THE STUDY OF THE BIODIVERSITY AND COMPARATIVE ANATOMY OF PETRIFIED WOOD IN THE AREA OF THE NORTHEASTERN RESEARCH INSTITUTE OF PETRIFIED WOOD AND MINERAL RESOURCES, THAILAND

Nareerat Boonchai

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การศึกษาความหลากหลายทางชีวภาพและกายวิภาคศาสตร์เปรียบเทียบของไม้กลายเป็นหิน ในพื้นที่สถาบันวิจัยไม้กลายเป็นหินและทรัพยากรธรณี ภาคตะวันออกเฉียงเหนือ ประเทศไทย

นางสาวนารีรัตน์ บุญไชย

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาชีววิทยาสิ่งแวดล้อม
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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นารีรัตน์ บุญไชย : การศึกษาความหลากหลายทางชีวภาพและกายวิภาคศาสตร์เปรียบเทียบของไม้กลายเป็นหิน ในพื้นที่สถาบันวิจัยไม้กลายเป็นหินและทรัพยากรธรณีภาคตะวันออกเฉียงเหนือ ประเทศไทย (THE STUDY OF THE BIODIVERSITY AND COMPARATIVE ANATOMY OF PETRIFIED WOOD IN THE AREA OF THE NORTHEASTERN RESEARCH INSTITUTE OF PETRIFIED WOOD AND MINERAL RESOURCES, THAILAND) อาจารย์ที่ปรึกษา : อาจารย์ ดร.พอล เจ โกรติ, 235 หน้า

ผลการศึกษาไม้กลายเป็นหิน 23 ชิ้น จากบริเวณชั้นกรวดมหายุคซีโนโซอิกตอนปลาย ภายในพื้นที่สถาบันวิจัยไม้กลายเป็นหินและทรัพยากรธรณีภาคตะวันออกเฉียงเหนือ จังหวัดนครราชสีมา จำแนกได้เป็นพืชใบเลี้ยงคู่ อย่างน้อย 7 วงศ์ 10 สกุล 17 ชนิด รวมถึง cf. *Mangiferoxylon* sp. 1 and sp. 2, Anacardiaceae *gen. indet.* (Anacardiaceae), *Canarium* sp. (Burseraceae), *Terminalia* sp. vel *Combretum* sp., *Terminalia* sp. 1 and sp. 2 (Combretaceae), *Irvingia* sp. (Irvingiaceae), *Cynometroxylon holdeni*, *Cynometroxylon* sp., cf. *Cynometroxylon* sp. 1 and sp. 2, cf. *Millettia* sp. 1 and sp. 2 (Leguminosae), *Careya* sp. 1 and sp. 2 (Lecythidaceae), *Azadirachta* sp. (Meliaceae), and family *incertae sedis* พรรณไม้บรรพกาลที่หลากหลายมีความใกล้เคียงกับพรรณไม้ปัจจุบันที่พบอยู่ทั่วไปในป่าเบญจพรรณ ป่าเต็งรังและป่าดิบแล้ง แสดงถึงสภาพภูมิอากาศที่ร้อนชื้นสลับแล้ง (Aw) และร้อนชื้นแบบมรสุม (Am) เช่นเดียวกับสภาพภูมิอากาศในปัจจุบัน แต่มีความชื้นสูงกว่า ตะกอนที่พบไม้กลายเป็นหินเป็นลักษณะของตะกอนแม่น้ำแบบธารประสานสาย และท่อนไม้อาจถูกกระแสน้ำของแม่น้ำโบราณที่ไหลเชี่ยวพัดพามาตกจม และฝังตัวในบริเวณนี้

สาขาวิชาชีววิทยา
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ลายมือชื่อนักศึกษา ____
ลายมือชื่ออาจารย์ที่ปรึกษา Paul J. Grote
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม Yongdong Wang
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม ____

NAREERAT BOONCHAI : THE STUDY OF THE BIODIVERSITY AND COMPARATIVE ANATOMY OF PETRIFIED WOOD IN THE AREA OF THE NORTHEASTERN RESEARCH INSTITUTE OF PETRIFIED WOOD AND MINERAL RESOURCES, THAILAND. THESIS ADVISOR : PAUL J. GROTE, Ph.D. 235 PP.

PETRIFIED WOOD/ BIODIVERSITY/ PALEOCLIMATE/ NAKHON RATCHASIMA/ NORTHEAST/ THAILAND

Twenty three specimens of petrified wood were collected from late Cenozoic gravel beds at the Northeastern Research Institute of Petrified Wood and Mineral Resources, Nakhon Ratchasima province, northeastern Thailand. They were assigned at least 17 species from 10 genera of 7 families of dicotyledons, including cf. *Mangiferoxylon* sp. 1 and sp. 2, Anacardiaceae *gen. indet.* (Anacardiaceae), *Canarium* sp. (Burseraceae), *Terminalia* sp. vel *Combretum* sp., *Terminalia* sp. 1 and sp. 2 (Combretaceae), *Irvingia* sp. (Irvingiaceae), *Cynometroxylon holdeni*, *Cynometroxylon* sp., cf. *Cynometroxylon* sp. 1 and sp. 2, cf. *Millettia* sp. 1 and sp. 2 (Leguminosae), *Careya* sp. 1 and sp. 2 (Lecythidaceae), *Azadirachta* sp. (Meliaceae), and family *incertae sedis*. The diverse paleoflora shows a close resemblance to the modern flora of mixed deciduous, dry dipterocarp, and dry evergreen forests, indicating that the paleoclimate was tropical wet and dry (Aw) and tropical monsoon (Am), corresponding to the present climate in the area but with higher humidity. The sediments show characters of a braided stream system, and the

logs were possibly transported by the strong water current and buried in an ancient river.

School of Biology

Academic Year 2008

Student’s Signature ________________

Advisor’s Signature ________________

Co-advisor’s Signature ______________

Co-advisor’s Signature ______________

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Who would have expected me to dive into the world of fossils again?

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CHAPTER I

INTRODUCTION

1.1 Rationale of the Study

An abundance of petrified wood has been discovered in Thailand. Many specimens are from alluvial and terrace deposits of the Mun and Chi river systems in the northeastern provinces of Nakhon Ratchasima, Buriram, Surin, Srisaket, Khon Kaen, Chaiyaphum, and Kalasin. The wood was frequently found in gravel beds while digging sand and gravel to sell for road construction. Nakhon Ratchasima is one of the most interesting areas in which this material can be studied. Many specimens of very well preserved gemstone-like petrified wood from the Cenozoic Era have been found around Suranaree subdistrict, Muang district (Jintasakul, 2005a; Haworth, Na Chiangmai, and Phiancharoen, 1966).

This petrified wood is very useful for the study of the diversity of plants in the past and the paleoenvironment as one of the representative localities in northeastern Thailand because many petrified wood specimens, including 7 *in situ* large petrified trunks, have been discovered. From the deposit of alluvial sediment and gravels, it is possible that this locality is where the main ancient river in the northeast flowed past (Jintasakul, personal communication). However, there are very few people who have studied petrified wood from Thailand, and, until recently, hardly any Thai researcher has studied these fossils in any detail. Without scientific understanding, a lot of petrified wood has been sold to other regions and overseas over the last 25 years.

A great deal of petrified wood has disappeared from the localities. This is a problem to consider seriously, for we are not only losing the natural resources from our region but also the key to knowledge of the ancient environment of the area in which we are living.

In 1995, the Northeastern Research Institute and Museum of Petrified Wood and Mineral Resources (NRIPM) was established and constructed at Ban Krok Duen Ha, Suranaree Subdistrict, Muang District, Nakhon Ratchasima, in honor of His Majesty the King, as a museum to conserve and preserve petrified wood, animal fossils, and mineral resources and to be a center of learning for students, researchers, and the general public (for academic value and tourism). The museum grounds cover approximately 12.4 hectares. About 7-10 large petrified trunks more than two meters long have been found *in situ*, lying in different directions, within an area of about 1.6 hectares (~ 10 rai), and more petrified wood was exposed during road construction and digging of a pond at the site. Therefore the study of petrified wood here is very important in order to learn about the diversity of plants in the past in Thailand, especially in the Northeast, and have a better understanding of plant evolution and paleoenvironment.

1.2 Research Objectives

1) To identify the diversity of petrified wood specimens in the area of the Northeastern Research Institute of Petrified Wood and Mineral Resources, Nakhon Ratchasima.
2) To investigate the depositional environment of the study area.
3) To interpret the paleoenvironment of the locality.

1.3 Scope and Limitations of the Study

An area of approximately 1.6 hectares (~ 10 rai) at the Northeastern Research Institute of Petrified Wood and Mineral Resources (also referred to as the Museum of Petrified Wood and Mineral Resources) (Fig. 1.1), Suranaree Subdistrict, which contains many *in situ* pieces of silicified wood, was selected as the site for the study. The study area lies from west to east parallel to Mittraphap- Nong Pling Road. The distribution and orientation of the embedded petrified logs were investigated. The anatomy and taxonomy of the petrified wood were studied and comparisons were made with modern wood. The results of the studies can allow conclusions to be made about the diversity of plants at the time of deposition and can be used to interpret the paleoenvironment in the study area.

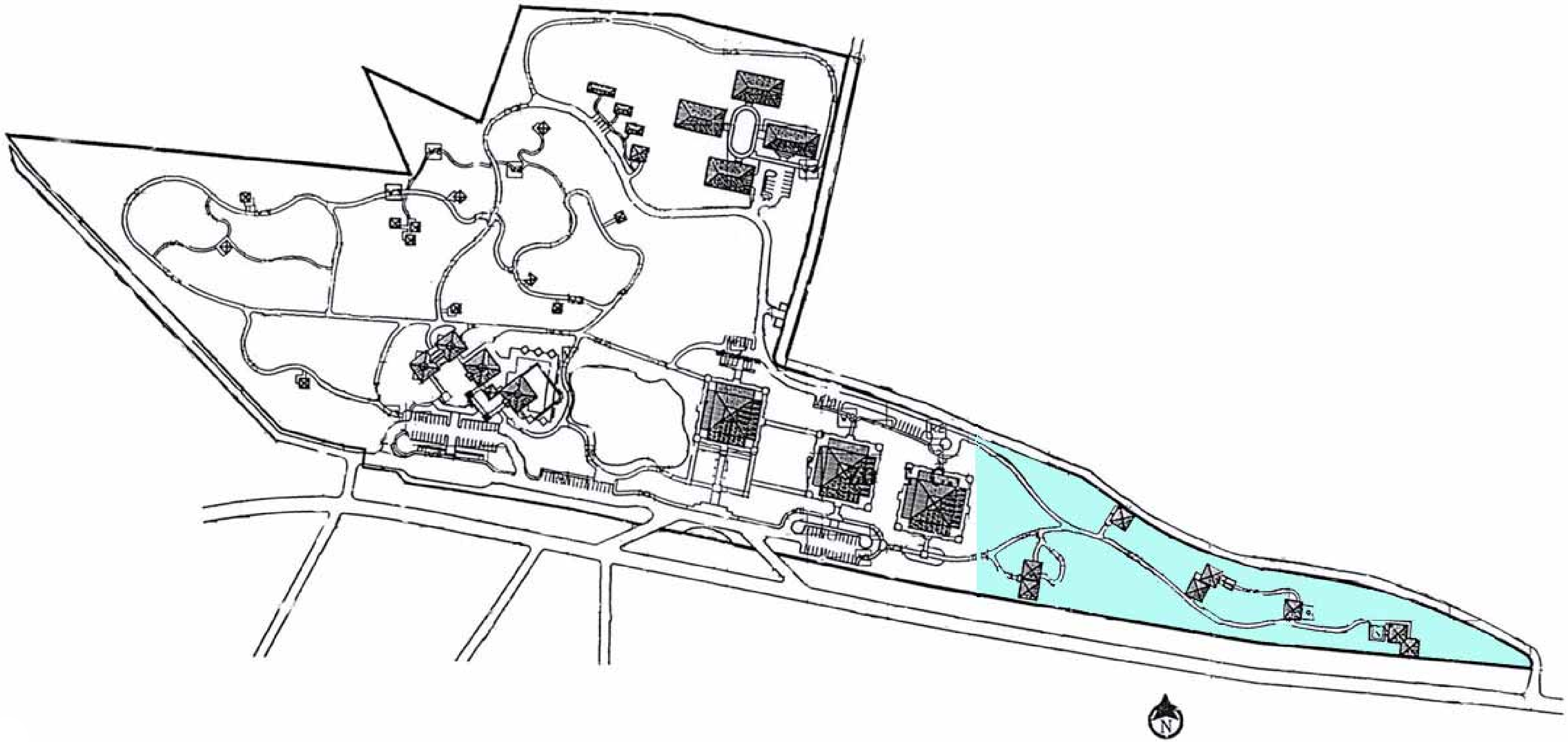

Figure 1.1 The study area of ~ 1.6 hectares (in blue color) within the museum grounds, where many *in situ* petrified wood pieces were discovered. Five large petrified trunks are lying under buildings in the eastern part of the area (Architecture Map of the museum, 2000).

1.4 Benefits of the Study

The study of petrified wood will give very fruitful information about the diversity of plants in the past and the differences between plant species in the past and the present. It will provide a better understanding of the evolution of plants and the plant community, climate, and past environment at the site of deposition.

Petrified wood from some localities provides important archeological evidence, such as in Myanmar, where tools from the Paleolithic period, made of petrified wood, were found from the Irrawaddy Valley during the “Anyathian Culture”. Many countries around the world have set up national parks, forest parks, or museums to preserve and conserve petrified wood, e.g., the Petrified Forest National Park in Arizona, USA (Jintasakul, 2548b; Deterra, 1983).

The information gained from this study can be used for developing exhibitions at museums, such as the Northeastern Research Institute of Petrified Wood and Mineral Resources, and at other organizations for exhibiting fossils to the public and making them realize the value of these natural resources. Furthermore, the collection of thin-section slides of petrified wood from this study will allow comparison with other petrified wood and modern wood found in Thailand and elsewhere.

CHAPTER II

LITERATURE REVIEW

2.1 Petrified Wood and Petrification

Petrified wood results from the petrification process in which wood is gradually replaced, cell by cell, by minerals in an oxygen-free environment. Firstly, permineralization occurs by the infiltration of the wood with a mineral-rich fluid. The minerals, such as silica, precipitate in cell lumens and intercellular spaces. Wood preserved at this stage can yield detailed information about the internal structure of the once-living plant (Arens *et al.*, 1998; Hamilton and Hamilton, 2003). If the replacement occurred as only one stage of permineralization by leaving organic cell walls and a resulting anatomically-preserved plant, it was regarded as *permineralization* (calcareous, siliceous, pyritic, etc.). In some cases, the organic cell walls might be secondarily replaced by a further permineralization with none of the organic materials remaining; the preservation at this stage is called *petrification* (Scott, 1983; Arens *et al.*, 1998). In petrified specimens, cellular details are lost because of the replacement of the organic material of the cell wall. These terms are here used in a precise, scientific sense. "Petrified" also has a commonly used meaning of any mineralized plant part, especially wood (Scott and Collinson, 1983).

Silica group minerals are common worldwide. Free silica, SiO_2, occurs most commonly as quartz, a mineral that has a larger number of distinct varieties with wider differences than any other mineral. Silicified wood is a common illustration of a quartz pseudomorph. The colors of petrified wood are different depending on the kind of minerals which replaced the wood (Hamilton and Hamilton, 2003).

2.2 The Discovery of Petrified Wood in Thailand

The first record of petrified wood in Thailand dates back to the reign of King Rama VI (1910 - 1925). The first report was by Högbom (1913). He made a note in “Geological investigation along the route” including the Korat railway that he noticed numerous silicified wood pieces in a remarkable gravel that was used in town and thought they seemingly occurred from the Tertiary, even though he had not observed them *in situ* yet. The wood was preliminarily examined by Dr. Th. G. Halle of Stockholm and concluded to be Dicotelydones.

The second record was in 1921, when petrified wood was discovered from the river bottom during railway construction across the Mun River. The wood was presented to King Rama VI by villagers and the leading engineer when he visited there to check the construction. Subsequently, the memorial monument of petrified wood and King Rama VI was set up at the railway crossing over the Mun River in Chaleom Phra Kiat district of Nakhon Ratchasima (Fig. 2.1) (Jintasakul, 2004, personal communication). However, no taxonomic study was reported from that period.

Figure 2.1 Memorial monument of King Rama the VI and petrified wood next to railway crossing the Mun River.

After that, since 1957, more petrified wood has been discovered from digging out gravel for highway and road construction in the northeast, e.g, Mitraphap Highway (Friendship Highway). The distribution of petrified wood from each province is shown in Fig. 2.2.

In Thailand, Lower Paleolithic tools made of petrified wood were reported for the first time in 1984. They are from Sung Noen district, Nakhon Ratchasima province. Archeologists have given the name “Sung Noen Culture” to signify the typical material for making tools of this culture. Many of them were brought to keep in a prehistoric museum at Faculty of Medicine, Siriraj Hospital, Bangkok (Sangvichien *et al.*, 1986). Now the museum is named the Sood Sangvichien Prehistoric Museum & Laboratory, within Siriraj Medical Museum, and exhibits many important artifacts from the life-time research of Prof. Sood Sangvichien on the prehistorical Thais during the Stone Age (Siriraj Hospital, Faculty of Medicine, 2006).

In 2000, Surinkhum *et al.* from the Department of Mineral Resources used Ground Penetrating Radar (GPR) for surveying and detecting the buried petrified wood in the gravel beds at the institute grounds. Some of the interpreted anomalies were investigated by digging pits with a back-hoe. Various sizes of petrified wood were found in seventeen pits. This area is now where the Northeastern Research Institute of Petrified Wood and Mineral Resources is standing. The five large *in situ* petrified trunks are still embedded in the ground. They are protected by pavilions, which are open to the public.

Figure 2.2 The major distribution of petrified wood discovered in Thailand (Jintasakul, 2006, personal communication).

2.3 Previous Studies of Petrified Wood from Thailand

The oldest petrified wood in Thailand studied taxonomically is from the Carboniferous period. A petrified stem of *Lepidodendron* sp. and fragments of pith casts of *Calamites* (? *Mesocalamites*) from Na Duang coal mine, Loei province, northeastern Thailand, were found and studied (Laveine *et al.*, 2003). Permian petrified wood from Petchabun province, upper central Thailand, was studied and assigned to *Dadoxylon walchiopremnoides* (Voltziales) by Vozenin-Serra in 1990. After that a new perminalized wood specimen of Ginkgophyta, very similar to an Euramerican wood, *Ginkgophytoxylon permiense,* from Southern France, was collected from another locality of the same province. This indicates that elements of the Euramerican flora reached central Thailand as well as to the Cathaysian region in the Middle – Late Permian (Berthelin *et al.*, 2006).

Extraordinarily abundant and very well preserved petrified wood from the Mesozoic-Cenozoic Eras has been found on the Khorat Plateau, Northeastern Thailand, along with some additional specimens from northern, central, and southern Thailand. Many of the specimens are structurally preserved with anatomical details, such as vessels, rays, parenchyma, and fibers. They represent remarkable and important evidence with which to investigate tropical vegetation history, paleoclimate, and the paleoenvironment in southeast Asia (Wang *et al.*, 2006). However, little research has been done. The first taxonomic study of petrified wood from Thailand was done by Prakash (1979), an Indian paleobotanist, on dicotyledonous wood from the Tertiary of Northeast Thailand. The wood belongs to different species from five genera: *Pahudioxylon sahnii, Cynometroxylon parainaequifolium, Millettioxylon indicum, Anogeissoxylon thailandicum,* and *Dryoxylon siamensis.*

Two papers by French researchers came out ten years later in 1989. One of the papers is on the study of silicified wood from the Pong Basin, North Thailand. A new genus and species from the family Menispermaceae was proposed in their study. The results revealed some resemblance to a ligneous flora from the Lower Siwalik beds in India (Vozenin-Serra *et al.*, 1989). Another paper showed very interesting fossil wood from alluvial deposits from the Mun River at Sarapee, Nakhon Ratchasima that yielded a high diversity of plants from a mixed deciduous forest probably not far from a river and ancient volcanoes. A comparison with fossil wood from other localities revealed close floristic resemblance with Myanmar, Western Bengal, and Kachchh (Vozenin-Serra and Privé-Gill, 1989). Vozenin-Serra and Privé-Gill (2001) published another paper on the fossil wood from Thailand focusing on the wood from Tha Chang, Nakhon Ratchasima.

Benyasuta (2003) was the first Thai person to engage in a taxonomic study of petrified wood from the Northeast of Thailand. His research showed that the anatomy of the fossil wood resembled that of wood of plants still living on the Khorat Plateau. He placed all of his specimens, collected from three provinces (Nakhon Ratchasima, Chaiyaphum, and Khon Kaen) in the Northeast of Thailand, into extant species except for one dicot and the palms. There are 18 species from 15 genera in 10 plant families.

For dicots, one species was reported for each genus as follows: *Homalium tomentosum*, *Careya sphaerica*, *Albizia lebbeck*, *Pahudioxylon sahnii*, *Dialium cochinchinense*, *Millettia leucantha*, *Duabanga grandiflora*, *Aquilaria* sp., *Anogeissus acuminata*, *Terminalia alata*, *Protium serratum*, *Dracontomelon dao*, *Holarrhena pubescens*, and *Wrightia arborea*. Four species were described for *Palmoxylon*, a form genus for palm wood.

In 2004, a team of three paleobotanists from China was formally invited by the Northeastern Research Institute of Petrified Wood and Mineral Resources to come and identify the petrified wood in Thailand. The petrified wood from the Northeastern region (Mesozoic to Cenozoic deposits) was identified to the family, generic, and species levels. The results from their identification of 117 specimens showed that the fossil wood totaled 50 species belonging to 19 genera from 11 families. Most of the fossils were angiospermous but some were gymnospermous. The gymnosperms are represented by two families, while nine families of angiosperms were discovered (Zhang *et al.*, 2004).

Based on the taxonomic and anatomical studies and identification of Cenozoic petrified wood of Thailand from 1979 to the present it is clear that the fossil floras had a high diversity, including about 64 species assigned to 34 genera and 17 families: Anacardiaceae, Annonaceae, Apocynaceae, Burseraceae, Combretaceae, Datiscaceae, Dipterocarpaceae, Ebenaceae, Euphorbiaceae, Flacourtiaceae, Lecythidaceae, Leguminosae, Lythraceae, Menispermaceae, Palmae, Sonneratiaceae, and Thymelaeaceae. *Palmoxylon* spp. are the only representatives of the monocotyledons (Benyasuta, 2003; Prakash, 1979; Vozennin-Serra and Privé-Gill, 1989, 2001; Vozenin-Serra, Privé-Gill, and Ginsburg, 1989; Wang *et al.*, 2006).

The Leguminosae, Combretaceae, and Dipterocarpaceae are the most diverse plant families in these wood assemblages. Some of the fossils represent the first report of the fossil wood taxa in Thailand (Zhang *et al.*, 2004). Among them, 14 specimens were collected from Ban Tak Forest Park of Tak province, northwestern Thailand. The identifications revealed that almost all belong to one family Leguminosae and eight of them are identified as the same genus *Pahudioxylon* (Zhang *et al.*, 2004), including the longest petrified trunk, 72.22 m in length and about 4 m in diameter at the base.

The fossil wood floras indicate that the paleoclimate in the Late Permian of Thailand was warm and humid because of lack of distinct annual rings. During the late Mesozoic Era, the tropical conifer vegetation in Northeast Thailand was dominated by the family Araucariaceae. During the Miocene to Pleistocene the major forests were both deciduous and dry evergreen according to the high species diversity and the presence of families such as the Combretaceae, Dipterocarpaceae, Lecythidaceae, and Leguminosae. The climates at the times of deposition were similar to the present climate (Berthelin *et al.*, 2006; Wang *et al.*, 2006).

2.4 Modern Flora of Northeastern Thailand and Nakhon Ratchasima

There are two main kinds of forest in Thailand: evergreen forest and deciduous forest. The evergreen forest is divided into 14 types including tropical rain forest, dry evergreen forest, mangrove forest, montane forests, and swamp forests. The deciduous forests are divided into 3 types: mixed deciduous forest, deciduous dipterocarp or dry dipterocarp forest, and pine-deciduous dipterocarp forest (Santisuk, 2006).

In the Northeast of Thailand, dry dipterocarp forest is the main forest type comprising 80% of all forests. The mixed deciduous forest is found scattered, and the dry evergreen forest can be found in areas such as at Khaoyai National Park. Distribution and types of forest in Nakhon Ratchasima are showed in Fig. 2.3. Studies on the diversity of plants in natural degraded forest of Suranaree University of Technology and the Northeastern Research Institute of Petrified Wood and Mineral

Resources, Suranaree subdistrict, were done and reported as follows:

2.4.1 Flora of Suranaree University

In 2002, Wara-Aswapati *et al.*, reported on the diversity of plants in Suranaree University of Technology, Suranaree subdistrict, which is about 2 km from the present study site. The flora in the university is the same as in dry dipterocarp and mixed-deciduous forests. The largest plant family found around the university is Leguminosae (approximately 68 species in the preliminary study). In 1999, Chomko studied the biodiversity of plants in a recovering forest in the academic zone of the university. He reported that the area is dry dipterocarp forest mixed with thorn forest; *Azadirachta indica* has the second highest density among the plants after *Olax scandes*, and *Terminalia* is diverse in number of species.

2.4.2 Diversity of plants in the Northeastern Research Institute of Petrified Wood and Mineral Resources (NRIPM)

The flora in NRIPM area is mixed deciduous, dry dipterocarp, and degraded forest. The trees commonly found are *Azadirachta indica*, *Shorea* spp., *Pterocarpus* sp., *Sindora siamensis*, *Cassia* spp., *Buchanania* spp., *Dillenia* spp, *Acacia*. etc. (Thailand Science and Technology Research Institute [TISIR], 2001).

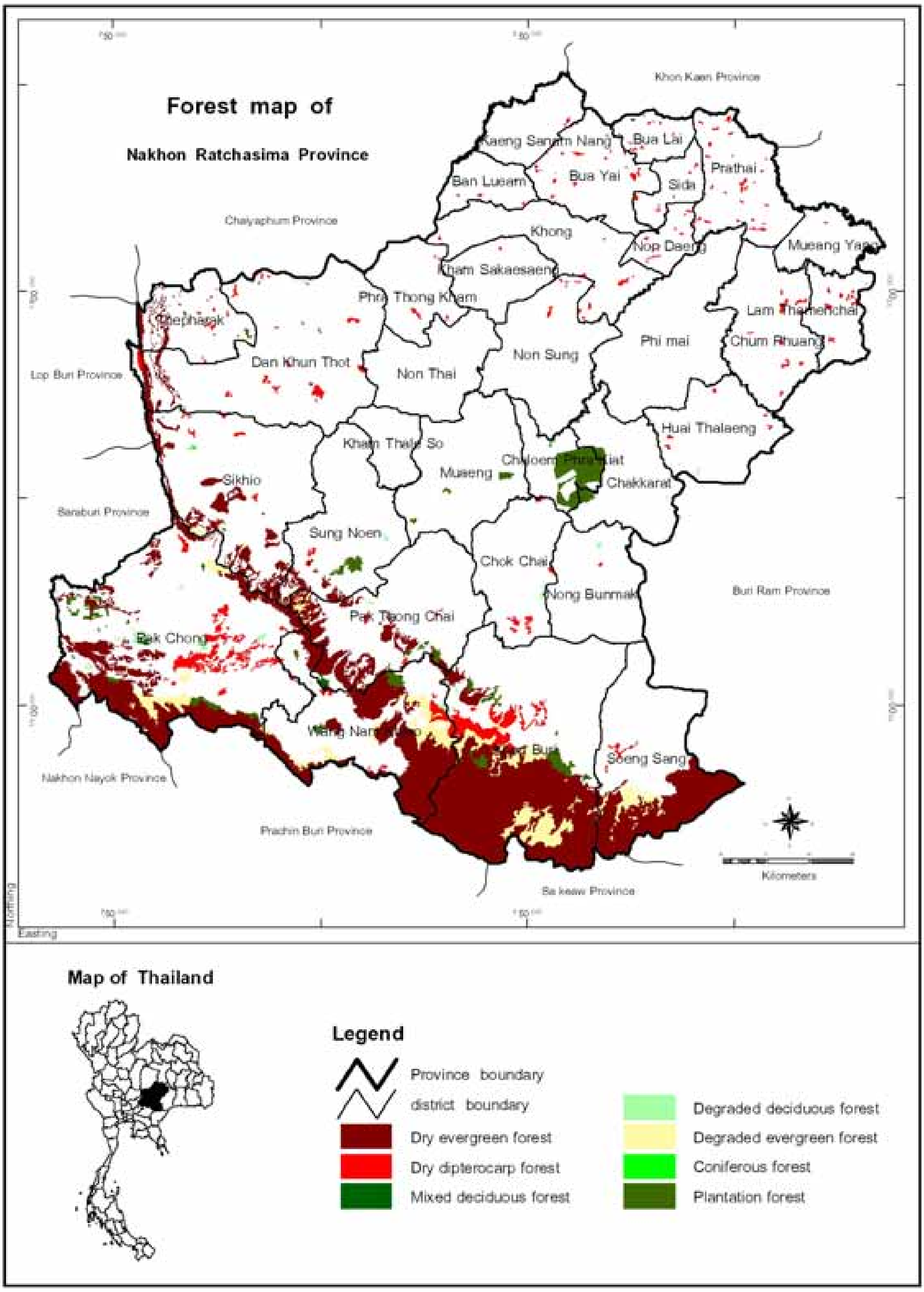

Figure 2.3 Forest types in Nakhon Ratchasima province (GIS program, 2007, modified from Land Development Department, 2000).

2.5 Overview of Geographic and Geological Information

2.5.1 Geography and Geology of Nakhon Ratchasima

Nakhon Ratchasima province lies between the parallels of 14˚ 7′ and 15˚ 46′ North Latitude, and between the meridians of 101˚ 11′ and 102˚ 53 ′East Longitude. It covers an area of approximately 20,193.96 km^2 or about 12.14 % of northeastern Thailand. It is located on the western end of the Khorat Plateau, separated from the Chao Phraya river valley by the Phetchabun and Dong Phaya Yen mountain ranges (Rajabhat Institute Nakhon Ratchasima (RIN), 1995).

Sediments and rocks in Nakhon Ratchasima were classified according to age and their characteristics (Fig. 2.4). There are 2 Quaternary deposits:

1. Quaternary alluvium (Qa: < 10,000 years) found in floodplains along rivers, such as the Mun, Lam Ta-khong, and Lam Phra-ploeng rivers.

2. Quaternary (Qt) and Neogene terrace (10,000 years - 23 millions years) with sediments consisting of sand, silt, gravels, often with laterite and lateritic soil. Many petrified trunks have been found in conglomerate and gravel beds of these sediments.

The lower levels comprise rock formations,such as Maha Sarakham, Khok Kruat, Phu Phan, Sao Khua, Phra Wihan, Phu Kradung, and Huai Hin Lat.

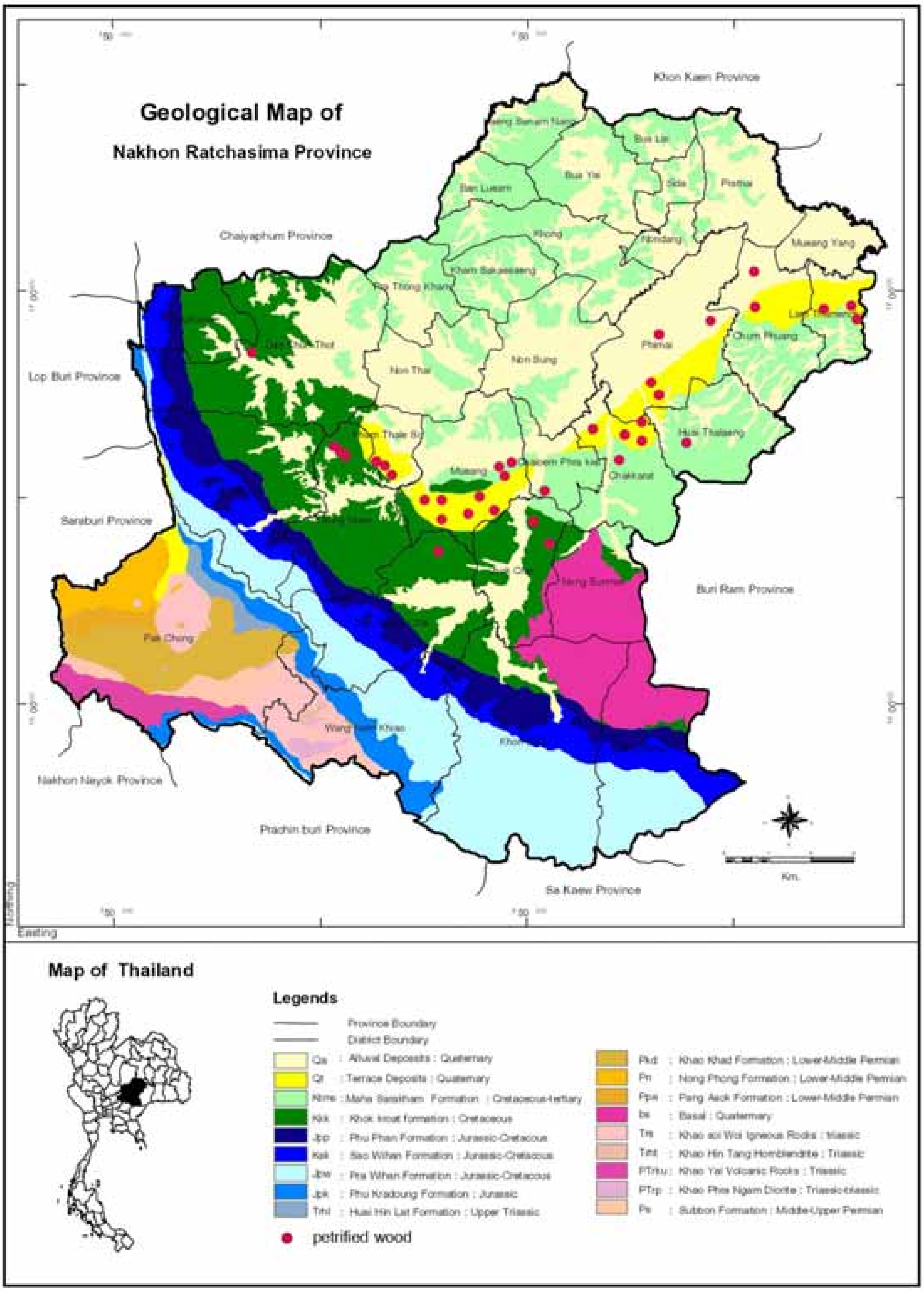

Figure 2.4 Geological map displaying the main distribution of petrified wood in Nakhon Ratchasima province (GIS program, 2004, modified from Department of Mineral Resources, 2004).

2.5.2 Geography and Geology of the Study Area

2.5.2.1 Previous studies on sediments

The topography of the institute and the surrounding areas is middle and high terrace from the Quaternary. The morphology is caused by deposition of fluvial sediments on the sedimentary rocks of the Khok Kruat Formation. The institute area is a gravelly terrace about 250 - 270 m above mean sea level (Fig. 2.6). It was formerly like a small hill, about 7 - 8 meters higher than the present area, and was called “Khao Kaew” (the crystal hill) because of the shiny quartz, chert, and sandstone in the beds. The gravels and sediments were taken for construction, such as for the military airfields and streets. From human activities since thirty years ago, the geographical area has changed. Much gravel had been taken away and some areas were reclaimed as rugged topography. The characteristics of minor topography in the institute area is varied, i.e., undulating, pond, quarry, and gully resulting from digging out gravels and lateritic soils by human activities (Jintasakul, 1995).

There are different assumptions from geologists about the sediments of this area. One of them is that there are two layers of gravel beds (Fig. 2.5). The upper layer consists of unsorted and unconsolidated sediments, resulting from sliding of higher sediments of the lower gravel bed. Sediments in the lower gravel bed are sorted. They are semi-consolidated and unconsolidated conglomerates in some areas (Jintasakul, 2008, personal communication). Another assumption is that these gravel beds are from the rock weathered in place (Chonglakmani, 2006, personal communication).

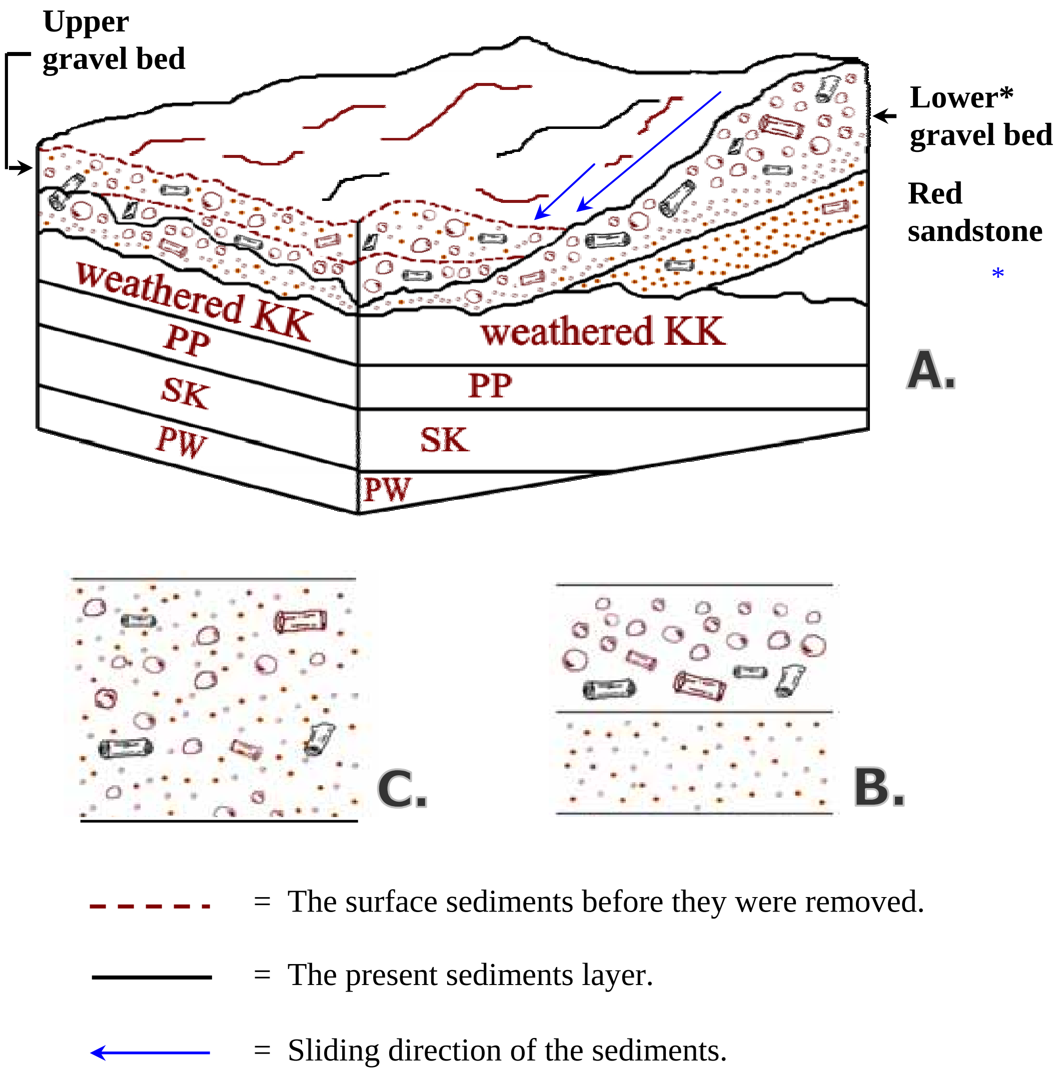

Figure 2.5 Geological section of the institute area (modified from RIN, 1995; Jintasakul, 2008, personal communication). **A.** Embedded petrified logs and fragments in red sandstone layer and gravel bed. **B.** Sorted sediments in lower gravel bed. **C**. Unsorted sediment in upper gravel beds.

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* The collected specimens in this study are from the Lower gravel bed.

In 2000, while using GPR for surveying petrified wood, Surinkam *et al.* reported, concerning the sediments covering the institute area including this study site, that there are two layers: the upper is represented by SS and the lower is RS (Fig. 2.7). The upper layer of unconsolidated sediments, consisting of sand particles, silt, and clay, was found in some areas. The lower layer consists of reddish sand deposits and non-sequence alternating of fine sand layers with coarse sand layers and gravel beds (from granule to pebble). This sediment layer has become consolidated by iron oxide cementation after exposure to the air. Petrified wood from the gravel beds is not large and includes log fragments, whereas most large petrified logs are found from the upper part of the reddish coarse sand layer, which is usually covered by sandstone, but exposed when the sandstone was removed

However, the large *in situ* trunks studied and collected from the study area were all found from the lower gravel beds.

2.5.2.2 Previous studies on taphonomy and petrification

- Assumption of how trees become petrified

A major factor causing wood to become petrified in the Northeast of Thailand, including in the study area, is the rich silica content of the water, resulting from the mineral composition of alluvial deposits. In some localities, silica content in waters from shale and siltstone of the Khok Kruat and younger formations is high, about 60 ppm. Two hypotheses are raised to explain why there is much dissolved silica in the water (Haworth *et al.*, 1966; Jintasaul, 2006, personal communication).

1) Hypothesis of alkaline solution

This assumption is based on the underground water of the institute area and surrounding areas in Suranaree subdistrict being rich in $CaCO_3$ resulting in alkaline water. The alkaline water can dissolve the surrounding gravels and sand, which are mostly quartz, causing an increased concentration of silica (SiO_2) in the water. The rich silica solution penetrated the wood and gradually replaced the cells until the wood was finally petrified. In case where the wood was acidic, the silica crystallized forming quartz crystals in lumina of the wood. As time went by, the wood became enriched with the crystals and gradually turn to stone.

2) Hypothesis of hydrothermal solution

The wood was buried in a hydrothermal solution, which was saturated by silica. The silica solution had seeped through the rock fractures or sediments and combined with underground water causing silica to crystallize in the cell spaces and replace the tissue of wood. There is evidence of volcanic activity and a siliceous rock layer in the river basin on the western side of the Mun River agreeing with this assumption (Jintasakul, 2006, personal communication).

- Assumption of how trees were buried in the institute area

There have been few reports of how the trees were buried in this study site. Bunopas *et al.* (2002 and 2003) published two papers that the large petrified trunks in the institute area were probably carried and buried because of earthflows resulting from an extraterrestrial impact in Buntharik, Ubon Ratchathani province, according to the discovery of splash tektites, dating close to 0.8ma, and catastrophic loess mixing with the Lower Pleistocene gravels at Ban Krok Duen Ha.

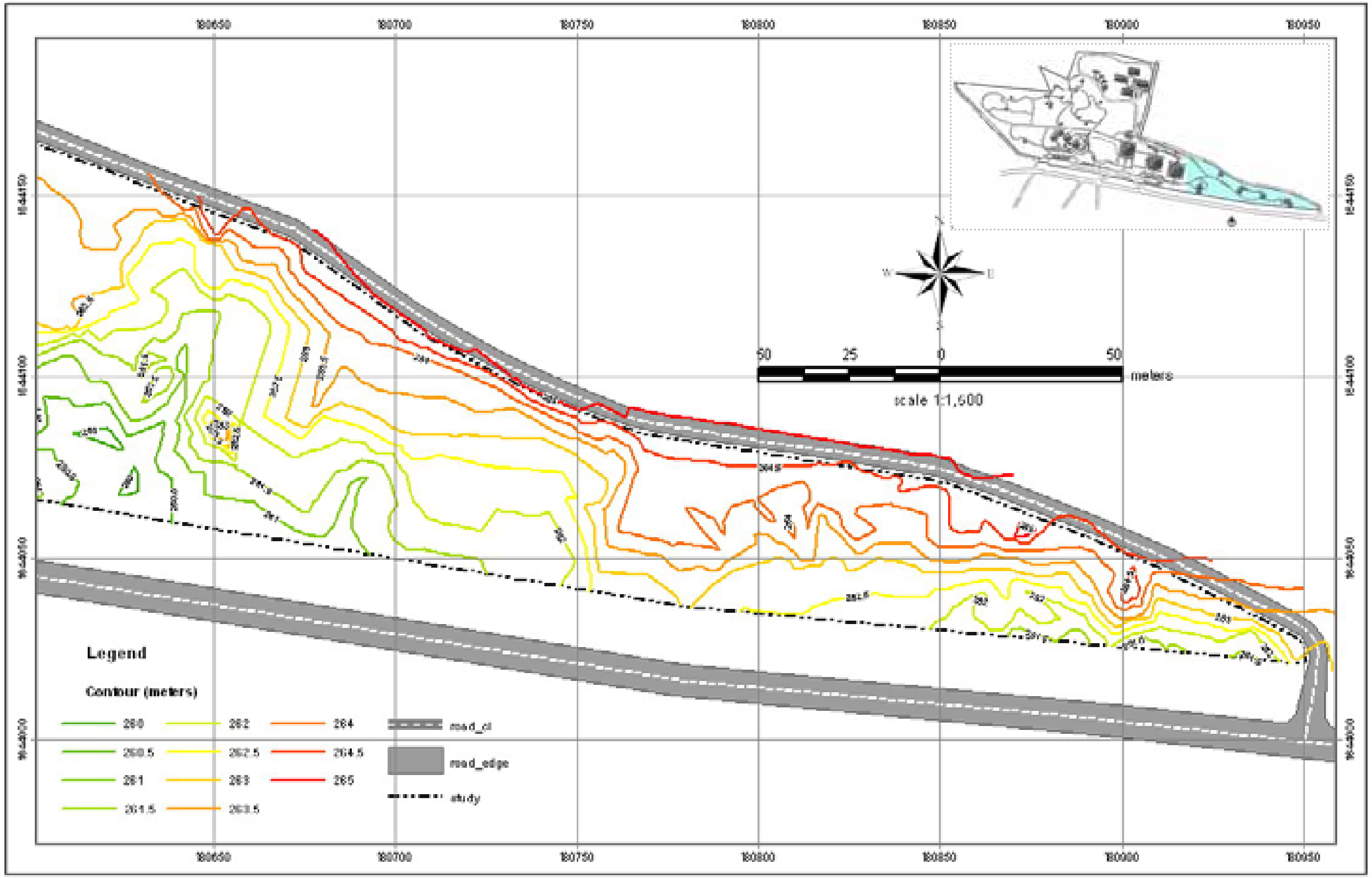

Figure 2.6 Map showing the altitude above mean sea level (GIS Program, 2008, modified from architecture map of NRIPM, 2000).

