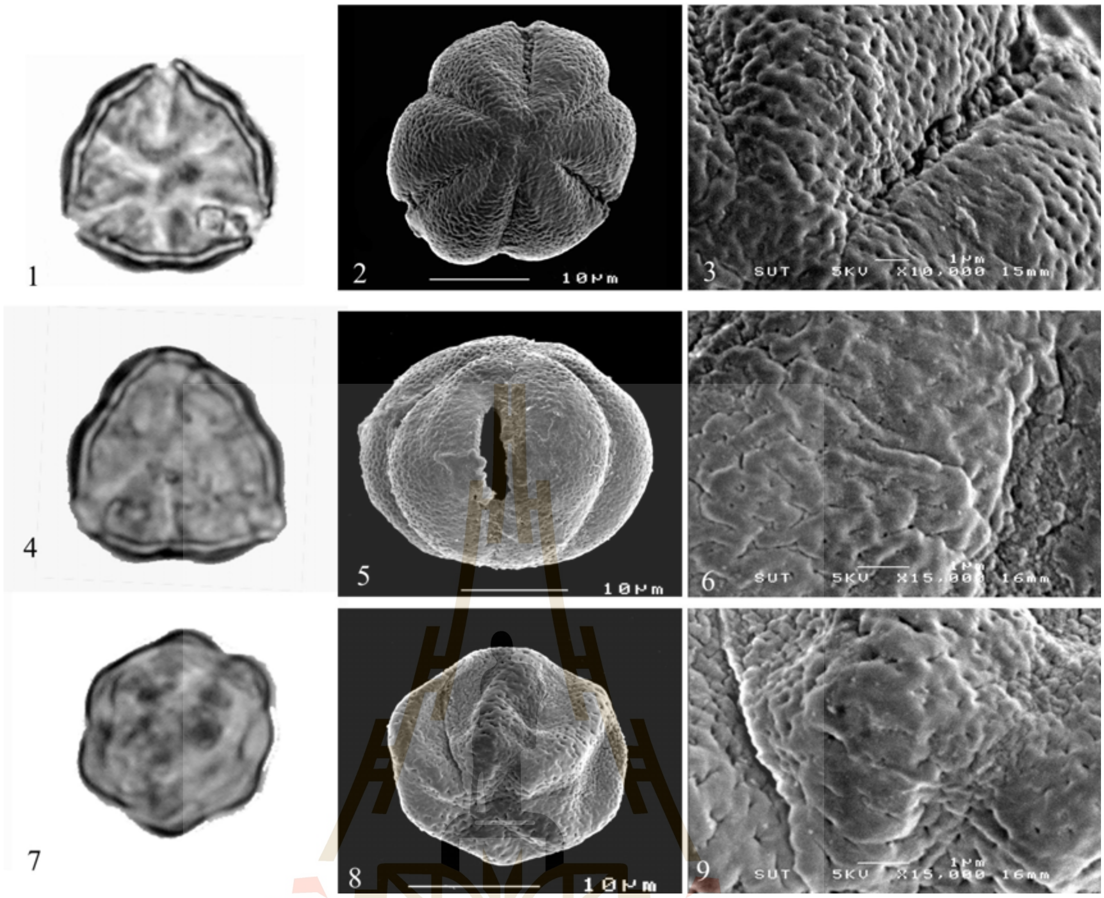


PLATE XII Figs. 1-3.Recent pollen of *Lumnitzera coccinea* (Gaudich.) Wight & Arn. (LM, SEM, and SEM close-up)

Figs. 4-6. Recent pollen of *Lumnitzera littorea* (Jack) Voigt (LM, SEM, and SEM close-up)

Figs. 7-9. Recent pollen of *Lumnitzera racemosa* Willd. (LM, SEM, and SEM close-up)

Dipterocarpaceae:

17 genera/ 680 species in the world (Stevens, 2001)

8 genera/ 70 species in Thailand (The Forest Herbarium, 2007)

***Dipterocarpus* sp.**

Plate XIII, Figs. 1-3

Shape: Spheroidal in polar view.

Size: 53 µm.

Aperture: Tricolpate.

Sculpture: Rugulate, broad and smooth muri.

Modern pollen of *Dipterocarpus alatus* Roxb. ex G.Don, *D. obtusifolius* Teijsm. ex Miq., and *Hopea ferrea* Laness. is provided for comparison in Plate XIII, Figs. 4-12, respectively. Sizes of *D. alatus* and *D. obtusifolius* pollen are apparently larger than that of *H. ferrea.* In polar view, it can be seen that the polar areas of both pollen genera are small. Long colpi distinctly separate pollen into three lobes. When the grain is flattened, it is easily recognized by its three lobes in polar view.

Rugulate sculpture of *D. alatus* is similar to that of *D. obtusifolius* with muri around 1 µm-wide. Smooth surface rugulae of *D. alatus* and rough surface rugulae of *D. obtusifolius* distinguish these two pollen species. Sculpture of *Hopea* is finely regulate, whereas shallow transversal grooves on muri surface create a beaded pattern. Based on the sculpture, the fossil pollen is classified as being closer to *D. alatus* than to the others.

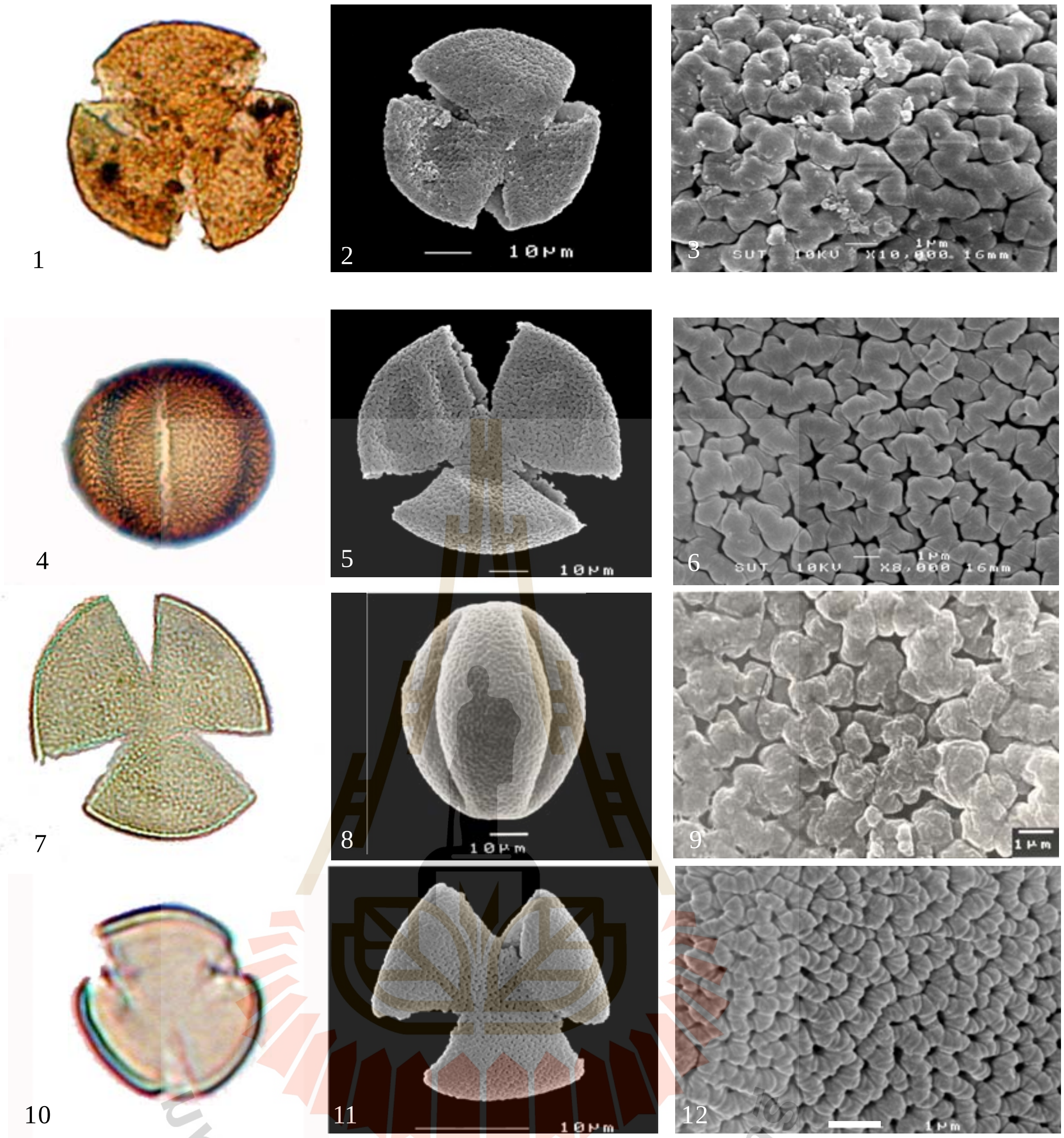


PLATE XIII

Figs. 1-3 *Dipterocarpus* sp. (LM, SEM, and SEM close-up)

Figs. 4-6 Recent pollen of *Dipterocarpus alatus* Roxb. ex G.Don (LM, SEM, and SEM close-up)

Figs. 7-9 Recent pollen of *D. obtusifolius* Teijsm. ex Miq. (LM, SEM, and SEM close-up), photographed by Wickanet Songtham

Figs. 10-12 Recent pollen of *Hopea ferrea* Laness. (LM, SEM, and SEM close-up)

Ebenaceae: 4 genera/ 490 species in the world (Stevens, 2001)

1 genera/ 60 species in Thailand (The Forest Herbarium, 2007)

***Diospyros* sp.**

Plate XIV, Figs. 1-3

Shape: Prolate in equatorial view.

Size: 24 x 14 µm.

Aperture: Tricolporate, colpi long almost equal to the polar axis.

Sculpture: Microverrucate with scabrae on the surface of the verrucae.

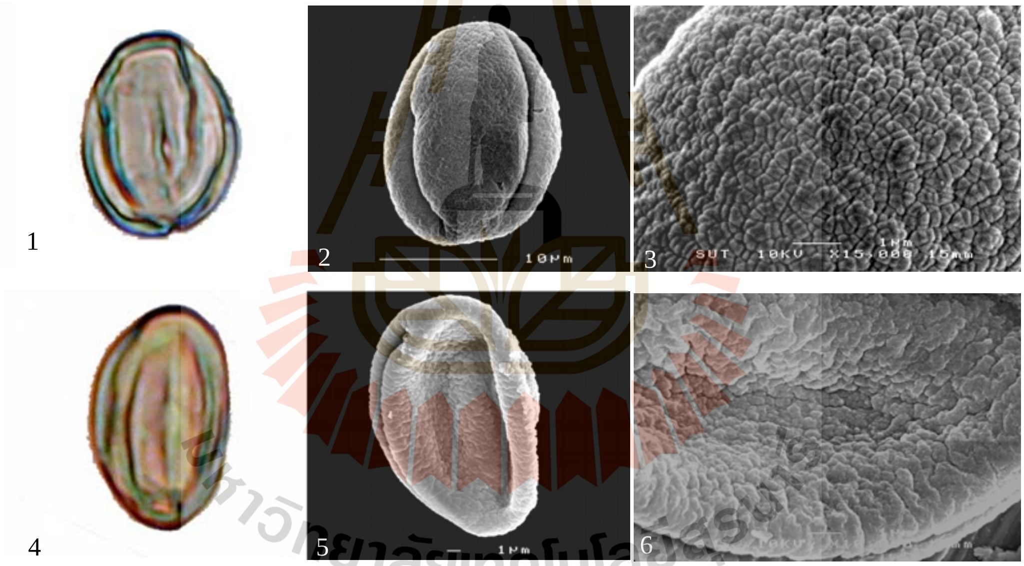


PLATE XIV Figs. 1-3. *Diospyros* sp. (LM, SEM, and SEM close-up)

Figs. 4-6. Recent pollen of *Diospyros ferrea* (Willd.) Bakh. var. *ferrea* (LM, SEM, and SEM close-up)

Euphorbiaceae: 218 genera/ 5735 species in the world (Stevens, 2001)

***Excoecaria/ Sapium* sp. 1**

Plate XV, Figs. 1-3

Shape: Prolate to spheroidal in equatorial view.

Size: 24 µm.

Aperture: tricolporate, ectoaperture long, costae colpi present, endoaperture narrowly elliptic.

Sculpture: reticulate, smooth surface along the colpus margin (lip-like).

***Excoecaria/ Sapium* sp. 2**

Plate XV, Figs. 4-6

Shape: Subtriangular in polar view.

Size: 22 µm.

Aperture: Tricolporate, costae colpi present.

Sculpture: Reticulate, colpus margin smooth.

***Excoecaria/ Sapium* sp. 3**

Plate XV, Figs. 7-9

Shape: Prolate in equatorial view.

Size: 27 x 19 µm.

Aperture: Tricolporate, colpi long, costae colpi present.

Sculpture: Reticulate, colpus margin distinctly present, smooth.

The thick exine with reticulate sculpture and smooth colpus margin are the recognizable characteristics for this group. However, there is not much modern referent pollen to compare with fossil pollen for identification. Modern pollen of *Sapium indicum* Willd. is provided for comparison in Plate XV, Figs. 10-12.

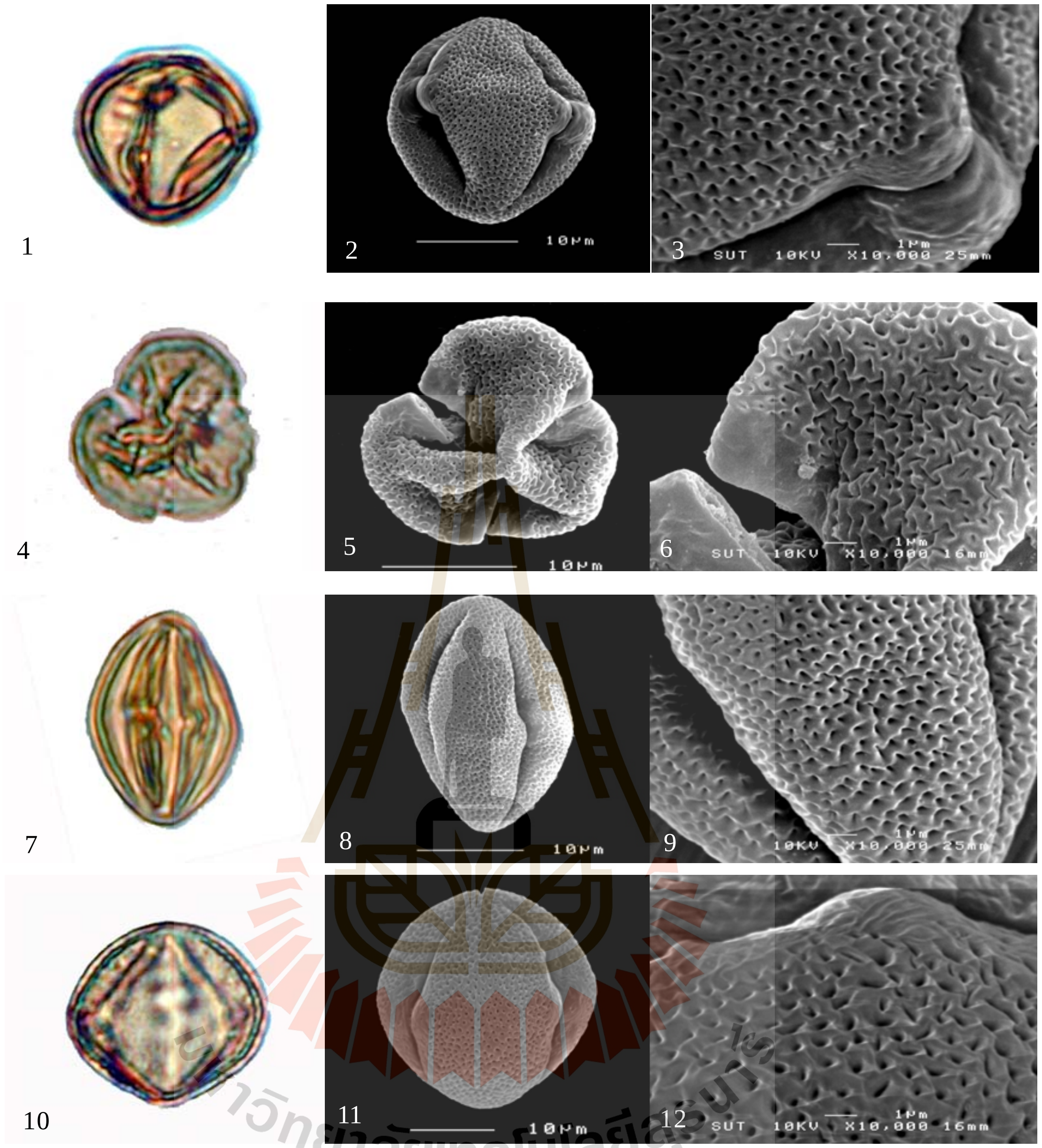


PLATE XV Figs. 1-3. *Excoecaria/ Sapium* sp. 1 (LM, SEM, and SEM close-up)

Figs. 4-6. *Excoecaria/ Sapium* sp. 2 (LM, SEM, and SEM close-up)

Figs. 7-9. *Excoecaria/ Sapium* sp. 3 (LM, SEM, and SEM close-up)

Figs. 10-12. Recent pollen of *Sapium indicum* Willd. (LM, SEM, and SEM close-up)

Fagaceae: 7 genera/ 670 species in the world (Stevens, 2001)

4 genera/ 120 species in Thailand (The Forest Herbarium, 2007)

***Quercus* sp. 1**

Plate XVI, Figs. 1-3

Shape: Spheroidal in equatorial view.

Size: 19-20 µm.

Aperture: Tricolporate.

Sculpture: Exine < 1 µm thick, scabrate to microrugulate; rod-like elements, randomly oriented arrangement.

***Quercus* sp. 2**

Plate XVI, Figs. 4-6

Shape: Prolate.

Size: Polar axis 24 µm, equatorial axis 17 µm.

Aperture: Tricolporate, colpi long.

Sculpture: Exine < 1 µm, scabrate to microrugulate; rod-like, randomly oriented arrangement.

Modern pollen of *Quercus oidocarpa* DC. is provided for comparison in Plate XVI, Figs. 7-9. The scabrate sculpture with rod-like elements and randomly oriented arrangement is a noticeable character for *Quercus* pollen.

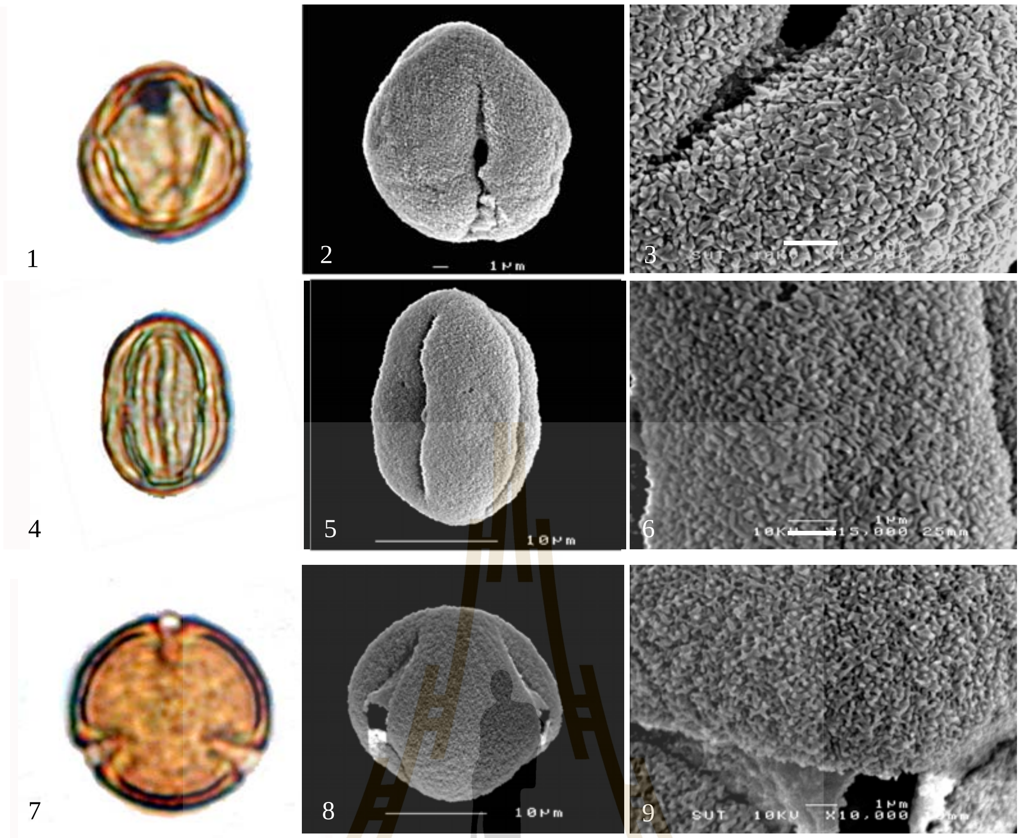


PLATE XVI Figs. 1-3 *Quercus* sp. 1 (LM, SEM, and SEM close-up)
Figs. 4-6 *Quercus* sp. 2 (LM, SEM, and SEM close-up)
Figs. 7-9 Recent pollen of *Quercus oidocarpa* DC. (LM, SEM, and SEM close-up)

Fagaceae gen. indet. 1

Plate XVII, Figs. 1-3

Shape: Prolate.

Size: Polar axis 24 µm, equatorial axis 9-10 µm.

Aperture: Tricolporate, colpi long, almost equal to polar axis.

Sculpture: Striate, irregular oriented rods, rods fused together.

Fagaceae gen. indet. 2

Plate XVII, Figs. 4-6

Shape: Prolate.

Size: 24 x 19 µm.

Aperture: Tricolporate, colpi long, almost equal to the polar axis.

Sculpture: Scabrate with small rod-like elements, irregularly oriented.

Modern pollen of *Castanopsis argentea* (Blume) A.DC. and *Lithocarpus longispinus* Barnett is provided for comparison in Plate XVII, Figs. 7-12. For pollen Fagaceae gen. indet. 1, shape and sculpture are similar to *C. argentea* and *L. longispinus*. Fagaceae gen. indet. 2 has pollen shape similar to Fagaceae gen. indet. 1, but its sculpture is more similar to *Quercus*.

