PETRIFIED WOOD OF NORTHEASTERN THAILAND AND ITS IMPLICATION ON BIODIVERSITY AND THE ECOSYSTEM DURING THE CENOZOIC ERA

Mr. Pramook Benyasuta

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ความหลากหลายทางชีวภาพและระบบนิเวศของพรรณไม้ยืนต้นในยุค ซีโนโซอิคโดยใช้ไม้กลายเป็นหินในภาคตะวันออกเฉียงเหนือของประเทศไทย

นายประมุข เพ็ญสุต

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

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ไม้กลายเป็นหินที่เก็บจากจังหวัดนครราชสีมา จังหวัดชัยภูมิและจังหวัดขอนแก่นจำแนกได้เป็น *Homalium tomentosum* (Vent.) Benth., *Careya sphaerica* Roxb., *Albizia lebbeck* (L.) Benth., *Pahudioxylon sahnii* Ghosh and Kazmii, *Dialium cochinchinense* Pierre, *Millettia leucantha* Kurz, *Duabanga grandiflora* (Roxb. ex DC.) Walp, *Aquilaria* sp., *Anogeissus acuminata* (Roxb. ex DC.) Guill. & Perr., *Terminalia alata* Heyne ex Roth, *Protium serratum* (Colebr.) Engl., *Dracontomelon dao* (Blanco) Merr. & Rolfe, *Holarrhena pubescens* Wall. ex G. Don, *Wrightia arborea* (Dennst.) Mabberley, และ *Palmoxylon* sp. จำนวน 4 ชนิด ในยุคไมโอซีนถึงยุคไพลสโตซีน พรรณไม้ที่จำแนกได้จากบรรพชีวินเป็นชนิดเดียวกับพรรณไม้ที่พบอยู่ทั่วไปในที่ราบสูงโคราช ในป่าดิบแล้ง และป่าเบญจพรรณ สภาพภูมิอากาศของที่ราบสูงโคราชในยุคไมโอซีน ถึง ยุคไพลสโตซีน มีสภาพใกล้เคียงกับสภาพภูมิอากาศในปัจจุบัน

สาขาวิชาชีววิทยา ลายมือชื่อนักศึกษา………........................…...................
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PRAMOOK BENYASUTA: PETRIFIED WOOD OF NORTHEASTERN THAILAND AND ITS IMPLICATION ON BIODIVERSITY AND THE ECOSYSTEM DURING THE CENOZOIC ERA, NAKHON RATCHASIMA, THAILAND.
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CENOZOIC/ MIOCENE/ PLIOCENE/ PLEISTOCENE/ PALEOCLIMATE/ PETRIFIED WOOD/ KHORAT PLATEAU

Petrified wood specimens were collected from three provinces in the Northeast of Thailand. The specimens from Nakhon Ratchasima, Chaiyaphum, and Khon Kaen were determined to *Homalium tomentosum* (Vent.) Benth., *Careya sphaerica* Roxb., *Albizia lebbeck* Benth., *Pahudioxylon sahnii* Ghosh and Kazmii, *Dialium cochinchinens*e Pierre, *Millettia leucantha* Kurz, *Duabanga grandiflora* (Roxb. ex DC.) Walp., *Aquilaria* sp*., Anogeissus acuminata* (Roxb. ex DC.) Guill. & Perr., *Terminalia alata* Heyne ex Roth*, Protium serratum* (Colebr.) Engl., *Dracontomelon dao* (Blanco) Merr. & Rolfe, *Holarrhena pubescens* Wall. ex G. Don.*,Wrightia arborea* (Dennst.) Mabberley, and 4 species of *Palmoxylon* sp. The fossils are attributed to a Miozene to Pleistocene age. Most taxa show resemblance to the modern taxa distributed in the Khorat Plateau at present. The past climate appears to resemble the current climate corresponding to dry evergreen to mixed deciduous forest.

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Pramook Benyasuta

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CHAPTER I

INTRODUCTION

Petrified wood was found more than one hundred years ago, in conglomerates bed in Northeast Thailand. Nowadays, many pieces of petrified wood are commonly found in some areas in unconsolidated sand and conglomerate sediments in the North, Northeast, and South of Thailand and are considered to be Mesozoic or Cenozoic. Research was chosen that allows a view of biodiversity from petrified wood fossils that were found in Thailand from a perspective over geologic time. Knowledge about the life of the past interval of geologic time is derived from fossils, and reconstruction of the flora, the communities of plants, and the climate in the past environments can be attempted. In the past two decades, the collection of petrified wood from the Cenozoic was increased in the North and the Northeast by geologists but the study in wood anatomical identification of petrified wood has been very little studied.

The petrified wood fossils preserved enough botanical information, to enable their study. The comparisons of petrified wood to Recent wood need the finest details of wood anatomy to classify the specimens. Maybe some extant wood will be found or a new genus to science will be discovered depending on the evolutionary change in species of Cenozoic plants and Recent plants.

The vegetation occupying similar climates in wide regions possesses similar physical characteristics and many similar taxa. On the other hand, vegetation occupying dissimilar climates in one region has typically different physical characteristics. The environment tends to select plants that have certain physical aspects for a given climatic type. Then it is expected that the present type of the tropical forest has similar physical characteristics as tropical forests in the Cenozoic era (Wolfe, 1978). Study of petrified wood fossils will give a better understanding of the life in the past intervals of geologic time. Fossils might reveal the ancient ecosystems and climate of the world in that era. The study of plant fossils in Thailand will show the change of paleoenvironment and evolution and distribution of plants. This research will add knowledge of floras concerning the Cenozoic era related to the Recent flora. In addition, some knowledge of fossil plant assemblages will provide information on the age of geological formations and may give information on the depositional environments for use in evaluation of mineral resources. The age of sediments can be interpreted by many types of fossils.

Palynological assemblages have been used to study the paleovegetation in many parts of Thailand, for example, Nong Ya Plong Tertiary basin in Central of Thailand. The pollen of temperate plants was identified which suggested that the paleovegetation of the Tertiary basin at Nong Ya Plong was temperate forest (Wattanasak, 1988, 1990). The palynological data was compared with the wood remains in the Miocene peat forming vegetation of northwest Germany for the gymnosperm plants, such as Cupressaceae, Taxodiaceae, and angiosperm plants, such as Leguminosae, Magnoliaceae, Lauraceae. The taxonomic list of the wood remains will be very short when compared to the taxonomic list of pollen (Figueiral et al., 1999). Additionally, the species of micromammal fossils from Kanchanaburi, Saraburi, and Nakhon Sawan in the Pleistocene were studied and can be used to reconstruct the paleoenvironment (Chaimanee, Haeger, and Suteethorn, 1993). The fossils of vertebrates are the available evidence to date the sediments (Buffetaut, 1989). If the other types of fossils are found in the same site as petrified wood, they will be the indicators to support the interpretation of the age of petrified wood fossils.

1. Scope and Limitation of Study

Petrified wood fossils were collected from deposits of several ages during the Cenozoic in Nakhon Ratchasima, Chaiyaphum, and Khon Kaen provinces, Northeastern Thailand. Selected specimens of petrified wood were studied taxonomically in the laboratory using microscopes. The information obtained from taxonomic studies can allow conclusions to be made about plant diversity and ecosystems.

2. The Study of Fossil Wood

Anatomically, wood is the secondary xylem of a plant. It is the product of the vascular cambium and it consists of cells or wood elements that have passed through various phases of development. All developmental phases of cellular division, differentiation and maturation taken together constitute wood formation (Larson, 1969). The growth of wood is affected by the environmental condition surrounding it. Each ring pattern in wood of each plant is unique, no two are ever exactly alike. They are as individualistic as fingerprints (Harlow, 1970). The anatomy of sterile parts such as wood may have the same characters but it could not determined if the fertile organs of the ancient plants and the Recent plants are the same.

Woods of gymnosperms, except the Gnophytes, are vesselless. Some primitive families of the angiosperms also are vesselless such as the family Winteraceae. The gymnosperms from the Nong Phai fossil wood in late Permian period, Paleozoic Era, were described and proposed as a new species of gymnosperm *Dadoxylon walchiopremnoides,* which is the oldest petrified wood found in Thailand (Vozenin-Serra, 1989a). Many of the gymnosperm woods in the Mesozoic era were permineralized and found as petrified wood in the North and Northeast of Thailand. *Araucarioxylon* sp., determined from petrified wood, was collected from Ban Kut Bot, Kuchinarai, Kalasin, by K. Ogura (Asama, 1973). According to Vozenin-Serra, Privé-Gill, and Ginsburg (1989a), the petrified wood collected in Pong basin, Phayao province, indicated a mangrove environment of Middle Miocene age.

Dicotyledonous wood is more varied than that of the gymnosperms, usually complex and has both vessels and tracheids, one or more categories of fibers, axial parenchyma and ray parenchyma of one or more kinds. The various anatomical structures in wood tend to specialize together, the rates of specialization of the structures in a given species differ, and this difference makes identification possible (Esau, 1970).

Many families of Recent plants in Thailand have been studied as published in the Flora of Thailand and Forest Research Bulletin. The macroscopic and microscopic structures of wood could show distinctive features that would allow identification of the wood (Chunwarin, 1970, Chunwarin and Sri-aran, 1973, Passabutr, 1987, Tonanon, 1996). The information of modern wood is very important for comparison with petrified wood.

Fossils of plant organs and fragments of plants are commonly found but very rarely are whole plants recorded. The past communities of plants are composed of numerous different types of plants but probably merely the durable parts of the arborescent plants or some leaves are preserved. The cells of terrestrial plants have rigid walls of cellulose. Leaves are more commonly preserved than the flesh of animals. After death, the whole trunk of plants buried in sediment and the spaces left inside the cell walls of woody tissue may be replaced by inorganic materials such as finely crystalline quartz, called chert. This filling process, which produces the fossils that are often called petrified wood, is known as permineralisation (Stanley, 1993). In 1934, the very famous study of G.R. Wieland on the petried wood of Bennettitales with recessed and unopened flowers from Karl-Marx-Stadt, which was found two hundred years ago in the vicinity of Wieliczka, Poland, linked the evidence on the history of development of the Bennettitales in the Jurassic and Cretaceous periods (Helms, 1985). The origin of plants in some families such as Fabaceae was studied from the fossils of fruits, leaflets, flowers, and wood. The interpretations of the biogeographic records show that the legume plants first appear in Late Cretaceous (Herendeen, 1992). The plants in Tertiary environments and paleoclimate, including evolution of angiosperms in Southeast Asia and India were reconstructed by using the fossil records from leaves and wood. Grote and Dilcher (1989) described a new genus of Theaceae, *Andrewsiocarpon*, based on fruit and seed remains from the Middle Eocene of southeastern North America.

Francis and Hill (1996) compared the anatomical features of fossil wood and leaves of *Nothofagus beardmorensis* from The Pliocene Sirus Group, Antarctica, to the Recent *Nothofagus beardmorensis* that grows in harsh conditions, at the same latitude as Southeast Asia and India. The result is the fossil and Recent plants have the similar anatomical features, expressing that the fossil plants from Antarctic grew in harsh conditions. From this assumption it could be concluded that the climate of Late Pliocene in the Antarctic was cooler than the Antarctic at the present climate. Wolfe (1978) assumed that vegetation occupying similar climates in different regions have typically the same physical characteristics. The environment tends to select plants that have certain physical aspects for a given climatic type. The present tropical forest has physical characteristics of vegetation similar to those of the tropical forest in the Cenozoic era. The paleoclimates can be reconstructed from the physical aspects of paleovegetation (Tiffney, 1977).

Much petrified wood has been found in every part of the world. Francis (1986) studied fossil wood from the Tertiary of Antarctica, determined to the present angiosperm *Nothofagus*. *Glenrosa nanjingensis* found in the Cretaceous of Nanjing, is believed to have grown near an inland marsh or water body under hot and arid climate (Zhizyan, Thevenard, Barake, and Guignard, 2000).

Edenoxylon arkinsoniaes , Anacardiaceae, was described from Southeast England and Western Scotland (Crawley, 1989).

Petrified wood has been recorded in many parts of Thailand. The petrified wood from the Khorat Group at Nakhon Ratchasima, and Chaiyaphum, Northeast Thailand, and some from Tak and Lamphun Northern Thailand, from the Cretaceous Period, Mesozoic Era, were collected but could not be identified taxonomically (Fossils in Thailand, 1969).

Endo (1964, 1966) studied the Li flora from Lamphun, which contained *Alnus thaiensis* Endo, *Sequoia langsdorfii* (Brongniart) Heer, *Taxodium thaiensis* Endo, *Sparganium thaiensis, Carpinus* sp., *Glyptostrobus europaeus* (Brongniart) Heer, *Fagus feroniae* Ung., *Quercus* cf. *lanceaefolia* Roxb., *Quercus protoglauca* Endo, *Salix* sp. and considered it to be Palaeogene in age.

Pong Basin, Payao, middle Miocene age, provided plants in the families Annonaceae, Menispermaceae, and Leguminosae (Ginsburg, 1989).

The outstanding changes between Late Mesozoic and Early Cenozoic are the disappearance of dinosaurs, flying reptiles, and toothed birds. The rise of early types of mammals and modern types of toothless birds are dominant. The abundance of angiosperms, many genera of trees, shrubs, and grass increased while the populations of the gymnosperm flora decreased. The good preservation of these fossils allows their use in correlating to the climate of that period.

3. Age of the Sites

The study deals with the Cenozoic era, which extends from 65 Ma BP to the Recent and comprises two periods, the Tertiary, aged 65-1.8 Ma BP, and the Quaternary, 1.8-2.5 Ma BP to the present. The Tertiary is recognized as a period that spans most of the time of the Cenozoic era. The Tertiary comprises five epochs, Paleocene, Eocene, Oligocene, Miocene, and Pliocene. The Quaternary contains the Pleistocene epoch (1.8-

2.5 Ma BP to 10,000 years before present), and the Recent or Holocene epoch, the last 10,000 years (Moore, 1949; Stewart and Rothwell, 1993).

Prakash (1979) studied fossil wood collected from Chaiyaphum, northeastern Thailand, and described it as *Pahudioxylon sahnii* which is similar to *Afzelia-Intsia.*

Fossil wood specimens from Tha Chang, Nakhon Ratchasima, attributed to a Lower Pleistocene age , were described as *Terminalioxylon paracoriaceum, Dipterocarus turbinatus,* and *Palmoxylon,* which correspond to a mixed deciduous forest association (Vozenin-Serra and Privé-Gill, 2001). Some fossil wood in Thailand is very similar to that of the fossil wood, *Shorea, Gluta Afzelia-Intsia, Sindora, Albizia,* and *Terminalia*, from the upper Tertiary sediments of Arunachal Pradesh, India.

4. Cenozoic Geology

The Mesozoic Khorat Group of Northeastern Thailand occurs extensively in the Khorat Plateau that extends into central Laos and Northern Cambodia. Nonmarine sedimentary rocks with similar lithologies occur in most of Southeast Asia, from Southern Thailand up to Sichuan, China. A continental fluvial-dominated siliciclastic sedimentation of the Khorat Group took place from the Late Triassic of the Lower Nam Phong Formation to the Early Cretaceous of the Khok Kruat Formation. Further fluvial and eolian siliciclastic deposits continued until during the early Paleocene, Tertiary Period (Mouret, Heggemann, Gouadain, and Krisadasima, 1993). The Quaternary deposits in Mo Din Dang Formation, Khon Kaen, are composed of sequences of eolian and fluvial deposits (Boonsener, 1991). It is possible to find fossils of petrified wood both in Mesozoic and Cenozoic deposits.

In 1983, Chaodumrong et al. (1983) reviewed the Tertiary sediments in the Khorat Plateau into two areas, the Khorat-Ubol basin in the south and Udon-Sakhon Nakhon basin in the north of the plateau. After the stratigraphic study, Chaodumrong and Chaimanii (2002) presented that there are no Tertiary sedimentary basins in the Khorat Plateau. Sinsakul, Chaimanee, and Tiyapirach (2000) clarified the geomorphology, lithology, depositional environments and fossils of the two basin, Khorat basin and Sakon Nakhon basin, of Khorat Plateau to Quaternary period. The Khorat basin is divided into high and low terraces. High terraces are composed of sand and gravel, semiconsolidated with fragments of petrified wood. The sediments of the low terraces consist of gravel set in sand and silt matrix, with a hard pan layer of laterite on the upper part. Chonglakmani (personal communication) aged Tambol Krok Duan Ha, the Nakhon Ratchasima petrified wood studied site, to Miocene because of the preservation of petrified wood in conglomeratic sandstone that is well cemented and deposited in a fluvial channel. The other two sites, in Chaiyaphum and Khon Kaen, are classified as Quaternary sediments by Chonglakmani.

5. Climate

Matumae and Itoh (1996) studied wood remains buried by the pyroclastic flow of Mount Aso, Japan, dominated by *Fagus crenate* and *Quercus mongolia,* typical in the cool temperate zone.

Suzuki and Terada (1996) studied fossil wood from the lower Miocene, Noto Peninsula, Japan, and determined three species of gymnosperms in the familes Taxaceae, Taxodiaceae, and Pinaceae, and 11 species angiosperms, in the families Juglandaceae, Betulaceae, Fagaceae, Ulmaceae, Tetracentraceae, Theaceae, Hamamelidaceae, Rosaceae, Aceraceae, Hippocastanaceae. All of these are plants in the temperate region, which grow in mixed mesic forests of conifer, deciduous dicotyledons and evergreen dicotyledons.

In the Pleistocene, during the ice age, *Picea glauca* survived on the gulf Coastal Plain in the Lower Mississippi Valley and migrated to south Florida and into Mexico of more than 1100 km. (Delcourt and Delcourt, 1996).

Duperon-Laudoueneix, and Duperon, J. (1995) revised the systematics of the Mesozoic and Cenozoic woods from Equatorial and North Equatorial Africa. Many dicotyledonous floras of Africa during the Cenozoic show temperate to tropical floral characteristics.

The Palaeogene flora of Li basin, identified from leaf fossils, consists of temperate plants(Endo, 1966) indicating that the climate of Li basin in the Palaeogen was as cool as the temperate climate.

Silicified wood from Doi Chang, Chiang Mai, dated to 18-19 Ma BP, Miocene age indicates a temperate climate (Ratanasthien, 2002).

6. Wood Preservation

The preservation of the cell wall morphology is petrification. Petrified wood fossils were preserved by infiltration with permineralising fluids of calcite, silica, and iron pyrite and crystallization occurred after infiltration. The first permineralisation filled the cell spaces, then the secondary permineralisation replaced the organic cell walls. When the first permineralisation occurs, leaving only the organic cell walls and finally no organic material is left. Both the organic matter and cell walls are absolutely decayed, and replaced by the second permineralisation. Infiltration is by permineralising fluids with crystallization of the three most common minerals associated with such preservations, calcite, silica, and iron pyrite. This preservation is less informative botanically and more complex to interpret than that of the first permineralisation (Scott and Collinson, 1983).

Silicified wood is permineralised with silica, while calcified wood is permineralised with calcite. The density of silicified wood is higher than that of calcified wood, varying according to the specific gravity of each mineral. The secondary permineralisation effects the quality of the preservation of wood (Jefferson, 1987). The level of underground water is the limiting factor of the perminalisation. A high level of underground water may allow permineralisation better than a low level of underground water.

Timing of perminalisation of wood is uncertain, varying with the environmental factors. Matumae and Itoh (1996) studied wood remains, determined to *Fagus crenate* and *Quercus mongolia*, buried by a pyroclastic flow for 80,000 years ago. The remains disintegrated and are deformed but they are still in the form of wood. Some wood deposited for millions of years is still wood, such as partially permineralised wood collected from the late Pliocene-early Pleistocene (1.8-2.5 Ma BP) in Antarctica, which can be cut with a knife (Francis and Hill, 1996).

Some wood drifted and deposited in the river as some petrified wood is found deposited in sand with pebbles of the old river. Sakala, Catherine, and Jean (1999) collected fossil wood together with many pebbles, distributed in a north-south direction, following the channel, in the Lower Eocene of Paris Pas, and described it as *Grangeonixylon* sp.

Petrified wood exposed to the air can be weathered from precipitation and heat from sunlight.

7. Radiation of Flora in Southeast Asia

Bande and Prakash (1986) compiled the data of Tertiary fossil wood in Southeast Asia and compared them to those in India. It appears that there is the migration of the flora between Southeast Asia and India. The family Araucariaceae, characteristic of the Southern hemisphere flora, Gondwana, is described from the Neogene in Burma (Prakash and Bande, 1986) and is presented in both the Paleogene and Neogene of India. It is possible that the *Araucaria* flora migrated from Gondwana through India via Burma to Thailand. *Araucarioxylon,* which shows affinities to *Agathis*, is also described from Plio-Pleistocene age deposits in Nakhon Ratchasima (Vozenin-Serra and Privé-Gill, 1989c).

Rutschmann, Torsten, and Elena (2003) studied the radiation of Crypteroniaceae by molecular dating. They found that the ancient Gondwanaland is the origin of Crypteroniaceae in the Early to Middle Cretaceous and dispersal occurred via the drifting India plate from Gondwanaland to Southeast Asia.

Fossil wood from Late Cretaceous sediments of the northern Antarctica region was described as *Sassafrasoxylon gottawaldii* of the family Lauraceae. It is the oldest record of a dicotyledonous plant of the family Lauraceae and may suggest that *Sassafras* occurred in Gondwana and radiated into the northern hemisphere (Poole, Richter, and Francis. 2000).

Fossil wood of *Sindora* of the family Leguminosae from the Oligo-Miocene of Saudi Arabia was determined, suggesting it dispersed from Africa to Asia (Privé-Gill, Thomas, and Lebret, 1999).

The radiation of plants is influenced by the fluctuation of the climate and physiological environment. The climate during the Cenozoic era experienced fluctuations, especially, during the Quaternary. The changes between glacial and interglacial intervals of this period are the main factors of the extinction and migration of the flora and fauna. The types and characters of the fossils could provide the evidence for this era (Moore, 1949).

CHAPTER II

MATERIALS AND METHODS

Fossils in the Korat Plateau, northeastern part of Thailand were surveyed and many specimens of petrified wood were found. Three provinces, Nakhon Ratchasima, Chaiyaphum, and Khon Kaen, were selected for the study of the fossil wood specimens. The selected localities are Tambol Khok Kruad, Amphoe Muang, Nakhon Ratchasima ; Ban Non Saad, Amphoe Khon Sawan, Chaiyaphum; Ban Kan Pradoo, Amphoe Phra Yuen, Khonkaen.

The fossil specimens were found both *in situ* and *ex situ*; the petrified wood in Tombol Khok Kruad, Amphoe Muang, Nakhon Ratchasima were found in the deforested area along the road. Because of road construction, some pits were dug and a lot of small broken pieces of petrified wood was present. There has been soil erosion in the deforested area, sweeping away the surface soil, and the local people find trunks of petrified wood. From the three locations, Tombol Khok Kruad, Amphoe Muang, Nakhon Ratchasima is the most deforested area; Ban Non Saad, Amphoe Khon Sawan, Chaiyaphum; and Ban Kan Pradoo, Amphoe Phra Yuen, Khon Khan, are commercial sand pits. Some petrified wood was dug up from the pits but there is some still remaining in the pits.

The petrified wood consist of large branches or trunk materials. Small pieces were broken from large trunks for study. Some wood was naturally broken in to small pieces, however. Phloem or bark was not present. From the outside, most specimens appeared well preserved, especially from Ban Khok Kruad, Nakhon Ratchasima. The poorly preserved specimens are the specimens from Ban Non Saad, Amphoe Khon Sawan, Chaiyaphum, for the specimens were not well permineralised and after fossilization, they were exposed to sunlight and high humidity for a long time, causing the outer part of the specimens to deteriorate. The small broken pieces of petrified wood were found on ground because of the erosion, the plant material probably entered a river channel and drifted into a river as driftwood before becoming waterlogged and sinking into the sediment. None of the wood specimens has evidence of boring by bivalves and therefore suggests a limited time for transportation. The specimens are silicified wood with petrifaction likely to have occurred while the sediment and wood was waterlogged. The only possible source of the silica, in the absence of volcanic ash, is thought to be from the diagenesis of clay minerals (Leopold and Barghoon, 1976, in Poole, and Davies, 2001). The collected specimens are deposited at the Center for Scientific Equipment, Suranaree University of Technology. Nakhon Ratchasima.

In initial studies, fossil petrified wood was prepared for and studied with a scanning electron microscope, JEOL JSM6400, operated at 5 KV by cutting petrified wood into small pieces, demineralization in 50% hydrofluoric acid for 30 seconds, thorough rinsing, and drying. Cleaned specimen were mounted on a SEM stub with Epoxy glue and coated with carbon or gold. The cellular detail from numerous magnified images showed very fine details more than the overall-view details for identification of specimens. The 10 to 400 times magnified details from SEM are more or less equal to the detail under a compound microscope, but use of SEM is more costly and requires a lot of time compared to work on a compound microscope.

On the other hand, study with a compound microscope permits use of specimens with larger size than the specimens on SEM stub and gives more continuous details than the study with SEM. Because of this, further SEM study was not continued.

Thin sections of silicified wood specimens were prepared to allow for examination of three dimensions using transverse, radial longitudinal, and tangential longitudinal sections. Cutting the large-sized specimen into a small cube was done with the heavy-duty commercial 24 inchs slab saw resulting in pieces not larger than the size of microscopic glass slide. After that, the studied surface of a specimen was properly polished with sand polisher, using silicon carbide grit sandpaper number 180, 320, 400, 600, and 1000, respectively. The specimens were repeatedly polished with carborandum alumina polishing powder of 0.3 and 0.05 μm respectively, to make the surface smooth without the scar of polishing by observing under a 10x hand-lens. The well-polished specimen surface was mounted on a microscope slide using Epox Fix glue and left for at least 48 hours until firmly fixed. Then the excess of the cubic specimen on the microscope slide was cut off using an Ingram Thin Section Cut-Off Saw Model 137U, leaving the sample on the microscope slide as thin as possible, about 1 mm. The last step was to gently grind the mounted specimen on the microscope slide with an Ingram Thin Section Grinder Model 400U until the sample was about 10 μm thick (Meylan and Butterfield, 1972, Stout and Spackman, 1987 Pasabutr, 1987). Prepared specimens were used for microscopic study. The above preparation of specimens for SEM study and thin sectioning was carried out at the Center for Scientific Equipment, Suranaree University of Technology.

Recent and fossil wood was studied to compare anatomical details. Recent wood specimens were studied at the Wood Herbarium, Royal Forestry Department, Bangkok. Collected woods from Arboretum and Herbarium, Queen Sirikit Botanic Garden, The Organization of Botanical Garden, Chiang Mai, were also studied.

The Recent wood specimens were prepared for microscopic study. The specimens were cut into three one-centimeter cubes with a wood saw, then boiled in a waterbath at 80°C for at least 8 hours until they became soft enough to make thin sections. The specimens were cut with a sliding microtome into sections about 10 µm thick. The specimens were stained with 1 % saffranin solution and dried on a dryer plate at 35°C overnight, fixed on micropscope slides with Permount and mounted with coverslips (Cutler and Gregory, 1998). Petrified wood and Recent wood were analyzed for macroscopic anatomical details with a 10x-hand lens and microscopic anatomical details with a Nikon compound microscope, photographed with a digital Nikon camera and a Nikon SLR camera attached to a compound microscope. The PAN Kodak Black and White films and Kodak 35 mm Color films were used for photograph.

The selected fossil localities in Northeast of Thailand are

1. Wat Krok Duen Ha, Tambol Khok Kruad, Amphoe Muang, Nakhon Ratchasima. N 14° 50’ 18”, S 102° 01’ 45”: (SUT locality 29).
2. Road side, Tambol Khok Kruad, Amphoe Muang, Nakhon Ratchasima. N 14° 51’ 31”, S 102° 01’ 38”: (SUT locality 28).
3. Ban Non Saad, Amphoe Khon Sawan, Chaiyaphum. N 15° 48’ 43”, S102° 13’ 25”: (SUT locality 5).

4. Ban Kok Saad , Amphoe Khon Sawan, Chaiyaphum. N 15° 50’ 40” , S 102° 14’ 45”: (SUT locality 6).
5. Ban Kan Pradoo1, Amphoe Phra Yuen, Khonkaen. N 16° 18’ 02”, S 102° 36’ 00”: (SUT locality 7).
6. Ban Kan Pradoo 2, Amphoe Phra Yuen, Khonkaen. N 16° 18’ 01”, S 102° 36’ 01”: (SUT locality 8).

Figure 2.1 A piece of petrified wood embedded in a conglomerate, Tambol KokKruad, Amphoe Muang, Nakhon Ratchasima.

Figure 2.2 Petrified wood found on the ground at Tambol Kok Kruad, Amphoe Muang, Nakhon Ratchasima.