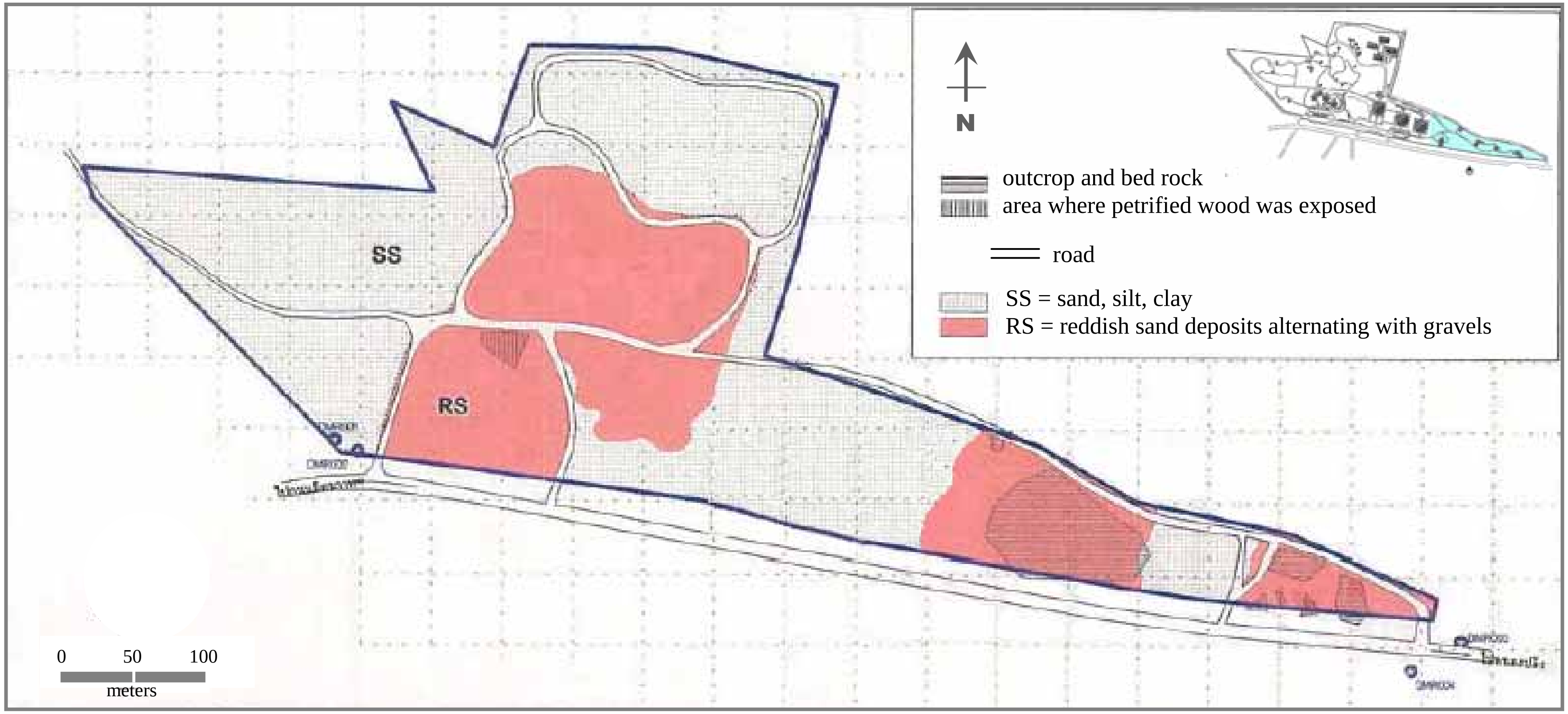

Figure 2.7 Geological map displaying the sediments of the institute area (modified from Surinkham *et al.*, 2003). The study site is at the eastern area of NRIPM as shown in blue color of the small map.

2.6. Identification of Fossil Wood

Identification of fossil wood is similar to modern wood identification but more complicated. Identifying fossil wood requires study of both living and fossil wood anatomy. Most fossil species are extinct. The wood has been changed and sometimes compressed during the taphonomical processes, and also the plant species have evolved through time. Therefore, paleobotanists usually give the ending "*-oxylon*" when naming the fossil wood scientifically. Three sections of petrified wood are all needed for identifying at the specific level for both gymnosperms and angiosperms.

Gymnosperms and angiosperms have different wood anatomical structures. Most gymnosperms have no vessels, but vessels do appear in *Gnetum*, *Ephedra*, and *Welwitschia.* Only *Gnetum* wood has been found in the fossil record (Barefoot *et al.*, 1982). In opposition, most angiosperms have vessels. There are about 8 genera, *Belliolum*, *Bubbia* (syn. *Tetrathalamus*), *Drimys*, *Exospermum*, *Pseudowintera*, *Tetracentron, Trochodendron,* and *Zygogynum* of modern angiosperms that have no vessels in the wood. In addition, a form genus of fossil wood, *Sanioxylon*, is considered a possible ancestral type of angiospermous wood without vessels (Barefoot *et al.*, 1982).

For angiosperms, the transverse section is the first important section to use in identifying wood at the generic level. The main characteristics used for identification are pores (vessels) and parenchyma, their number, size, arrangement, and distribution, plus the presence of thick and thin walled fibers. Secondly, the width of rays, i.e., uniseriate, biseriate, multiseriate; ray height, and presence of storied rays are observed and measured in tangential section. Thirdly, ray tissue (homogeneous or heterogeneous) and cellular composition are studied in radial sections. Other characteristics, such as vessel perforations, simple or multiple (scalariform, ephedroid, reticulate), intervessel pits, and spiral thickenings in some genera, may sometimes be seen both in radial and tangential sections.

CHAPTER III

MATERIALS AND METHODS

3.1 Materials

3.1.1 Petrified wood

3.1.1.1 Twenty three petrified wood specimens from the study area.

3.1.1.2 Thin-section slides (Fig. 3.1B) and photographs of petrified wood of the Northeastern Research Institute Museum of Petrified Wood and Mineral Resources (NRIPM).

Photographs and some slides of petrified wood from northeastern Thailand from the NRIPM collection, made and identified by Prof. Wu Zhang, Prof. Shaolin Zheng, and Dr.Yongdong Wang, were studied to compare fossil wood anatomy with petrified wood (Fig. 3.1A) from the study site.

3.1.2 Modern wood

Slides of modern wood (Fig. 3.1C).showing resemblance to fossil wood were studied at the Royal Forest Department (which is now the National Park, Wildlife and Plant Conservation Department) in Bangkok, where there is a wood herbarium with a large collection of modern wood samples from around Thailand and some from overseas. Some wood pieces from the collection were used to make additional slides.

Figure 3.1 Slides used in this study. **A.** Slides of petrified wood from the study site. **B.** Slides of petrified wood of NRIPM collection from northeastern Thailand. **C.** Slides of modern wood, both the old permanent slides (right) and new slides from the wood herbarium.

3.2 Methods

3.2.1 Field data collecting

The study site was mapped and divided into grids (each 20 x 20 m) in 16 columns and 8 rows with rope (Fig. 3.2 and 3.3 A-C). The grids were labeled A to P from west to east and 1 to 8 from north to south. Four of five previously found petrified logs were excavated again, then re-buried for protection. The soil covering was removed by hoe and spade to expose some parts of the petrified wood, which were then brushed with a broom to protect the wood surface from being scratched by digging.

Approximately 4x4x4 cm petrified wood pieces from large embedded petrified trunks were cut with a cutting saw, using a diamond blade (Fig. 3.4C). Other fragmentary petrified wood specimens were randomly collected (Fig. 3.4A). All specimens were given a location code number and measured for size (Fig. 3.4B). Five large, embedded petrified trunks were measured for their orientation and vertical position. The orientation of the long axis of each trunk was established using a Taylor instrument compass, oriented to north, and then reading the degrees east or west of the north position. The vertical positions were determined by using a SOKKIΔ C30 (D10341) transit no.184659.

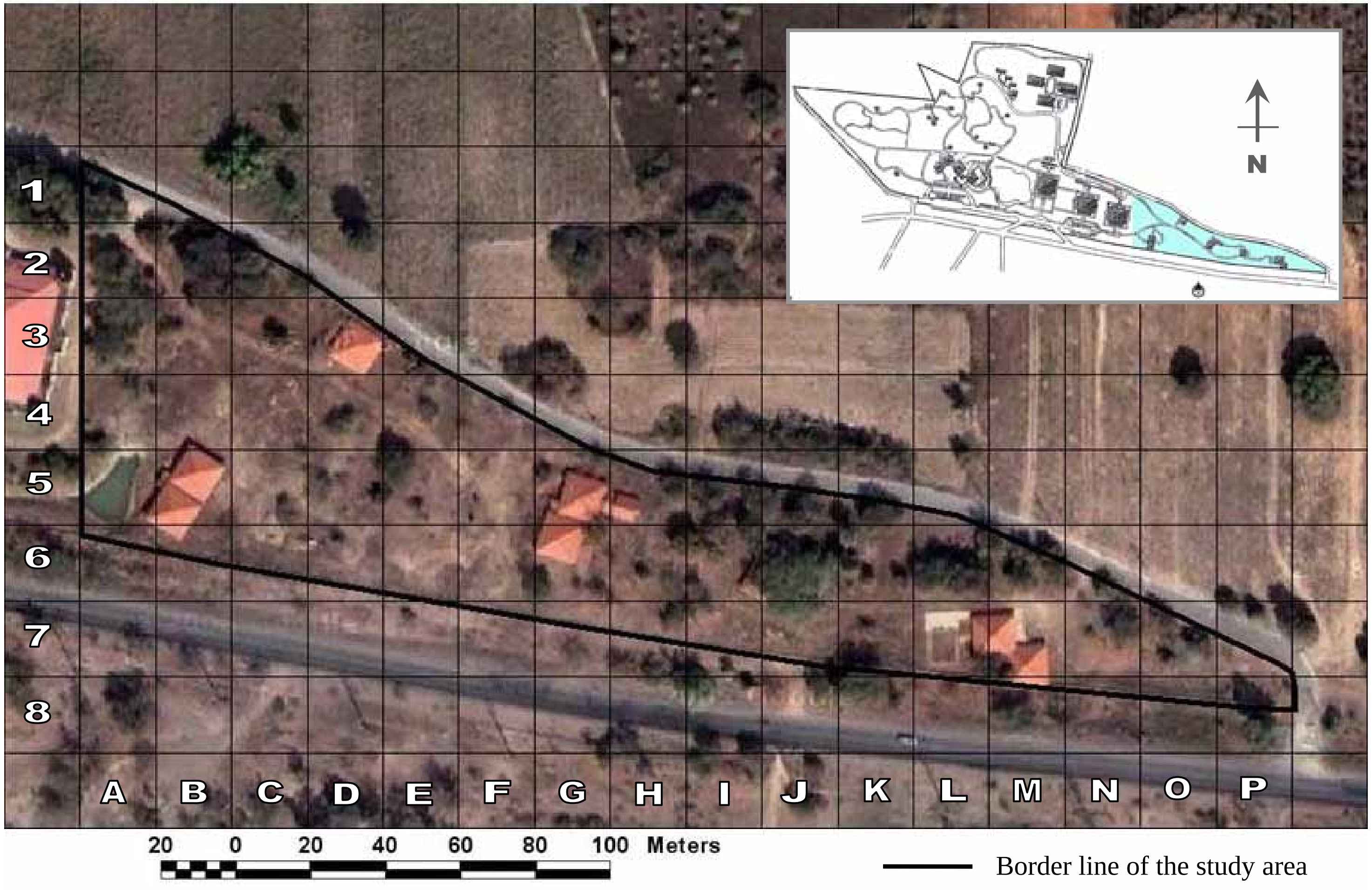

Figure 3.2 Satellite image of the study site in museum area and the grids (modified from Google Maps, 2008).

Figure 3.3 Part of the study area divided into grids with rope.

Figure 3.4 Field work. **A.** Collecting specimens and describing field data. **B.** Measuring a specimen. **C.** Cutting a specimen from a large log to prepare in the lab.

3.2.2 Laboratory work

3.2.2.1 Preparing petrified wood slides

Petrified wood specimens (Fig. 3.7 D&E) were prepared in the laboratory for anatomical study by making petrographic thin sections (approximately 0.3 mm thick). The specimens were marked for cutting three sections and separated in boxes to prevent confusion (Fig. 3.7F). Each specimen was cut into transverse, tangential, and radial sections. First, a cut* was made along a marked line for a transverse section (Fig. 3.7 A-C). Then, the specimen was cut along the radial and tangential lines until there was a section approximately 3 - 4 mm thick for each of the 3 orientations.

The laboratory research was initially carried out at the Center for Scientific and Technological Equipment, Suranaree University of Technology. The large-sized specimens were cut* with a large diamond blade cutting saw into a small cube, a suitable size for the standard biological slide, and then polished* by a polishing machine with sand paper numbers 100, 320, 600, 1,000, and velvet, respectively, until the surface was smooth. Then each specimen was fixed onto a glass slide with epoxy and allowed to dry for at least 12 hours. After that, the other side of the specimen was cut to make a petrographic thin section. Because of a broken cutting machine specimen holder, the thin section preparation for this research was continued at the Nanjing Institute of Geology and Palaeontology (NIGPAS) (Fig. 3.8 A-D) in Nanjing, China, and some additional collected specimens were prepared at the Department of Geology, Chiangmai University (CMU) in Chiangmai, Thailand.

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* During cutting and polishing a specimen, the cut or polished surface must be kept wet with water to reduce heat and sparking, allowing a smoother process.

At NIGPAS, the specimens were cut into transverse, tangential, and radial sections (Fig. 3.9 A&B) and then polished coarsely with silicon carbide (#240) and polished finely with optical alumdum (#600), respectively, to make the surface smooth (Fig. 3.9 C&D). This was checked by spreading a little water over the surface of the petrified wood and watching the surface drying; if any corner or area dried rather slowly that area might have been polished a bit too much or unevenly. A rather strong attractive force could be felt between the petrified wood surface and the glass during fine polishing, indicating a sufficient amount of polishing.

Each glass slide was slightly polished with powder for a moment to make sure that it was not too slippery when attaching a thin section of wood. After that, the thin section of petrified wood was rinsed, dried, and fixed onto the slide with Abienic balsam (Fig. 3.10A). The slides were left until the Abienic balsam solidified. Each petrified wood slide was then polished with the polishing machine again, using polishing powder as mentioned above.

Each slide was occasionally checked during the polishing process to be sure that it was being polished in the horizontal plane, not an inclined plane. The polishing direction was constantly changed while polishing the petrified wood to erase the scratches on the specimen surface from the previous direction. The polishing of the specimen was continued until the section was about 1 mm thick. The slide was then rinsed with water and another fine grained polishing powder was used for fine polishing in the same way as the coarse polishing. The slide was checked for thickness and quality using a compound or stereo microscope. The wood anatomical structures of the fossil specimens should be visible clearly and the sections not too thick or too thin to avoid losing some cellular structures. The slides were rinsed with water again and left to dry. The slide was covered with a thin cover glass using Abienic balsam (Fig. 3.11A), attempting to remove any air bubbles (Fig. 3.11B). The slide was left until the resin had strongly fixed the cover glass onto the slide of petrified wood. Resin sticking outside the cover glass was removed by using sharp blade (Fig. 3.12A) and then washed with alcohol. The slide was dried by quick heating (Fig. 3.12B) or air dried and was then ready for study with a microscope. The steps of petrified wood preparation are briefly shown in Fig. 3.6.

At the Department of Geology, CMU, the slide preparation process was similar, but differed in using material such as silicon carbide abrasive powder (Fig. 3.5B & C) for polishing (Grit[*] 100, 300, 400, 600, and 1,000, respectively). An Ingram thin section grinder model 400U (Fig. 3.5A) was used for final polishing of the specimen surface before covering with a cover glass. The slides at the Dept. of Geology are shorter than standard biological slides, because the longer slides could not be used with the machine. Epoxy was used to fix the cover glass onto the petrified wood slide.

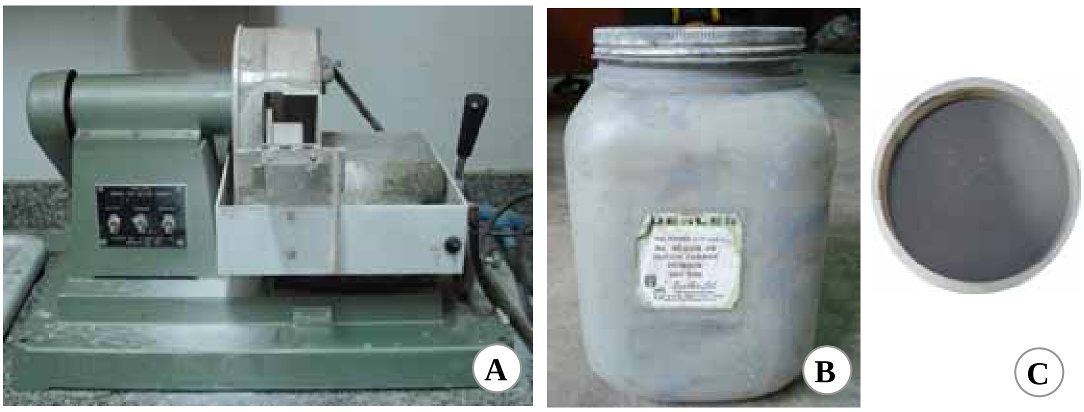


Figure 3.5 A. Ingram thin section grinder. **B. & C.** Silicon carbide abrasive powder.

[*] Always rinse out the old powder or change the polishing dish when changing to a different grit size powder. Mixing of grit powder causes scratches on the specimen surface

Preparing petrified wood slides

Mark the specimen for cutting three sections (transverse, radial, and tangential).

⇩

Cut petrified wood along the lines with a cutting saw.

⇩

Polish the specimen (from coarse to fine) until the surface is smooth using

⇩		⇩		⇩
Sand paper	or	Polishing powder	or	Silicon carbide powder
(SUT)		(NIGPAS)		(CMU)
100, 320, 600 (coarse)		Silicon carbide (240)		100, 300, 400, 600
1,000, velvet (fine)		Optical alumdum (600)		1,000 and 1,200

⇩

Rinse the specimens with water and dry the specimens on a hot plate.

⇩

Fix the specimen onto the polished glass slide using

⇩		⇩
Epoxy	or	Abienic or Canada balsam
dry for 12 hours		dry for 6 hours

(attempting to remove the air bubbles, if any).

⇩

Cut and/or polish another side of the specimen (as mentioned above) until smooth.

⇩

Rinse the specimen slide with water and let it dry.

⇩

Cover the thin section with a cover slip (using Abienic or Canada balsam or epoxy).

⇩

Let the specimen dry.

⇩

The slide is ready for study with a microscope.

Figure 3.6 Diagram showing method in preparing petrified wood slide.

Figure 3.7 A. - C. show the well preserved areas of the specimens in transverse section. **D. & E.** show petrified wood pieces, about 4x4x4 cm or 5x5x5 cm, that were selected and cut from the field. **F.** The specimens were marked for cutting into three sections and separated in each box.

Figure 3.8 Cutting and polishing machines at NIGPAS, Nanjing, China.

A. The cutting machines for large specimens.

B. A cutting machine for small specimens.

C. The polishing machines for coarse polishing, using silicon carbide no. 240 (green powder, which is shown on the upper right side).

D. A polishing machine for fine polishing, using the optical alumdum no. 600 (white powder).

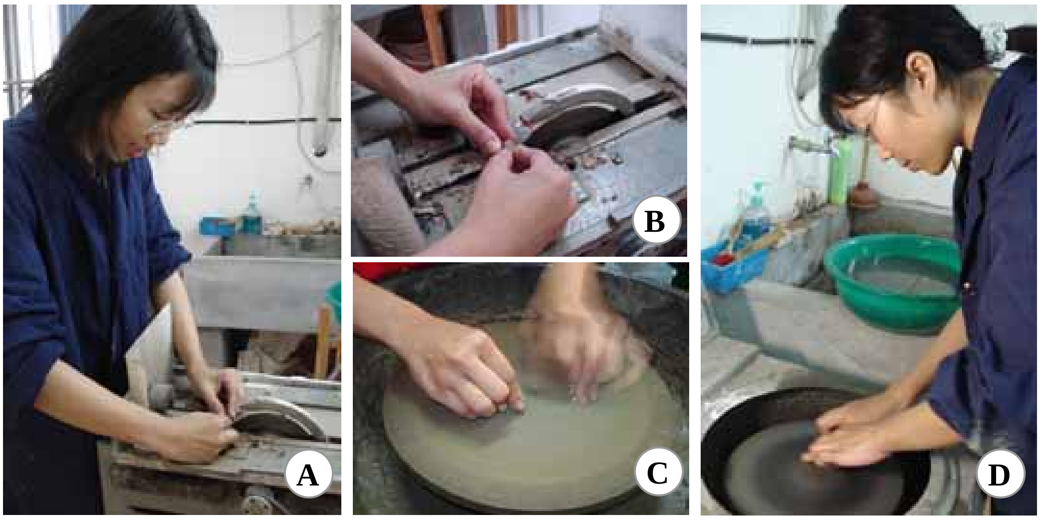


Figure 3.9 Cutting **(A& B)** and polishing **(C & D)** petrified wood specimens.

Figure 3.10 Drying petrified wood specimens and polished slides on a hot plate and using the heat to fix a specimen onto a slide with Abienic Balsam in laboratory of NIGPAS **(A)** and Deparment of Geology, CMU **(B)**. The glass slides in the right figure are shorter than those in the left figure.

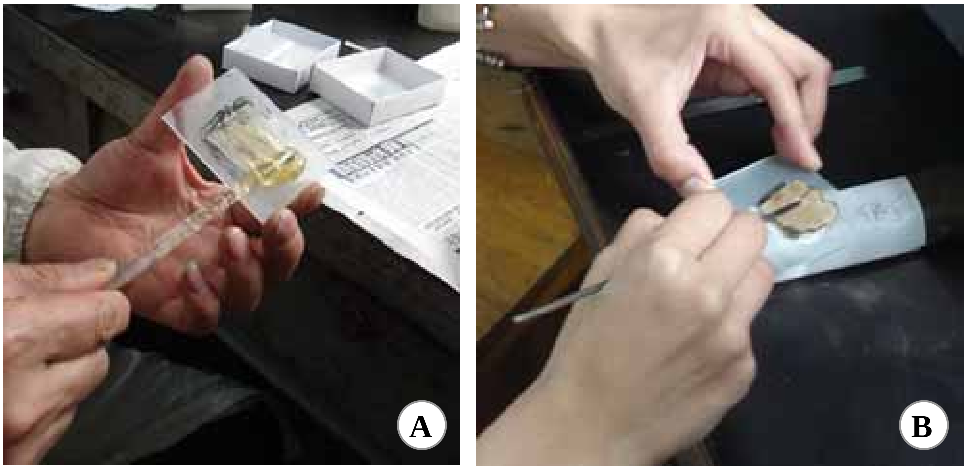


Figure 3.11 A. Fixing a specimen with Abienic balsam*.

B. Removing air bubbles from a slide.

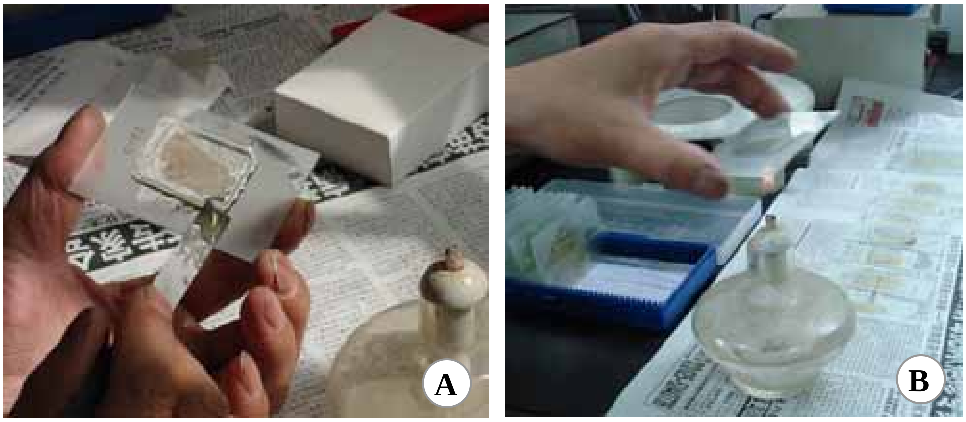


Figure 3.12 A. Removing excess Abienic balsam.

B. Drying a petrified wood slide by quick heating.

* Using Abienic or Canada balsam to fix a specimen onto a slide is less time consuming and makes it easier to get rid of air bubbles from the slide than using epoxy. However, the slides should be kept away from a hot environment.

In my opinion, using polishing powder, as at NIGPAS, was the best method for producing good quality slides and the most efficient in time. The last step of making a thin section before covering with a cover slip was better done by hand polishing than by using a machine. Although using a machine helped make petrified wood sections more consistently, there was a chance of slides breaking. However, it is difficult to consistently polish in one plane by hand polishing, depending on personal experience.

Using a large slide for a large well preserved specimen area is better to allow observation of wood anatomical features, e.g., vessel porosity and pattern of parenchyma.

3.2.2.2 Preparing modern wood slides

All microscopic photos of modern wood were taken by an Olympus DP11 camera and an Olympus B-51TF. No. 1G13104 compound microscope at the Forest Products Research Center. Steps for modern wood slide preparation are briefly shown in Fig. 3.13.

Preparing modern wood slides

Select wood sample (Fig 3.14A).

⇩

Cut the wood into approximately 2x2x2 cm cubes using a saw (Fig. 3.14B).

⇩

Boil the wood for at least 6 hours or overnight [1,2] (Fig. 3.14C).

⇩

Cut thin sections with a sliding microtome, using a brush to put water on wood (make wood wet all the time during sliding) [3,4,5] (Fig. 3.14D).

⇩

Put the thin section of wood into a dish with water.
(Use a separate dish for each wood specimen and also each section to avoid confusion. Don't forget to put the label on each.)

⇩

Drop 2-3 drops of Safranin into the dish to dye the wood and leave it for about 4 hours (Fig. 3.14E&F).

⇩

Transfer the thin section to 30% ethanol: 70% water solution to rinse excess safranin.

⇩

Remove torn regions of the wood thin section with a sharp blade.

⇩

Place the thin section onto a slide, add 2-3 drops of water, and cover with a cover slip.

⇩

Then seal with clear nail polish and let it dry.

Note:
1. Different woods require different lengths of time to soften, depending on the hardness of the wood.
2. If boiling > 1 wood piece, each should be labeled or marked.
3. Cut at a thickness of 25 - 30 μm to make the surface smooth and discard.
4. Cut in range of 10 - 15 μm for making thin wood section.
5. If the wood is drier and harder to slide (or observed from the non-smooth surface or sticking of the wood), bring the wood to boil again and cut later.

Figure 3.13 Diagram showing method in preparing slide of modern wood.

Figure 3.14 **A. & B.** Samples of modern wood. **C.** Boiling wood.

D. Cutting thin sections of wood with a microtome.

E. and **F.** Dying with safranin.

3.2.3 Identifying fossil wood

A compound light microscope was used to compare the anatomy with that of Recent wood. Photomicrographs of fossil wood were mostly taken by an Olympus BX-41 microscope at NIGPAS. Additional photographs of the prepared thin sections were made at the Shenyang Institute of Geology and Mineral Resources, Shenyang, China. Microscopic analysis was continued in Thailand at Suranaree University of Technology and at the wood herbarium of the Forest Products Research Center of the National Park, Wildlife and Plant Conservation Department, Bangkok.

The description of microscopic characters of petrified wood was made, mainly using the IAWA list of microscopic features for hardwood identification (Wheeler *et al.*, 1989) and other literature. Anatomical characters, such as the size and arrangement of vessels, vessel element length, intervessel pits, axial parenchyma, fibers, and rays, were observed and measured. The pieces and slides of modern wood were studied mainly from wood herbarium collections by hand lens and under a compound light microscope, respectively. Some Recent wood was cut to make additional slides. Additional information was investigated from the literature and databases from the Internet, e.g., Inside Wood (2004-onwards). The habitat, community, and climate of Recent nearest living relative tree species of the fossil wood were studied in an attempt to reconstruct the past plant communities and climate.

CHAPTER IV

RESULTS

4.1 Diversity and Comparative Anatomy of Petrified Wood

4.1.1 Systematics and diversity of petrified wood

Twenty three petrified wood specimens from 10 rai (~ 16,000 m^2) within the Northeastern Research Institute of Petrified Wood and Mineral Resources were studied and assigned to about 17 species of 10 genera from 7 families. They are all dicotyledonous as follows:

Family Anacardiaceae

Anacardiaceae *gen. et* sp. *indet.* (N8)

cf. *Mangiferoxylon* sp.1 (G5)

cf. *Mangiferoxylon* sp. 2 (N7-3)

Family Burseraceae

Canarium sp. (B5)

Family Combretaceae

Terminalia vel *Combretum* (A4-1)

Terminalia sp. 2 (M7-1, M7)

Family Irvingiaceae

Irvingia sp. (L7)

Family Leguminosae

Subfamily Caesalpinioideae

Cynometroxylon holdeni (F5-1, F-5-2, I2-2, I2-3, M1-4, M8)

Cynometroxylon sp. (N7-1)

cf. *Cynometroxylon* sp. 1 (M1-1)

cf. *Cynometroxylon* sp. 2 (O7)

Subfamily Papilionoideae

cf. *Millettia* sp. 1 (I2-1)

cf. *Millettia* sp. 2 (C4)

Family Lecythidaceae

Careya sp. 1 (A4-4)

Careya sp. 2 (I6)

Family Meliaceae

Azadirachta sp. (A4-2)

Angiospermous fossil wood (D4)

4.1.2 Comparative anatomy and description of petrified wood

Explanations:

For the descriptions in this research, I mainly follow the IAWA (International Association of Wood Anatomists) List of Microscopic Features for Hardwood Identification, 1989, such as:

1. Vessel lumina are measured, excluding the cell wall, for at least 25 vessels. Each solitary vessel and each vessel in radial multiples is measured for both tangential (t.d.) and radial (r.d.) diameter. However, for any specimen that clearly has different vessel sizes, i.e., no. B5, the vessels are measured for 2 size classes, the large solitary vessels and the small vessels in clusters.

Very small = $\leq$ 50 µm, Small = 50 - 100 µm, Medium = 100 - 200 µm, Large = $\geq$ 200 µm

2. Intervessel pit size: the horizontal diameter is measured.

   Minute = $\leq$ 4 µm, Small = 4 - 7 µm, Medium = 7 - 10 µm, Large = $\geq$ 10 µm

However, some additional details are added to allow comparison with the descriptions in the older literature, i.e.,

1. Both range and mean of the tangential diameter of vessel lumina and intervessel pits are given. (Previous research papers on fossil wood, e.g., The Palaeobotanist from 1965 - 1983, described only the range, but gave no information on the mean.)
2. Ray description is mainly from rays seen in radial section and follows IAWA (1981) instead of Kribs's ray types because Kribs's ray types are not agreed upon universally by wood anatomists (Metcalfe and Chalk, 1983). However, the terms homocellular or heterocellular are used for individual rays, and homogeneous (all ray cells procumbent or all ray cells square or upright) or heterogeneous (body ray cells procumbent with $\geq$ 1 row of upright and/or square marginal cells) are confined to use for describing ray tissue systems to avoid confusion (Metcalfe and Chalk, 1983). In addition, using these terms sometimes may help to make it easier to understand basic ray cellular composition when investigating and comparing the characters of rays from the literature on modern wood and fossil wood because of variation in description and classification in different literature.
3. Abbreviations for each section for figures:

   Transverse section = Tv   Tangential section = Tg   Radial section = R

Family Anacardiaceae Lindl.

Genus Anacardiaceae *gen. indet.*

Species Anacardiaceae *gen. et* sp. *indet.*

Locality: Institute of Petrified Wood and Mineral Resources, grid no.N8

Specimen number: N8 (Figs. 4.1 - 4.3)

Preservation: The specimen preservation is moderate; transverse and tangential sections are not very clear but cellular structure can be seen in some areas. Radial sections are rather poorly preserved but features of rays can be determined in some areas.

Description

Growth ring boundaries absent. Wood diffuse-porous.

Vessels 6 - 9/mm^2. Vessels usually medium and some small, tangential diameter (t.d.) 90 - 150 µm (mean 121.2 µm), radial diameter (r.d.) 90 - 200 µm (mean 149.2 µm). Vessels solitary as well as in radial multiples of 2 or sometimes 3, very rarely in diagonal pattern and/or tangential pairs or clusters. Solitary vessel outline rounded to oval. Vessel element length 160 - 430 (500) µm (mean 303.53 µm); perforation plates simple. The sample is poorly preserved in tangential section; intervessel pits cannot be seen.

Paratracheal axial **parenchyma** vasicentric, parenchyma sheath narrow forming complete sheath 1 - 2 (3) cells wide around vessels.

Rays 1-3 (mostly 2) seriate, thin-walled, some with 2 - 3 seriate portions as wide as uniseriate portions. Tangential height various (215, 235) 250 - 350 (400 - 435) µm (average 311 µm) and width 24 - 40.8 µm. Rays heterocellular consisting of body procumbent cells with 2 - 3 rows of upright and/or square marginal ray cells

(Fig. 4.3A). Rays non-storied or partly irregularly storied. Rhomboidal (prismatic) crystals present in upright and/or square ray cells (Fig. 4.2B).

Fibers very poorly preserved.

Affinities

The main characters of specimen no. N8 are small to medium vessels, solitary as well as in radial multiples of 2 - 3, simple perforation plates, vasicentric paratracheal axial parenchyma, rays (1) 2 (3) seriate, thin-walled, heterocellular, consisting of body procumbent cells with 2 - 4 rows of upright and/or square marginal ray cells, rays non-storied or partly irregularly storied, and prismatic crystals present in upright and/or square ray cells. These features show similarities with the modern wood of the family Anacardiaceae.

It is found that rhomboidal crystals are present in wood in many fewer taxa than in other parts of the plant. The rhomboidal crystals occur in rays of approximately 33 genera of Anacardiaceae (Carlquist, 2001).

Many species of fossil wood of Anacardiaceae were studied from Europe, the Americas, Russia, and Asia (especially India). Some are known from the Cretaceous. Awasthi (1966) reported that anacardiaceous fossil wood from the Tertiary of Hungary was recorded by Unger in 1850 and identified as *Rhoidium juglandinum*. The later following records by others are *Anacardioxylon spondiaeforme, A. uniradiatum, A. magniporosum, A. caracole, A. mangiferoides, A. semecarpoides, Edenoxylon parviareolatum, Schinoxylon actinoporosum, Glutoxylon burmense, G. bengalensis, G. chowdhurii, Buchananioxylon indicum, Dracontomelumoxylon mangiferumoides, Melanorrhoeoxylon garbetaense, Mangiferoxylon assamicum, M. scleroticum,* and *Swintonioxylon hailakandiense* (Awasthi 1966; Prakash and

Awasthi, 1971; Prakash and Tripathi, 1970; Roy and Ghosh, 1981).

In Southeast Asia, *Rhoidium philippinense* was reported in 1889 from the Tertiary of the Philippines; *Swintonia floribunda* in 1980 from the Tertiary of Myanmar and fossil wood of *Dracontomelon dao* was described in 2003 from the Miocene-Pleistocene of northeastern Thailand (Awasthi, 1966; Prakash and Bande, 1980; Benyasuta, 2003).

This fossil specimen is different from *Glutoxylon* because *Glutoxylon* has 1 - 2 seriate, mostly uniseriate rays, while this specimen has 1 - 3 (mostly 2) seriate rays . It is not likely to be *Holigarnoxylon* either because of the presence of aliform and aliform-confluent parenchyma in *Holigarnoxylon*, while aliform-confluent parenchyma is not present in this fossil.

Gluta and *Melanorrhoea* have larger tangential diameters of vessels, parenchyma in rather irregularly spaced bands, homogeneous rays, uniseriate (partly 2 seriate) rays, and 3 - 4 seriate rays with radial resin canals (Ogata *et al*., 2008). *Campnosperma* and *Spondias* have 1 - 3 to multiseriate rays. The fossil specimen is quite different and not assigned to be in any of these four genera.

Some of the fossil wood characters are similar with *Dracontomelon* (Fig. 4.5), but the fossil shows closer resemblance to both fossil and modern wood of *Buchanania* (Fig. 4.4) and *Mangifera* (Figs. 4.9 - 4.13). Growth rings are rather distinct in *Mangifera* and *Mangiferoxylon,* delimited by terminal parenchyma, and paratracheal parenchyma is vasicentric to aliform and aliform to confluent, whereas growth rings are indistinct and paratracheal parenchyma vasicentric in the fossil specimen rather than aliform. However, Prakash and Tripathi (1970) noted that anatomy can vary in modern wood of *Mangifera indica,* such as variation in the distribution pattern of parenchyma and in ray structure.

Vessels are mostly large in *Buchananioxylon*, although they can be small to medium in some species, i.e., *Buchananioxylon indicum*, which shows closest affinity to the extant *Buchanania latiflora* (Roy and Ghosh, 1981). *Buchanania arborescens* differs from the fossil as most vessels are in radial multiples very commonly $\geq$ 6, with few vessels solitary or in radial multiples of 2 - 3 (only FRI slide).

Dracontomelon sp. (Fig. 4.5) is similar with this specimen in having axial parenchyma vasicentric, exclusively biseriate rays, and rays heterocellular. Septate fibers are present in *Dracontomelon*, but the fibers in this specimen are rather poor preserved and septate fibers are not observed. In additionally, vessels in *Dracontomelon* are less density in number and are more often solitary (70%); ray are higher (up to 0.8 mm) than this fossil (Dong and Baas, 1993).

Pleiogynium spp., e.g., *Pleiogynium timorense* is also similar with this fossil in having parenchyma vasicentric, vessels are sometimes in diagonal pattern, and rays are homocellular and 2-3 seriate (inside wood, 2004-onwards).

Because intervessel pits cannot be seen in longitudinal sections and the preservation of fibers is poor and cannot be determined in this fossil, I therefore place the fossil wood at the family level with possible affinity to *Buchanania, Dracontomelon*, and *Pleiogynium*.

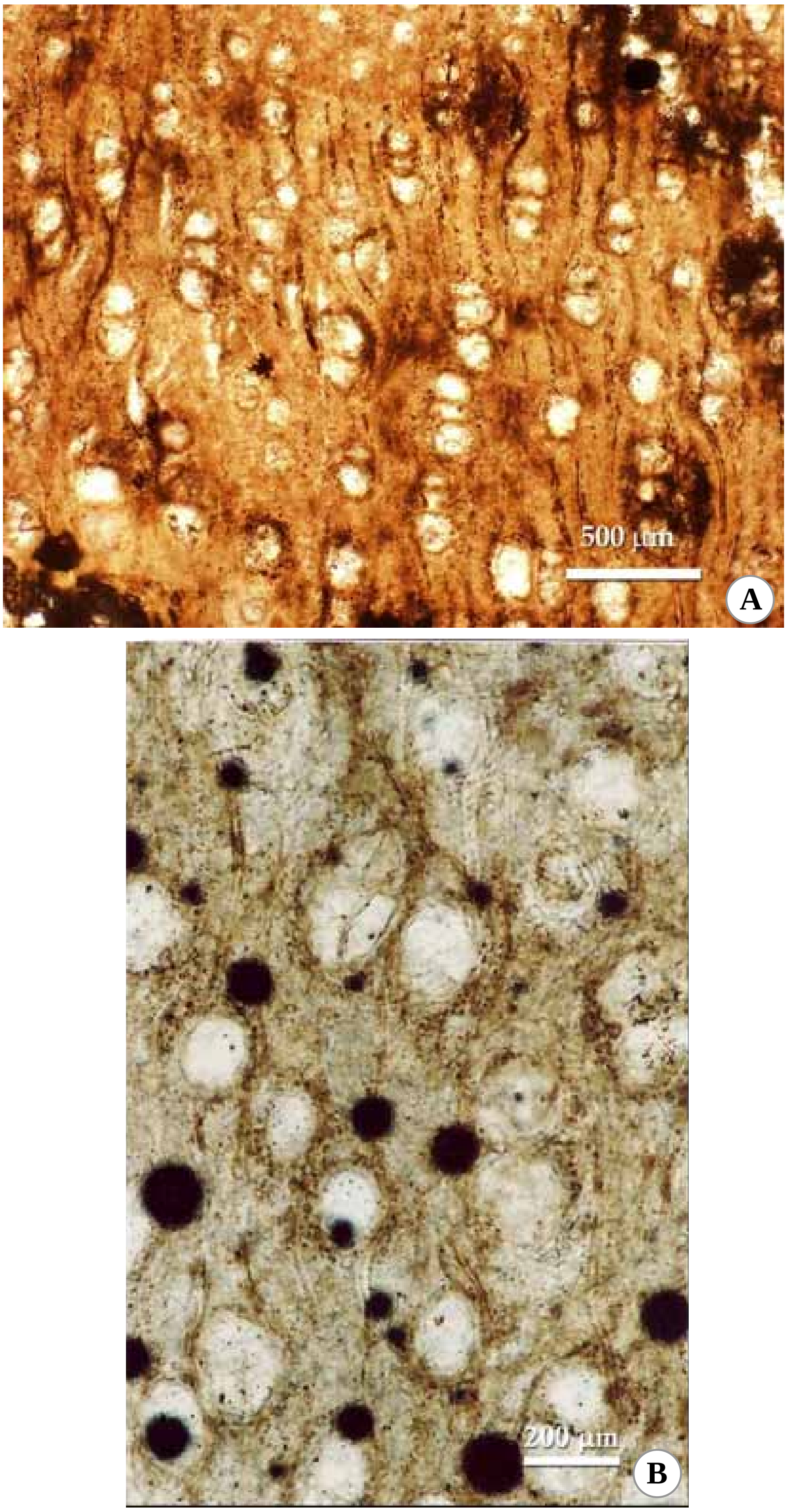


Figure 4.1 Thin section of slide N8 showing transverse section. **A.** Vessels solitary and in radial multiples of 2-3. **B.** Vessel in diagonal pattern and axial parenchyma vasicentric.

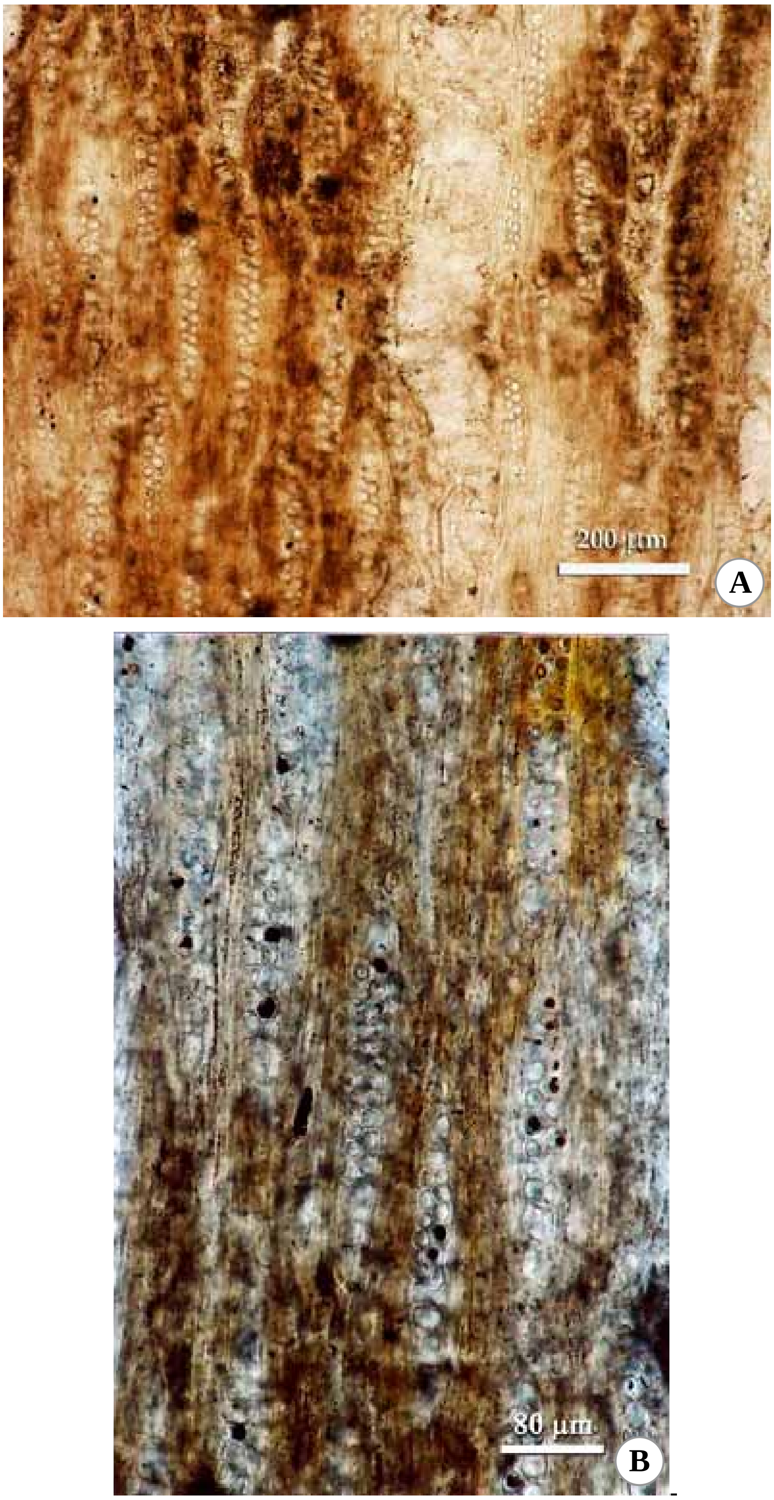


Figure 4.2 Thin section of slide N8 showing tangential section. **A.** Exclusively biseriate rays, non-storied rays. **B.** Rhomboidal crystals appearing in upright ray cells (arrows), and non-septate fibers.