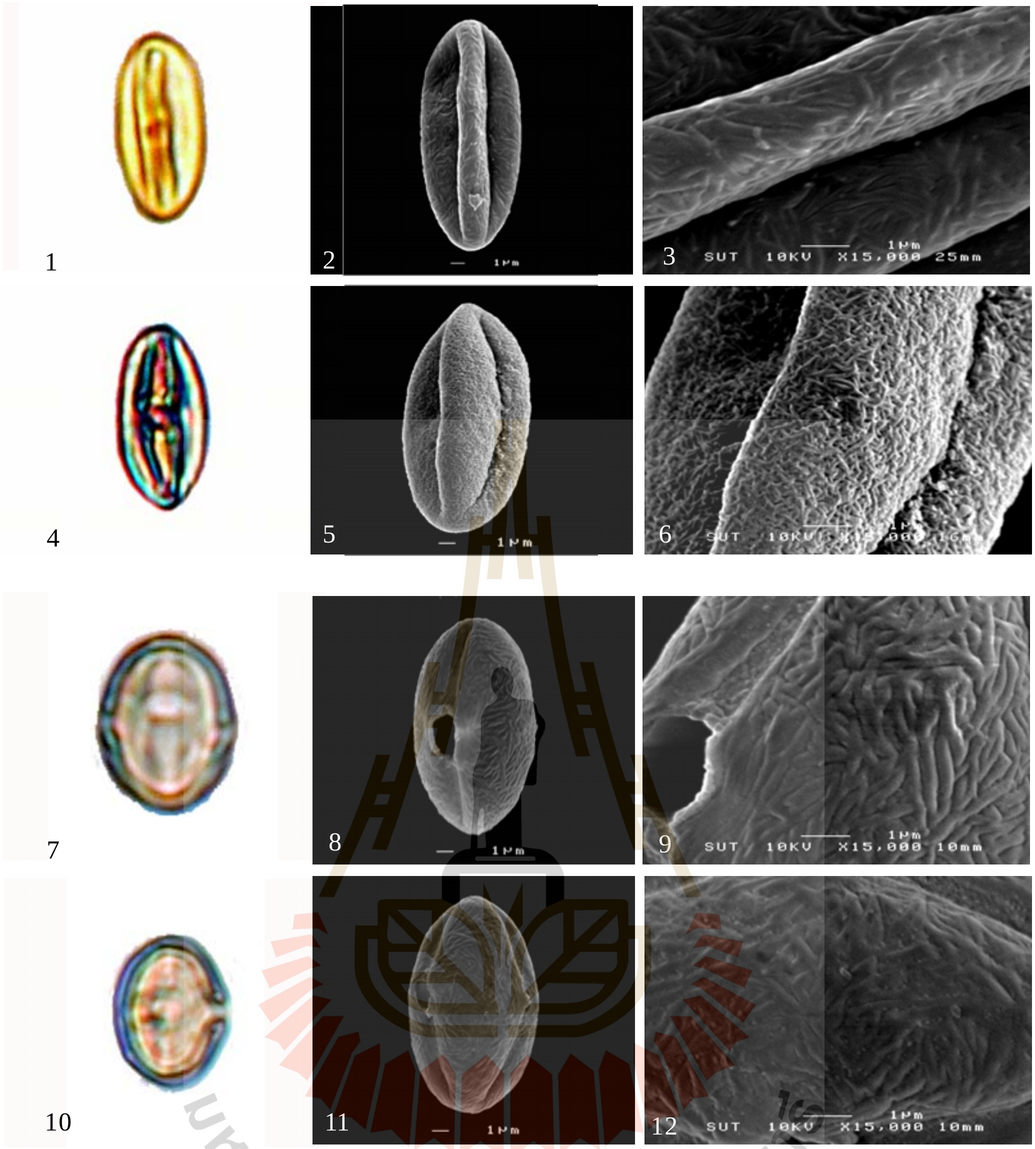


PLATE XVII: Figs. 1-3. Fagaceae gen. indet. 1 (LM, SEM, and SEM close-up)

Figs. 4-6. Fagaceae gen. indet. 2 (LM, SEM, and SEM close-up)

Figs. 7-9. Recent pollen of *Castanopsis argenta* (Bl.) A.DC. (LM, SEM, and SEM close-up)

Figs. 10-12. Recent pollen of *Lithocarpus longispinus* Barnett (LM, SEM, and SEM close-up)

Lythraceae: 31 genera/ 620 species in the world (Stevens, 2001)

6 genera/ 30 species in Thailand (The Forest Herbarium, 2007)

***Lagerstroemia* sp. 1**

Plate XVIII, Figs. 1-3

Shape: Spheroidal in polar view.

Size: 24 µm.

Aperture: Tricolporate with 6-pseudocolpi formed as shallow grooves, colpi longer than pseudo-colpi.

Sculpture: Exine very thick, rugulate, rugulae broad.

***Lagerstroemia* sp. 2**

Plate XVIII, Figs. 4-6

Shape: Subprolate in equatorial view.

Size: 27 x 24 µm.

Aperture: Tricolporate, colpi long , 6-furrows created pseudo-colpi.

Sculpture: Exine very thick (~2.5 µm), rugulate, rugulae dense.

Modern pollen of *Lagerstroemia macrocarpa* Wall. is provided for comparison in Plate XVIII, Figs. 7-9. The distinctly thick exine is a noticeable character of this genus. The nexine and sexine separately are clearly distinguishable under the light microscope.

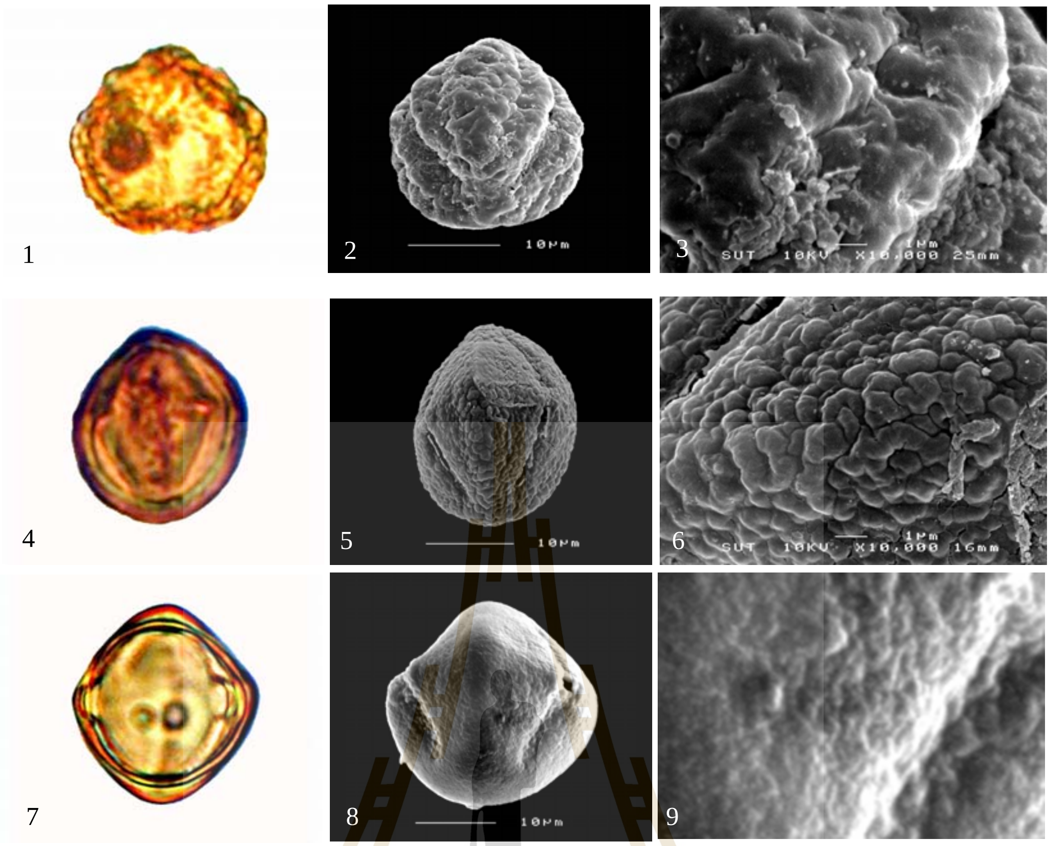


PLATE XVIII Figs. 1-3 *Lagerstroemia* sp. 1 (LM, SEM, and SEM close-up)

Figs. 4-6 *Lagerstroemia* sp. 2 (LM, SEM, and SEM close-up)

Figs. 5-7 Recent pollen of *Lagerstroemia macrocarpa* Wall. (LM, SEM, and SEM close-up)

Menispermaceae: 70 genera/ 420 species in the world (Stevens, 2001)

22 genera/ 51 species (with 9 endemic species) in Thailand

(The Forest Herbarium, 2007)

Menispermaceae gen. indet.

Plate XIX, Figs. 1-3

Shape: Spheroidal in polar view.

Size: 22 µm.

Aperture: Syncolporate.

Sculpture: Reticulate.

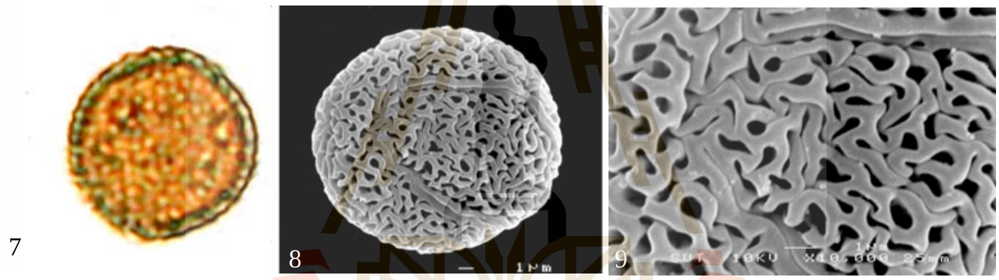


Plate XIX Figs. 1-3 Menispermaceae gen. indet. (LM, SEM, and SEM close-up)

Myrtaceae: 131 genera/ 4620 species in the world (Stevens, 2001)

12 native, 2 introduced genera/ 115 species in Thailand (The Forest Herbarium, 2007)

Myrtaceae gen. indet. 1

Plate XX, Figs. 1-3

Shape: Subtriangular.

Size: 13 µm.

Aperture: Tricolporate, parasyncolpate.

Sculpture: Verrucate, more psilate around the aperture.

Myrtaceae gen. indet. 2

Plate XX, Figs. 4-6

Shape: Subtriangular.

Size: 15 µm.

Aperture: Tricolporate, parasyncolpate.

Sculpture: Psilate with microgranules.

Modern pollen of *Melaleuca quinquenervia* (Cav.) S.T.Blake and *Syzygium gratum* (Wight) S.N. Mitra var. *gratum* is provided in Plate XX, Figs. 7-12.

The pollen are generally similar in shape, size, and aperture in this family. They are basically classified into three pollen types; syncolpate, parasyncolpate, and brevicolpate with various sculptural types such as verrucate, rugulate, and rarely smooth. However, features of pollen grain do not provide good taxonomic evidence for species identification (Kantachote, 2004).

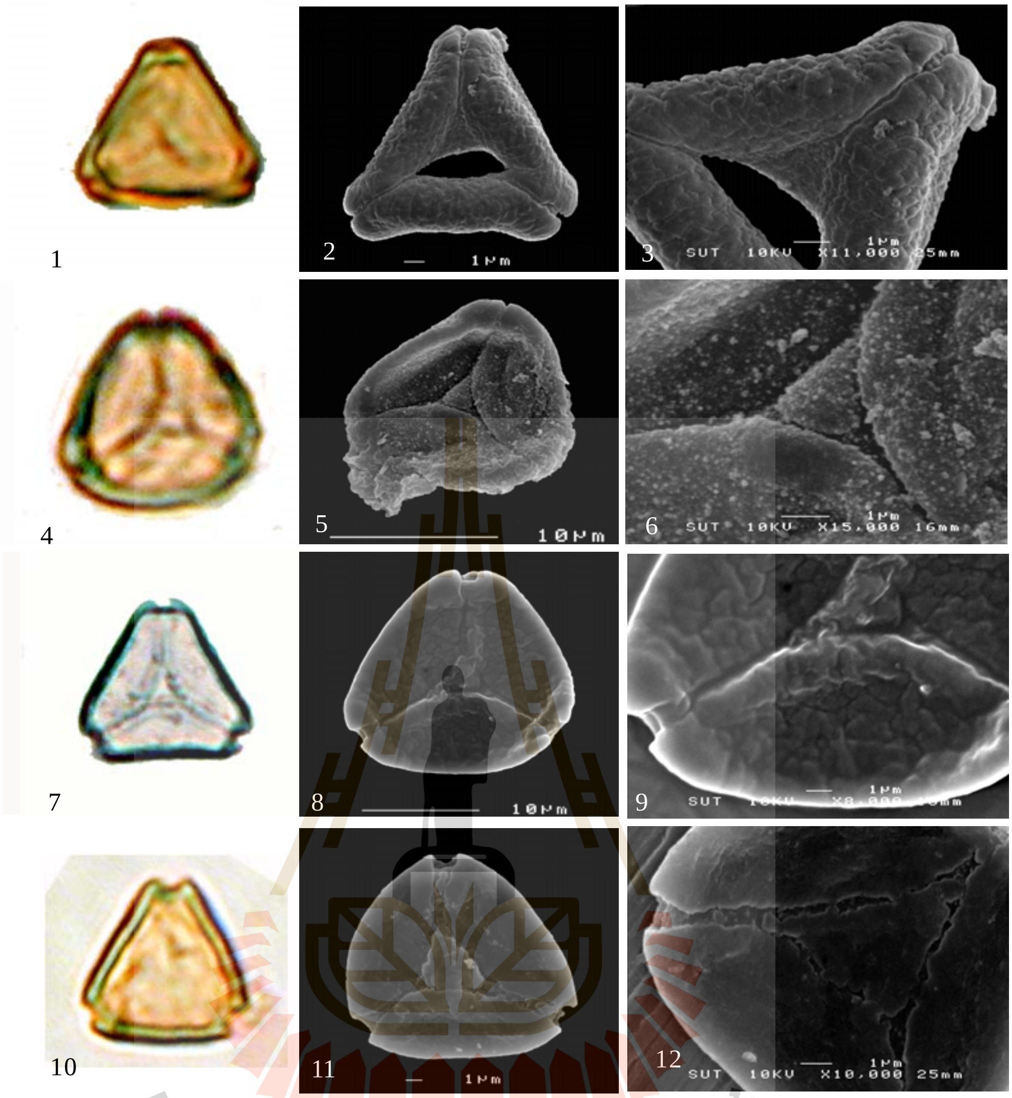


PLATE XX Figs. 1-3. Myrtaceae gen. indet. 1 (LM, SEM, and SEM close-up)

Figs. 4-6. Myrtaceae gen. indet. 2 (LM, SEM, and SEM close-up)

Figs. 5-7. Recent pollen of *Melaleuca quinquenervia* (Cav.) S.T.Blake (LM, SEM, and SEM close-up)

Figs. 10-12. Recent pollen of *Syzygium gratum* (Wight) S.N. Mitra var. *gratum* (LM, SEM, and SEM close-up)

Rhizophoraceae: 16 genera/ 149 species in the world (Stevens, 2001)

7 genera/ 14 species occurred in Thailand (The Forest Herbarium, 2007)

Rhizophoraceae gen. indet. 1

Plate XXI, Figs. 1-3

Shape: Spheroidal in polar view.

Size: 19 µm.

Aperture: Tricolporate, colpi medium long.

Sculpture: Finely reticulate.

Rhizophoraceae gen. indet. 2

Plate XXI, Figs. 4-6

Shape: Prolate in equatorial view.

Size: 17 x 14 µm.

Aperture: Tricolporate, colpi medium long.

Sculpture: Finely reticulate to rugulate.

Rhizophoraceae gen. indet. 3

Plate XXI, Figs. 7-9

Shape: Spheroidal in polar view.

Size: 19 µm.

Aperture: Tricolporate, colpi medium long, endoaperture wide, fastigiate, costae colpi prominent.

Sculpture: Finely reticulate.

Rhizophoraceae gen. indet. 4

Plate XXI, Figs. 10-12

Shape: Spheroidal in polar view.

Size: 19 µm.

Aperture: Tricolporate, colpi medium long, endoaperture wide.

Sculpture: Perforate.

Modern pollen of *Rhizophora mucronata* Poir., *Rhizophora apiculata* Blume, *Ceriops targal* (Perr.) C.B.Rob., *Ceriops decandra* (Griff.) Ding Hou, and *Bruguiera gymnorrhiza* (L.) Savigny is provided for comparison in Plate XXII, Figs. 1-15.

Pollen in this group is similar to each other. *R. mucronata* is the largest whereas *C. targal* is the smallest. However, their sizes vary and overlap exists among and between genera. Sculpture is also overlapping, varying from perforate to finely reticulate. This makes it difficult to classify fossil pollen of Rhizophoraceae to the generic or specific levels.

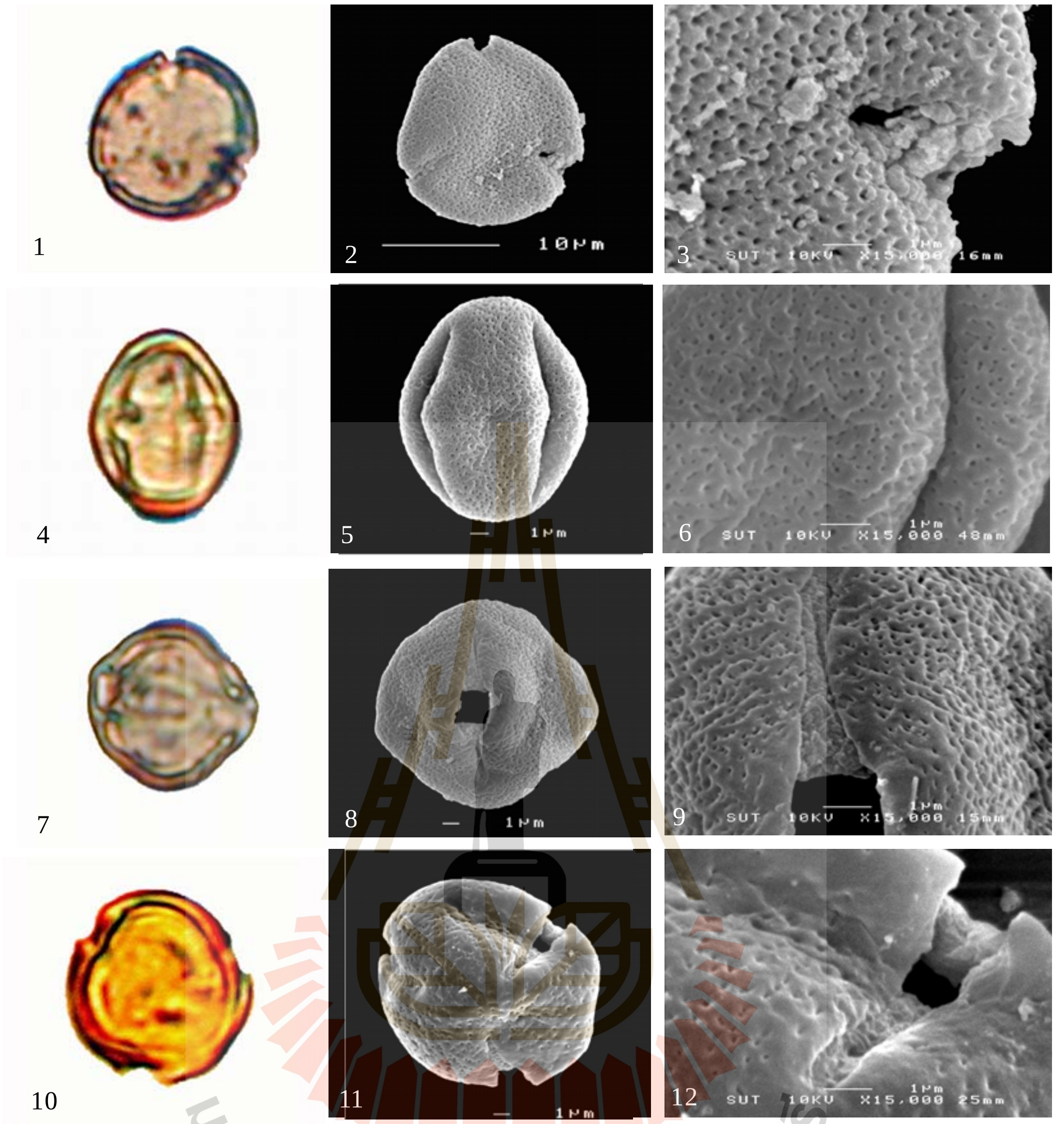


PLATE XXI Figs. 1-3. Rhizophoraceae gen. indet. 1 (LM, SEM, and SEM close-up)

Figs. 4-6. Rhizophoraceae gen. indet. 2 (LM, SEM, and SEM close-up)

Figs. 5-7. Rhizophoraceae gen. indet. 3 (LM, SEM, and SEM close-up)

Figs. 7-9. Rhizophoraceae gen. indet. 4 (LM, SEM, and SEM close-up)

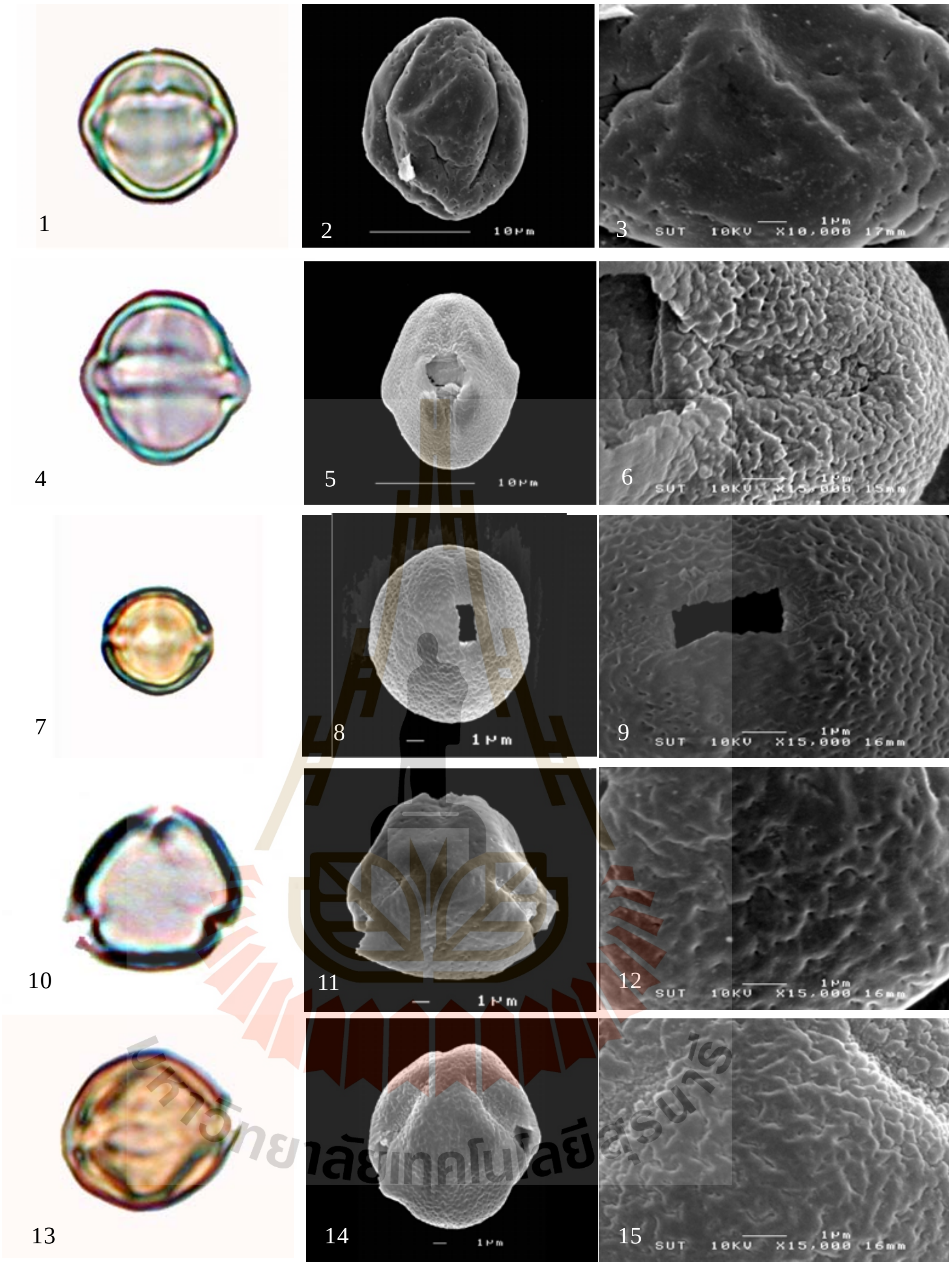


PLATE XXII

Figs. 1-3. *Rhizophora mucronata* Poir. (LM, SEM, and SEM close-up)

Figs. 4-6. *Rhizophora apiculata* Blume (LM, SEM, and SEM close-up)

Figs. 5-7. *Ceriops targal* (Perr.) C.B.Rob. (LM, SEM, and SEM close-up)

Figs. 7-9. *Ceriops decandra* (Griff.) Ding Hou (LM, SEM, and SEM close-up)

Figs. 10-12. *Bruguiera gymnorrhiza* (L.) Savigny (LM, SEM, and SEM close-up)

Rubiaceae: 660 genera/ 11150 species in the world (Stevens, 2001)

105 genera/ 600 species in Thailand (The Forest Herbarium, 2007)

***Canthium* sp.**

Plate XXIII Figs. 1-3

Shape: Subtriangular, sides convex.