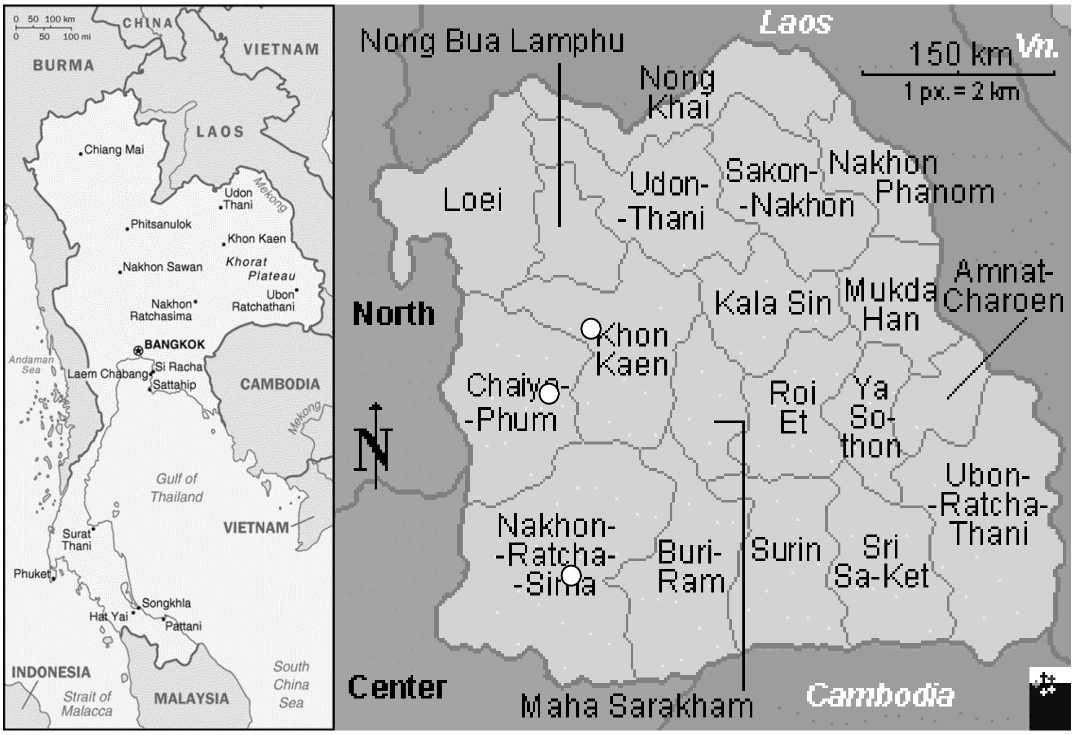


Figure 2.3 The localities of study sites in Tambol Khok Kruad, Amphoe Muang, Nakhon Ratchasima, Ban Non Saad, Amphoe Khon Sawan, Chaiyaphum, and Ban Kan Pradoo1, Amphoe Phra Yuen, Khonkaen.

CHAPTER III

SYSTEMATICS OF WOOD ANATOMY

Selected specimens from 5 locations of Chaiyaphum, Khon Kaen and Nakhon Ratchasima provinces were studied. The specimens are identified to the following taxa :

Family Flacourtiaceae

Homalium tomentosum (Vent.)Benth.

Family Lecythidaceae

Careya sphaerica Roxb.

Family Fabaceae

Mimosoideae

- *Albizia lebbeck* Benth.

Caesalpinoideae

- *Pahudioxylon sahnii* Ghosh and Kazmii
- *Dialium cochinchinense* Pierre

Papilionoideae

- *Millettia leucantha* Kurz

Family Sonneratiaceae

Duabanga grandiflora (Roxb. ex DC.) Walp.

Family Thymelaeaceae

Aquilaria sp.

Family Combretaceae

- *Anogeissus acuminata* (Roxb. ex DC.) Guill. & Perr.
- *Terminalia alata* Heyne ex Roth

Family Burseraceae

Protium serratum (Colebr.) Engl.

Family Anacadiaceae

Dracontomelon dao (Blanco) Merr.& Rolfe

Family Apocynaceae

- *Holarrhena pubescens* Wall. ex G. Don.
- *Wrightia arborea* (Dennst.) Mabberley

Family Arecaceae

Palmoxylon sp. 1

Palmoxylon sp. 2

Palmoxylon sp. 3

Palmoxylon sp. 4

Flacourtiaceae

Homalium Jacq.

Enum. Syst. Pl.: 5, 24 (1760)

Homalium tomentosum (Vent.) Benth.

Jour. Linn. Soc., Bot. 4: 34 (1860)

Diagnosis

Growth rings not clear. Wood diffuse porous. Vessels small to medium (tangential diameter 90 to 110 μm), diameter regular, not visible to the naked eye, frequently solitary as well as in radial multiples of 2 to 3 rarely 4, with 11-13 vessels per mm^2; frequently touch one side of rays, vessel elements short to moderate, 120 to 400 μm long with simple perforation plates.

Axial parenchyma obsucured.

Tyloses scarcely

Xylem rays very fine and numerous, mainly biseriate, occasionally triseriate, scarcely uniseriate 200 to 1250 μm average 800 μm high in tangential section, 12-13 per horizontal mm, heterocellular Krib type I, with procumbent and upright cells, occasionally Krib type II, non-storied.

Fibers are libriform, non-septate.

Locality: SUT loc.28

Specimen Number: SUT 337

<u>Wood Anatomy</u>

<u>Microscopic Characters</u>

Growth ring not clear.

Vessels: Small to mdedium, pores shape elliptic to obovate, usually regular, mostly uniform in size, few, frequently solitary, as well as multiple pores, 2 in group, rarely 3 in group, the tangential diameters 90-110 µm, and radial diameters 160-240 µm simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 200 x 100 µm, 250 x 160 µm

Pore group of three: 80 x 100 µm, 100 x 110 µm, 110 x 110 µm

Vessel abundance 11-13 per mm^2, percentage of solitary pores 26.7%, and multiple pores 73.3%. Vessel elements are short to moderate, 120-400 µm long. Pit ovate, 4 µm in diameter.

Perforation plates simple but occasionally obscured by tyloses. Intervessel pits alternate, mostly polygonal.

Parenchyma: very sparse, diffuse scanty apotracheal parenchyma, distribute as rare cells in fibrous tissue.

Xylem rays abundant, mostly biseriate, occasionally triseriate, and seldom uniseriate, very high rays 200-1250 µm, 30-50 µm wide. Multiseriate rays have very long uniseriate portion, composed of upright cells. Multiseriate portion composed of both procumbent and up right cells (Krib heterocellular type I), occasionally Krib type II.

Fibers non-septate, libriform.

Affinities

The important characters of the fossil are vessels small to medium sized, multiple pores more than solitary pores, intervessel pits alternate, axial parenchyma very sparse, rarely diffuse scanty, non-storied arrangement of ray parenchyma, rays mainly biseriate occasionally triseriate and uniseriate, heterocellular Krib type I, occasionally Krib type II, and libriform or non-septate fibers. These features indicate its affinities with the wood of *Homalium* Jacq. (Lemmens, Soerianegara, and Wong, 1995). The vessels of *Homalium* are mostly small as well as vessels in wood of the family Annonaceae and some genera of Apocynaceae. The significant feature of plant in the family Flacourtiaceae is parenchyma being absent or rarely sparse. The axial parenchyma of Annonaceae is mostly abundant, while *Alstonia,* and *Holarrhena* of Apocynaceae lack of parenchyma but have intervessel pits that are scalariform (Chunwarin, 1970). (see Appendices A, Appendices B, Table 2). Intervessels pits are also scalariform in *Hydnocarpus* of Flacourtiaceae.

Homalium damrongianum Craib has wood with multiseriate rays of 3-4, and pore sized, tangential diameter of about 150 µm. These characteristics of both rays and vessels are not similar to these of the fossil specimen. Rays of *H. foetidum* are higher than those in the fossil specimen.

The pore density of the specimen, 11-13 vessels per mm^2, is less than that of *H. tomentosum,* which has about 18-30 vessels per mm^2 (Chunwarin and Sri-Aran, 1970). There is no previous record about fossil woods in this family in Southeast Asia.

The specimen shares the same characters with modern wood of *Homalium tomentosum* (Vent.) Benth.,except the density of vessels. In my opinion, this fossil specimen should be placed in the extant species *Homalium tomentosum* (Vent.) Benth., it does not need to have a new name.

Figure 3.1 Transverse section, tangential section, and radial section of fossil wood of *Homalium tomentosum* (Vent.)Benth.

Lecythidaceae

Careya Roxb.

Pl. Coromandel 3: 13, t.218 (1811)

Careya sphaerica Roxb.

Pl. Coromandel 3: 13, t.218 (1811)

Diagnosis

Growth rings not clear. Wood diffuse porous. Vessels small to medium (tangential diameter 130 to 230 μm), diameter regular, visible to the naked eye, mostly solitary, occasionally arranged in multiple pores of 2 to 3, with 3-4 vessels per mm^2; vessel elements moderate, 240 to 700 μm long with simple perforation plates.

Axial parenchyma scanty, both paratrachael and apotracheal, occurring as a few cells enclosing the vessel; apotracheal parenchyma diffuse and distributed as occasional solitary parenchyma or in fibrous tissue.

Tyloses present.

Xylem rays large and numerous, mainly 3-5 seriate, 300 to 1400 μm high in tangential section, 8-12 per horizontal mm, occasionally uniseriate or biseriate rays, homocellular or heterocellular with procumbent cells, or procumbent and upright cells. Non-storied rays.

Fibers are libriform, non-septate.

Resin canals present, diameters average 90 μm.

Locality: SUT Loc. 29

Specimen number: SUT 330

Wood Anatomy

Microscopic Characters

Growth ring not distinct.

Vessels: Pores shape round, oval to obovate, usually regular, mostly uniform in size, some smaller vessels very few, mostly solitary, occasionally multiple pores, 2 in group, rarely 3 in group, not tangential pairs or cluster, the tangential diameters 130-230 µm, and radial diameters 160-290 µm simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 200 x 220 µm, 200 x 200 µm

Pore group of three: 240 x 210 µm, 300 x 210 µm, 300 x 160 µm

Vessel abundance 3-4 per mm^2, percentage of solitary pores 97%, and multiple pores 3%. Vessel elements are short to moderate, 240-700 µm long.

Perforation plates simple but occasionally obscured by tyloses.

Parenchyma: axial parenchyma scarcely, mainly vasicentric, forming a 1-3 cell sheet, width of bands is greater closer to vessels than further away from them, apotracheal parenchyma, sparsely diffuse as solitary cells or in fibrous tissue.

Xylem ray very high, mostly 3-5 seriate, scarcely uniseriate or biseriate, 300–1400 µm high, average 1000 µm, 50-60 µm wide, non-storied, mostly heterocellular, composed of both upright and procumbent cells.

Fibers non-septate, libriform

Affinities

The important characters of the fossil, are as follows: vessels small to medium sized, mostly medium solitary vessels, oval, tylosed in simple perforation, axial parenchyma mainly scanty paratracheal parenchyma, diffuse apotracheal parenchyma, non- storied arrangement of ray parenchyma, rays mainly 3-5 seriate occasionally 1,2 seriate, homocellular or heterocellular and libriform or non-septate fibers. These features indicate its affinities with the wood of the families Apocynaceae, Dipterocarpaceae and Lecythidaceae. The genera of Dipterocarpaceae have high and long xylem rays but differ from the fossil specimens in having wide band resin canals. In the family Apocynaceae, the genera *Alstonia* and *Holarrhena* show some similarity in having scanty paratracheal parenchyma (see Appendices B, Table 2), but these also differ from the fossil specimen in having shorter xylem rays.

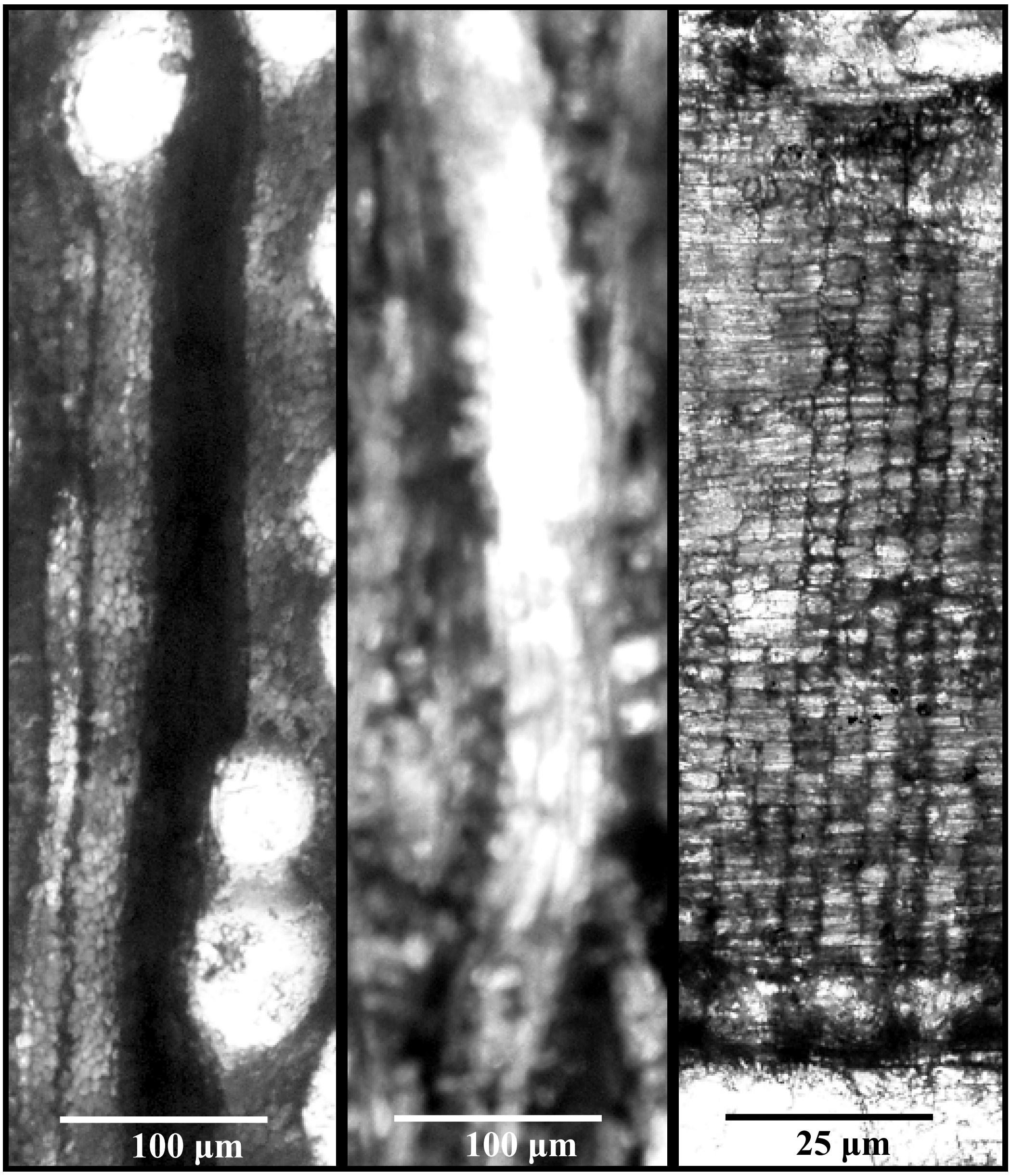
The genera *Barringtonia* and *Careya* of the family Lecythidaceae show the closest affinity to the fossil specimen. *Barringtonia* differs in having aliform confluent paratracheal parenchyma always present and having xylem rays up to 4 mm high. (Prakash, and Dayal, 1964, see Appendices B, Table 6) .

The similarity of the fossil specimen in shape, the pattern of distribution of vessels, perforation plates, axial parenchyma and xylem rays shows the affinity to *Careya* under *Careya sphaerica* Roxb.

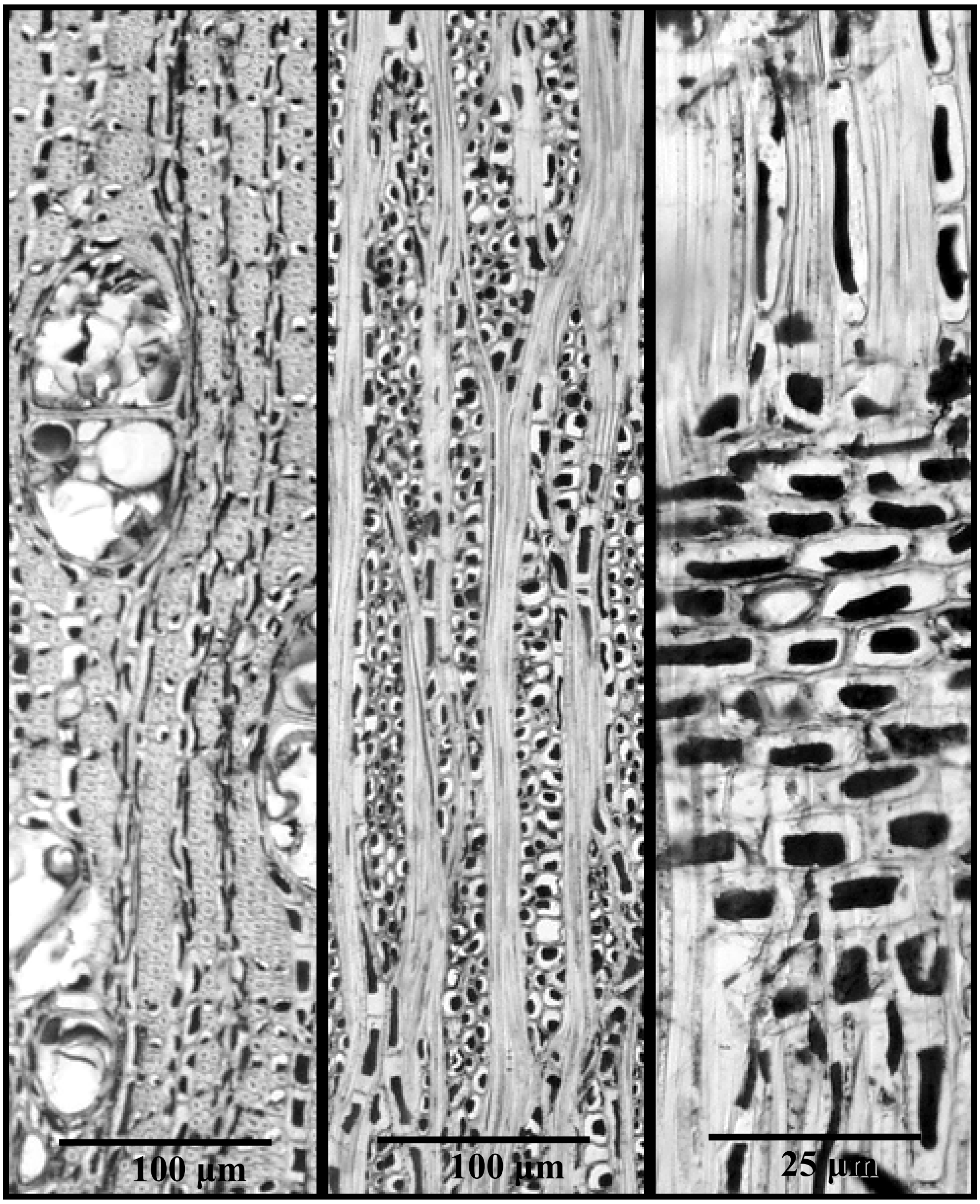
Some Tertiary fossil woods were identified to have the similarity to *C. arborea. Careyoxylon pandicherriense* from South India has indistinct growth rings, small vessels, 60-250 µm tangential diameter, 1-4 radial in width, closed to the fossil specimen . Prakash and Tripathi (1970) described a new species, *Careyoxylon kuchilense*, from Tertiary of Assam sediments, showing characters close to those of

Careya sphaerica, but differing in having growth rings. In both *Careyoxylon* species, short radial rows of 2-3 vessels are abundant. The fossil specimen differs in having mostly solitary vessels. Prakash (1979) studied fossil woods from the northeast of Thailand and suggested that one species was most similar to *Careya sphaerica*, but differed in having homogeneous xylem rays and proposed it as *Dryoxylon siamensis*, waiting for the next investigation.

In my opinion, this fossil should be placed in the extant species *Careya sphaerica* Roxb. because it shares the same characters with the modern wood even though there are some variation. It does not need to have a new name and hence it is placed in the extant species.



Figuer 3.2 Transverse section, tangential section, and radial section of fossil wood *Careya sphaerica* Roxb.



Figuer 3.3 Transverse section, tangential section, and radial section of *Careya sphaerica* Roxb.

Fabaceae

Mimosoideae

Albizia Durazz

Mag. Tosc. 3: 11

Albizia lebbeck (L.) Benth.

Diagnosis

Growth rings not clear. Wood diffuse porous. Vessels medium to small (tangential diameter 140 to 240 μm), diameter regular, visible to the naked eye, mostly solitary, occasionally arranged in multiple pores of 2 to 3, 4, with 2-3 vessels per mm^2; vessel elements moderate, 240 to 700 μm long with simple perforation plates.

Axial parenchyma abundant, both paratrachael and apotracheal, mostly vasicentric abundant to confluent, encircling vessels on both sides and occasionally extending as lateral projections across the ray and joining the other vessels. Apotracheal parenchyma is sparse and distributed as occasional cells in fibrous tissue.

Tyloses present.

Xylem rays fine and numerous, mainly triseriate, occasionally biseriate, 170 to 320 μm in tangential section, 17-22 cells in vertical row, 3–5 per horizontal mm, heterocellular with procumbent cells, storied.

Fibers are libriform, non-septate.

Locality: SUT loc. 5

Specimen numbers: SUT 301, SUT 307

Wood Anatomy

Microscopic characters

Growth rings not distinct.

Vessels: Pores shape round, oval to obovate, usually regular, mostly uniform in size, smaller vessels very few, frequently solitary, occasionally multiple pores, 2 in group, rarely 3 in a group, rarely in tangential pairs or clusters, the tangential diameters 140-240 µm, and radial diameters 160-300 µm simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 90 x 140 µm, 200 x 240 µm

Pore group of three: 70 x 160 µm, 60 x 200 µm, 160 x 210 µm

Pore group of four: 130 x 150 µm, 140 x 190 µm, 200 x 200 µm, 260 x 200 µm

Vessel abundance 2-3 per mm^2, percentage of solitary pores 82.1%, and multiple pores 17.9%. Vessel elements are short to moderate, 240-700 µm long.

Perforation plates simple but occasionally obscured by tyloses.

Parenchyma: axial parenchyma abundant, mainly vasicentric abundant, forming 4-5 cell sheet, occasionally aliform to confluent paratracheal parenchtyma, encircling the vessels, occasionally extending as lateral projections and joining the adjacent vessels, apotracheal parenchyma sparse and distributed as occasional cells in fibrous tissue.

Xylem rays mostly biseriate, 200– 430 µm high, 7-20 cells high, 40 µm wide, occasionally triseriate rays, 240-320 µm high, 9-19 cells high, 60 µm wide, storied, mostly homocellular with procumbent cells but sometimes marginal cells twice as high as body cells, composed of both upright and procumbent cells.

Fibers non-septate, libriform

Affinities

The important characters of the fossil are vessels small to medium sized, axial parenchyma mainly vasicentric abundant, occasionally aliform to confluent, ripple marks present due to storied arrangement of ray parenchyma, rays mainly biseriate, occasionally triseriate, homocellular and libriform or non-septate fibers. These features indicate its affinities with the wood of *Albizia* Durazz (Sosef, Hong, and Pawirohatmodjo, 1998, Pearson and Brown, 1932a). Among various species of Albizia examined, *Albizia acle* is distinct in having ray parenchyma mainly uniseriate. *Albizia ferruginea, A. carrii, A. gummifera, A. toona,* and *A. xantoxylon* are distinct in having parenchyma mainly aliform paratrachael. *Albizia odoratisima* is distinct in having small vessels, frequently vessel grouped in an aggregate (see Appendices A, Appendices B, Table7). The anatomical features of this fossil specimen show the most resemblance with *Albizia lebbeck* Benth.

Indian paleobotanists have investigated many specimens of fossil woods from India and Burma, Prakash placed fossil wood showing affinity to *Albizia* under *Albizinium* Prakash (Awasthi and Mehrotra, 1997). Fossil wood similar to *Albizia lebbeck* from Burma was studied and named *Albizinium eolebbekianum* Prakash (Prakash and Bande, 1980) (see Appendices C, Table 11). Vozenin-Serra and Privé-Gill (1989c) likewise placed wood similar to *Albizia lebbeck* from Thailand in *Albizinium eolebbeckianum.* On the other hand, Awasthi and Mehrotra (1997) identified fossil wood from India similar to *Albizia lebbeck* as *Albizinium* *pondicherriense* Awasthi. In my opinion, this fossil should be placed in the extant species *Albizia lebbeck* Benth., because the fossil wood share the same characters with the modern wood. It does not need to have a new name and hence it is placed in the extant species.

Figure 3.4 Transverse section, tangential section, and radial section of fossil wood of *Albizia lebbeck* (L.) Benth.

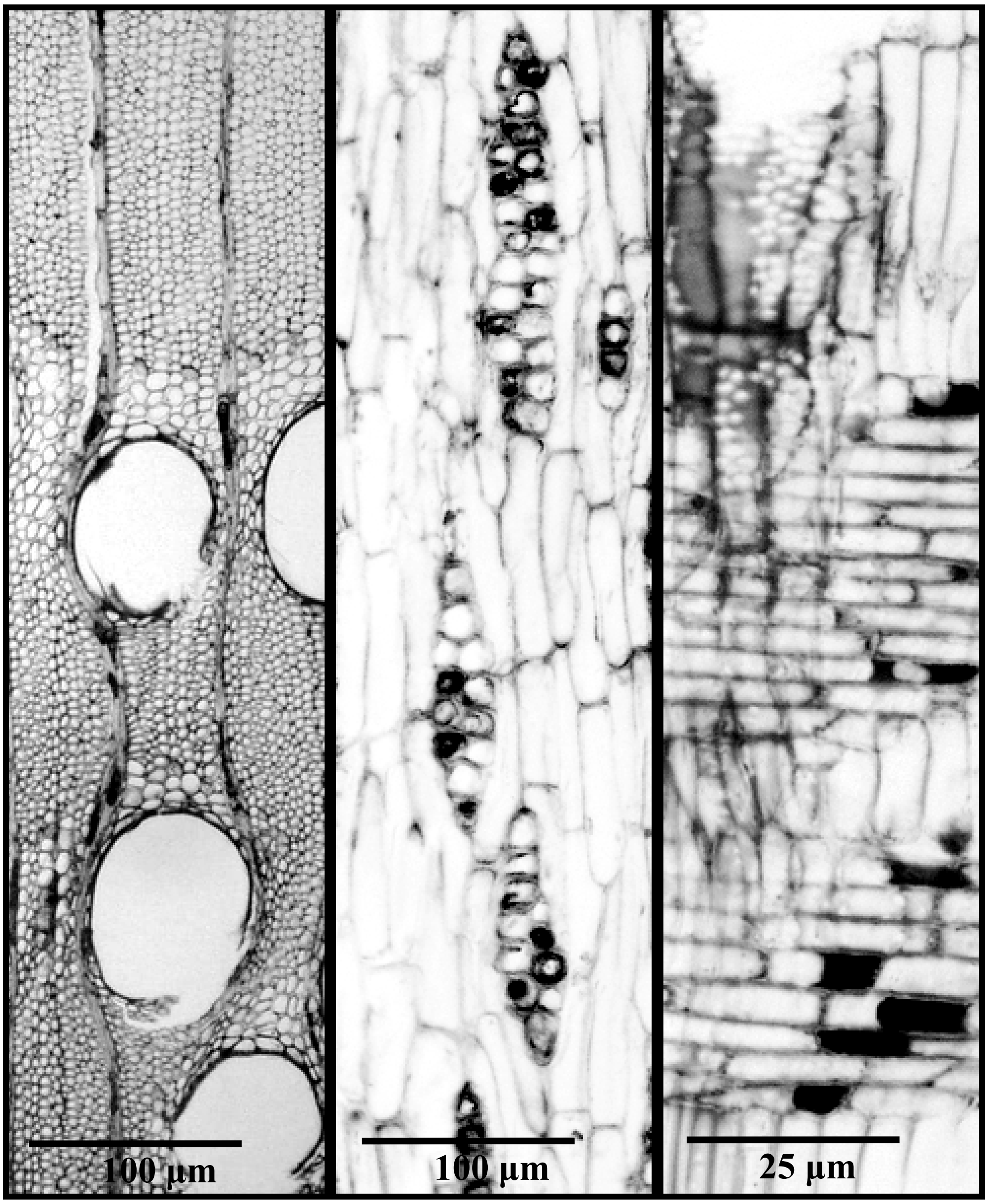


Figure 3.5 Transverse section, tangential section, and radial section of *Albizia lebbeck* (L.) Benth.