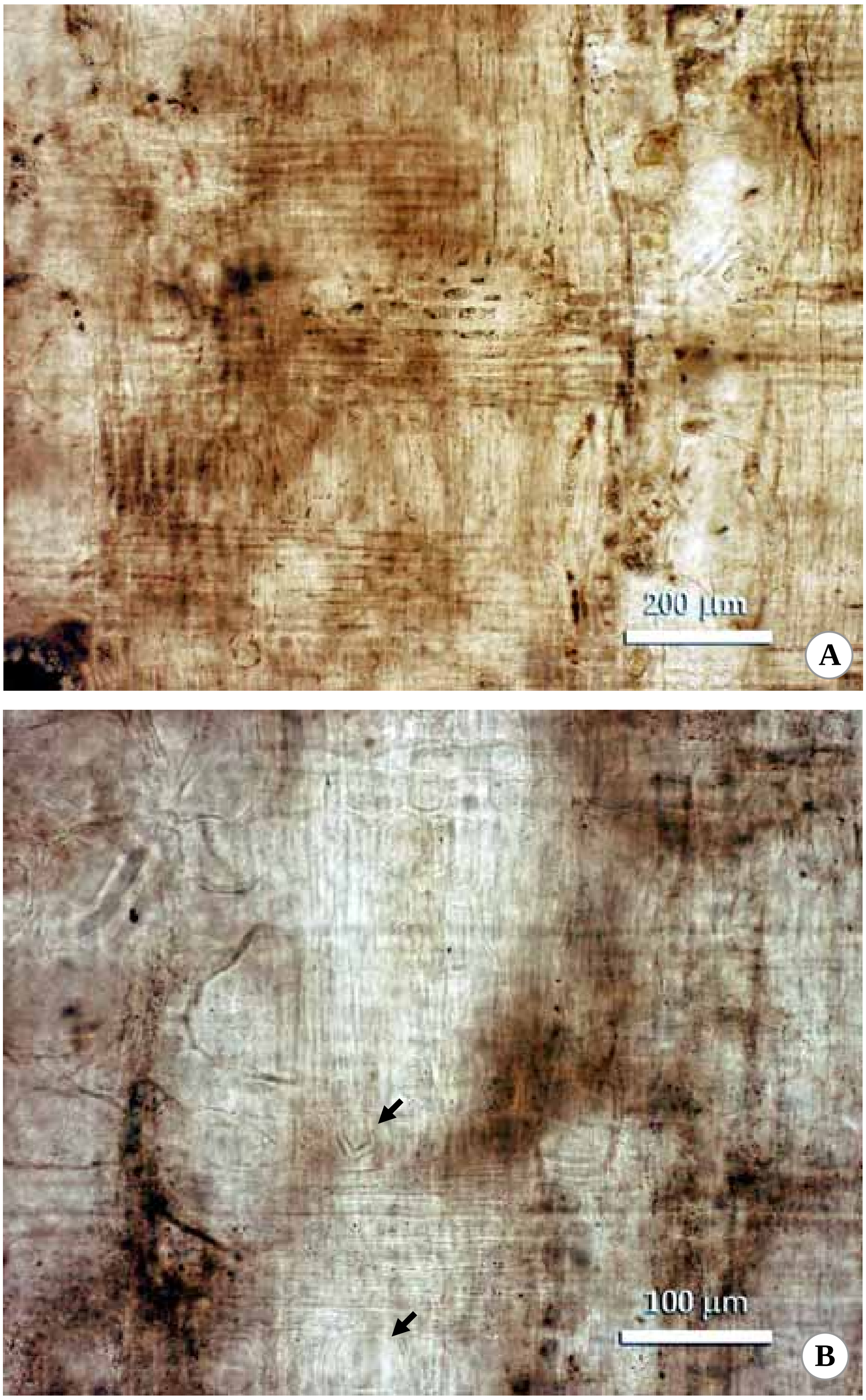


Figure 4.3 Thin section of slide N8 showing radial section. **A.** Rays consisting of procumbent body ray cells with 2 - 3 rows of upright and/or square marginal ray cells. **B.** Rhomboidal crystals present in upright marginal ray cells (arrows).

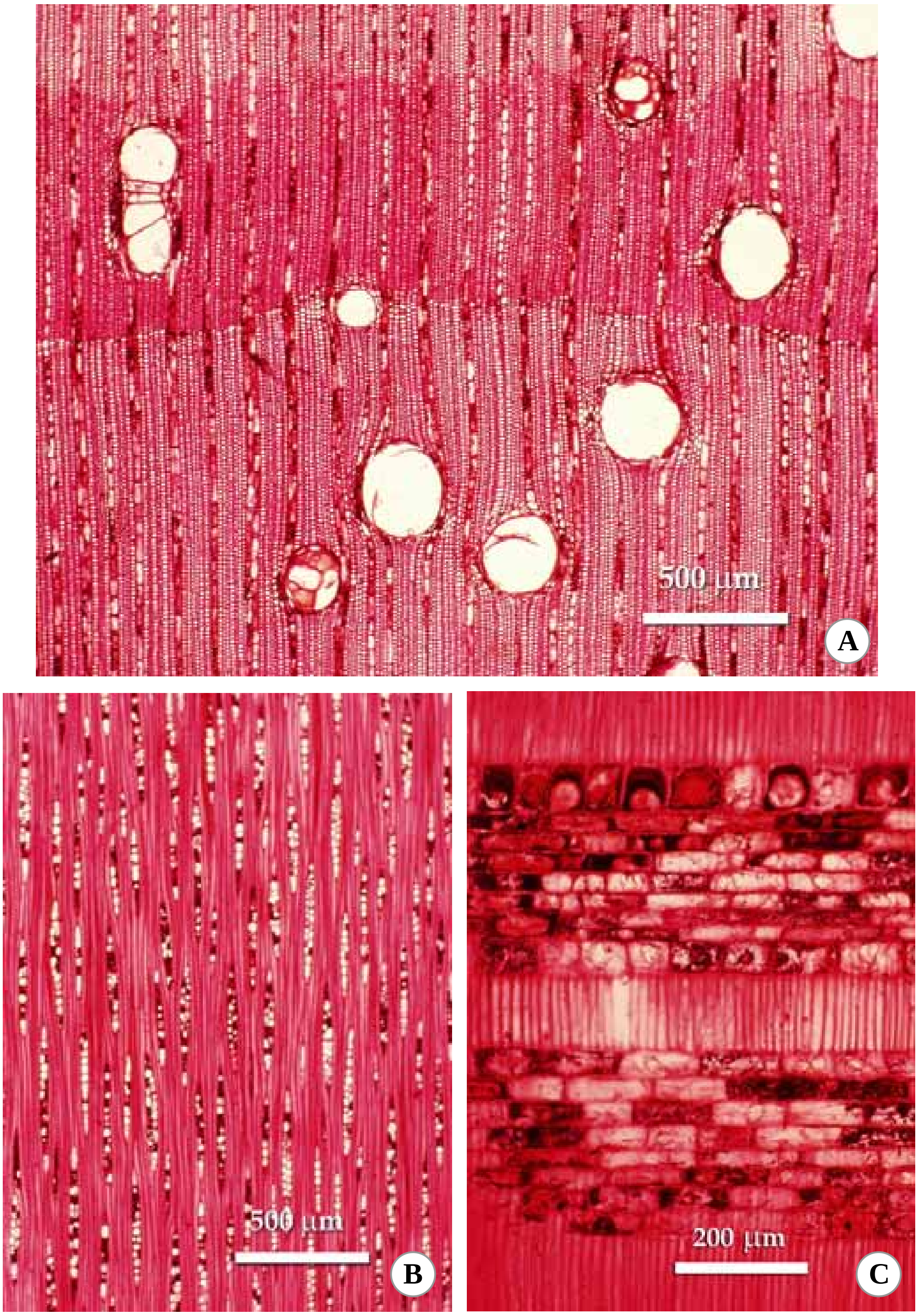


Figure 4.4 Thin section of *Buchanania* sp. **A.** (Tv) Vessels solitary and in radial multiples of 2 - 3. **B.** (R) Heterogeneous rays; body ray cells procumbent with a row of upright and/or square marginal ray cells (upper) and all procumbent ray cells (lower). **C.** (Tg) Exclusively biseriate and non-storied rays and septate fibers.

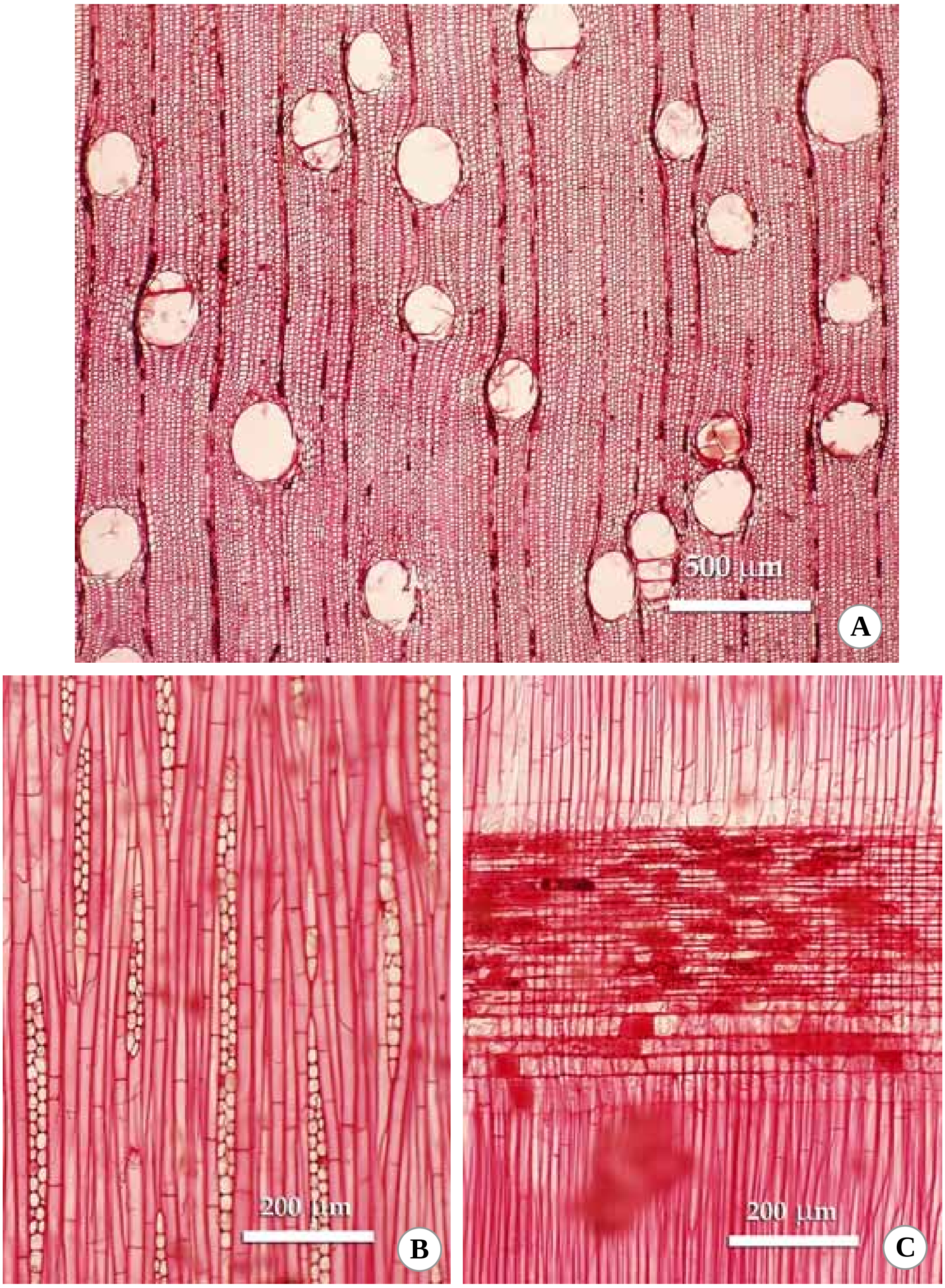


Figure 4.5 Thin section of *Dracontromelon* sp. **A.** (Tv) Vessels solitary and in radial multiples of 2 - 3. **B.** (Tg) Exclusively biseriate and non-storied rays and septate fibers. **C.** (R) Rhomboidal crystals in hexagonal shape present in ray cells; body ray cells procumbent with 1 - 3 rows of upright and/or square marginal ray cells.

Family Anacardiaceae Lindl.

Genus *Mangiferoxylon*

Species cf. *Mangiferoxylon* sp. 1

Locality: Institute of Petrified Wood and Mineral Resources, grid no.G5

Specimen Number: G5 (Figs. 4.6- 4.8)

Preservation: The preservation of this specimen is moderate, fairly well preserved in tangential and radial sections, but not so well in transverse section. Only a little area of the transverse section can be seen accurately in the right plane.

Growth ring boundaries absent. Wood diffuse-porous.

Vessels 4 - 6 /mm^2. Vessels small to medium sized, t.d. 90 - 140 µm (mean 107.3 µm), r.d. 110 - 210 µm (mean 146.7 µm). Most vessels solitary and some in radial multiples of 2, and a few 3. Solitary vessel outline round to elliptic. Vessel element length 150 - 475 µm (mean 281.4 µm). Perforation simple; **intervessel pits** alternate, vestured, and small sized, about 4 - 5 µm in diameter. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell.

In cross section, yellowish brown and dark deposits appearing to completely fill some vessel lumina; deposits often appearing collected at the end of vessel elements in longitudinal sections.

Paratracheal **axial parenchyma** vasicentric about 1 - 2 cells around vessels.

Rays 1 - 2 seriate, very rarely 3 seriate, and 6 - 28 (33) cells high. The terminal cell of the ray very close to another ray cell and often fused with it, when seen with the microscope using a 40X or 100X magnification, sometimes appearing like very long rays. Non-storied, tangential height (65) 115 - 500 (620,720) µm (average 314.71 µm) and 15 - 50 µm width. Heterogeneous rays consisting of homocellular rays with all ray cells procumbent, and heterocellular rays with procumbent and square cells mixed throughout the rays. Rhomboidal crystals are present in some ray cells (Fig. 4.8B).

Fiber non-septate, unable to determine the wall thickness from cross section.

Affinities

The main characters of specimen no. G5 are small to medium sized vessels, solitary vessels in the majority and some in radial multiples of 2 (3), simple perforations; alternate intervessel pits, vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cell, vasicentric parenchyma, rays 1 - 2 seriate, very rarely 3 seriate, and non-storied, heterogeneous rays.

These features show a close resemblance to the characters of modern woods of the family Anacardiaceae, especially the heterogeneous rays that are mostly found in wood of Anacardiaceae. This fossil is unlike *Campnosperma* because *Campnosperma* has a higher density of vessels (up to 20 vessels/mm^2), most vessels are in radial multiples of 2 (3), and rays often have radial resin canals. It is different from *Gluta* and *Melanorrhoea* because irregularly spaced bands of axial parenchyma in these two genera are rather distinct but absent in this specimen. This specimen is not *Spondias* either, because rays in *Spondias* are broader from 1 - 3 to 1 - 6 seriate, or can be 2 sizes in some species, and rays are higher, up to 1,000 - 1,800 µm (Ogata *et al.*, 2008). The possible genera are *Dracontomelon* and *Mangifera*. Although this fossil has vasicentric axial parenchyma more similar to that of *Dracontomelon* than *Mangifera*, the rays are uniseriate (partially 2-seriate), which is closer resemblance to *Mangifera*. However, intervessel pits are smaller in this specimen as in some fossil wood of *Mangifera*; therefore I place this fossil in the form genus cf. *Mangiferoxylon*.

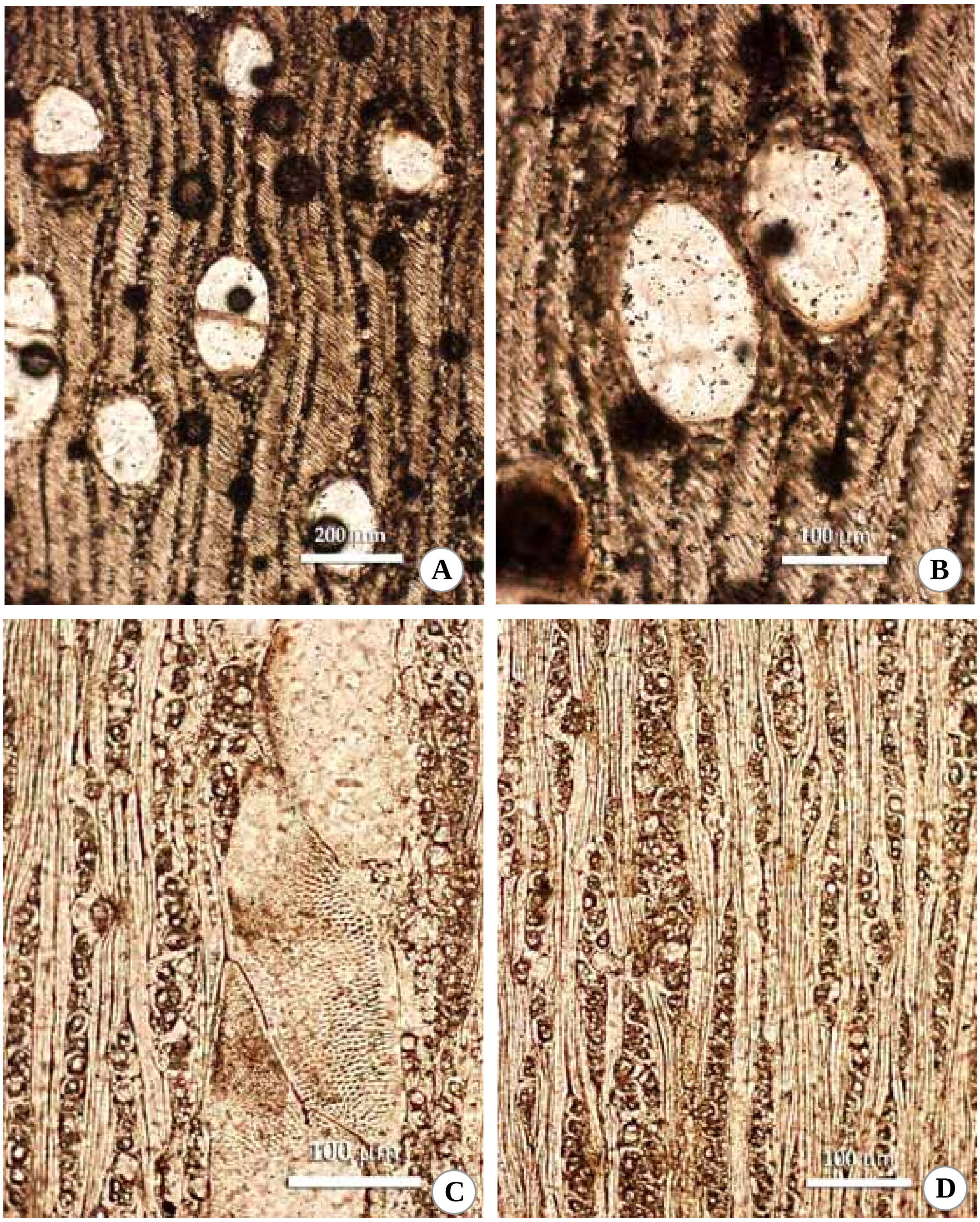


Figure 4.6 Thin section of slide G5. **A.** and **B.** (Tv) Vessels solitary and in radial multiples of 2 - 3; axial parenchyma vasicentric. **C.** (Tg) Alternate intervessel pits. **D.** (Tg) Rays 1 (or partially 2) seriate, non-storied; and non-septate fibers.

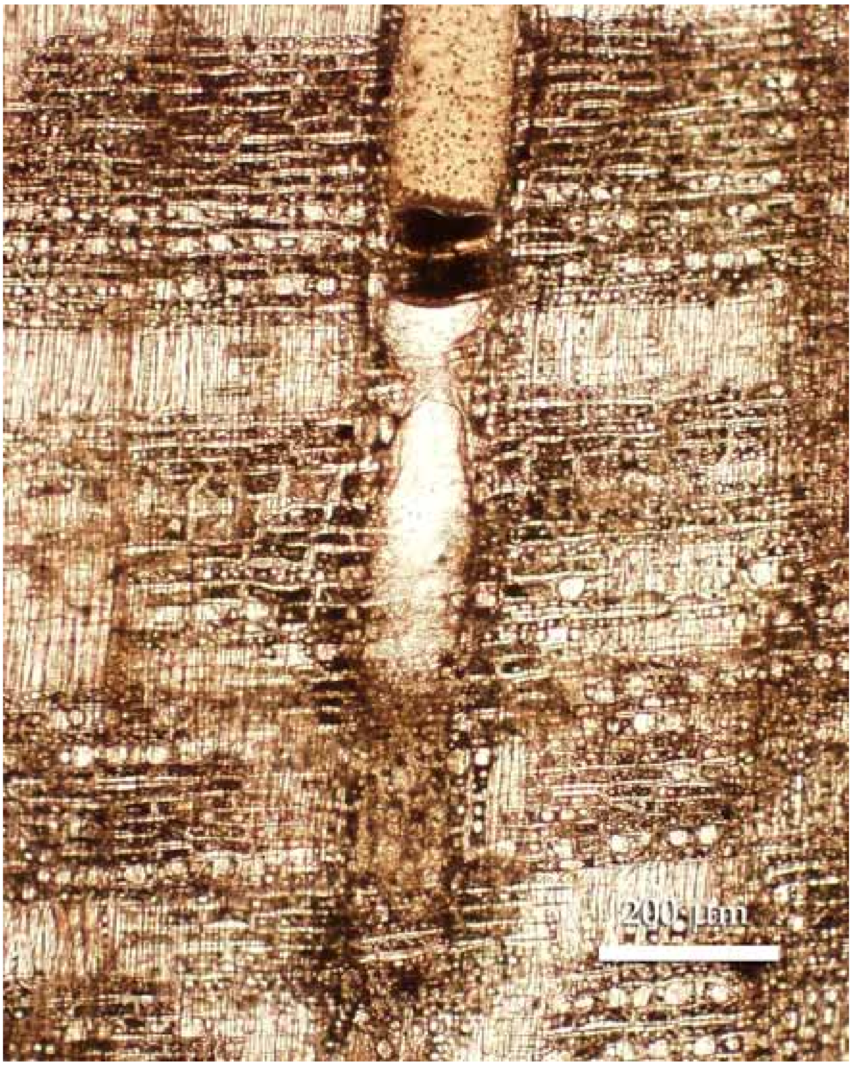


Figure 4.7 Thin section of slide G5 in radial section. Heterogeneous rays. Some rays consisting of all procumbent cells and some with procumbent and square cells mixed throughout the ray.

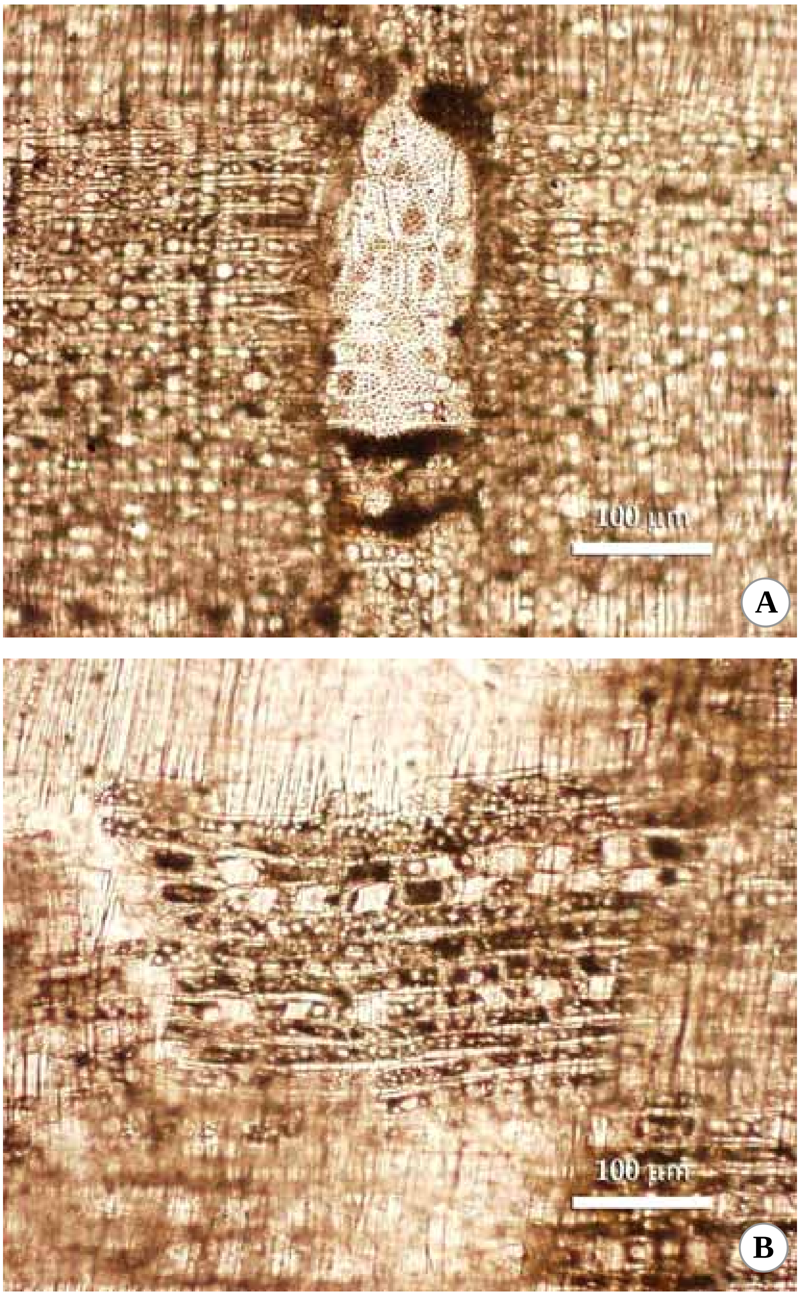


Figure 4.8 Thin section of slide G5 in radial section. **A.** Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. **B.** Rhomboidal crystals in ray cells.

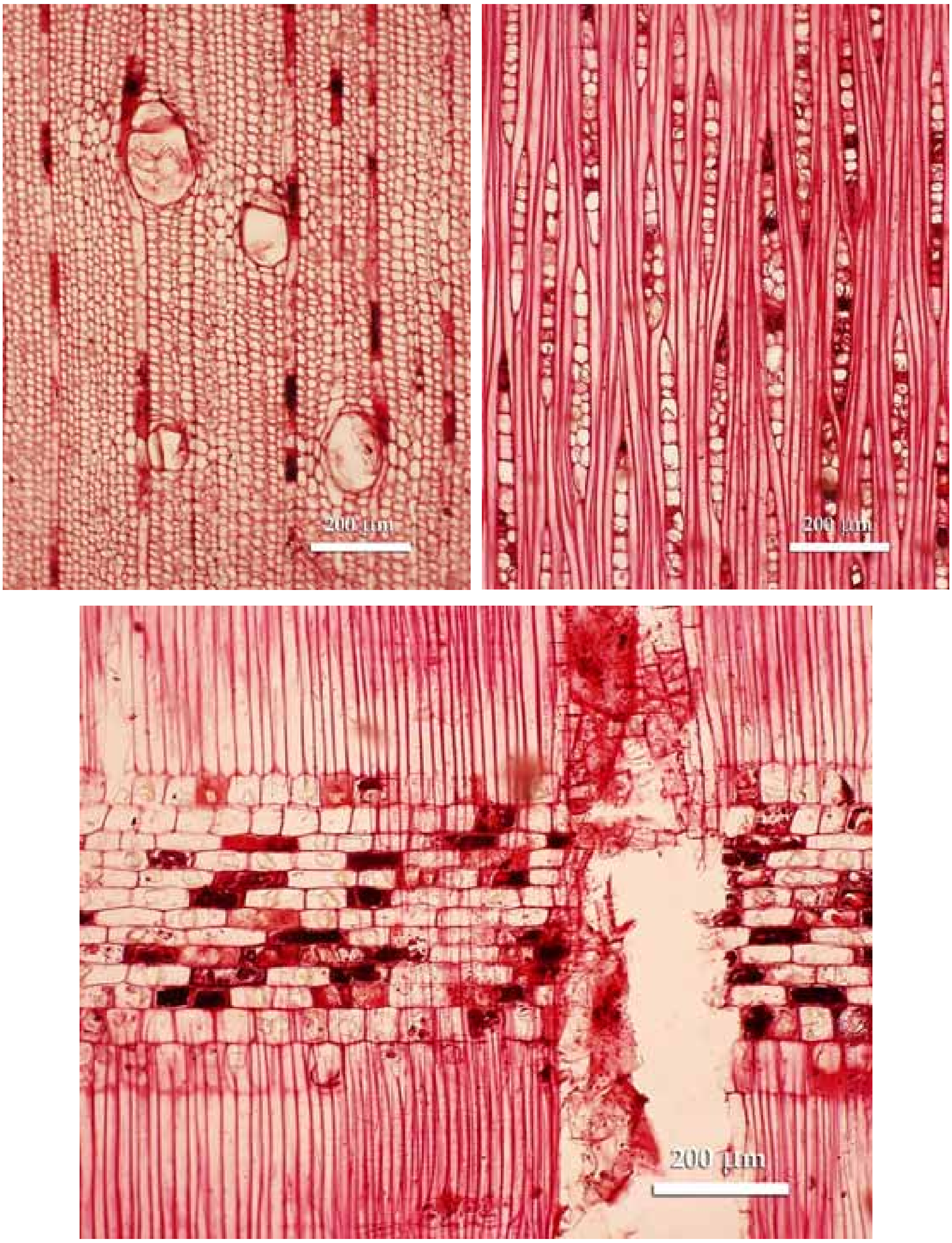


Figure 4.9 Thin section of *Mangifera camptosperma*. **A.** (Tv) Solitary vessels and in radial multiples of 2; axial parenchyma vasicentric. **B.** (Tg) Rays 1 (or partially 2) seriate, non-storied; and non-septate fibers. **C.** (R) Rays consisting of procumbent body ray cells and square or upright marginal cells. Rhomboidal crystals in ray cells.

Family Anacardiaceae Lindl.

Genus *Mangiferoxylon*

Species cf. *Mangiferoxylon* sp. 2

Locality: Institute of Petrified Wood and Mineral Resources, grid no. N7

Specimen number: N7-3 (Figs. 4.10 - 4.12)

Preservation: The specimen is fairly well preserved in three sections. No compression present in this specimen.

Description

Growth ring boundaries absent. Wood diffuse-porous.

Vessels 7 - 9/mm^2. Vessels small to medium sized, t.d. 80 - 140 µm (mean 104 µm), r.d. 90 - 200 µm (mean 144 µm). Solitary vessels dominant, some in radial multiples of 2, occasionally 3, and very few 4, or rarely in a diagonal pattern. Solitary vessel outline rounded or ovate. Vessel element length (70) 140 - 400 (490 - 600) µm (mean 276.67 µm). Perforation plates simple.

Intervessel pits alternate, vestured, and minute to small sized, 3 - 4 µm in diameter. Vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cell.

Axial parenchyma paratracheal and banded; paratracheal axial parenchyma lozenge-aliform and confluent, sometimes forming irregular bands.

Rays 1 - 2 (mostly 1, very rarely 3) seriate, sometimes 2 ray cells appearing in the middle of uniseriate ray or a large ray cell appearing among biseriate rays or alternation between one and two ray cells in the same ray. Rays non-storied, (1, 2) 5 - 23 (29) cells high, varying in tangential height ranging from (55 - 100) 165 - 470 µm (average 239.57 µm) and width (10) 15 - 45 µm. Heterogeneous rays consisting of homocellular rays (all procumbent ray cells) and heterocellular rays (procumbent and square cells mixed throughout the rays).

Fibers non-septate, thin to thicked-wall.

Affinities

The main characters of specimen no. N7-3 are small to medium sized vessels, often solitary, some in radial multiples of 2 - 4, simple perforation plates, alternate intervessel pits, vestured and minute sized, 3 - 4 µm in diameter, vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cell, paratracheal axial parenchyma lozenge-aliform and confluent, 1 - 2 (3) seriate rays, heterogeneous, and non-storied, and non-septate fibers.

These features show similarities with the modern wood of the families Leguminosae, Combretaceae, and Anacardiaceae. However, wood of the Anacardiaceae has a large size of intervessel pits and heterogeneous rays, except *Gluta* and *Melanorrhoea*, which have homogeneous rays (Awasthi, 1966).

The possible genus closest to this fossil is *Mangifera*, in which axial parenchyma is aliform to confluent and sometimes forming irregular bands (Fig. 4.13A), and rays are usually uniseriate or partially 2 seriate (Fig. 4.13B-C). However, intervessel pits in this specimen are smaller than in modern wood of *Mangifera*, whereas they are found to be smaller in the form genus *Mangiferoxylon*, which shows closest resemblance to modern wood of *Mangifera*. This specimen is unlike specimen G5 in the pattern of axial parenchyma. Therefore, I place this fossil in the form genus as cf. *Mangiferoxylon* sp. 2 (see wood anatomical information of other genera of Anacardiaceae in affinities of N8 and G5 page 47 - 49 and 57, respectively).

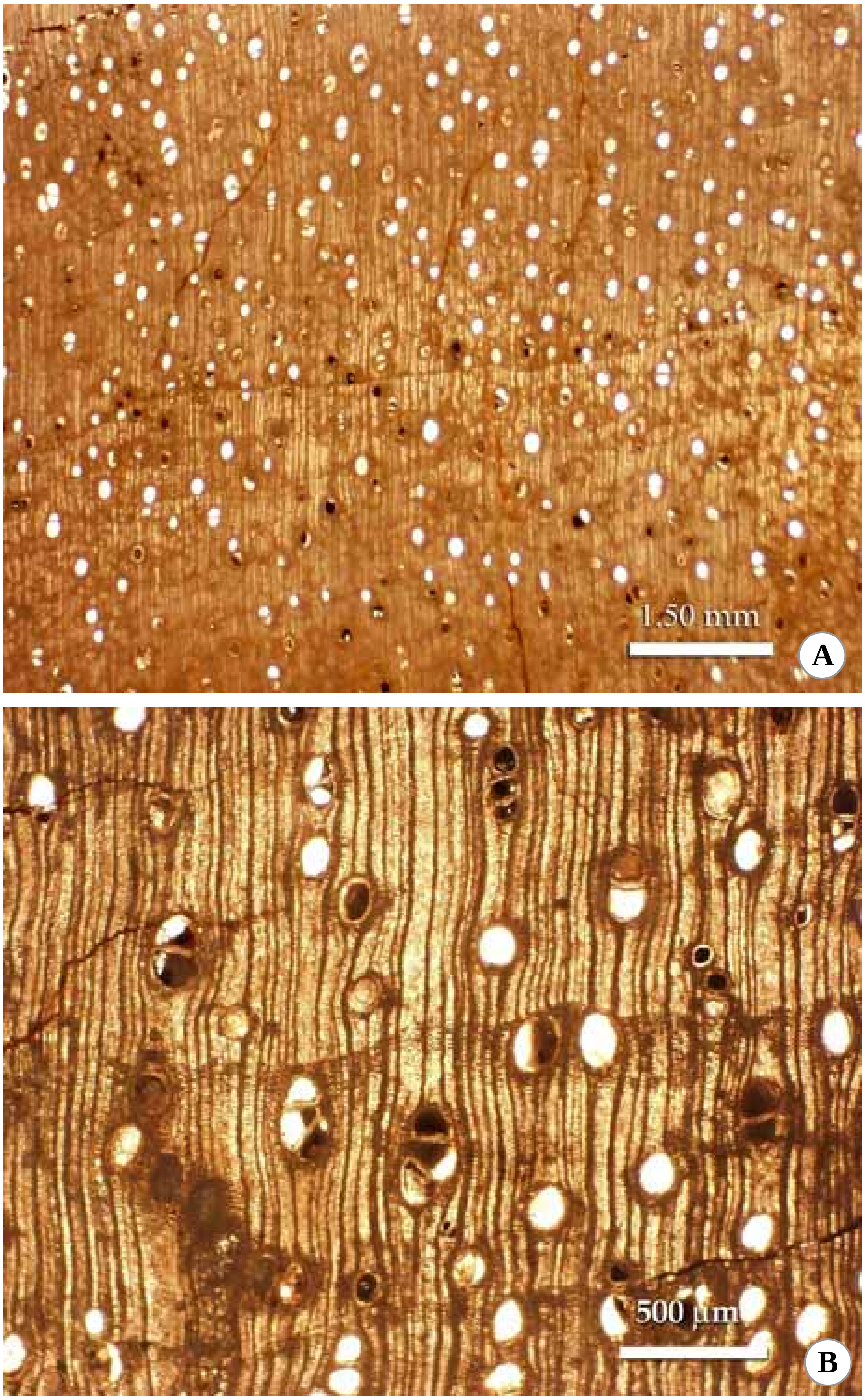


Figure 4.10 Thin section of N7 - 3 (Tv). **A.** Diffuse-porous distribution of vessels. **B.** Vessels solitary and in radial multiples of 2 - 3, or rarely vessels in a diagonal pattern; axial parenchyma vasicentric or lozenge-aliform and confluent.

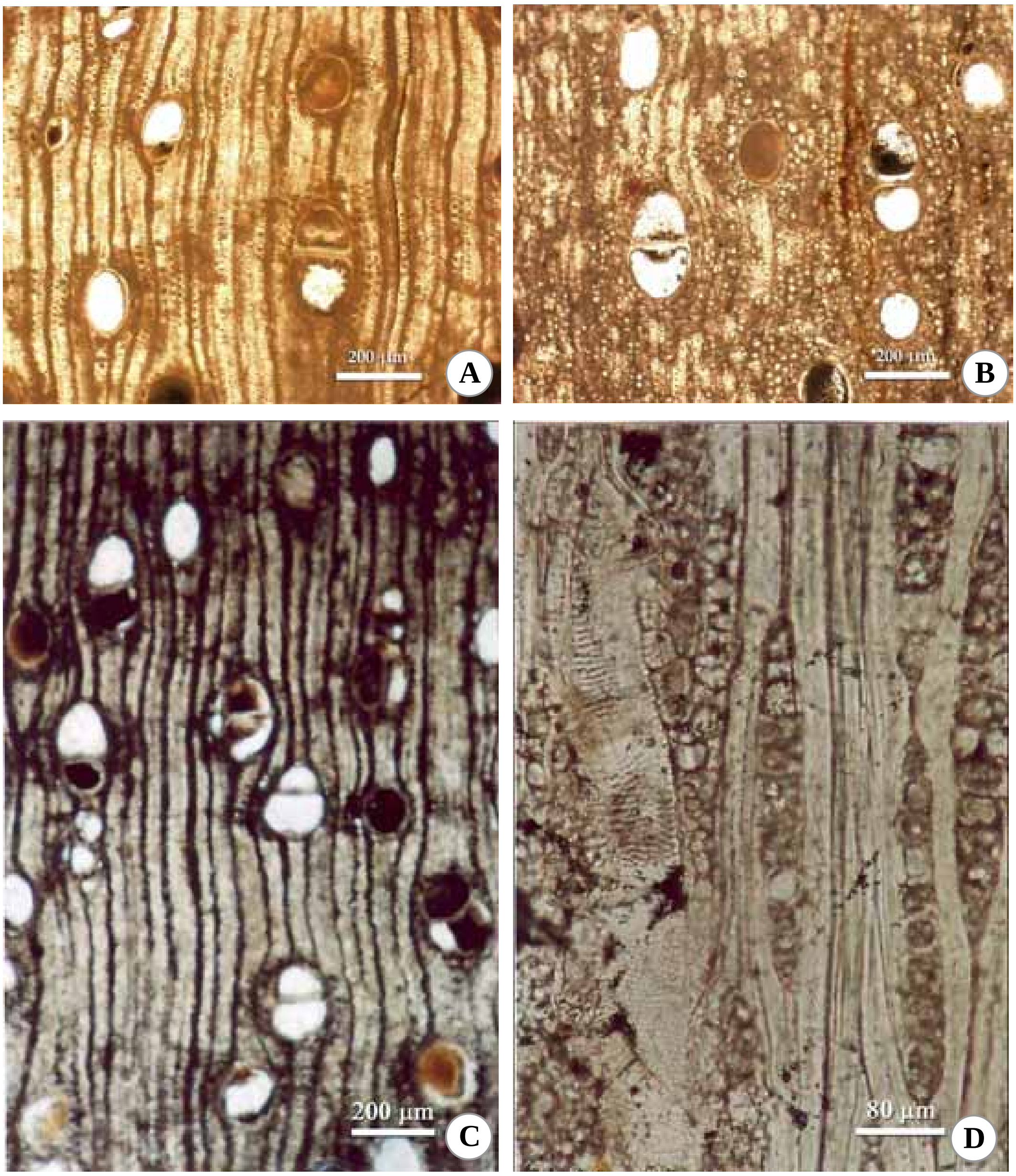


Figure 4.11 Thin section of N7 - 3. **A.** (Tv) Axial parenchyma vasicentric and confluent. **B.** (Tv) Lozenge-aliform axial parenchyma. **C.** Vasicentric to lozenge-aliform axial parenchyma. **D.** (Tg) Alternate intervessel pits; 1 seriate (partially 2-seriate) rays.

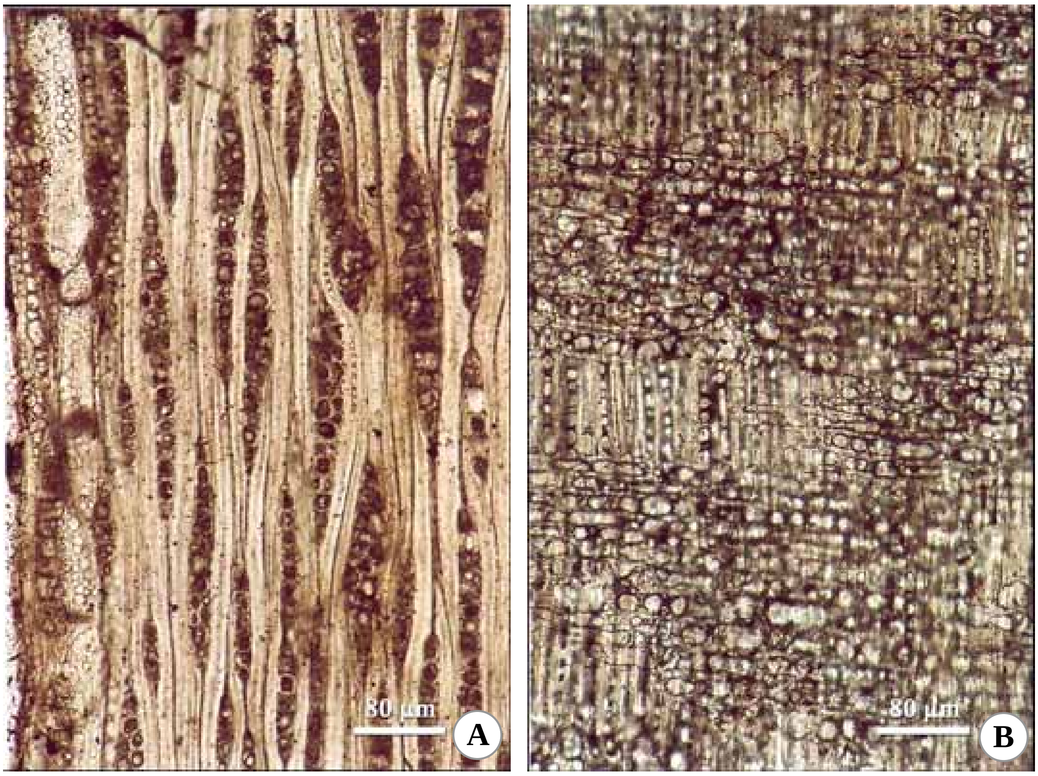


Figure 4.12 Thin section of slide N7 - 3. **A.** (Tg) Uniseriate (partially 2-seriate) or 1 - 2 seriate rays, non-storied. Non-septate fibers. **B.** (R) Heterogeneous rays consisting of both all procumbent ray cells and procumbent and square cells mixed throughout the rays.

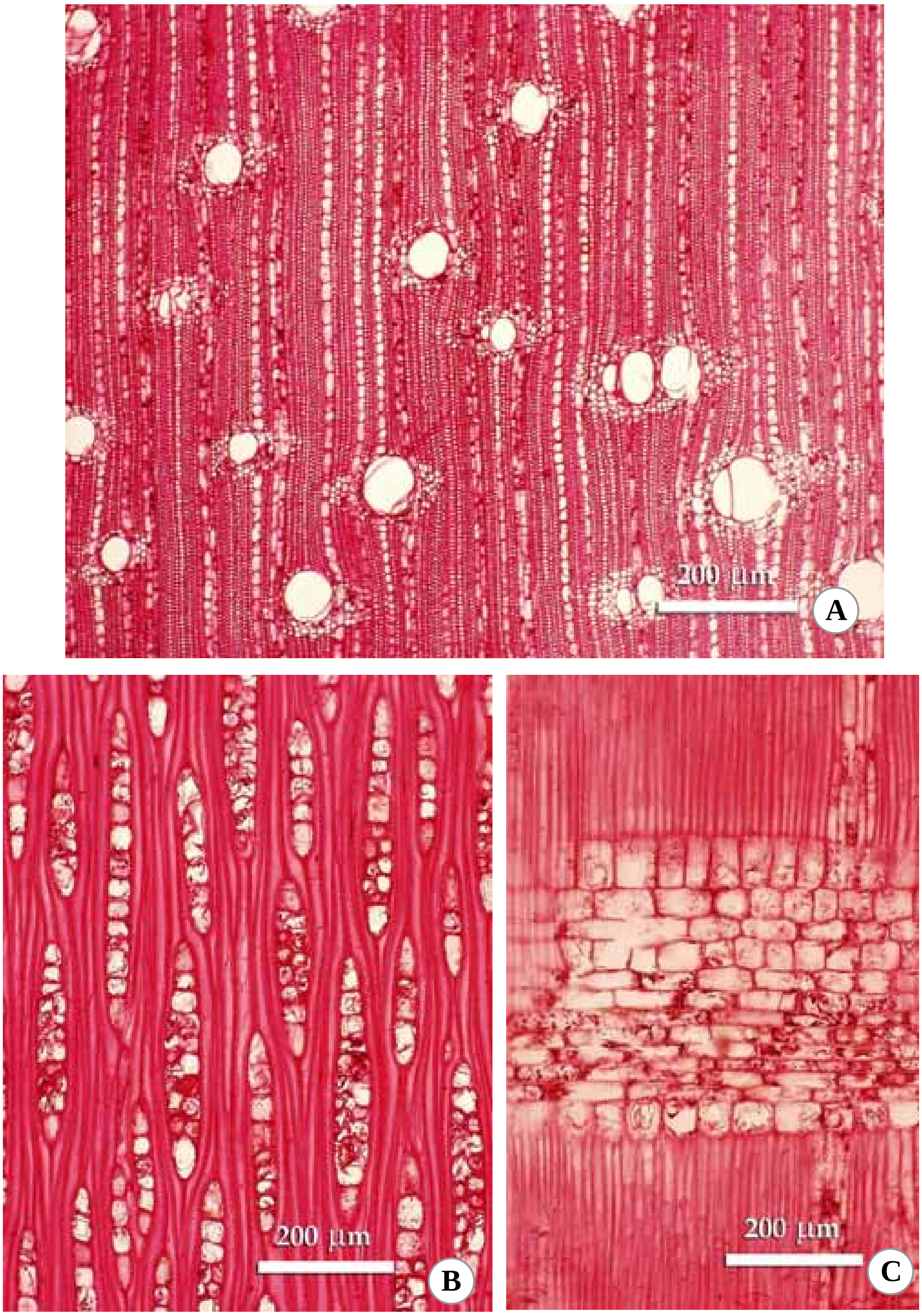


Figure 4.13 Thin section of *Mangifera caloneura*. **A.** (Tv) Axial parenchyma lozenge-aliform to confluent. **B.** (Tg) Uniseriate (partially 2-seriate) or 1 - 2 seriate rays, non-storied, and non-septate fibers. **C.** Rhomboidal crystals present in ray cells; body ray cells procumbent with a row of upright or square marginal cells.