Size: 41 µm.

Aperture: Triporate, angulaperturate.

Sculpture: Finely reticulate, lumen < 1 µm across.

The fossil pollen shows a clear resemblance to pollen of *Canthium* spp. for example *Canthium dicoccum* (Gaertn.) Merr. and *C. glabrum* Bl. as shown in Plate XXIII, Figs. 4-6 and 7-9.

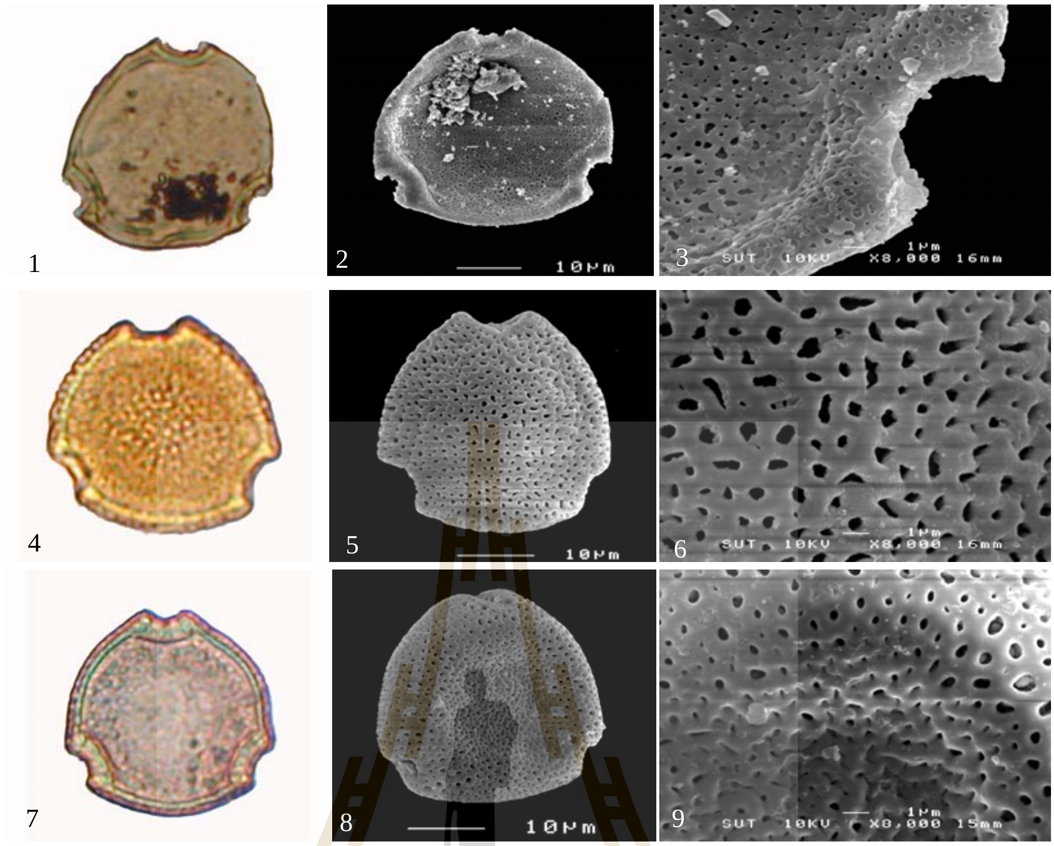


PLATE XXIII

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

Figs. 4-6 Recent pollen of *Canthium dicoccum* (Gaertn.) Merr. (LM, SEM, and SEM close-up)

Figs. 7-9 Recent pollen of *Canthium glabrum* Bl. (LM, SEM, and SEM close-up)

Salicaceae: 55 genera/ 1010 species in the world (Stevens, 2001)

1 genus/ 2 species have been recorded in Thailand (The Forest Herbarium, 2007)

***Salix* sp. 1**

Plate XXIV, Figs. 1-3

Shape: Subtriangular, trilobed in polar view.

Size: 26 µm.

Aperture: Tricolpate.

Sculpture: Tectum reticulate, finely reticulate around the apertural area and gradually coarsening towards the mesocolpium.

***Salix* sp. 2**

Plate XXIV, Figs. 4-6

Shape: Prolate in equatorial view.

Size: 31 x 22 µm.

Aperture: Tricolpate, colpi long.

Sculpture: Tectum reticulate, becoming finer towards the colpi.

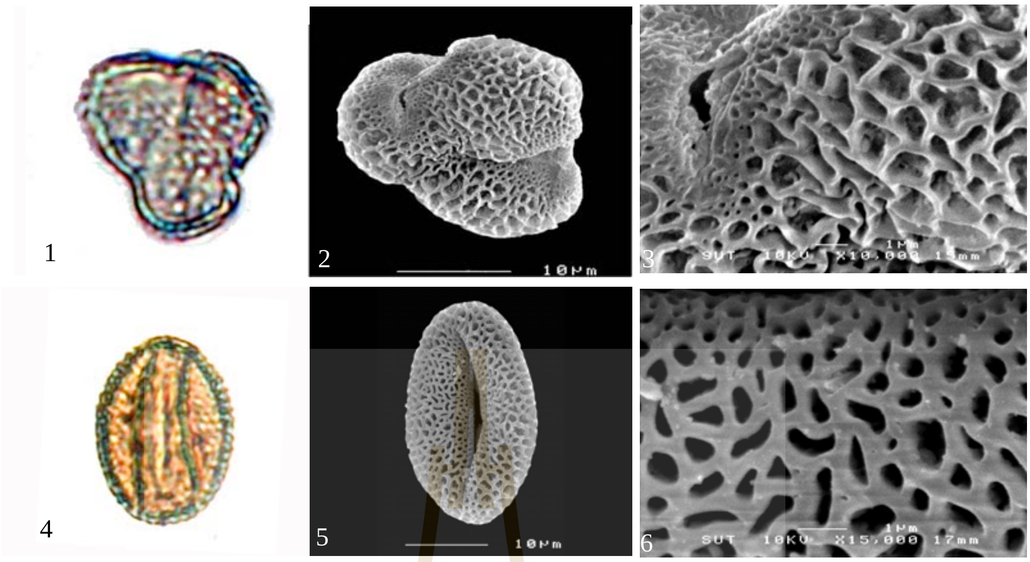


PLATE XXIV Figs. 1-3 *Salix* sp. 1 (LM, SEM, and SEM close-up)

Figs. 4-6 *Salix* sp. 2 (LM, SEM, and SEM close-up)

Sonneratiaceae:

2 genera/ 5 species in Thailand (The Forest Herbarium, 2007)

***Sonneratia alba* J.Sm.**

Plate XXV, Figs. 1-3

Shape: Prolate.

Size: 43 x 24 µm.

Aperture: Triporate, pore protruding.

Sculpture: Fine to coarse verrucate-rugulate around the pores, exine thick at the polar cap, which is smooth or perforate; meridional ridges distinctly present linking the porate fields to the poles.

***Sonneratia* sp. 1**

Plate XXV, Figs. 7-9

Shape: Prolate, elliptical in equatorial view.

Size: 32 x 27 µm.

Aperture: Triporate, pore slightly protruding.

Sculpture: Verrucate at the equatorial area, large verrucae around the pores, polar cap smooth and exine thick, polar cap and equatorial area distinctly separated, meridional ridges absent.

***Sonneratia* sp. 2**

Plate XXV, Figs. 10-12

Shape: Prolate to obtuse, diamond-shaped in equatorial view.

Size: 29 x 21 µm.

Aperture: Triporate, pores slightly protruding.

Sculpture: Verrucate at the equatorial area, exine thick at the polar cap, smooth to faintly striate at the polar cap, polar cap and equatorial area distinctly separated, meridional ridges absent.

***Sonneratia* sp. 3**

Plate XXV, Figs. 13-15

Shape: Prolate, elliptical in equatorial view.

Size: 39 x 29 µm.

Aperture: Triporate, pores protruding.

Sculpture: Verrucate at the porate fields, meridional ridges present with coarser verrucae, polar area coarsely perforate, polar and equatorial areas not distinctly separated.

Modern pollen of *Sonneratia alba* J.Sm. is provided for comparison in Plate XXV, Figs. 4-6. The *S. alba* pollen clearly shows the well-developed meridional ridges, with polar caps enclosing the elliptical porate fields. The larger size, presence of meridional ridges in *S. alba* was mentioned by Muller (1978) to distinguish it from *S. caseolaris.* Except for *S. alba*, other *Sonneratia* species have similar characteristics of size, smooth polar cap area, and protruding pores making it difficult to distinguish each species from the others.

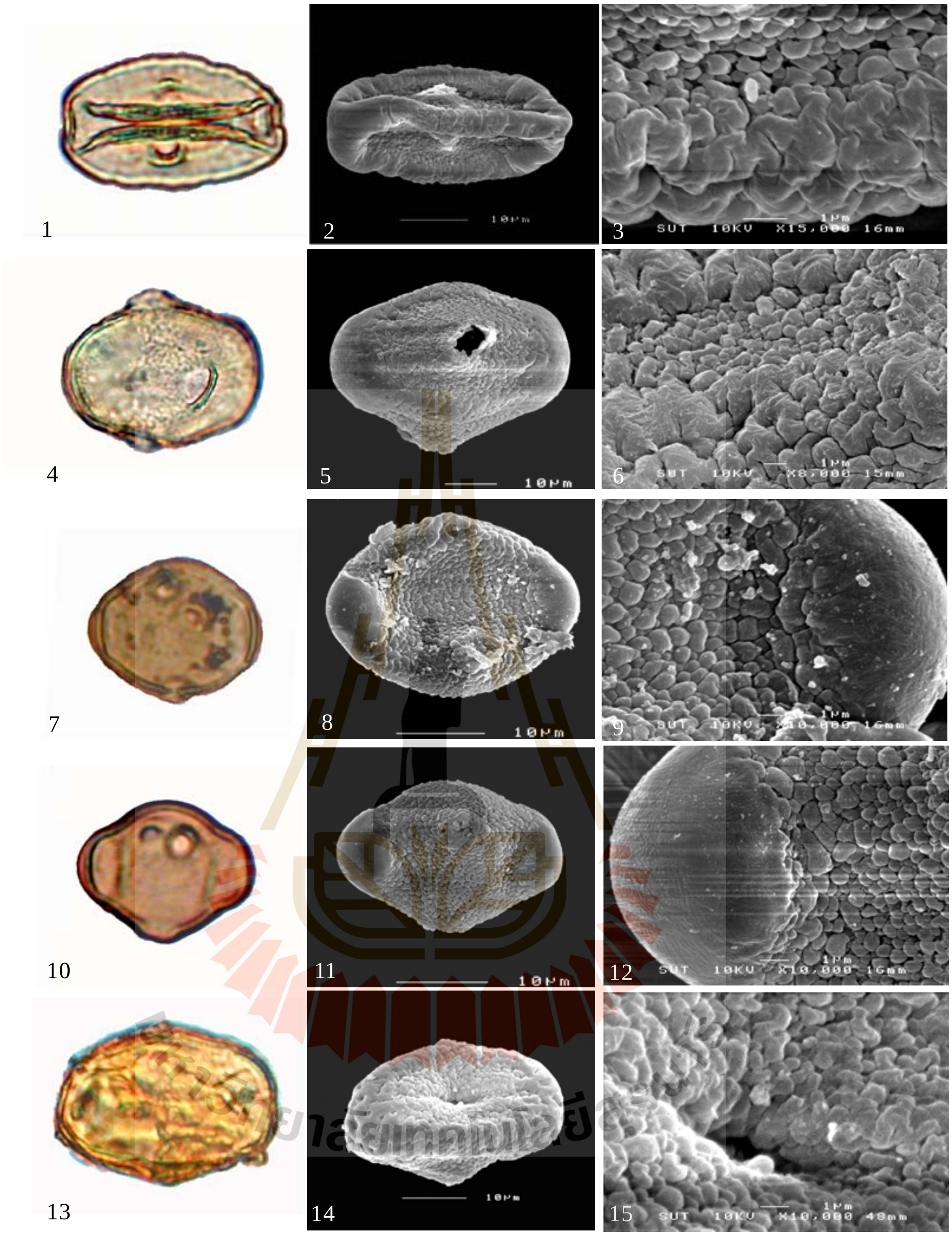


PLATE XXV

Figs. 1-3. *Sonneratia alba* J.Sm. (LM, SEM, and SEM close-up)

Figs. 4-6. Recent pollen of *Sonneratia alba* J.Sm. (LM, SEM, and SEM close-up)

Figs. 7-9. *Sonneratia* sp. 1 (LM, SEM, and SEM close-up)

Figs. 10-12. *Sonneratia* sp. 2 (LM, SEM, and SEM close-up)

Figs. 13-15. *Sonneratia* sp. 3 (LM, SEM, and SEM close-up)

Arecaceae: 187 genera/ 2000 species in the world (Stevens, 2001)

31 genera/ 150 species in Thailand (The Forest Herbarium, 2007)

Borassus flabellifer L.

Plate XXVI, Figs. 1-3

Shape: Elliptical in equatorial view.

Size: 53 x 34 µm.

Aperture: Monosulcate.

Sculpture: Foveolate with dispersed large gemmae.

***Calamus* sp. 1**

Plate XXVI, Figs. 7-9

Shape: Elliptical in polar view.

Size: 29 x 27 µm.

Aperture: Dicolpate.

Sculpture: Reticulate.

***Calamus* sp. 2**

Plate XXVI, Figs. 10-12

Shape: Elliptical in polar view.

Size: 24 x 19 µm.

Aperture: Dicolpate.

Sculpture: Rugulate to vermiculate, muri fused to each other.

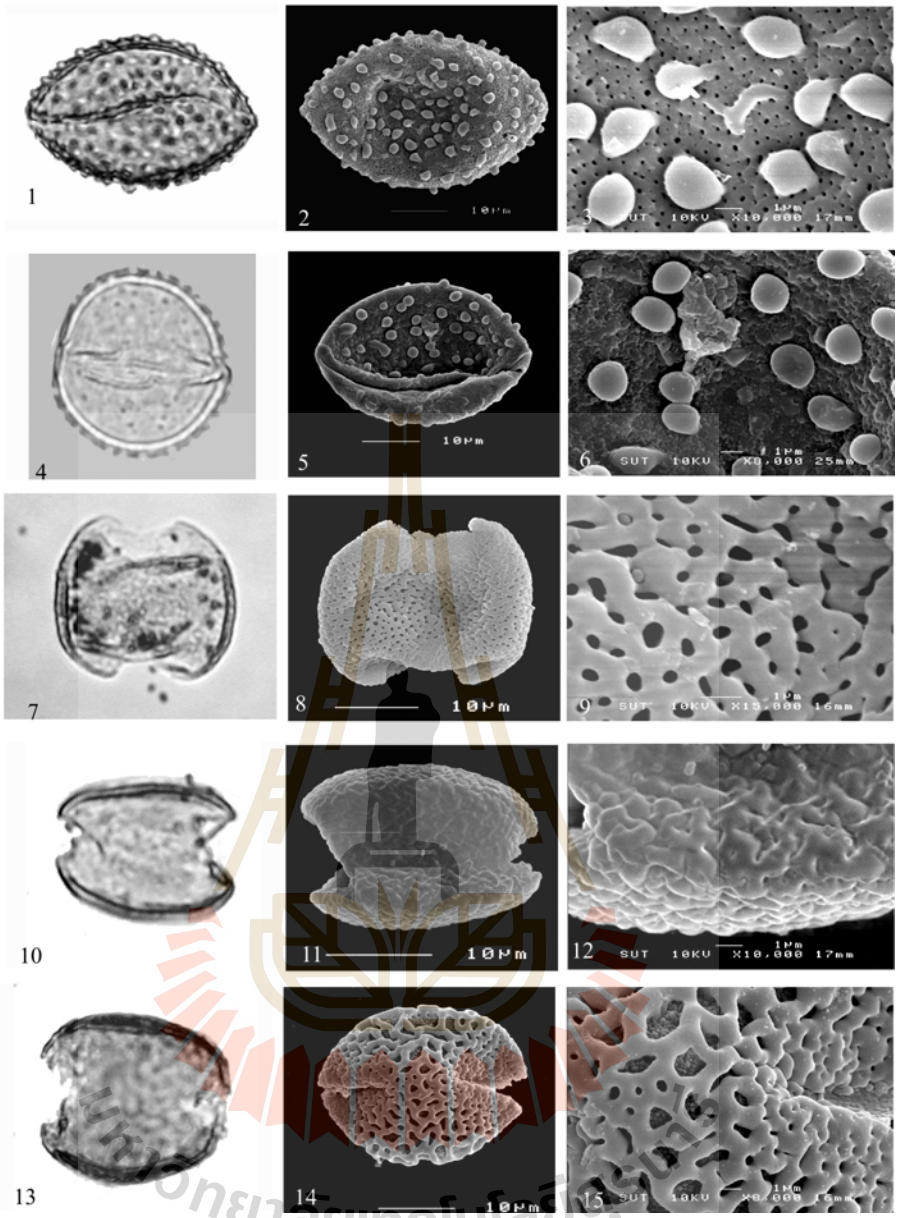


PLATE XXVI

Figs. 1-3. *Borassus flabellifer* L. (LM, SEM, and SEM close-up)

Figs. 4-6. Recent pollen of *Borassus flabellifer* L. (LM, SEM, and SEM close-up)

Figs. 7-9. *Calamus* sp. 1 (LM, SEM, and SEM close-up)

Figs. 10-12. *Calamus* sp. 2 (LM, SEM, and SEM close-up)

Figs. 13-15. Recent pollen of *Calamus rudentum* Lour. (LM, SEM, and SEM close-up)

***Oncosperma* sp.**

Plate XXVII, Figs. 1-3

Shape: Prolate.

Size: 17 x 27 µm.

Aperture: Monosulcate, long, pollen grain often broken into 2 halves along the aperture.

Sculpture: clavate to spinulate, grooves present along the spines, reticulate at the base between spines.

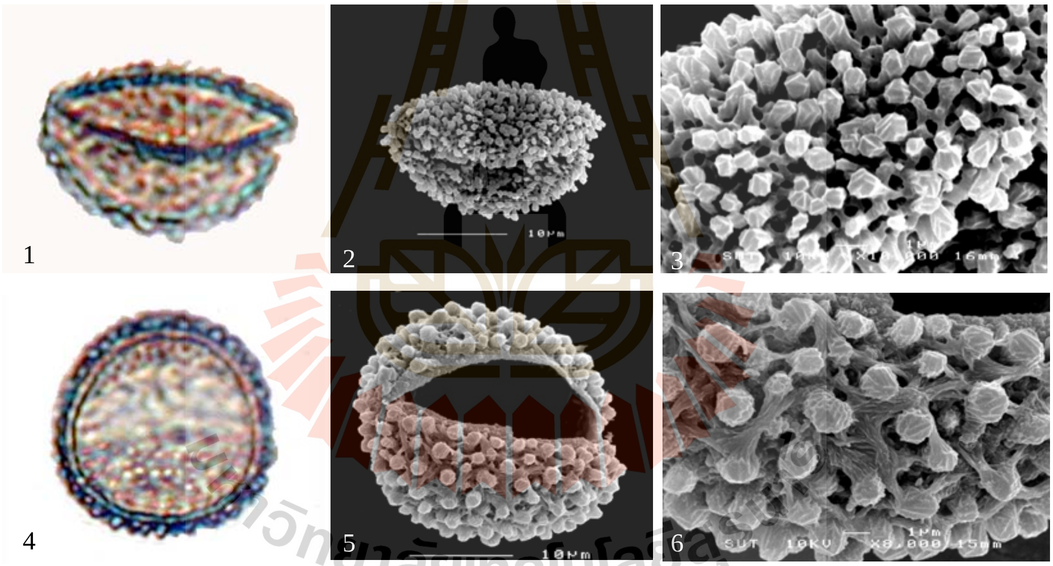


PLATE XXVII

Figs. 1-3. *Oncosperma* sp. (LM, SEM, and SEM close-up)

Figs. 3-4. Recent pollen of *Oncosperma tigillarium* (Jack) Ridl. (LM, SEM, and SEM close-up)

Cyperaceae: 98 genera/ 4350 species in the world (Stevens, 2001)

Cyperaceae gen. indet.