Fabaceae

Caesalpinioideae

Pahudioxylon Chowdhury

Pahudioxylon sahnii Ghosh and Kazmii (1961)

Diagnosis

Growth rings clear. Wood diffuse porous. Vessels medium to small (tangential diameter 75 to 330 µm), diameter regular, visible to the naked eye, mostly solitary, sometimes arranged in multiple pores of 2 to 3, occasionally 4, 5, with 1.5-2.5 vessels per mm^2; vessel elements long, 120-1250 µm long with simple perforation plates.

Axial parenchyma abundant, both paratrachael and apotracheal, mostly winged aliform to confluent, completely surrounding vessels and occasionally extending as lateral projections across the ray and joining the other vessels. Apotracheal parenchyma is scanty and found in groups.

Tyloses present.

Xylem rays fine and numerous, mainly biseriate, occasionally triseriate, 200-300 µm in tangential section, 10-22 cells in vertical row, 7-9 per horizontal mm, heterocellular with procumbent cells, non-storied.

Fibers are libriform, non-septate.

Locality: SUT loc. 7, SUT loc. 28

Specimen numbers: SUT 314, SUT 338

Wood Anatomy

Microscopic Characters

Growth rings distinct due to vessels being marked by a difference in vessel frequency.

Vessels: Pores shape round, oval to obovate, usually regular, wider in early wood, narrow in late wood, usually absent in the inner part of the growth rings. frequently solitary, occasionally multiple pores, 2, 3 in a group, rarely 4, 5 in a group, the tangential diameters 75-330 µm, and radial diameters 80-450 µm; simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 120 x 125 µm, 100 x 120 µm

Pore group of three: 180 x 200 µm, 180 x 110 µm, 190 x 180 µm

Pore group of four: 130 x 150 µm, 140 x 190 µm, 200 x 200 µm, 260 x 200 µm

Vessels abundance 3-4 per mm^2, percentage of solitary pores 93.2%, and multiple pores 6.8%. Vessel elements are short to moderate, 120-1250 µm long.

Perforation plates simple but occasionally obscured by tyloses.

Parenchyma: axial parenchyma abundant, mainly aliform, forming a 3-4 cell sheets, occasionally confluent paratracheal parenchyma, encircling the vessels, and extending as lateral projections forming bands of 2-5 cells wide across the rays and joining the adjacent vessels, scanty apotracheal parenchyma found in groups.

Xylem rays mostly biseriate, 200-380 µm high, 7-17 cells high, 30-50 µm wide, average 40 µm, occasionally triseriate rays, 240-450 µm high, 13-22 cells high, 60 μm wide, non-storied, or sometimes show obscured storied, mostly heterocellular with procumbent cells and square cells.

Fibers non-septate, libriform.

Affinities

The important characters of the fossil, are growth rings distinct, vessels medium to small sized, axial parenchyma mainly aliform to confluent, obscured storied arrangement of ray parenchyma, rays mainly biseriate occasionally triseriate, homocellular and libriform or non-septate fibers. These features indicate its affinities with the wood of *Afzelia* and *Intsia* of the subfamily Caesalpinioideae, family Fabaceae.

Pahudioxylon is defined to include fossil wood of *Afzelia-Intsia*, comprised of 13-18 species (Mehrota, Awasthi, and Dutla, 1999, Vozenin-Serra and Privé-Gill, 1989c, 1989c). The minor variations of the specimens are considered to establish the species. Comparing the fossil specimen to these species, the most resemblance is with *Pahudioxylon sahnii* Ghosh & Kazmi, 1961. Anyway, the significant characters of the fossil show resemblance to not only *Afzelia xylocarpa* (Kurz) Craib but also to *Intsia palembanica* Miq. The two genera of *Afzelia* and *Intsia* are impossible when using sterile materials to be distinguish them from each other (Chunwarie and Sriaran, 1974; Soerianegara and Lemmens, 1994).

Vozenin-Serra and Privé-Grill (1989c, 2001) studied fossil wood from Tha Chang, Nakhon Ratchasima, and named fossil wood-like *Afzilia* to *Pahudioxylon sahnii* as well as Prakash (1979) studied fossil wood of *Pahudioxylon sahnii* from northeastern Thailand (see Appendices B, Table 7, Appendices C, Table 12).

In my opinion, this fossil wood should be placed in *Pahudioxylon sahnii* Ghosh and Kazmii (1961) for this species is the first established and has the very close affinities to this fossil wood (Prakash, 1979).

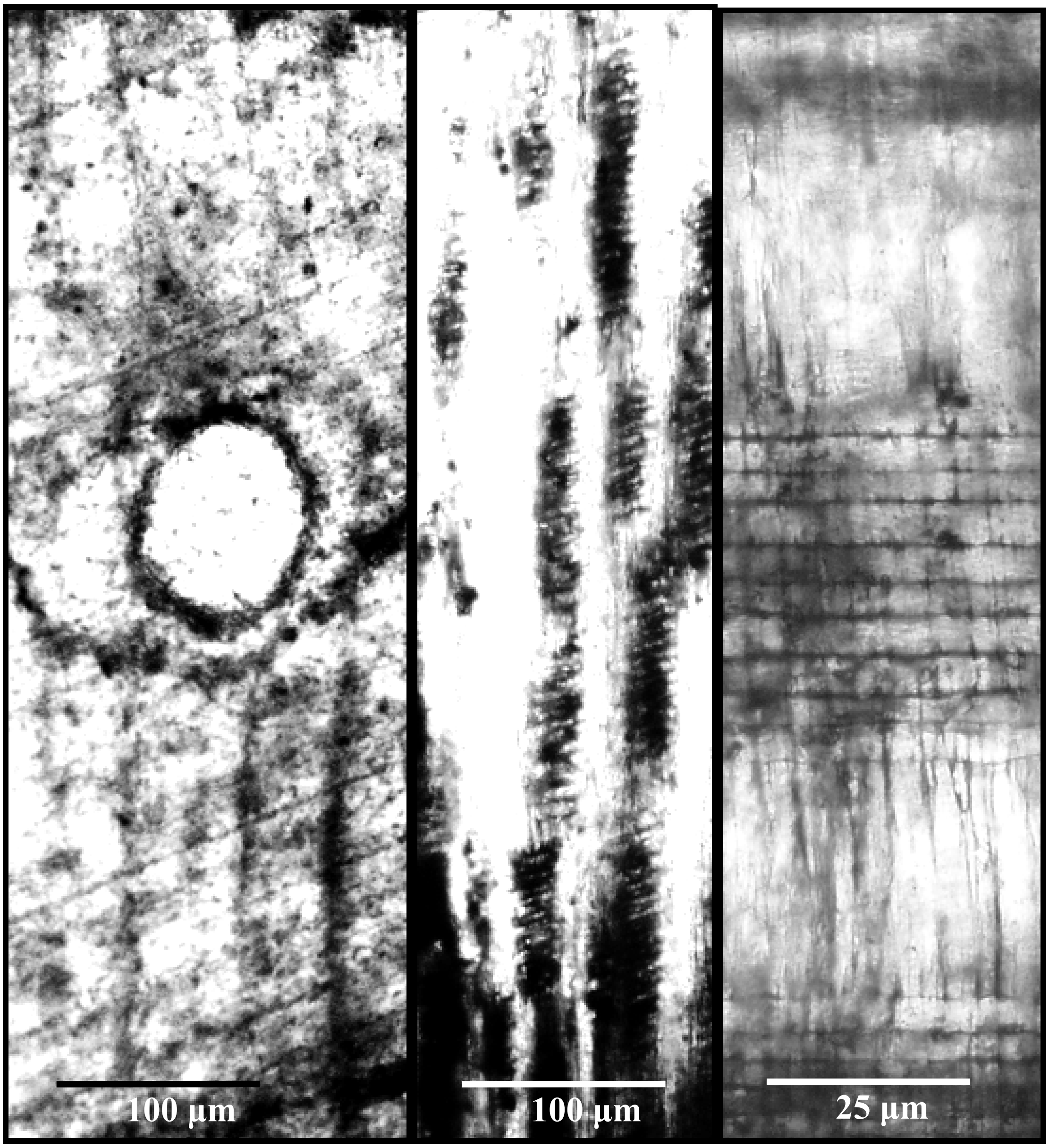


Figure 3.6 Transverse section, tangential section, and radial section of *Pahudioxylon sahnii* Ghosh and Kazmii

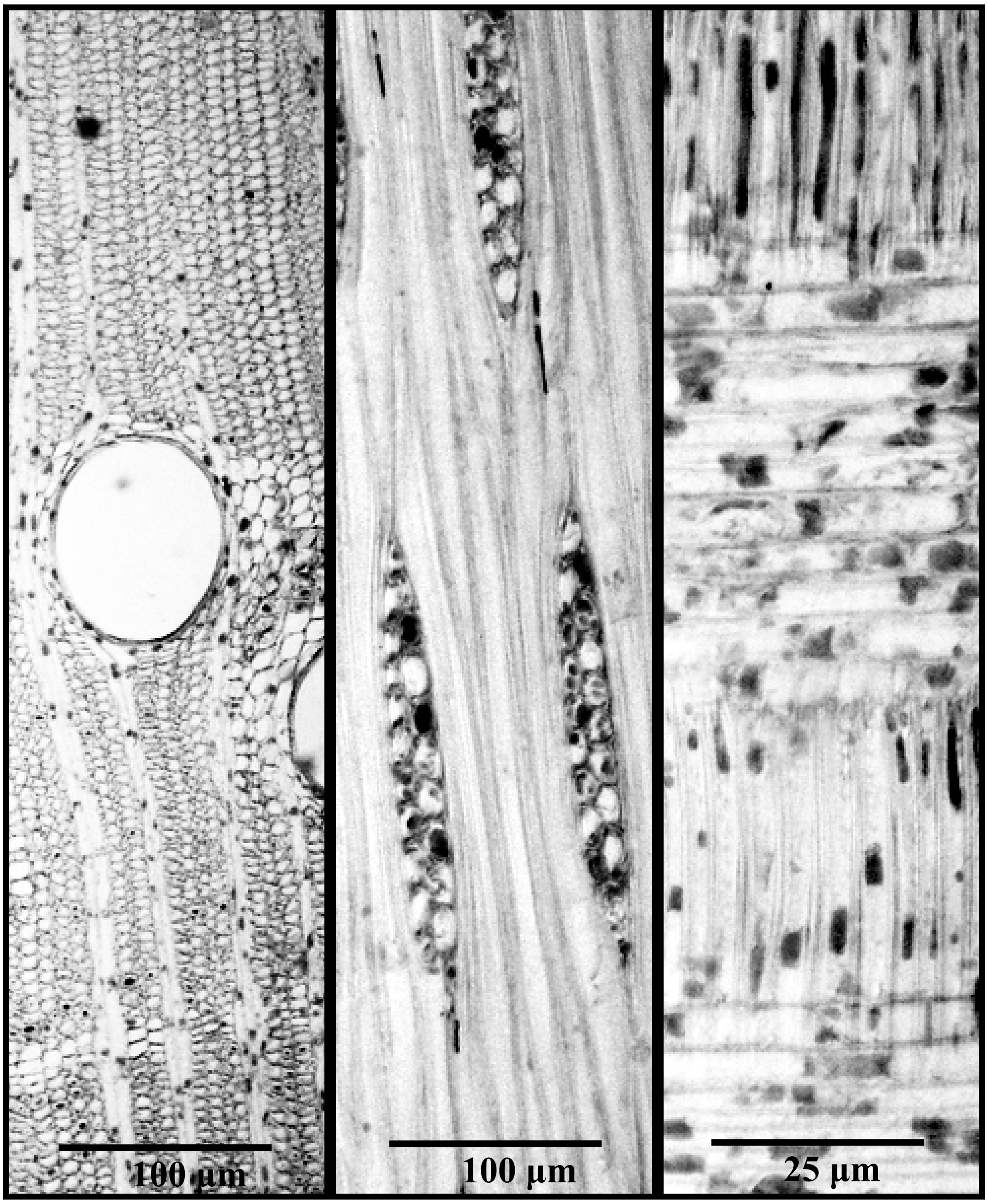


Figure 3.7 Transverse section, tangential section, and radial section of *Afzelia xylocarpa* Roxb.

Fabaceae

Caesalpinioideae

Dialium L.

Mant. Pl.(Syst. Nat.ed. 12, Vol.2): 3 (1767)

Dialium cochinchinense Pierre

Fl forest. Cochinch. fasc. 24: pl. 384A (1898)

Diagnosis

Growth rings: not distinct. Wood diffuse porous. Vessels medium to small (tangential diameter 120-180 μm), diameter regular, not visible to the naked eye, mostly solitary arranged obliquely, occasionally arranged in radial multiples of 2-3, with 2-3 vessels per mm^2; vessel elements short, 120-250 μm long with simple perforation plates.

Axial parenchyma apotracheal, banded usually one side of the band touching the vessels, bands usually 5-6 cells wide.

Tyloses present.

Xylem rays biseriate, occasionally triseriate, 150-250 μm high in tangential section, 5–7 per horizontal mm, homocellular with procumbent cells, fine and numerous, the length of ray cells about 10 cells per mm in horizontal.

Fibers libriform, non-septate.

Locality: SUT loc. 28

Specimen number: SUT 336

Wood Anatomy

Microscopic Characters

Growth rings: not distinct.

Vessels: Pores shape round to oval or elliptical but usually irregular, mostly uniform in size, frequently solitary, occasionally multiple pores, 2-3 in a group, rarely 4 – 5 in a group; tangential diameters 120-180 µm, and radial diameters 150-280 µm

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 140 x 140 µm, 150 x 160 µm

Pore group of three: 120 x 120 µm, 120 x 140 µm, 120 x 120 µm

Vessels abundance 2-3 per mm^2; percentage of solitary pores 90.0%, and multiple pores 10%. Vessel elements short to moderate, 120-250 µm long. Perforation plates simple but occasionally obscured by tyloses.

Parenchyma: axial parenchyma abundant, mainly apotracheal, wide-banded, bands usually 5-6 cells wide, continuous and regularly spaced from each other, 3-4 bands per radial mm, paratracheal parenchyma mostly narrow vasicentric, encircling the vessels mostly 1-3 cells wide. Small silica bodies deposit in axial parenchyma cells.

Xylem rays: rays are mostly biseriate, 200–430 µm high, 7-20 cells high, 40 µm wide, occasionally triseriate rays, 240-320 µm high, 9-19 cells high, 60 µm wide, storied, essentially homocellular with procumbent cells but sometimes marginal cells twice as high as body cells.

<u>Affinities</u>

The rays of the fossil specimens are storied and fibers are libriform, indicating possible affinity with the following possible tropical species:

Caesalpiniodeae:	*Albizia, Bauhinia, Caesalpinia, Cassia, Dialium, Koompassia*,
Mimosoideae:	*Parkia*
Papilionoideae:	*Millettia, Dalbergia, Pterocarpus*
Meliaceae:	*Cedrela, Swietenia, Xylocarp*us
Rutaceae:	*Chloroxylon*
Sapindaceae:	*Sapindus*
Sterculiaceae	*Kleinhovia*
Tiliaceae:	*Christiania, Nesogordonia, Pentace* (Carlquist, 1988)

The difference between wood with growth and without growth rings is used to group these genera.

The wood with growth rings is present in *Chloroxylon, Kleinhovia* (Ilec, 1991), *Millettia*, *Cedrela, Sapindus* (Chunwarin and Sri-aran, 1974, Bande, 1981), *Swietenia* (Soerianegara and Lemmens, 1994), *Sapindus* (Ilec, 1991, Poole and Wilkinson, 1992).

The wood without growth rings can be grouped as to the types of axial parenchyma.

- Group of wood with mainly paratrachael parenchyma

Axial parenchyma of *Albizia* (Prakash and Bande, 1980, Awasthi and Mehrotra, 1997), *Cassia, Parkia* (Ilec, 1991, Sosef, Hong, and Pawirohatmodjo, 1998, Chunwarin and Sri-aran, 1974), and *Koompassia* are aliform type (Soerianegara and

Lemmens, 1994), *Caesalpinia* is vasicentric (Ilec, 1991), and *Bauhinia* confluent (Sosef, Hong, and Pawirohatmodjo, 1998) (see Appendices B, Table 7).

- Group of wood with mainly apotrachael parenchyma with narrow band: *Dalbergia Pterocarpus, Pentace* (Chunwarin and Sri-aran, 1974),

Group of wood with mainly apotrachael parenchyma with wide-band: *Sapindus* with growth ring (Ilec, 1991, Poole and Wilkinson, 1992) and *Dialium* without growth ring (Metcalfe and Chalk, 1989, Pearson and Brown, 1932a). From these characters, the fossil specimens show close resemblance to the wood of *Dialium*. The important characters of the fossil are vessels medium to small sized, ripple marks present due to storied arrangement of ray parenchyma and especially axial parenchyma occurring mainly in apotracheal wide bands. Rays are mainly biseriate, occasionally triseriate, homocellular with procumbent cells, and fibers are libriform or non-septate. These features indicate the fossil wood shares the same characters with the modern wood of *Dialium cochinchinense* Pierre (Pearson and Brown, 1932a, Chunwarin and Sri-aran, 1974, Soeroamegara and Lemmens, 1994). In my opinion, this fossil should be placed in the extant species *Dialium cochinchinense* Pierre.

Figure 3.8 Transverse section, tangential section, and radial section of fossil wood of *Dialium cochinchinense* Pierre

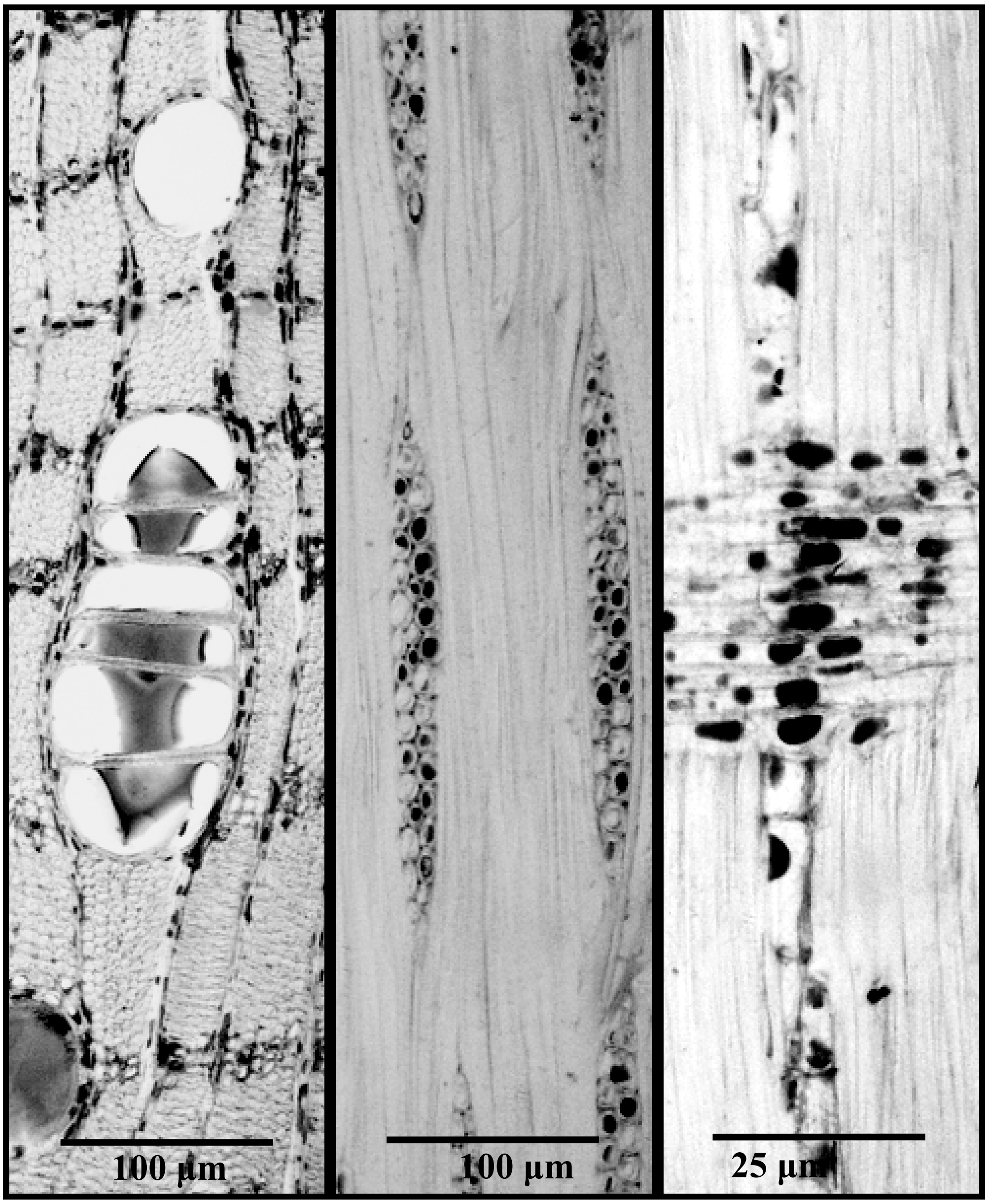


Figure 3.9 Transverse section, tangential section, and radial section of *Dialium cochinchinense* Pierre

Fabaceae

Papilionoideae

Millettia Wight & Arnott

Prodromus Florae Peninsulae Indiae Orientalis (1834).

Millettia leucantha Kurz

Diagnosis

Growth rings clear. Wood diffuse porous. Vessels small to medium (tangential diameter 80-140 µm), diameter regular, not visible to the naked eye, mostly solitary, occasionally arranged in multiple pores of 2-3, with 7-8 vessels per nm^2; vessel elements moderate, 200-600 µm long, with the simple perforation plates.

Axial parenchyma abundant, visible to the naked eye, both paratrachael and apotracheal, mostly vasicentric abundant to confluent, encircling vessels on both sides and occasionally extending as lateral projections across the ray and joining the other vessels. Wide-banded apotracheal parenchyma abundant.

Tyloses present.

Xylem rays fine and numerous, mainly biseriate, occasionally triseriate, 200-600 µm high in tangential section, 30-50 µm wide, 10-12 per horizontal mm Homocellular with procumbent cells, non-storied.

Fibers are libriform, non-septate.

Locality: SUT loc. 28

Specimen number: SUT 331

Wood Anatomy

Microscopic Characters

Growth rings distinct.

Vessels: Pores shape round, oval to obovate, usually regular, mostly uniform in size, frequently solitary, occasionally multiple pores, 2 in group, rarely 3 in group, the tangential diameters 80-140 µm, and radial diameters 110-200 µm simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 110 x 140 µm, 120 x 130 µm

Pore group of three: 140 x 110 µm, 30 x 100 µm, 140 x 110 µm

Vessel abundance 7-8 per mm^2, percentage of solitary pores 20.0%, and multiple pores 80.0%. Vessel elements are short to moderate, 200-600 µm long.

Perforation plates simple but occasionally obscured by tyloses.

Parenchyma: visible to naked eye; axial parenchyma abundant, mainly confluent paratracheal parenchyma, forming a 2-3 cell sheet, encircling the vessels, occasionally extending as lateral projections and joins the adjacent vessels, wide-banded apotracheal parenchyma abundant, 2-3 cells wide.

Xylem ray mostly biseriate, 200–600 µm high, 30-50 µm wide, occasionally triseriate rays, 250-500 µm high, 60 µm wide, non-storied, essentially homocellular with procumbent cells (Krib Homocellular type I).

Fibers non-septate, libriform

<u>Affinities</u>

The important characters of the fossil are vessels small to medium sized, axial parenchyma, mainly as wide banded apotracheal parenchyma, non-storied arrangement of parenchyma rays, rays mainly biseriate, homocellular xylem rays. These features indicate its affinities with the wood of Combretaceae, Fabaceae, and some Moraceae.

The genera *Terminalia* and *Combretum* have the diffused vessel arrangement and banded parenchyma but differ in having mainly uniseriate rays (see Appendices B, Table 4).

Ficus of the family Moraceae has the banded parenchyma but differs in having high and wide rays compared to the fossil wood.

Cynometra, Koompassia and *Millettia* of the family Fabaceae show similar characteristics to that of the fossil wood. *Cynometra,* however, differs in having storied rays while *Koo cmpassia* has narrow banded parenchyma (Bande and Prakash, 1986). (see Appendices B, Table 7).

The fossil wood resembles *Millettia leucantha* Kurz (Chunwarin and Sri-arun, 1974). The difference is that the xylem rays is wider, 30-50 µm, than that of *M. leucantha*. Prakash (1979) named fossil woods from Northeastern Thailand as *Millettioxylon indicum* Awasthi, which shows a close resemblance to the modern wood of *Millettia pendula* Benth. which is the synonym of *Millettia leucantha* Kurz

In my opinion, this fossil should be described as *Millettia leucantha* Kurz, because the fossil wood share the same characters with the modern wood of *Millettia leucantha* Kunz.

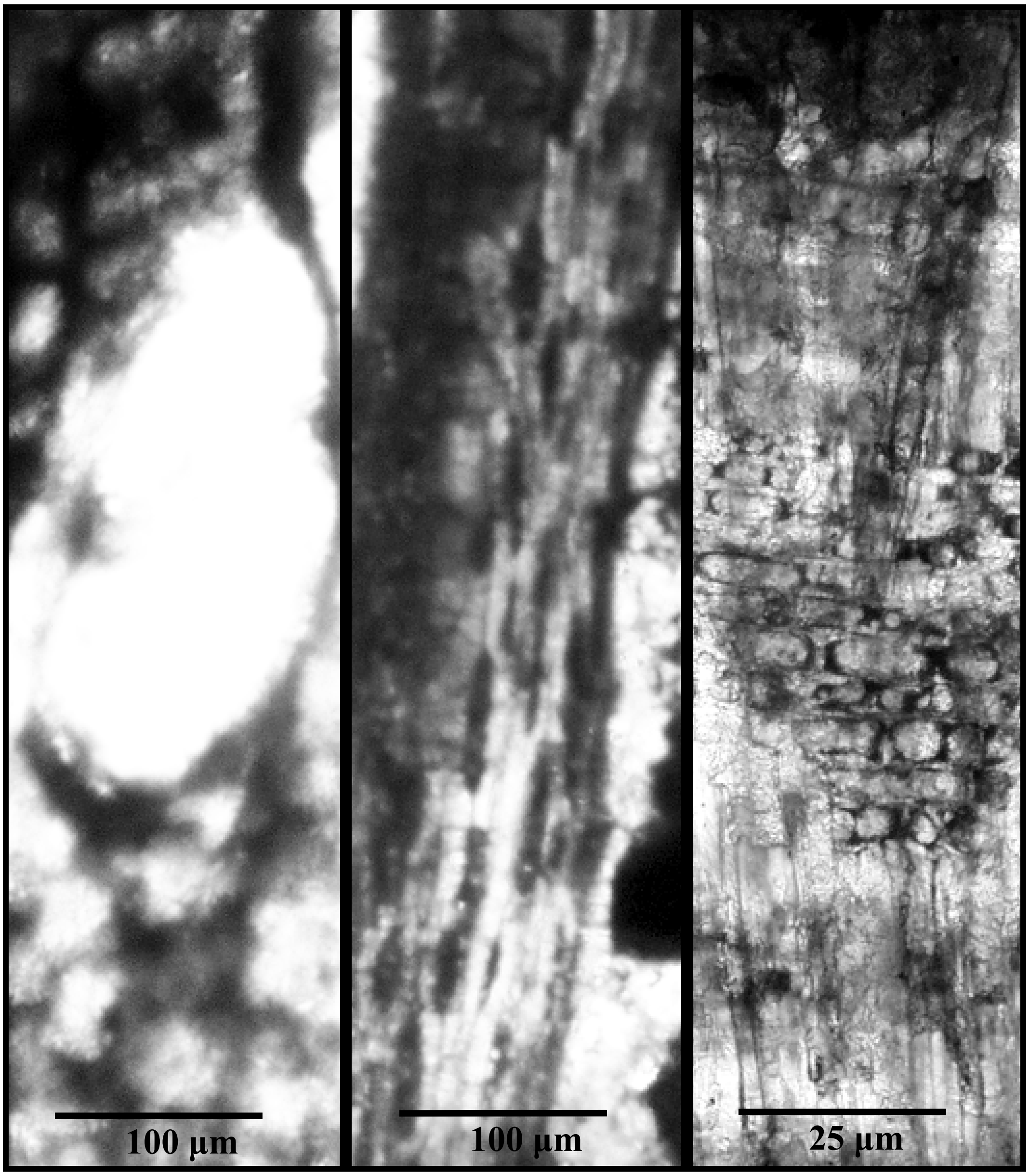


Figure 3.10 Transverse section, tangential section, and radial section of fossil wood of *Millettia leucantha* Kurz

Sonneratiaceae

Duabanga Buch-Hamh

Trans. Linn. Soc., London 17: 177 (1837)

Duabanga grandiflora (Roxb. ex DC.) Walp.