Family Burseraceae Kunth

Genus *Canarium* L.

Species *Canarium* sp.

Locality: Institute of Petrified Wood and Mineral Resources, grid no.B5

Specimen Number: B5 (Figs. 4.14 - 4.16)

Preservation: The preservation is fair.

Description

Growth ring boundaries absent. Wood diffuse-porous.

Vessels 1 - 3 /mm^2. Vessels usually medium to large, few small sized, t.d. (80) 120 - 250 µm (mean 177.2 µm), r.d. (20 - 100) 150 - 270 µm (mean 185.5 µm). Most vessels solitary and occasionally in radial multiples of 2 - 3, rarely 4, and few touching or tangential side. Solitary vessel outline rounded. Brownish deposits appearing in some vessel lumina. Hexagonal shapes present in all vessels, especially in longitudinal section where they can be clearly seen as triple concentric rings of hexagonal shapes throughout all vessels.

Vessel element length (80 - 100) 130 - 250 (300) µm (mean 188.4 µm). Perforation plates simple. **Intervessel pits** alternate, vestured, and small sized, about 4.8 µm in diameter. Some black deposits appearing collected at the end of vessel elements.

Axial parenchyma scanty to vasicentric narrow sheath, one cell layer, and in marginal or seemingly marginal bands. Axial parenchyma diffuse; single parenchyma strands or pairs of strands distributed irregularly among the fibrous elements of the wood. Parenchyma cells $\geq$ 8 cells in height per parenchyma strand.

Rays (1) 2-3 (4) seriate, 5- 18 cells high, thick-walled, tangential height

(100) 130 - 330 (400 - 430) µm (average 232.33 µm) and width 24 - 53 µm, dark deposits filling in lumens of all ray cells. Homogeneous ray tissue composed of heterocellular rays; body ray cells procumbent with 1 row of upright or square marginal cells. Rays non-storied or a few ray cells irregularly storied in some areas.

Fibers non-septate and very thin-walled.

Affinities

The main characters of this specimens are medium to large vessels, most solitary and occasionally in radial multiples of 2 - 3, rarely 4, solitary vessel outline rounded, perforation plates simple, alternate and vestured intervessel pits, small sized about 4.8 µm in diameter. The axial parenchyma is scanty to vasicentric, forming a narrow sheath, one cell layer thick, and in marginal or seemingly marginal bands; either or more parenchyma cells are present per parenchyma strand. Rays are (1) 2 - 3 (4) seriate, non-storied or a few ray cells irregularly storied in some areas. The rays are Homogeneous, consisting of body ray cells procumbent with 1 row of upright or square marginal cells. Fibers are septate and very thin-walled.

These features show many typical features more similar with modern wood of the family Burseraceae than with wood of other families. In wood of Burseraceae axial parenchyma is not well developed, vasicentric in narrow sheaths or scanty paratracheal, rounded solitary vessels are predominant rather than in radial multiples, and rays are 1 - 3 (4) seriate. In addition, rays are rather Homogeneous throughout the family, composed of body ray cells procumbent with 1 - 4 rows of upright or square marginal cells, the number of rows of upright or square marginal cells varying in the same genus and different in each species (Ogata *et al*., 2008; Ilic, 1991).

There are about three different features of this fossil specimen differing from

Burseraceae as follows: 1. Radial resin canals are often present in most genera of Burseraceae (except *Santiria*). 2. Fibers are exclusively septate with one to several distinct septa per fiber, but sometimes only partly septate fibers are present. 3. The wood of Burseraceae has a greater number of vessels/ mm^2 than in this fossil, e.g., usually 4 - 10 in *Canarium* and 6 - 22 (usually 10 - 16) in other genera (especially *Dacryodes, Garuga, Santiria,* and *Triomma*) (Ogata *et al*., 2008).

Radial resin canals are not observed in this fossil (Fig. 4.10). Septate fibers are not clearly seen in this specimen and sometimes what seems like a septum (at 40X, and 100X magnification) is the line of the crystal edge or deposit; when adjusting the focus (at 200X) or using larger magnification (400X), the fibers are determined as being non-septate. However, the radial resin canal in the genus *Canarium* is commonly absent in the species with silica grains (Ogata *et al.*, *2008*). This shows the possibility of this fossil specimen to be *Canarium* sp. (Fig. 4.17 - 4.19), because the number of vessels is variable depending on the environment and amount of precipitation where the tree grows. The fossil is unlike *Canarium denticulatum,* however, in which the rays are mostly uniseriate or partially biseriate and very narrow.

Although radial resin canals are not present in *Santiria*, this fossil is not considered to be *Santiria* sp. because rays of *Santiria* are exclusively uniseriate, whereas they are (1) 2 - 3 (4) in this specimen (Ogata *et al*., 2008). This fossil is not *Tetragastris* because it has a greater density of vessels/mm^2 and especially at the marginal band. Canals and vessels are very crowded in some species of *Tetragastris*, and radial multiples of vessels are more common than solitary vessels as well as in *Trattinickia*, whereas almost all vessels in this specimen are solitary.

In my opinion from comparing its characters with modern wood genera of Burseraceae, this fossil can be assigned to *Canarium* sp.

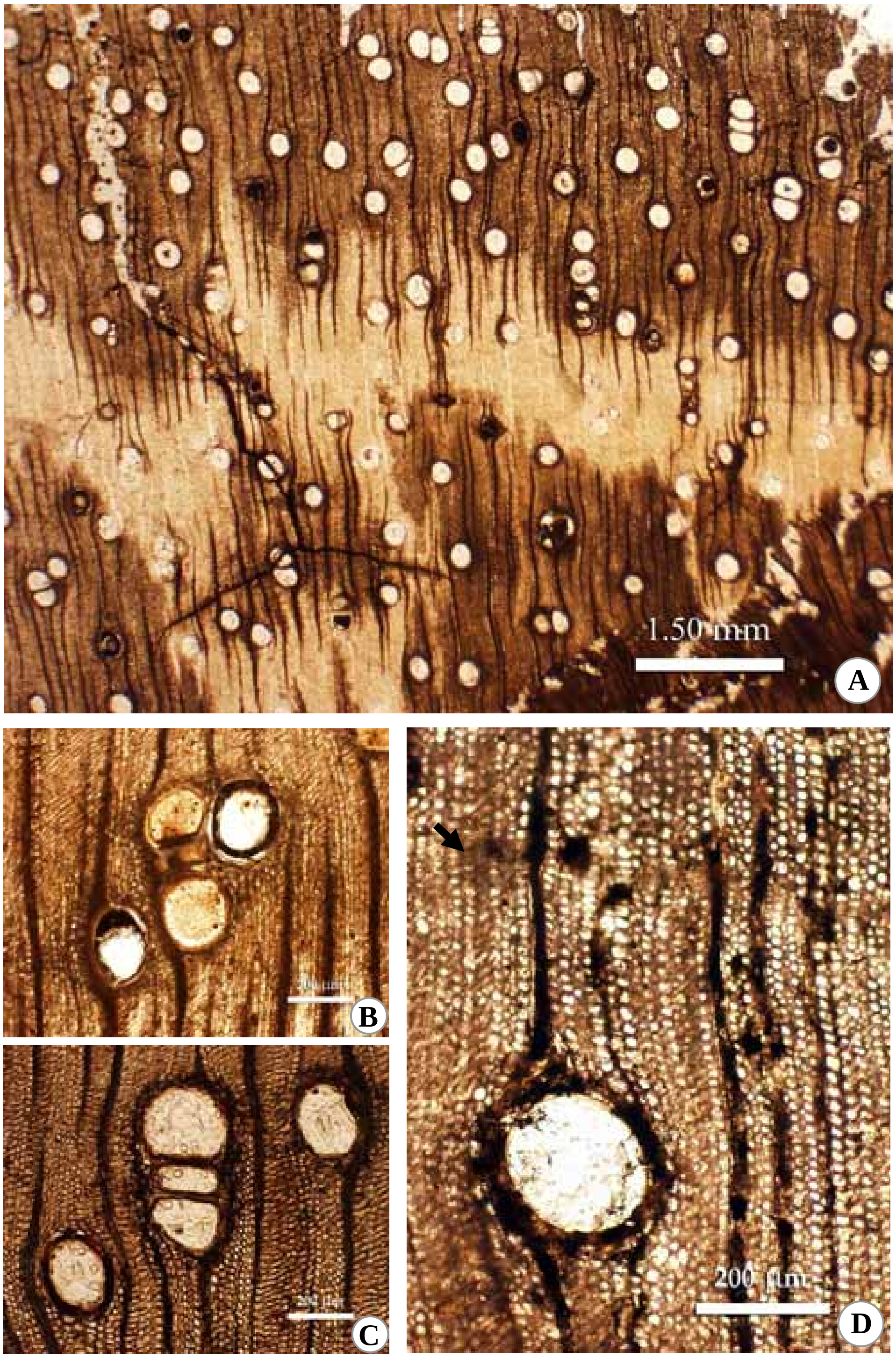


Fig 4.14 Thin section of B5 in transverse section. **A.** Vessels solitary and in radial multiples of 2 - 3 (4) and a few touching on tangential side. **B.** and **C.** Axial parenchyma scanty to vasicentric narrow sheath. **D.** Parenchyma in marginal or seemingly marginal bands (arrow).

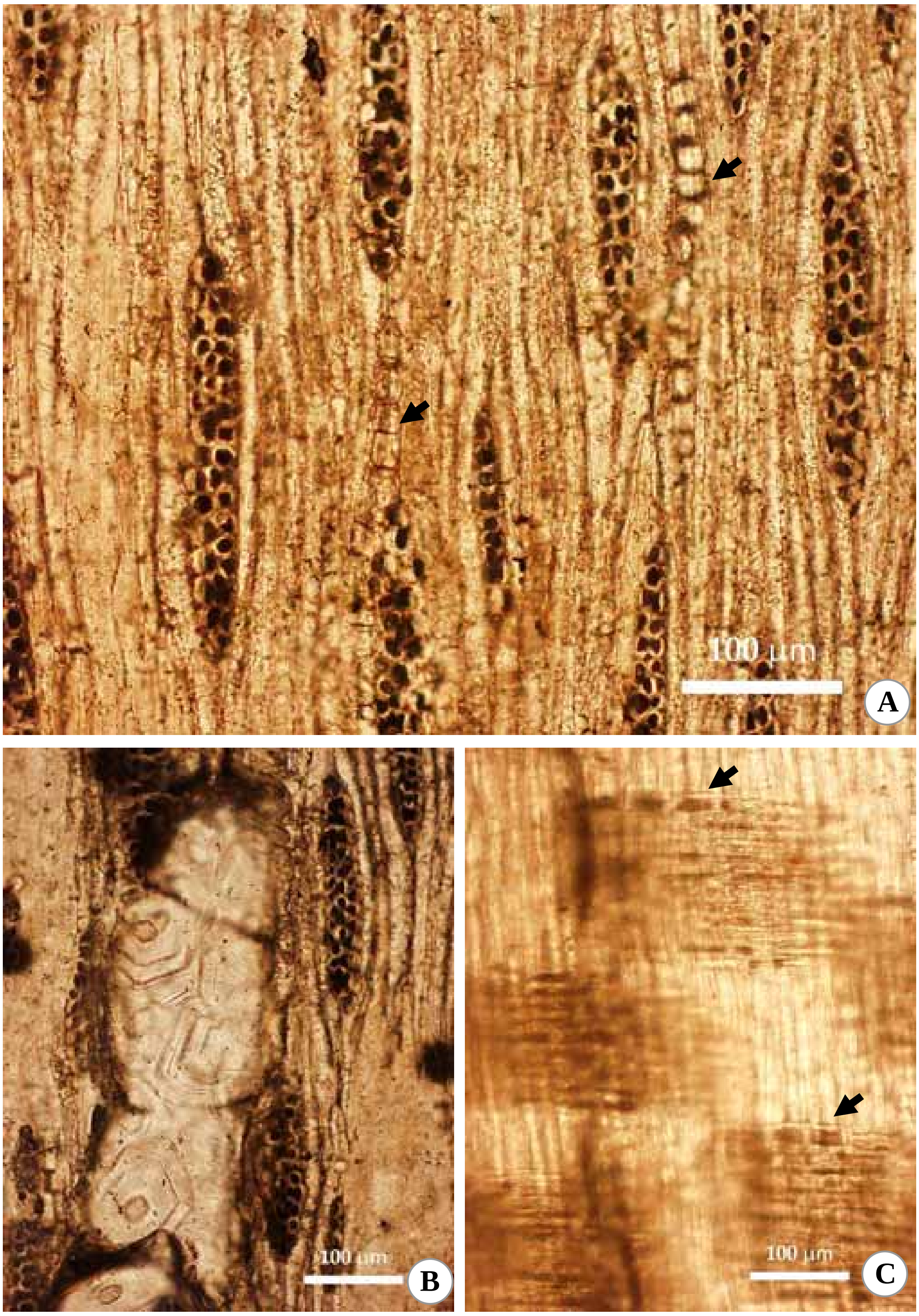


Figure 4.15 Thin section of B5. **A.** (Tg) Non-storied, 1 - 3 seriate rays and ≥ 8 cells per parenchyma strand (arrow). **B.** (Tg) Hexagonal crystals filling in vessel lumina. **C.** (R) Body ray cells procumbent with one row of square marginal cells (arrow).

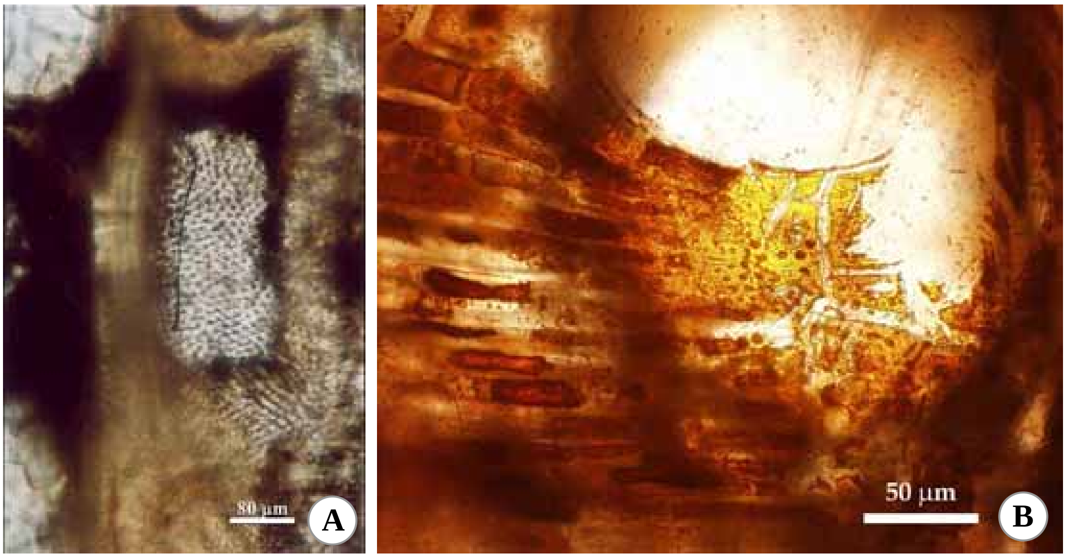


Figure 4.16 Thin section of B5 in radial section. **A.** Alternate intervessel pitting. **B.** Vessel-ray pitting.

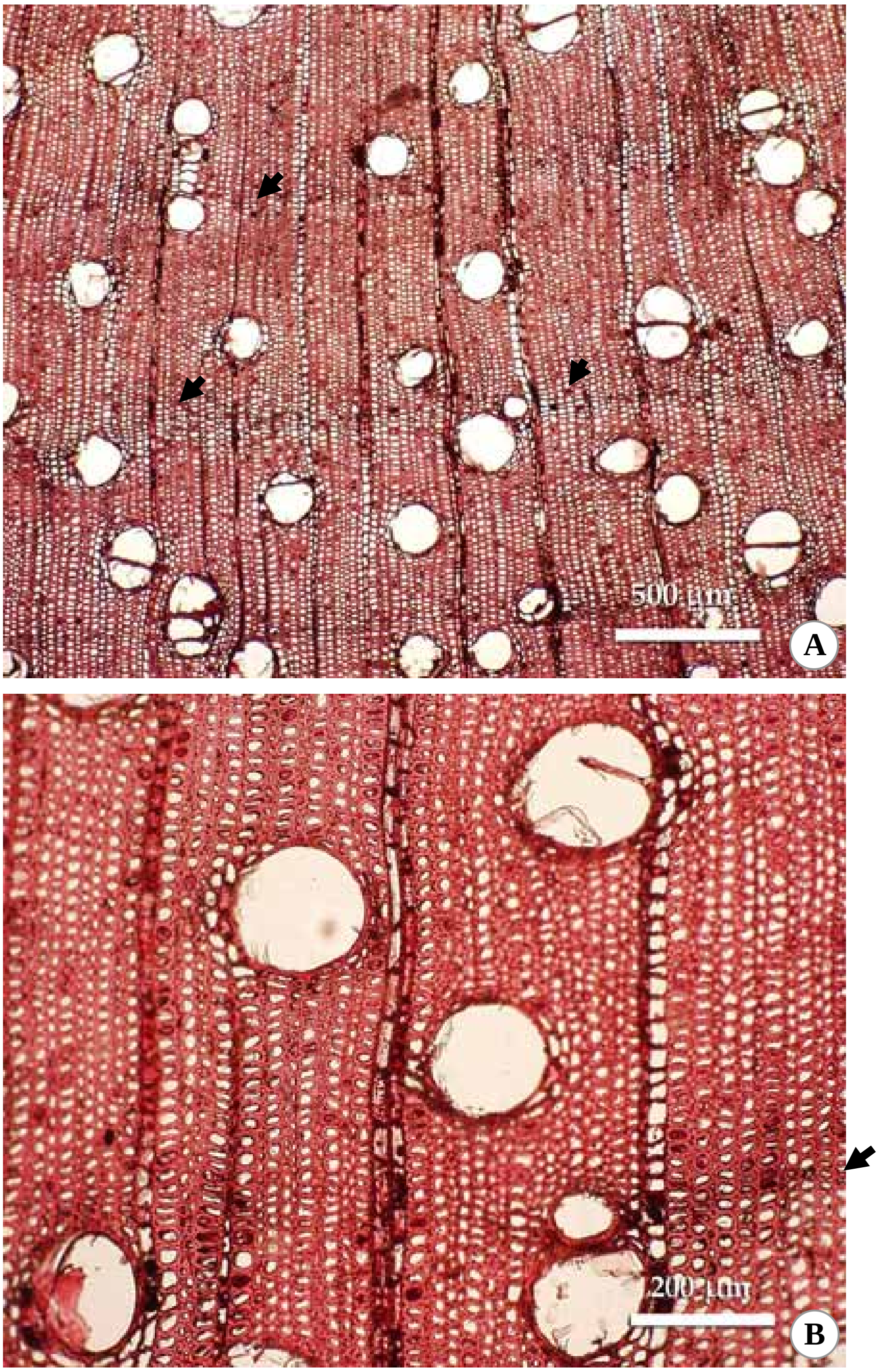
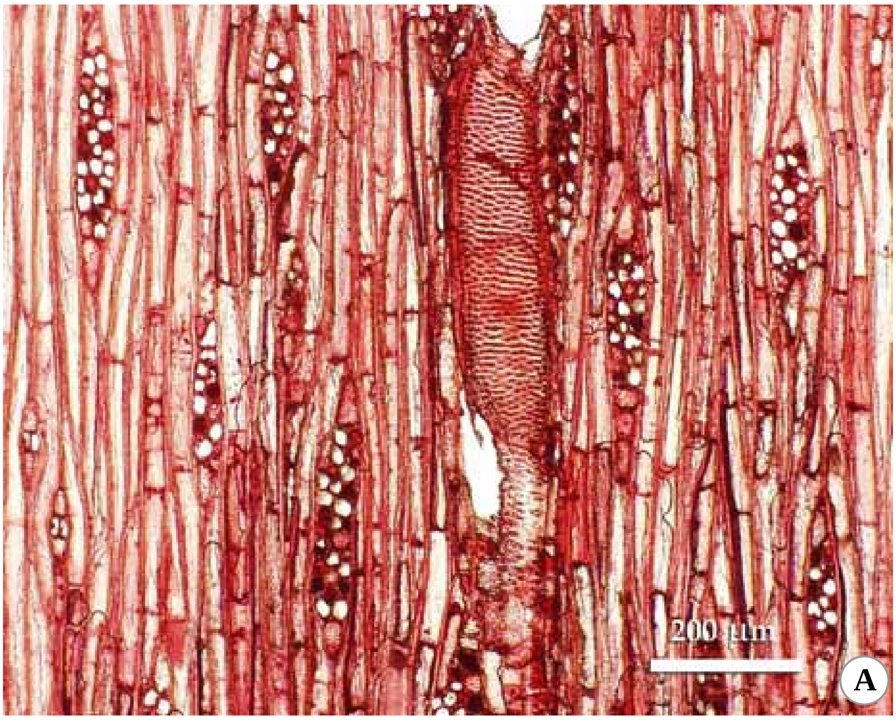


Figure 4.17 Thin section of *Canarium venosum* in transverse section. **A.** and **B.** Vessels solitary and in radial multiples of 2 - 3 (4), axial parenchyma scanty to vasicentric narrow sheath, parenchyma in marginal or seemingly marginal bands (arrows).



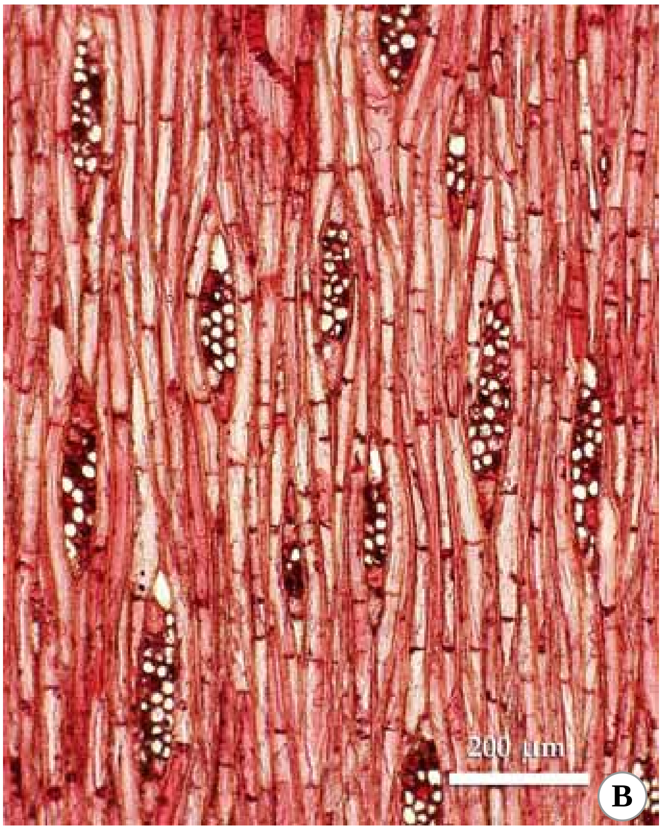


Figure 4.18 Thin section of *Canarium venosum* in tangential section. **A.** Alternate intervessel pitting. **A.** and **B.** Non-storied, 1 - 3 seriate rays, and septate fibers.

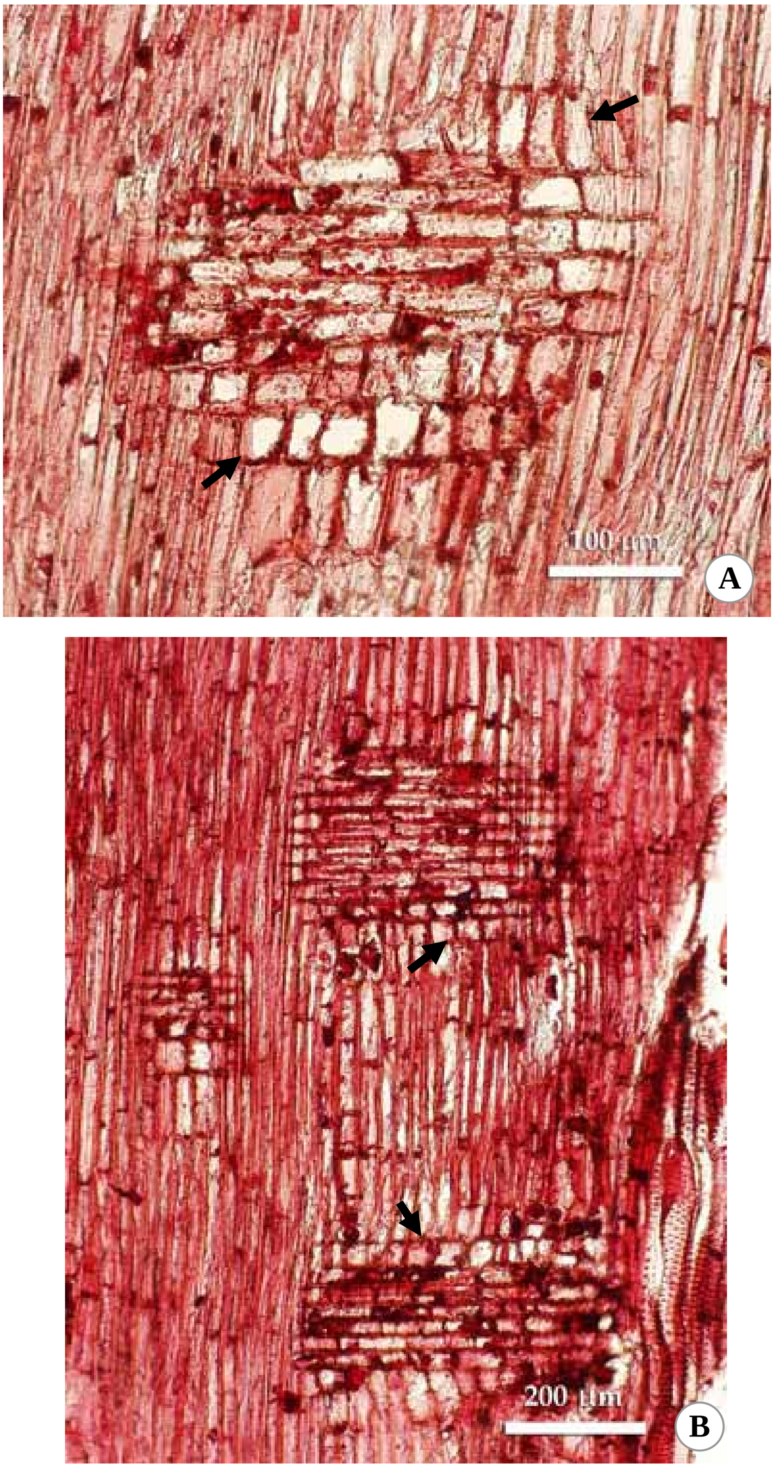


Figure 4.19 A. and **B.** Thin section of *Canarium venosum* in radial section. Body ray cells procumbent with one row of square marginal cells (arrows).

Family Combretaceae R. Br.

Genus *Terminalia* L. vel *Combretum* Loefl.

Locality: Institute of Petrified Wood and Mineral Resources, grid no. A4-1.

This specimen was cut from a large fragmented log, which was discovered about two meters below the surface during digging out of the sediment for making a water reservoir. The log was broken and was removed from the original site.

Specimen Number: A4-1 (Figs. 4.20 - 4.21)

Preservation: The preservation is moderate in cross and tangential sections, but the radial section is not very clear.

Description

Growth rings indistinct or absent. Wood diffuse-porous.

Vessels 5 - 8/mm^2, small to medium sized, t.d. 60 - 150 µm (mean 104.2 µm), r.d. (50) 90 - 200 µm. (mean 142 µm). Vessels mostly solitary and some in radial multiples of 2 - 4. Vessel element length 100 - 350 µm (mean 240 µm), many hexagonal and rhombohedral crystals found in vessel lumina. Solitary vessel outline is oval to elliptic (mostly oval, a few round); in multiples of 2 - 4, the area of contact is flattened, vessel-members truncate; perforation simple.

Intervessel pits vestured, alternate, and medium to large sized, 8 - 12 µm in diameter. Vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cell.

Axial parenchyma vasicentric, sometimes lozenge - aliform to short wing-aliform. Vasicentric parenchyma forming 1 - 3 (4) cell wide sheath around the vessels. Five to 8 cells per parenchyma strand present, especially close to vessels.

Rays mostly uniseriate or a few uniseriate-partially biseriate in the same row, or cell in the middle broader or longer than others, approximately (2) 3 - 16 cells in height, tangential height (60 -) 110 - 400 (- 495) μm (average 240.83 μm) and width 15 - 35 (40 - 45) μm; rays heterogeneous, some rays with all procumbent cells whereas some rays composed of procumbent, square, and upright cells mixed throughout the ray (Fig. 4.16D); rays non-storied or irregularly storied in some regions, black deposits appearing in some ray cells.

Fibers non-septate and thin to thick-walled.

Affinities

The main characters of this specimen are small to medium size vessels, vasicentric axial parenchyma, sometimes lozenge-aliform to short winged-aliform, alternate intervessel pits, simple perforation plates; non-storied, mainly uniseriate and sometimes biseriate rays, heterogeneous ray cells, and non-septate fibers. These features show similarities with the modern wood of the families Leguminosae and Combretaceae.

In Leguminosae, apotracheal banded parenchyma is very common and most xylem rays of wood are multiseriate, mostly 2 - 5 seriate in Mimosoideae and mostly 2 - 3 seriate in Caesalpinioideae and Papilionioideae. Only some species are exclusively uniseriate or with a few biseriate rays (Metcalfe and Chalk, 1950). These features are different from those of this fossil, so it likely does not belong to Leguminosae.

Most fossil wood records of Combretaceae are assigned to *Terminalioxylon*, while some are assigned to *Combretoxylon* and *Anogeissusoxylon*, which show resemblance to modern wood of *Terminalia*, *Combretum*, and *Anogeissus*, respectively (Chowdhury and Tandon, 1964).

Anogeissus is different from *Terminalia* in vessel groupings, in which *Anogeissus* is commonly in radial multiples while the vessels are more solitary in *Terminalia*.

Terminalia tomentosa (syn. *T. alata*) (Figs. 4.24 - 4.25) and *T. ajuna* (Figs. 4.22 - 4.23) have Homogeneous rays consisting of all procumbent ray cells and non-septate fibers, but this fossil specimen has heterocellular rays, composed of procumbent, square, and a few upright cells. Septate fibers are also present. Thus the fossil is considered a different species from *T. tomentosa.*

The fossil has been compared with various species of both *Terminalia* and *Terminalioxylon*. About eighteen species of *Terminalioxylon* fossil wood showing resemblance to *Terminalia* are so far known. These species have medium to large vessels, but vessels of the fossil specimen are small to medium size. Some other characters of some species match with this specimen, such as rays being uniseriate or sometimes biseriate and fibers being thin to thick-walled and septate. However, they differ in other characters, e.g., ray cellular composition.

Some species of *Combretum* have similarity with this fossil, e.g., *C. glutinosum* and *C. micranthum,* in which similar size of vessel diameter, vessel element length, ray exclusively uniseriate, procumbent, square and upright cells mix throughout the ray. Nevertheless, intervessel pit size of *Combretum* spp. are usually small whereas medium to large in this fossil specimen.

As the preservation of the specimen is not sufficient for identification to the species level, therefore this specimen is identified as *Terminalia* L. or *Combretum* Loefl.

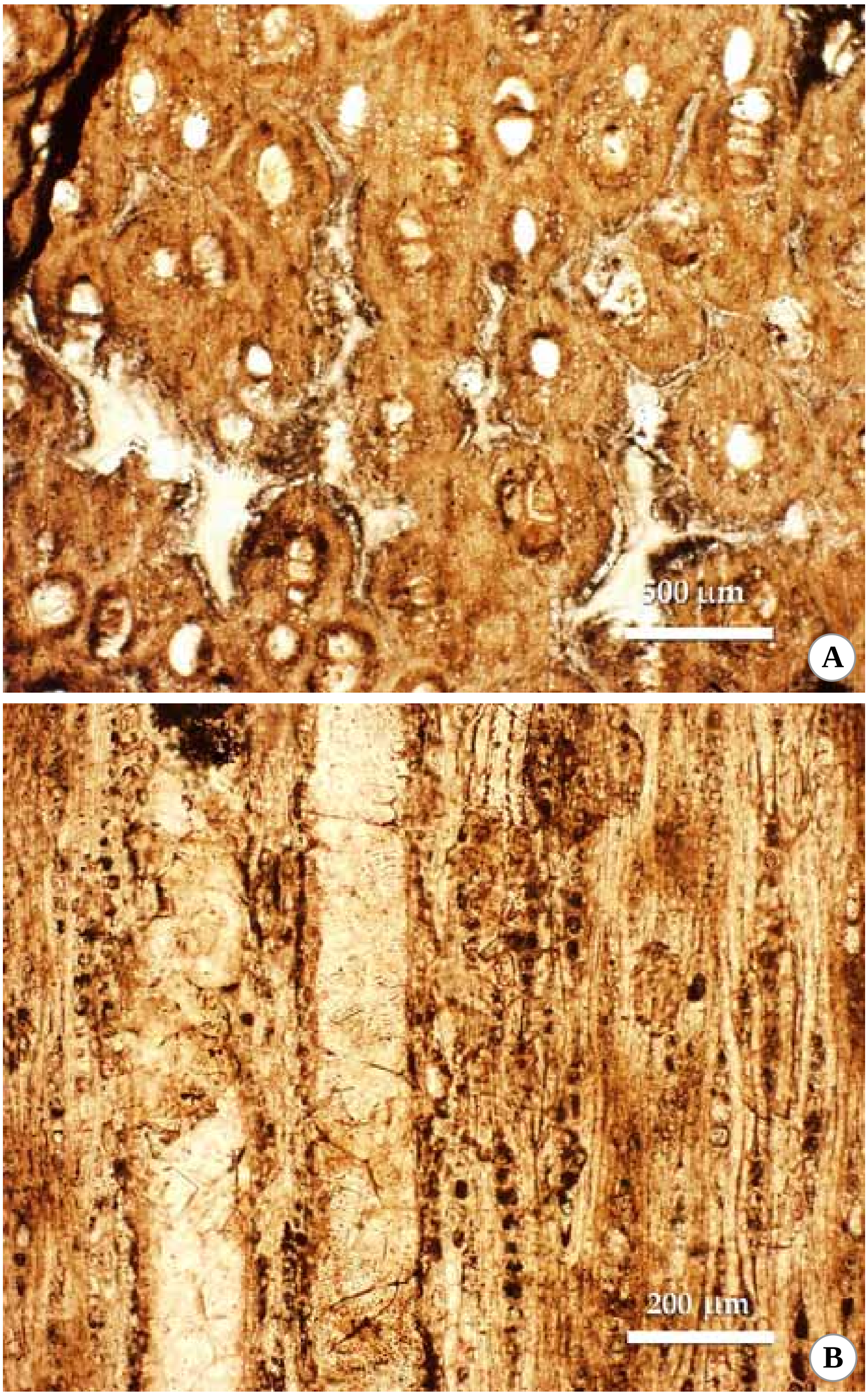


Figure 4.20 Thin section of slide no. A4-1. **A.** (Tv.) Vessels solitary and in radial multiples of 2 - 4 and axial parenchyma vasicentric to lozenge-aliform. **B.** (Tg.) Mostly uniseriate rays and a few 1 (with partially 2) seriate rays. Intervessel pits can be seen on the vessel walls.

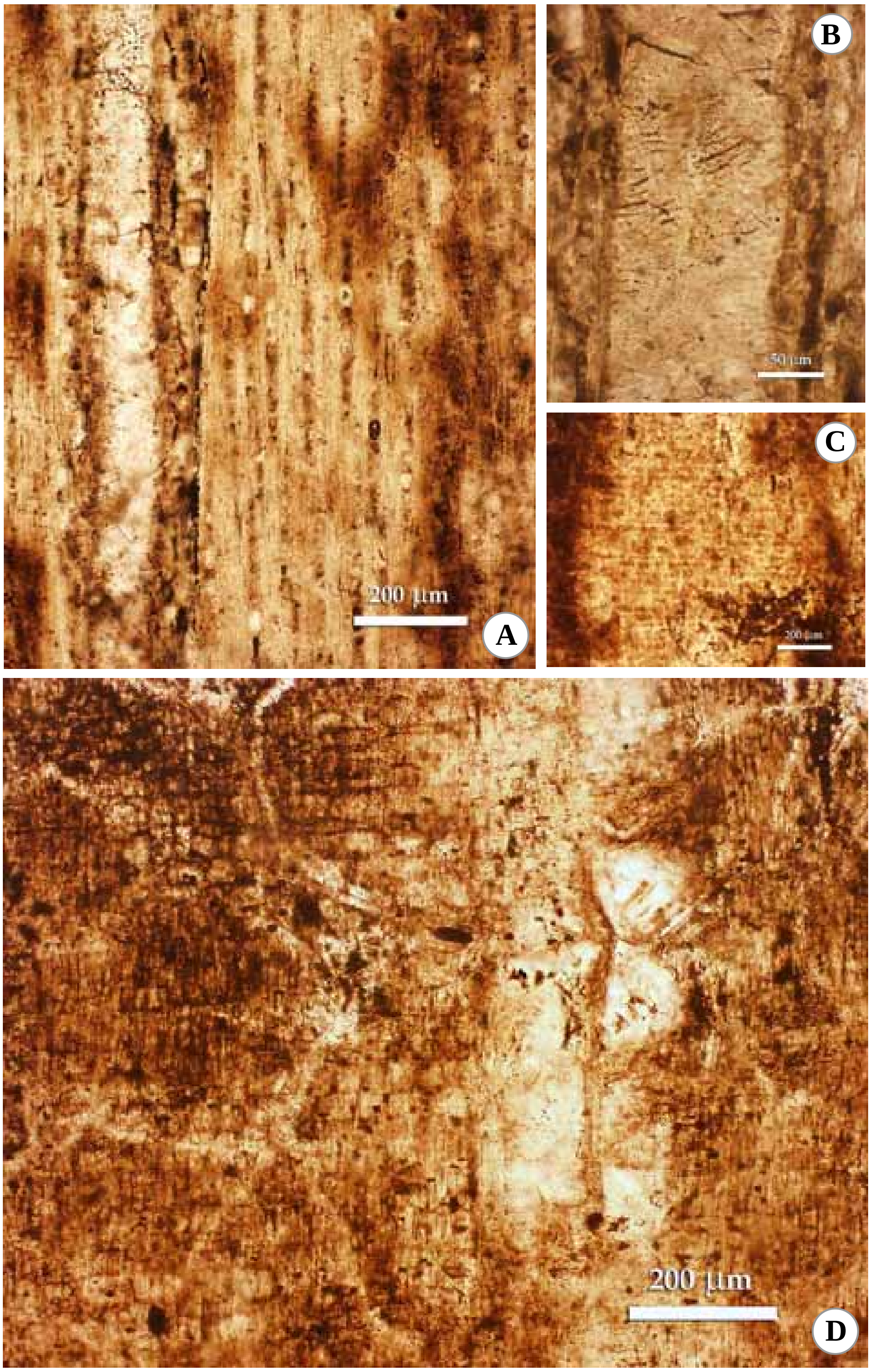


Figure 4.21 Thin section of slide no.A4-1. **A.** (Tv.) Uniseriate rays and non-storied structure. **B.** Medium to large alternate intervessel pits. Heterogeneous rays consisting of **C.** all procumbent ray cells and **D**. (R) rays with procumbent, square and upright cells mixed throughout the ray.

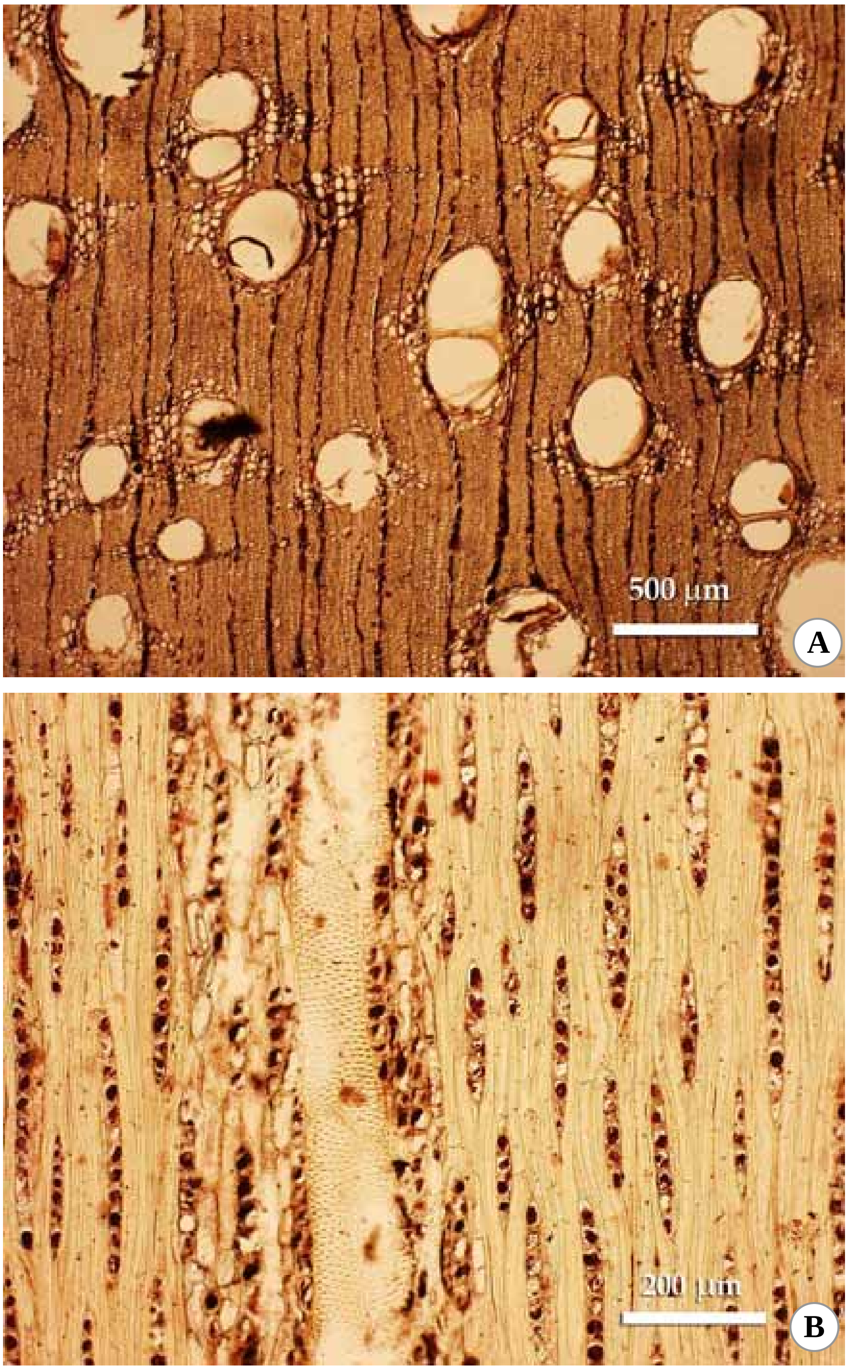


Figure 4.22 Thin section of modern wood, *Terminalia arjuna.* **A.** (Tv) Vessels solitary or in radial multiples of 2, axial parenchyma aliform and in marginal or seemingly marginal bands. **B.** (Tg) Rays exclusively uniseriate (with a few partially biseriate) and non-storied, alternate intervessel pitting; non-septate fibers.

Figure 4.23 Thin section of modern wood, *Terminalia arjuna*, showing Homogeneous rays consist of all procumbent ray cells.

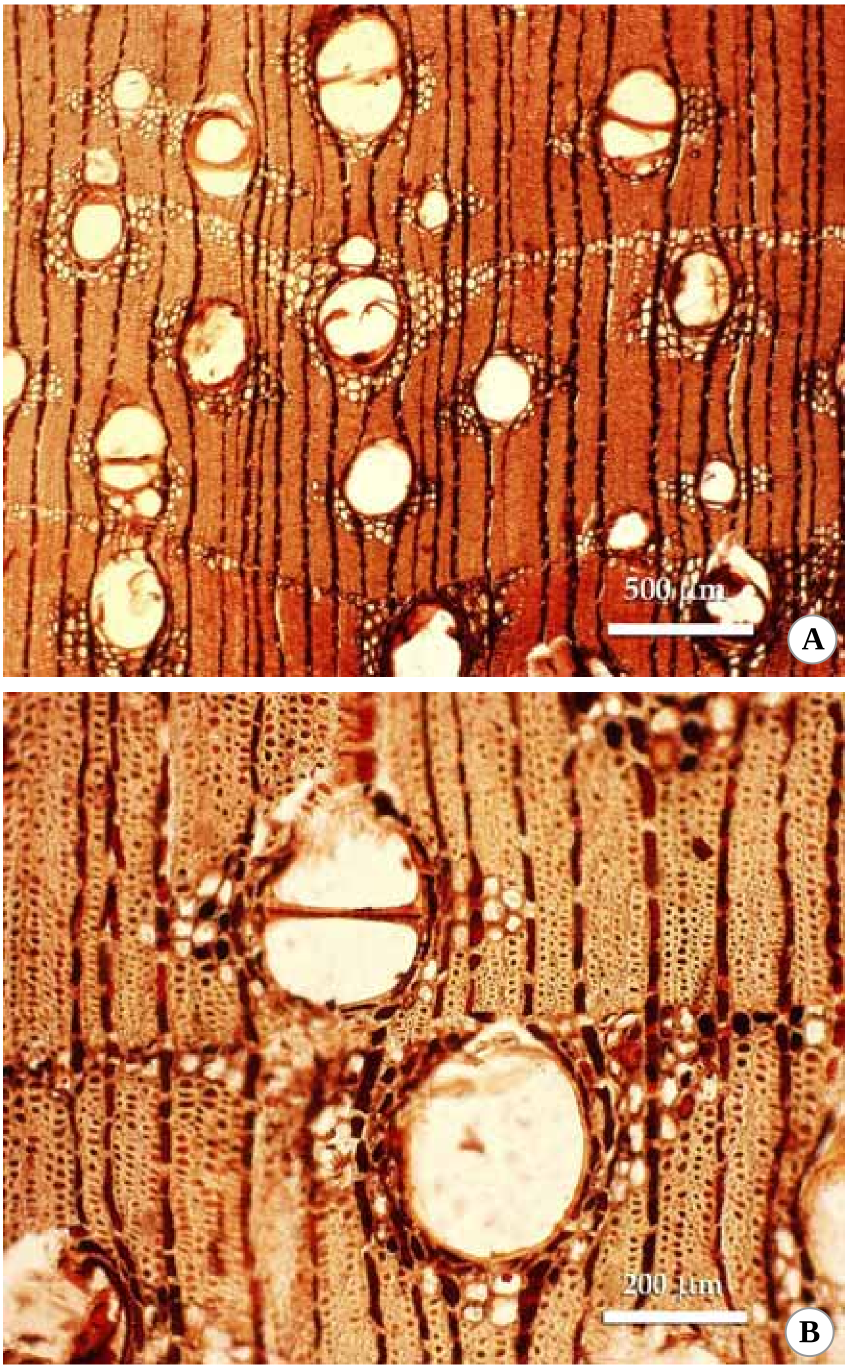


Figure 4.24 Thin section of modern wood, *Terminalia tomentosa* (slide no.FRI876), in transverse section. **A.** and **B.** Vessels solitary or in radial multiples of 2; axial parenchyma aliform and in marginal or seemingly marginal bands. **B.** Fibers thin-to thick-walled.