Plate XXVIII, Figs. 1-3

Shape: Triangular, apex rounded.

Size: 31 x 22 µm.

Aperture: 1-4 aperturate, elongate or spheroidal apertures.

Sculpture: Scabrate, aperture membrane with microrugulate-scabrate ornamentation.

Poaceae: 668 genera/ 10035 species in the world (Stevens, 2001)

100 genera/ 600 species in Thailand (The Forest Herbarium, 2007)

Poaceae gen. indet. 1

Plate XXVIII, Figs. 4-6

Shape: Spheroidal.

Size: 34 µm.

Aperture: Monoporate, pore annulate, diameter of the pore 3 µm.

Sculpture: Exine 1.2 µm-thick, microverrucate with microechinae.

Poaceae gen. indet. 2

Plate XXVIII, Figs. 7-9

Shape: Spheroidal.

Size: 31-32 µm.

Aperture: Monoporate, pore annulate, diameter of the pore 1 µm.

Sculpture: Microverrucate with microgranules near pore.

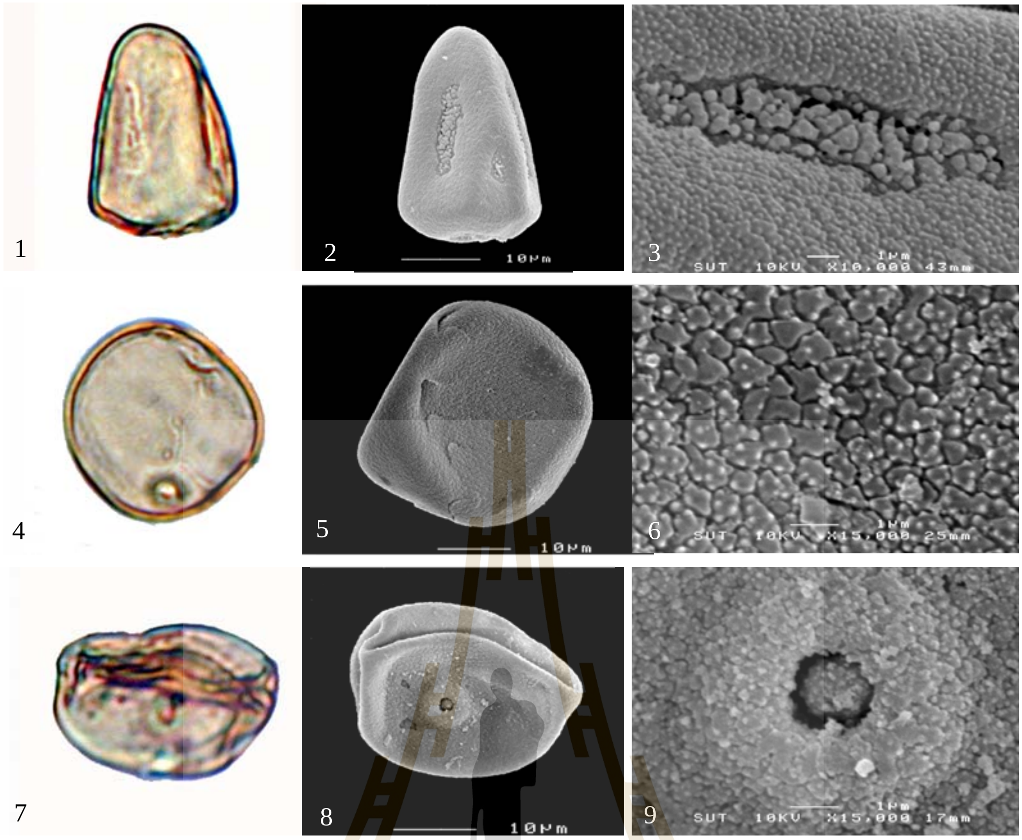


PLATE XXVIII

Figs. 1-3 Cyperaceae gen. indet. (LM, SEM, and SEM close-up)

Figs. 4-6 Poaceae gen. indet. 1 (LM, SEM, and SEM close-up)

Figs. 5-7 Poaceae gen. indet. 2 (LM, SEM, and SEM close-up)

CHAPTER V

POLLEN ASSEMBLAGES AND POLLEN ANALYSIS

This chapter mainly describes the results of the study of the pollen assemblages in the different layers and their correlation to the sedimentology of the study site in Songkhla Lake Basin. Pollen assemblages are exhibited in the form of pollen diagrams which were prepared using the TILIA program.

5.1 Lithology of the study site: the Songkhla Lake Basin

Information on the lithology of the study site is derived from two sediment cores. The 40 m-depth sediment core No. SE2-1 was studied and described by Tiyapairach (1999). He identified ten layers as mentioned in chapter II. A reexamination of this core indicates that it consists of 6 layers as described in Fig. 5.1.

Another sediment core retrieved from the same locality is 8 m long. This core is referred to as No. SUT-1 and subdivided into five layers as shown in Fig. 5.2. The description is based on color, grain size, and grain components.

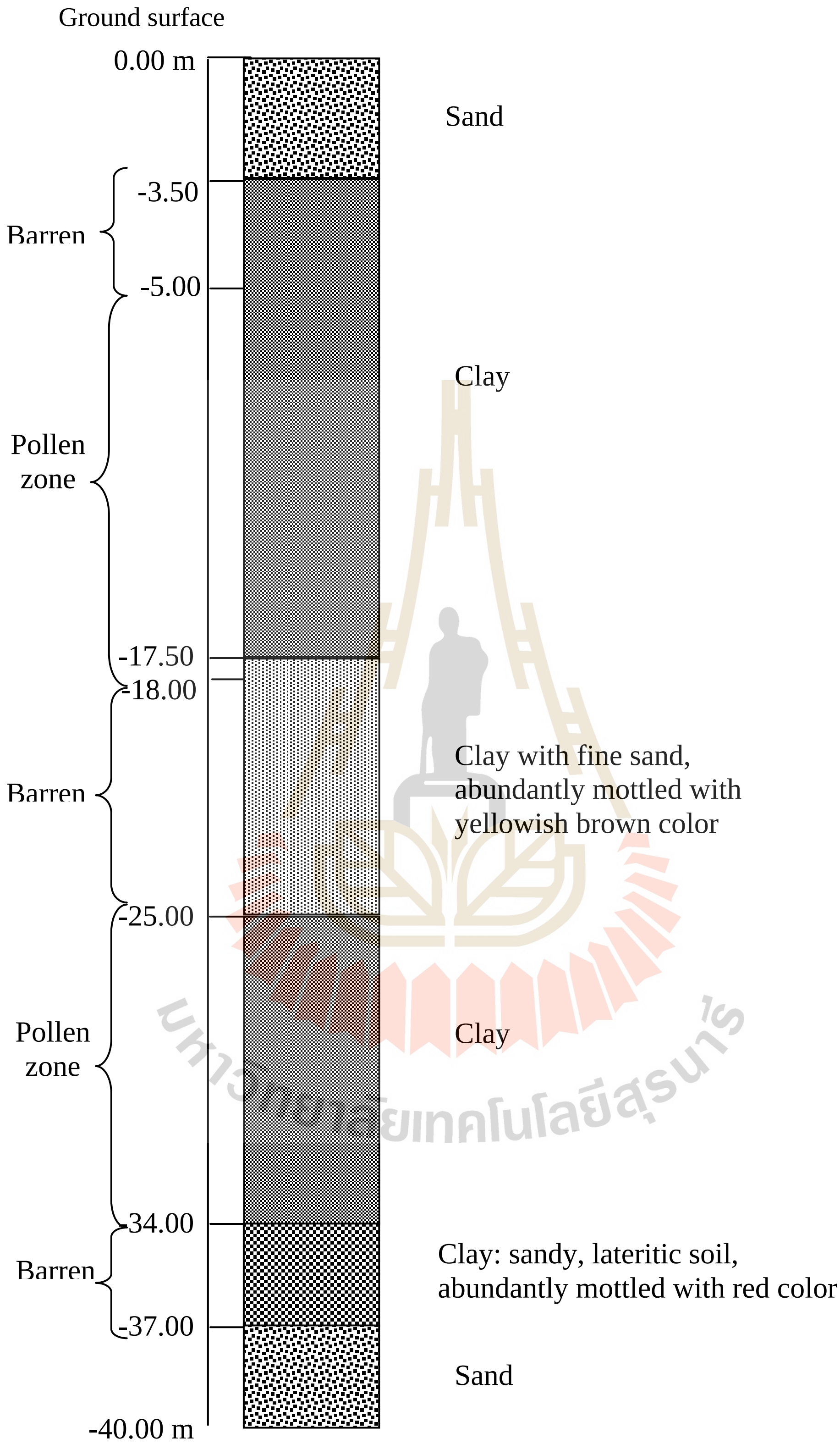


Fig. 5.1 Core description of SE2-1 (0-40 m) modified from Tiyapairach (1999).

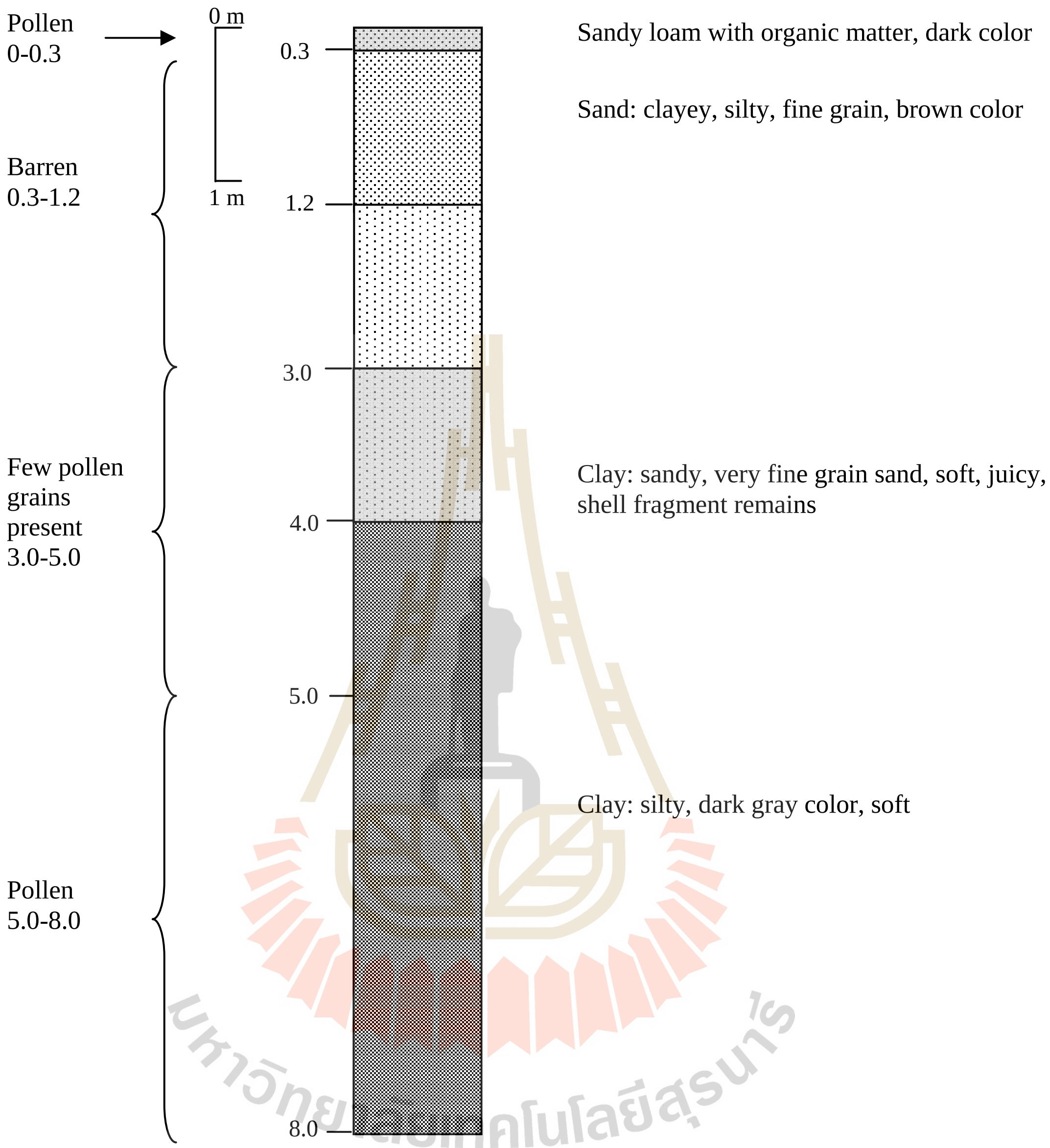


Fig. 5.2 Core description of SUT-1 (0-8 m)

5.2 Chronology

Altogether four sediment samples were sent for dating to Beta Analytic Inc. (Miami, Florida, USA): three sediment samples from core SE2-1 and one sample from core SUT-1. These samples were analyzed using AMS radiocarbon dating technique. AMS or Accelerator Mass Spectrometry is a new technique of radiocarbon dating which was developed in the late 1970s. By this technique one can date very small carbon samples, such as a grain of rice, some pollen grains, seeds, or tiny pieces of charcoal (Higham, T. http://www.c14dating.com/k12.html). This is important for this study because each sediment sample left from pollen extraction processes is very small.

The sample at 24.5 meter-depth, the lowest dated layer, of SE2-1 was Late Pleistocene in age. The uppermost dated layer at 7.5 meter-depth of core SE2-1 was found to belong to the Holocene epoch. Addition chronology was obtained from a previous study of core SE2-1. The layer at 31 meter-depth was found to be 30,950 ± 620 BP (Tiyapairach, 1999). Details of the radiocarbon dates mentioned above are provided in Table 5.1 and Fig. 5.3.

Table 5.1 List of radiocarbon ages of sediment cores in the study site.

Depth (m)	**Radiocarbon ages (BP)**		
	Core SE2-1 (40 m)		**Core SUT-1 (8 m)**
	In this study	Tiyapairach, 1999	In this study
7.5	6440 ± 50	-	6950 ± 50
17.5	8220 ± 50	-	
24.5	33870 ± 280	-	
31.0	-	30950 ± 620	

The ages obtained from core SE2-1 in this study are not in complete agreement with the study by Tiyapairach (1999). The age of the clay in his study is younger than that of the overlying layer in this study. This disagreement may come from dating technique, sample contamination, etc. The radiocarbon ages will be correlated to pollen evidence, lithology, and sea level history.

However, it can be stated unequivocally that the period covered in this study is from >33,870 ± 280 BP, which is in the Late Pleistocene, until the present day.

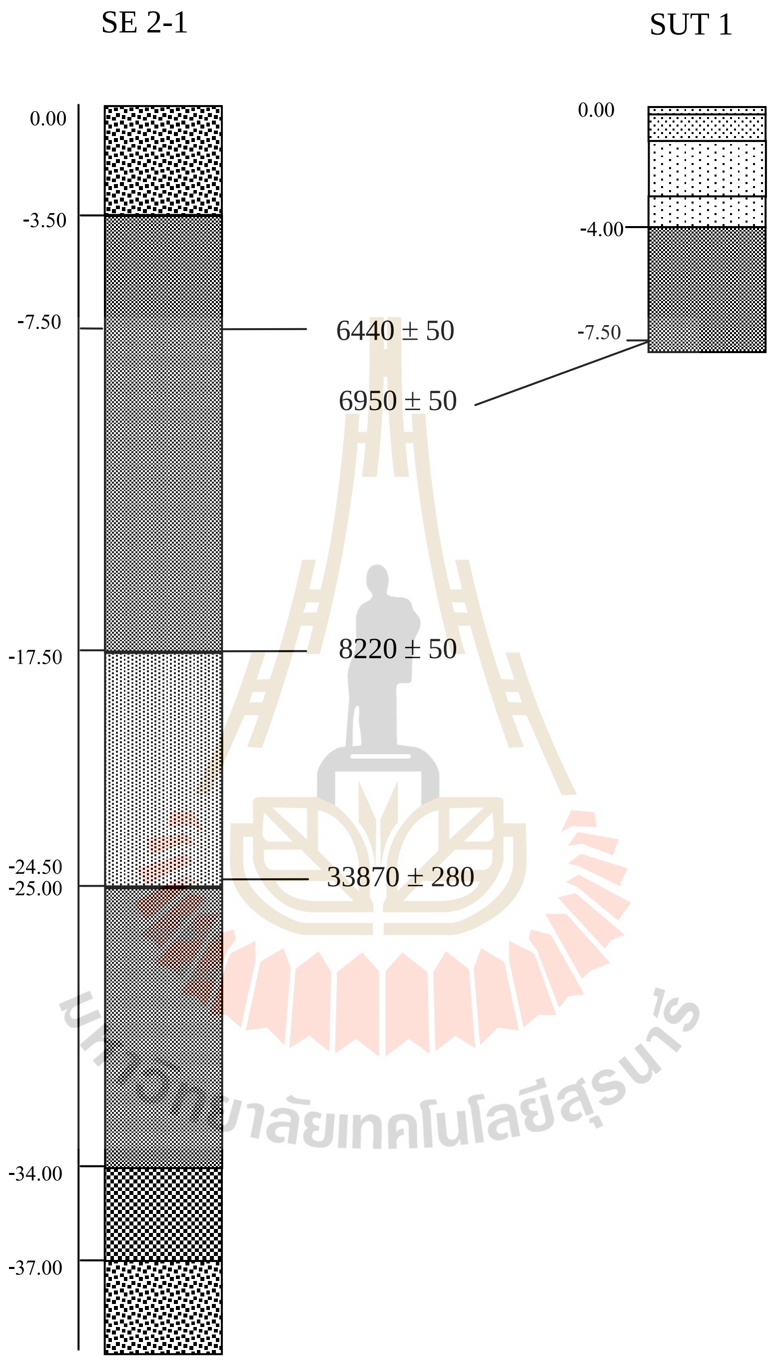


Fig. 5.3 Radiocarbon ages

5.3 Pollen diagrams

5.3.1 Pollen diagram construction

The matrix pollen data from the study was managed by numerical processes and presented in the form of pollen diagrams. By presenting the information in the form of a diagram, it is much easier to visualize the important information found in the course of this study (Faegri and Iversen, 1989). In the field of Quaternary research, pollen diagrams are helpful for plant community and ecological interpretations. They enable a qualitative and quantitative representation of the plants occurring in the pollen assemblages. However, it has to be kept in mind that these pollen data are just fragmented pieces of information retrieved from the pollen taphocoenoses in the past. Moreover, there are factors of qualities in fossilization and preservation of each kind of pollen, as well as in methods of sampling and extraction. So, circumspection is needed in the process of interpretation.

Pollen data from stratigraphical samples were numerically prepared and then graphically displayed in the form of a pollen diagram. The vertical axis (y) represents depths, ages, and horizon axis of pollen abundance in each sample. The x-axis displays each pollen taxon percentage arranged in order of ecological groups. Within a group, taxa were arranged in alphabetical order.

Pollen diagrams of cores no. SE2-1 and SUT-1 were grouped into seven categories based on classification of modern plant communities of Thailand and the Malay-Thai peninsula vegetation (Santisuk, 1984; 2006).

Group 1: The mangrove type, consisting of true mangroves, such as Rhizophoraceae, *Acanthus, Avicennia, Brownlowia, Excoecaria, Lumnitzera, Sonneratia, and Xylocarpus.*

Group 2: The back mangrove type, consisting of *Barringtonia, Nypa fruticans, Oncosperma, Suaeda maritima*.

Group 3: The beach forest type, consisting of *Thespesia* and *Casuarina*.

Group 4: The lowland forest type, comprising *Calamus* (Arecaceae), *Canthium*, *Castanopsis/Lithocarpus*, *Dacrydium*, *Diospyros*, *Dipterocarpus*, *Elaeocarpus*, *Ilex*, *Lagerstroemia*, Myrtaceae, *Podocarpus*, *Quercus*, Sapotaceae, *Pinus*.

Group 5: The grass group, consisting of Asteraceae, Cyperaceae, and Poaceae.

Group 6: Pteridophytes, consisting of *Stenochlaena palustris*, other monolete, and trilete fern spores.

Group 7: Indeterminate group

5.3.1.1 Pollen sum

Each percentage expression in the pollen diagram is the proportion calculated based on the pollen sum. So the percentage of one type influences that of others within the pollen sum (Moore et al., 1991). This could be a problem if there is a high number of local pollen in the assemblage caused by fluctuation of local pollen due to changes in local environmental factors. However, the major pollen present in this study apparently indicates local rather than regional vegetation. So, the pollen diagrams in this study can be assumed to reflect local changes in the plant communities. The problem of relative influence of local and regional pollen fluctuation does not concern us much in this study. The pollen sum used in the calculation of the percentages included every group except the Indeterminatae.

The indeterminate group consists of diverse pollen types which could not be identified to a particular taxon, which means they also could not be allocated to the regional or local vegetation. To prevent this large group from affecting the proportions of other taxa, this group was excluded from the pollen sum. However, to indicate its change, it was displayed as percentages based on the sum of the identifiable pollen and spores.

5.3.1.2 Zonation of pollen diagrams

As the pollen diagrams investigated in this study cover thousands of years, it is quite complicated to investigate how vegetation changed through time. Pollen diagram zoning was therefore conducted as a tool for the interpretation of ecological changes. A zone in the diagram is a biostratigraphic unit based on the pollen assemblage obtained from each sample. A pollen zone is defined in relation to the presence/absence of taxa in the pollen assemblage. The pollen percentages are not taken into account in the construction of the zones (Faegri and Iversen, 1989).

In this study, pollen data were prepared to be graphed in the form of a pollen diagram by use of the software TILIA and TILIA*GRAPH (version 2.0.b.4) created by Dr. Eric Grimm (Illinois State Museum, USA). The procedure of the program followed the Tilia manual written by Rob Craigie and Heather Sugden. The constrained incremental sum of square cluster analysis (CONISS) was made by the CONISS program associated with TILIA software. The dendrograms obtained after running CONISS were considered as tools to define zone boundaries. Once decisions had been made, horizontal lines were drawn across the diagram.