Report. Bot. Syst. 2:114 (1843)

Diagnosis

Growth rings not clear. Wood diffuse porous. Vessels medium to small (tangential diameter 120-260 μm), diameter regular, visible to the naked eye, occasionally solitary, frequently arranged in multiple pores of 2 to 3, 4, with 6-7 vessels per mm^2, mostly touching one side of the rays; vessel elements moderate, 200-300 μm long, with simple perforation plates.

Axial parenchyma scarce, both paratrachael and apotracheal, rarely vasicentric scanty, half-encycling vessels on one side, apotracheal parenchyma rarely and distributed as occasional cells in fibrous tissues.

Tyloses present.

Xylem rays fine and numerous, mainly uniseriate, Krib heterocellular type I, occasionally biseriate, 120-420 μm high in tangential section, 7–9 per horizontal mm, heterocellular with procumbent and upright cells, non-storied.

Fibers are libriform, non-septate.

Locality: SUT loc.8

Specimen Number: SUT 315

Wood Anatomy

Microscopic Characters

Growth rings not distinct.

Vessels: Pores shape elliptic, oval to obovate, usually regular, mostly uniform in size, some smaller vessels, vessels wider in early wood, grading into narrower late wood vessels, frequently solitary, some are in group of 2, occasionally 3 in a group, rarely in tangential pairs or cluster, the tangential diameters 120-260 µm, and radial diameters 200-350 µm simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 220 x 170 µm, 220 x 200 µm

Pore group of three: 220 x 170 µm, 210 x 200 µm, 150 x 190 µm

Vessels abundance 6-7 per mm^2, percentage of solitary pores 16.7%, and multiple pores 83.3%. Vessel elements are short to moderate, 200-300 µm long.

Perforation plates simple but occasionally obscured by tyloses.

Parenchyma: axial parenchyma rare, scarcely vasicentric scanty, paratracheal parenchtyma, half-encircling the vessels on one sides, apotracheal parenchyma sparse and rarely distribute as occasional cells in fibrous tissue. Intervessel pits alternate.

Xylem rays mainly uniseriate, occasionally birseriate, 120– 420 µm high, 40 µm wide, non-storied, mostly homocellular with procumbent cells, scarcely heterocellular rays, composed of both upright and procumbent cells

Fibers non-septate, libriform.

<u>Affinities</u>

The important characters of the fossil, are vessels small to medium sized, axial parenchyma mainly vasicentric scanty slightly aliform, non-storied arrangement of ray parenchyma, rays mainly uniseriate occasionally biseriate, homocellular, fibers are libriform or non-septate. These features indicate its affinities with the wood of Magnoliaceae, Malvaceae, Burseruaceae, *Dracontomelon* of Anacardiaceae, as well as the families of Flacourtiaceae and Sonneratiaceae (see Appendices A, Appendices B, Table 1, Table 3,).

The genera *Magnolia, Manglietia* show similar features to the fossil specimens, such as the diffused vessels, scarce parenchyma, vessels touch to one side of the rays but differs in having oil glands in rays, but the vessels are smaller than the fossil specimen. The investigation of the family Malvaceae, they differ in having high rays up to 1200 μm with non-storied arrangement of ray.

The genus *Canarium* of the family Burseraceae shows the closest affinities with the fossil specimen, but differs in having ray parenchyma arrangement in heterocellular Krib type III.

Dracontomelon of the family Anacardiaceae differs in having mostly biseriate rays, Krib type II. *Holarrhena* of the family Flacourtiaceae differs in having small vessels and xylem rays fine and numerous, 16-18 per horizontal mm (see Appendices B, Table 2). *Sonneratia* and *Duabanga* of the family Sonneratiaceae show the same characters of the fossil specimen, but *Sonneratia* differs in having the non-storied rays arrangement while *Duabanga* is storied. The similarity of the fossil specimen in shape, the pattern of distribution of vessels, axial parenchyma, and xylem rays shows the affinity to *Duabanga grandiflora* (Roxb. ex DC.) Walp.

Fossil wood from South India were studied and named *Sonneratioxylon preapetala* (Awasthi, 1969). Vozenin-Serra, Privé-Gill and Gingsburg (1989b, 1989c 2001) studied fossil wood from Northeast of Thailand and identified it as *Sonneratioxylon preapetalum* (see Appendices B, Table 8; Appendices C, Table 15). *Sonneratioxylon preapetalum* from both sites shows high density of vessels, 20-26 per mm^2, and ray densityof 20-25 rays per mm The vessel density of the fossil specimen being studied is 6-7 per mm^2 and ray density, 7-9 per horizintal mm

In my opinion, this fossil should be placed in the extant species *Duabanga grandiflora* (Roxb. ex DC.) Walp. because it shows the same characters as the Recent wood. It does not need to have a new name even though there is no previous report on the genus *Duabanga* and the extant species *Duabanga grandiflora* (Roxb. ex DC.) Walp.

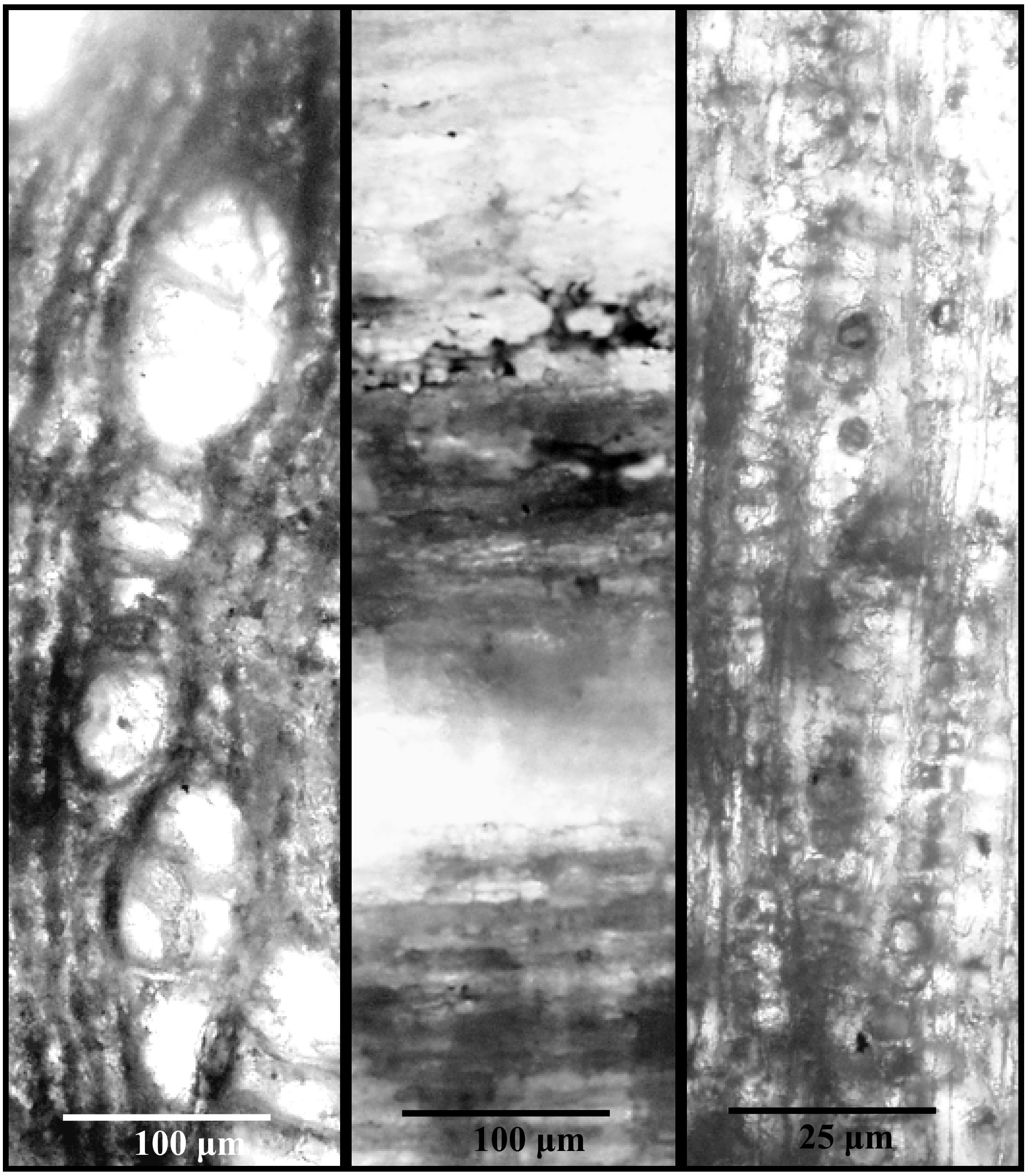


Figure 3.11 Transverse section, tangential section, and radial section of fossil wood of *Duabanga grandiflora* (Roxb. ex DC.)

Thymelaeaceae

Aquilaria Lamk.

Jour. Bot (1892) 4: 217-219

Aquilaria sp.

Diagnosis

Growth rings wanting. Wood diffuse porous. Vessels medium to small (tangential diameter 40-100 μm), diameter regular, not visible to the naked eye, rarely solitary, mostly arranged in multiple pores of 2 to 3, 4, with 8-12 vessels per mm^2; vessel elements moderate, 60-400 μm long with simple perforation plates, interxylary phloem present.

Axial parenchyma abundant, both paratrachael and apotracheal, mostly vasicentric abundant, encircling vessels on both sides, apotracheal parenchyma diffuse in aggregate or scattered bands in a few instances.

Tyloses present.

Xylem rays fine and numerous, mainly uniseriate, occasionally biseriate, 160-430 μm in tangential section, 17-22 cells in row, 8-12 per horizontal mm, heterocellular with procumbent and up right cells.

Fibers are libriform, non-septate.

Locality: SUT loc. 7

Specimen number: SUT 103

Wood Anatomy

Microscopic characters

Growth rings not distinct.

Vessels: Pores shape round, oval to obovate, usually regular, mostly uniform in size, frequently solitary, some in group of 2, occasionally 3 in group, not tangential pairs or cluster, the tangential diameters 40-100 μm, and radial diameters 50-160 μm simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 40 x 120 μm, 30 x 50 μm

Vessels abundance 2-3 per mm^2, percentage of solitary pores 20%, and multiple pores 80%. Vessel elements are short to moderate 60-400 μm long.

Perforation plates simple but occasionally obscured by tyloses.

Parenchyma: axial parenchyma abundant, mainly vasicentric abundant, forming a 4-5 cell sheet, encircling the vessels, apotracheal parenchyma abundant and diffuse in aggregate or scattered bands in a few instance.

Axial parenchyma thickened in the form of interxylary phloem present.

Xylem rays mainly uniseriate, 160-430 μm high, 17-22 cells high, 40 μm wide, non-storied, mostly heterocellular Krib type I, compose of both upright at the end of rays and procumbent cells.

Fibers non-septate, libriform

Affinities

The important characters of the fossil are vessels small to medium sized, axial parenchyma mainly vasicentric abundant, rippled, non-storied arrangement of ray parenchyma, rays mainly uniseriate, heterocellular, non-septate fibers, and interxylary phloem present. These features indicate its affinities, especially interxylary phloem which is the systematically significant for wood anatomy (Cronquist, 1988), with the wood of *Thunbergia* of Acanthaceae, *Combretum* of Combretaceae, *Stychnos* of Loganiaceae and *Aquilaria* of Thymeleaceae (see Appendices A, Appendices B, Table4).

The genus *Thunbergia* of the family Acanthaceae consists of mostly shrubs, often twining, with interxylary phloem strands in extensive parenchyma. On the other hand, in *Combretum* of Combretaceae, the mode of interxylary phloem is to occur in confluent axial parenchyma.

Strychnos of Loganiaceae has a large amount of interxylary phloem in a centripetal. Phloem strands, round, large, and crushed at the abaxial side occur in *Strychnos* as well as in *Aquilaria* of the family Thymelaeaceae (Carlquist, 1961, 1988).

The different features between *Strychnos* and *Aquilaria* are multiseriate (2-3 seriate) rays and semi-ring porous wood with small vessels found in *Strychnos*. The uniseriate rays and interxylary phloem are the significant characters of *Aquilaria* (Peason and Brown, (a) 1932). These anatomical features of this fossil specimen show the most resemblance with *Aquilaria* Lamk.

The investigation of the wood anatomy of *Aquilaria malaccensis* found some difference in size of rays and size of intervessel pits. Anyway, because of the improper fossilization, vessels, the fossil specimen is not well preserve, making it is hard to look through clearly the characters of the fossil. In my opinion, this fossil should be placed in the extant genus *Aquilaria* Lamk.

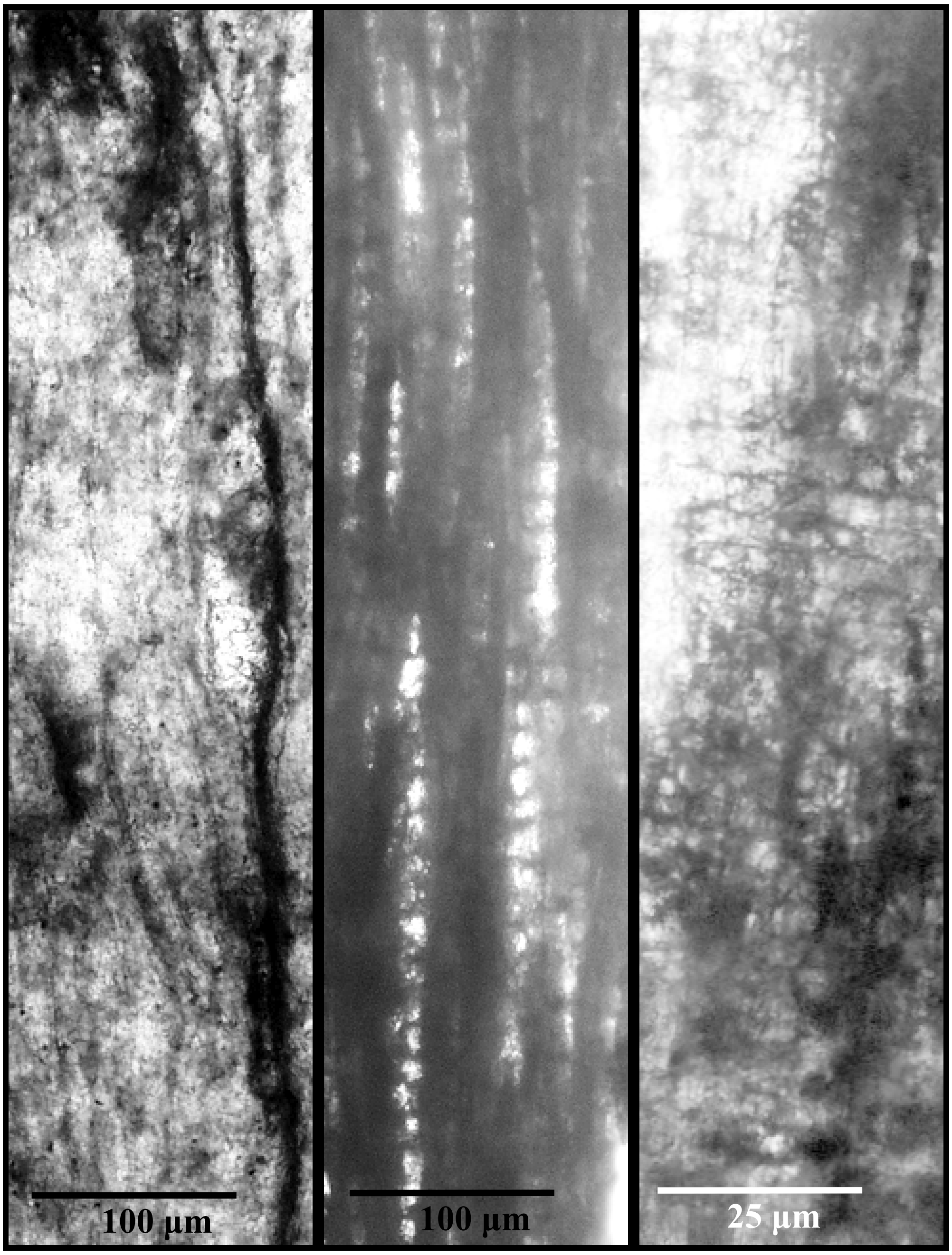


Figure 3.12 Transverse section, tangential section and radial section of fossil wood of *Aquilaria* sp.

Combretaceae

Anogeissus (DC.) Guill.& Perr.

Fl. Seneg. Tent. 1: 279, t.65 (1832)

Anogeissus acuminata (Roxb. ex DC.) Guill.& Perr.

Fl. Seneg. Tent. 1: 279, t.65 (1832)

Diagnosis

Growth rings not clear. Wood ring porous. Vessels small (tangential diameter 160-200 μm), diameter regular, not visible to the naked eye, occasionally solitary, mostly radial in multiples of 2 to 3, 4, with 4-10 vessels per mm^2; vessel elements short, 30-110 μm long with simple perforation plates.

Axial parenchyma abundant, both paratrachael and apotracheal, mostly aliform to confluent, encircling vessels on both sides and occasionally extending as lateral projections across the ray and joining the other vessels. The other diffuse parenchyma sparse and distribute as occasional cells in fibrous tissue.

Tyloses present.

Xylem rays fine and numerous, mainly uniseriate, occasionally biseriate, 220 - 1200 μm high in tangential section, 3–4 per horizontal mm, homocellular with procumbent cells, storied, frequently Heterocellular Krib type II.

Fibers are libriform, non-septate.

Locality: SUT loc. 6

Specimen number: SUT 312

Wood Anatomy

Microscopic Characters

Growth rings not distinct.

Vessels: Small, pore shape round, oval to obovate, usually regular, mostly uniform in size, smaller vessels very few, occasionally solitary, frequently in radial multiples of 2-3 to 4 in a group, occasionally 5 in a group, not in tangential pairs or clusters, the tangential diameters 80-120 µm, and radial diameters 160-230 µm, simple perforations.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 100 x 100 µm, 130 x 100 µm

Pore group of three: 170 x 240 µm, 160 x 130 µm, 190 x 180 µm

Pore group of four: 190 x 200 µm, 190 x 150 µm, 160 x 160 µm, 130 x 220 µm

Vessels abundance 4-10 per mm^2, percentage of solitary pores 35.7%, and multiple pores 64.3%. Vessel elements are short to very short, 30-110 µm long.

Perforation plates simple but occasionally obscured by tyloses.

Parenchyma: axial parenchyma abundant, mainly aliform to confluent, forming a 3-5 cell sheets, encircling the vessels, occasionally extending as lateral projections and joining the adjacent vessels, diffuse apotracheal parenchyma sparse and distribute as occasional cells in fibrous tissues.

Xylem rays mostly uniseriate, 220–1200 µm high, 20 µm wide, occasionally biseriate rays, non-storied, mostly homocellular with procumbent cells but sometimes marginal cells twice as high as body cells, rarely heterocellular rays, composed of both upright and procumbent cells. Fibers non-septate, libriform.

<u>Affinities</u>

The important characters of the fossil are the characters vessels small to medium sized, ring porous wood, multiple pores 2-4, axial parenchyma mainly vasicentric scanty, occasionally aliform to confluent, rays mainly uniseriate, occasionally biseriatae, heterocellular, and libriform non-septate fibers. These features indicate its affinities with the wood of the families Fabaceae, Burseraceae, and Combretaceae. The genus *Protium* of the family Burseraceae differs in having scanty parenchyma. Wood of the Fabaceae can have aliform parenchyma as in the specimen can but differs in not having pore chains. *Terminalia* and *Anogeissus* of the family Combretaceae are considered. The fossils of these two genera have always been put into the genus Terminalioxylon. The difference between *Terminalia* and *Anogeissus* is the arrangement of the vessels in the pore chains, which is always found in *Anogeissus* (see Appendices II, Table 4). In my opinion, this specimen shows resemblance to *Anogeissus accuminata* (Roxb. ex DC.) Guill. & Perr. The specimen is determined to *Anogeissus accuminata* (Roxb. ex DC.) Guill. & Perr.

Figure 3.14 Transverse section, tangential section, and radial section of fossil wood of *Anogeissus acuminata* (Roxb. ex DC.) Guill. & Perr.

Combretaceae

Terminalia L.

Sys. Nat. ed.12., 2: 673 (1767); Mant. Pl.: 21.128 (1767)

Terminalia alata Heyne ex Roth

Nov. pl. sp.: 379 (1821) 164 (1873)

Diagnosis

Growth rings clearly seen. Wood diffuse porous. Vessels small to large (tangential diameter 70-200 μm), diameter regular, visible to the naked eye, mostly solitary, occasionally arranged in multiple pores of 2-3, rarely 4, with 2-3 vessels per mm^2; vessel elements moderate, 240-700 μm long with simple perforation plates.

Axial parenchyma abundant, both paratrachael and apotracheal, mostly vasicentric abundant to confluent partially or completely, encircling vessels on both sides and occasionally extending as lateral projections across the rays and joining the other vessels. The other wide banded apotracheal parenchyma are numerous as broken to continuous tangential bands and distributed as occasional cells in fibrous tissue.

Tyloses not frequent, crystals present.

Xylem rays fine and numerous, mainly uniseriate, occasionally biseriate, 110 - 800 μm high in tangential section, 7-22 cells in row, 7-9 per horizontal mm, homocellular with procumbent cells, non-storied.

Fibers are libriform, non-septate.

Locality: SUT loc. 28

Specimen number: SUT 318, SUT 323, and SUT 333

Wood Anatomy

Microscopic Characters

Growth ring distinct.

Vessels: Pores shape round, oval to obovate, usually regular, mostly uniform in size, some smaller vessels very few, frequently solitary, occasionally multiple pores, 2 in group, rarely 3, 4, in a group, rarely in tangential pairs or cluster, the tangential diameters 70-200 μm, and radial diameters 80-140 μm simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 90 x 140 μm, 200 x 240 μm

Pore group of three: 70 x 160 μm, 60 x 200 μm, 160 x 210 μm

Pore group of four: 130 x 150 μm, 140 x 190 μm, 200 x 200 μm, 260 x 200 μm

Vessels abundance 2-3 per mm^2, percentage of solitary pores 82.1% and multiple pores 17.9%. Vessel elements are moderate to high, 240-700 μm long.

Perforation plates simple.

Parenchyma: axial parenchyma abundant, mainly vasicentric abundant, forming a 4-5 cell sheet, occasionally aliform to confluent paratracheal parenchyma, encircling the vessels, occasionally extending as lateral projections and joining the adjacent vessels, wide banded apotracheal parenchyma abundant, 4-8 cell wide, as broken to continuous tangential bands. Xylem rays mostly uniseriate, 200–430 μm high, 7-20 cells high, 40 μm wide, occasionally biseriate rays, 110-800 μm high, average 350 μm high, 40-60 μm wide, non-storied, essentially homocellular with procumbent cells, weakly heterocellular. Fibers non-septate, libriform

Affinities

The important characters of the fossils are vessels small to large size, axial parenchyma mainly vasicentric abundant, occasionally aliform to confluent, wide banded parenchyma, non-storied, rays mainly uniseriate, mostly homocellular xylem rays, simple perforation plate, non-septate fibers. These features indicate their affinities with the wood of the families Fabaceae, Moraceae, and Combretaceae.

Ficus genera of the family Moraceae has the wide-banded parenchyma but differs in having bi-triseriate xylem rays.

The woods of *Cynometra* of the family Fabaceae differs in having mainly biseriate xylem rays as well as the wood of *Koompassa* of the family Fabaceae has narrow banded parenchyma (see Appendices B, Table 7).

The fossils of the family Combretaceae only present to genus *Terminalioxylon* for the fossil wood of *Terminaria,* which there is a large numbers of 250 species distributed in the tropical region. Many fossil woods were studied and named to *Terminalioxylon* species. (Mädel-Angeliewa and Müller-Stoll, 1973) described 2 species of *Terminalioxylon* which corresponding to the genera *Terminalia*, *Combretum* and *Anogeissus*.

Prakash (1981) studied fossil wood like *Terminalia manii* from Uttar Pradesh, India, and named *Terminalioxylon palaeomanii*. The study of fossil woods from Burma, Chowdhury and Tandon (1964) identified the fossil to the modern plants, *Terminalia tomentosa* W&A (synonym of *Terminalia alata* Heyne ex Roth)

Fossil wood like *Terminalioxylon coriaceum* Prakash & Awasthi from Nakhon Ratchasima named *Terminalioxylon coriaceum* (Vozenin-Serra and Privé-Gill, 2001) (see Appendices B, Table 4).

The fossil woods showing resemblance with *Terminalia* particularity with *Terminalia alata* Heyne ex Roth. In my opinion, this fossil should be placed in the extant species *Terminalia alata* Heyne ex Roth for it shares the same characters of the Recent wood.

Figure 3.15 Transverse section, tangential section, and radial section of fossil woodd of *Terminalia alata* Heyne ex Roth

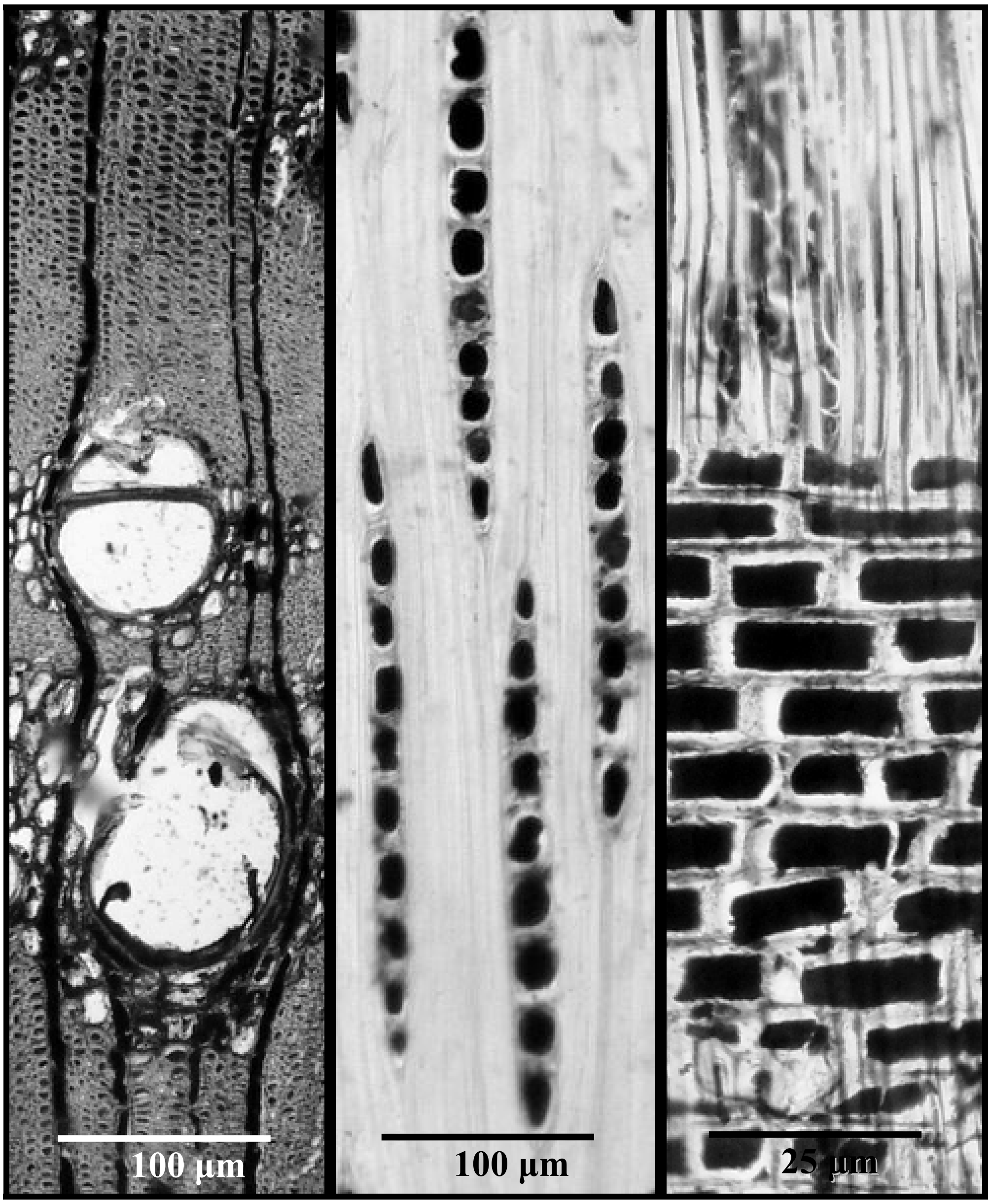


Figure3.16 Transverse section, tangential section, and radial section of

Terminalia alata Heyne ex Roth

Burseraceae

Protium Burm.f.