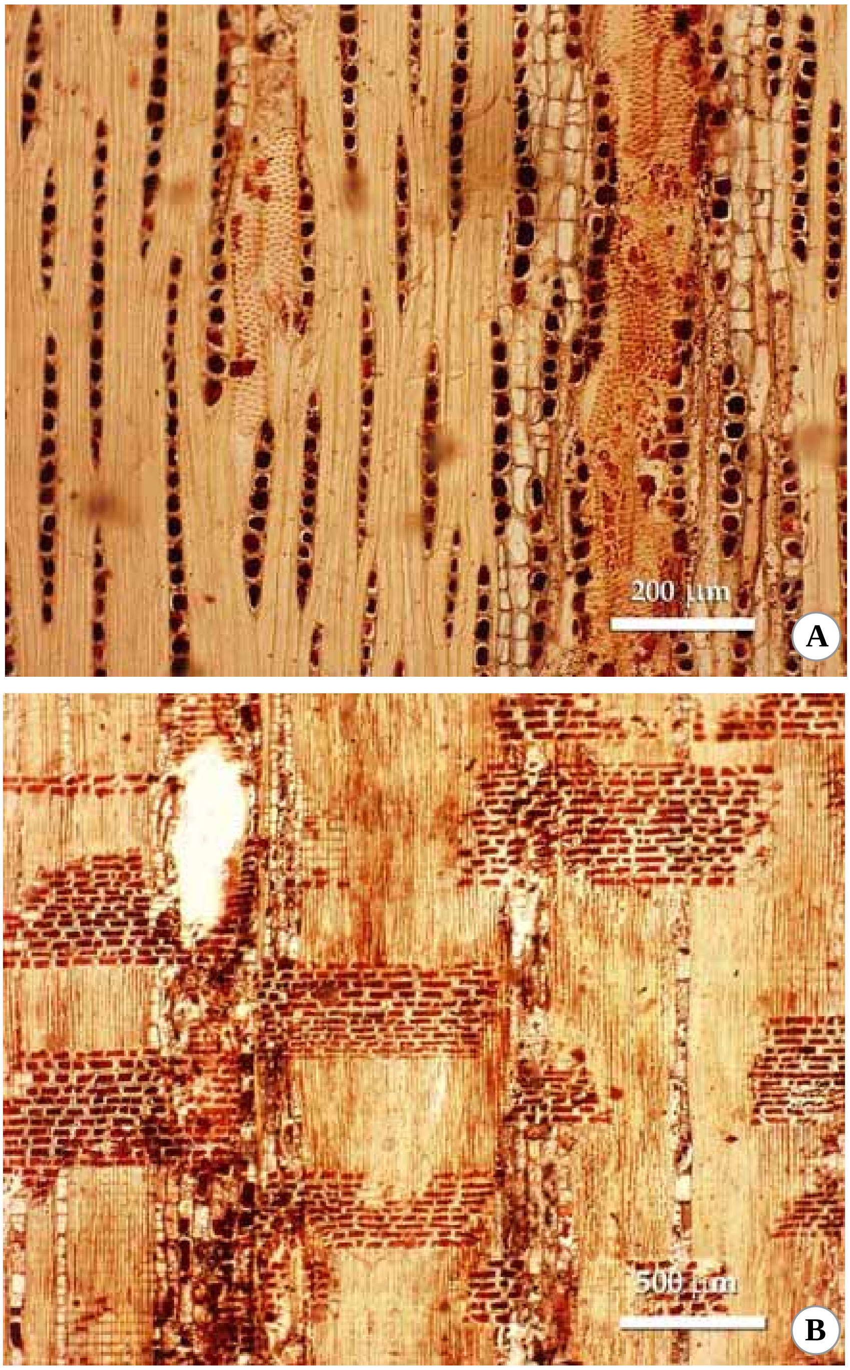


Figure 4.25 Thin section of modern wood, *Terminalia tomentosa.* **A.** (Tg) Rays exclusively uniseriate and non-storied; alternate intervessel pitting; non-septate fibers. **B.** (R) Homogeneous rays consisting of all procumbent ray cells.

Family Combretaceae R. Br.

Genus *Terminalia* L.

Species *Terminalia* sp 2.

Locality: Institute of Petrified Wood and Mineral Resources, grid no. M7

Specimen Number: M7-1 (Figs. 4.26 - 4.28) and M7-2 (Figs. B1 - B3)

Growth ring boundaries absent. Wood diffuse-porous.

Vessels 2 - 6 /mm^2. Vessels small to medium, t.d. 80 - 150 µm (mean 115.2 and 144.1 µm, for the 2 specimens), r.d. 90 - 210 µm (mean 157 and 158 µm). Solitary vessels are dominant and some in radial multiples of 2 - 3, very rarely 4 or 5. Solitary vessel outline round to oval (mostly oval). Vessel element length 150 - 540 µm (mean 341.56 µm). Perforations simple; intervessel pits alternate, vestured, and medium sized 7.20 - 10.80 µm in diameter. Vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cell. In cross section, yellowish brown and dark deposits appear to completely fill some vessel lumina, and, in longitudinal sections, deposits often appear collected at the end of vessel elements.

Axial parenchyma aliform, lozenge to short wing-aliform. Axial parenchyma in marginal or in seemingly marginal bands.

Rays 1 - 2 seriate (often 1), rays 7 - 21 cells high, tangential height (90 - 120) 145 - 500 (760) µm (average 210.14 and 338.29 µm) and width 15 - 50 µm, non-storied. Parenchyma strands, 5 - 8 cells, sometimes present, especially close to vessels. Rays homogeneous comprising of homocellular rays, all ray cells procumbent.

Fibers non-septate and very thick-walled.

Affinities

The main characters of the two specimens are small to medium vessels sized, the majority solitary and some in radial multiples of 2 - 3 (4 - 5), simple perforations, and alternate, vestured intervessel pits, medium sized 8 - 10 μm in diameter. Deposits appear to completely fill some vessel lumina and collect at the end of vessel elements. Axial parenchyma is aliform, lozenge to short wing-aliform, and in marginal or in seemingly marginal bands. The rays are 1 (2), non-storied, Homogeneous with all ray cells procumbent. Fibers are non-septate and very thick-walled.

The features of simple perforation plates, alternate intervessel pits, and aliform axial parenchyma show similarities to the modern wood of *Intsia* and *Afzelia* of Leguminosae and *Terminalia* of Combretaceae**.** However, wood of *Intsia* and *Afzelia***,** including their related fossil wood, *Pahudioxylon*, has small intervessel pit size and rays 1 - 3 seriate (mostly biseriate), whereas this fossil specimen has medium intervessel pit size and mostly uniseriate, sometimes biseriate rays. These features indicate closests affinity to the genus *Terminalia* (Fig. 4.17 - 4.20).

Fossil wood similar to *Terminalia* has been studied and given the generic name of *Terminalioxylon* by Shönfeld in 1947 (Chowdhury and Tandon, 1964). There are at least about 19 species of *Terminalioxylon* studied from India, Burma (Myanmar), and Thailand (Chowdhury, and Tandon, 1964; Prakash (1966, 1981); Ramanujam, 1966; Prakash and Awasthi, 1971). The species found in Thailand are *Terminalioxylon coriaceum* and *T. burmense* by Vozenin-Serra and Privé-Gill (1989).

Study of fossil wood of *Terminalia tomentosa* from the Tertiary of Burma (Myanmar) by Chowdhury, and Tandon (1964) showed that all anatomical details of the fossil agree with those of modern wood of *T. tomentosa* and no evidence of evolution from diffuse-porous toward ring porous wood was observed. Thus they placed the wood in an extant taxon. More recently Benyasuta (2003) reported petrified wood of *Terminalia alata* (syn. *Terminalia tomentosa*), from the Miocene to the Recent in Nakhon Ratchasima, using the name of the extant species.

In my opinion the two fossil specimens can be placed in a modern genus, as *Terminalia* sp. (See description of each specimen and figures of M7 in Appendix B.)

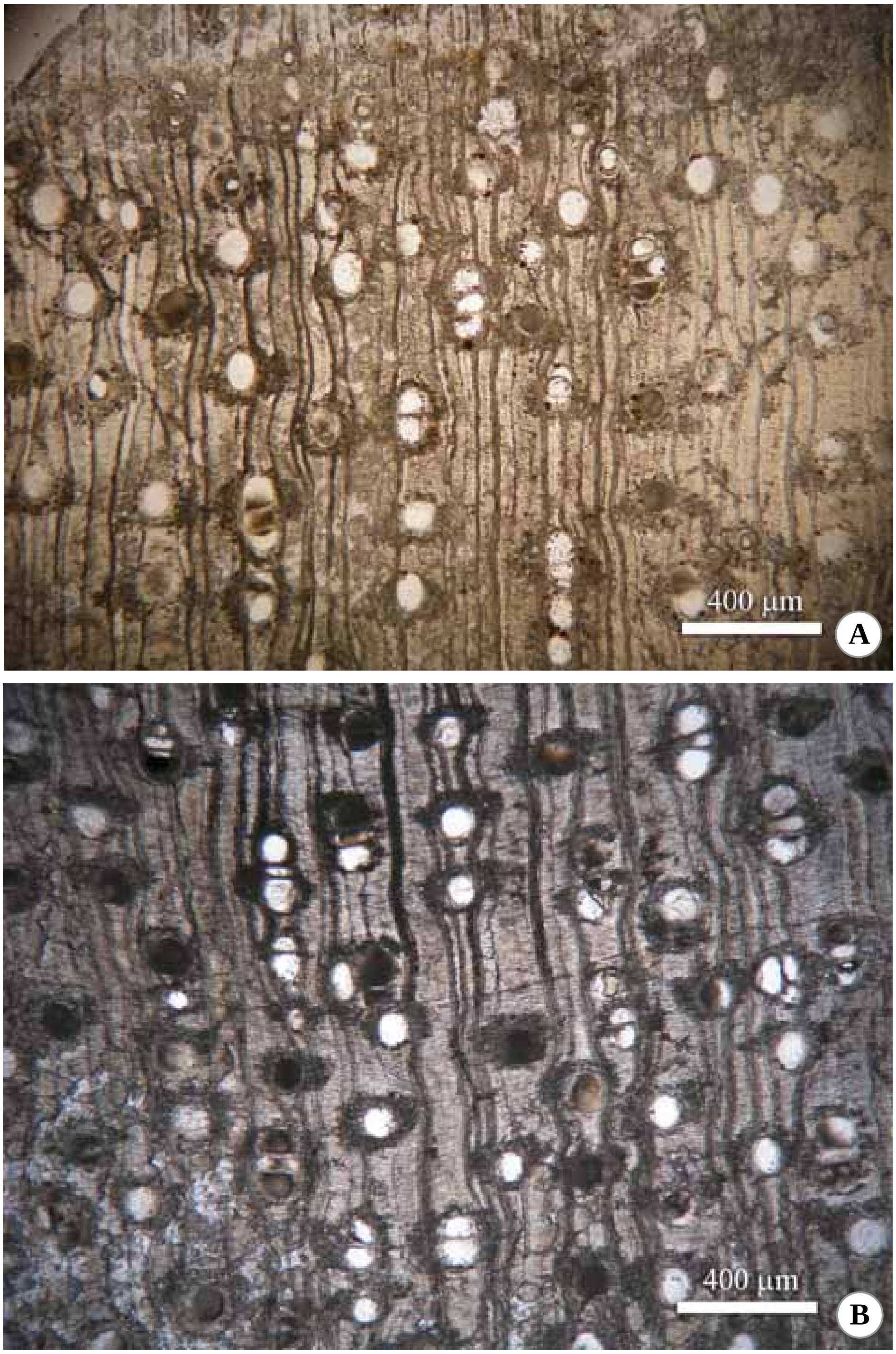


Figure 4.26 Thin section of fossil wood M7-1 in transverse section. **A.** Diffuse-porous wood; axial parenchyma aliform. Most vessels are solitary and occasionally in radial multiples of 2 - 4. **B.** Axial parenchyma lozenge to short wing-aliform and in marginal or in seemingly marginal bands.

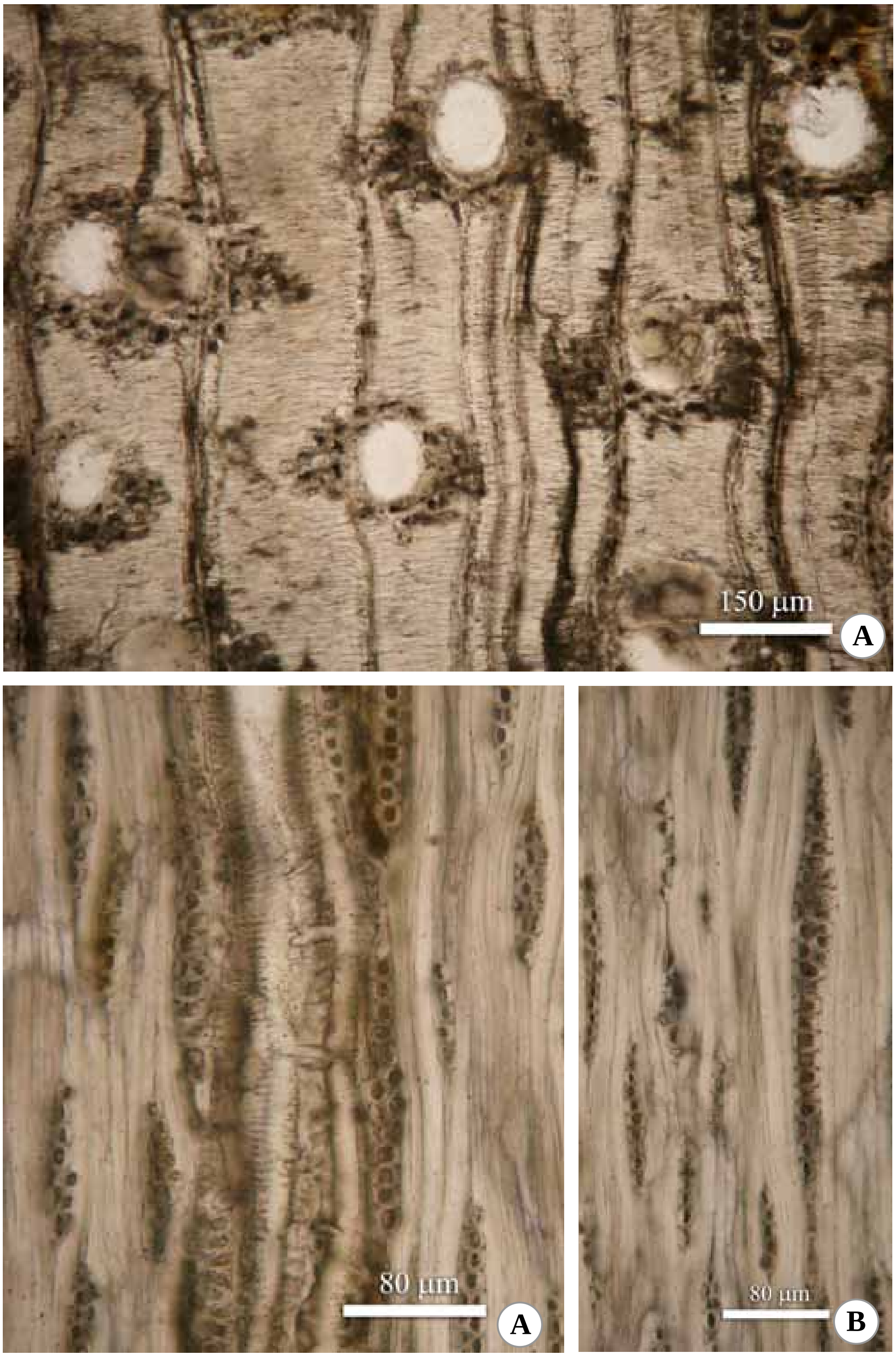


Figure 4.27 Thin section of fossil wood M7-1. **A.** (Tv) Aliform parenchyma **B.** (Tg) Non-storied, 1 - 2 seriate (or 1 seriate with partially 2 seriate) rays and non-septate fibers.

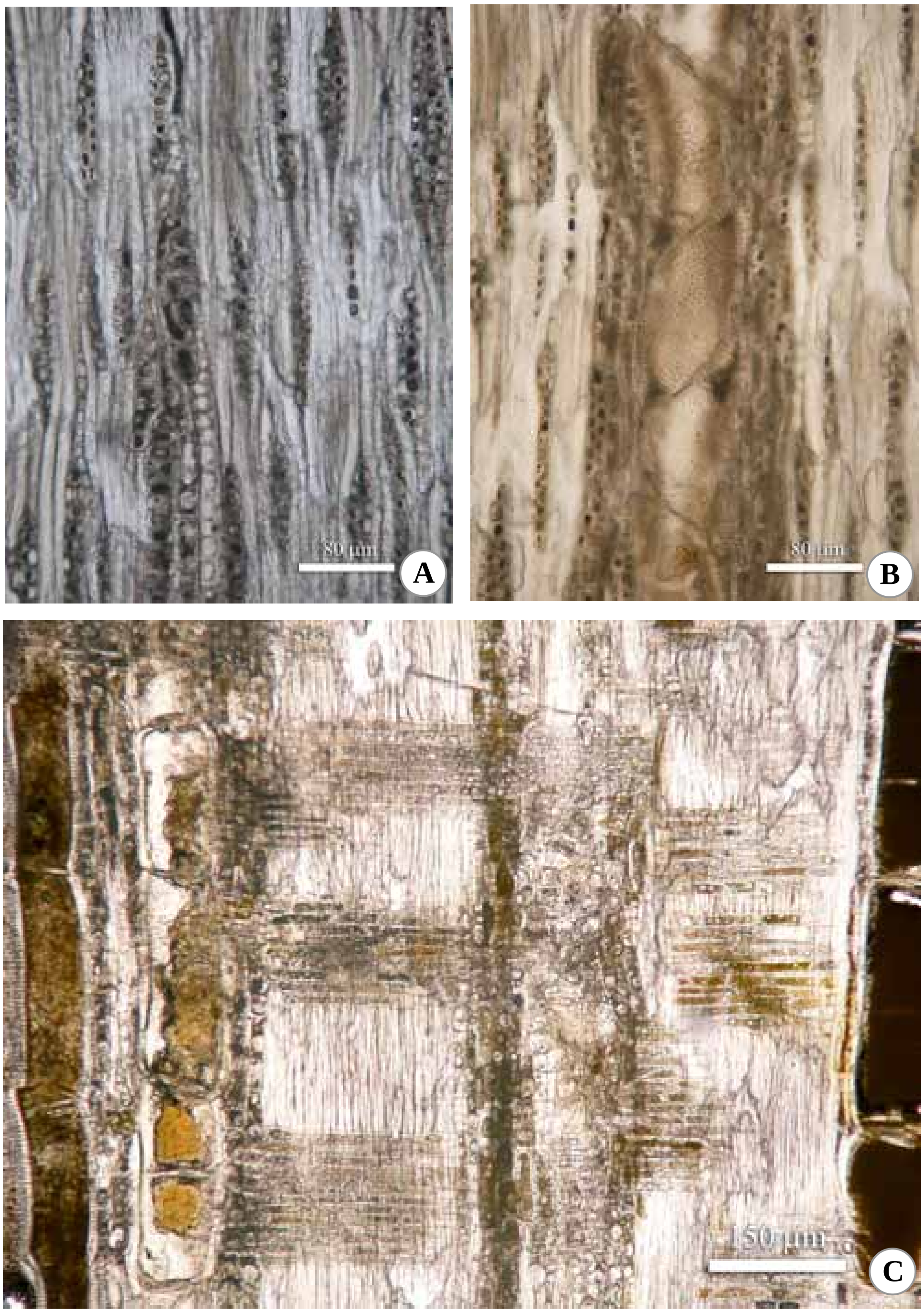


Figure 4.28 Thin section of fossil wood M7-1. **A.** More than eight parenchyma cells per strand (arrow) **B.** (Tg) Alternate intervessel pits **C.** Homogeneous rays; all ray cells are procumbent. Deposits are blocking the vessel lumina.

Family Irvingiaceae Exell and Mendonça

Genus *Irvingia* F.Muell.

Species *Irvingia* sp.

Locality: Institute of Petrified Wood and Mineral Resources, grid no. L7

Specimen Number: L7 (Figs. 4.29 - 4.32)

Preservation: The preservation in transverse and tangential sections of this specimen are medium, but the radial section is not well preserved.

Growth ring boundaries absent. Wood diffuse-porous.

Vessels 4 - 7/mm^2. Vessels small to medium sized, t.d. 110 - 190 µm (mean 136.4 µm), r.d. 90 - 240 µm (mean 179.2 µm). Vessels mostly solitary, sometimes in radial multiple of 2 - 3. Solitary vessel outline round to slightly ovate. Vessel element length (170) 270 - 460 (490) µm (mean 351.61 µm). Many hexagonal shape in vessel element and some fibers. Perforation simple; **intervessel pits** alternate, vestured, and minute to small about 3.12 - 5.28 µm in diameter. Vessel-ray pits not clearly observed. In cross section, yellowish brown and dark deposits appear to completely fill some vessel lumina and in longitudinal sections, deposits often appear collected at the end of vessel elements.

Axial parenchyma paratracheal vasicentric, banded parenchyma ~ (2) 3 - 4 cells wide, consistently alternate with the thicker fiber bands in width and looking reticulate (parenchyma in continuous tangential lines of approximately the same width as the rays but are rather thicker, regularly spaced and forming a network with the rays). Parenchyma strands were observed but the preservation is not sufficient to specific the exactly number of cells. There were possibly eight (5 - 8) cells per strand.

Rays 1 - 2 seriate, usually non-storied, tangential height 250 - 450 (500) µm (average 349 µm) and width 20 - 35 µm. Heterocellular body ray cells procumbent with 1 row of upright or square marginal cells.

Fibers very thick-walled, presence of septate fibers cannot be determined because the preservation is not good enough.

Affinities

The main characters of specimen no. L7 are small to medium vessels, mostly solitary, sometimes in radial multiple of 2 - 3, simple perforations, alternate and vestured intervessel pits, minute to small, vasicentric paratracheal axial parenchyma, banded parenchyma ~ 3 - 4 cells wide alternating with the thicker fiber bands and look like reticulate, 1 - 2 seriate rays, non-storied, heterocellular, and very thick-walled fibers.

These features show the dominant characters of wood of the families Leguminosae and Irvingiaceae. Among the Leguminosae, the axial parenchyma in cross section is especially similar to that of *Dialium* in Caesalpinioideae and *Dalbergia* in Papilionoideae. However, the storied structures of their rays are quite different from this fossil specimen, in which *Dialium* spp. and *Dalbergia* have storied rays**,** whereas non-storied or some irregularly storied rays are present in this fossil; additionally, vessels in *Dalbergia* are of two sizes.

In Irvingiaceae, the wood of the genus *Irvingia,* i.e, *Irvingia malayana* (Fig. 4.33 - 4.35) has similar features with this fossil in both banded parenchyma pattern and non-storied rays. In my opinion, this fossil should be placed as *Irvingia* sp.

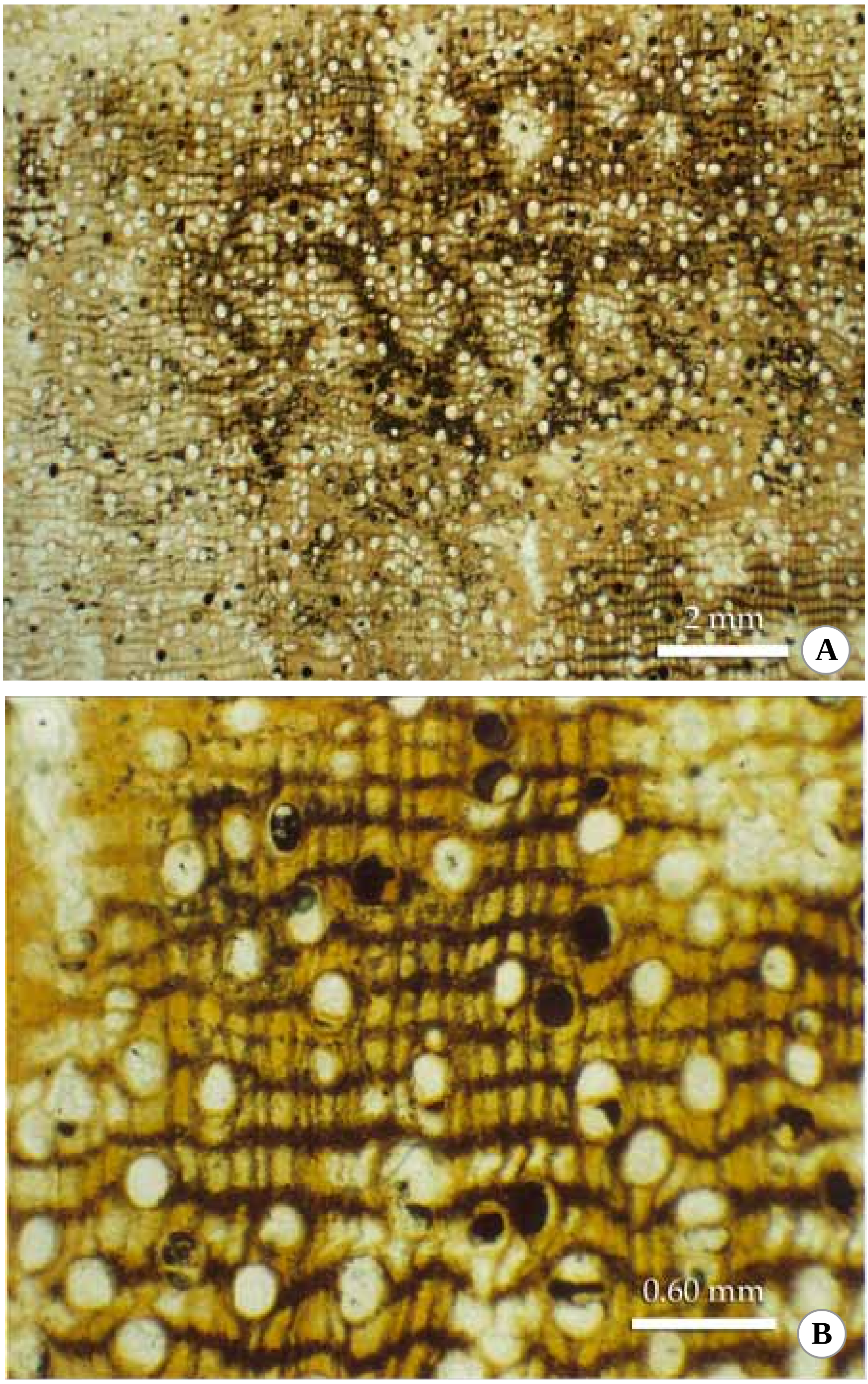


Figure 4.29 Thin section of fossil wood L7 in transverse section. **A.** Vessel distribution, wood diffuse-porous. **B.** Axial parenchyma ~ 2 - 4 cell thick bands. Almost all vessels are solitary; vessels in radial multiples of 2 - 3 are rare.

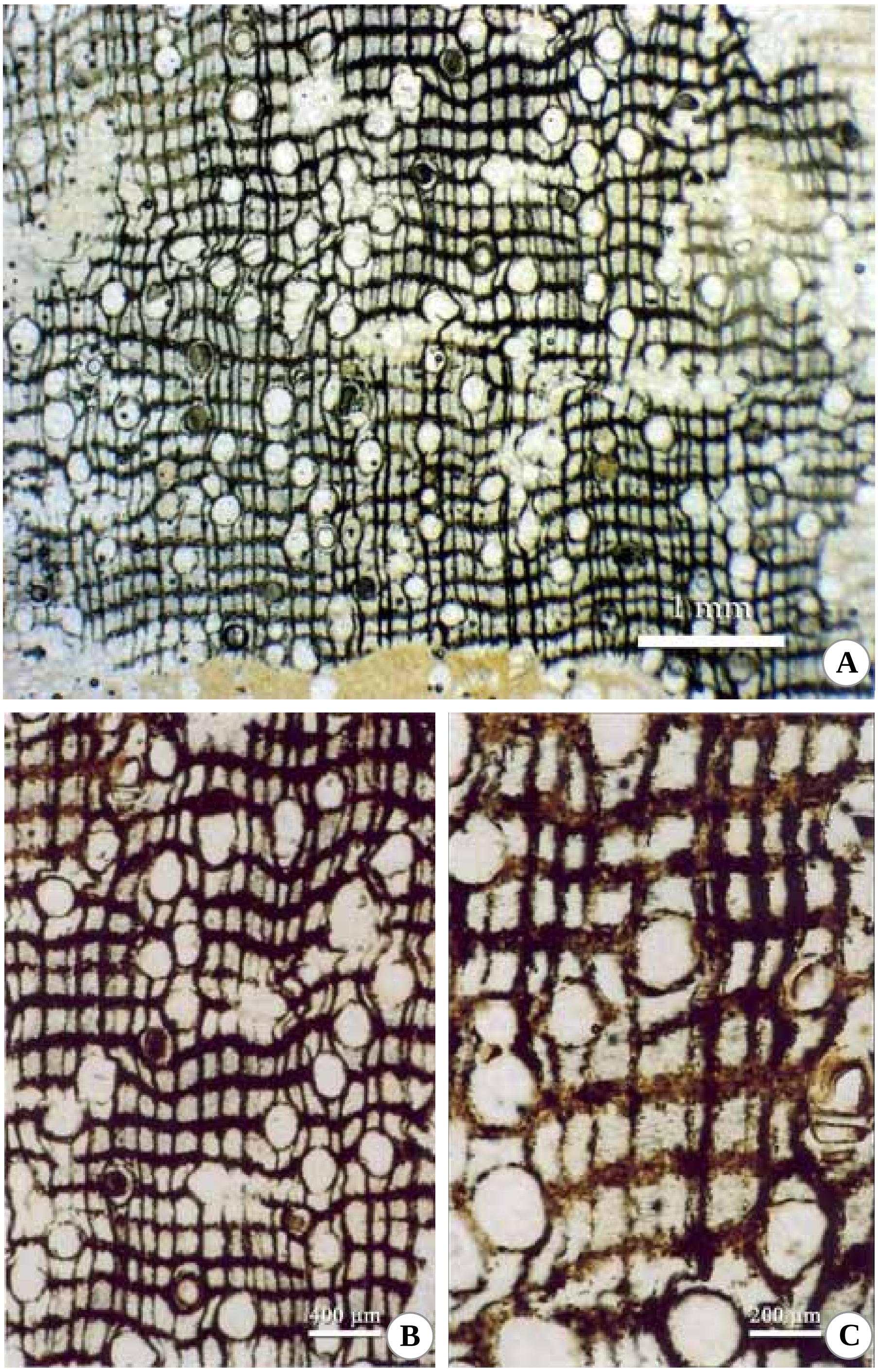


Figure 4.30 Thin section of fossil wood L7 in transverse section. **A.** and **B.** Axial parenchyma in continuous narrow bands in similar width as the rays, but mostly parenchyma rather thicker, appearing reticulate. **C.** Fibers very thick-walled.

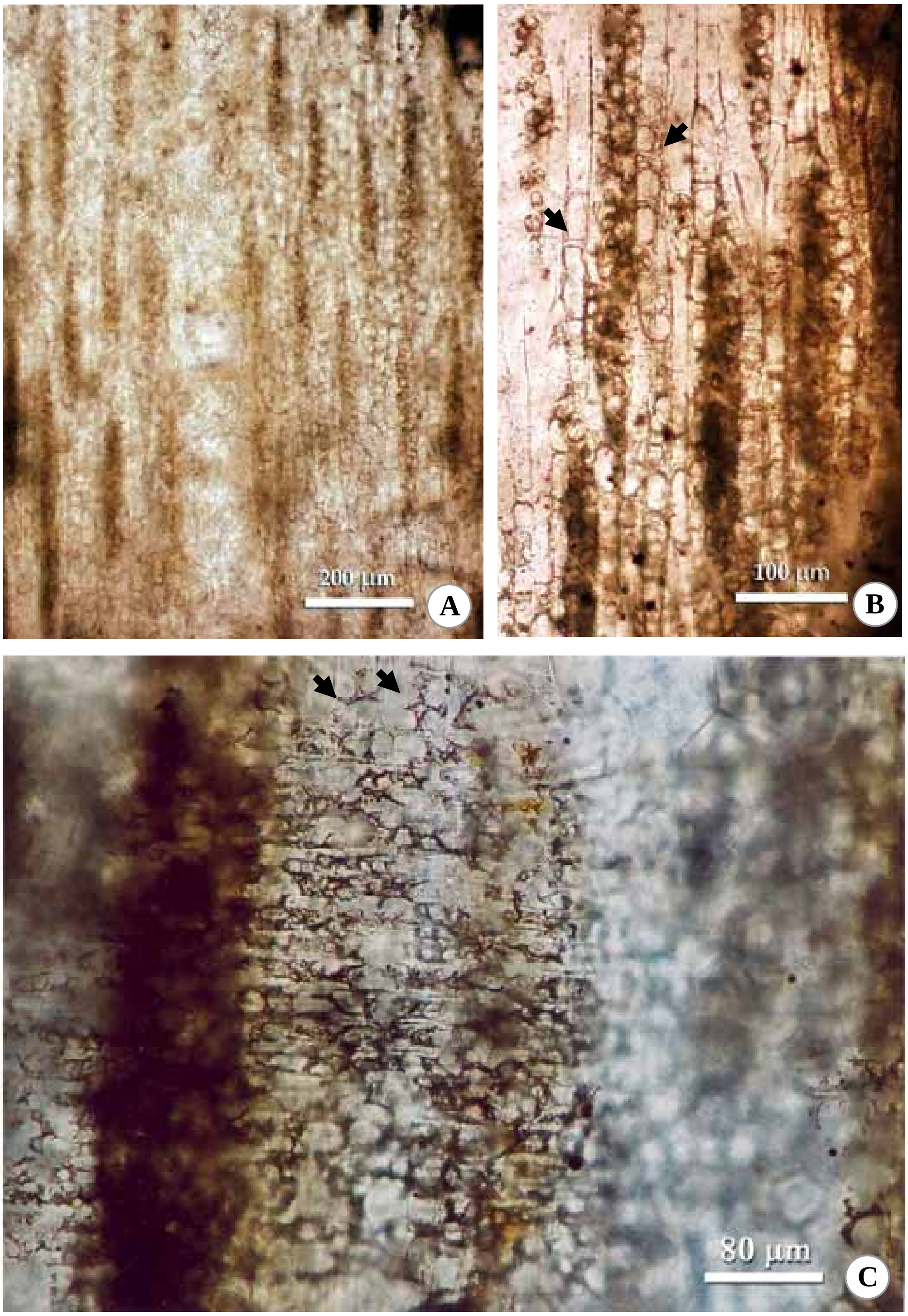


Figure 4.31 Thin section of fossil wood L7. **A.** (Tg) Non-storied, 1 - 2 seriate rays. **B.** (Tg) Parenchyma strand cells (arrows). **C.** Body ray cells procumbent with one row of upright and/or square marginal cells (arrows) are observed.

Figure 4.32 Thin section of fossil wood L7 in radial section. Body ray cells procumbent with one row of upright and/or square marginal cells (arrows).

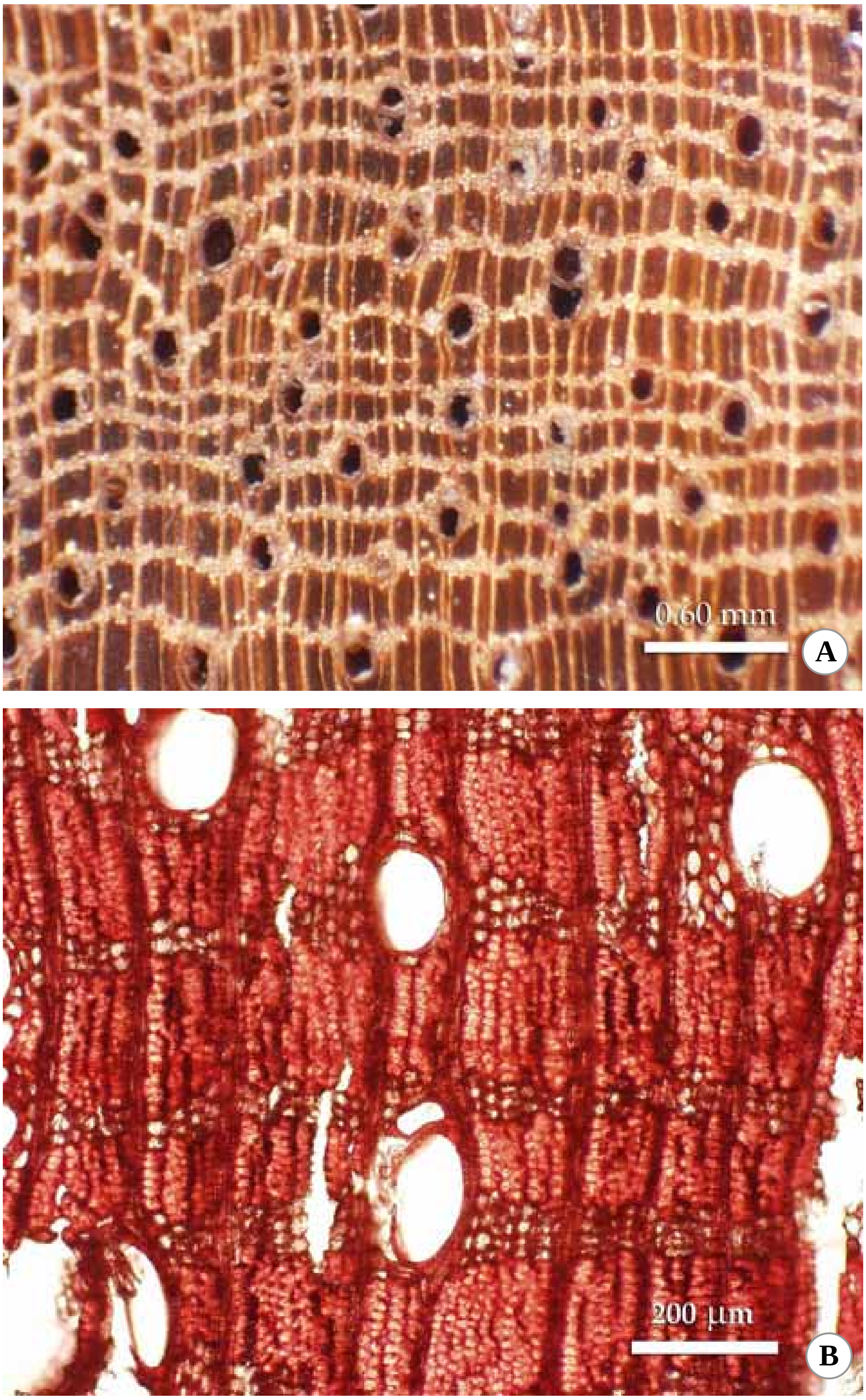


Figure 4.33 Thin section of modern wood of *Irvingia malayana* in transverse section.

A. Banded parenchyma, very thick-walled fibers (arrows).

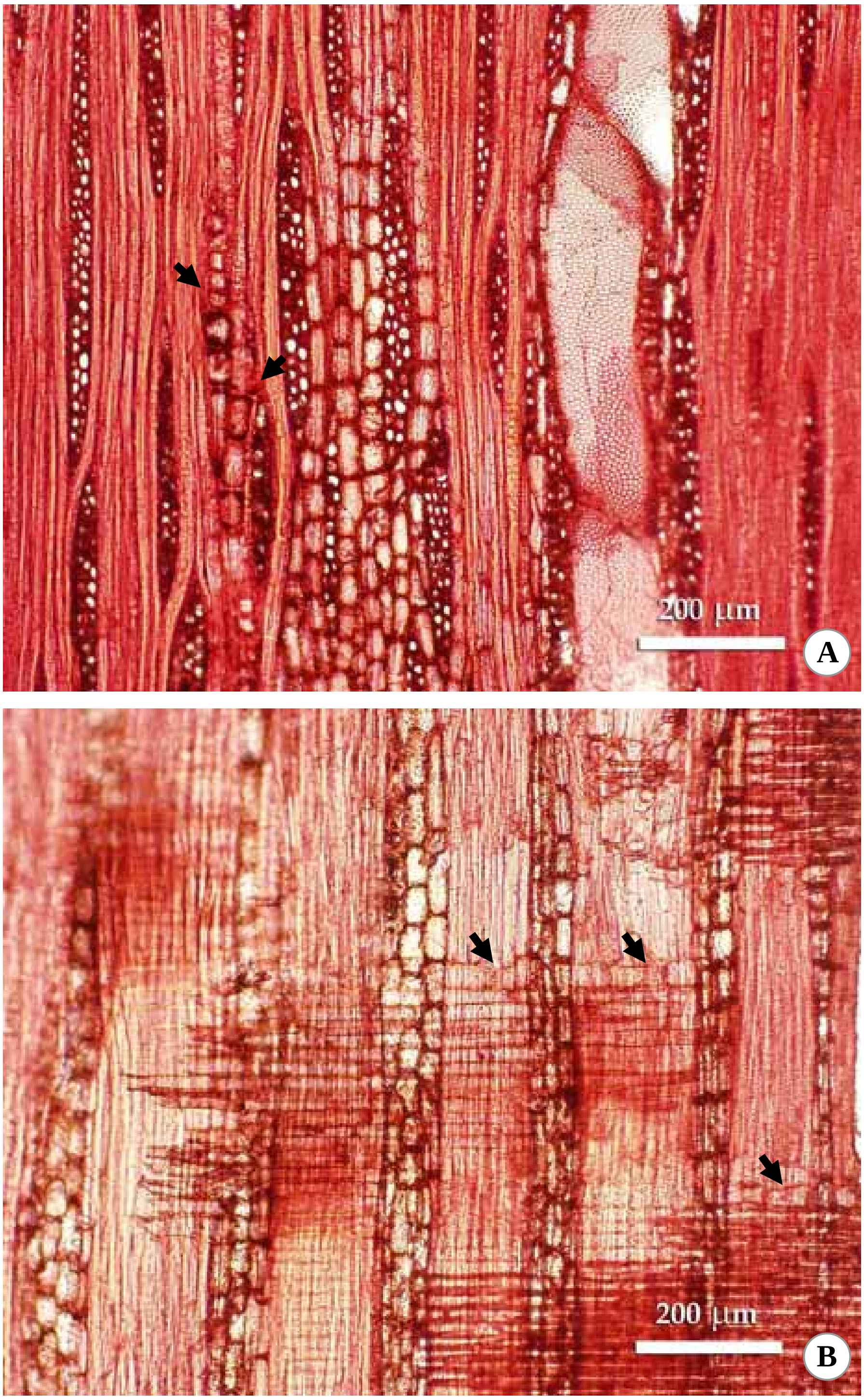


Figure 4.34 Thin section of *Irvingia malayana*. **A.** (Tg) polygonal shape, alternate intervessel pits, rays are 1 - 3 seriate and non-storied, 5 - 8 cells per parenchyma strand (arrow). **B.** (R) body ray cells procumbent with a row of square marginal cells (arrows).

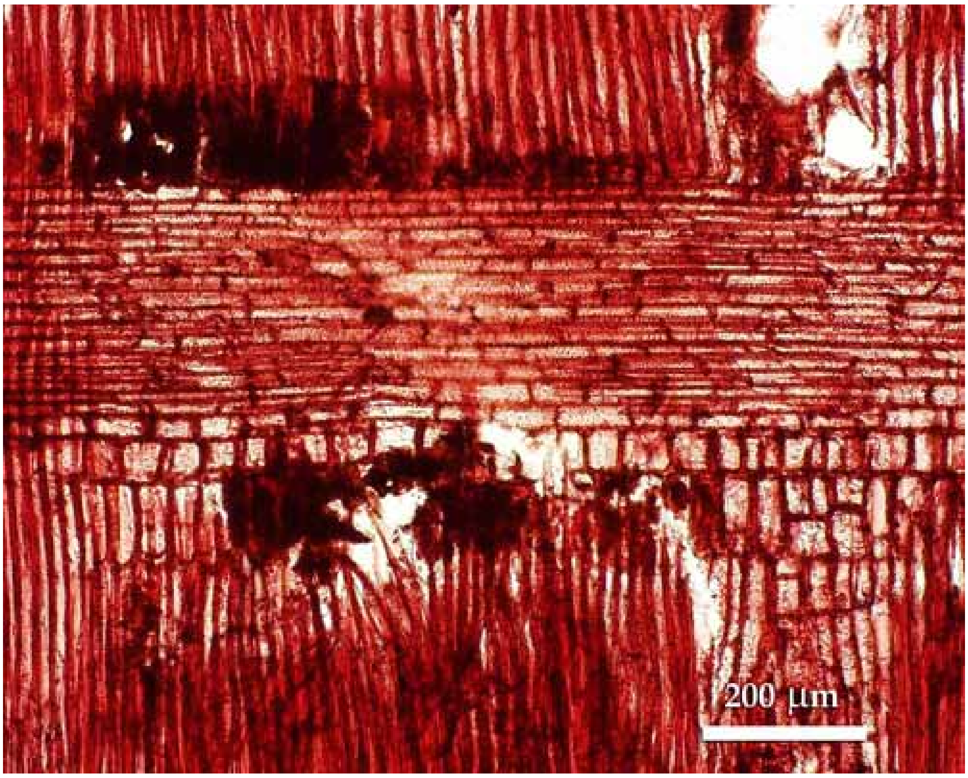


Figure 4.35 Thin section of *Irivingia malayana* in radial section, body ray cells procumbent with a row of square marginal cells (arrows).