Zonations of pollen diagrams in core no. SE2-1 and SUT-1 were made based on the representation of the pollen belonging to groups 1 - 6: mangrove, back mangrove, beach, lowland forest, grass, and pteridophytes.

5.3.2 Description of pollen diagrams

5.3.2.1 An overview of the pollen diagrams

There is pollen occurrence from 5 - 33 meters depth in sediment core no. SE2-1. However, pollen was absent in some depth intervals. The significant pollen barren intervals were between 17.5 - 24.5 and 30.5 - 32.5 meters depth. For core no. SUT-1, pollen occurrence started at 0.18 meters to 0.3 m, followed by a barren interval to 5 meters. Pollen is present again in the layers from 5 - 8 m.

In both pollen diagrams, the dominant family is the Rhizophoraceae. It occupied more than 40-80 percent in samples of core no. SE2-1. This is similar to percentages of Rhizophoraceae in most samples in core no. SUT-1, except the sample at 0.18 meters depth, the uppermost layer, which has no Rhizophoraceae pollen. These pollen percentages indicate that mangrove was the most important element at the study site.

5.3.2.2 Description of pollen zones in core no. SE2 - 1

The pollen diagram with the cluster analysis dendrogram of core no. SE 2-1 is presented and the zonation defined as shown in Figure 5.3. Based on pollen composition, the diagram is divided into two zones: SE-1 and SE-2. Zone SE-1 is moreover divided into three sub-zones: SE-1.1, SE-.2, and SE-1.3. Pollen compositions in different zones are described below.

Zone SE-1

This zone is defined from depth 33 - 13.5 meters. It is clearly represented by constant and very high percentages of Rhizophoraceae (>80 %). Presence of other elements from mangrove, back mangrove, beach, and lowland forest enabled this zone to be divided into two sub-zones as follows:

- Sub-zone SE-1.1 occurred at depths between 24.5 - 33 meters. In addition to the high percentage of Rhizophoraceae, other mangrove pollen is present (< 5%) such as *Lumnitzera*, *Avicennia*, *Acanthus*, *Sonneratia*, and *Xylocarpus*. Pollen from the back mangrove is also present in very small percentages (< 5%), such as *Oncosperma* type and *Suaeda maritima*. Lowland pollen, viz., Myrtaceae, Arecaceae, *Podocarpus*, *Castanopsis/Lithocarpus*, *Diospyros*, *Dipterocarpus*, and *Quercus* also contributed less than 5%. The pollen of Rhizophoraceae, *Lumnitzera,* Myrtaceae, and Arecaceae are present in every layer of the zone, while other types are only sporadically present. No pollen from the beach forest group is present in this zone.

Apart from the four pollen groups described above, grasses, Pteridophyta, and indeterminate pollen are present in every layer of this zone: Poaceae (<10%), Pteridophyta (10 - 15%), and a declining curve of indeterminate proportion from ~25% at the bottom horizon to ~10% in the uppermost horizon of the zone.

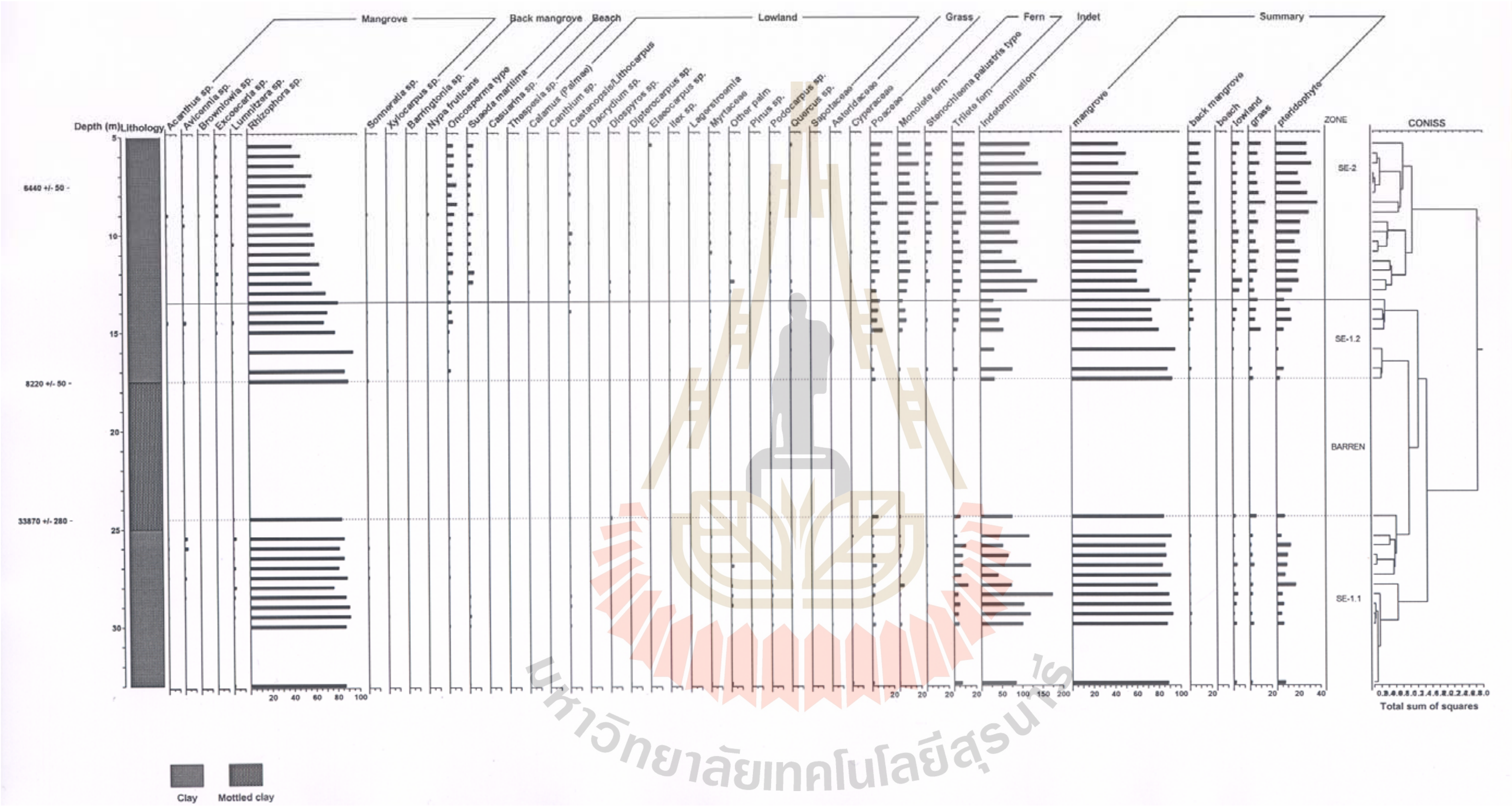


Fig 5.4 Pollen diagram of core no. SE 2.1

Between sub-zones SE1-1 and SE1-3, at depths 17.5 - 24.5 meters, there are very few or no pollen found, so this section is defined as a barren zone, SE1-2. Lithological characteristics in this interval suggest an oxidized sediment zone.

- Sub-zone SE1-3 occurred at depths between 13 - 17.5 meters. Although it is characterized by a high percentage of Rhizophoraceae (80 - 95%), this family is less well represented as in SE1-1. Pollen belonging to the mangrove group present in sub-zone SE1.1 (*Lumnitzera*, *Avicennia*, *Acanthus*, *Sonneratia*, and *Xylocarpus*) are still present in this zone in similar percentages (<5%). However, *Acanthus* and *Excoecaria* are better represented. Of the back mangrove pollen group, *Oncosperma* is present at approximately 5%. There is a greater amount of pollen from the lowland forest group in this sub-zone, such as *Calamus*, *Castanopsis*/*Lithocarpus*, *Diospyros*, *Dipterocarpus*, *Ilex*, *Lagerstroemia*, *Podocarpus*, *Quercus*, Arecaceae, and Myrtaceae. *Quercus* and Myrtaceae pollen are continuously present. However, percentages of lowland pollen still remain at a very low level (<5%). Some pollen taxa are just present as a very few grains, such as *Calamus*, *Lagerstroemia*, and *Podocarpus*.

Compared to SE1-1, the proportion of Poaceae pollen has increased to approximately 5%. There is a similar trend in the percentages of Pteridophyte spores, both monolete and trilete types, rising from 5% in the lowermost horizon to ~13% in the top horizon of this zone. Of the Pteridophytes, spores of *Stenochlaena palustris* type are clearly and continuously present. With regard to the indeterminate pollen, the pollen proportion increased to 25% in the top horizon.

Zone SE–2

This zone from 13.5 to 5.0 meters, is characterized by a gradual decline in Rhizophoraceae pollen from ~65% to 40%. *Excoecaria*, *Avicennia*, and *Lumnitzera* are still found in similar proportions to the previous zone, but *Acanthus* is found in more horizons. A very few grains of *Brownlowia* are found in this zone. Pollen of *Oncosperma* and *Suaeda maritima* are now regularly present at ~5%. A small number of *Nypa fruticans* pollen grains is found in horizons of this zone. *Castanopsis/Lithocarpus*, *Dipterocarpus*, Myrtaceae, Arecaceae, *Podocarpus*, and *Quercus* are found in almost every horizon, while *Calamus* and *Ilex* occur sporadically in some horizons. However, none of them are well represented in the sequence. A few pollen grains of *Dacrydium*, *Eleaocarpus*, *Pinus*, and Sapotaceae appear for the first time in this zone.

Pollen of the grass group displays a gradual increase (5% - 10%). At 20 - 30% pteridophyte spores have become an important component with *Stenochlaena palustris* represented by >5%. The indeterminate group is continuously present, composing between 10% - 25% of the assemblage.

5.3.2.3 Description of pollen zone in core no. SUT-1

Pollen is not present throughout this eight meter core. Between 5 - 0.18 meters the sediments are barren. Percentages of each pollen type in groups of mangrove, back mangrove, beach, lowland forest, grass, and pteridophytes were determined by calculating the pollen sum of these six groups. Indeterminate pollen and spore percentages were based on the sum of identifiable pollen and spores. The dendrogram used for defining the zonation in this diagram, was based on presence/absence of pollen taxa belonging to the six groups used above. Based on this composition, the diagram is divided into two zones: SUT1 and SUT2 as shown in Figure 5.4. The pollen composition in each zone is described as follows:

Zone SUT1

This zone started from the base of the core at 8 m-depth and finished at 5 meters-depth. Pollen composition in this zone is characterized by the predominant elements of Rhizophoraceae with rather constant percentage (40% - 60%), but its curve tends to decline at the very top layer. The Rhizophoraceae are accompanied by other members of the mangrove group: *Excoecaria* (~5%), very low levels of *Avicennia*, and *Lumnitzera*, *Sonneratia*, and *Xylocarpus*, which are only present in some horizons.

Back mangrove pollen is represented by 5% *Oncosperma* and *Suaeda maritima*. *Barringtonia* and *Nypa fruticans* appear in some layers but their percentages are not significant. *Casuarina*, which is considered to represent the beach forest, is present continuously in almost every layer but the proportion of this wind-pollinated taxon is less than 1%.

Pollen of many lowland elements such as Myrtaceae, C*astanopsis/Lithocarpus*, Arecaceae, *Dipterocarpus*, *Podocarpus*, *Quercus*, *Calamus*, *Canthium*, *Ilex*, and *Dacrydium* is present. However, none of these taxa is represented by as much as 5%. Poaceae is present in percentages between 5 and 10% with a slight increase towards the end of the zone. Pteridophytes are well-represented at 20 - 40%. They start rising at the beginning of the zone, reaching 40% around the middle, followed by a decrease towards the end of the zone. However, no significant change in the percentage of *Stenochlaena palustris* is recognizable.

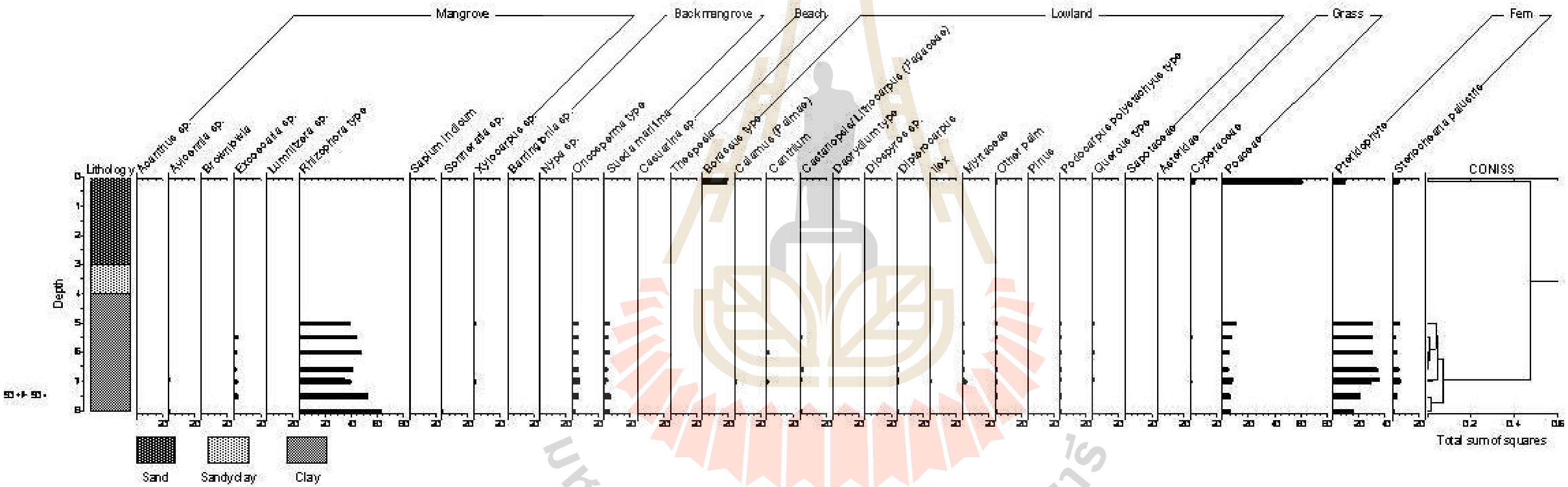


Fig 5.5 Pollen diagram of core no. SUT-1

The indeterminate pollen represents a high proportion of the pollen. It is never less than 20% throughout this zone. The proportion reaches 30% at around seven meters depth, followed by a decrease to 20%, and a subsequent increase to 35% at the end of the zone.

After this zone, there is a gap of pollen occurrence at depths between 5 - 0.18 meter. The only sample with pollen present is at 0.18 meters, which is defined as pollen zone SUT2.

Zone SUT2

This assemblage is completely different from the previous zone because no pollen of mangrove, back mangrove, and beach floras is present anymore. The assemblage consists of lowland forest, grass, pteridophytes, and indeterminate pollen.

The lowland floras, which are well represented in this zone, are very different from those in the previous zone. There is the first occurrence of *Borassus* pollen and it becomes the predominant pollen (20%) in the group, while many other elements are absent such as *Calamus*, *Canthium*, *Castanopsis/Lithocarpus*, *Dacrydium, Dipterocarpus, Ilex,* and *Quercus.* However, Myrtaceae (<5%), other palms (<5%), and *Podocarpus* (~1%) are still present.

Poaceae pollen is abundant (60%), while pteridophytes and indeterminates are represented by ~10% and ~15%, respectively.

5.4 Ecosystems reconstruction

Pollen present in the pollen diagrams were grouped into 7 vegetation groups based on the ecology of the parent plants as stated before. Presence of pollen spectra can be linked to the ecosystems and environment of the study site in the particular time period. Pollen diagrams of both cores suggested types of vegetation and ecosystems as described below.

Mangrove: group 1

Back mangrove: group 2

Beach: group 3

Lowland: group 4

Grasses: group 5

Pteridophytes: group 6

Indeterminatae: group 7

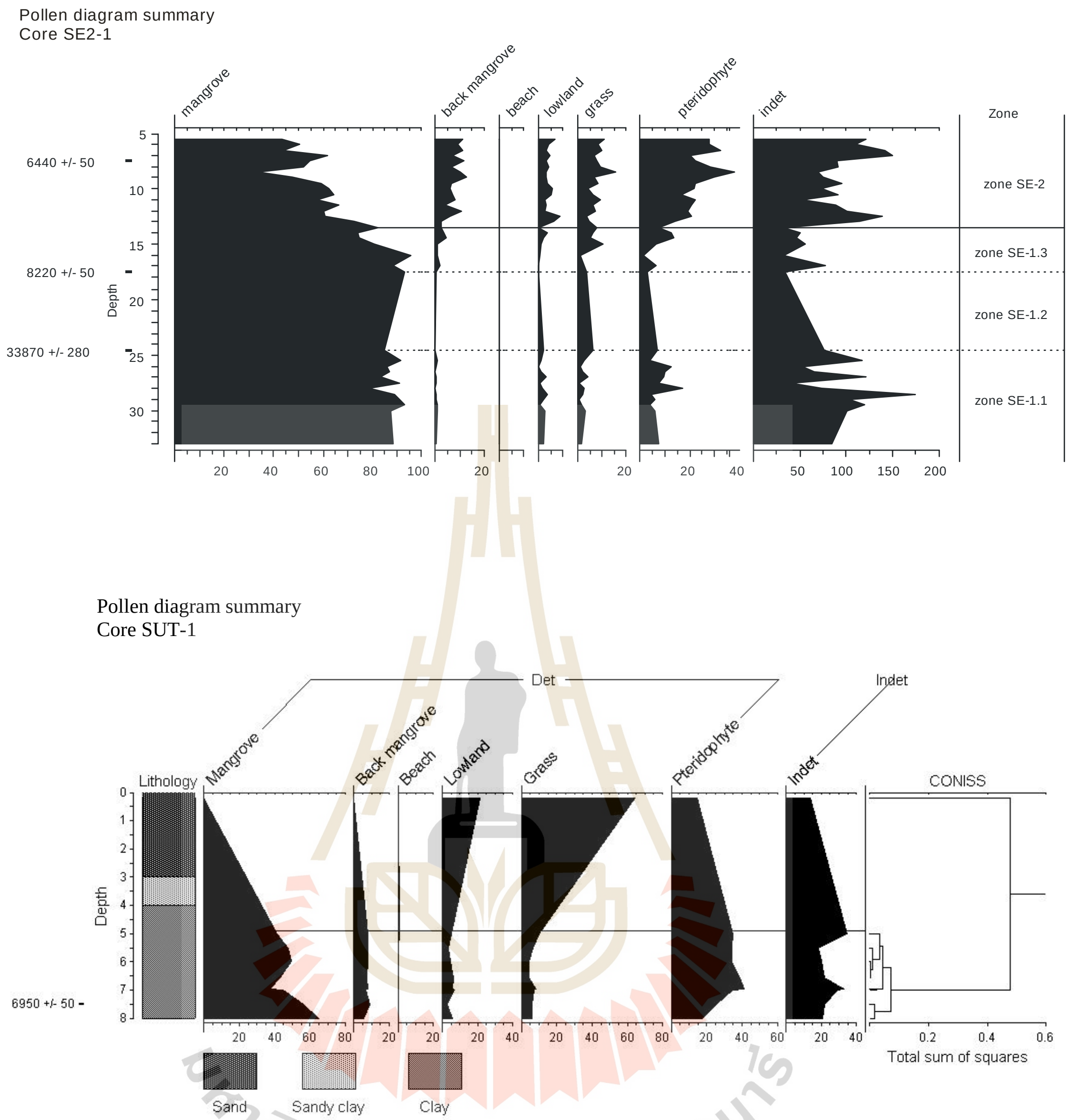


Fig 5.6 Pollen diagram summary of core no. SE2-1 and SUT-1

5.4.1 Mangrove vegetation[(1)]

This is the main group of pollen present in the study site with almost 80% of total identifiable pollen. This component is clearly dominated by the taxa of Rhizophoraceae, along with lower relative percentages of *Avicennia, Sonneratia, Acanthus*, and minor amounts of *Excoecaria*, *Lumnitzera*, and *Xylocarpus*.

The Rhizophoraceae are trees with stilts and knee-like roots for breathing and supporting the tree. They prefer growing in wet, muddy, and silty sediments in the tidal zone. They can survive inundation by salt water twice a day. Their flowers are wind pollinated in *Rhizophora* and insect pollinated in the other genera (Tomlinson et al., 1979). Today, this family in Thailand has members mostly growing in mangrove areas, namely *Rhizophora apiculata* Bl., *R. mucronata* Poir., *Ceriops tagal* (Perr.) C.B. Rob., *C. decandra* (Griff.) Ding Hou, *Bruguiera cylindrica* Bl., *B. gymnorrhiza* (L.) Savingny, *B. parviflora* (Roxb.) Wight and Arn. ex Griff., and *B. sexangula* (Lour.) Poir. (DingHou, 1970).

Avicennia (Avicenniaceae), members of the mangrove group, are trees tolerant of a wide salinity range. In addition to the salinity factor, they prefer low sloping areas, so they are widely distributed in coastal regions and stands of mangrove. In mangrove areas of eastern Thailand, they are usually found landwards of the Rhizophoraceae group. The pencil-like pneumatophores protect them from suffocation when growing in oxygen-poor mud. Their flowers are small, insect pollinated, and with low pollen productivity (Ng and Sivasothi, 2001). In Thailand today, there are four species of *Avicennia*, namely *A. alba* Bl., *A. marina* Forssk., *A. tomentosa* Jacq., and *A. officinalis* L.

Sonneratia (Sonneratiaceae) is a genus of trees with cone-shaped pneumatophores adapted for growing in the tidal zone. *Sonneratia alba* J. Sm. is highly tolerant of salinity, so it is often found growing associated with taxa of Rhizophoraceae and *Avicennia* spp. on the seaward side of the mangrove zone. Other members, such as *S. ovata* Backer, *S. griffithii* Kurz, and especially *S. caseolaris* (L.) Engl., prefer growing in environments with more freshwater input such as areas near tidal rivers or channels. The flowers are ephemeral (one-night blooming) and pollinated by bats (Santisuk, 1992).

Acanthus species are shrubs growing on mud near the high tide mark. They can be found growing under trees or in open areas of disturbed mangrove. They particularly prefer areas with more freshwater input, such as along river banks. *Acanthus ebracteatus* Vahl and *A. ilicifolius* L. both grow in mangrove areas of Thailand today (Aksornkoae et al., 1992).