Fl. indica 88: (1768)

Protium serratum (Colebr) Engl.

Fl. indica 88: (1768)

Diagnosis

Growth rings not clear. Wood diffuse porous. Vessels medium to small (tangential diameter 110-160 µm), diameter regular, visible to the naked eye, mostly solitary, occasionally arranged in multiple poresof 2-3, with 5-6 vessels per mm^2; vessel elements moderate, 175-400 µm long with simple perforation plates.

Axial parenchyma scanty, both paratrachael and apotracheal, rarely vasicentric scanty, toughing vessels on one side. The other apotracheal parenchyma is sparsed and distribute as occasional cells in fibrous tissues.

Tyloses present.

Xylem rays fine and numerous, mainly uniseriate, occasionally biseriate, 120-500 µm high in tangential section, 10–11 per horizontal mm, heterocellular with procumbent cells, non-storied rays.

Fibers are libriform, non-septate.

Locality: SUT loc. 29

Specimen number: SUT 325

Wood Anatomy

Microscopic characters

Growth rings not distinct.

Vessels: Pores shape round, oval to obovate, usually regular, mostly uniform in size, some smaller vessels very few, frequently solitary, occasionally multiple pores, 2 in a group, rarely 3 in a group, the tangential diameters 110-160 µm, and radial diameters 110-250 µm touch one side of the rays, simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 160 x 140 µm, 150 x 140 µm

Pore group of three: 140 x 130 µm, 150 x 160 µm, 150 x 150 µm

Vessel abundance 7-8 per mm^2, percentage of solitary pores 83.4%, and multiple pores 16.6%. Vessel elements are short to moderate, 175-400 µm long.

Perforation plates simple but occasionally obscured by tyloses.

Parenchyma: axial parenchyma scarce, rarely vasicentric scanty, and occasionally paratracheal parenchyma diffuses in aggregate, sparse and distributed as occasional cells in fibrous tissue.

Xylem rays mainly uniseriate, 100–500 µm high, 40-60 µm wide, occasionally biseriate rays, 250-450 µm high, 30-40 µm wide, non-storied rays, mainly heterocellular rays composed of both upright and procumbent cells.

Fibers non-septate, libriform

Affinities

The important characters of the fossil are vessels medium to small sized, axial parenchyma rarely vasicentric scanty, occasionally diffuse scanty, non-storied arrangement of ray parenchyma, rays mainly biseriate occasionally triseriate, heterocellular Krib type II, and libriform, non-septate fibers. These features indicate its affinities with the wood of Magnoliaceae, Anacardiaceae, Flacourtiaceae, Sonneratiaceae, and Burseraceae (see Appendices A, Appendices B, Table 1, 3, 5, and 8).

The Magnoliaceae differs in having oil gland while Anacardiaceae differs in having resin ducts (Cronquist, 1988). On the other hand, the Flacourtiaceae differ in having small vessels and xylem fine and numerous. The Sonnerratiaceae mainly have uniseriate rays.

The similarity of the fossil specimen in size, the distribution pattern of vessels, and the axial parenchyma of xylem rays show the affinities with *Protium serratum* (Colebr) Engl.

In my opinion, this fossil should be placed in the extant species *Protium seratum* (Colebr) Engl., for it shares the same characters with the modern wood, even though there has been no previous report on fossil of the genus *Protium* or the extant species *Protium serratum* (Colebr) Engl.

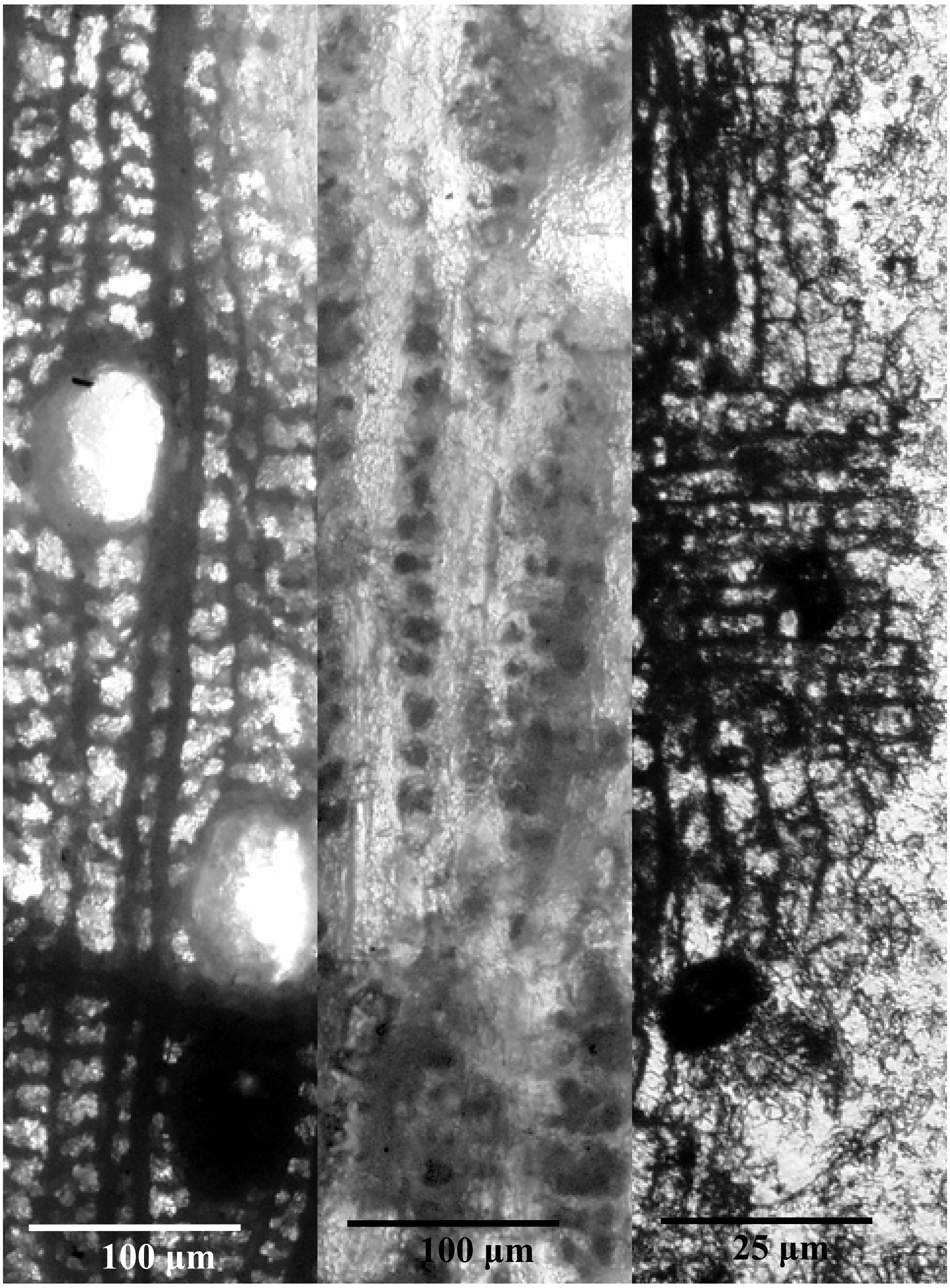


Figure 3.17 Transverse section, tangential section, and radial section of fossil wood of *Protium serratum* (Colebr.) Engl.

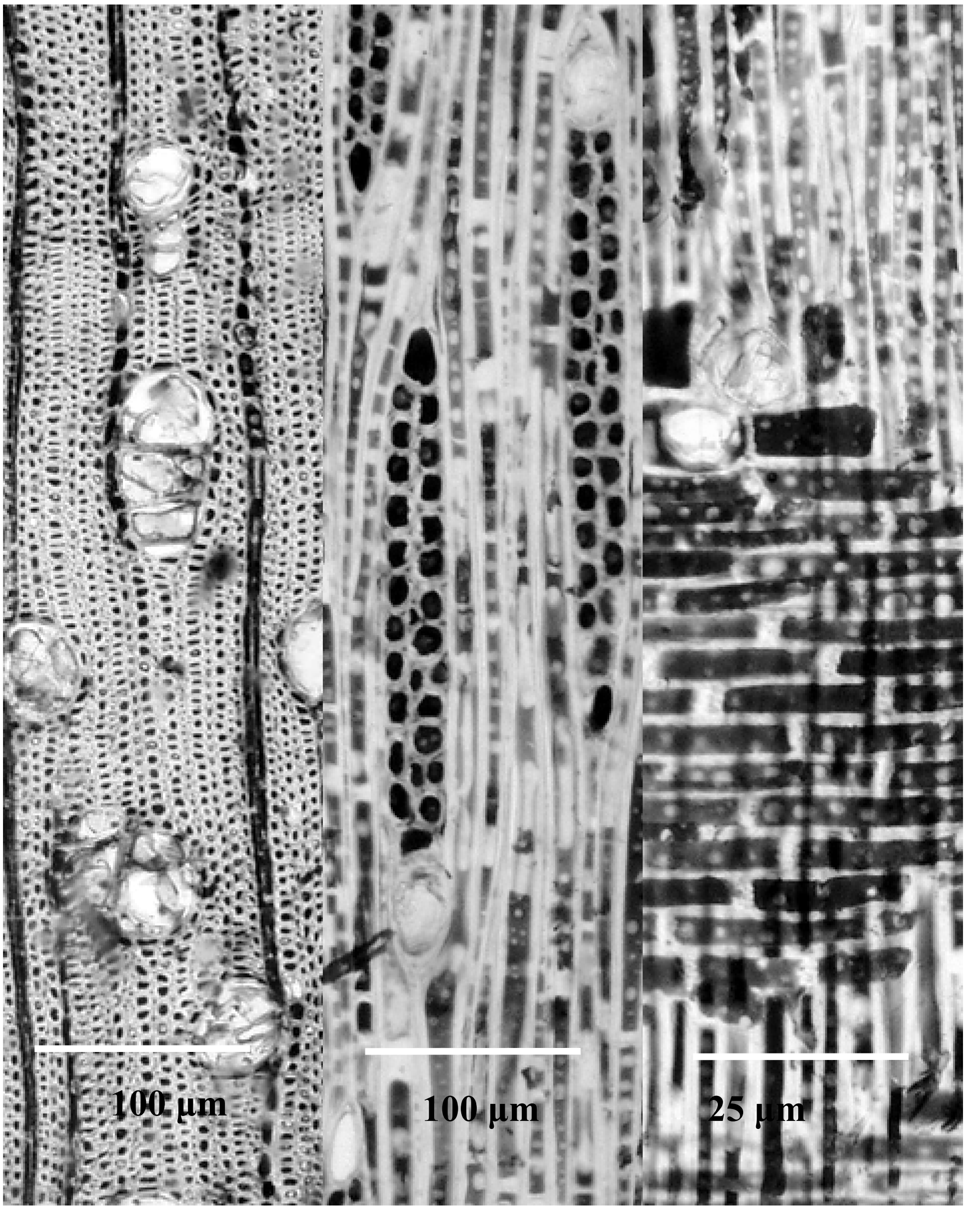


Figure 3.18 Transverse section, tangential section, and radial section of *Protium serratum* (Colebr.) Engl.

Anacardiaceae

Dracontomelon Blume.

Mus. Bot. Ludg.-Bat. 1: 231 (1850)

Dracontomelon dao (Blanco) Merr. & Rolfe

Philipp. Journn. Sci., Bot. 3: 108 (1908)

Growth rings not clear. Wood diffuse porous. Vessels medium to small (tangential diameter 90-200 μm), diameter regular, visible to the naked eye, mostly solitary, and in radial multiple of 2-3, sometimes in clusters with much smaller cluster, with 3-4 vessels per mm^2; vessel elements moderate, 110-1100 μm long with the simple perforation plates.

Axial parenchyma very few, both paratrachael and apotracheal, mostly vasicentric scanty encycling vessels on both sides. The other diffuse apotracheal parenchyma abundant sparse and distribute as occasional cells in fibrous tissue.

Tyloses present.

Xylem rays high and numerous, mainly biseriate, rarely uniseriate, 150-400 μm in tangential section, 40 μm wide, 4-6 per horizontal mm, heterocellular with procumbent cells, non storied.

Fibers are libriform, non-septate.

Locality: SUT loc. 28

Specimen number: SUT 305

<u>Wood Anatomy</u>

<u>Microscopic Characters</u>

Growth rings not distinct.

Vessels: Pores shape elliptic to obovate, usually regular, mostly uniform in size, some smaller vessels very few, frequently solitary, some are 2 in group frequently solitary, occasionally multiple pores, 2,3 in group, rarely in tangential pairs or cluster, the tangential diameters 90-200 μm, and radial diameters 250-420 μm, simple perforation. Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 300 x 320 μm, 250 x 200 μm

Pore group of three: 220 x 220 μm, 250 x 260 μm, 160 x 190 μm

Vessel abundance 3-4 per mm^2, percentage of solitary pores 87.5%, and multiple pores 12.5%. Vessel elements are short to moderate, 110-1100 μm long.

Perforation plates simple.

Parenchyma: axial parenchyma abundant, mainly vasicentric abundant, forming a 1-3 cell sheet, occasionally aliform paratracheal parenchtyma, encircling the vessels, apotracheal parenchyma sparse and distributed as occasional cells in fibrous tissue.

Xylem rays mainly biseriate, 150-400 μm high, 30-50 μm wide, occasionally triseriate rays, 200-300 μm high, 40-50 μm wide, non-storied rays. mostly heterocellular with procumbent cells.

Fibers non-septate, libriform.

Affinities

The important characters of the fossil shows the character of vessels small to medium sized, axial parenchyma mainly vasicentric scanty, occasionally aliform to confluent, ripple marks present due to storied arrangement of ray parenchyma, rays mainly biseriate occasionally triseriate, homocellular and libriform or non-septate fibers. These features indicate its affinities with the wood of the families Magnoliaceae, Malvaceae, Burseraceae, Flacourtiaceae, Sonneratiaceae and *Dracontomelon* of family Anacadiaceae (Poole, 2001) (see Appendices A, Appendices B, Table 1, 3, and 8).

The family of Magnoliaceae differs from the fossil specimens in having oil glands in xylem ray. The ray size, 1200 μm, of Malvaceae is higher than that of the specimen. The non-parenchyma, parenchyma scanty, character of Burseraceae, Flacourtiaceae, and Sonneratiaceae are quite distinct and differ from the fossil specimens. *Dracontomelon* of the family Anacardiaceae resembles the fossil specimen.

Prakash (1981) identified fossil wood from Uttra Pradesh, India and placed it in *Dracontomeloxylon mangiferumoides* Ghosh & Roy, 1979 which is synonym of *Dracontomeloxylon mangiferumoides*, the fossil from West Bengal. Both show resemblance to *Dracontomelon mangiferum* (synonym to *Dracontomelon dao* Merr & Rolfe.) (see Appendices A; Appendices B, Table 1; Appendices C, Table 20).

Anyway, the anatomical features of this fossil specimen show the most resemblance to *Dracontomelon dao* (Blanco) Merr. & Rolfe. The height of ray of the specimen is 200-300 μm while the ray of *Dracontomelon dao* is 150-200 μm high. In my opinion, this fossil should be placed in the extant species, *Dracontomelon dao*

(Blanco) Merr. & Rolfe because they share the same characters even differing in the height of the rays. It is not necessary to propose a new species for a specimen having close affinities.

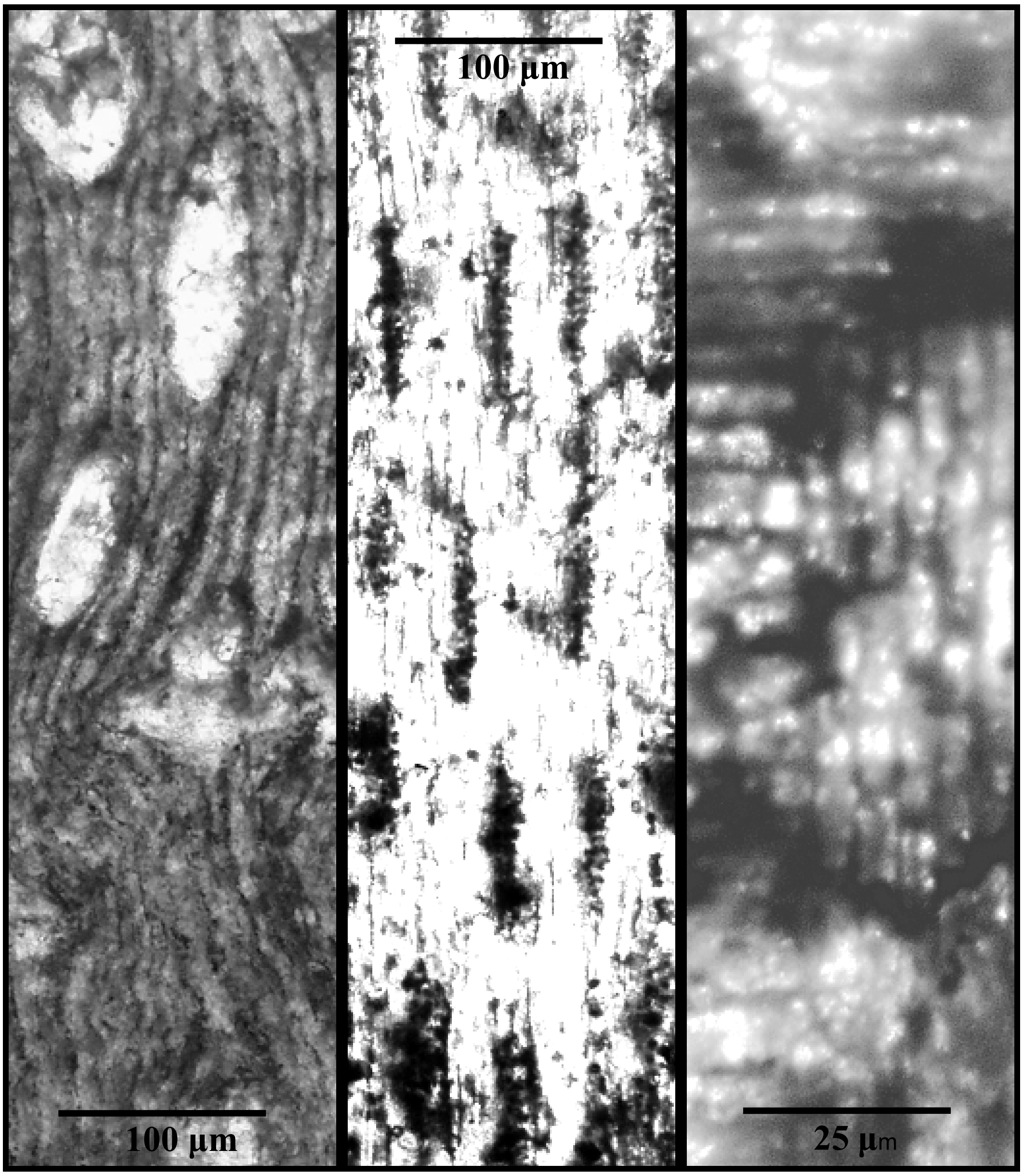


Figure 3.19 Transverse section, tangential section and radial section of fossil wood of *Dracontomelon dao* (Blanco) Merr. & Rolfe

Apocenaceae

Holarrhena R. Br.

Asclep. 51, 1810.

Holarrhena pubescens Wall. ex G. Don.

Gen. Syst. 3: 78. 1837.

Growth rings not clear. Wood diffuse porous. Vessels small (tangential diameter 30-160 µm), diameter regular, not visible to the naked eye, mostly solitary, occasionally arranged in multiple pores of 2 to 3, 4, with 15-17 vessels per mm^2; vessel elements moderate, 800-2200 µm long with simple perforation plates.

Axial parenchyma occasionally, both paratrachael and apotracheal, occasionally vasicentric scanty, Diffuse apotracheal parenchyma sparse and distribute as occasional cells in fibrous tissues. Intervessel pits scalariform.

Tyloses not present.

Xylem rays fine and numerous, mainly biseriate, occasionally uniseriate, 140-400 µm in tangential section, 16-18 per horizontal mm, Uniseriate and biseriate rays scarcely, homocellular or heterocellular with procumbent cells, heterocellular with procumbent cells, and upright Krib type I, non-storied.

Fibers are libriform, non-septate.

Locality: SUT Loc. 28

Specimen number: SUT 335

Wood Anatomy

Microscopic characters

Growth rings not distinct.

Vessels: Small, pores shape round, oval to obovate, usually regular, mostly uniform in size, frequently solitary, some are 2 in group, rarely to be 3 in group, rarely in tangential pairs or cluster, the tangential diameters 30-160 µm, and radial diameters 30- 200 µm simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 120 x 110 µm, 120 x 110 µm

Pore group of three: 120 x 90 µm, 110 x 100 µm, 140 x 100 µm

Pore group of four: 100 x 100 µm, 100 x 110 µm, 90 x 70 µm, 90 x 60 µm

Vessels abundance 5-5.5 per mm^2, percentage of solitary pores 79.2%, and multiple pores 20.8%. Vessel elements are moderate,% large 800-2200 µm long.

Perforation plates simple.

Parenchyma: axial parenchyma few, mainly vasicentric abundant, forming a group of all torch to some parts of vessels. Diffuse scanty apotracheal parenchyma, sparse and distribute as occasional cells in fibrous tissue.

Xylem rays exclusively biseriate, 140-400 µm high, 20-30 µm wide, occasionally uniseriate rays, non-storied, essentially heterocellular with procumbent cells but sometimes uniseriate zone compose of up right cells and few up right cells in multiseriate portion of multiseriate rays.

Fibers non-septate, libriform.

Affinities

The important characters of the fossil, such as growth rings indistinct, vessels small, intervasicular pits scalariform, axial parenchyma mainly vasicentric scanty paratracheal perenchyma, diffuse scanty apotracheal parenchyma, non-storied arrangement of parenchyma rays: rays mainly biseriate occasionnally uniseriate, heterocellular and libriform or non-septate fibers. These features indicate its affinities with the wood of Annonaceae, Apocynaceae, and Flacourtiaceae.

Canangium, Miliusa, and *Saccopetalum* are similar to fossil specimen in gross features, such as growth ring indistinct, small diffused vessels, differ in possession of narrow-banded apotracheal parenchyma.

Homalium of Flacourtiaceae differs in having intervasicular pits alternate. The genus *Hydnocarpus* of Flacourtiaceae is close similar with the fossil specimen, such as small diffused vessels, intervesicular pits scalariform, but differs in absent of parenchyma, and growth rings present (see Appendices A; Appendices B, Table 5).

The significant feature of Apocynaceae is intervasicular pits scalariform (Cronquist, 1988) *Alstonia, Wrightia* and *Holarrhena* are considered. *Holarrhena* are closer affinities to the fossil specimen than the other two genera. *Alstonia* differs in having medium vessels, and frequently in multipores of 4.

Wrightia has fine-banded apotracheal parenchyma distribute without reference to vessels in scalariform pattern (Cronquist, 1988)

The similarity of the fossil specimen in shape, the distribution pattern of vessel, intervasicular pits, xylem ray, show the affinities with *Holarrhena pubescens* Wall. ex G. Don.

There is no report of fossil wood placed in the genera *Holarrhena* or the extant species *Holarrhena pubescens* Wall. ex G. Don.

Figure 3.20 Transverse section, tangential section, and radial section of fossil wood of *Holarrhena pubescens* Wall. ex G. Don.

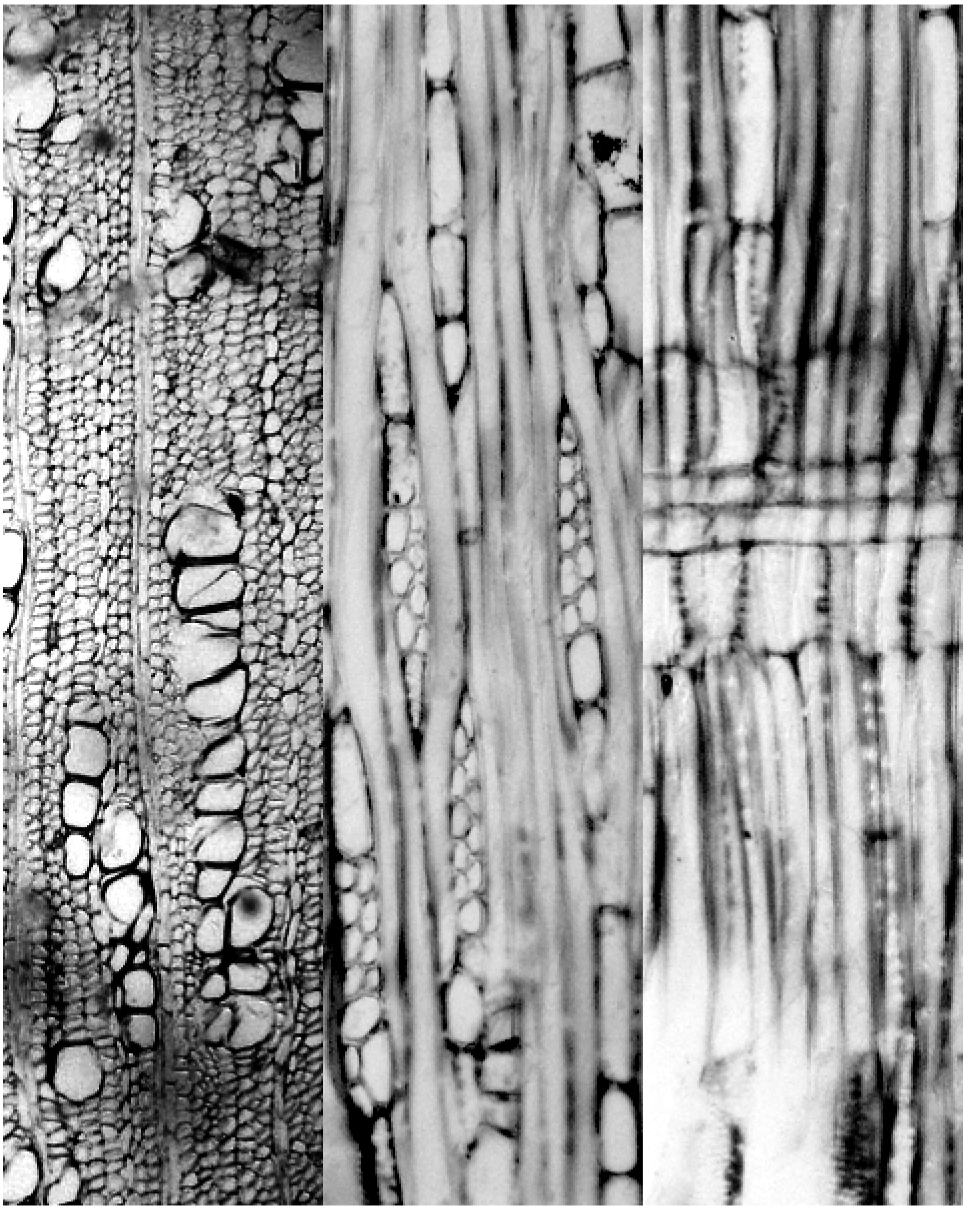


Figure 3.21 Transverse section, tangential section, and radial section of

Holarrhena pubescens Wall. ex G. Don.

Apocynaceae

Wrightia R.Br.

On Asclepiad.: 762 (1810)

Wrightia arborea (Dennst.) Mabberley

Taxon 26: 533 (1977)

Growth rings not clear. Wood ring porous. Vessels small (tangential diameter 40-50 μm), diameter regular, not visible to the naked eye, occasionally solitary, mostly arranged in multiple pores of 2-6, numerous abundant, mainly touch to one side of the rays; vessel elements moderate, 220-400 μm long with the simple perforation plates.

Axial parenchyma scarcely, apotracheal parenchyma sparse and distributed as occasional cells in fibrous tissue. Intervessel pit, opposite.

Tyloses present.

Xylem rays very fine and numerous, mainly uniseriate, 20-40 μm in tangential section, 18-21 per horizontal mm, heterocellular with procumbent cells, storied.

Fibers are libriform, non-septate.

Locality: SUT loc. 28

Specimen number: SUT 322

<u>Wood Anatomy</u>

<u>Microscopic characters</u>

Growth rings not clear.

Vessels: Pores shape round, oval to obovate, usually regular, mostly uniform in size, frequently solitary, mostly multiple pores, 2-6 in group, not in tangential pairs or cluster, the tangential diameters 40-50 μm, and radial diameters 35-50 μm simple perforation.

Measurement of pore groups (tangential diameter x radial diameter)

Pore group of two: 40 x 30 μm, 40 x 50 μm

Pore group of three: 40 x 30 μm, 55 x 30 μm, 50 x 40 μm

Pore group of four: 50 x 60 μm, 50 x 35 μm, 50 x 30 μm, 50 x 30 μm

Vessel abundance numerous, percentage of solitary pores 27.3%, and multiple pores 72.7%. Vessel elements are short to moderate, 100-220 μm long. Intervessel pits opposite.