Family Leguminosae Juss.

Genus *Cynometroxylon* Chowdhury and Ghosh, 1946

Species *Cynometroxylon holdeni* (Gupta) Prakash and Bande, 1980

Specimen number: F5-1 (Figs. 4.36 - 4.37), F5-2 (Figs. B4 - B5), I2-2 (Figs. B6 - B8), I2-3 (Figs. 4.38 - 4.40 and Figs. B9A - B), M1-4 (Figs. B10 - B13), M8 (= NRRU 60) (Figs. B14 - B16)

Description

Growth ring boundaries indistinct or absent. Wood diffuse-porous.

Vessels 3 - 6 /mm^2. Vessels medium or some small sized t.d. (40 - 50) 60 - 210 µm (mean 113.17 µm), r.d. 90 - 280 µm (mean 171.52 µm). Vessels solitary as well as in radial multiples of 2, and sometimes in radial multiples of 3 - 4 (5); vessel clusters absent or rarely present in some specimens. Solitary vessel outlines usually oval to sometimes elliptic or round in some specimens. Brownish or black deposits and crystals are apparent in some vessel lumina.

Vessel element length (60 - 150) 190 - 480 µm (mean 260.87 µm). Simple perforation plates. **Intervessel pits** alternate, minute to small sized, 3 - 5 (6) µm, polygonal in shape. Vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cell.

Axial parenchyma banded, commonly (2) 3 - 7 (-9) cells wide. Bands of parenchyma alternating with bands of fibers. Parenchyma bands in continuous tangential lines wider than rays in transverse section. Occasionally, parenchyma bands bifurcate and then join with other bands above and below. Parenchyma in marginal or seemingly marginal bands observed in some specimens (Figs. B4.A - B4.B)

Rays 1-3 seriate (very rarely 1 or 4 seriate in some specimens), 7 - 28 cells high; tangential height (80 - 115) 165 - 440 (580) µm (average 273.51 µm) and width (10) 15 - 45 (55) µm. Rays usually non-storied, occasionally irregularly storied and storied also in the same specimen. Rays heterocellular consisting of procumbent body ray cells with one row of upright/and or square marginal cells.

Fibers thick to very thick-walled (usually very thick) and non-septate.

Affinities

The main characters of these specimens are as follows: vessels solitary as well as in radial multiples of 2 - 3 (- 5), rarely in clusters, simple perforation plates, intervessel pits alternate, minute to small; rays 1 - 3 (4) seriate, usually non-storied, few irregularly storied and storied, heterocellular; fibers thick to very thick-walled and non-septate.

These features show close resemblance to modern wood of the family Leguminosae, in which they are typical characters of Caesalpinioideae, especially the genus *Cynometra*, and Papilionoideae, genus *Millettia*. Many fossil wood specimens showing close resemblance to these two genera have been found from India, Burma, and Thailand. Their anatomical features were studied and they were given the form generic names *Cynometroxylon* Chowdhury and Ghosh, 1946, and *Millettioxylon* Awasthi, 1967, respectively (Prakash, 1975 and Prakash and Bande, 1980).

However, most xylem rays in wood of the genus *Millettia* and fossil wood *Millettioxylon* are storied, homogeneous and homocellular, consisting of all procumbent cells, whereas rays of *Cynometra* are non-storied, sometimes with a slight tendency to storied arrangement (Prakash, 1979; Prakash and Bande, 1980; Ogata *et al*., 2008).

Rays in these fossil specimens are heterocellular and mainly non-storied, but sometimes irregularly storied and very rarely storied rays occur in the same specimen, which is similar to modern wood *Cynometra* and fossil wood of *Cynometroxylon*.

After *Cynometroxylon* was first proposed in 1946, additional species were reported from India and Burma, e.g., *C. indicum*, *C. schlagintweitii*, and *C. siwalicus*. Because slightly different features of parenchyma band width, ray size, and vessel size, used to separate fossil wood species, were found to vary within modern wood of the same species of *Cynometra*, fossils of *Cynometroxylon* were reinvestigated and later combined into one species, *Cynometroxylon holdeni* (Gupta) Prakash and Bande (1980). Wood of this species shows nearest affinities to modern wood of both *Cynometra ramiflora* (Fig. 4.41) and *C. polyandra* (Fig. 4.42) (Prakash and Bande, 1980).

There have been two species of *Cynometroxylon* reported from Thailand so far, *C. parainaequifolium* (Prakash, 1979) and *C. schlagintweitii* (Vozenin-Serra and Privé-Gill, 1989), of which the latter one should be grouped in *C. holdeni* as mentioned above. *C. parainaequifolium* is similar to modern wood of *Cynometra inaequifolia* (Prakash, 1979). Although vessel size and parenchyma bands of *C. parainaequifolium* are similar to those of the fossil specimens from the study site, the density of vessels (6 - 7/mm^2) and ray height (13 - 60 cells high) are rather higher.

C. holdeni shows diverse characteristics in different specimens, such as rays usually being non-storied, 1 - 4 (mostly 2 - 3) seriate or 1 - 3 seriate or 1 - 2 seriate, and ray height ranging up to 85 cells in one specimen, while only 5 - 25 cells in another. The range of their vessel sizes is from t.d. 50 - 225 µm and r.d. 65 - 250 µm (Prakash and Awasthi, 1971; Prakash and Bande, 1980).

These features show a very close resemblance to the specimens no. F5-1, F5-2, I2-2, I2-3, M1-4, and M8 in this study.

Rays in modern wood of *Cynometra* spp. are reported so far as only being 1 - 3 cells wide and about 600 - 1500 µm high (InsideWood, 2004-onwards; Ogata *et al.*, 2008) while these characters are more variable in *Cynometroxylon* spp.

Petrified wood specimens from the study area share characters most closely with fossil wood specimens of *Cynometroxylon holdeni*. Therefore, I assigned them to be *Cynometroxylon holdeni* (Gupta) Prakash and Bande, 1980.

(See more descriptions and features of each specimen in Appendix B.)

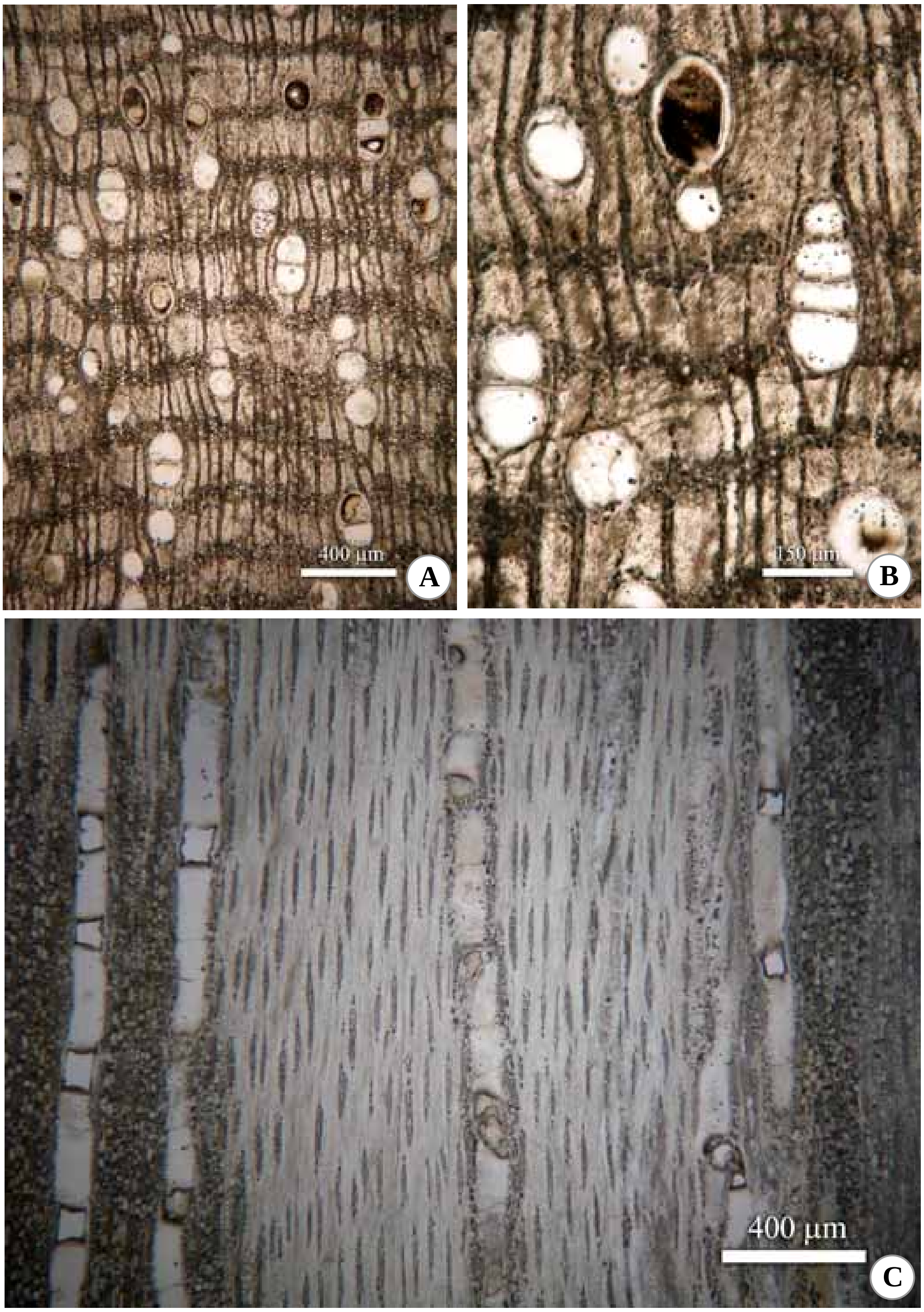


Figure 4.36 Fossil wood of F5-1. **A. & B.** (Tv) Banded parenchyma alternating with fiber bands. Vessels solitary and in radial multiples of 2 - 4. Fibers very thick-walled. **C.** (Tg) Rays non-storied, irregularly storied, and storied in the same specimen.

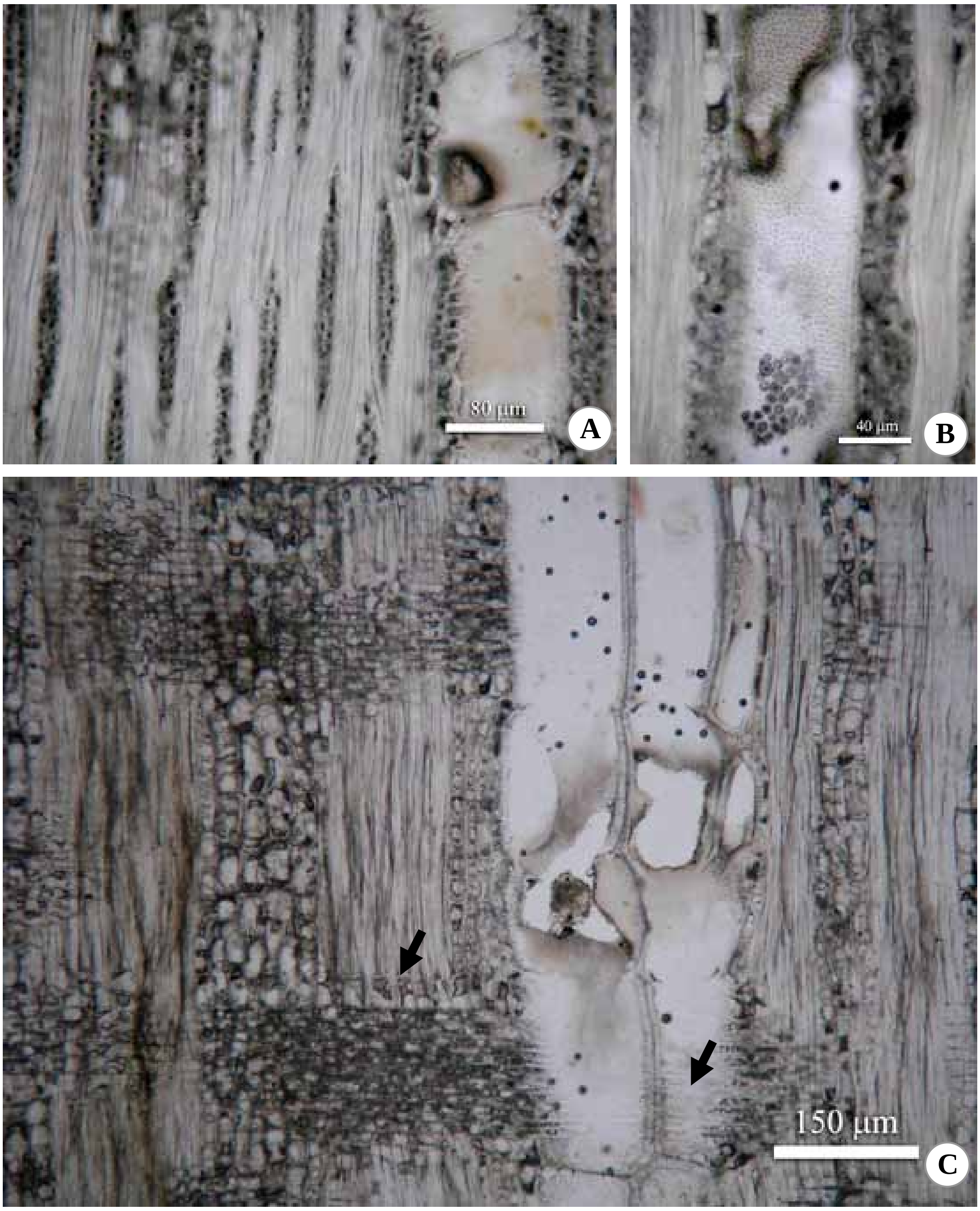


Figure 4.37 Fossil wood of F5-1. **A.** (Tg) (1) 2 (3) seriate rays. **B.** (Tg) Vessel element showing alternate pits. **C.** (R) Body ray cells procumbent with one row of upright and/or square marginal cells (arrow). Vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cells (arrow).

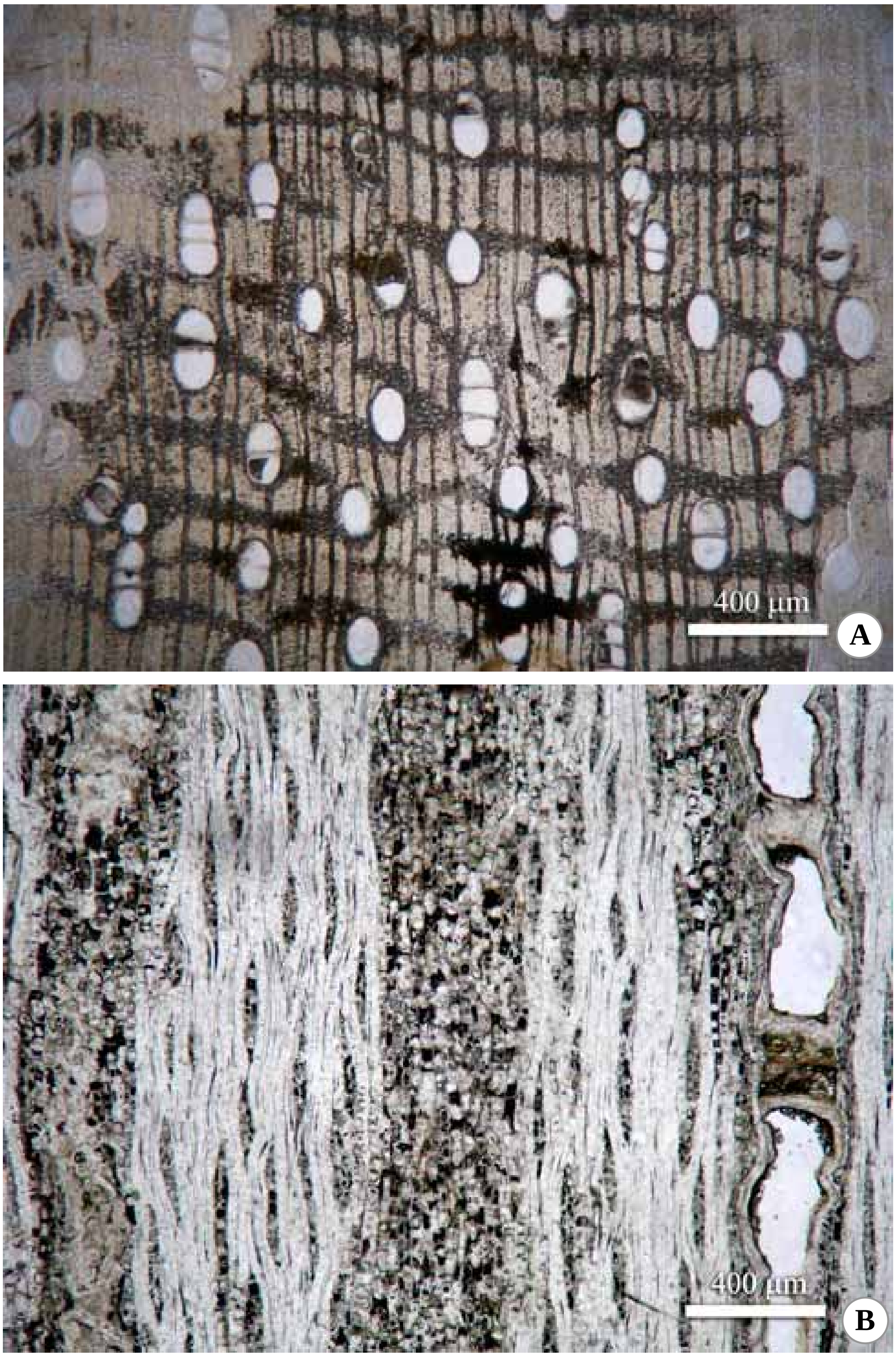


Figure 4.38 Thin section of fossil wood I2 - 3. **A.** (Tv) Vessels solitary and in radial multiples of 2 - 3 (4). Axial parenchyma aliform and banded, bands are occasionally bifurcate and then joining with other upper and lower bands. **B.** (Tg) Non-storied and 1 - 2 seriate rays and non-septate fibers.

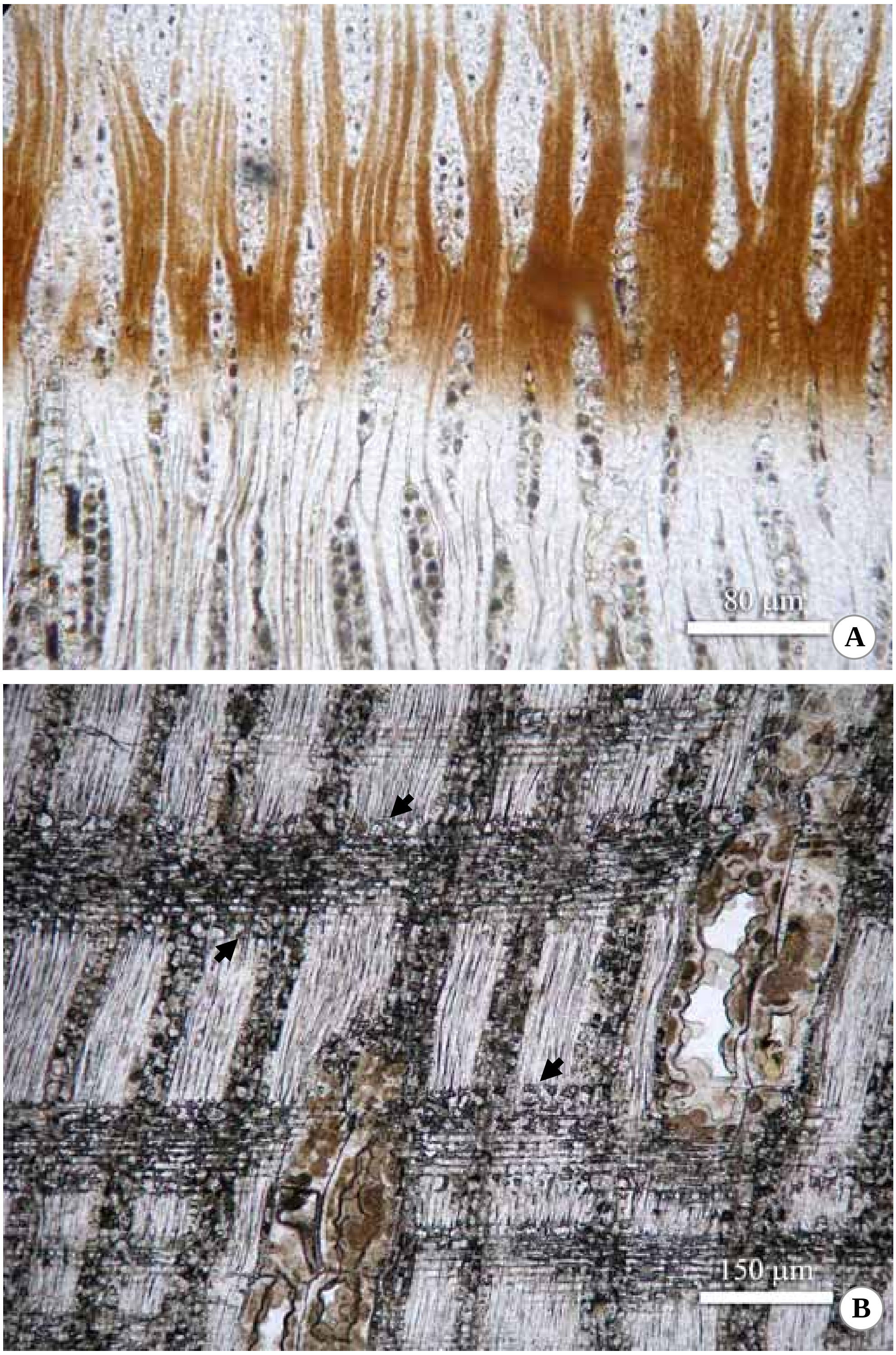


Figure 4.39 Thin sections of fossil wood I2-3. **A.** (Tg) Uni-biseriate rays and non-septate fibers. **B.** (R) Brownish round shape materials are filled in vessel lumina, body ray cells procumbent with one row of upright and/or square marginal cells (arrows).

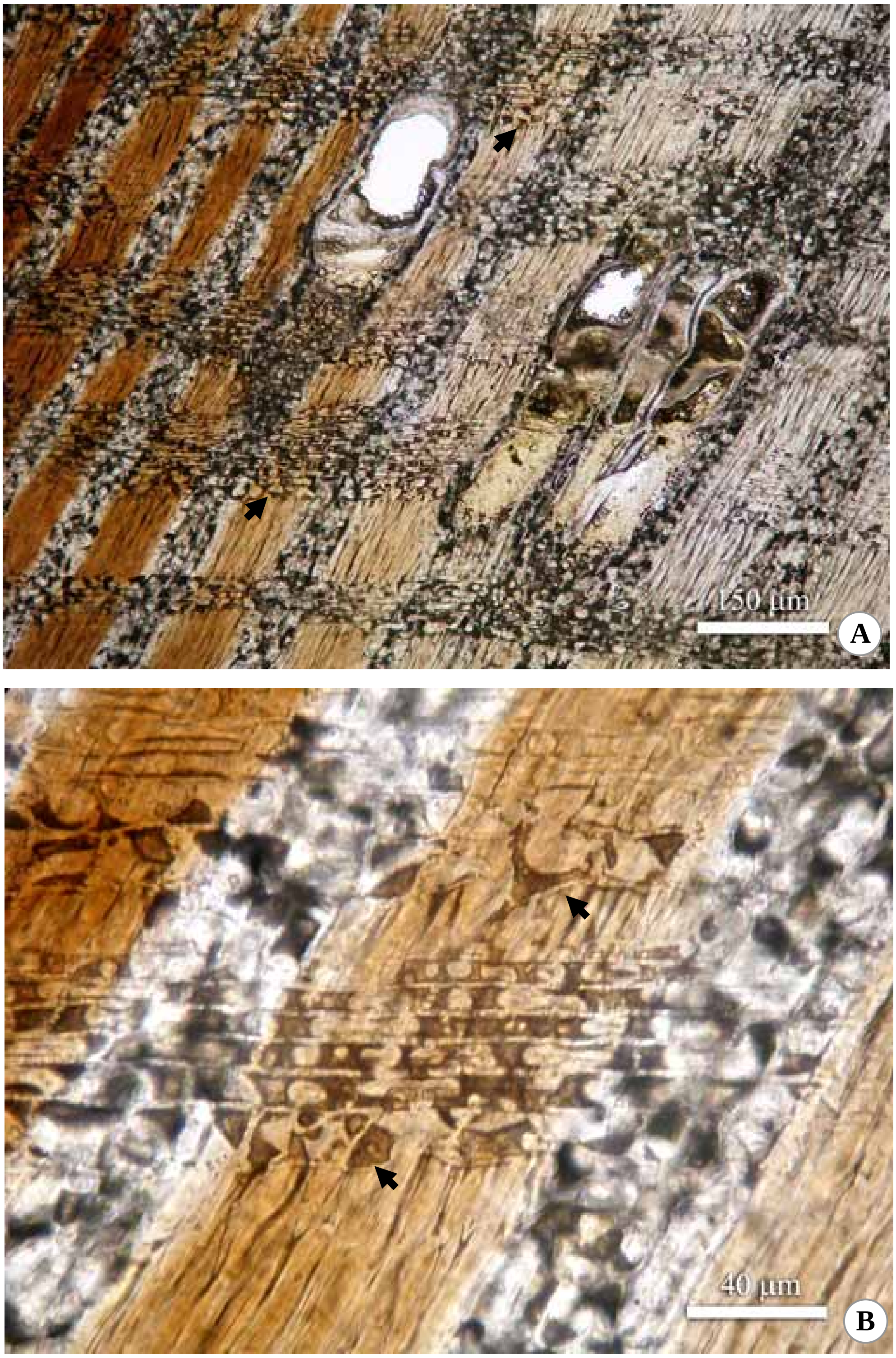


Figure 4.40 Thin sections of fossil wood I2-3 in radial section. **A.** and **B.** Body ray cells procumbent with one row of upright and/or square marginal cells (arrows).

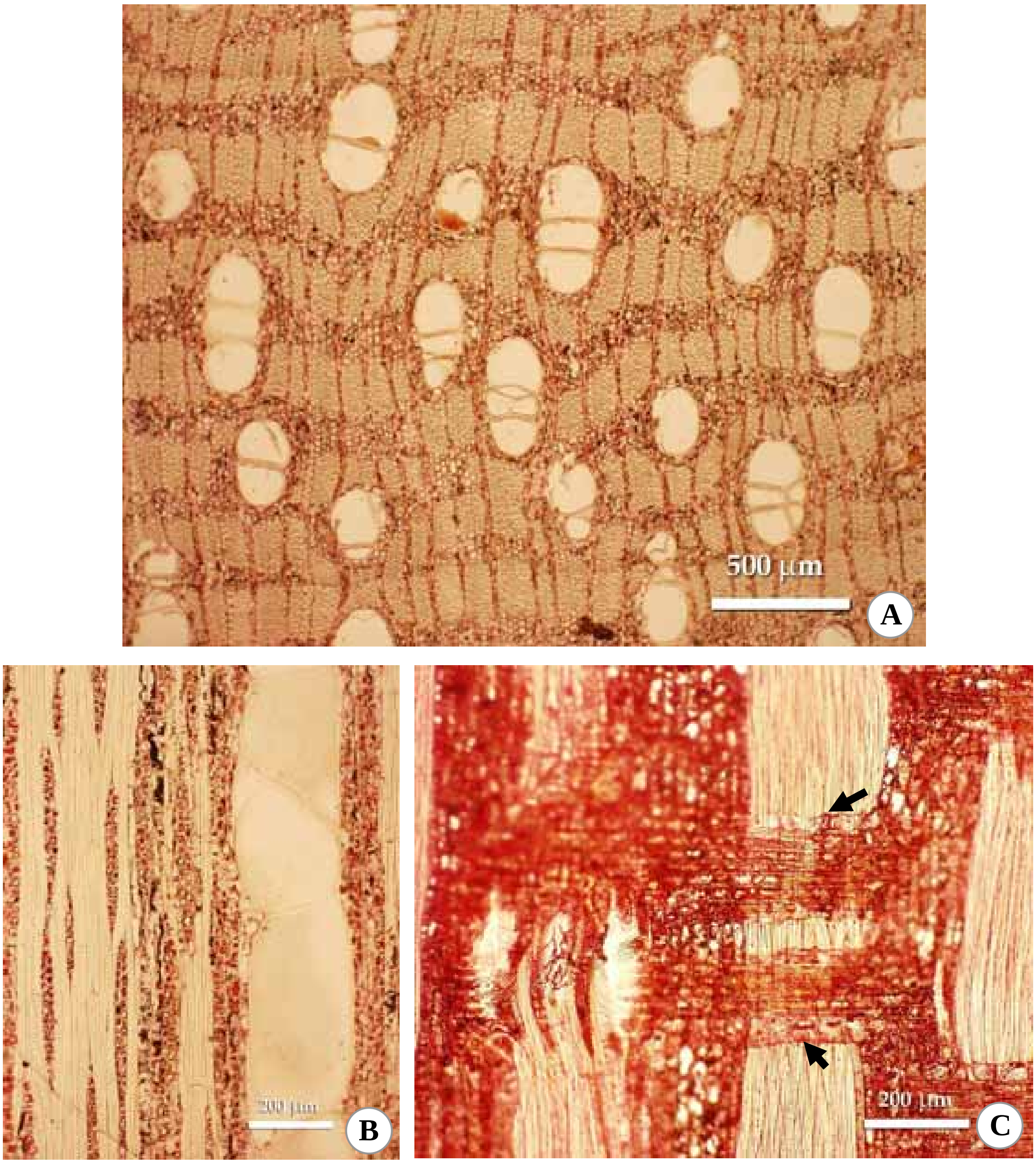


Figure 4.41 Thin section of modern wood, *Cynometra ramiflora*. **A.** (Tv) Banded parenchyma alternating with fibers bands. Vessels solitary and in radial multiples of 2 - 4. Fibers very thick-walled. **B.** (Tg) Rays (1) 2 (3) seriate and non-storied. Intervessel pits alternate. **C.** (R) Body ray cells procumbent with one row of upright and/or square marginal cells (arrow). Vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cells.

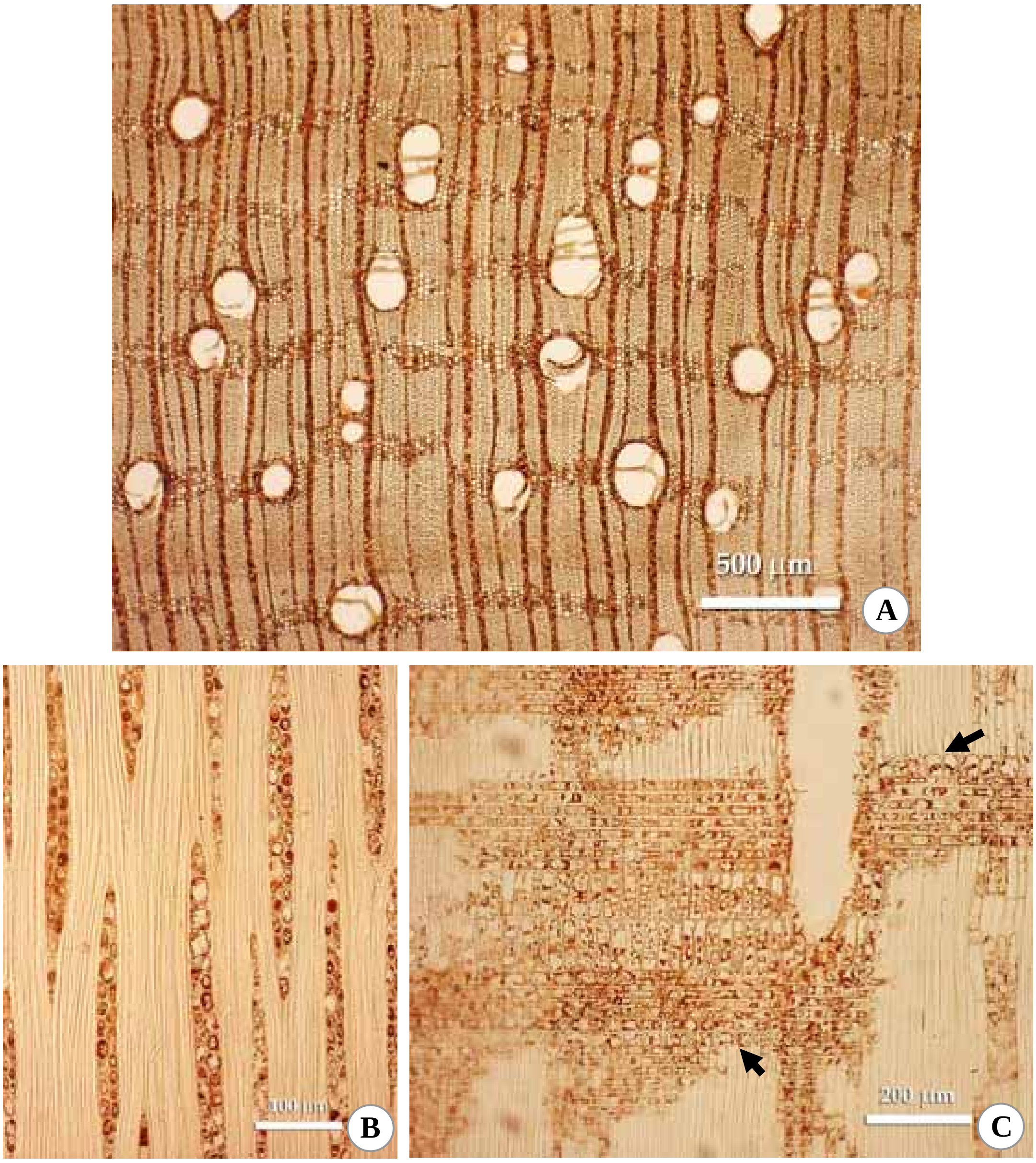


Figure 4.42 Thin section of modern wood, *Cynometra polyandra* **A.** (Tv) Banded parenchyma alternating with fibers bands. Vessels solitary and in radial multiples of 2 - 4. Fibers very thick-walled. **B.** (Tg) Rays (1) 2 (3) seriate and non-storied. **C.** (R) Body ray cells procumbent with one row of upright and/or square marginal cells (arrow).

Family Leguminosae Juss.

Genus *Cynometroxylon* Chowdhury and Ghosh, 1946

Species *Cynometroxylon* sp. 1

Locality: Institute of Petrified Wood and Mineral Resources, grid no. N7

Specimen number: N7-1 (Figs. 4.43 - 4.45)

Preservation: The specimen is fairly well preserved in three sections. No compression is present in this specimen.

Description

Growth ring boundaries indistinct or absent. Wood diffuse-porous.

Vessels 2 - 3 /mm^2. Vessels usually small, t.d. 45 - 100 µm (mean 68 µm), r.d. 45 -120 µm (mean 76.8 µm). Vessels solitary ~ 55% and some in radial multiples of 2 - 3 (often 2, few 3). Solitary vessel outline rather ovate. Vessel element length (200, 290) 370 - 480 (600) µm (mean 322.33 µm). Perforation simple; intervessel pits alternate, vestured, and minute to small (usually small) 3.50 - 5 µm in diameter.

Axial parenchyma vasicentric, banded, ~ 4 - 8 cells wide alternating with fiber bands. The spacing of parenchyma bands are distinctly observed in two zones; wider or of the same width as fiber bands (Fig 4.43A). Parenchyma bands consistently inclined about 45˚in relation to the rays (Fig 4.43A - C).

Rays (2) 3 - 4 (5) seriate (very rarely 1) and about 6 - 15 cells high, the terminal cell of some rays, or sometimes the cell wall, are in contact with the cell of another ray; at a magnification of 40X or 100X appearing like one long ray constricted in the middle. Ray tangential height (150) 170 - 430 (500) µm (average 290.33 µm) and width (30) 45 - 75 µm, rays heterocellular consisting of body ray cells procumbent with one row of square marginal cells. Rays slightly show a tendency to storied arrangement, some storied, and rarely non-storied; parenchyma strand present occasionally.

Fibers very thick-walled and non-septate.

Affinities

The main characters of specimen no. N7-1 are as follows: vessels usually small, vessels solitary or some in radial multiples of 2 - 3, perforations simple, intervessel pits alternate, vestured, axial parenchyma vasicentric, parenchyma bands alternating with the fiber bands, rays (2) 3 - 4 (5) seriate and about 6 - 15 cells high, heterocellular consisting of procumbent body ray cells with one row of square marginal cells, most rays irregularly storied, some storied, and a few non-storied, and fibers very thick-walled and non-septate.

These features show some similarities to wood from the family Leguminosae, Caesalpinioideae, especially the genus *Cynometra* (Figs. 4.41 - 4.42), and Papilionoideae, *Millettia* (Figs. 4.50 - 4.51). However, this fossil shows closer resemblance to modern wood of *Cynometra* than *Millettia*, in which rays are non-storied and heterocellular (see the differences between wood of *Millettia* and *Cynometra* on page 103 in the discussion of affinities of *Cynometroxylon holdeni*).

This fossil is different from modern wood of *Cynometra* in ray width and height (see more information on page 105), but has characters that agree with those of the organ genus, *Cynometroxylon* Chowdhury and Ghosh, 1946. The specimen is not like *Cynometroxylon holdeni* and *C. parainaequifolium* in having smaller vessel size, slightly thicker parenchyma bands, and rays much wider, nearly two times the width of those in the previous reported specimens.

It is also unlike fossil wood *Cynometroxylon tertiarum* from India (close resemblance to modern wood *Cynometra alexandri*), in which rays are dominantly uniseriate, occasionally biseriate, homocellular, and storied (Mehrotra, 1997).

Thus, I identify this specimen as *Cynometroxylon* sp., probably a new species.

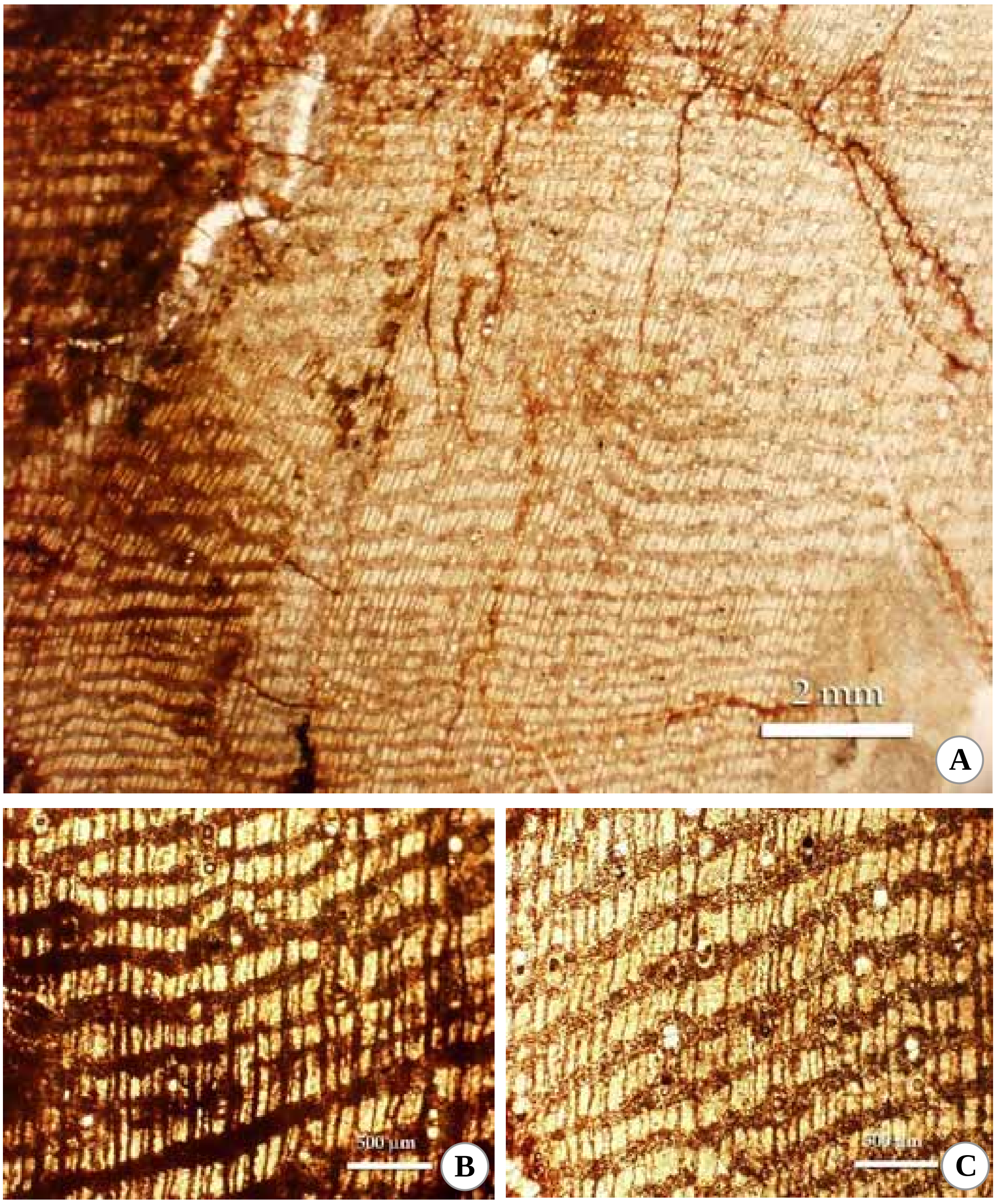


Figure 4.43 Thin section of fossil wood N7-1 in transverse section. **A.** Distribution of vessels, wood diffuse-porous, solitary vessels dominant, two sizes of thickness of parenchyma bands. **B.** and **C.** Parenchyma bands arranged at an approximately 45 degree angle in relation to the rays.

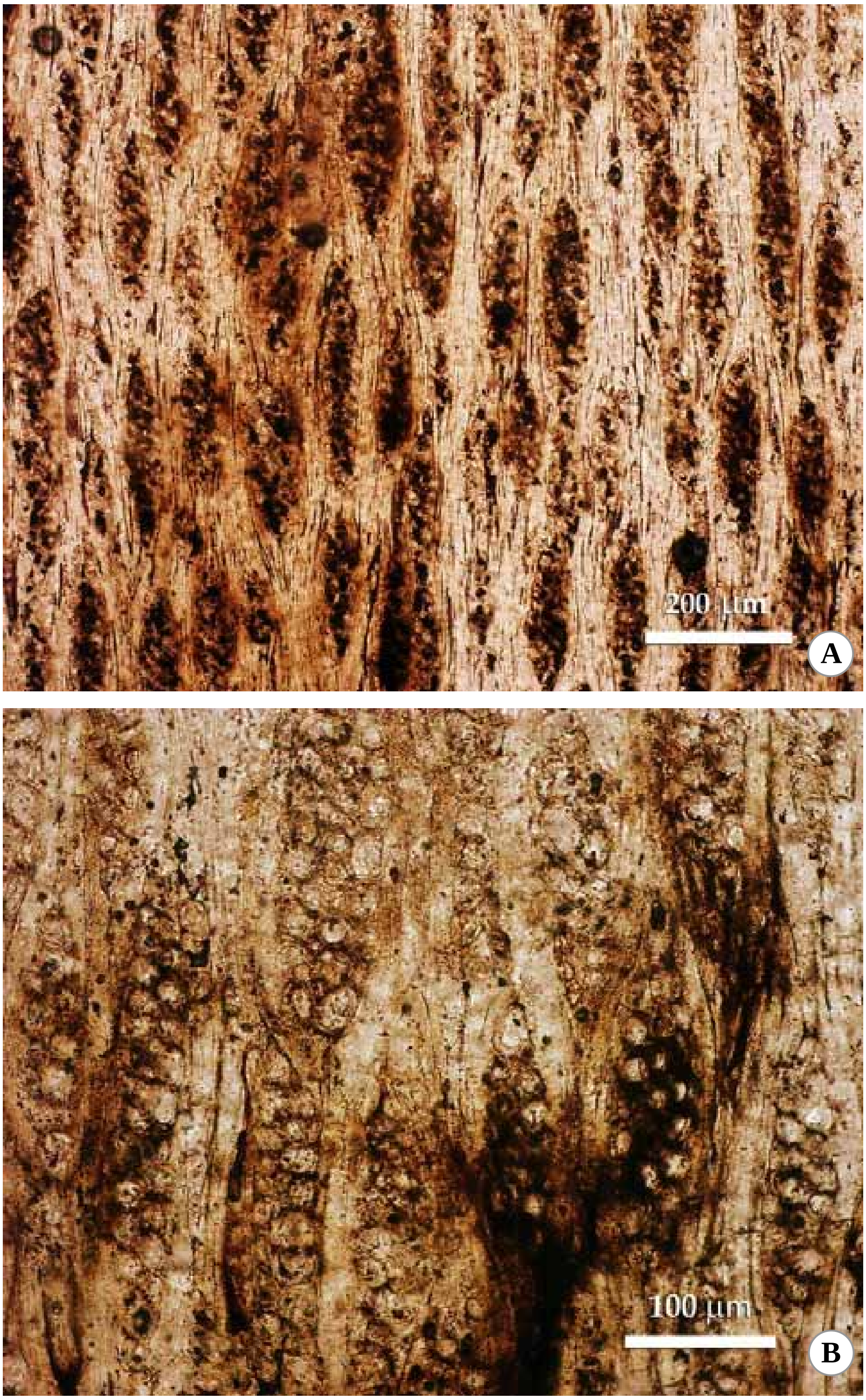


Figure 4.44 Thin section of fossil wood N7-1 in tangential section. **A.** Non-storied rays and non-septate fibers. **B.** Rays commonly 2 - 4 seriate.

Figure 4.45 Thin section of fossil wood N7-1 in radial section. **A.** and **B.** Body ray cells procumbent with one row of upright and/or square marginal cells (arrows).

Family Leguminosae Juss.

Genus *Millettia* Wight & Arn.

Species cf. *Millettia* sp. 1

Locality: Institute of Petrified Wood and Mineral Resources, grid no. C4

Specimen Number: C4 (Figs. 4.46 - 4.49)

Preservation: The preservation is fair in some areas, but fibers and parenchyma are not very well preserved in cross section. The tangential section is well preserved and details can be seen clearly. The radial section is ok.

Description:

Growth ring boundaries indistinct. Wood semi-ring-porous.