Lumnitzera (Lythraceae) pollen is very rare. The parent plants occur on the landward side of Rhizophoraceae, *Avicennia*, and *Sonneratia* in the mangrove zone.

Xylocarpus (Meliaceae) trees are often found on the landward side of the mangrove stands where the forest floor is higher and salinity is lower than that experienced by other mangrove species (Aksornkoae et al., 1992).

Excoecaria agallocha L. (Euphorbiaceae) is a tree with wind-pollinated flowers associated with mangrove forests. It usually grows on either stony or muddy ground at the high tide mark as a marginal mangrove element (Ng and Sivasothi, 2001).

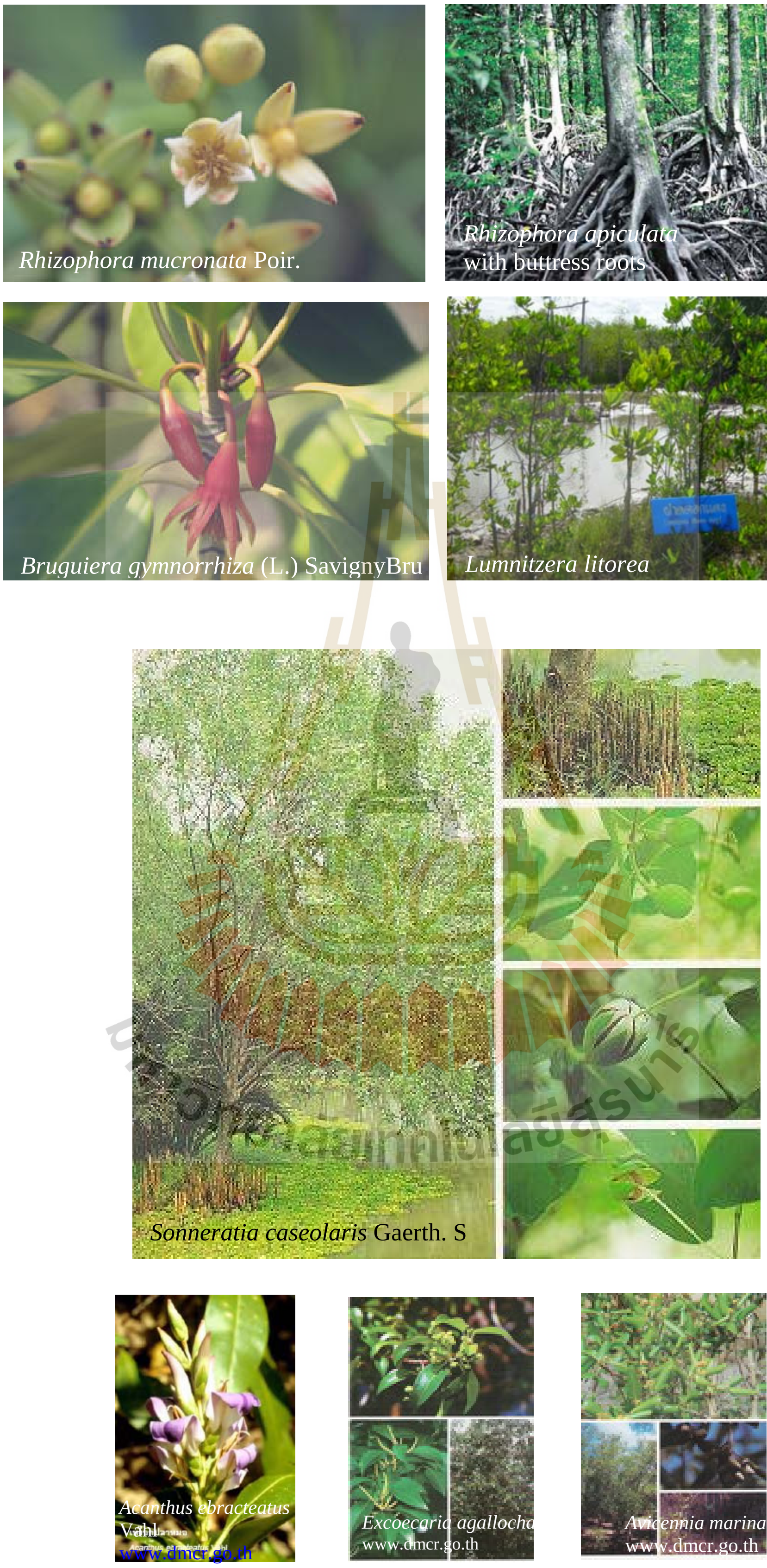


Fig 5.7 Photographs of some mangrove plants

The presence of mangrove pollen types suggests marine or mangrove environments in this area at that time. The assumption that this area used to be a marine flooded area is supported by the data of inundation frequencies of mangrove plant species in Table 5.2 (Santisuk, 1983). It demonstrates that mangrove species (classes 1-5 in Table 5.2) are flooded by salt water at least twice a month. Moreover, a study by Somboon (1990) shows that pollen of mangrove plants is likely to be deposited close to the parent plants. The present habitat of these mangrove plants is mud flats, suggesting that the deposited area was supported by inland freshwater runoff bringing inland sediment to be deposited as a muddy flat.

Table 5.2 Inundation classes of some plants in tidal zone (after Santisuk, 1983)

Species	Inundation classes					Adjacent and Inland Vegetation@
	1	2	3	4	5	
Rhizophora apiculata		xxxxxx	xxxxxx	xxx		
R. mucronata	xxx	xxxxxx	xxxxxx			
Bruguiera cylindrica			xxxxxx	xxxxxx		
B. gymnorrhiza			xxxxxx	xxxxxx	xxxxxx	
B. hainesii			xxxxxx	xxxxxx	xx	
B. parviflora			xxxxxx	xxxxxx	xxx	
B. sexangula				xxxxxx	xxxxxx	
Ceriops decandra				xxxxxx	xxxxxx	
C. tagal			xxxxxx	xxxxxx		
Avicennia alba	xxx	xxxxxx	xxxxxx			
A. marina	xxx	xxxxxx	xxxxxx			
A. officinalis			xxxxxx	xxxxxx	xxxxxx	
Sonneratia alba	xxxxx	xxxxxx	xx			
S. caseolaris			xx	xxxxxx	xxxxxx	
S. griffithii			xxxxx	xxxxxx	xxxxxx	
S. ovata			xxxxx	xxxxxx	xxxx	
Xylocarpus gangeticus					xxxxxx	xx
X. granatum			xxxxx	xxxxxx	xxxxxx	
X. moluccensis				xxxxxx	xxxxxx	
Lumnitzera littorea				xxxxxx	xxxxxx	
L. racemosa				xxxxxx	xxxxxx	
Excoecaria agallocha				xxxxxx	xxxxxx	

Table 5.2 (Continued)

Species	Inundation classes 1	2	3	4	5	Adjacent and Inland Vegetation[@]
Acanthus ebracteatus				xxxxxx	xxxxxx	
A. ilicifolius				xxxxxx	xxxxxx	
Oncosperma tigillaria					xxxxxx	xxxxx
Barringtonia asiatica					xxxxxx	xxxxxxxxxxx
B. racemosa					xxxxxx	xxxxxxxxxxx

1 = Flooded 56-62 times/ month; 2 = flooded 45 – 56 times/ month; 3 = flooded 20 – 45 times/ month; 4 = flooded 2 – 20 times/ month; 5 = flooded up to twice a month; @ = beach, fresh water, peat swamp vegetation or salt flat.

Although Rhizophoraceae seemed to be the most dominant element of the mangrove assemblages, it might or might not have been the most abundant of the parent plants at the site because studies of mangrove forest and Recent marine sediments found that the pollen percentages always show over-representation of Rhizophoraceae but under-representation of *Avicennia*, *Acanthus*, *Excoecaria*, and *Lumnitzera* compared to the real floristic composition (Thanikaimoni, 1987; Somboon, 1990). The reasons could be because the higher pollen productivity of plants of Rhizophoraceae allowed them to deposit more pollen than the others; the smaller size of pollen grains also allowed them to spread and be deposited in wider areas (Muller, 1959).

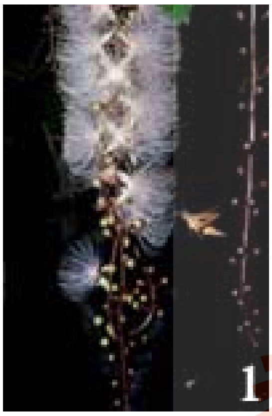
5.4.2 Back mangrove vegetation[(2)]

Back mangrove vegetation is represented by low percentages of *Barringtonia, Oncosperma, Nypa fruticans*, and *Suaeda maritima* pollen.

The parent plant of *Oncosperma* (Arecaceae) is a palm tree and has both brackish and wetland representatives, while *Barringtonia* (Barringtoniaceae) can be found situated inland from the swamp and in lowland forest. Pollinators of *Barringtonia* flowers are bats or insects, mainly moths.

Suaeda maritima (Chenopodiaceae) is the only native species of the genus *Suaeda* in Thailand today. The parent plant is a herb, usually growing in saline and dry soil of the back mangrove habitat (Chayamarit, 2005).

Nypa fruticans (Arecaceae) is usually considered as a mangrove palm, but it is actually found in areas of low salinities and sluggish water, fed by nutrient-rich freshwater. It can be found far inland where tides have little influence, but soil does not dry out for too long (Ng and Sivasothi, 2001). So, it is considered an element of the back mangrove flora in this study.



Barringtonia racemosa being visited by a moth at night (http://ipmb.sinica.edu.tw/

Present coring site position *Nypa fruticans* http://www.dmcr.go.th/

Male inflorescences of *Nypa fruticans* http://mangrove.nus.edu.sg/

Fig. 5.8 Photographs of some back mangrove plants

The presence of pollen of back mangrove plants suggests that there were freshwater sources in the surrounding areas forming the brackish environment. Pollen from this habitat was then transported by stream or wind to be deposited in the study site. Since *Barringtonia*, *Nypa fruticans,* and *Oncosperma* are pollinated by insects, their pollen is normally distributed in areas close to the parent plants. As a result their pollen has little chance of being transported and deposited in distant areas.

This evidence can indicate local ecosystems at that time. When the study site is inundated by seawater, the area will be occupied by mangrove, so the back mangrove pollen is relatively poorly represented compared to periods of regression.

5.4.3 Beach forest vegetation[3]

The presence of this vegetation is indicated by pollen of *Casuarina* and *Thespesia*. This group suggests a sand ridge or sand bar environment deposition.

Since *Casuarina* is a wind-pollinated tree, it produces a large amount of pollen, which is distributed and deposited over a wide area. The low percentages (<1%) found at the study site probably indicate that there were no *Casuarina* parent plants growing in the study site but that its pollen was transported by wind or water from sand ridge environments behind the mangrove zone or from the seaside at some distance from the study site.

Fig. 5.9 Photographs of some beach forest plants

5.4.4 Lowland forest vegetation[4]

Pollen in this group was poorly represented. Pollen of lowland forest comprised diverse pollen types, but each of them was found as only a very few grains from the following taxa: Myrtaceae, Fagaceae, Menispermaceae, *Calamus* (Arecaceae), other palms (Arecaceae), *Ilex* (Aquifoliaceae), *Podocarpus* (Podocarpaceae), *Castanopsis/Lithocarpus*, *Quercus* (Fagaceae), *Eleaocarpus* (Eleaocarpaceae), *Diospyros* (Ebenaceae), *Lagerstroemia* (Lythraceae), *Dipterocarpus* (Dipterocarpaceae), and Sapotaceae.

Myrtaceae
www.dnp.go.th/

Melaleuca sp.

Castanopsis wallichii
Santisuk, 2000

Fig. 5.10 Photographs of some lowland forest plants

Although *Podocarpus* has been frequently interpreted as plants of high elevations, two of six species of *Podocarpus* s.l. in Thailand, namely *P. motleyi* (Parl.) Dummer and *P. polystachyus* R. Br. ex Endl. can be found at low altitudes. They usually grow in the lowland tropical evergreen forests or in swamp forests. While *P. polystachyus* is frequently found in evergreen forest at altitude about 800 m, it often occurs at lower elevations along the seashores or along rivers and even in mangrove swamps. So *Podocarpus* pollen type in this study is considered to be a representative of the lowland forest.

Dipterocarpus pollen, which is present as a few isolated grains in some layers, is of particular interest. In southern Thailand today the tropical evergreen rain forest (elevation < 1,000 m) is dominated by a number of *Dipterocarpus* spp., such as *Dipterocarpus kerrii, D. grandiflorus, D. gracilis, D. chartaceus, D. dyeri*, and *D. hasseltii* (Santisuk, 2006). Morley (2000) has pointed out that Dipterocarpaceae is the most species-rich woody family in SE Asian lowland evergreen rain forests with its center of diversity in Borneo and the surrounding regions. The presence of *Dipterocarpus* pollen probably indicates the presence of lowland forest around the area at that time. Their low pollen percentages may be caused by the over-representation of the mangrove species.

Calamus and other palms are also characteristic of lowland evergreen rain forest as understory plants (Morley, 2000).

The above taxa are representatives of lowland forest. This demonstrates that the lowland forest was already established in the Sathingpra Peninsula at that time, and the above pollen might have been transported by stream, wind, and insects into the marine environment. Another possible explanation is that these groups of pollen might have been transported from the distant mainland on the west side of Songkhla Lake, which still has some lowland communities. The presence of these plants suggests the presence of tropical forest until the late Holocene.

After that, the lowland vegetation was dominated by *Borassus* sp. (Arecaceae). Today *Borassus flabellifer* is widely established in the lowland, especially along dikes of paddy fields.

Fig. 5.11 Photographs of paddy fields with *Borassus flabellifer* around the study site.

5.4.5 Grasses [(5)]

Grasses, including Poaceae, Cyperaceae, and Asteraceae, are quite common in the area. They normally occupy open areas and grow well in a dry climate. The presence of this group is indicative of a seasonal climate. According to pollen evidence, grasses were relatively rare in this area until the very late Holocene when Poaceae pollen increased sharply to 60%. This may be related to clearing forest land for rice cultivation in the area.

5.4.6 Pteridophytes [(6)]

Ferns are also common in the palynomorph assemblages. This group of plants prefers high humidity habitats. *Acrostichum* species are often found in mangrove forests. *Stenochlaena palustris* is also associated with mangroves as a climbing fern on the mangrove trees. This fern is also a representative of the humid lowland environment. Today it is common in the study site, even though there are no longer any mangroves. The presence of other ferns is probably related to the rich moisture of mangrove, brackish, and freshwater habitats around the area.

5.4.7 Indeterminate pollen (7)

The unknown pollen group, comprising many types of pollen, is well-represented. They could be inland pollen transported to the site. The fact that there are so many Indeterminatae indicates the high diversity of the flora at that time.

Moreover, there are other palynomorphs present in samples. Various types of fungal spores present in the sediment suggest a forest floor with high moisture and under the shade of the closed canopy. Dinoflagellate cysts indicate a certain amount of marine influence.

5.5. Vegetation changes

The presence of all these vegetation groups indicates high diversity in the study area. During the Late Pleistocene to Holocene the Sathingpra Peninsula was occupied by many types of vegetation, such as mangrove, back mangrove, and beach forest communities mixed with fern species, whereas landward areas were covered by swamp, lowland, and grass communities. These vegetation types seem to have existed in the area for a long time. In the mid-Holocene, around 6,000 BP, terrestrialization resulted in the inland floras taking over from the mangrove floras.

At some time in the late Pleistocene, prior to 33,870 ± 280 BP, pollen evidence suggests the mangrove community was predominant in the area along with near shore communities influenced by the sea-level. However, the presence of lowland floras indicates the existence of lowland forest around the area. These kinds of vegetation indicate a warm and humid climate during that time.

During the barren pollen period, (33,870 ± 280 BP to 8,220 ± 50 BP), it does not mean that there was no vegetation in or around the area but the barren pollen occurrence might be due to oxidizing conditions, preventing the pollen from being preserved. Lithological characteristics of these intervals suggests that this could be during the time that the sea-level was low and the area was exposed to the atmosphere causing the sediment to become oxidized as shown in the abundantly mottled sediment.

After the barren pollen period came the Holocene. Similar groups of vegetation reimmigrated into the area with a dominance of mangrove. After that, pollen of mangrove vegetation started to decline while inland vegetation such as back mangrove, grasses, ferns, and lowland started to increase. Decrease of mangrove pollen in sediment can be an indicator of a retreating shoreline from the study site. Then the inland vegetation replaced the mangroves in the area.

During the Late Holocene, at a depth of 5 m - 18 cm, there is another barren zone. There is no pollen preserved in samples from this interval. The sediments are sandy clay to sand, suggesting high energy sedimentation. Being porous, these sediments were easily oxidized and therefore not suitable for pollen preservation.

At the very top of the SUT-1 core, pollen evidence indicates similar vegetation to that of the present day. There is no pollen of mangrove, back mangrove, and beach vegetation present. In its place pollen from inland plants suggests that the shoreline had receded quite a distance from the site. The inland pollen is dominated by *Borassus* sp., grasses, and ferns. In the study site today, there are many paddy fields with *Borassus* on the dikes. This may indicate that there was already human settlement in the area.

5.6 Sea level changes

Pollen evidence from this study can supply evidence for sea level changes by presence or absence of plants influenced by the marine environment such as mangrove, back mangrove, and beach vegetation. However, lithological characteristics are needed to combine with the above pollen evidence for environmental interpretation.

A high percentage of mangrove pollen suggests that the study site was prone to marine flooding and situated close to the shoreline. When mangrove pollen decreased but back mangrove and lowland pollen increased, the shoreline must have receded.

In the same way, if the pollen indicates that there was no marine-influenced vegetation present but abundant inland vegetation, the shoreline must have retreated even further. For example, the study site today has paddy fields and orchards with no marine-influenced vegetation present, because the shoreline today is about 2 km from the study site.

In some sediment sequences, there are barren zones with a few or no pollen present. In the barren zone at a depth of 24.5 - 17.5 m in core SE2-1, the sediment is mainly clay which is silty, sandy, and abundantly mottled. Although the sediment is not very different from the previous or later zone, the abundant mottling suggests oxidation. Since the other sediments were not affected, oxidation must have occurred shortly after deposition. The most likely scenario is that deposition was followed by regression, during which the sediments were exposed subaerially or entered the vadose zone.

During the Late Pleistocene Glacial Maximum (~18,000 BP) sea level dropped considerably and turned the Gulf of Thailand into dry land (Morley, 2000). The barren zone in this study could date from the Last Glacial Maximum. A date of 33,870 ± 280 immediately under the barren zone and an age of 8,220 ± 50 yr BP directly above it would bracket the regression to ca. 32,700 - ca. 8,500 BP.

Sediment characteristics of the barren zone at a depth of 5 - 0.18 m in core SUT-1 may be interpreted in relation to the different shoreline position. The sediment is sandy clay to sand suggesting a high energy depositional environment in which pollen is unable to be preserved. This may have occurred at the sandy beach near the shore which has no freshwater sources. This kind of environment may be similar to the sandy beach at the shoreline 2 km away from the study site today.

However, some sea level studies suggest that there was a marine transgression during the mid-Holocene which caused a marine ingression as far as Senaniwet housing, Bangkok (Somboon, 1988) or to Khok Phanom Di, Chonburi province, central Thailand (Maloney, 1988) based on mangrove evidence. This indicates that the relative sea level rose during the mid-Holocene before falling to its present level. This evidence supports the assumption that the study site was under water during the mid-Holocene.

The shoreline positions, in relation to position of the study site, are reconstructed using pollen evidence and lithological characteristics as shown in the figures below (Figs. 5.12, 5.13).

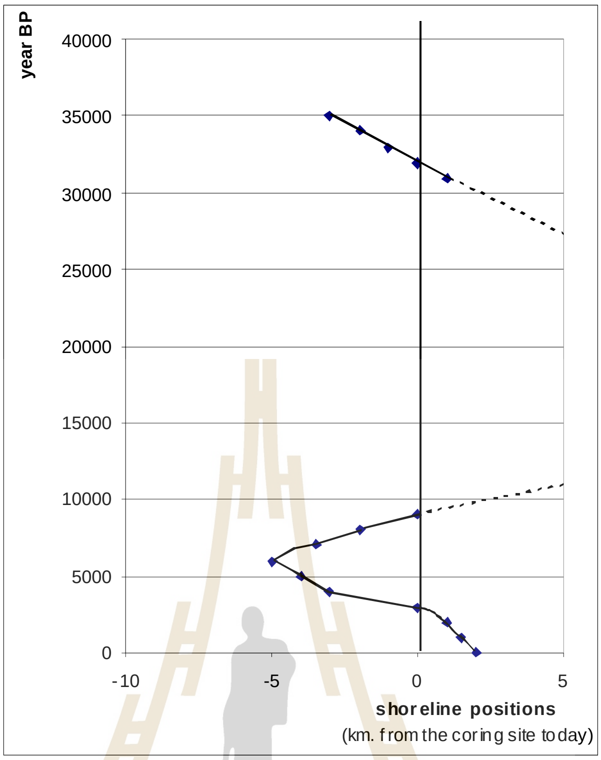


Fig. 5.12 Shoreline reconstruction (continuous line based on pollen data, dashed line made from other sources).

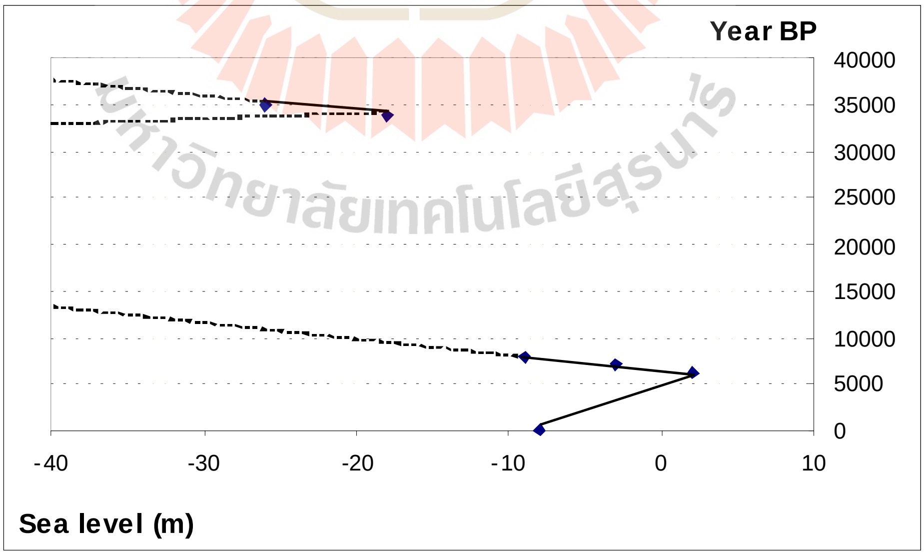


Fig. 5.13 Sea level reconstruction: continuous line made from estimates related to this study, dashed line made from estimates from other sources, present mean sea level is at 0 m.