Perforation plates simple but occasionally obscured by tyloses.

Parenchyma: axial parenchyma scarcely, mainly diffuses apotracheal parenchyma sparse and distributed as occasional cells in fibrous tissue.

Xylem rays fine, mostly uniseriate, 20–40 μm vertical high, 20 μm wide, 18-21 per horizontal mm, non-storied, mostly heterocellular Krib type I, compose of mainly upright and procumbent cells.

Fibers non-septate, libriform.

Affinities

The important characters of the fossil, such as growth rings indistinct, vessels small, not visible to naked eye, axial parenchyma diffuse apotracheal parenchyma, non-storied arrangement of ray parenchyma, rays mainly uniseriate occasionally biseriate, heterocellular and libriform or non-septate fibers. These features indicate its affinities with the wood of Annonaceae, Flacourtiaceae, Apocynaceae (Middleton, 1999, Chunwarin and Sri-Aran, 1974)).

The genus *Holarrhena* of Family Apocynaceae differs in having intervessel pits scalariform, as well as *Alstonia*.

The Family Flacourtiaceae is similar to fossil specimen in many features, but differs in non-parenchyma or scanty parenchyma.

Annonaceae, genera *Canangium, Miliusa,* and *Saccopetalum* are close similar with the fossil specimen, sucs as small diffused vessels, fine banded apotracheal parenchyma distribute without reference to vessels in scalariform pattern, differ in having multiseriate rays, high rays, up to > 1000 μm.

Wrightia arborea (Dennst.) Mabberley show the affinity such as shape, size, distribution pattern of vessels, axial parenchyma, and xylem rays, similar with the fossil specimen.

In my opinion, this fossil should be placed in the extant species *Wrightia arborea* (Dennst.) Mabberley. There is no need to have a new name even though there is no report of fossil wood placed in this extant genera or species.

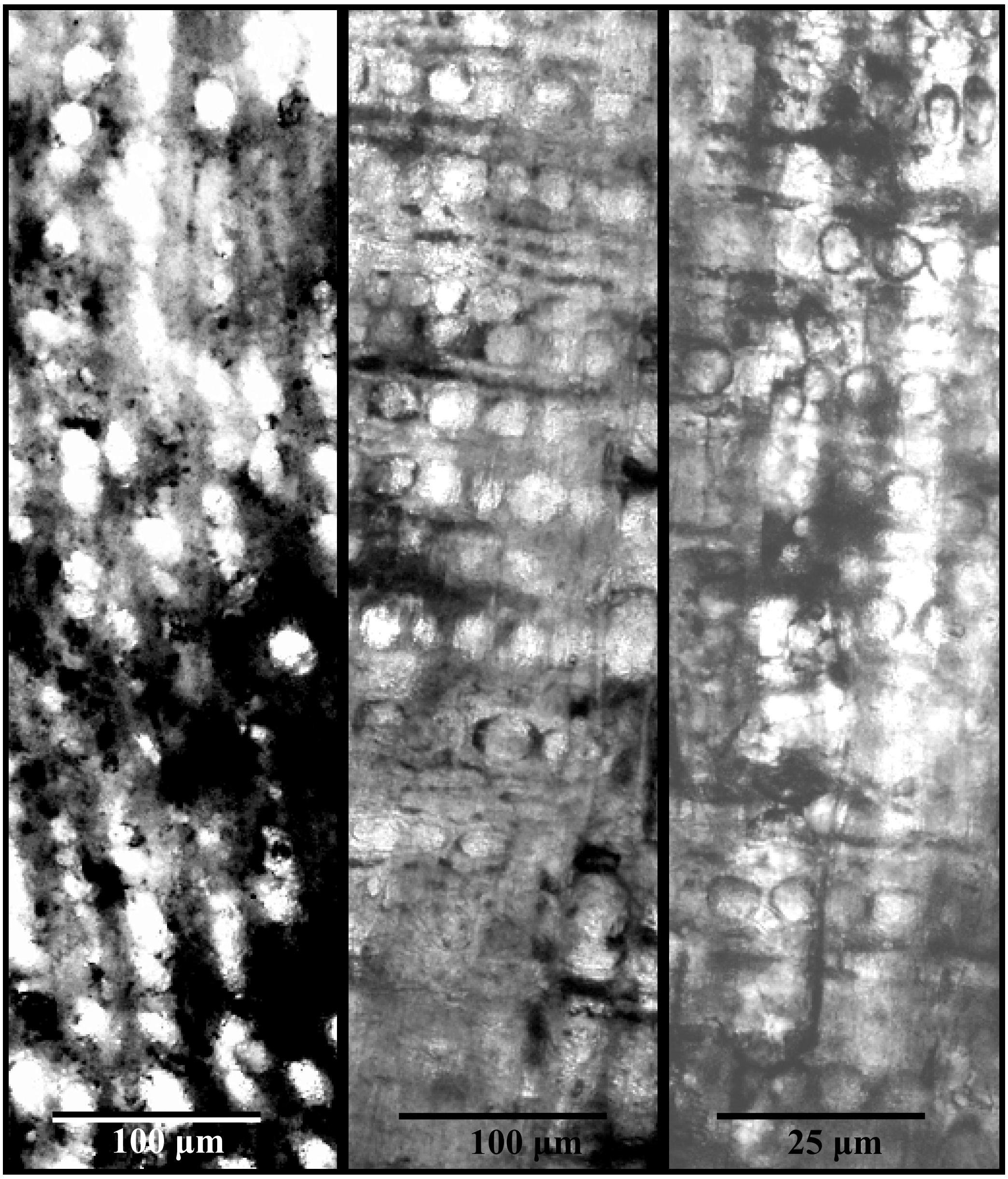


Figure 3.22 Transverse section, tangential section, and radial section of fossil wood of *Wrightia arborea* (Dennst.) Mabberley

Arecaceae

Palmoxylon Schenk (1882)

Engler, A. 3: 353-358.

Palmoxylon sp.

There is no cambium in palm stems and thus do not show secondary thickening. Their wood comprise of ground tissue in which vascular bundles are scattered. Vascular bundles contain xylem and phloem surrounded by sclerenchyma cells.

Locality: SUT loc. 28

Specimen number: SUT 70, 71, 72, 73

<u>Wood Anatomy</u>

<u>Microscopic characters</u>

Growth rings absent.

Vascular bundles scatter in the ground tissue of the wood which comprise of xylem and phloem,

Measurement of vascular bundle (tangential diameter x radial diameter) and density

Palmoxylon sp. 1: 500 x 1500 μm, 45 bundles per cm^2

Palmoxylon sp. 2: 1000 x 1500 μm, 50 bundles per cm^2

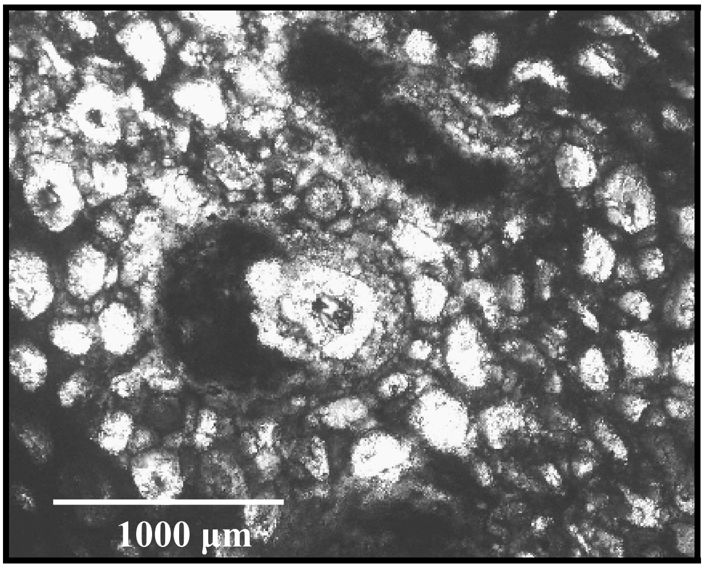
Palmoxylon sp. 3: 500 x 1000 μm, 40 bundles per cm^2

Palmoxylon sp. 4: 500 x 750 μm, 100 bundles per cm^2

Affinities

The family Arecaceae comprises about 2,500 species, and is mainly found in the tropics and subtropics. The anatomay of stem of palm differs from the dicotyledon wood. Palm lacks of cambium to have the secondary growth. The vesssel elements are vascular bundles which scattered in the parenchymatic ground tissue (Uhl, 1987, Tomlinson, 1990, Sosef, Hong, and Prawirohatmodjo, 1998).

The four specimens have the vascular bundles as the plant in the family Arecaceae. Their density, sizes, and shapes of vascular bundles differ. However, it is difficult to distinguish different exant genera of palms by the stem anatomy, and so the four specimens are placed in the genus *Palmoxylon* (Read and Hickey,1972, Wheeler and Manchester, 2002).



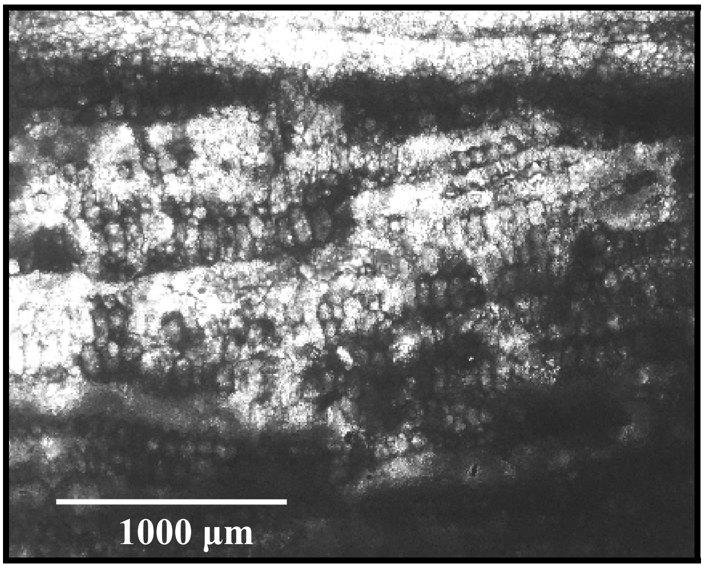
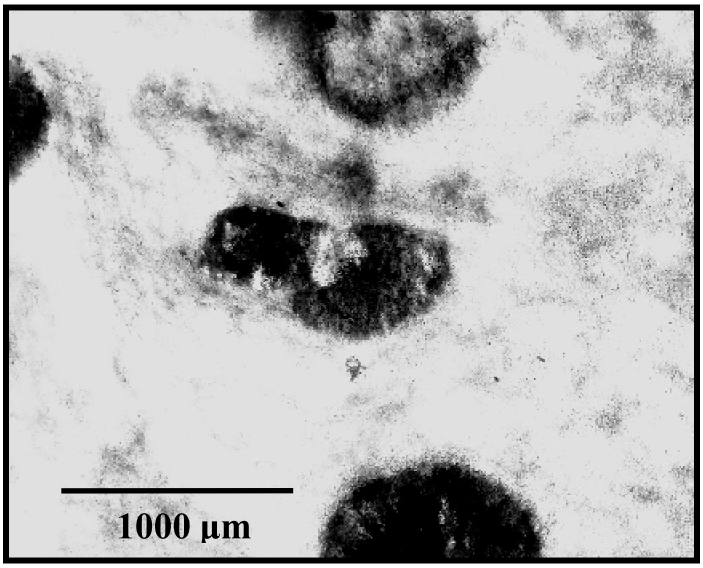


Figure 3.21 Transverse section and tangential section of

Palmoxylon sp. 1



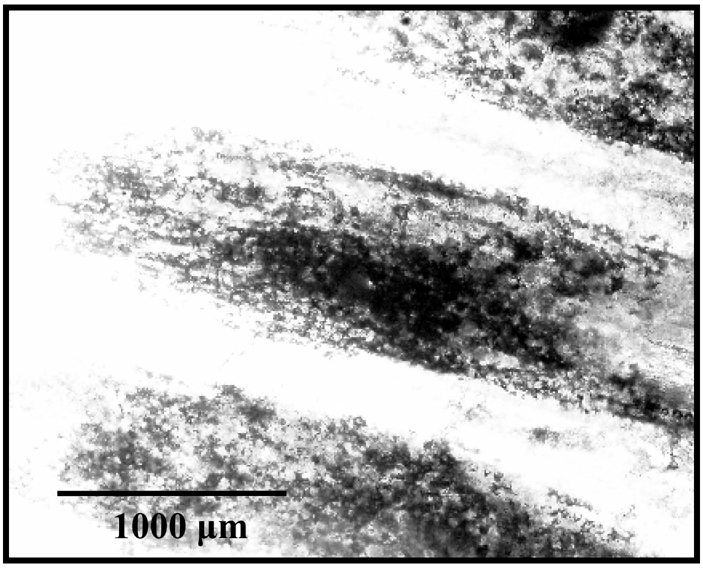


Figure 3.22 Transverse section, tangential section of

Palmoxylon sp. 2

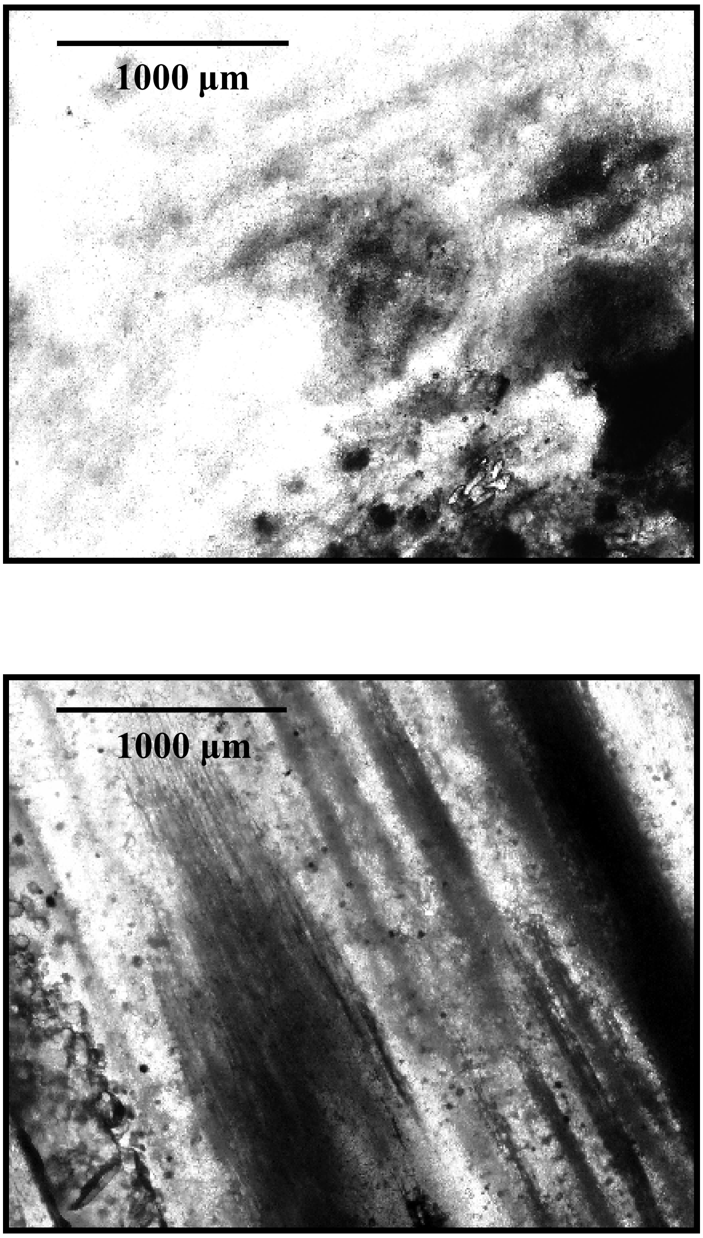


Figure 3.23 Transverse section, tangential section of *Palmoxylon* sp. 3

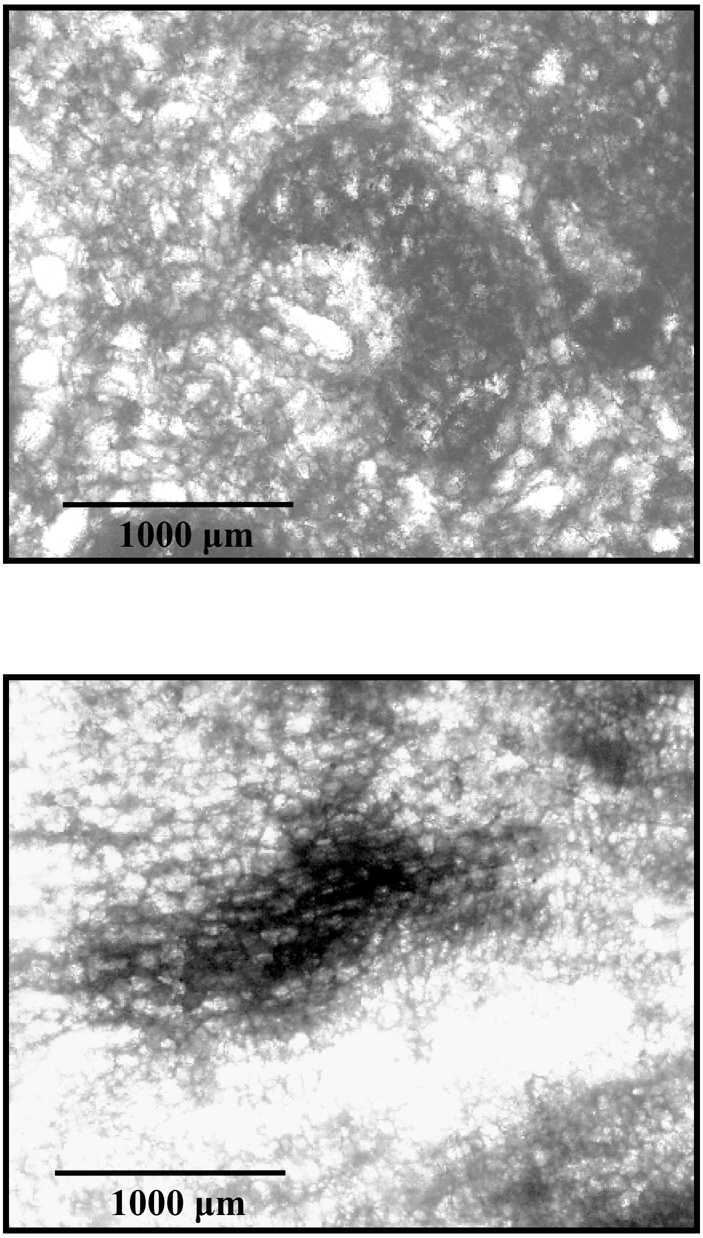


Figure 3.24 Transverse section and tangential section of *Palmoxylon* sp. 4

CHAPTER IV

DISCUSSION

4.1 Taphonomic Studies

Many logs of petrified wood are found deposited in the site Ban Krok Duen Ha, Nakhon Ratchasima. They are well preserved, many of them laid in the same direction, the base of the logs directed toward the south. I assume these logs drifted along the river and were deposited in the bottom of the river in the dry season.

In the present time, for example, the rivers in the north of Thailand always flood in the rainy season and carry many logs along with the water. Many logs can be seen that drifted to the water gate or the weir of the diversion dams. At the end of the rainy season, the water flow decreases, the water level is reduced, the waterway sometimes becoming almost dry. Some islands may form in the middle of the river, having very small water channels on the sides of the bank, and the logs lie on the bottom of the river. The light and small log may be turned occasionally to any direction by the water flow, while the heavy logs are not much changed because of their weight, they lie parallel to the course of the river. The deposition may occur because some logs block the water channel, retarding water flow. The sediment is deposited over the logs and causes the water to divert to a new water channel, maybe from one side to the other side of the river body. The next rainy season, water flows through the new water channel and erodes the bank, making the river wider. At that time, the logs have already been deposited in the bottom of the river.

In the same way, log of petrified wood in the site Ban Krok Duen Ha, Nakhon Ratchasima may have been deposited by this same phenomenon. Even though there are some logs oriented in the other direction not parallel to the course of the river, it is possible because they are small logs which can be rotated by the water flow to the other direction. However, large log are less likely to turn so they precisely indicate the direction of the river. The type of the river should not be a meandering river because the water energy is medium, it should be a nearly straight river.

There is the question for how logs come to the river. Ratanasthien (1994) explained that there was a heavy storm and heavy rain to flush the logs to the river for she found a big pile of logs. This phenomenon is possible to occur. In the other way, logs are always wiped out from the forest every rainy season, especially small logs, some broken logs, or the logs of the plants growing along the river which are easily moved to the main river. If there is some place acting as a natural weir, obstructing the floating logs, the accumulation of logs could be found. The second phenomenon should always occur for we seldom find a complete stump of petrified wood. After the deposition, the logs were infiltrated with water and then permineralised with crystals of silicate, which dissolve in the groundwater, resulting petrified wood.

The petrified wood from Ban Krok Duen Ha, Nakhon Ratchasima was deposited quite shallowly near the topsoil, about 0.2-1 m deep in a sandstone layer with some gravel, 0.2-1 cm, with some pieces of petrified wood cemented to the conglomeratic sandstone. Chonglukmani (in publishing) determined the sediment to the Miocene which means the age of the petrified wood in this site is 26 Ma BP or younger.

The fossil wood from Chaiyphum and Khon Kaen was found mostly as fracture or broken pieces of wood. One large log was found but most of it was buried underground. The depositional environments of the fossils in both sites were fluvial. The sediment consists of round gravel, 1-2 cm in diameter, sand and silt, unconsolidated or some semiconsolidated. There are no fossils that could allow age determination. The fossil wood was deposited in sand, clay and gravel, about 0.5-2 m below the topsoil of the sediments. In sand layer, about 3 m deep, which occasionally could find petrified wood deposited, but this site could not find fossils in sand layer. The fossil woods are not well preserved, there is a lot of weathering. Scattered small pieces of wood were found around the sites. From this evidence, I conclude that petrified wood from both sites was deposited in an old river because of the gravel and sand sediment. It is possible the logs fell down and drifted along the river, later sinking and being deposited in the bottom of the river. The process of primary and secondary permineralisation occurred and preserved them. Most of the fossil wood from these two sites is poorly preserved. This may be caused by the secondary permineralization, the replacement of the cell wall, not being complete. The size of the gravel shows the river was a medium energy river. The sediment of these sites appropriates to the Quaternary sediment in Khorat basin, the age of the sediment not older than 2.5 Ma BP.

4.2 The Fossil Wood was Found in Each Sites:

The fossils woods from Chaiyaphum are determined to

- *Albizia lebbeck* Benth

- *Anogeissus acuminata* (Roxb. ex DC.) Guill. & Perr.

From Khon Kaen:

Pahudioxylon sahnii Ghosh and Kazmii

Albizia lebbeck Benth

Duabanga grandiflora (Roxb. ex DC.)

Aquilaria sp.

From Nakhon Ratchasima:

Homalium tomentosum Benth.

Careya sphaerica Roxb.

Pahudioxylon sahnii Ghosh and Kazmii

Dialium cochinchinense Pierre

Milletti. leucantha Kurz

Terminalia alata Heyne ex Roth

Protium serratum (Colebr.) Engl.

*Dracontomelon dao (*Blanco) Merr. & Rolfe

Holarrhena pubescens Wall. ex G. Don.

Wrightia arborea (Dennst.) Mabberley

and 4 species of *Palmoxylon* sp.

4.3 The Distribution and Habitat of Modern Species Related to fossil woods

The genus *Homalium* comprises of over 200 species through out the tropics and sometimes in the subtropics. About 32 species are found in Southeast Asia: Philippines 11 species, new Guinea 11 species, Peninsular Malaysia 8 species, Borneo 5 species, Sumatra and Sulawesi 4 species, Java 3 species, Moluccas 2 species, and

Lesser Sundra Island 1 species. There are 11 species of *Homalium* is found in every part of Thailand, mostly abundant in the peninsular of Thailand.

H. tomentosum is distributed from the north: Chiang Mai to central part, Southeast: Ratchaburi, Southwest Kanchanaburi, Northeast: Nakhon Ratchasima through Rayong, scarcely in the peninsular. They are also found in Java, Burma, Cambodia, and Laos. The distribution of *H. tomentosum* is scattered from North-eastern India through Burma, Thailand and Indo-china, and in eastern Java. Habitat of *H. tomentosum* is strictly on well-drained site in dry climate. Seed germination is low.

H. tomentosum is a deciduous tree, up to 30-40 m tall, not grow in cluster, found in mix deciduous forest, occasionally with bamboo, and in teak forest, at low altitude; the optimized climate is dry monsoon and calcareous soil. The stems are fire-resistant and have the hard and heavy wood.

The genus *Careya* of the family Lecythidaceae comprises 4 species, are distributed from Afghanistan, Laos, Cambodia, Vietnam and Malaysia. *Careya* is closely related to *Planchonia* and both are placed in subfamily Planchonioideae, as well as Barringtonia. Takhtajan (1997) placed *Careya* in Barringtoniaceae according to the pollen type of Planchonioideae is unique among the angiosperms.

C. arborea grows well in well drained, sandy, or even rocky soils, locally in evergreen or deciduous forest, slightly seasonal forest. Growth is poor in perhumid regions. The tree is highly fire-resistant and coppices well. The fruit and new leaf are edible but the seeds are slightly poisonous.

The genus *Albizia* consists of 150 species and is the pantropical distribution. It is distributed from Africa, Madagascar and tropical America. About 20 species are found in Southeast Asia. *Albizia lebbeck* is probably the tropical mainland plant of Asia and East Africa. It is found in evergreen and deciduous forest.

Anogoeissus consist of 8 species, are found in Africa 1 species, southern Arabia 3 species, India, Sri Lanka, Nepal, Burma, Laos, Vietnam, and 2 species in Thailand. The habitat is deciduous or semi-evergreen forest, up to 1300 m altitude. They are also found in teak forest and understorey of dipterocarp forest, mixed deciduous forest, bamboo forest and even in under semi-arid conditions as dry rocky hills.

Afzelia consists of 15 species, about 10 species are found in Africa. Three species occurred in Malesian region and are distributed to eastern Sumatra, western Java. *Afzelia xylocarpa* is the native to mainland Southeast Asia , Burma, Indo-China, Thailand, (Tonanon, 1999). *Afzelia* scatters in mixed deciduous and dry evergreen forest, usually on well drained soils, at low altitudes, up to 800 m altitude. *Afzelia xylocarpa* is distributed in every part, exclude south, of Thailand. .

Dialium comprised of 30 species, it is the pantropical distribution, 20 species are found in Africa, 1 species in America. It is distributed abundantly in Southeast Asia but not cross the Wallace's line which lines between Borneo and Sulawesi (eastern of Malesia) (Tonanon, 1999). It may be the species of a western Malesia origin. *Dialium* grows well in rain forest, scatters and some are found along river banks and swamp area, in lowlands occasionally up to 1150 m altitude. *Dialium cochinchinense* is found in north of Thailand to Chumporn province in south of Thailand. *Dialium* is found in deciduous forest, are scattered and some are found along river banks.

Millettia consists of 130 species, shrubs, climbing shrubs and trees. They widely spread through the tropical and subtropical regions of Africa, Southeast Asia, China, and Australia. About 25 species are found in India, about 16 species in Thailand. They are scattered in the north and distributed through the south of Thailand to Malaysia. *M. leucantha* is a medium tree, found in the north and northeast of Thailand. It is scattered in mix decideous forest (Heywood, 1979, Takhtajan, 1980, Larsen, Saksuwan, and Vidal, 1984).

The genus *Duabanga* consists of 2 species (*D. grandiflora* and *D. moluccana*) and is distributed from the eastern Himalayas to New Guinea; eastern India, Burma, Cambodia, Lao, Vietnam, Thailand, Yunnan, Malesia and Indonesia (except Sumatra and Western Java) *D. grandiflora* is scattered in mainland of South-East Asia. In Thailand, they are distribute from North to South of the country: Chiang Rai, Chiang Mai, Phrae; North-Eastern: Nong Khai, Nakhon Ratchasima, Ubon Ratchathani; South-Eastern: Chonburi, South-Western: Kanchanaburi; Central: Saraburi; South: Chumphon, Satun, Yala.(Santisuk, 1992). It grows along the rivers, especially in hilly country on the moist valley slopes. *Duabanga* is placed in the family Lythraceae. Takhtajan (1997) considered *Duabanga* to represent a family Duabangaceae, close relative to Lythraceae.

Duabanga is a pioneer species and found up to 1,200 m altitude the seedlings are very light demanding and grow well in open areas. The very small winged seeds, about 7,000-8,000, contain in a single fruit and disperse by wind. Their flowers bloom in the night time, pollinate by the bats and fall the next morning. Tree is deciduous or partially deciduous for a brief period. (Awasthi, 1969; Lemmens, Soeriangara, and

Wang, 1995, Santisuk, 1992).). *Duabnga* is a well dispersed plant because of numerous seeds and seedlings grow well in open area.