Vessels 4 - 7 /mm^2. Vessels small to medium size, t.d. (40) 50 - 130 µm (mean 87.6 µm), r.d. (60) 80 - 160 (180) µm (mean 128.4µm). Vessels solitary about 60 %, some in radial multiples of 2 - 3, few 4. Solitary vessel outline is rather rounded. Vessel element length (100) 150 - 275 (325) µm (mean 215.52 µm). Perforation simple; intervessel pits alternate, vestured, and small sized about 4 - 5 µm in diameter.

Axial parenchyma bands alternating with fiber bands of nearly the same thickness, some bands are thinner than fiber bands and bifurcate (Fig. 4.39B).

Rays 1 - 2 (very rarely 3) seriate, (6 - 7) 10 - 18 (25) cells high, tangential height quite variable (115 - 125) 150 - 320 (355 - 510) µm (average 232.14 µm) and width (10) 15 - 35 (40 - 45) µm. Storied and non-storied rays appearing in the same specimens. Most ray cells procumbent, a few body ray cells procumbent with 1 row of upright or square marginal cells are observed.

Fibers very thick-walled and non-septate.

Affinities

The main characters of this specimen are small to medium size vessels, many vessels solitary and some in radial multiples of 2 - 3, few 4, perforation simple, alternate, vestured, intervessel pits, small size, banded parenchyma, thick walled fibers, rays 1 - 2 (very rarely 3) seriate, storied and non-storied These features show similarities with the wood of Leguminosae and *Lagerstromia* of Lythraceae.

However, this fossil specimen is different from *Lagerstromia* in which semi-ring porous wood, rays 1 - 2 seriate and ray storied present, non-septate fiber**,** whereas ring-porous wood is distinct in *Lagerstromia,* rays are exclusively uniseriate and non-storied, and fibers are all septate with several septa per fibers (Ogata *et al.*, 2008). So this specimen is not assigned to be *Lagerstromia* spp.

This fossil shows closer resemblance to modern wood of *Cynometra* (Figs. 4.41- 4.42) (Caesalpinioideae) and *Millettia* (Figs. 4.50 - 4.51) (Papilionoideae) of Leguminosae. However, rays in this specimen are mainly storied, which is closer in resemblance to *Millettia*.

In my opinion, the fossil should be placed as cf. *Millettia* sp. 1 (see the differences between wood of *Millettia* and *Cynometra* on page 103 and more information about modern wood and fossil wood of *Millettia* on pages 129).

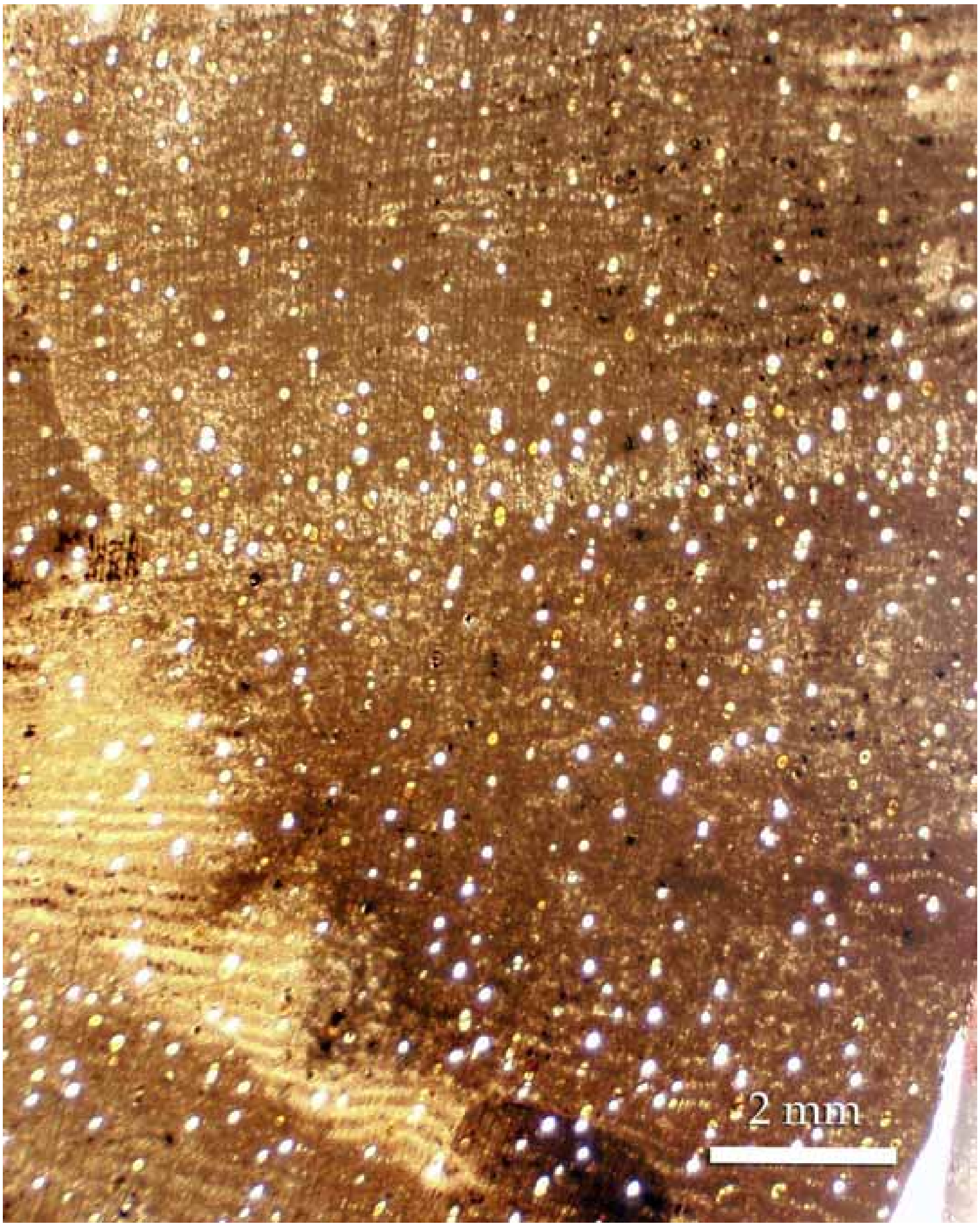


Figure 4.46 Thin section of fossil wood C4 in transverse section, showing vessel distribution, semi-ring porous wood, and banded parenchyma.

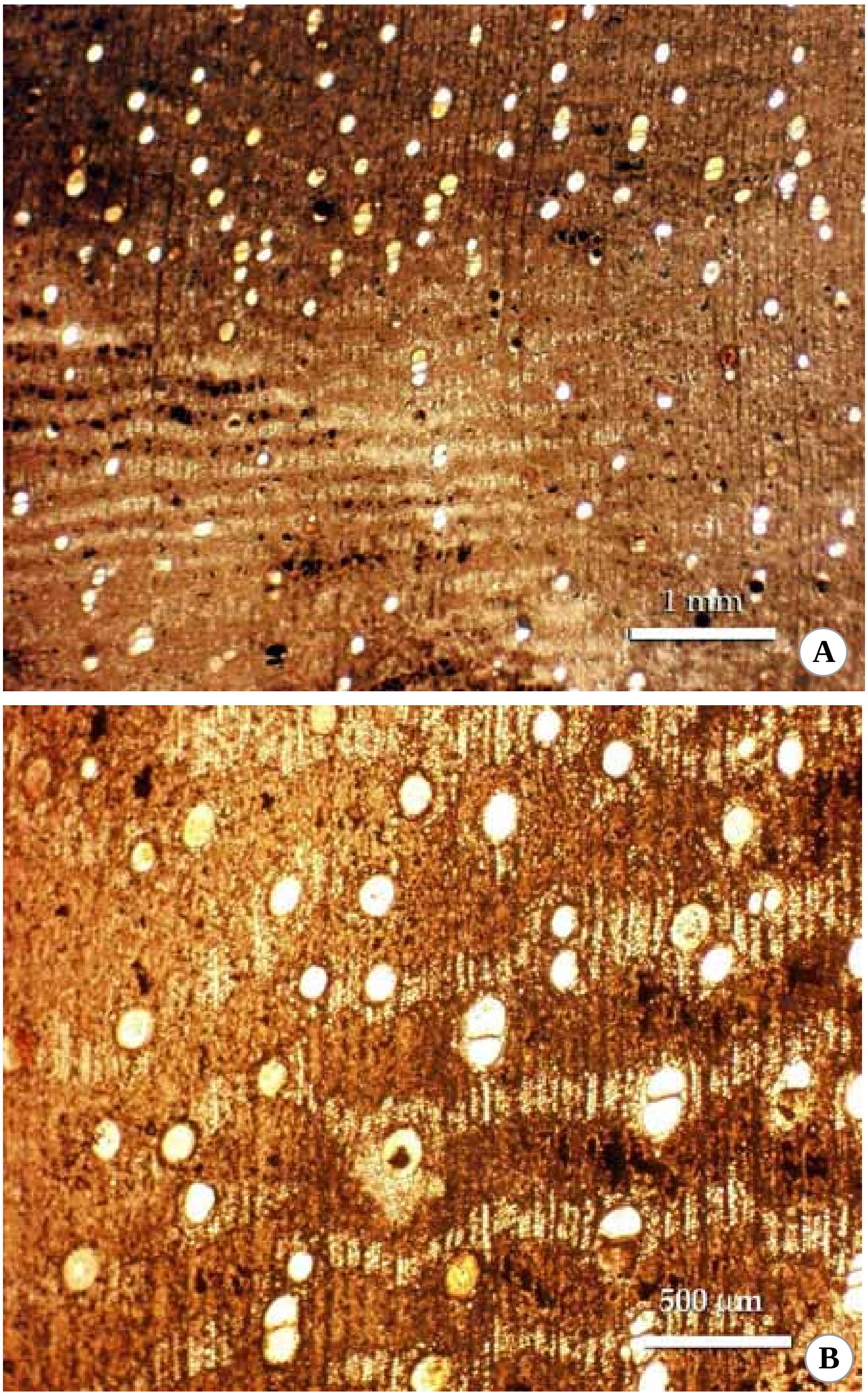


Figure 4.47 Thin section of fossil wood C4, transverse section. **A.** The majority of vessels solitary and vessels sometimes in radial multiples of 2 - 4. Parenchyma bands alternating with fiber bands of nearly the same width. **B.** Parenchyma bands sometimes wavy and bifurcate, and are occasionally thinner than fiber bands.

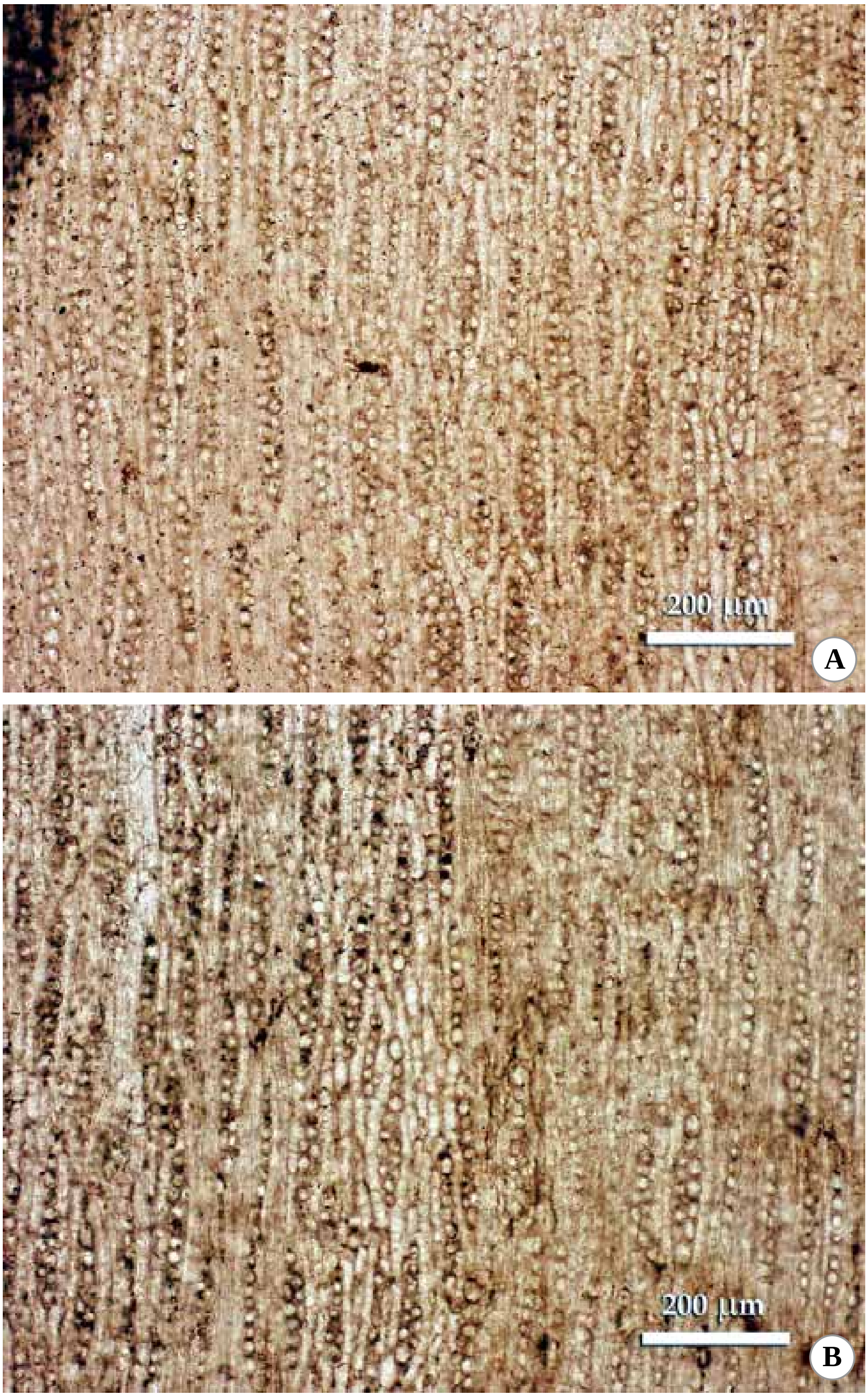


Figure 4.48 Thin section of fossil wood C4, tangential section. **A.** Storied rays **B.** Non- storied (left) and storied rays (right) present in the same specimen.

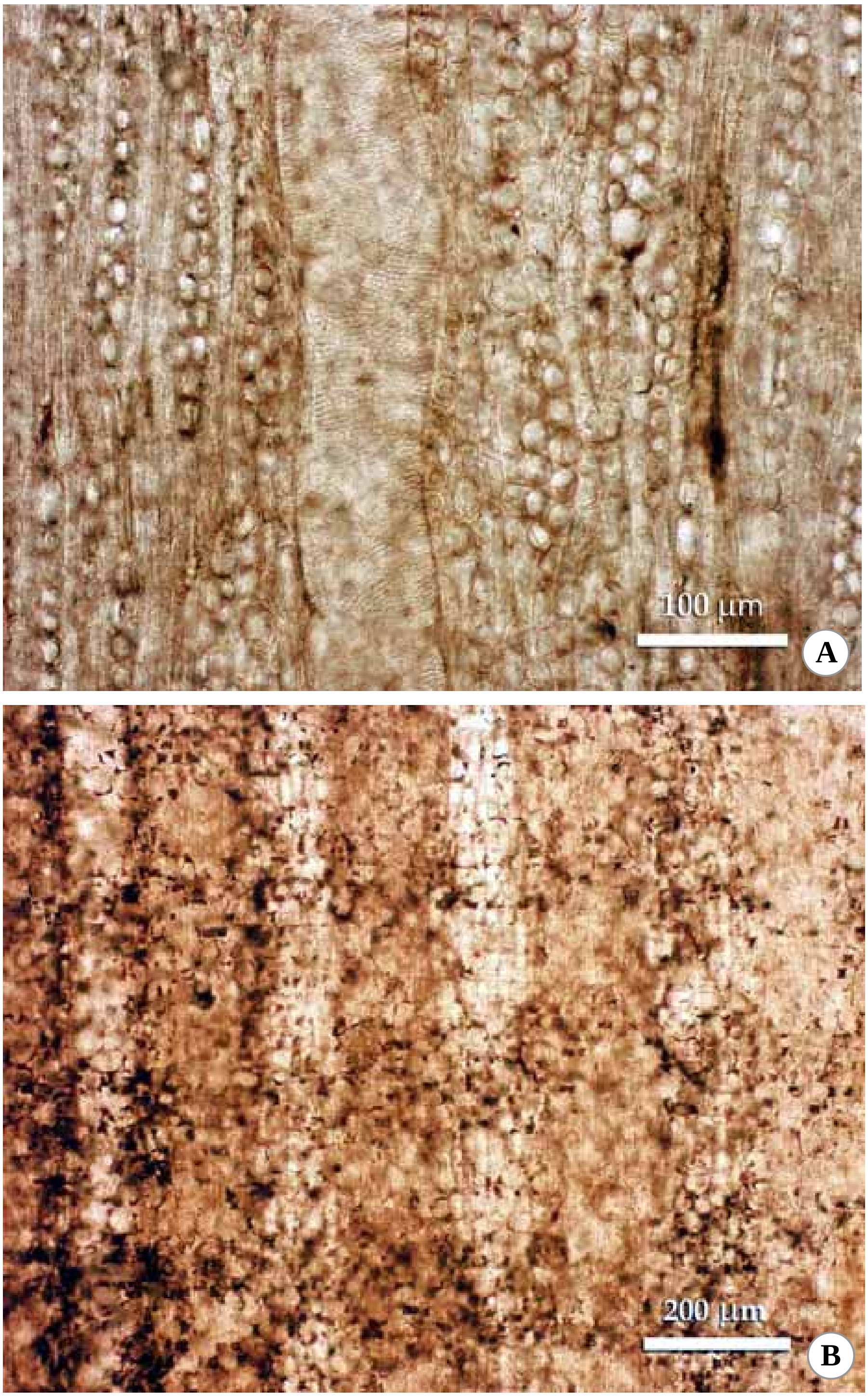


Figure 4.49 Thin section of fossil wood C4. **A.** (Tg) Alternate intervessel pitting and 1 - 2 seriate rays. **B.** (R) Procumbent ray cells can be observed, but the preservation is not good, ray cellular composition cannot be observed in detail.

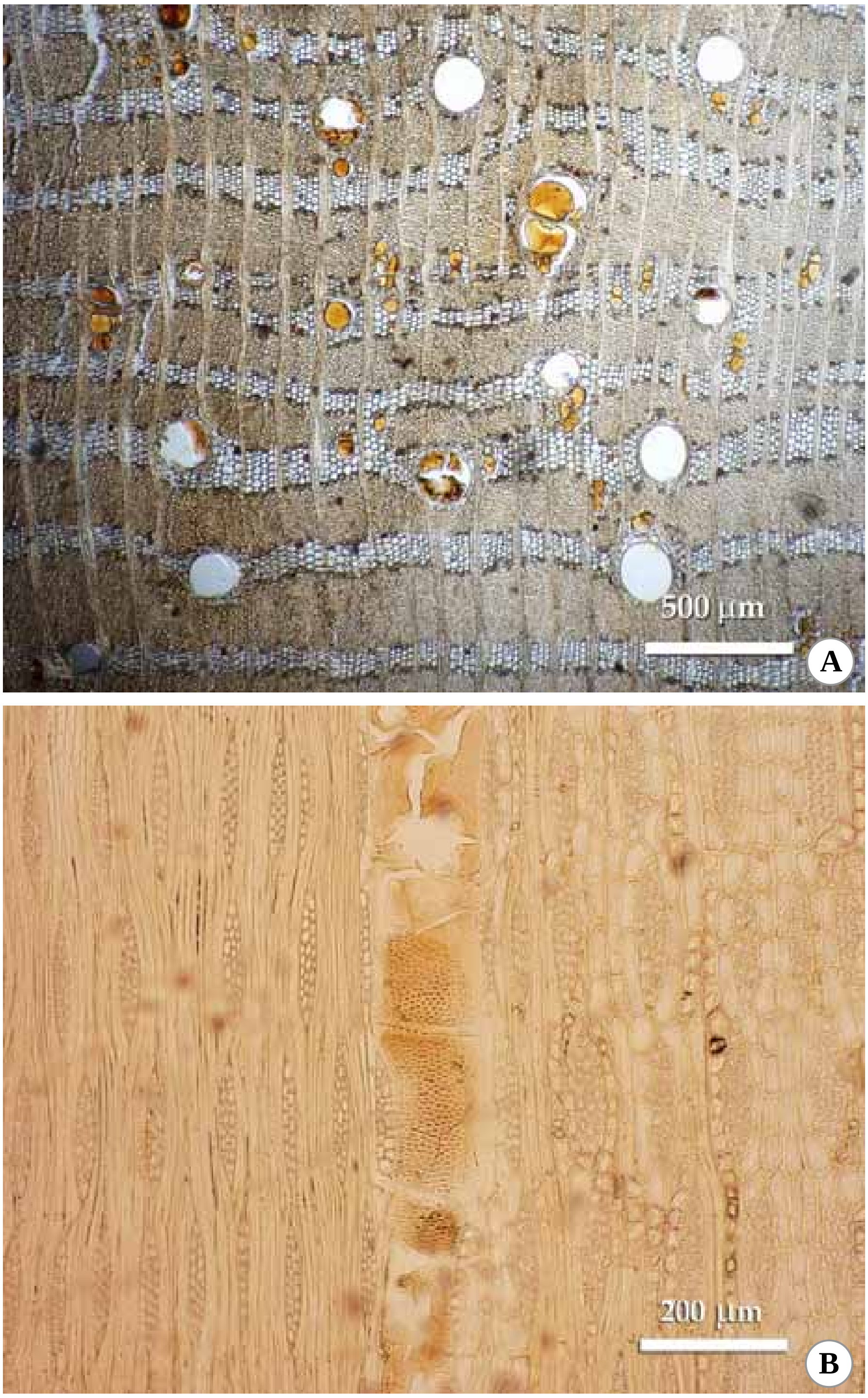


Figure 4.50 Thin sections of modern wood, *Millettia leucantha*. **A.** (Tv) (slide no. FRI636) Banded parenchyma alternate with fiber bands. **B.** (Tg) (slide no. FRI610) 1 - 3 seriate rays in storied arrangement. Non-septate fibers, alternate intervessel pits, and prismatic crystals in chambered axial parenchyma cells.

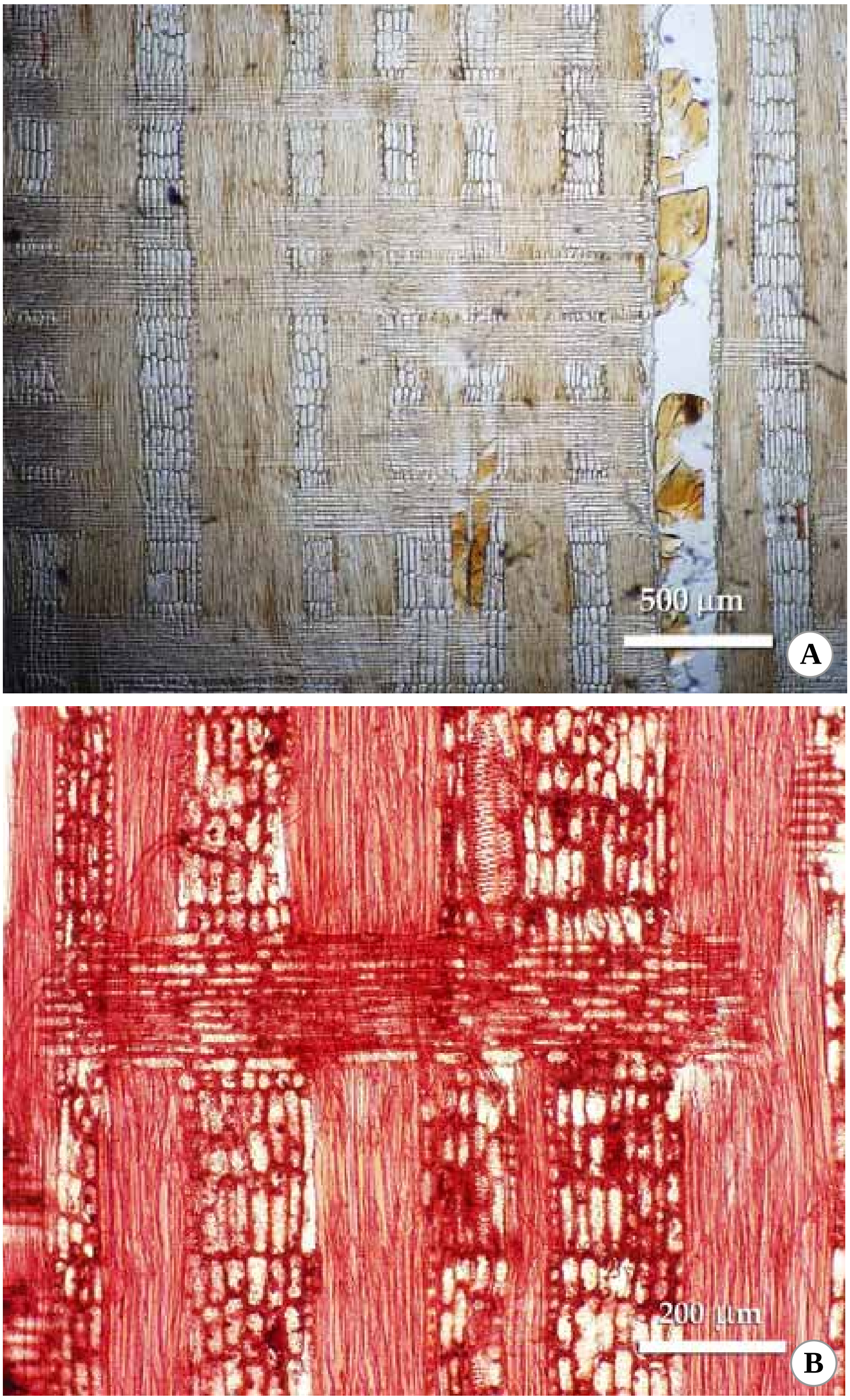


Figure 4.51 Thin sections of modern wood, *Millettia leucantha*. **A.** (R) (slide no. FRI636) Homogeneous ray tissues. **B.** Homocellular ray cells are all procumbent.

Family Leguminosae Juss.

Genus *Millettia* Wight & Arnott

Species cf. *Millettia* sp. 2

Locality: Institute of Petrified Wood and Mineral Resources, grid no. I2

Specimen number: I2-1 (Figs. 4.52 - 4.53)

Preservation: The preservation of this specimen is not good; fibers are very poorly preserved, rays rarely preserved, parenchyma preserved in few areas; vessels and their walls are fairly well preserved. Evidence of compression present in some features of wood.

Description

Growth ring boundaries absent. Wood diffuse-porous.

Vessels 5 - 6/mm^2. Vessels small to medium sized, t.d. 70 - 150 (180) µm (mean 113.8 µm), r.d. (110) 150 - 270 µm (mean 195.9 µm). Most vessels solitary, some in radial multiples of 2 - 4 (rarely 5); solitary vessel outline oval or some compressed into elliptic shape. Vessel element length 100 - 310 µm (mean 198.85 µm). Simple perforation plates. Hexagonal shaped crystals present throughout vessels. Brownish and black deposits often appearing to collect at the end of vessel elements.

Intervessel pits alternate, but preservation not good enough for measurement; vessel ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cells.

Axial parenchyma bands 3 - 8 cells wide. Vessels often present in between banded parenchyma rather than among bands of fibers.

Rays poorly preserved, but visible in some areas. Rays storied, estimated to be (1) 2 - 3 seriate. Ray tangential height 190 - 365 (400 - 550) µm (average 316.33 µm) and width (12) 14.4 - 24 (26.4) µm. Procumbent ray cells are present; however, the exact type of ray cellular composition cannot be determined from radial section. The rays are homocellular and seemingly homogeneous adjudged from tangential section.

Fibers very thick-walled, non-septate.

Affinities

The main characters of this specimen are small to medium vessels. Most solitary, some in radial multiples of 2 - 4 (rarely 5), simple perforation plates, alternate intervessel pits, and vessel-ray pits with distinct borders. Additionally axial parenchyma is banded 3-8 cells wide, rays are estimately (1) 2 - 3 seriate, and fibers are very thick-walled and non-septate.

These features show close resemblance with modern wood of the family Leguminosae and are typical characters of Caesalpinioideae, especially the genus *Cynometra* (Fig. 4.41 - 4.42), and Papilionoideae, genus *Millettia* (Fig. 4.50 - 4.51)

Many fossil woods, which show close resemblance to these two genera from India, Burma, and Thailand, have been studied for anatomical characteristics. They were named *Cynometroxylon* and *Millettioxylon*, respectively (Prakash, 1979).

However, rays in wood of *Cynometra* and fossil wood of *Cynometroxylon* are mostly non-storied ray or sometimes show a slight tendency to storied arrangement. These rays are heterocellular consisting of procumbent body ray cells with 1 - 2 rows of upright and/or square marginal cells. Most xylem rays in wood of the genus *Millettia* are storied and homogeneous, which is closest in resemblance to modern wood of *Millettia.*

The fossil wood *Millettioxylon* was proposed in 1967 by Awasthi for a fossil resembling *Millettia* from southern India. From studying modern wood of

Leguminosae to identify the fossil wood from the Lower Siwalik beds of Himachal Pradesh in India, Prakash (1975) suggested that woods of *Millettia* can be seperated into 3 anatomical groups; 1. *Millettioxylon*, which includes *Millettia prainii*, *M. pendula*, and *Pongamia glabra*. *Millettioxylon* has moderately broad banded parenchyma, storied in vessels, parenchyma, and rays, ~ 1 - 4 seriate (mostly 2 - 3).

2. *Eumilletioxylon*, includes other species of *Millettia* such as *M. auriculata, M. atite, M. griffoniana, M. laurentii, M. caffra, M. racemosa, M. thompsonii, M. macrostachya,* and *M. atropurpurea,* because of the wood having very broad banded parenchyma, wider xylem rays (1 - 8 seriate), and thick to very thick-walled fibers.

3. *Dialiumoxylon* consists of two species of *Millettia* (*M. pulchra* and *M. drastica*), 11 species of *Dialium*, 3 species of *Swartzia*, and *Craibia affinis*. The later group all predominantly has narrow banded parenchyma, thick-walled fibers, and a storied structure of vessels, parenchyma, and rays.

Benyasuta (2003) described fossil wood of *Millettia leucantha* Kurz from Nakhon Ratchasima, but it is different from the fossil wood specimen in the present study. The radial multiples of vessel pores in his specimen are 2 (rarely 3) and rays are non-storied, while in the I2-1 specimen the radial multiples of vessels vary from 2 - 4, rarely 5, and rays are storied. Thus this petrified wood is a different species from the fossil wood described by Benyasuta.

However, the preservation is not good enough for identifying the wood species and due to it showing features closest to those of *Millettia*, which include anatomical characters of *Millettia* spp. broader than those of *Millettioxylon*. I therefore place this specimen at the generic level as cf. *Millettia* sp.

Figure 4.52 Fossil wood of I2-1 in transverse section showing vessel distribution as diffuse-porous wood. Vessels solitary or some in radial multiples of 2 - 3. Banded parenchyma.

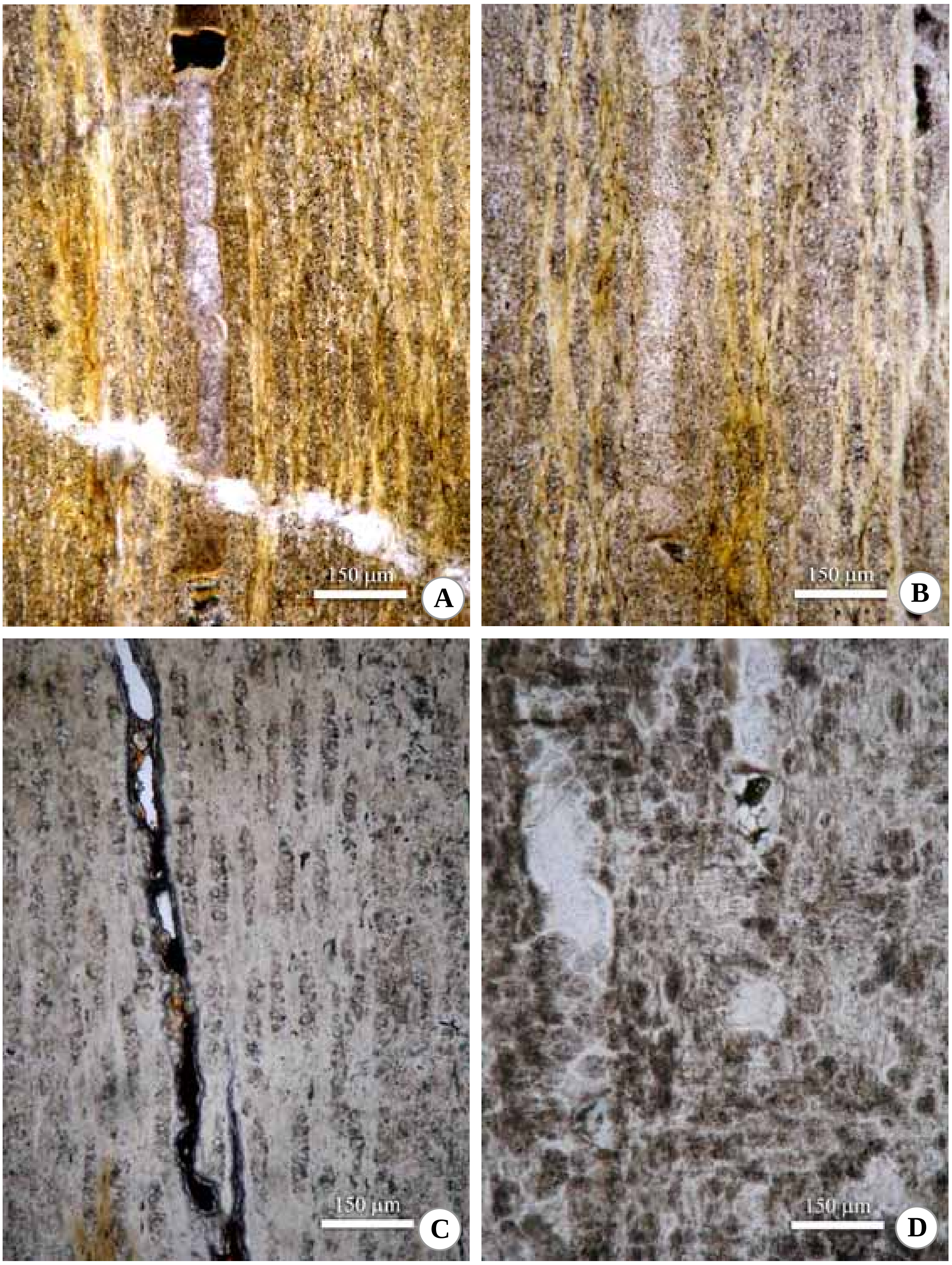


Figure 4.53 Fossil wood I2-1. **A - C.** (Tg.) Storied rays are present, rays approximately 2 - 3 seriate. **D.** (R) Rays poorly preserved; cannot determine exactly type of ray cellular composition; however, some procumbent ray cells are observed.

Family Leguminosae Juss.

Genus cf. *Cynometroxylon* Chowdhury & Ghosh, 1946

Species cf. *Cynometroxylon* sp.

Locality: Institute of Petrified Wood and Mineral Resources, grid no. M1

Specimen number: M1-1 (Figs. 4.54 - 4.57)

Preservation: The specimen is very well preserved, can be seen very clearly in all sections.

Description

Growth ring boundaries indistinct. Wood semi-ring porous.

Vessels 3 - 8/mm^2. Vessels usually medium and a few small sized, t.d. (60) 90 -170 µm (mean 126.7 µm), r.d. 90 - 240 (300 - 390) µm (mean 194.7 µm). Vessels mostly solitary and few in radial multiples of 2 - 3. Polygonal shapes and some deposits appearing in lumina of vessels. Some vessel elements with octagonal-rounded shapes. Vessel element length 170 - 540 µm (mean 321.33 µm). Simple perforation plates.

Intervessel pits alternate, shapes of alternate pits hexagonal and polygonal, small size, 4 - 5 µm in diameter. Vessel-ray pits seemingly with much reduce borders to apparently simple: pits rounded or angular.

Paratracheal **axial parenchyma** vasicentric. Banded parenchyma 3 - 7 cells in width.

Rays 1 - 2 seriate (very rarely 3 seriate) and (7 - 8) 13 - 32 (-38) cells high, cells procumbent, 260 - 540 (630 - 790) µm in tangential height (average 482.67µm) and (15 - 20) 25 - 35 (40 - 45) µm in width. Some terminal ray cells contacting other terminal ray cells and appearing as one long ray. Non-storied rays; cellular composition not clearly seen, but heterocellular, body ray cells procumbent with one row of upright and/or square marginal cells observed in some rays.

Fibers very thick-walled, non-storied, septate and non-septate fibers present in the same sample.

Affinities

The main characters of specimen no. M1-1 are small (few) to medium (usually) vessel, most solitary and few in radial multiples of 2 - 3, hexagonal and polygonal shape, small sized, and alternate intervessel pits, simple perforation plate, vasicentric and banded axial parenchyma. Rays are 1 - 2 seriate (very rarely 3 seriate), non-storied, heterocellular. Very thick-walled, septate and non-septate fibers are present.

These features show the similarities with the modern wood of the family Leguminosae; *Cynometra* (Figs. 4.41 - 4.42) (Caesalpinioideae) and *Millettia* (Figs. 4.50 - 4.51) (Papilionoideae). However, rays in this specimen are non-storied and heterocellular, which is closer in resemblance to modern wood of *Cynometra* than *Millettia*. In my opinion, it should be placed as a form genus cf. *Cynometroxylon* sp. (See the differences between wood of *Millettia* and *Cynometra* on page 103 and more information about modern wood and fossil wood of *Cynometra* on pages 104 -105.)

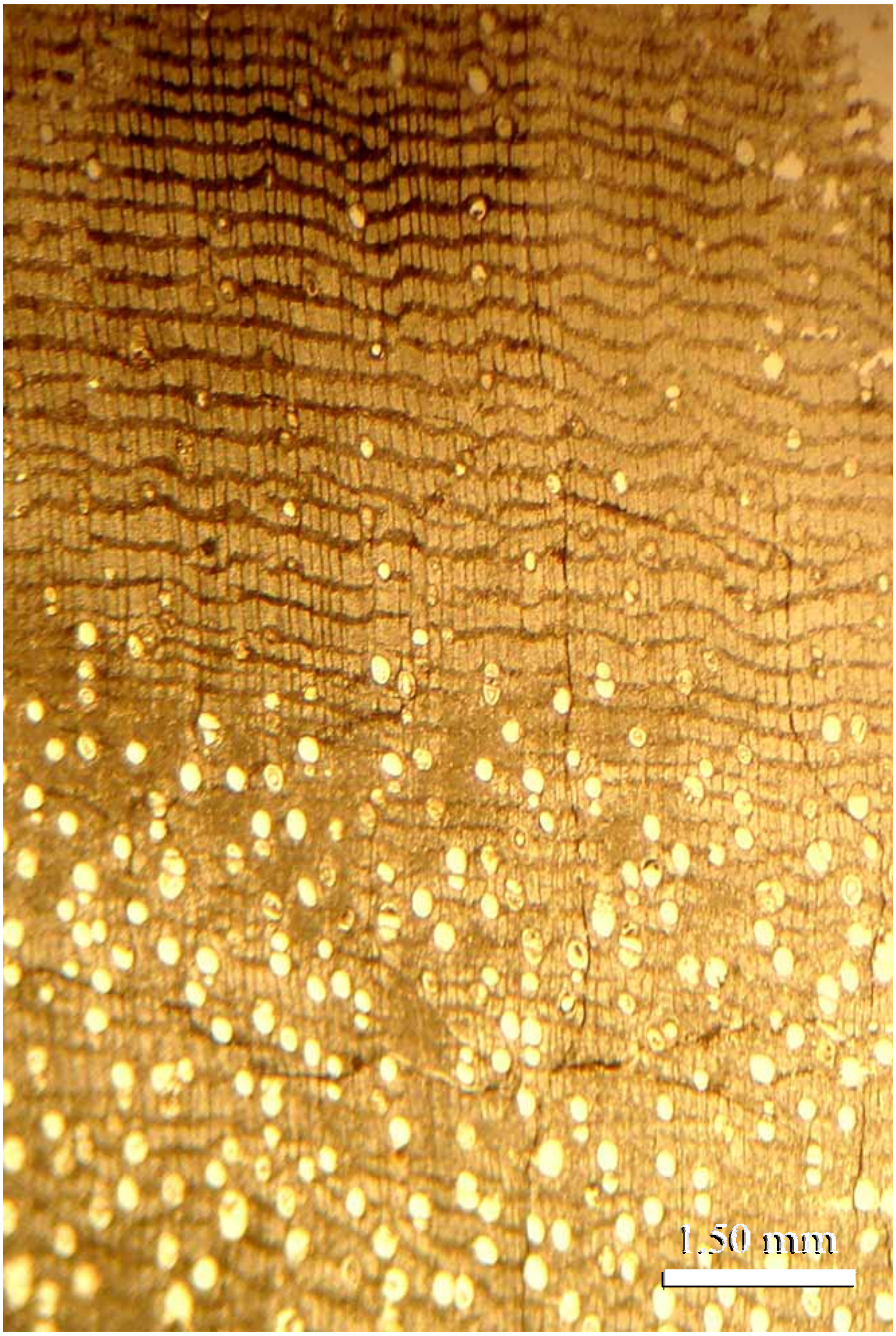


Figure 4.54 Thin section of fossil wood M1-1 in transverse section, showing the distribution of vessels and porosity, semi-ring porous wood, and banded parenchyma.

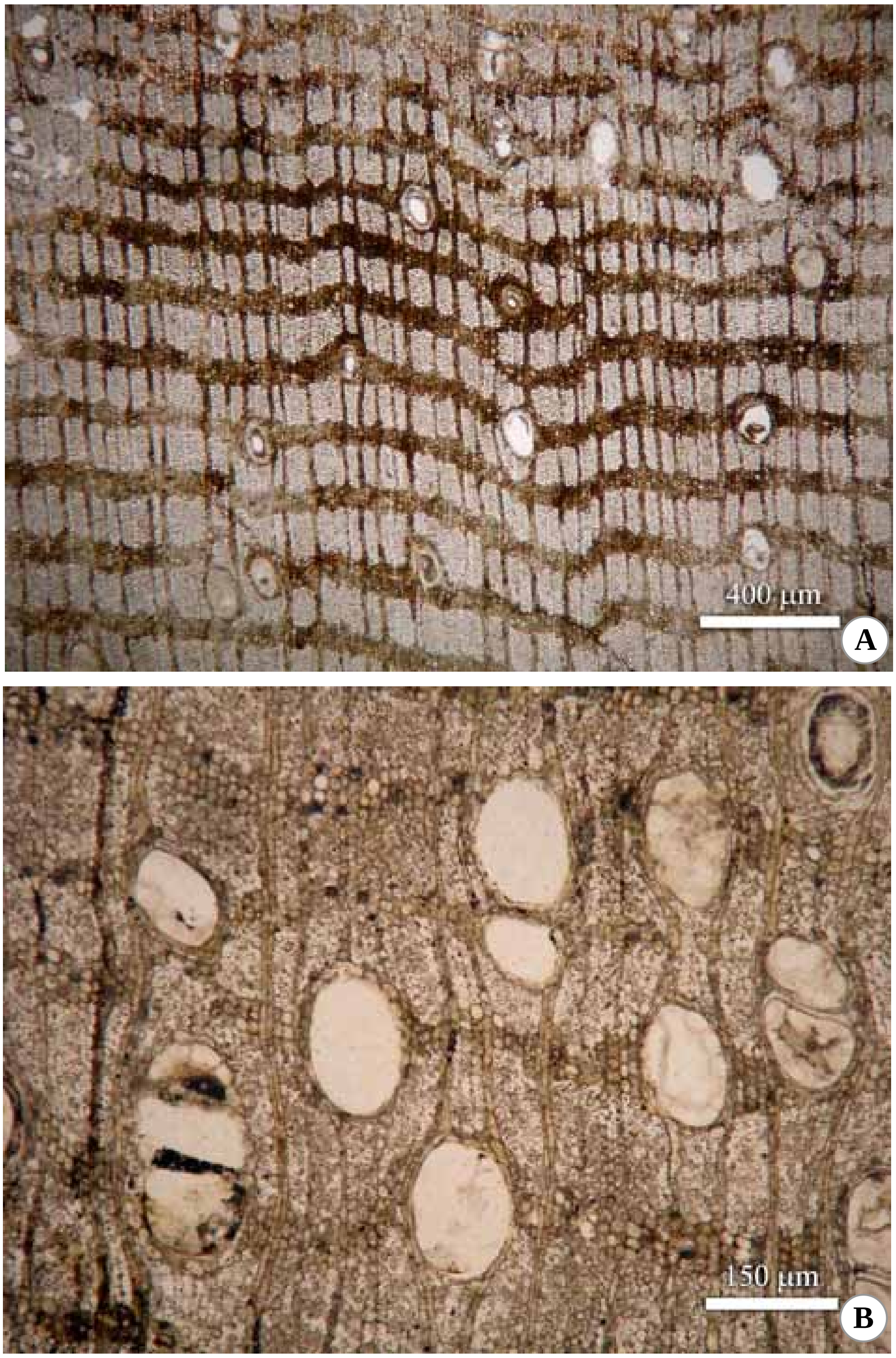


Figure 4.55 Thin section of fossil wood M1-1. **A.** Solitary vessels are majority. Axial parenchyma bands alternating with fiber bands. Vessels occasionally in radial multiples of 2 - 3.