The sediment sample at a depth of 24.5 meters below ground level has an age of 33,870 ± 280 BP. The ground level today is 8 meters above mean sea level. Without considering local tectonic effects, C14 dating precision, and stratigraphic errors, it could be estimated that the sea level at that time was about 17 m below present sea level (Fig. 5.12). Between 8,220 and 6,440 year BP, 10.5 meters of sediment were deposited. The sediment accumulation rate was approximately 1 m in 170 years or almost 6 mm per annum. Using this information, sea levels were plotted against time and trends of change were made in the graph above.

However, the position of the sea level at about 30,000 yr BP is still disputed. Studies by Woldstedt in Europe and Dreimannis and Goldthwait in North America mentioned sea levels varying from above present sea level to ~50 m below (Chappell and Veeh, 1978). The study of coral reefs on the Huon Peninsula, New Guinea, suggested 40 to 42 m below present sea level (Chappell and Veeh, 1978). A sea level of approximately 17 meter below present sea level at 33,870 ± 280 BP would seem to date from before the major regression of the Last Glacial Maximum during which the Pacific and Indian Oceans sank to about -125 to -150 m below present sea level. The estimated sea levels presented in this study are an attempt to provide evidence for discussion and require to be examined in the light of future studies.

CHAPTER VI

CONCLUSIONS

6.1 Taxonomic identification of fossil pollen

The Late Quaternary fossil pollen and spores from Songkhla Lake Basin, southern Thailand originated from ferns, gymnosperms, and angiosperms. While some of the fossil pollen could be identified to the species level, most were referred to genera or families.

Fifteen spore types belonging to 7 families of the Pteridophyta were discovered, i.e., Blechnaceae with *Stenochlaena palustris* (Burm.f.) Bedd., Cyatheaceae with Cyatheaceae gen. indet. 1 and 2, Davalliaceae with *Davallia* spp. 1 and 2, Gleicheniaceae with *Dicranopteris* sp. and Gleicheniaceae gen. indet., Polypodiaceae with *Polypodium* spp. 1 and 2, Pteridaceae with *Pteris* spp. 1 and 2, Pteridaceae gen. indet. 1 and 2, and Schizaeaceae with *Anemia* sp. Lycopodiophyta was represented by one family: Lycopodiaceae with *Lycopodium cernuum* L.

Gymnospermous pollen were classified into 5 pollen types, belonging to two families, viz., Pinaceae, represented by *Pinus* sp., *Dacrydium* sp., and Podocarpaceae, represented by *Podocarpus imbricatus* Bl., and *Podocarpus* spp. 1 and 2.

The angiospermous pollen belongs to 22 families, namely, Acanthaceae with *Acanthus* spp. 1 and 2, Aquifoliaceae with *Ilex* spp. 1 and 2, Avicenniaceae with *Avicennia* spp. 1 and 2, Barringtoniaceae with *Barringtonia acutangula* (L.) Gaertn., Betulaceae with *Betula* sp., Casuarinaceae with *Casuarina* sp., Chenopodiaceae with

Suaeda maritima (L.) Dumort., Combretaceae genera indet. 1, 2, 3, 4, and 5, Dipterocarpaceae with *Dipterocarpus* sp., Ebenaceae with *Diospyros* sp., Euphorbiaceae with *Excoecaria/Sapium* spp. 1, 2, 3, Fagaceae with *Quercus* spp. 1, 2 and gen. indet. 1, 2, Lythraceae with *Lagerstroemia* spp. 1 and 2, Menispermaceae gen. indet., Myrtaceae gen. indet. 1, 2, Rhizophoraceae gen. indet. 1, 2, 3, 4, Rubiaceae with *Canthium* sp., Salicaceae with *Salix* spp. 1, 2, Sonneratiaceae with *Sonneratia alba* J.Sm. and *Sonneratia* spp. 1, 2, 3, Arecaceae with *Borassus flabellifer* L., *Calamus* spp. 1, 2, 3, *Oncosperma* sp., Cyperaceae gen. indet., and Poaceae gen. indet. 1, 2.

The presence of diverse pollen from various families is evidence for plant diversity in the area since the Late Quaternary. The palynoflora found in this study is mostly similar to the extant flora in Thailand today.

6.2 Ecological interpretation from pollen assemblages

The pollen identified in this study mostly belongs to tropical plants. The habitat of each pollen parent plant was investigated and used for the interpretation of the environment at the time of deposition. Based on their plant ecology, six community types were recognized, namely, mangrove, back mangrove, beach forest, lowland forest, ferns, and grasses.

Pollen diagrams were created using the pollen counts. The apparently dominant taxon is the Rhizophoraceae, a member of the mangrove community. The diagram suggested that there were mangrove communities in this area for some time prior to 33,870 ± 280 BP in the Late Pleistocene. The presence of mangrove pollen suggests marine deposition in this area at that time. The present habitat of these mangrove plants is mud flats, suggesting that the area was fed by freshwater runoff bringing inland sediments, which were deposited as a muddy layer.

Lowland forest pollen types are present in very small numbers. However, as these plants are generally animal pollinated, they are usually under-represented. The very presence of their pollen indicates the existence of lowland forest not too far from the seashore.

From 33,870 ± 280 BP to 8,220 ± 50 BP, there is no pollen in the sediments. This time interval covers the late Pleistocene glacial maximum period, when the area became dry land. The exposure of the sediments to the atmosphere probably destroyed the pollen by oxidation.

After 8,220 ± 50 BP, mangrove forest was again dominant in the area. A significant vegetation change was found at the very top of the core with pollen assemblages similar to those derived from the present day vegetation. There is no mangrove present, and grass pollen and lowland forest increased. The decrease of mangrove pollen can be an indicator of marine regression from the study site and its replacement by inland vegetation.

6.3 Suggestions for future research

6.3.1 To obtain a more detailed picture of mangrove pollen changes through time, the sediment should be sampled at smaller intervals. The information can then be used in a comprehensive study of shoreline position and sea level changes.

6.3.2 Mangrove pollen is a good indicator for marine influence in the area. So it can be used for the investigation of ancient shorelines in relation to archaeological sites.

6.3.2 Changes in the composition of the inland forest during the Late Quaternary are worth investigating in more detail. In order to highlight the lowland forest pollen, the sediment core should be taken more inland, such as in lakes or valleys. In this way the over-representation of the mangrove pollen can be avoided.

6.3.3 The establishment of a comprehensive collection of Recent pollen is a prerequisite for the accurate identification of fossil pollen grains. Only then will it be possible to undertake exhaustive paleoecological studies.

6.3.4 Modern surface pollen assemblages should be studied to serve as modern vegetation analogs. Modern surface sampling sites should cover various natural microhabitats near the coring site.

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APPENDIX A

LIST OF MODERN POLLEN REFERENCES FROM PSU HERBARIUM

Family	Scientific name	SN number	Plant specimen collector	Date of pollen collection
ALANGIACEAE	*Alangium griffithii* (Cl.) Harms	180302	J.F. Maxwell	4-Jun-04
ALANGIACEAE	*Alangium griffithii* (Cl.) Harms	180308	T. Santisuk	4-Jun-04
AMARANTHACEAE	*Aerva lanata* (L.) Juss.	192445	Patchanee Tuntibunpakul	4-Jun-04
AMARANTHACEAE	*Alternanthera philoxeroides* (Mart.) Gries.	180347	W. Ramsri	4-Jun-04
ANACARDIACEAE	*Anacardium occidentale* L.	180398	G. Congdon	4-Jun-04
ANACARDIACEAE	*Bouea macrophylla* Griff.	180400	J.F. Maxwell	4-Jun-04
ANACARDIACEAE	*Bouea oppositifolia* (Roxb.) Meisn.	180403	G. Congdon	4-Jun-04
ANACARDIACEAE	*Bouea macrophylla* Griff.	180485	K. Larsen, S.S. Larsen, S.S.Renner, C.Niyomdham	4-Jun-04
ANACARDIACEAE	*Buchanania arborescens* (Bl.) Bl.	180416	J.F. Maxwell	4-Jun-04
ANACARDIACEAE	*Buchanania latifolia* Roxb.	192496	J. Leerativong	4-Jun-04
ANACARDIACEAE	*Buchanania sessifolia* Bl.	180420	J.F. Maxwell	4-Jun-04
ANACARDIACEAE	*Buchanania siamensis* Miq.	180429	C. Phengklai et al.	4-Jun-04
ANACARDIACEAE	*Dracontomelon dao* (Blanco) Merr.	180433	J.F. Maxwell	4-Jun-04
ANACARDIACEAE	*Drimycarpus luridus* (Hook.f.) Merr.	180434	J.F. Maxwell	4-Jun-04
ANACARDIACEAE	*Gluta tavoyana* Wall. ex Hook.f.	180439	J.F. Maxwell	4-Jun-04

FAMILY	Scientific name	SN number	Plant specimen collector	Date of pollen collection
ANACARDIACEAE	*Gluta* (q.v. *Melanorrhoea glabra* Wall.)	180441	J.F. Maxwell	4-Jun-04
ANACARDIACEAE	*Lannea coromandelica* (Houtt.) Merr.	180444	J.F. Maxwell	4-Jun-04
ANACARDIACEAE	*Mangifera foetida* Lour.	180446	J.F. Maxwell	4-Jun-04
ANACARDIACEAE	*Mangifera indica* L.	192449	Ratsadaporn Panich	4-Jun-04
ANACARDIACEAE	*Mangifera pentandra* Hook.f.	180447	J.F. Maxwell	4-Jun-04
ANACARDIACEAE	*Parishia insignis* Hook.f.	180451	G. Congdon	4-Jun-04
ANACARDIACEAE	*Parishia pubescens* Hook.f.	180453	C. Niyomdham	4-Jun-04
ANACARDIACEAE	*Pentaspadon curtisii* (King) Corner	180454	G. Congdon	4-Jun-04
ANACARDIACEAE	*Rhus wallichii* Hook.f.	180455	S. Reynolds	4-Jun-04
ANACARDIACEAE	*Semecarpus curtisii* King	180466	G. Congdon	4-Jun-04
ANACARDIACEAE	*Spondias pinnata* (L.f.) Kurz	180481	J.F. Maxwell	4-Jun-04
ANACARDIACEAE	*Swintonia floribunda* Griff.	180483	J.F. Maxwell	4-Jun-04
APOCYNACEAE	*Agnrosma marginata* (Roxb.) G. Don	180749	J.F. Maxwell	4-Jun-04
APOCYNACEAE	*Alstonia macrophylla* Wall. ex G. Don	180767	J.F. Maxwell	4-Jun-04
APOCYNACEAE	*Alyxia reinwardtii* Bl.	180782	J.F. Maxwell	4-Jun-04

Family	Scientific name	SN number	Plant specimen Collector	Date of pollen collected
APOCYNACEAE	*Epigynum auritum* (C.K. Schneid.) Tsiang & P. T. Li	180809	J.F. Maxwell	4-Jun-04
ACANTHACEAE	*Acanthus ebracteatus* Vahl	192794	Nongyoa	28-Sept-05
ACANTHACEAE	*Acanthus ilicifolius* L.	180001	H & C	28-Sept-05
APOCYNACEAE	*Cerbera odollam* Gaertn.	192506	S. Lapukeaw	28-Sept-05
APOCYNACEAE	*Cerbera manghas* L.	192505	S. Lapukeaw	28-Sept-05
BORAGINACEAE	*Cordia cochinchinensis* Gagn.ep	181458	J.F. mMaxwell	28-Sept-05
CHENOPODIACEAE	*Suaeda maritima* (L.) Dumorto	192707	C. Leeratiwong	28-Sept-05
COMBRETACEAE	*Lumnitzera coccinea* W. & A.	181723	Congdon	28-Sept-05
COMBRETACEAE	*Lumnitzera littorea* (Jack) Voigt.	181725	C. Phengklai et al.	28-Sept-05
COMBRETACEAE	*Lumnitzera racemosa* Willd. vVar. *racemosa*	181729	C. Phengklai et al.	28-Sept-05
COMPOSITAE	*Pluchea indica* (L.) Less.	181927	P. Siriragsa	28-Sept-05
EBENACEAE	*Diospyros ferrea* (Willd.) Bukh. var. *ferrea*	182874	J.F. Maxwell	28-Sept-05
EUPHORBIACEAE	*Sapium indica* Willd.	183764	P. Siriragsa	28-Sept-05
GOODENIACEAE	*Scaevola taccada* (Gaerth.) Roxb.	184072	Anupong	28-Sept-05
LECYTHIDACEAE	*Barringtonia acutangula* (L.) Gaertn. ssp. *spicata* (Bl.) Payens	185079	P. Sirirugsa	28-Sept-05
LECYTHIDACEAE	*Barringtonia pendula* (Griff.) Kurz.	185091	J.F. Maxwell	28-Sept-05

Family	Scientific name	SN number	Plant specimen collector	Date of pollen collected
LECYTHIDACEAE	*Barringtonia macrostachya* (Jack) Kurz	185085	J.F. Maxwell	28-Sept-05
LEGUMINOSAE	*Caesalpinia crista* L.	185193	NiYom	28-Sept-05
LEGUMINOSAE	*Intsia bijuga* (Colebr.) Kuntze	185284	P. Sirirugsa	28-Sept-05
LEGUMINOSAE	*Derris trifoliata* Lour.	185588	P. Sirirugsa & M. Still	28-Sept-05
MELIACEAE	*Xylocarpus granatum* Koen.	191503	Charan Leeratiwong	28-Sept-05
MELIACEAE	*Xylocarpus* cf. *moluccensis* Corner	186614	Congdon	28-Sept-05
MELIACEAE	*Xylocarpus obovatus* Juss.	186615	C. Phengklai et al.	28-Sept-05
PODOCARPACEAE	*Podocarpus neriifolius* D. Don	187998	J.F.Maxwell	28-Sept-05
RHIZOPHORACEAE	*Bruguiera cylindrica* (L.) Bl.	188196		28-Sept-05
RHIZOPHORACEAE	*Bruguiera gymnorrhiza* (Lamk.)	191696	Dararad Choosawad	28-Sept-05
RHIZOPHORACEAE	*Bruguiera parviflora* (Roxb.) W & A. ex Griff.	191664	ดาราวัลย์ กาญจนรุจิ	28-Sept-05
RHIZOPHORACEAE	*Bruguiera sexangula* (Lour.) Poir.	191697	Jirawat Jatkew	28-Sept-05
RHIZOPHORACEAE	*Bruguiera sexangula* (Lour.) Poir.	188209	C. Phengklai et al.	28-Sept-05

Family	Scientific name	SN number	Plant specimen collector	Collector number	Date of pollen collection
AQUIFOLIACEAE	*Ilex cymosa* Bl.	180934	J. F. Maxwell	85-195	28-29-Dec-05
ARECACEAE	*Calamus aranthophyllus* Becc.		C. Phengklai et al.	3629	28-29-Dec-05
ARECACEAE	*Calamus* sp.		Kai Larsen	41407	28-29-Dec-05
ARECACEAE	*Calamus bousigonii* Becc.		J.F. Maxwell	84-373	28-29-Dec-05
ARECACEAE	*Calamus rudentum* Roxb.	191982	P. Ritthisunthorn	4	28-29-Dec-05
ARECACEAE	*Calamus* sp.		J.F. Maxwell	87-487	28-29-Dec-05
ARECACEAE	*Calamus longisetus* Griff.		A.S.Barfod, W. Ueachirakan		28-29-Dec-05
ARECACEAE	*Calamus palustris* Griff.		J.F. Maxwell	86-178	28-29-Dec-05
ARECACEAE	*Calamus rudentum* Lour.		J.F. Maxwell	85-517	28-29-Dec-05
ARECACEAE	*Calamus perigrinus* Furtadoa..		A.S.Barfod, W. Ueachirakan	41725	28-29-Dec-05
ARECACEAE	*Caryota mitis* Lour.	187718	Students	5P	28-29-Dec-05
ARECACEAE	*Oncosperma tigillariuma* (Jack) Ridl.		A.S.Barfod, W. Ueachirakan	41791	28-29-Dec-05
ARECACEAE	*Phoenix roebelenii* O' Brien ex C. Robelen		A.S. Barfod, W. Ueachirakan	41434	28-29-Dec-05
ASTERACEAE	*Wedelia biflora* DC.	181997	G,. Congdon	C 92	28-29-Dec-05

Family	Scientific name	SN number	Plant specimen collector	Collector number	Date of pollen collection
AVICENNIACEAE	*Avicennia alba* Bl.			C 389	28-29-Dec-05
AVICENNIACEAE	*Avicennia officinalis*, L.inn			N 15	28-29-Dec-05
AVICENNIACEAE	*Avicennia tomentosa* Jacq.			PS 389	28-29-Dec-05
BORAGINACEAE	*Cordia cochinchinensis* Gagn.ep	181458	J. F. Maxwell	85-573	28-29-Dec-05
CASUARINACEAE	*Casuarina equisetifolia* J. R. & G.$ 6 Forst.	181569	Hamilton & Smitinand		28-29-Dec-05
DIPTEROCARPACEAE	*Dipterocarpus alatus* Roxb. eEx G. Don	182754			28-29-Dec-05
DIPTEROCARPACEAE	*Anisoptera stellata*	182751			28-29-Dec-05
DIPTEROCARPACEAE	*Hopea ferrea* Laness.	182773			28-29-Dec-05
DIPTEROCARPACEAE	*Hopea ferrea* Laness.	182776			28-29-Dec-05
DIPTEROCARPACEAE	*Hopea odorata* Roxb.	182782			28-29-Dec-05
DIPTEROCARPACEAE	*Hopea odorata* Roxb.				28-29-Dec-05
DIPTEROCARPACEAE	*Hopea odorata* Roxb.				28-29-Dec-05
EUPHORBIACEAE	*Excoecaria agallocha* L.	183427	P. Sirirugsa	845	28-29-Dec-05
EUPHORBIACEAE	*Glochidion littorale* Bl.	183520	J.F. Maxwell	86-880	28-29-Dec-05

Family	Scientific name	SN number	Plant specimen collector	Collector number	Date of pollen collection
FLACOURTIACEAE	*Scolopia macrophylla* (W.&A.) Clos. By J.F. Maxwell 18 Oct-1985, previous is ...rhinanthera (Benn.) Clos.	183961	P. Sirirugsa	649	28-29-Dec-05
FLACOURTIACEAE	*Scolopia macrophylla* (W.&A.) Clos.	183963	J.F.Maxwell	85-985	28-29-Dec-05
FLAGELLARIACEAE	*Flagellaria indica* L.	183972	students	3	28-29-Dec-05
FLAGELLARIACEAE	*Flagellaria indica* L.		K K et al	12	28-29-Dec-05
HERNANDIACEAE	*Hernandia nymphaeifolia* (Prist) Kubitzkixi	184749	Congdon	969	28-29-Dec-05
JUGLANDACEAE	Juglandaceae	191276	Rossarin Pollawat	11	28-29-Dec-05
LAURACEAE	*Cassytha rfiliformis* L.		Viroj		28-29-Dec-05
LEGUMINOSAE	*Parkia speciosa* Hassk.		Ratana	I 01	28-29-Dec-05
LEGUMINOSAE	*Caesalpinia digyna* Rottl.	185196	จรรยา ลิมบานเย็น		28-29-Dec-05
LEGUMINOSAE	*Caesalpinia bundu* (L.) Roxb.		Congdon	C.155	28-29-Dec-05
LEGUMINOSAE	*Parkia speciosa* Hassk.	185832	J.F.Maxwell	85-431	28-29-Dec-05
LYCOPODIACEAE	*Lycopodium cernuum* L.	186058	J.F.Maxwell	85-758	28-29-Dec-05
LYCOPODIACEAE	*Lycopodium clavatum* L.	192777	C. Loratiwong	2002-74	28-29-Dec-05

Family	Scientific name	SN number	Plant specimen collector	Collector number	Date of pollen collection
LYCOPODIACEAE	*Lycopodium cernuum* L.	186058	J.F.Maxwell	85-758	28-29-Dec-05
LYCOPODIACEAE	*Lycopodium phlegmaria* L.		W. Ramari	13	28-29-Dec-05
LYTHRACEAE	*Pemphis acidula* J.R. & G. Forst.		P. Sirirugsa	406	28-29-Dec-05
LYTHRACEAE	*Pemphis acidula* J.R. & G. Forst.	186096	P. Sirirugsa	PS 427	28-29-Dec-05
MALVACEAE	*Thespesia populuca* Kostel		Supinya Sandam	2	28-29-Dec-05
MELASTOMACEAE	*Melastoma saigonense* (Kuntze) Merr. (*M. villosuma* Lodd Sims.)		C. Phengklai et al	3327	28-29-Dec-05
MELASTOMACEAE	*Melastoma saigonense* (Kuntze) Merr. (*M. villosum* Sims) (Kuntze) Merr. (villosum Lodd.)				28-29-Dec-05
MENISPERMACEAE	*Tinospora* cf. *curtisii* Ridl.	186668	G Congdon	1143	28-29-Dec-05
MORACEAE	*Ficus annulata* Bl.		J.F. Maxwell	85-643	28-29-Dec-05
MYRICACEAE	*Myrica esculenta* Bach.-Ham. Ex D. Don			514	28-29-Dec-05
MYRISTICACEAE	*Horsfieldia irya* (Gaerthn.) Warb.	186939	J.F. Maxwell	85-328	28-29-Dec-05
MYRSINACEAE	*Ardisia littoralis* Andr.	187053	J.F. Maxwell	85-740	28-29-Dec-05
MYRSINACEAE	*Rapanea porteriana* (A. DCc.) Mez.	191554	Shanat Phetsri	Sp. 14	28-29-Dec-05
MYRSINACEAE	*Myrsine umbellata* A. DC.		P. Sirirugsa	501	28-29-Dec-05