The genus *Aquilaria* consists of about 15 species, mostly shrub, are scattered from eastern India and Burma through Southeast Asia to the Philippines, and Malaysia (Pearson, 1932b). It is found in evergreen to dry evergreen forest in northeast and east of Thailand.

The genus *Anogoeissus* consists of 8 species, are found in Africa 1 species, southern Arabia 3 species, India, Sri Lanka, Nepal, Burma, Laos, Vietnam, and 2 species in Thailand. It is found in deciduous or semi-evergreen forest, up to 1300 m altitude, are also a in teak forest and understorey of dipterocarp forest, mixed deciduous forest, bamboo forest and even in under semi-arid conditions as dry rocky hills. *Anogeissus acuminata* is distributed in India, Burma, Indochina and every part of Thailand.

The genus *Terminalia* consists of about 200 species, it is pantropical genus which distributed in tropical region, subtropical and coastal regions. About 30 species in America, 30 species in Africa, 35 species in Madagascar, 70 in Asia and 29 species in Australia and Australasia. There are 17 species in Thailand (The Forest Herbarium, Royal Forest Department, 2001). The habitat is the canopy or subcanopy of the evergreen to semi-deciduous forest or sometimes deciduous forest. They prefer moist locations as periodically flooded riparian forest, but are also found in hill forest, teak forest and dry mixed dipterocarp forest, the climate ranges from ever wet to seasonal. *T. alata* is distributed in India, Burma, and Indo-China, every part of Thailand except in south. (Nanakorn, 1985). It grows in mixed deciduous forest, and dry mixed dipterocarp forest, often on alluvial soils up to 1000 m altitude.

The genus *Protium* consist of 85 species, most of them are found in tropical America, Madagascar, and from India to Indochina, Thailand , Java, Philippines. There is only 1 species is found in continental Asia, *Protium serratum*. It is distributed in every part of Thailand. It grows in evergreen or semi deciduous, lowland, up to 800 m altitude.

The genus *Dracontomelon* consists of 8 species that are distributed in India, Burma, Indo-China, Thailand, Malaysia, and Indonesia, to Solomon Island, New Caledonia and Fiji. *Dracontomelon dao (*Blanco) Merr. & Rolfe has the largest area of distribution, from India to Solomon Island. It is distributed in every part of Thailand. It is scattered in evergreen or semi-deciduous forest (monsoon forest) at low altitude, rarely 500-1000 m altitude, in a high rainfall area or moist area as swamp land.

The genus *Holarrhena* consists of 4 species from Africa and Asia, 2 species are found in Thailand. It is distributed in Eastern and Southern Africa, India, Nepal, Bangladesh, Burma. China, Laos, Cambodia, Vietnam, and Thailand. *H. pubescens* is found from the north, northeastern through the south of Thailand. The habitat is found in grassland, open forest or clearings in thick forest, from the lowland up to 1100 m altitude.

The genus *Wrightia* consists of 26 species, which are distributed in India, Burma, Indo-Chin, South China, Thailand, Malaysia, Indonesia, to Solomon Island, and northeastern Australia. Most of the species are found in India and Indo-China, and only 5 species in Malesian area. There are 9 species in Thailand.

Wrightia grows from evergreen rain forest to savanna and thickets along the beach. The altitude range is from sea level to 1800 m, in lowland hill evergreen to deciduous primary or secondary forest. *W. arborea* is found in areas with and annual rainfall if 875-3750 mm. It is distributed from India, Sri Lanka, Burma, Southern China Laos, Vietnam to Thailand (Botanical Division, Royal Forest Department, 1972, 1975, 1983).

The family Palmae is the main characteristic plant of tropical and subtropical regions. This family is distributed in the tropics of Africa, America, and Asia. The root of the palm will died at temperature less than –8ºC. The coldest temperature that palm can survived is 8ºC mean annual temperature (Uhl and Dransfield, 1987).

4.4 Paleoclimate

There are only 2 species from Chaiyaphum, and 4 species from Khon Kaen are determined for the fossils in these sites are not well preserved. The age of these plants are aged to Quaternary, not older than 2.5 Ma BP.

Both species of fossil woods, *Albizia lebbeck* Benth *Anogeissus acuminata* (Roxb. Ex DC.) Guill & Perr, shared the same habitats; they grew in evergreen forest to the deciduous forest. There is one point to discuss for *Anogeissus acuminata*, a pioneer species. It is possible that when the bank of the river eroded, the area in that vicinity was opened. Maybe the pioneer species *Anogeissus acuminata* succeeded to that area. Later, the direction of the water channel changed again, the place where *Anogeissus acuminata* stood eroded again causing it to fall into the river, or there was a heavy rain which eroded the bank and flushed it into the river. In the present day, these two plants are still abundant in the Khorat Plateau. Even though there is very little evidence, the plants indicate that the climate in Chaiyaphum in the Quaternary more or less resembled that of the present day.

The fossil wood from Khon Kaen was determined to four species, *Pahudioxylon sahnii* Ghosh and Kazmii*,* *Albizia lebbeck* Benth, *Duabanga grandiflora* (Roxb. ex DC.) and *Aquilaria* sp. The modern species are still found in the Northeast. They are found in the moist area along the river, such as *Afzelia xylocarpa*, as is *Intsia* which is found in the South. *Duabanga grandiflora* is also a pioneer species, which maybe occupied the open area along the bank, and fell into the river in the same way as mentioned for *Anogeissus acuminata. Aquilaria* sp. also provides good evidence, for it grows in the evergreen forest and moist area as a second or third stratum in the forest, indicating that this area in Quaternary should be evergreen forest or semi-evergreen forest and the climate should be cooler than present day, and the precipitation should higher than 1000 mm annually. I could not say that the Quaternary climate in Khon Kaen differed from that of Chaiyaphum, because the flora in Chaiyaphum has only two species.

Fifteen species of fossil wood were found in Nakhon Ratchasima: *Homalium tomentosum, Careya arborea* Roxb., *Pahudioxylon sahnii* Ghosh and Kazmii, *Dialium cochinchinensis* Pierre, *Millettia. leucantha* Kurz., *Terminalia alata* Heyne ex Roth, *Protium serratum* (Colebr.) Engl., *Dracontomelon dao (*Blanco) Merr. & Rolfe, *Holarrhena pubescens* Wall. ex G. Don., *Wrightia arborea* (Dennst.) Mabberley, and 4 species of *Palmoxylon* sp. The habitat of these plant can be grouped into 4 types:

1. *Holarrhena pubescens,* found in grassland, open forest or clearings in thick forest.

2. Plants often growing along the river : *Duabanga grandiflora, Dialium cochinchinense,* and *Afzelia xylocarpa,*

3. Plants growing in mixed deciduous and dry evergreen forest *Millettia leucantha, Protium serratum*

4. Plants growing in a high rainfall area or moist area as swamp area. *Dracontomelon dao*, *Wrightia arborea* and palm trees.

From these habitats, the reconstruction of the paleoecosystem of the forest could be as follows: these ecosystems could be highland with high rainfall for plants in moist area can grow such as *Dracontomelon dao*, *Wrightia arborea* and palm trees. There were streams from the highland to the lowland along which *Duabanga grandiflora, Dialium cochinchinense, Afzelia xylocarpa* were scattered. In the low land there was mixed deciduous forest connected to evergreen forest with *Millettia leucantha, Protium serratum Dialium cochinchinense* and *Afzelia xylocarpa.* There was some open dry area in which was found *Holarrhena pubescens* and *Homalium tomentosum*. The climate should more or less resemble that of the present day.

From the geological record, there were many glacial periods and interglacial periods that occurred during the Quaternary period. The fluctuation of the climate significantly effected the communities of the plants in those times (Hall, 2002). The tropical plants would have to migrate to the warmer places in the glacial period and to move back when the climate was warmer in the interglacial period. The migration of plants occurred for the survival, on the other hand, it is the mechanism of the distribution of plants for the succession to the optimal area. The modern plants still survive from the Cenozoic expressing that the fluctuation of the climate in Thailand did not strongly effect the survival of plants.

The migration of plant is quite interesting, for example, there are many records of the fossils of *Afzelia* sp. in the tropical zone of India but the genus is not found in present day India. This extinction of *Afzelia* shows that even if there is the migration of plants, it is not necessary that every plant can survive and migrate back to the same site, maybe because of many other physical factors that limit the migration, such as topography, wind etc. Otherwise, the interaction between plants and animals should be considered. The dispersion of seeds and the pollination by animals are major factors of the migration of plants along with the physical factors. If there were not enough animals or the animals became extinct, the dispersion of plants would be limited. The other factor is the competition between the plant species; the succession of the plants in the community could be the other factor for the migration and extinction of the plant species.

4.5 Conclusion

From the fossil wood determination, the fossil plants resemble those of the present day. The fossil wood in Chaiyaphum and Khon Kaen is from the Plio-Pleistocene, about 5 Ma BP to 10 Ka BP, and the plants and climate at least during the time of deposition more or less resembled those of the present day. The precipitation could be higher than at the present because the ecosystem was semi-evergreen forest or riparian forest.

The fossil wood in Nakhon Ratchasima could be determine to Miocene up to Recent, 20Ma BP up to the present, because the oldest age of *Terminalia alata* is 20 Ma BP (Chowdhury, and Tandon, 1964). The ecosystem is evergreen forest connected to the deciduous forest with streams flowing from the highland to the lowland. The climate almost resembled that of the present day with a little more humidity and precipitation.

These results should not be considered representative of the overall climate of the Plio-Pleistocene or Miocene for the time period of the deposition of the fossils studied is a small fraction of the 25 million years of the Miocene to Pleistocene. At least, it can be interpreted that during particular periods of time there was a warm climate, suitable to the tropical plants, and those plants could survive to the present day.

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APPENDICES

APPENDICES A

Recent wood species surveyed for comparison with fossil taxa(speciemens from Wood Herbarium of Royal Forestry Department)

Family Annonaceae

Annona mannii Oliv.

Cananga latifolia Finet. et Gagnep.

Cananga odorata Hook f. et Th.

Enantia chlorantha Oliv.

Goniothalamus macrophyllus Hook f. et Th

Meiogyne virgate Miq.

Milliusa velutina Hook f.

Metrephora vandiflora Kurz.

Platymitra siamensis Craib

Polyalthia cerosoides Benth.

Polyalthia debilis Finet et Gagnep.

Polyalthia suaveolens Engl. et Dieb.

Polyalthia viridis Craib

Saccopetalum lineatum Craib

Sageraea lancedata Miq.

Family Anacardiaceae

Anacardium excelsum Skeels.

Bouea microphylla Griff.

Bouea oppositifolia (Roxb.) Adells.

Buchanamia arborescens Blume

Buchanamia latifolia Roxb.

Campnosperma auriculata Hook f.

Family Anacardiaceae

Dracontamelon dao Merr.

Gluta sp.

Family Anacardiaceae

Holigana kurzil King.

Koordersiodendron pinnatum Merr.

Lannea stuhllmannii Engl.

Mangifera altissima Blco.

Mangifera caloneura Kurz.

Mangifera camptosperma Pierre

Mangifera indica Linn.

Melanorrhoea sp.

Melanorrhoea usitata Wall.

Odina wodier Roxb.

Pentuspadon velutinus Hook f.

Pistacia chinensis Bunge.

Poupartia axillaris King & Prain. = *Choerospundias axillaris* B.L.Burtt et Hill

Rhodospaera rhodanthema Engl.

Rhus diversiloba Torr. & Gray.

Rhus glabra Linn.

Rhus japonica Linn.

Rhus succedanea Linn.

Rhus tricocarpa Miq.

Sclerocarya caffra Sond.

Tapirira guianensis Aubl.

Family Apocynaceae

Alstonia boonei De Wild.

Alstonia scholaris R.Br.

Alstonia macrophylla Wall.

Alstonia spatulata Blume.

Alstonia spectabilis Kurz.

Dyera costulata Hook f.

Dyera lowii Hook f.

Holarrhena probescens Wall.

Wrightia tomentosa Roem & Schultes

Family Boraginaceae

Cordia alliodora Oken.

Cordia clarkei Brac. ex Pram.

Cordia didrotona Forst. f.

Family Burseraceae

Aucoumea klaineana Pierre

Bursera serrata Colebr.

Canarium aspernum Benth.

Canarium denticulatum Bl.

Canarium kerri Craib

Canarium indicum Stickm.

Canarium schweinfurthii Engl.

Canarium venosum Craib

Dacryodes buettneri H. J. Lam.

Dacryodes edulis H. J. Lam.

Dacryodes pubescens H. J. Lam.

Garuga pinnata Roxb.

Protium serratum Engl.

Tetragastris panamensis O. Ktze.

Tetragastris lawrenca Standl.

Tetragastris malaccensis Hook f.

Family Combretaceae

Anogeissus acuminata Wall.

Combretum quadrangulare Kurz.

Lumnitzera littorea Voigt.

Terminalia alata Heyne ex Roth

Terminalia amazonia Exel.

Terminalia arjuna Bedd.

Terminalia belerica Roxb.

Terminalia catappa Retz.

Terminalia citrina Roxb.

Terminalia complanata K.Schum.

Terminalia cremilata Roth.

Terminalia glaucifolia Craib

Terminalia ivorensis A. Cher.

Terminalia triptera Stapf.

Family Combretaceae

Terminalia manii King et Muell. Arg.

Terminalia myriocarpa Van Heurck.

Terminalia obliqua Craib

Terminalia paniculata W.&A.

Terminalia pierrei Gagnep.

Terminalia procera Roxb.

Terminalia sumatrana Miq.

Terminalia superba Engl. et. Diels.

Family Fagaceae

Quercus petraea

Quercus pyrenaica Willd.

Quercus robur Linn.

Quercus rubra Linn.

Quercus serrata Thunb.

Family Flacourtiaceae

Kiggelaria africana Linn.

Hydnocarpus ilicifolias King

Hydnocarpus anthelminthicus Pierre

Homalium tomentosum Benth.

Homalium foetidum Roxb.

Homalium damrongianum Craib

Caseraria calva Craib

Dovyalis eaffra (Harv. et. Sond.) Warb.

Family Guttiferae

Calophyllum benjamina Ridley

Calophyllum fhloribundrum Hk f.

Calophyllum inophyllum Linn.

Cratoxylun arborecens Blume

Cratoxylun celebicum Blume

Cratoxylun formosum Dyer

Family Guttiferae

Garcinia cornea Linn.

Garcinia hanburyi Hook f.

Garcinia thorelii Pierre

Mammea siamensis Kosterm.

Mesua ferrea Linn.

Family Lecythidaceae

Barringtonia acutangula Gaertn.

Careya arborea Roxb.

Lecythis longipes Poit.

Family Fabaceae

Acacia catedrum Willd.

Acacia arabica Willd.

Acacia auriculaeformis A. Cunn.

Acacia confusa Merr.

Acacia leucophloea Willd.

Acacia mangium Willd.

Acacia melanoxylon R.Br.

Acacia modesta Wall.

Acacia mollissima Willd.

Acacia nigrescens Oliv.

Acacia saligna Wendl.

Acacia siamensis Craib

Acrocarpus fraximifolius Wight & Asn.

Adenanthera intermedia Merr.

Adenanthera microsperma Teysm.

Afronmosia elata Harms.

Afzelia africana Smith.

Afzelia bipindensis Harm.

Afzelia cochinchinensis Pierre.

Afzelia rhomboidea Prain.

Afzelia xylocarpa Craib.

Albizia acle Merr.

Albizia ferruginea Benth.

Albizia lebbeck (L.) Benth.

Family Fabaceae

Albizia lucida Benth.	*Albizia odoratissima* Benth.
Albizia praecox Mart.	*Albizia procera* Benth.
Albizia retusa Benth.	*Bauhinia* sp.
Brachystegia eurycoma Harms.	*Burkea africana* Hook.
Butea frondosa Roxb.	*Caesalpinia echinata* Lam.
Caesalpinia sappan Linn.	*Calpocalyx heitzii* Pell.
Cassia bakeriana Craib	*Cassia fistula* Linn.
Cassia garrettina Craib	*Cassiajavanica* L.
Cassia siamea Lamk.	
Castanospermum australe A.Cunn.	*Cathormiom umbellatum* Kosterm
Cladrastis platycarpa Makino	*Cercidium floridum* Tul.
Copaifera tessmannii Harms.	*Cordyla africana* Lour.
Crudia chrysantha K. Schum.	*Cynometra ananta* Hutch. et. Dalz.
Cynometra polyandra Roxb.	*Cynometra ramiflora* Linn.
Dalbergia bariensis Pierre	*Dalbergia cochinchinense* Pierre
Dalbergia cultrata Graham	*Dalbergia latifolia* Roxb.

Dalbergia ingrescens Kurz	*Dalbergia oliveri* Gamble
Family Fabaceae	
Dalbergia sissoo Roxb.	*Dialium cochinchinense* Pierre.
Dialium guineense Willd.	*Dicorynia rubra* Miq.
Dipteryx odorata Willd.	*Distemonanthus benthamianus* Baill.
Enterolobium cyclocarpum Gris.	*Eperua falcata* Aubl.
Erythrina suberosa Roxb.	*Erythrophleum guineense* G.Don.
Erythrophleum ivorense A. Cher.	*Erythrophleum succirubrum* Gagnep
Erythrophleum teysmannii Guib	*Gleditsia japonia* Nak.
Gleditsia triacantho Linn.	*Gossweilerodendron balsamiferum* Hams.
Hardwickia binata Roxb.	*Hymenaea courbaril* Linn.
Intsia bakeri Prair.	*Intsia bijunga* O. Ktz.
Intsia retusa O.Ktz.	*Kingiodendron alternifolium* Merr. et Rolf.
Koompassia borneensis Merr.	*Koompassia exelsa* (Bea.) Taub.
Koompassia malaccensis Benth.	*Laburnum anagyroides*

	Med.
Laburnum amurensis Rupr. et Max.	*Milletta atropurpurea* Benth.
Milletita caffra Meissn.	*Millettia leucantra* Kurz
Millettia versicolor Welw. ex Bak.	Millettia pachycarpa Benth
Millettia pulchra Benth. Kurz.	*Millettia xylocarpa Miq.*
Millettia caerulea Baker	*Millettia gaucescens Kurz.*
Myrocarpus frondosus Fr. All.	
Myroxylon balsamum (L.) Harnus.	*Newtonia budanannii* Gilbert et Boutique.
Ormosia coccinea Jack	*Parkia biglobosa* Benth.
Parkia filicoidea Welw. ex Oliv.	*Parkia javanica* Merr.
Parkia pendula Benth.	*Parkia venose* Benth.
Parkia paniculata Benth.	*Peltophorum dasyrachis* Kurz
Peltophorum inerme Llanos.	*Peltophorum macrophylla* Benth.
Peltophorum africana Hook f.	*Piptadeniastrum africanum* Brenam.
Piptadeniastrum confertum Benth.	*Piptadeniastrum Flexicault* Coult.
Piptadeniastrum jiringa Pram.	*Pongamia pinnata* Merr.

Prosopis pubescens Benth.

Pterocarpus erinaceus Poir.

Pterocarpus indicus Willd.

Pterocarpus macrocarpus Kurz

Family Fabaceae

Pterocarpus soyauxii Taub.

Pterocarpus tinctorius Welw.

Pterocarpus vidalianus Rolf.

Robinia pseudoacacia Linn.

Samanea saman Merr.

Sindora coriacea Prain

Sindora maritina Pierre

Sindora siamensis Teijsn. ex Miq.

Sindora supra Merr.

Vataicreopsis speciosa Ducke.

Virgilia oroboides Salter.

Vouacapoua americana Aubl.

Xylia dolabriformis Benth.

Xylia kerrii Craib & Hutch.

Family Lythraceae

Lagerstroemia calyculata Kurz.

Lagerstroemia cuspidata Wall.

Lagerstroemia floribunda Jack	*Lagerstroemia anceolata* Wall.
Lagerstroemia parviflora Roxb.	*Lagerstroemia speciosa* Pers.
Lagerstroemia subcostata Dros.	*Lagerstroemia tomentosa* Presl.
Lagerstroemia villosa Wall.	*Lafoensia punicifolia* DC.

Family Magnoliaceae

Liriodendron tulipifera Linn.	*Magnolia acuminata* Linn.
Magnolia hypoleuca Sieb. et Zucc.	*Magnolia odorata* Thunb.
Manglietia insignis Bl.	*Michelia champaca* Linn.
Michelia kachirachirai H. Keng.	*Talauma gioi* A. Cher.

Family Malvaceae

Bombycidendron vidalianum M.&R.	*Coelostegia griffithii* Benth.
Cullenia excelsa Wight.	*Hibiscus macrophyllus* Roxb.
Hibiscus tiliaceus Linn.	*Kydia calycina* Roxb.
Thespesia populnea Soland.	

Family Melastomataceae

Dactylocladus stenostachys Oliv.

Family Meliaceae

Aglaia anadamania Heirn.

Aglaia odoratissima Blume

Aglaia pirifera Hance.

Amoora cucullata Roxb.

Family Meliaceae

Amoora polystachya Hook f. & Jackson

Chukrasia tabularis A. Juss.

Chukrasia schumanii A. DC.

Chukrasia velutina W. & R.

Disoxylon altissimum Merr.

Lansium domestiam Corr.

Sandoricum indicum Corr.

Toona calantas Merrill & Rolfe

Toona ciliata M. Roen.

Family Moraceae

Artocarpus anisophylla Miq.

Artocarpus elastica Rein.

Artocarpus lakoocha Roxb.

Artocarpus lanceofolius Roxb.

Broussonetia papyrifera Vent.

Cudrania javanensis Treail.

Ficus callosa Willd.

Ficus cunia Buh. & Han.

Ficus glomerata Roxb.

Streblus asper Lour.

Family Myrtaceae

Eucalyptus acmenioides Schau.

Eucalyptus capitellata Sm.

Eugenia cumini Druce.

Eugenia grata Wight.

Melaleuca leucadendron Linn.

Syzygium grande Walp.

Family Rubiaceae

Adena cordifolia Benth. et Hk.f.

Adena polycephala Benth.

Anthocephalus cadamba Miq.

Canthiun nitidum Craib

Cinchona sp.

Gardenia collinsae Craib

Gardenia obtusifolia Roxb.

Hymenodictyon excelsum Wall.

Mitragyna brunonis Craib

Morinda coreia Han.

Nauclea brunnea Craib

Nauclea diderridrii Merril.

Nauclea obtusa Bl.

Nauclea orientalis Linn.

Neonauclea calycina Merr.

Neonauclea sessilifolia Merr.

Paederia tomentosa Blume.

Randia longespina DC.

Tarenna hoaensis Pit.

Family Rutaceae

Limonia acidessimea Linn.

Murraya paniculata Jack

Zanthoxylum budrunga Wall.

Family Sapotaceae

Madhuca pierrei H. J. Lam	*Manilkara hexandra*
Dubard.	
Manilkara kauki Dubard.	*Mimusops elengi* Linn.

Family Sapotaceae

Mimusops heckelii Hutch. et Dalz.	*Palaquium odoratam* Engl.

Family Sonneratiaceae

Duabanga moluccana Bl.	*Duabanga sonneratioides* Hun. L. (syn. *D. grandiflora* Roxb.)
Sonneratia alba J. Sm.	*Sonneratia caseolaris* Engl.

Family Theaceae

Adinandra milletii Berth. et Hook.f.	*Camellia japonica* Linn.
Gordonia lasianthus Linn.	*Stewartia monadelpha* Sieb et Zucc.

Family Thymeleaceae

Aquilaria crassna Pierre et Lecomte	*Aquilaria malaccensis*
Lam.	

APPENDICES B

Table 1 Affinities of recent wood species of Anacardiaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Family Anacardiaceae			
Anacardium excelsum Skeels.	Mostly solitary, avg. t.d. 270 μ r.d. 300 μ, 1-1.5 vessels/mm^2	Paratrachael aliform	biseriate, 6 rays/mm, 350-400 μ high, 95-40 μ wide, homogeneous
Bouea microphylla Griff.	Mostly solitary, avg. t.d. 160 μ r.d. 200 μ, 2-2.5 vessels/mm^2	Apotrachael band	1-2 seriate, mainly uniseriate, 6 rays/mm, 350-400 μ high, 35-40 μ wide, homogeneous
Buchanamia arborescens Blume.	Mostly solitary, avg. t.d. 220 μ r.d. 200 μ, 1-1.5 vessels/mm^2	Apotrachael	1-3 seriate, mainly biseriate, 4 rays/mm, 200-330 μ high, 30-40 μ wide, homogeneous

Table 1 (continued) Affinities of recent wood species of Anacardiaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Buchanamia latifolia Roxb.	Mostly pore chain, avg. t.d. 180 µr.d. 140 µ, 4-5 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 11 rays/mm, 200-300 µ high, 25-30 µ wide, homogeneous
Campnosperma auriculata Hook f.	Solitary and in radial multiple of 2-3, avg. t.d. 160 µ r.d. 120 µ, 14-15 vessels/mm^2	Apotrachael	mainly biseriate, 4 rays/mm, 400-580 µ high, 15-20 µ wide, homogenous
Dracontamelon dao Merr.	Solitary and in radial multiple of 2-3, avg. t.d. 200 µ r.d. 3000 µ, 3-4 vessels/mm^2	Paratrachael vasicentric	1-3 seriate, mainly biseriate, 4 rays/mm, 300-550 µ high, 30-35 µ wide, homogenous

Table 1 (continued) Affinities of recent wood species of Anacardiaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Gluta sp.	Mostly solitary, avg. t.d. 250 μ r.d. 280 μ, 1-1.5 vessels/mm^2	Apotrachael band	mainly uniseriate, 8 rays/mm, 200-450 μ high, 15-20 μ wide, homogeneous
Holigana kurzil King.	Mostly solitary, avg. t.d. 350 μ r.d. 250 μ, 1-1.5 vessels/mm^2	Paratrachael confluent	1-3 seriate, mainly triseriate, 9 rays/mm, 200-550 μ high, 25-50 μ wide, heterogeneous
Koordersiodendron pinnatum Merr.	Mostly solitary, avg. t.d. 210 μ r.d. 180 μ, 5-6 vessels/mm^2	Apotrachael band	2-3 seriate, mainly biseriate, 6 rays/mm, 300-420 μ high, 30-40 μ wide, homogeneous
Lannea coromandelica (Houtt)Merr.	Mostly solitary, avg. t.d. 210 μ r.d. 180 μ, 5-6 vessels/mm^2	Apotrachael band	2-3 seriate, mainly biseriate, 6 rays/mm, 300-420 μ high, 30-40 μ wide, homogeneous

Table 1 (continued) Affinities of recent wood species of Anacardiaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Mangifera altissima Blco.	Mostly solitary, avg. t.d. 400 μ r.d. 300 μ, 1-1.5 vessels/mm^2	Apotrachael band	1-2 seriate, mainly biseriate, 9 rays/mm, 250-350 μ high, 30-40 μ wide, homogeneous
Mangifera camptosperma Pierre.	Mostly solitary, avg. t.d. 200 μ r.d. 170 μ, 5-6 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 7 rays/mm, 300-400 μ high, 20-30 μ wide,
Melanorrhoea usitata Wall.	Mostly solitary, avg. t.d. 190 μ r.d. 150 μ, 1-1.5 vessels/mm^2	Apotrachael band	mainly uniseriate, 6 rays/mm, 250-450 μ high, 25-30 μ wide, homogeneous
Pentaspadon velutinus Hook f.	Mostly solitary, avg. t.d. 120 μ r.d. 70 μ, 15-18 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 7 rays/mm, 280-400 μ high, 25-50 μ wide, homogeneous

Table 1 (continued) Affinities of recent wood species of Anacardiaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Pistacia chinensis Bunge.	Mostly solitary, avg. t.d. 120 μ r.d. 100 μ, 10-12 vessels/mm^2	Apotrachael	mainly 5-seriate, 8 rays/mm, 200-400 μ high, 40-90 μ wide, homogeneous
Poupartia axillaris King & Prain.	Mostly solitary, avg. t.d. 140 μ 7 r.d. 110 μ, 5-6 vessels/mm^2	Apotrachael	1 and 5 seriate, mainly 5-seriate, rays/mm, 150-400 μ high, 20-50 μ wide, homogeneous
Rhus diversiloba Torr. & Gray	Mostly solitary, avg. t.d. 110 μ r.d. 70 μ, 18-20 vessels/mm^2	Apotrachael	1-3 seriate, mainly triseriate, 8 rays/mm, 280-400 μ high, 25-50 μ wide, homogeneous
Rhus japonica Linn.	Mostly solitary, avg. t.d. 120 μ r.d. 70 μ, 15-18 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 7 rays/mm, 600-1000 μ high, 25-50 μ wide, homogeneous