Family	Scientific name	SN number	Plant specimen collector	Collector number	Date of pollen collection
MYRTACEAE	*Melaleuca cajuputi* Powell	191565	O. N. et al	52	28-29-Dec-05
MYRTACEAE	*Melaleuca leucadendra* (L.) L.		C. Phengklai et al	3758	28-29-Dec-05
NELUMBONACEAE	*Nelumbo nucifera* Gaertn.			PK 58	28-29-Dec-05
NYMPHAEACEAE	*Nymphaea p nouchali* Burnm. Ff.			242	28-29-Dec-05
NYMPHAEACEAE	*Nymphaea lotus* L.			PK 60	28-29-Dec-05
ONAGRACEAE	*Jussiaea linifolia* Vahl.	191614		14	28-29-Dec-05
ONAGRACEAE	*Ludwigia adscendens* (L.) Hara.	191616		1	28-29-Dec-05
ONAGRACEAE	*Ludwigia adscendans* (L.) Harra.	191617		4	28-29-Dec-05
ONAGRACEAE	*Ludwigia hyssopifolia* (G. Don) Exell			86-87	28-29-Dec-05
ONAGRACEAE	*Ludwigia hyssopifolia* (G. Don) Exell				28-29-Dec-05
ONAGRACEAE	*Ludwigia linifolia* Poir.			4	28-29-Dec-05
ONAGRACEAE	*Ludwigia peruviana* (L.) Hara			86-861	28-29-Dec-05
PANDANACEAE	*Pandanus* sp.		J.F. Maxwell	84-361	28-29-Dec-05
PANDANACEAE	*Pandanus* sp.	192089	Parinya Sukkaewmanee	PK 21	28-29-Dec-05
PLUMBAGINACEAE	*Aegialitis rotundifolia* Roxb.		Congdon	C 737	28-29-Dec-05

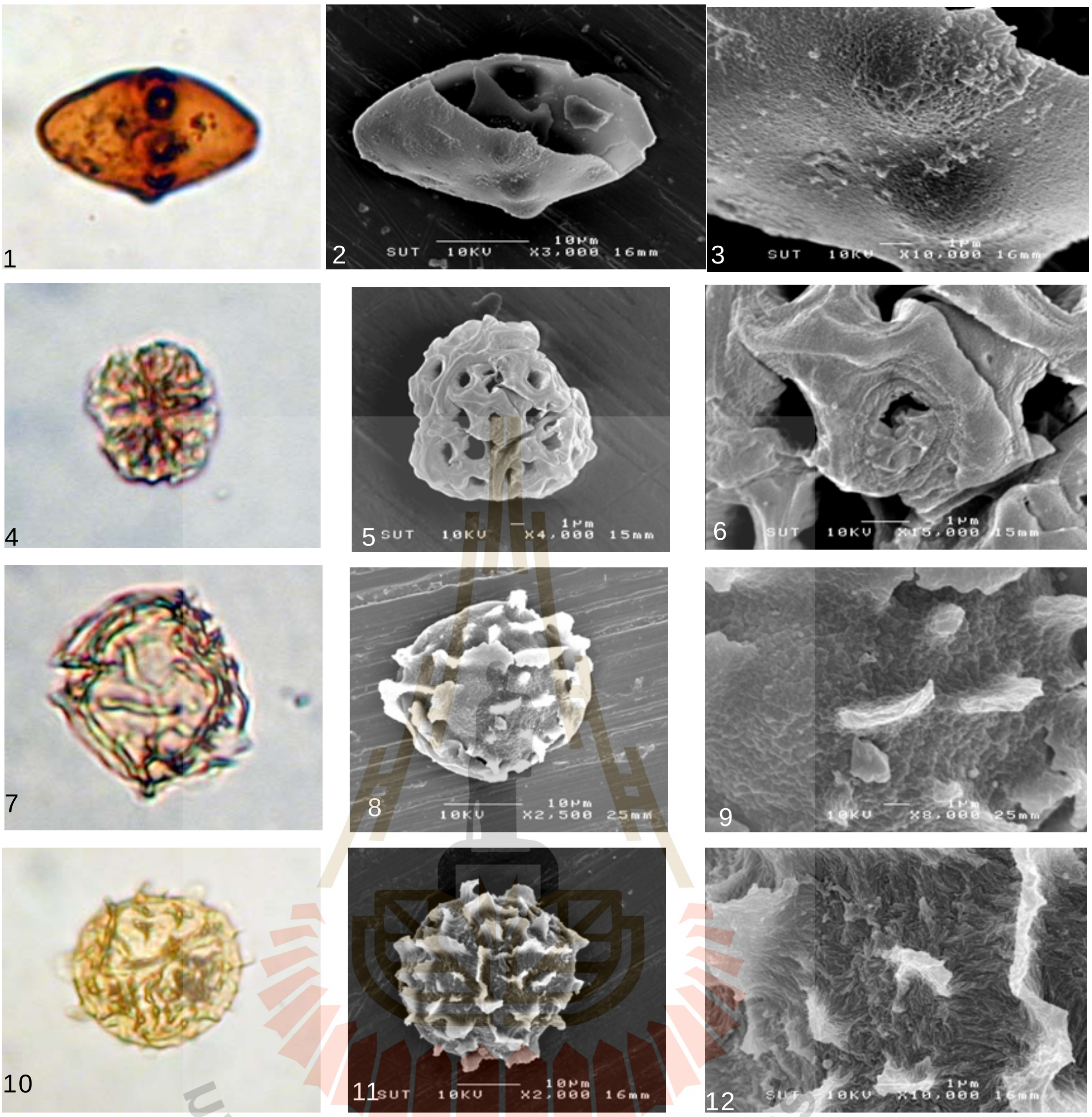
Family	Scientific name	SN number	Plant specimen collector	Collector number	Date of pollen collection
PTERIDACEAE	*Acrostichum aureum* L.inn.	188130		263	28-29-Dec-05
PTERIDACEAE	*Pteris blumeana* Agar.	192380		19	28-29-Dec-05
PTERIDACEAE	*Pteris ensifbormis* Burm. fF.	188134		86-1008	28-29-Dec-05
PTERIDACEAE	*Pteris excelsa* Gaud.			3883	28-29-Dec-05
PTERIDACEAE	*Pteris grevilleanna* Wall. eEx Agar.	188142		87-255	28-29-Dec-05
PTERIDACEAE	*Pteris longipinnula* Wall. Eex Agar.			C 1211	28-29-Dec-05
PTERIDACEAE	*Pteris subquinata* Wall. eEx Agar.	192385		20	28-29-Dec-05
PTERIDACEAE	*Pteris vittata* L.	188145			28-29-Dec-05
PTERIDACEAE	*Stenochlaena palustris* (Burm.) Bedd.	188150			28-29-Dec-05
PTERIDACEAE	*Lygodium circinatum* (Burm.f) SwW.	192391			28-29-Dec-05
PTERIDACEAE	*Lycodium* sp.				28-29-Dec-05
RHIZOPHORACEAE	*Ceriops decandra* (Griff.) Ding Hou		H&C	258	28-29-Dec-05
RHIZOPHORACEAE	*Ceriops tagal* (Perr.) C. B. Robinson		น.ส.อุษณีย์ โชติศิริ	10	28-29-Dec-05

Family	Scientific name	SN number	Plant specimen collector	Collector number	Date of pollen collection
RHIZOPHORACEAE	*Ceriops targal* (Perr.) C. B. Robinson (C.B' Robinson)	191677	น.ส.วรวัลย์ เกษตรอนันต์	9	28-29-Dec-05
RHIZOPHORACEAE	*Rhizophora apiculata* Bl. Syn	191684	Wanisa Kantamanee	3	28-29-Dec-05
RHIZOPHORACEAE	*Rhizophora mucronata* Poir.		น.ส.สุจิน ชุมประเสริฐ	7	28-29-Dec-05
RHIZOPHORACEAE	*Scyphiphora hydrophyllacea* Gaertn. f.		P. Sirirugsa	751	28-29-Dec-05
RUATACEAE	*Atalantia monophylla* (L.) DC.		J.F. Maxwell	84-531	28-29-Dec-05
RUBIACEAE	*Canthium diccoccum* (Gaertn.) Merr. Vvar. *Dicoccum*	191708		85-456	28-29-Dec-05
RUBIACEAE	*Canthium* sp.			B 906	28-29-Dec-05
RUBIACEAE	*Canthium grabrum* Bl.	191720		86-743	28-29-Dec-05
SAPINDACEAE	*Allophyllus cobbe* (L.) Raeusch.		J.F. Maxwell	86-393	28-29-Dec-05
SAPINDACEAE	*Pometia pinnata* J.R. & G. Forst.	189357		85-1025	28-29-Dec-05
SAPOTACEAE	*Planchonella obovata* (R.Br.) Pierre		J.F. Maxwell	85-538	28-29-Dec-05
SCHIZACEAE	*Lygodium microphyllum* (Cav.) R. Br.				28-29-Dec-05
SCHIZACEAE	*Lygodium salicifolium* Presl.	192398			28-29-Dec-05

Family	Scientific name	SN number	Plant specimen collector	Collector number	Date of pollen collection
SCHIZACEAE	*Schizaea dichotoma* (L.) Sm.	192400			28-29-Dec-05
SONNERATIACEAE	*Sonneratia alaba* J. Smith		P. Sirirugsa	544	28-29-Dec-05
SONNERATIACEAE	*Sonneratia griffithii* Kuryz	191841	Phongtheera Buapet	1	28-29-Dec-05
SONNERATIACEAE	*Sonneratia ovata* Backer		P. Sirirugsa	532	28-29-Dec-05
STERCULIACEAE	*Herietiera littorallis* Dry. Eex W. Ait.		P. Sirirugsa	545	28-29-Dec-05
VERBENACEAE	*Clerodendrum inerme* (L.) Gaertn.		P. Sirirugsa	647	28-29-Dec-05

APPENDIX B

OTHER PALYNOMORPHS



Figs. 1-3: Fungal spore (LM, SEM, and SEM closed-up)

Figs. 4-6: Alga (LM, SEM, and SEM closed-up)

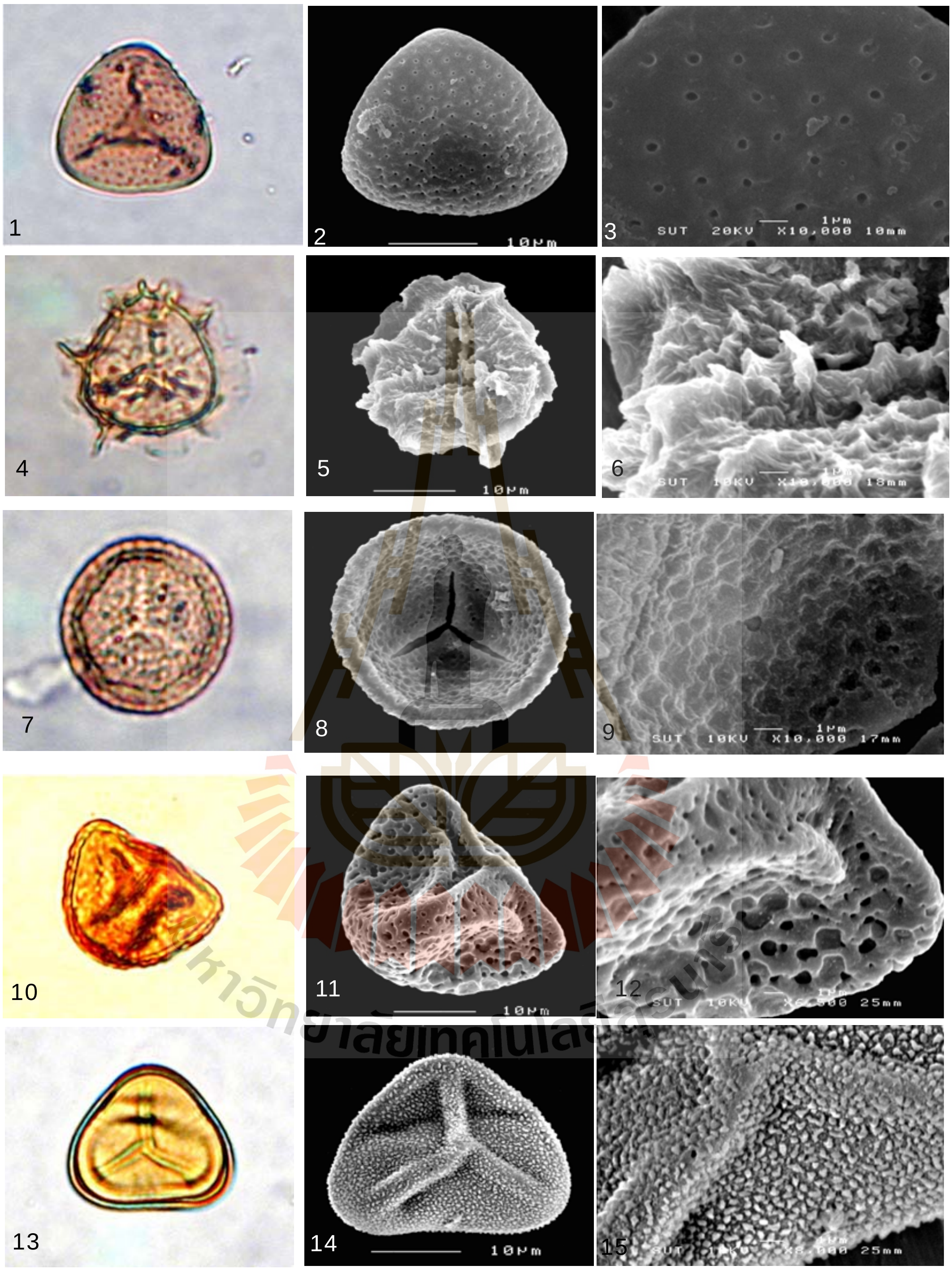
Figs. 7-9: Dinoflagellate cyst sp.1 (LM, SEM, and SEM closed-up)

Figs. 10-12: Dinoflagellate cyst sp.2 (LM, SEM, and SEM closed-up)

APPENDIX C

INDETERMINATE SPORES AND POLLEN

INDETERMINATE SPORES



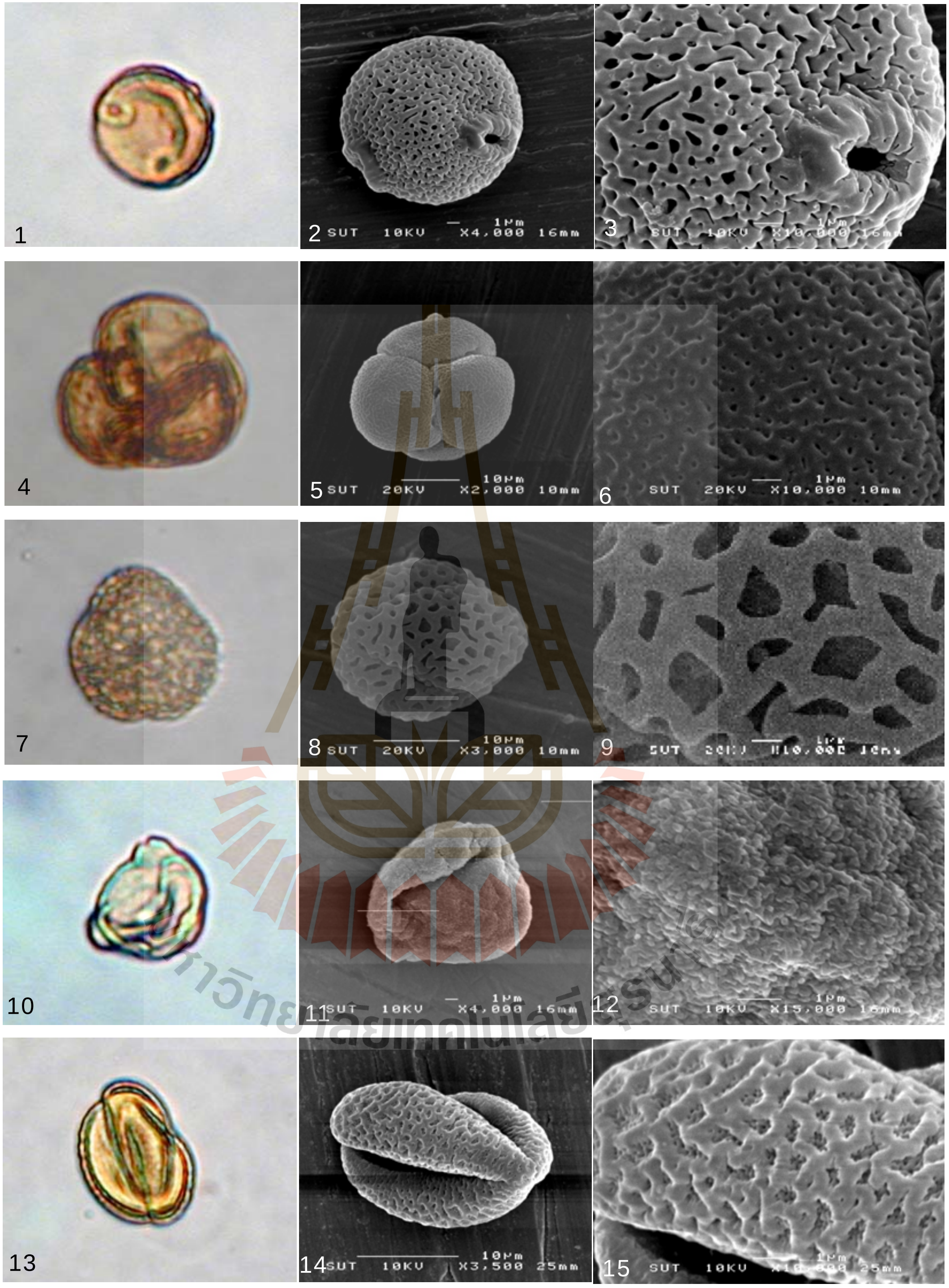
Spore type 1: figs. 1-3

Spore type 2: figs. 4-6

Spore type 3: figs. 7-9

Spore type 4: figs. 10-12

INDETERMINATE POLLEN

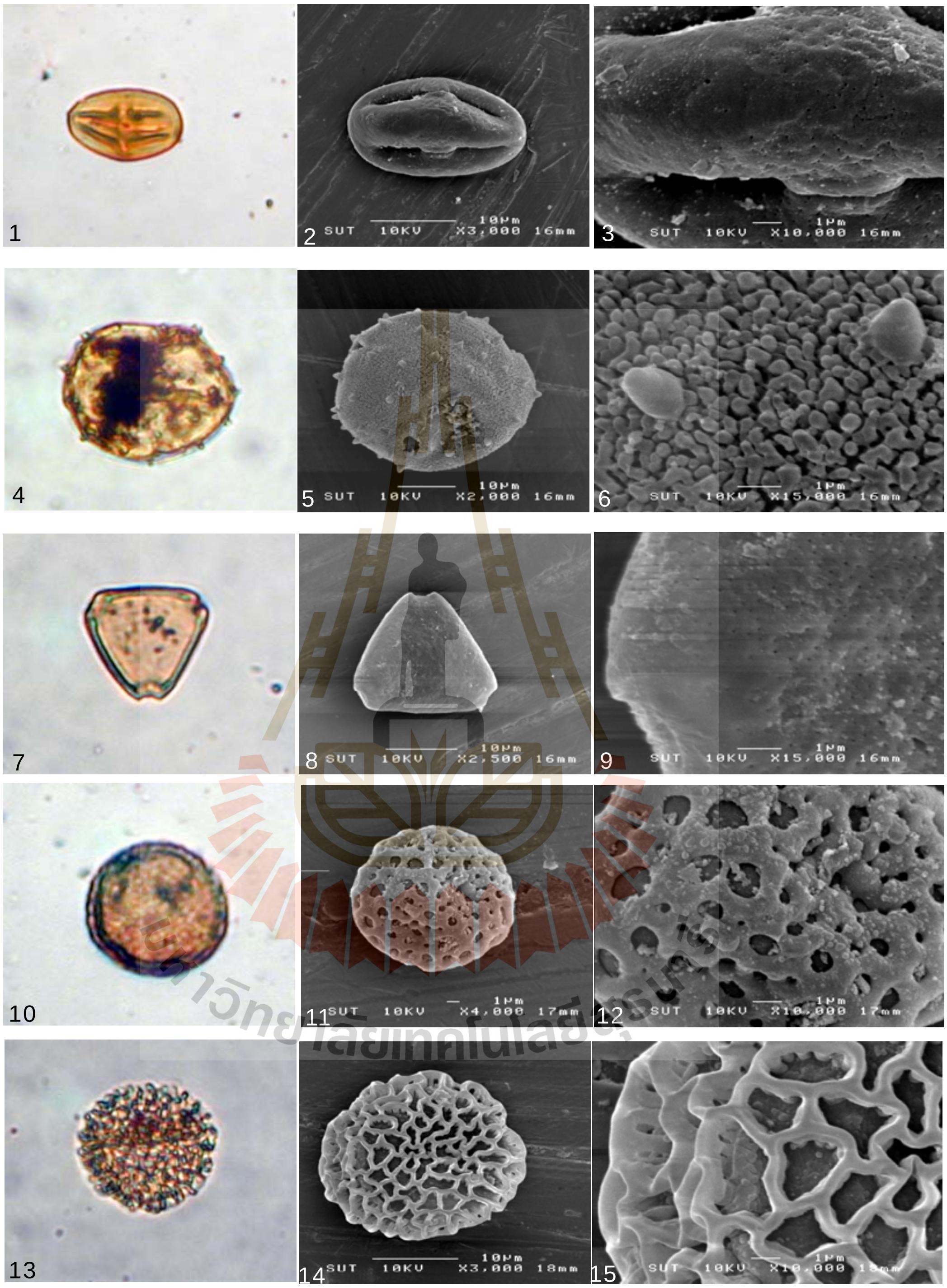


Unknown pollen type 1: figs. 1-3, Unknown pollen type 2: figs. 4-6,

Unknown pollen type 3: figs. 7-9, Unknown pollen type 4: figs. 10-12,

Unknown pollen type 5: figs. 13-15

INDETERMINATE POLLEN (Continued)



Unknown pollen type 6: figs. 1-3, Unknown pollen type 7: figs. 4-6,

Unknown pollen type 8: figs. 7-9, Unknown pollen type 9: figs. 10-12,

Unknown pollen type 10: figs. 13-15

CURRICULUM VITAE

Name:	Mrs. Wipanu Rugmai	
Date of Birth:	18 March 1972	
Place of birth:	Nakhon Si Thammarat Province, Southern of Thailand	
Nationality:	Thai	
Education:	1978 – 1984	Primary School (Chomchon Piboonsongkhram School, Nakhon Si Thammarat province)
	1984 – 1990	High School (Had Yai Wittayalai School, Had Yai, Songkla province)
	1990 – 1994	B.Sc. Chemistry (Prince of Songkla University, Songkhla province)
	1995 – 2000	M.Sc.(Tech.of Env. Management) (Mahidol University, Nakhon Prathom province)