Table 1 (continued) Affinities of recent wood species of Anacardiaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Sclerocarya caffra Sond.	Radial multiple, avg. t.d. 130 μ r.d. 100 μ, 6-8 vessels/mm^2	Apotrachael	2-4 seriate, mainly 4-seriate, 6 rays/mm, 150-400 μ high, 40-50 μ wide, homogeneous
Spondias pinnata (L.f.) Kurz	Mostly solitary, avg. t.d. 200 μ r.d. 200 μ, 15-18 vessels/mm^2	Apotrachael	5-7 seriate, mainly 5-seriate, 4 rays/mm, 250-800 μ high, 40-90 μ wide, homogeneous
Tapirira guianensis Aubl.	Mostly solitary, avg. t.d. 210 μ r.d. 160 μ, 2-5 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 5 rays/mm, 300-700 μ high, 30-50 μ wide, homogeneous

Table 2 Affinities of recent wood species of Apocynaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Apocynaceae			
Alstonia boonei De Wild.	Mostly multiple pore, avg. t.d.100 μ, r.d. 150 μ, 6-7 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 6 rays/mm, 300-700 μ high, 30-40 μ wide, hetrogeneous
Alstonia macrophylla Wall..	Mostly pore chain, avg. t.d.120 μ, r.d. 100 μ, 47-50 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 8 rays/mm, 400-600 μ high, 20-30 μ wide, heterogeneous
Alstonia scholaris R.Br	Mostly multiple pore, avg. t.d.200 μ, r.d. 150 μ, 3-4 vessels/mm^2	Apotrachael	mainly uni and bi seriate, 7 rays/mm, 400-700 μ high, 20-35 μ wide, heterogeneous

Table 2 (continued) Affinities of recent wood species of Apocynaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Alstonia spectabilis Kurz.	Mostly pore chain, avg. t.d. 120 μ, r.d. 100 μ, 27-30 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 6 rays/mm, 300-700 μ high, 20-30 μ wide, heterogeneous
Dyera costulata Hook f.	Mostly multiple pore, avg. t.d.150 μ, r.d. 120 μ, 2-3 vessels/mm^2	Apotrachael	1 and 3 seriate, mainly triseriate, 6 rays/mm, 400-600 μ high 20-60 μ wide, heterogeneous
Dyera lowii Hook f.	Mostly multiple pore, avg. t.d. 200 μ, r.d. 100 μ, 2-4 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 6 rays/mm, 200-750 μ high, 20-50 μ wide, heterogeneous
Holarrhena probescens Wall.	mulitple pore, avg. t.d.60 μ r.d. 90 μ, 15-17 vessels/mm^2	Apotrachael	1-3seriate, mainly biseriate, 8 rays/mm, 120-350 μ high, 20-30 μ wide, heterogenous

Table 2 (continued) Affinities of recent wood species of Apocynaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Wrightia tomentosa Roem & Schultes	Mostly pore chain, avg. t.d. 50 μ r.d. 50 μ, 23-25 vessels/mm^2	Apotrachael	1-2 seriate, mainly uniseriate, 5 rays/mm, 300-700 μ high, 30-50 μ wide, heterogeneous

Table 3 Affinities of recent wood species of Burseraceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Family Burseraceae			
Aocoumea klaineana Pierre.	Mostly solitary, avg. t.d. 210 µ r.d. 140 µ, 4-5 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 4 rays/mm, 250-300 µ high, 20-30 µ wide, homogeneous
Bursera serrata Colebr.	Mostly solitary, avg. t.d. 140 µ r.d. 100 µ,13-15 vessels/mm^2	Apotrachael	1-3 seriate, mainly biseriate, 10 rays/mm, 250-300 µ high, 20-30 µ wide, homogeneous
Canarium aspernum Benth.	Mostly solitary, avg. t.d. 110 µ r.d. 140 µ ,6-7 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 5 rays/mm, 350-350 µ high, 20-30 µ wide, homogeneous

Table 3 (continued) Affinities of recent wood species of Burseraceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Canarium denticulatum Bl.	Mostly solitary, avg. t.d. 150 µ r.d. 100 µ, 3-4 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 9 rays/mm, 250-400 µ high, 15-20 µ wide, homogeneous
Canarium kerri Craib.	Mostly solitary, avg. t.d. 350 µ r.d. 200 µ, 2-3 vessels/mm^2	Apotrachael	2-3 seriate, mainly triseriate, 4 rays/mm, 300-450 µ high, 40-50 µ wide, homogeneous
Canarium indicum Stickm.	Mostly solitary, avg. t.d. 210 µ r.d. 200 µ, 5-6 vessels/mm^2	Apotrachael	mainly biseriate, 5 rays/mm, 250-400 µ high, 30-40 µ wide, homogeneous
Canarium schneinfurthii Engl.	Mostly solitary, avg. t.d. 260 µ r.d. 200 µ, 2-3 vessels/mm^2	Apotrachael	mainly triseriate, 5 rays/mm, 400-600 µ high, 50-70 µ wide, homogeneous

Table 3 (continued) Affinities of recent wood species of Burseraceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Canarium venosum Craib.	Mostly solitary, avg. t.d. 220 µ 3 r.d. 200 µ, 4-5 vessels/mm^2	Apotrachael	2-3 seriate, mainly triseriate, 12 rays/mm, 300-400 µ high, 40-55 µ wide, homogeneous
Dacryodes buettneri H. J. Lam.	Mostly solitary, avg. t.d.3210 µ r.d. 300 µ, 4-5 vessels/mm^2	Apotrachael	mainly biseriate, 4 rays/mm, 300-400 µ high, 80-90 µ wide, homogeneous
Dacryodes pubescens H. J. Lam.	Mostly solitary, avg. t.d. 180 µ r.d. 100 µ, 4-5 vessels/mm^2	Apotrachael	mainly biseriate, 5 rays/mm, 200-300 µ high, 25-30 µ wide, homogeneous
Garuga pinnata Roxb.	Mostly solitary, avg. t.d. 300 µ r.d. 220 µ, 7-8 vessels/mm^2	Apotrachael	2-3 seriate, mainly biseriate, 4 rays/mm, 300-500 µ high, 30-40 µ wide, homogeneous

Table 3 (continued) Affinities of recent wood species of Burseraceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Protium serratum Engl.	Mostly solitary, avg. t.d. 200 μ r.d. 130 μ, 8-9 vessels/mm^2	Apotrachael	2-3 seriate, mainly biseriate, 6 rays/mm, 150-250 μ high, 30-40 μ wide, homogeneous
Tetragastris panamensis O. Ktze.	Mostly solitary, avg. t.d. 160 μ r.d. 110 μ, 12-14 vessels/mm^2	Apotrachael	1-2 seriate, mainly biseriate, 7 rays/mm, 250-300 μ high, 20-30 μ wide, homogeneous

Table 4 Affinities of recent wood species of Combretaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Anogeissus acuminata Wall.	Mostly solitary, avg. t.d. 150 μ r.d. 100 μ, 9-10 vessels/mm^2	Paratrachael confluent	mainly uniseriate, 15 rays/mm, 3000-500 μ high, 15-20 μ wide, homogeneous
Combretum quadrangulare Kurz.	Mostl solitary, avg. t.d. 180 μ r.d. 150 μ, 2-3 vessels/mm^2	Paratrachael	mainly uniseriate, 15 rays/mm, 150-200 μ high, 10-15 μ wide, homogeneous
Lumnitzera littorea Voigt.	Mostly solitary, avg. t.d. 80 μ r.d. 90 μ, 22-24 vessels/mm^2	Apotrachael band	mainly uniseriate, 10 rays/mm, 70-200 μ high, 10-15 μ wide, homogeneous
Terminalia alata Heyne.	Mostly solitary, avg. t.d. 200 μ r.d. 180 μ, 2-3 vessels/mm^2	Paratrachael vasiicentric	mainly uniseriate, 8 rays/mm, 100-300 μ high, 15-20 μ wide, homogeneous

Table 4 (continued) Affinities of recent wood species of Combretaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Terminalia amazonia Exel.	Mostly solitary, avg. t.d. 200 µ r.d. 180 µ, 4-8 vessels/mm^2	Paratrachael	mainly uniseriate, 10 rays/mm, 200-500 µ high, 15-20 µ wide, homogeneous
Terminalia arjuna Bedd. .	Mostly solitary, avg. t.d. 400 µ r.d. 300 µ, 3-4 vessels/mm^2	Paratrachael	mainly uniseriate, 12 rays/mm, 100-300 µ high, 15-30 µ wide, homogeneous
Terminalia catappa Retz. .	Mostly solitary, avg. t.d. 260 µ r.d. 220 µ, 6-8 vessels/mm^2	Paratrachael	mainly triiseriate, 7 rays/mm, 300-840 µ high, 40-50 µ wide, homogeneous
Terminalia chebula Retz. .	Mostly solitary, avg. t.d. 210 µ r.d. 160 µ, 6-7 vessels/mm^2	Paratrachael	mainly uniseriate, 12 rays/mm, 200-600 µ high, 20-25 µ wide, homogeneous

Table 4 (continued) Affinities of recent wood species of Combretaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Terminalia citrina Roxb. .	Mostly solitary, avg. t.d. 70 μ r.d. 60 μ, 30-35 vessels/mm^2	Paratrachael	1-3 seriate, mainly uniseriate 14 rays/mm, 200-500 μ high, 15-20 μ wide, homogeneous
Terminalia complanata K.Schum.	Mostly solitary, avg. t.d. 340 μ r.d. 280 μ, 4-5 vessels/mm^2	Paratrachael	1,3 seriate, mainly triseriate, 4 rays/mm 100-400 μ high, 30-40 μ wide, homogeneous
Terminalia crenulata Roth. .	Mostly solitary, avg. t.d. 100 μ r.d. 160 μ, 3-4 vessels/mm^2	Paratrachael	mainly uniseriate, 15 rays/mm, 120-250 μ high, 20-25 μ wide, homogeneous
Terminalia glaucifolia Craib. .	Mostly solitary, avg. t.d. 200 μ r.d. 100 μ, 2-3 vessels/mm^2	Paratrachael	mainly uniseriate, 9 rays/mm, 100-350 μ high, 10-15 μ wide, homogeneous

Table 4 (continued) Affinities of recent wood species of Combretaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Terminalia ivorensis A. Cher.(Af) .	Mostly solitary, avg. t.d. 260 μ r.d. 200 μ, 4-8 vessels/mm^2	Paratrachael	1-2. Seriate,mainly biseriate, 5 rays/mm, 100-400 μ high, 10-35 μ wide, homogeneous
Terminalia manii King.	Mostly solitary, avg. t.d. 200 μ r.d. 180 μ, 4-8 vessels/mm^2	Paratrachael	mainly biseriate, 10 rays/mm, 200-500 μ high, 15-20 μ wide, homogeneous
Terminalia myriocarpa Heuickit	Mostly solitary, avg. t.d. 150 μ r.d. 250 μ, 2-3 vessels/mm^2	Paratrachael	mainly uniseriate, 7 rays/mm, 100-300 μ high, 10-15 μ wide, homogeneous
Terminalia obliqua Craib.	Mostly solitary, avg. t.d. 160 μ r.d. 100 μ, 6-7 vessels/mm^2	Paratrachael	mainly uniseriate, 8 rays/mm, 100-300 μ high, 10-15 μ wide, homogeneous

Table 4 (continued) Affinities of recent wood species of Combretaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Terminalia paniculata W.&A.	Mostly solitary, avg. t.d. 150 μ r.d. 70 μ, 4-5 vessels/mm^2	Paratrachael	mainly uniseriate, 9 rays/mm, 100-300 μ high, 15-20 μ wide, homogeneous
Terminalia pierrei Gagneb.	Mostly solitary, avg. t.d. 160 μ r.d. 110 μ, 12-14 vessels/mm^2	Paratrachael	1-2 seriate, mainly biseriate, 7 rays/mm, 250-300 μ high, 20-30 μ wide, homogeneous
Terminalia procera Roxb.	Mostly pore chain, t.d. 160 μ r.d. 110 μ, 12-14 vessels/mm^2	Paratrachael	1-2 seriate, mainly biseriate, 7 rays/mm, 250-300 μ high, 20-30 μ wide, homogeneous
Terminalia sumatrana Miq.	Mostly solitary, avg. t.d. 160 μ r.d. 110 μ, 12-14 vessels/mm^2	Paratrachael	1-2 seriate, mainly biseriate, 7 rays/mm, 250-300 μ high, 20-30 μ wide, homogeneous

Table 4 (continued) Affinities of recent wood species of Combretaceae

	VESSELS	**PARENCHYMA**	**XYLEM RAYS**
Terminalia superba Engl. et. Diels.	Mostly solitary, avg. t.d. 160 μ r.d. 110 μ, 12-14 vessels/mm^2	Paratrachael	1-2 seriate, mainly biseriate, 7 rays/mm, 250-300 μ high, 20-30 μ wide, homogeneous

Table 5 Affinities of recent wood species of Flacourtiaceae

	VESSELS	**PARENCHYMA**	**XYLEM RAYS**
Caseraria calva Craib. .	Mostly solitary, avg. t.d. 100 μ r.d. 60 μ, 32 vessels/mm^2	absent or rarely Apotracheal	mainly triseriate, 9 rays/mm, 60-900 μ high, 50-60 μ wide, heterogeneous
Kiggelaria africana Linn.	Mostly solitary, avg. t.d. 80 μ r.d. 50 μ, 20 vessels/mm^2	absent or rarely Apotracheal	1-3 seriate, mainly biseriate, 10 rays/mm, 250-550 μ high, 20-60 μ wide, heterogeneous
Hydnocarpus ilicifolius King.	Mostly solitary, avg. t.d. 30 μ r.d. 50 μ, 40 vessels/mm^2	absent or rarely Apotracheal	1,3 seriate, mainly triseriate, 36 rays/mm, 200-700 μ high, 20-30 μ wide, heterogeneous
Homalium damrongianum Craib.	Mostly solitary, avg. t.d. 120 μ r.d. 80 μ, 4 vessels/mm^2	absent or rarely Apotracheal	1,3 seriate, mainly triseriate, 10 rays/mm, 200-550 μ high, 20-60 μ wide, heterogeneous

Table 5 (continued) Affinities of recent wood species of Flacourtiaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Homalium foetidum Roxb. .	Mostly solitary, avg. t.d. 100 μ r.d. 90 μ, 17-19 vessels/mm^2	absent or rarely Apotracheal	1-3 seriate, mainly biseriate, 16 rays/mm, 200-300 μ high, 20-30 μ wide, heterogeneous
Homalium tomentosum Benth. .	Mostly solitary, avg. t.d. 100 μ r.d. 80 μ, 12-13 vessels/mm^2	absent or rarely Apotracheal	1-3 seriate,mainly biseriate, 10 rays/mm, 200-600 μ high, 30-40 μ wide, heterogeneous

Table 6 Affinities of recent wood species of Lechythidaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Barringtonia acutangula Gaertn. .	Mostly solitary, avg. t.d. 120 µ r.d. 200 µ, 4-5 vessels/mm^2	Apotracheal	3-4 seriate,mainly triseriate, 8 rays/mm, 50-2250 µ high, 10-70 µ wide, homogeneous
Barringtonia sp.	Mostly solitary, avg. t.d. 230 µ r.d. 170 µ, 3-4 vessels/mm^2	Apotracheal	1-4 seriate,mainly triseriate, 8 rays/mm, 250-700 µ high, 30-70 µ wide, homogeneous
Careya arborea Roxb. .	Mostly solitary, avg. t.d. 220 µ r.d. 170 µ, 3-4 vessels/mm^2	Apotracheal	2-5 seriate,mainly triseriate, 13 rays/mm, 150-1100 µ high, 30-60 µ wide, homogeneous
Planchonia papuana	Mostly solitary, avg. t.d. 280 µ r.d. 240 µ, 7-8 vessels/mm^2	Apotracheal	1-3 seriate,mainly triseriate, 7 rays/mm,400-550 µ high, 30-50 µ wide, homogeneous

Table 7 Affinities of recent wood species of Fabaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Afzelia africana Smith.	Mostly solitary, avg. t.d.110 μ r.d. 90 μ, 2-3 vessels/mm^2	Paratracheal	mainly triseriate, 5 rays/mm 250-350 μ high, 40-60 μ wide, heterogenous
Afzelia xylocarpa Craib.	Mostly solitary, avg. t.d.280 μ r.d. 200 μ, 2-3 vessels/mm^2	Paratracheal	mainly triseriate, 7 rays/mm 150-250 μ high, 25-30 μ wide, homogenous
Afzelia sp.	Mostly solitary, avg. t.d.370 μ r.d. 300 μ, 7-8 vessels/mm^2	Paratracheal	1-2 seriate, mainly biseriate, 7 rays/mm, 250-310 μ high, 25-50 μ wide, homogenous
Intsia bakeri	Mostly solitary, avg. t.d.320 μ r.d. 260 μ, 2-3 vessels/mm^2	Paratracheal	1-2 seriate, mainly biseriate, 5 rays/mm, 250-400 μ high, 30-40 μ wide, homogenous

Table 7 (continued) Affinities of recent wood species of Fabaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Intsia bijunga Kuntz	Mostly solitary, avg. t.d. 320 µ r.d. 250 µ, 1-2 vessels/mm^2	Paratracheal	1-2 seriate, mainly biseriate, 7 rays/mm, 350-400 µ high, 30-40 µ wide, homogenous
Intsia retusa Kuntz	Mostly solitary, avg. t.d. 190 µ r.d. 150 µ, 3-4 vessels/mm^2	Paratracheal	1-2 seriate, mainly biseriate, 5 rays/mm, 300-400 µ high, 30-40 µ wide, heterogenous
Intsia sp.(N. Borrneo)	Mostly solitary, avg. t.d. 400 µ r.d. 400 µ, 2-3 vessels/mm^2	Paratracheal	mainly biseriate, 5 rays/mm, 400-500 µ high, 25-30 µ wide, homogenous
Intsia sp.(Malaysia)	Mostly solitary, avg. t.d. 260 µ r.d. 170 µ, 2-3 vessels/mm^2	Paratracheal	1-3 seriate, mainly triseriate, 5 rays/mm, 300-450 µ high, 30-40 µ wide, homogenous

Table 7 (continued) Affinities of recent wood species of Fabaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Albizia acle Merr.	Mostly solitary, avg. t.d. 200 µ r.d. 180 µ, 1-2 vessels/mm^2	Paratracheal	1-2 seriate, mainly uniseriate, 5 rays/mm, 200-250 µ high, 10-15 µ wide, homogenous
Albizia ferruginea Benth.	Mostly solitary, avg. t.d. 300 µ r.d. 220 µ, 1-2 vessels/mm^2	Paratracheal	2-3 seriate, mainly triseriate, 5 rays/mm, 150-300 µ high, 15-20 µ wide, homogenous
Albizia lebbek Benth.	Mostly solitary, avg. t.d. 200 µ r.d. 180 µ, 2-3 vessels/mm^2	Paratracheal	2-3 seriate, mainly triseriate, 5 rays/mm, 200-250 µ high, 20-30 µ wide, homogenous
Albizia lebbekoides Benth	Mostly solitary, avg. t.d. 300 µ r.d. 200 µ, 1-2 vessels/mm^2	Paratracheal	3-4 seriate, mainly triseriate, 4 rays/mm, 300-400 µ high, 30-40 µ wide, homogenous

Table 7 (continued) Affinities of recent wood species of Fabaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Albizia odoratissima Benth.	Mostly solitary, avg. t.d. 170 μ r.d. 140 μ, 2-3 vessels/mm^2	Paratracheal	1-3 seriate, mainly triseriate, 7 rays/mm, 100-300 μ high, 20-30 μ wide, homogenous
Albizia procera Benth	Mostly solitary, avg. t.d. 250 μ r.d. 250 μ, 1-2 vessels/mm^2	Paratracheal	1-3 seriate, mainly biseriate, 7 rays/mm, 200-250 μ high, 20-25 μ wide, homogenous
Dialium cochinchinensis Pierre	Mostly solitary, avg. t.d. 160 μ r.d. 150 μ, 2-3 vessels/mm^2	Paratracheal	2-3 seriate, mainly biseriate, 6 rays/mm, 150-250 μ high, 20-35 μ wide, homogenous
Dialium sp. (Malaysia)	Mostly solitary, avg. t.d. 240 μ r.d. 200 μ, 3-4 vessels/mm^2	Paratracheal	mainly biseriate, 9 rays/mm, 200-850 μ high, 15-30 μ wide, homogenous

Table 7 (continued) Affinities of recent wood species of Fabaceae

	VESSELS	**PARENCHYMA**	**XYLEM RAYS**
Milletia atropurpurea Benth.	Mostly solitary, avg. t.d. 220 µ r.d. 170 µ, 2-3 vessels/mm^2	Paratracheal	2-3 seriate, mainly triseriate, 7 rays/mm, 100-300 µ high, 50-60 µ wide, homogenous
Milletia caffra Meissn.	Mostly solitary, avg. t.d. 140 µ r.d. 150 µ, 6-7 vessels/mm^2	Paratracheal	4-6 seriate, mainly 4-6 seriate, 5 rays/mm, 300-900 µ high, 30-70 µ wide, homogenous
Milletia leucantra Kurz.	Mostly solitary, avg. t.d. 120 µ r.d. 100 µ, 7-8 vessels/mm^2	Paratracheal	2-3 seriate, mainly biseriate, 7 rays/mm, 200-600 µ high, 30-50 µ wide, homogenous
Milletia versicolor Welw. ex Bak.	Mostly solitary, avg. t.d .140 µ r.d. 120 µ, 6-8 vessels/mm^2	Paratracheal	1-4 seriate, mainly triseriate, 8 rays/mm, 200-650 µ high, 20-60 µ wide, homogenous

Table 8 Affinities of recent wood species of Sonneratiaceae

	VESSELS	PARENCHYMA	XYLEM RAYS
Duabanga sonneratioides Hun. L. (syn. D. grandiflara Roxb.)	Mostly solitary, avg.t.d. 250 μ r.d. 200 μ, 6-7 vessels/mm^2	Aporatracheal	1-2 seriate, mainly uniseriate, 9 rays/mm, 100-450 μ high, 30-40 μ wide, heterogenous
Sonneratia alba J. Sm.	Mostly multiple pores, avg.t.d. 140 μ, r.d. 100 μ, 12-14 vessels/mm^2	Aporatracheal	mainly uniseriate, 17 rays/mm, 100-500 μ high, 10-15 μ wide homogenous
Sonneratia caseolario Engeln.	Mostly multiple pores, avg.t.d.100 μ, r.d. 70 μ, 12-14 vessels/mm^2	Aporatracheal	mainly uniseriate, 16 rays/mm, 100-450 μ high, 10-15 μ wide, homogenous

APPENDICES C

Table 9 Distribution of Recent *Homalium* and related fossil wood.

	Homalium	*Homalium tomentosum*	Fossils
Thailand	+	+	*Homalium tomentosum*
Burma	+	+	
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+	-	
Sumatra	+	-	
Java	+	-	
India	-	-	
Africa	+	+	
South America	-	-	

Table 10 Distribution of Recent *Careya* and related fossil wood.

	Careya	*Careya arborea*	Fossils
Thailand	+	+	*Careya arborea*
Burma	+	+	Caryoxylon *pondicherriense*
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+	-	
Sumatra	+	-	
Java	+	-	
India	-	-	Caryoxylon *pondicherriense*
Africa	+	-	
South America	-	-	

Table 11 Distribution of Recent *Albizia* and related fossil wood.

	Albizia	*Albizia lebbeck*	Fossils
Thailand	+	+	*Albizia lebbeck*
Burma	+	+	*Albizinium eolebbekianum*
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+	+	*Leguminosites (Albizia)*
Sumatra	+	+	
Java	+	+	
Philippines	+	+	
India	+	+	*Albizinium eolebbekianum*
Africa	+	+	*Leguminoxylon albizziae*
South America	+	-	

Table 12 Distribution of Recent *Afzelia, Intsia* and related fossil wood.

	Afzelia-Intsia	*Afzelia xylocarpa*	*Pahudioxylon sahnii*
Thailand	+	+	+
Burma	+	+	+
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	+
Borneo	+	-	+
Sumatra	+	-	
Java	+	-	
India	-	-	+
Africa	+	-	
South America	-	-	

Table 13 Distribution of Recent *Dialium* and related fossil wood.

	Dialium	*Dialium cochinchinensis*	Fossils
Thailand	+	+	*Dialium cochinchinensis*
Burma	+	+	
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+	-	
Sumatra	+	-	
Java	+	-	
Philippines	-	-	
India	-	-	
Africa	+	-	*Dialium aethiopica*
South America	-	-	

Table 14 Distribution of Recent *Millettia* and related fossil wood.

	Millettia	*Millettia leucantha*	Fossils
Thailand	+	+	*Millettia leucantha*
Burma	+	+	
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+		
Sumatra	+		
Java	+		
India	-	+	
Africa	+	+	*Millettioxylon pongamiensis*
South America	-	-	*Millettioxylon embergeri*

Table 15 Distribution of Recent *Duabanga* and related fossil wood.

	Duabanga	*Duabanga grandiflora*	Fossils
Thailand	+	+	*Duabanga grandiflora*
Burma	+	+	
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+	+	*Duabangoxylon tertiarum*
Sumatra	+	+	
Java	+	+	
Philippines	+	+	
India	-	-	
Africa	-	-	
South America	-	-	

Table 16 Distribution of Recent *Aquilaria* and related fossil wood.

	Aquilaria	*Aquilaria* sp.	Fossils
Thailand	+	+	*Aquilaria* sp.
Burma	+	+	
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+	+	
Sumatra	+	+	
Java	+	+	
Philippines	+	+	
India	+	+	
Africa	-	-	
South America	-	-	

Table 17 Distribution of Recent *Anogeissus* and related fossil wood.

	Anogeissus	*Anogeissus accuminata*	Fossils
Thailand	+	+	*Anogeissus accuminata*
Burma	+	+	
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	-	-	
Sumatra	-	-	
Java	-	-	
India	+	+	*Anogeissuxylon bussonii*
Africa	+	+	*Anogeissuxylon bussonii*
South America	-	-	

Table 18 Distribution of Recent *Terminalia* and related fossil wood.

	Terminalia	*Terminalia alata*	Fossils
Thailand	+	+	*Terminalia alata*
			Terminalioxylon burmense
			Terminalioxylon coriaceum
Burma	+	+	*Terminalioxylon burmense*
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+	-	*Terminalioxylon tertiarum*
Sumatra	+	-	*Terminalioxylon tertiarum*
Java	+	-	
Philippines	+	-	
India	-	-	*Terminalioxylon paleomanii*
Africa	+	-	*Terminalioxylon* spp.
Australia	+	-	

Table 19 Distribution of Recent *Protium* and related fossil wood.

	Prtotium	*Prtotium serratum*	Fossils
Thailand	+	+	*Prtotium serratum*
Burma	+	+	
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+	-	
Sumatra	+	-	
Java	+	-	
India	+	+	
Africa	+	-	
South America	-	-	

Table 20 Distribution of Recent *Dracontamelon* and related fossil wood.

	Dracontamelon	*Dracontamelon da*	Fossils
Thailand	+	+	*Dracontamelon dao*
Burma	+	+	
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+	+	
Sumatra	+	+	
Java	+	+	
Philippines	+	+	
India	+	+	*Dracontamelon mangiferoides*
Africa	-	-	
South America	-	-	

Table 21 Distribution of Recent *Holarrhena* and related fossil wood.

	Holarrhena	*Holarrhena pubescens*	Fossils
Thailand	+	+	*Holarrhena pubescens*
Burma	+	+	
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	-	-	
Sumatra	-	-	
Java	-	-	
Philippines	-	-	
India	+	+	
Africa	+	+	
South America	-	-	

Table 22 Distribution of Recent *Wrightia* and related fossil wood.

	Wrightia	*Wrightia arborea*	Fossils
Thailand	+	+	*Wrightia arborea*
Burma	+	+	
Cambodia	+	+	
Laos	+	+	
Vietnam	+	+	
Borneo	+	-	
Sumatra	+	-	
Java	+	-	
Philippines	+	-	
India	+	+	
Africa	+	-	
South America	-	-	

CURRICULUM VITAE

I, Pramook Benyasuta, am a government employee of The Botanical Garden Organization. I was born in Bangkok. I studied at Saint Gabriel's College for twelve years and attended Kasetsart University, earned a Bachelor of Science degree in Biology in 1977 and a Master of Science in Botany from Chulalongkorn University in 1982. After graduating, I was a research assistant in National Research Institute, counterpart of JICA project of Department of Agriculture, scientist in Department of Veterinary and later transferred to Research and Development Division, Royal Irrigation Department. At present, I work in Queen Sirikit Botanic Garden.

I am married to Sununta, a scientist of RID, and we have a son and a daughter, Patison and Sutassa. My family is in Bangkruai, Nonthaburi.