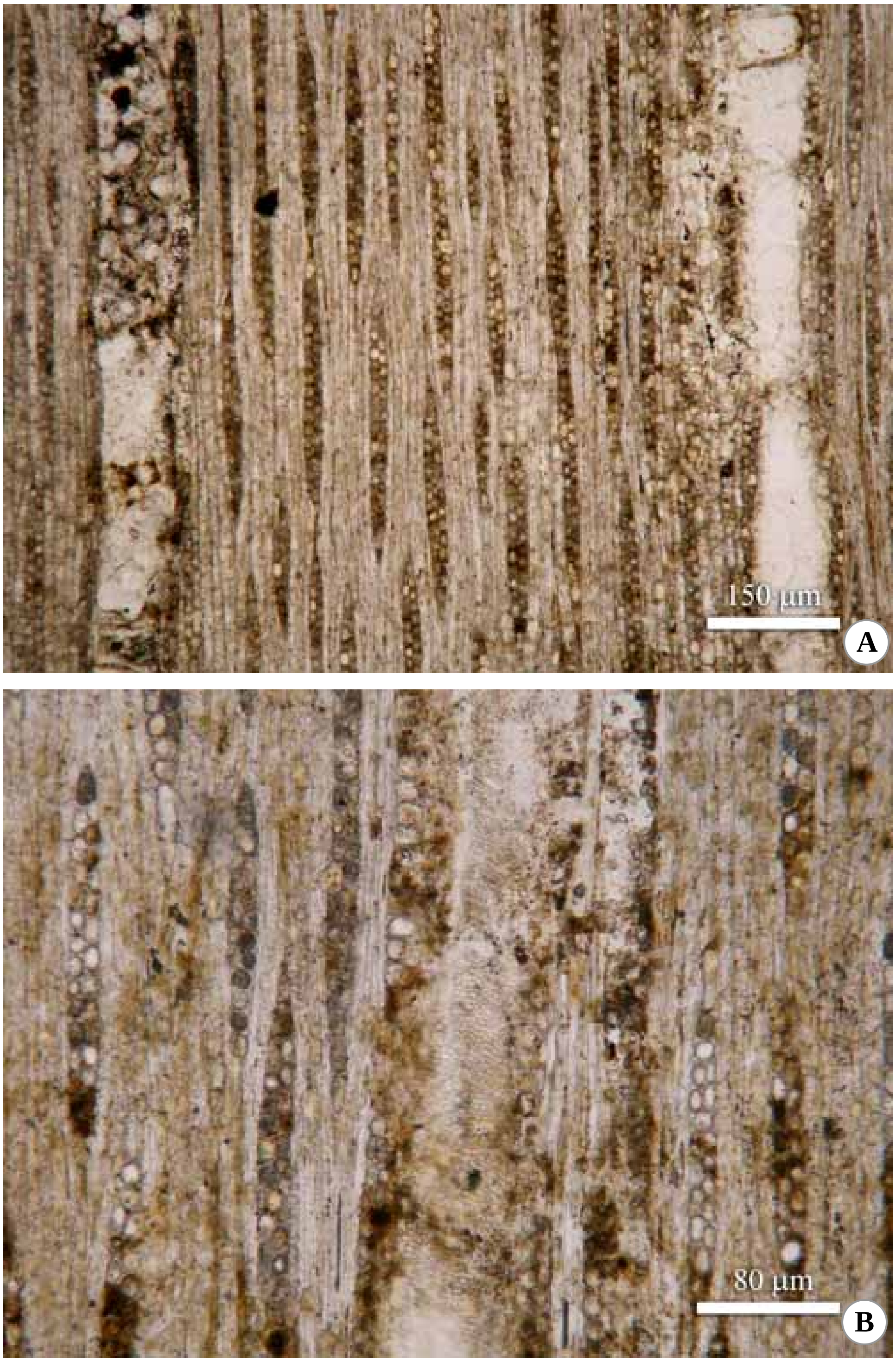


Figure 4.56 Thin section of fossil wood M1-1 in tangential section. **A.** Exclusively biseriate and non-storied rays and non-septate fibers. **B.** Alternate vessel pitting.

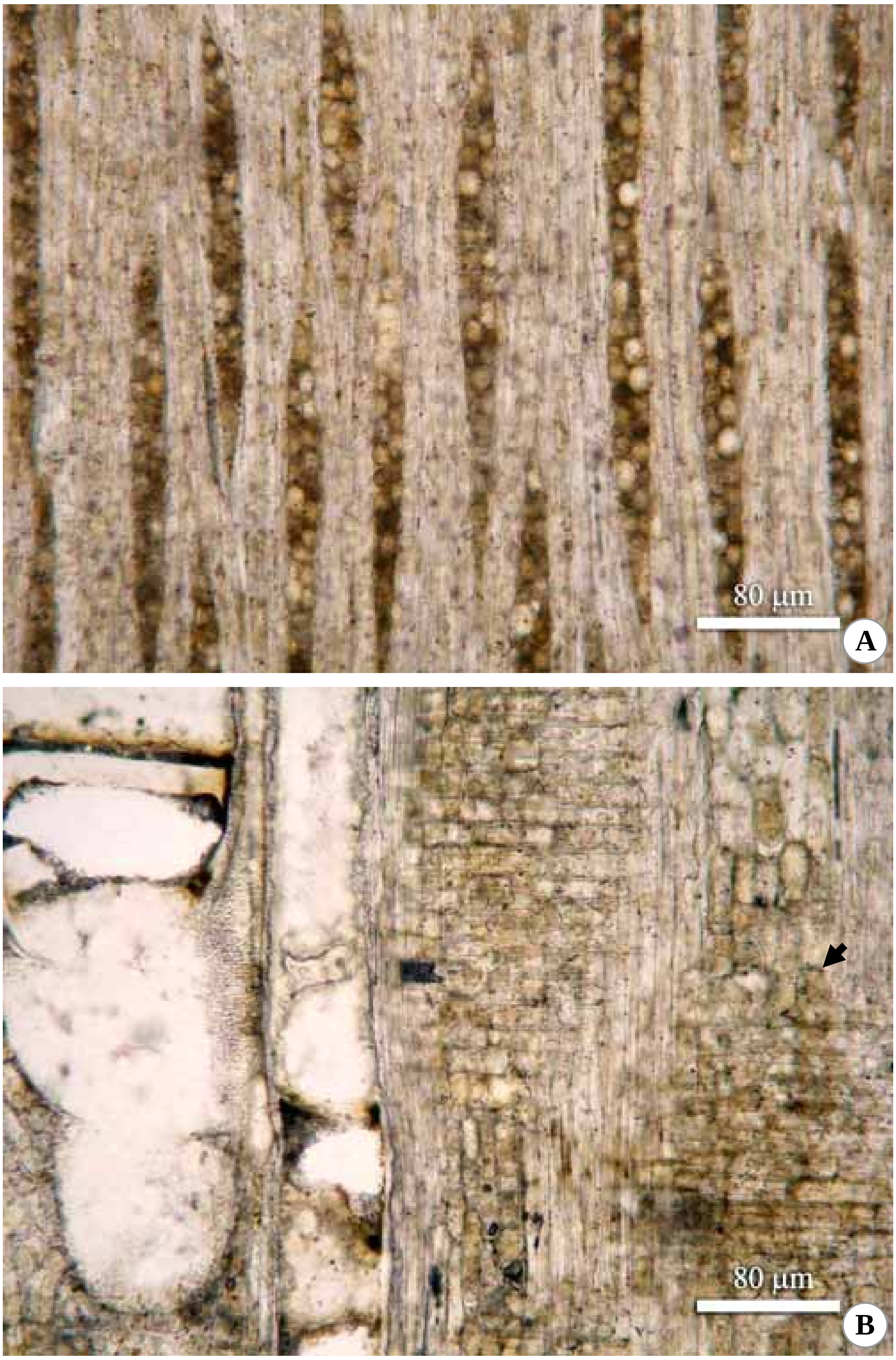


Figure 4.57 Thin section of fossil wood M1-1. **A.** (Tg) Biseriate and non-storied rays and non-septate fibers. **B.** (R) Body ray cells procumbent with one row of square marginal cells (arrows).

Family Leguminosae Juss.

Genus cf. *Cynometroxylon*

Species cf. *Cynometroxylon* sp.

Locality: Institute of Petrified Wood and Mineral Resources, grid no. O7

Specimen number: O7 (Figs. 4.58 - 4.60)

Preservation: The specimen is very well preserved in all sections. No compression characters.

Description

Growth ring boundaries indistinct. Wood diffuse-porous.

Vessels 3-6 /mm^2. Vessels small to medium sized, t.d. (40 - 50) 70 - 150 µm (mean 89.3 µm), r.d. 90 - 200 µm (mean 153 µm). Vessels quite often solitary, some in radial multiples of 2 or occasionally 3. Solitary vessel outline ovate. Vessel element length 100 - 310 µm (mean 198.85 µm). Perforation plates simple.

Intervessel pits alternate, vestured, and minute to small, 3.50 - 5 µm in diameter. Deposits often appearing collected at the end of vessel elements in longitudinal sections.

Axial parenchyma with differing pattern in two zones: one with paratracheal axial parenchyma aliform or confluent and some diffuse without bands. Another zone with axial parenchyma bands 3 - 6 cells wide, occasionally parenchyma bands bifurcating and then joining with other bands on the upper and lower sides. 3 - 4 cells per parenchyma strand rarely present.

Rays (1) 2 - 3 (mostly 3) seriate and (7 - 9) 14 - 25 (45) cells high, tangential height 135 - 475 (520, 710, 850) µm (average 322.92 µm) and width (20 - 35) 40 - 55 µm width, irregularly storied or occasionally non-storied. Sometimes terminal ray cells contact with the terminal cell of another ray and seemingly forming one long ray if observed using a 40X or 100 X magnifications. Sometimes 2 - 3 rays touching each other and likely becoming a very long ray. Rays heterocellular, body ray cells procumbent with one row of upright and/or square marginal cells.

Fibers non-septate, thick to very thick - walled.

Affinities

The main characters of specimen no. O7 are small to medium sized vessels, vessels often solitary, some in radial multiples of 2 - 3, simple perforation plates, intervessel pits alternate, vestured, and minute to small, two zones of axial parenchyma, aliform to confluent and banded 3-6 cells wide, rays (1) 2 - 3 (mostly 3), irregularly storied and occasionally non-storied, heterocellular, body ray cells procumbent with one row of upright and/or square marginal cells, fibers non-septate and thick to very thick-walled.

These features show close resemblance with modern wood of the family Leguminosae. The pattern of axial parenchyma in two zones is very typical in modern wood of the genus *Pterocarpus* (Papilionoideae) in transverse section. However, this fossil is rather different from *Pterocarpus* in longitudinal section, in that rays of *Pterocarpus* are exclusively uniseriate and are non-storied**,** whereas rays in this specimen are wider (1) 2 - 3 seriate. One specimen shares some characters with *Cynometra inaequiflolia* (Richter and Dallwitz, 2000 - onwards). Although fossil wood close to *C. inaequiflolia* from northeast Thailand was assigned to *Cynometroxylon parainaequiflolium* by Prakash (1979) no distinct alternatio of two parenchyma zones are mentioned. In addition, rays in this fossil, (1) 2 - 3 (mostly 3) seriate, are wider than in the rays of *C. parainaequiflolium* that are 1 - 2 (mostly 2) seriate. Other characters such as vessel size, vessel element length, intervessel pits, fibers, and heterocellular rays agree with those of *C. parainaequiflolium* and are not so different from the characters of other fossil wood species of *Cynometroxylon*. Therefore, in my opinion this fossil should be placed as cf. *Cynometroxylon* sp.

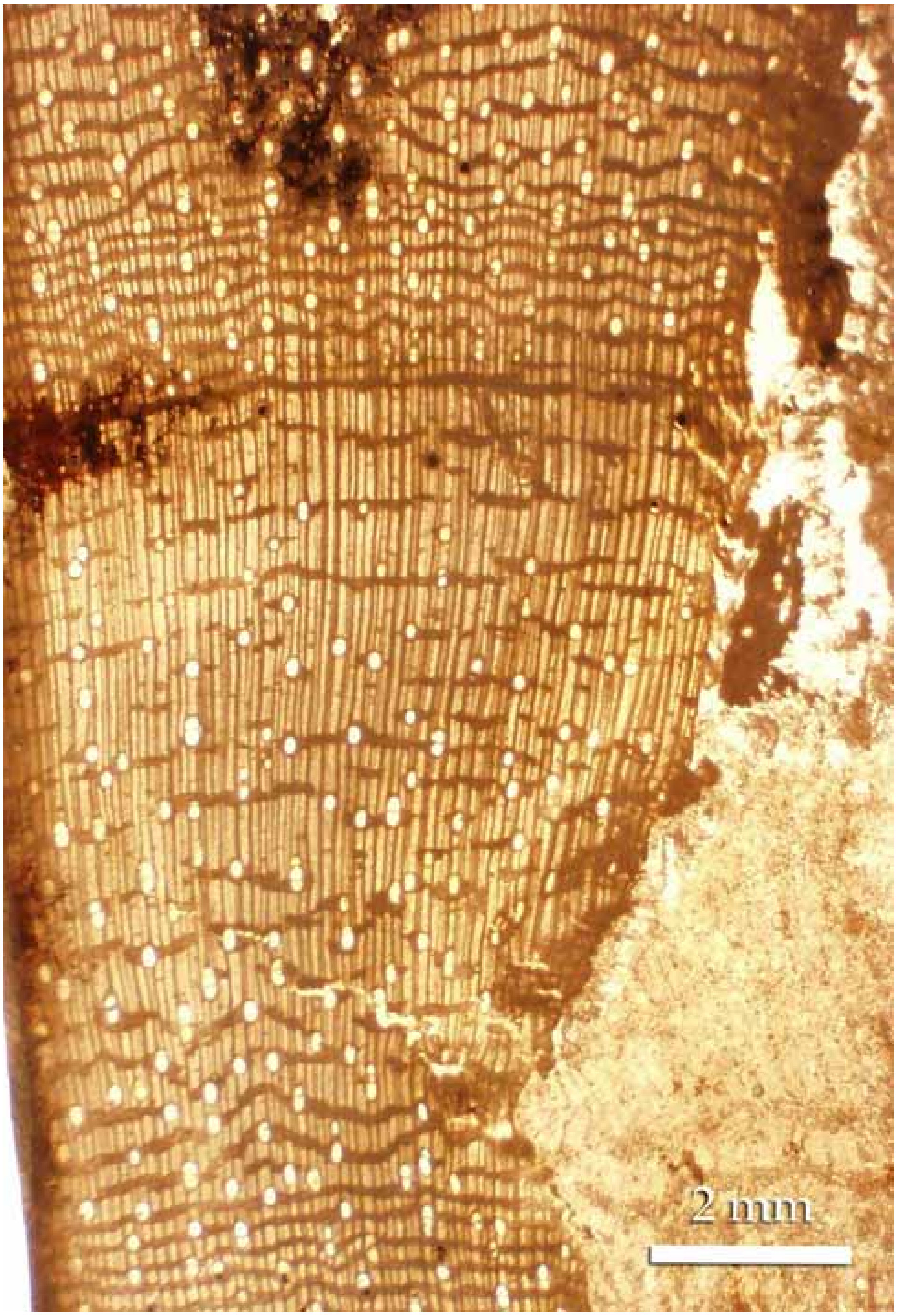


Figure 4.58 Thin section of O7 in transverse section showing diverse pattern of axial parenchyma (bands, aliform, confluent, and diffuse) present in the same specimen. Vessels solitary and in radial multiples of 2 (rarely 3).

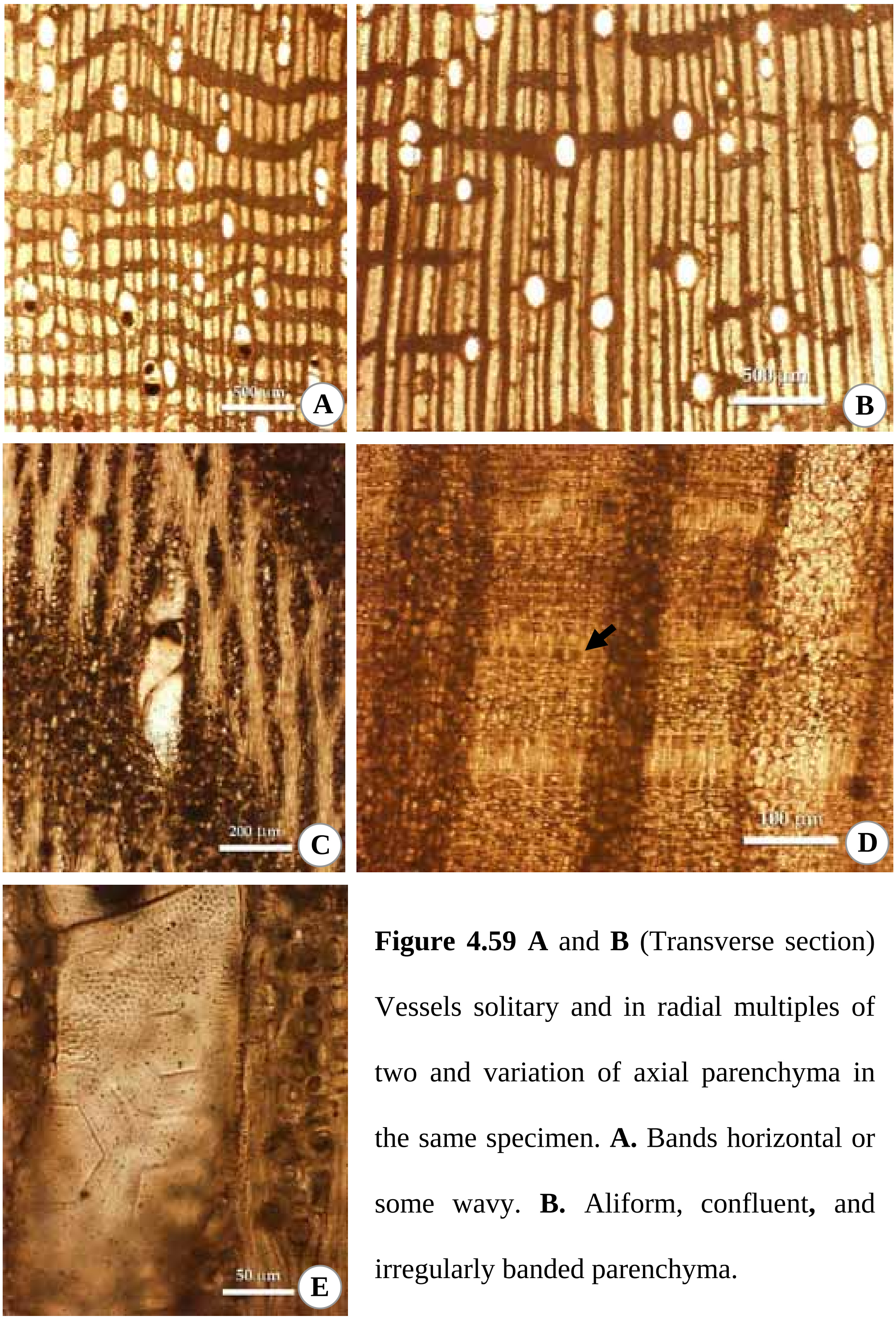


Figure 4.59 A and **B** (Transverse section) Vessels solitary and in radial multiples of two and variation of axial parenchyma in the same specimen. **A.** Bands horizontal or some wavy. **B.** Aliform, confluent**,** and irregularly banded parenchyma.

C. (Tg) Irregularly storied or occasionally non-storied, 2 - 3 seriate rays; non-septate fibers. **D.** (R) Body ray cells procumbent with 1 row of square/upright marginal cells (arrow). **E.** (Tg) Alternate intervessel pits.

Figure 4.60 Thin section of O7 in radial section showing simple perforation plates of vessel elements (arrows).

Family Lecythidaceae Poiteau

Genus *Careya* Roxb.

Species *Careya* sp. 1

Locality: Institute of Petrified Wood and Mineral Resources, grid no. A4-4

This specimen is a small fragment, probably *ex situ*, mixed with gravels on the surface. The whole specimen was picked up for making thin sections.

Specimen Number: A4-4 (Figs.4.61 - 4.62)

Preservation: The preservation is moderate; cellular details are not very clearly seen, but can be described in some areas.

Description

Growth ring boundary indistinct. Wood diffuse-porous.

Vessels 5 - 6 /mm^2. Vessels small to medium sized, t.d. (60) 70 - 140 µm (mean 102.8 µm), r.d. 70 - 190 (200) µm (mean 128.4 µm). Vessels solitary as well as vessels in radial multiples of 2, sometimes 3, very rarely 6. Solitary vessel outline round to oval (mostly oval), but some compressed and distorted in shape. Vessel element length 300 - 500 (550) µm (mean 377.2 µm). In longitudinal view, many layers of brownish - black deposits overlapping each other like fans or clouds in the middle of vessel lumina, probably tyloses that were partially or completely blocking the vessel lumina (Fig. 4.61C).

In cross section, black and yellowish brown deposits (probably tyloses?) appearing to completely fill many vessel lumina. Black deposits at the ends of vessel elements. Hexagonal shapes appearing in some vessels. Simple perforation plate.

Intervessel pits alternate, vestured, minute sized, 2 - 3 µm in diameter. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cells.

Apotracheal **axial parenchyma** diffuse in aggregates. Axial parenchyma in marginal or in seemingly marginal bands, parenchyma cells $\geq$ 8 cells per parenchyma strand, appearing throughout the longitudinal sections, especially close to vessels.

Rays 1 - 3 seriate, non-storied, tangential height 270 - 880 µm (average 411.5 µm) and width (15 - 20) 25 - 40 (50) µm. Body ray cells procumbent with 1 - 2 rows of upright or square marginal cells.

Fibers thick to very thick-walled and non-septate.

Affinities

The main characters of this specimen are as follows: vessels small to medium size, axial parenchyma diffuse in aggregates, axial parenchyma in marginal or in seemingly marginal bands, intervessel pits alternate, simple perforation plate, rays 1 - 3 seriate and non-storied, heterogeneous ray cells, and non-septate fibers. These features show similarities with wood of the families Apocynaceae, Dipterocarpaceae, Lecythidaceae, and Sapotaceae.

However, most wood of Dipterocarpaceae has intercellular canals and is very variable in ray height, often > 1 mm, and sometimes up to 6 mm (IAWA, 1989, Beyasuta, 2003). Helical thickenings are present in wood of Apocynaceae (Carlquist, 2001), and in most wood of Sapotaceae vessels in radial multiples is rather predominant. These features do not appear in this fossil specimen.

In the family Lecythidaceae, *Barringtonia*, and *Careya* have some features similar to those of this fossil specimen, e.g., having axial parenchyma diffuse in aggregates. However, axial parenchyma sheaths around vessels of *Barringtonia* are broader and rays are thicker than in the fossil. In some species, aliform to confluent axial parenchyma is always present and xylem rays are up to 4,000 - 5,300 µm high and (1 - 2) 3 - 7 (10) seriate (Benyasuta, 2003; Prakash and Tripathi, 1972; Metcalfe and Chalk, 1957, Lens *et al.,* 2007; Ogata *et al.*, 2008).

Fossil wood specimens resembling *Barringtonia* and *Careya* were studied and placed in the form genera *Barringtonioxylon* Shallom, 1960, and *Careyoxylon* Awasthi, 1970, respectively. Species of *Careyoxylon* were studied and given names such as *Careyoxylon kuchilense* and *C. pondicherriensis* (Prakash and Tripathi, 1972).

The wood structure of *C. kuchilense* resembles that of the modern species *Careya arborea*. However, the fossil wood in this study is different from those fossil species in the width and height (in number of cells) and in intervessel pit size, minute in this specimen but small to medium in *C. kuchilense.*

In Thailand, Prakash (1979) reported fossil wood of the Lecythidaceae, *Dryoxylon siamensis*, from the northeast that shows nearest resemblance to *Careya arborea* Roxb. (syn. *C. sphaerica* Roxb.) (Fig. 4.63), proposing this fossil under the non-committal genus because of rays that differ in being homogeneous in the fossil wood. Benyasuta (2003) described fossil wood of *Careya sphaerica* from Nakhon Ratchasima. His specimen is different from this specimen in vessel and ray size. The fossil wood of his specimen has vessels that are medium to large (130 - 230 µm) while those of this specimen are small to medium. The rays of his specimen are 3 - 5 seriate and the highest rays reaches 1.4 mm, but the rays of this specimen are 1 - 3 seriate and the height is less than 1 mm.

The fossil wood has many similarities with modern wood of *Careya arborea*, but differs in characters of rays; *C. arborea* has rays ranging to > 1 mm or 150 - 1100 µm in height and about (1 - 2) 3 - 4 cells wide (Benyasuta, 2003; Inside Wood, 2004-

onwards) and size of intervessel pits is medium to large. However, rays of the fossil specimen are 1-3 seriate and shorter in tangential high; the intervessel pits are minute. As this fossil specimen is rather different from the other species, I identify this specimen at the genus level as *Careya* sp.

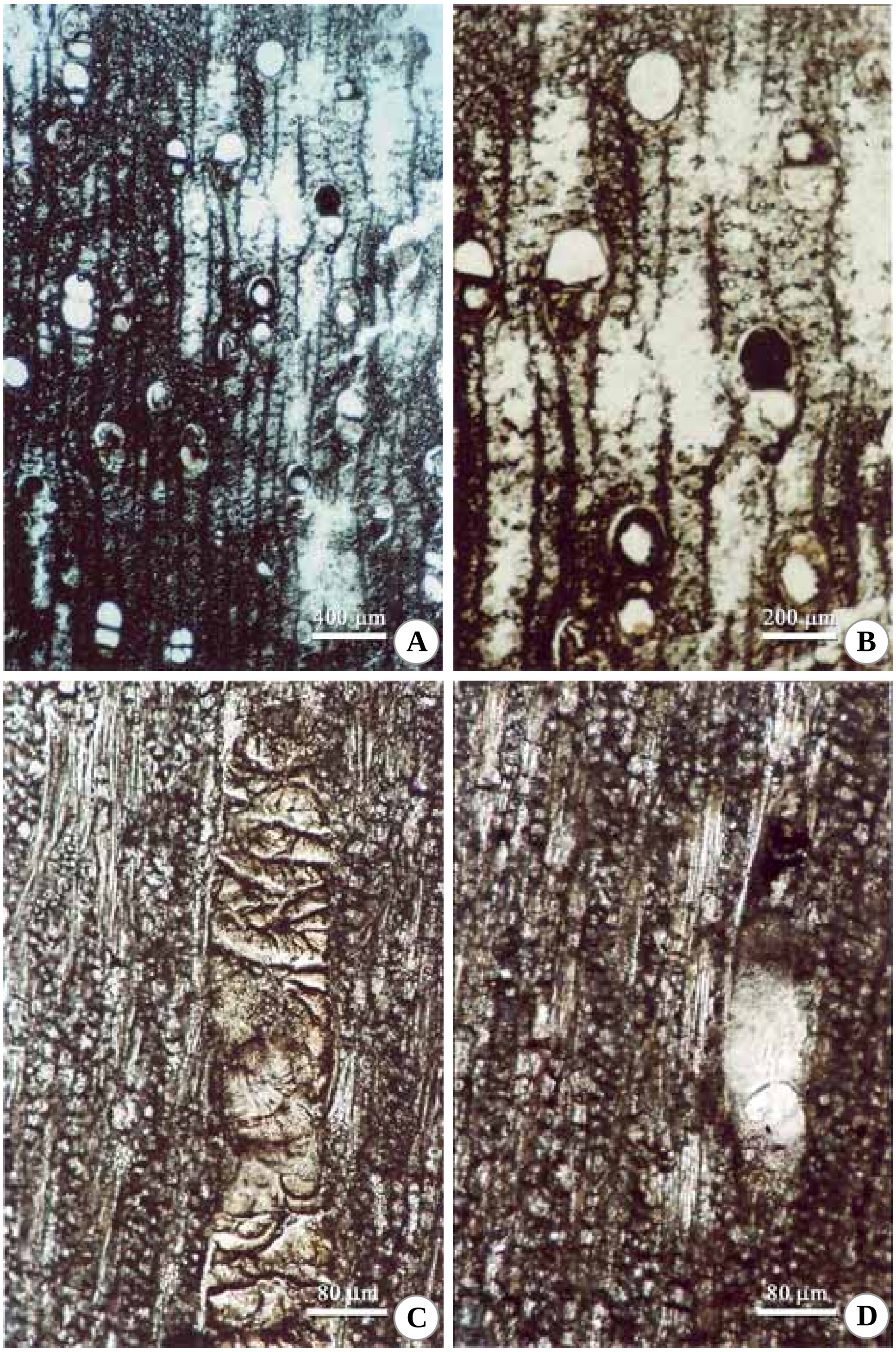


Figure 4.61 Thin section of A4-4. **A.** and **B.** (Tv) Vessels solitary and in radial multiples of 2 (rarely 3), and axial parenchyma diffuse in aggregates. **C.** (Tg) Non-storied, 1 - 3 seriate rays. Deposits completely blocking the vessel lumina. **D.** Simple perforation plate.

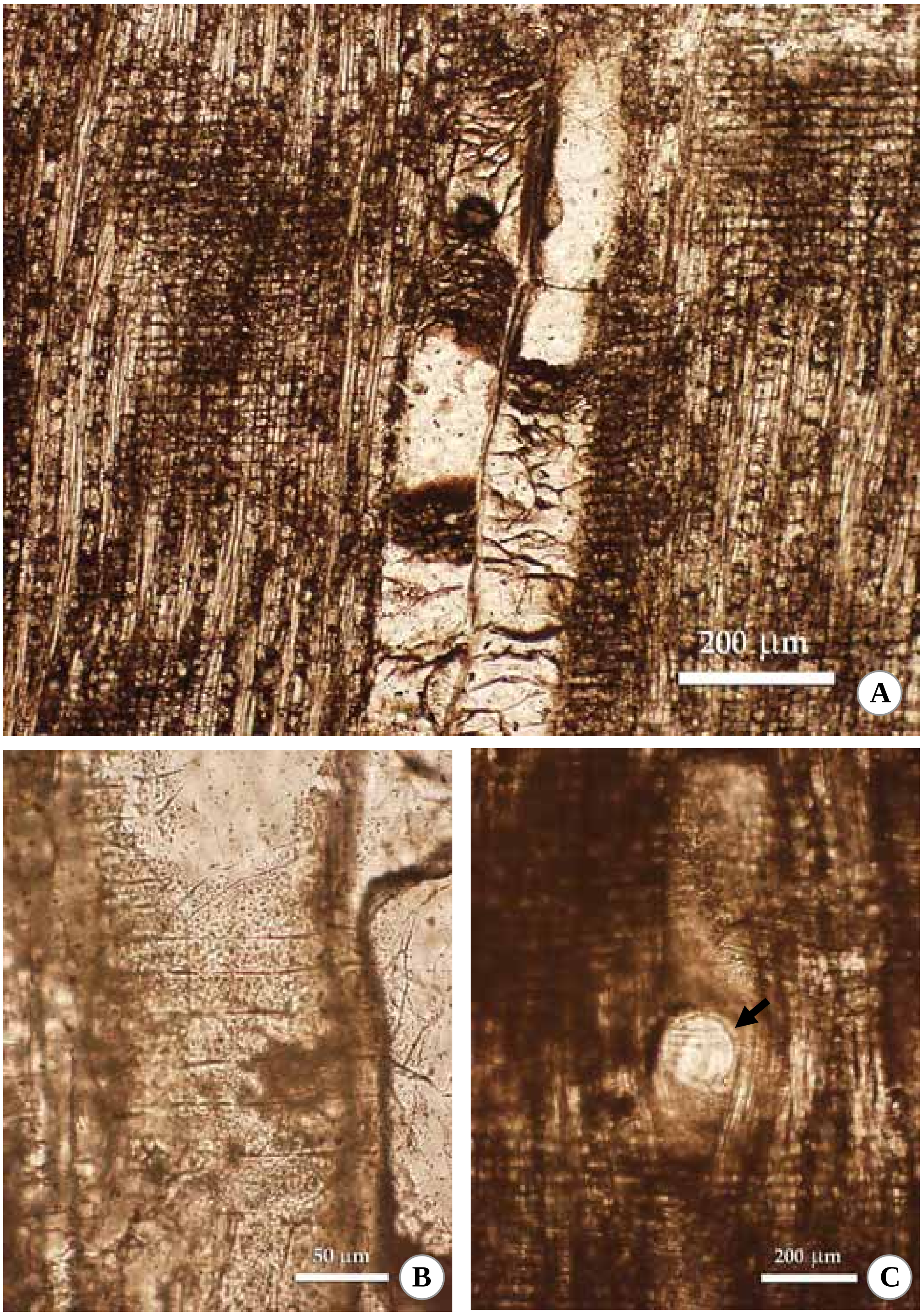


Figure 4.62 Thin section of A4-4 in radial section. **A.** Body ray cells procumbent. **B.** Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. **C.** Simple perforation plate.

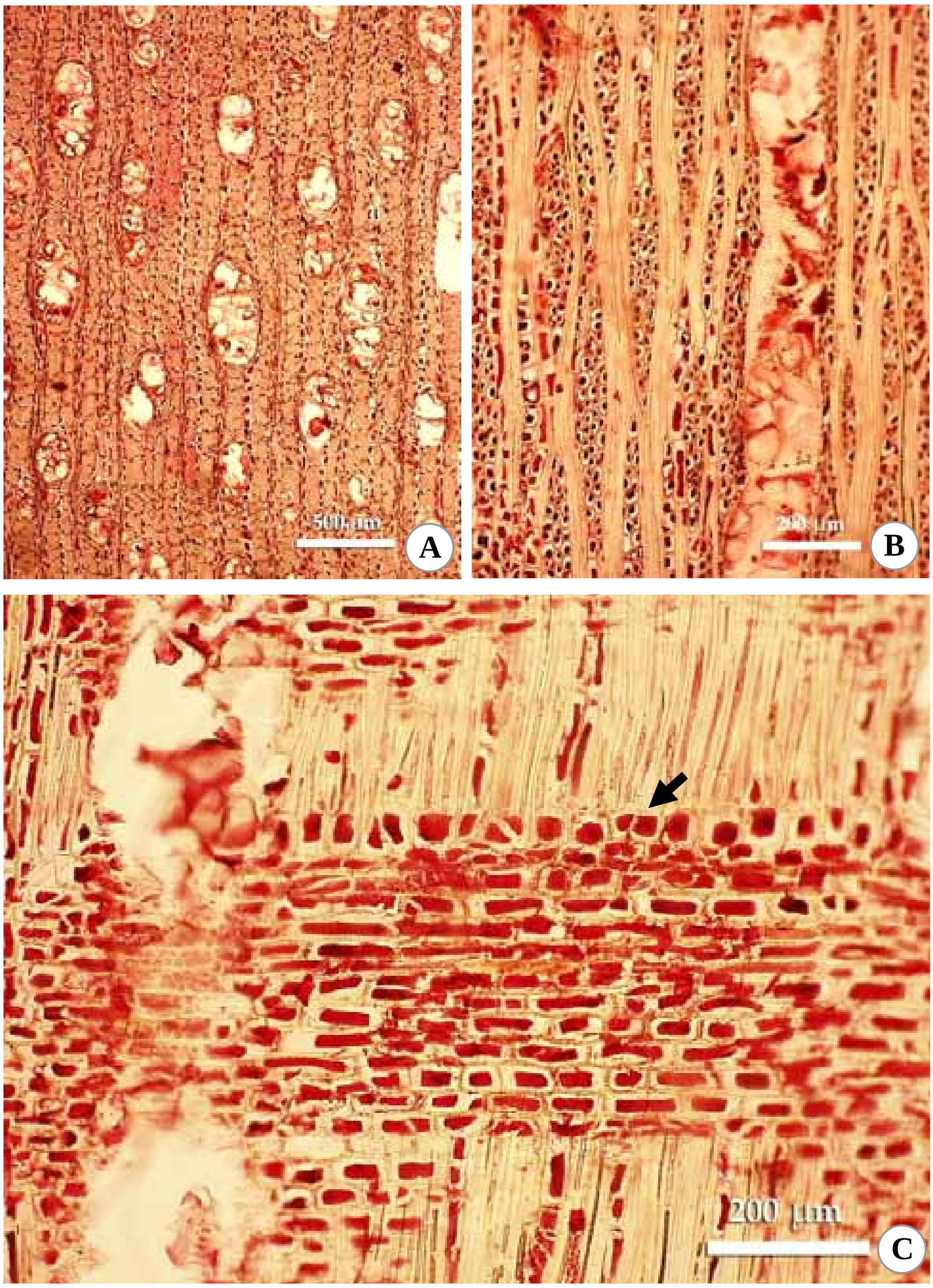


Figure 4.63 Thin section of modern wood, *Careya arborea*. **A.** (Tv) Vessels solitary and in radial multiples of 2 - 5, and axial parenchyma diffuse in aggregates. **B.** (Tg) Non-storied, 1 - 4 seriate rays, non-septate fibers, and alternate intervessel pits. **C.** Body ray cells procumbent with one row of upright and/or square marginal cells. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cells.

Family Lecythidaceae Poiteau

Genus *Careya* Roxb.

Species *Careya* sp. 2

Locality: Institute of Petrified Wood and Mineral Resources, grid no. I6

Specimen Number: I6 (Figs. 4.64 - 4.65)

Preservation: This specimen preservation is moderate in all three sections, but fibers are very poor preserved.

Growth ring boundaries indistinct or absent. Wood diffuse-porous.

Vessels 2 - 5 /mm^2. Vessels small to medium sized, t.d. (70 - 100) 130 - 250 µm (mean 167.9 µm), r.d. (70 - 130) 190 - 320 (380) µm (mean 233.4 µm). Vessels solitary and some in radial multiples of 2, very rarely 3. Solitary vessel outline elliptic. Vessel element length 135 - 420 µm (mean 275.83 µm). Intervessel pits alternate, medium sized about 7 - 10 µm, rather poor preserved, but can see in little area.

Many clear brownish hexagonal shape and large distort rounded-hexagonal shape present throughout vessels.

Paratracheal axial **parenchyma** vasicentric, apotracheal axial parenchyma diffuse-in-aggregates.

Rays (1) 2 seriate and non-storied, tangential height 150 - 475 (570, 900) µm (average 318.6 µm) and 25 - 45 µm width. Procumbent ray cells can be seen, but cannot determine type of ray cells, whether all ray cells procumbent or body ray cells procumbent with one of upright/square marginal cell, because the specimen is not well preserved.

Fiber not well preserved, unable to determine.

Affinities

The main characters of this specimen are vessels small to medium sized, vessels solitary and some in radial multiple of 2, very rarely 3. Intervessel pits alternate, medium size. Paratracheal axial parenchyma vasicentric and apotracheal parenchyma diffuse-in-aggregates. Rays (1) - 2 seriate and non-storied. These features show similarities with wood of the families Apocynaceae, Dipterocarpaceae, Lecythidaceae, and Sapotaceae.

However, almost wood of Dipterocarpaceae has intercellular canals and is very variable in ray height, often > 1 mm, and sometimes up to 6 mm (IAWA, 1989, Beyasuta, 2003). Helical thickenings are present in wood of Apocynaceae (Carlquist, 2001) and most wood of Sapotaceae rather in predominant in vessels radial multiples**.** These features do not typically appear in this fossil specimen.

In the family Lecythidaceae, *Barringtonia, Planchonia,* and *Careya* and have some similar affinities to this fossil specimen, but this fossil is closest resemblance to modern wood of *Careya* (Fig. 4.63) (see more details of difference between each genera from affinities of A4-4 pages 145 - 146).

This specimen is also different from fossil wood of *Careya sphaerica*, which described by Benyasuta in 2003 and also different from A4-4 in intervessel pit size. Therefore I assign this specimen as *Careya* sp. 2

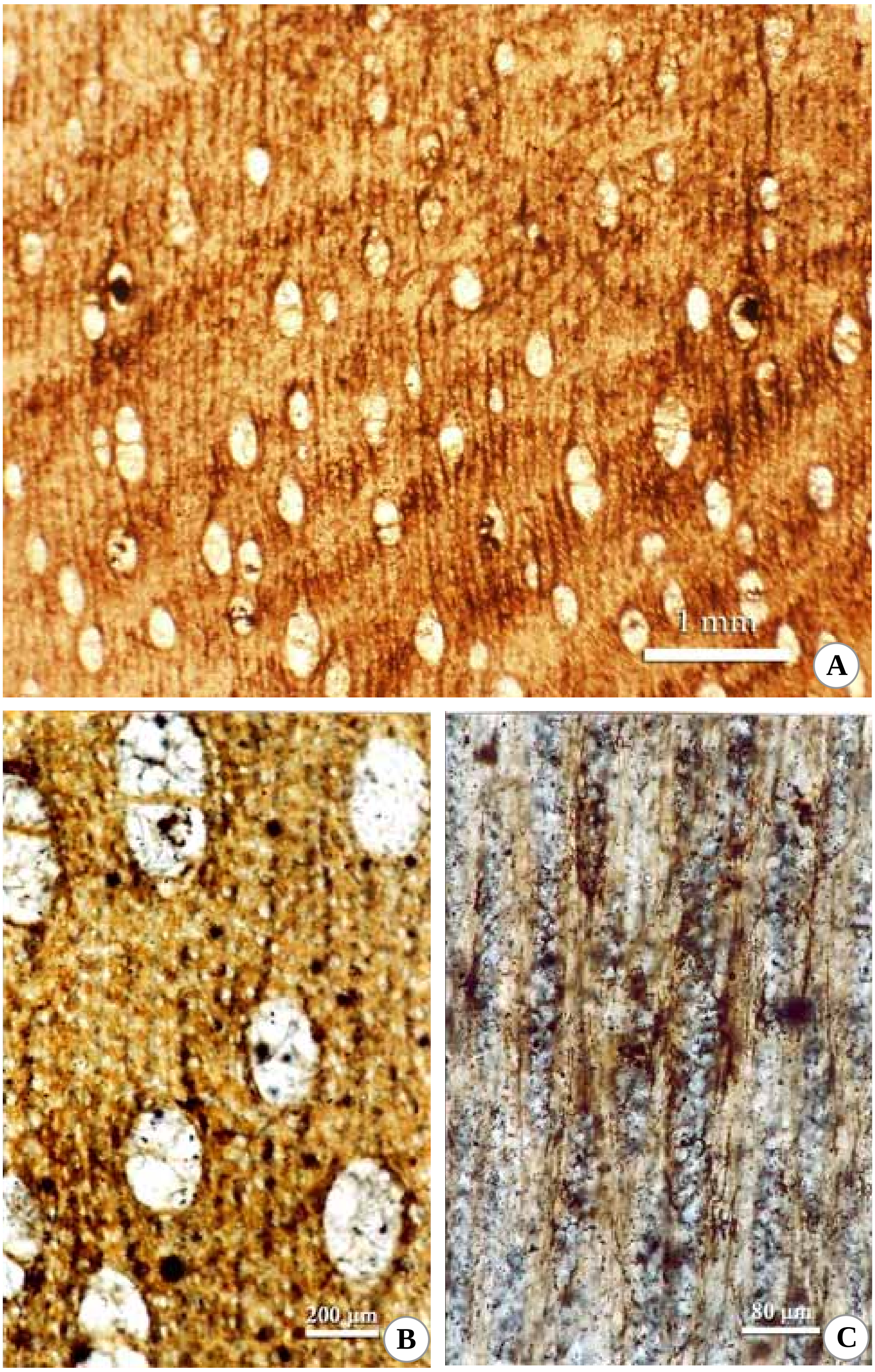


Figure 4.64 Thin section of I6. **A.** (Tv) Wood diffuse-porous, vessels solitary and in radial multiples of 2 (rarely 3) and **B.** (Tv) Axial parenchyma diffuse in aggregates **C.** (Tg) Non-storied, 1 - 2 seriate rays.

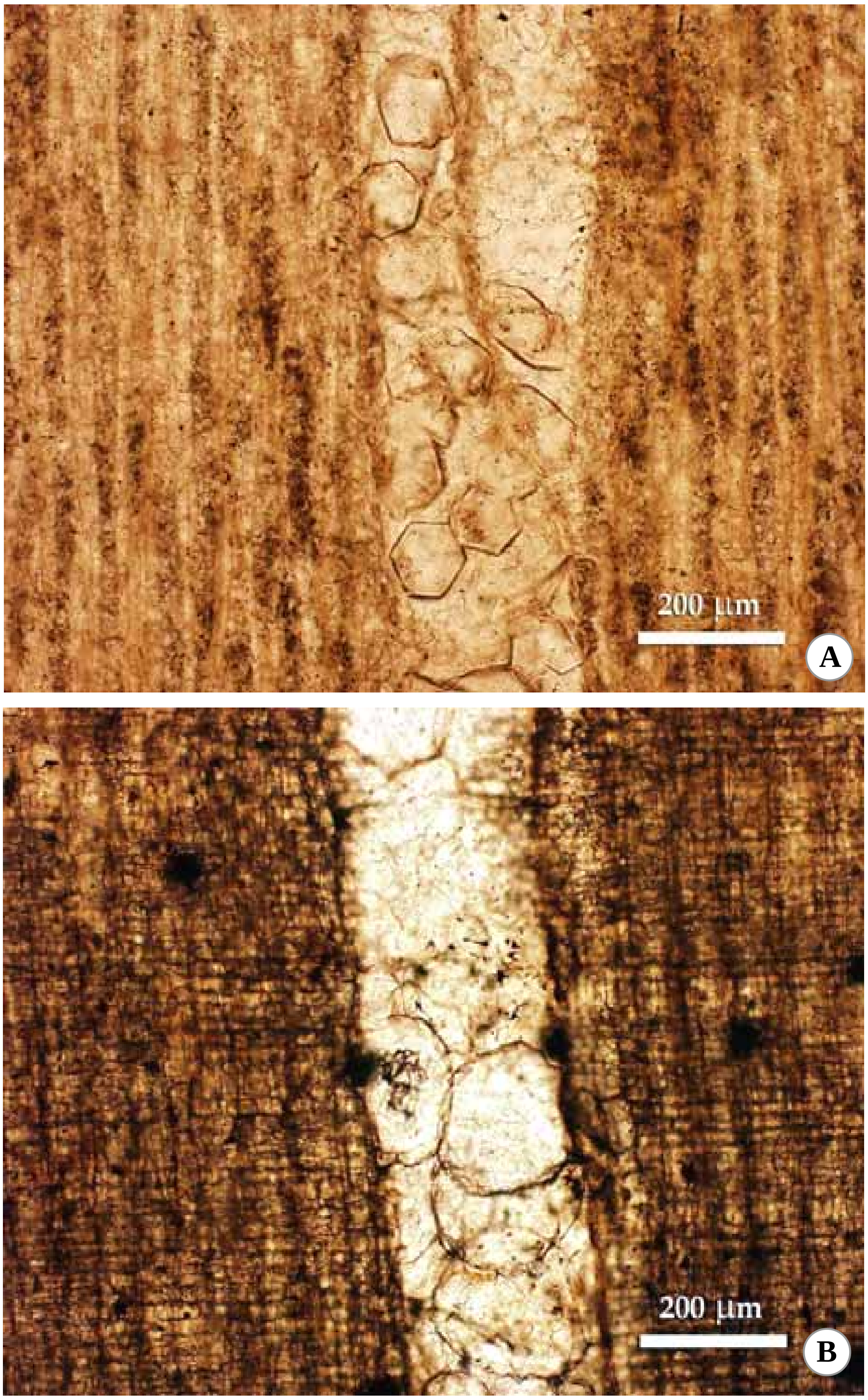


Figure 4.65 Thin section of I6. **A.** (Tg) Non-storied, 1 - 2 seriate rays and hexagonal crystals in vessel lumina. **B.** (R) Procumbent ray cells can be seen, cannot determine type of ray cells because the preservation is not good.

Family Meliaceae Juss.

Genus *Azadirachta* A.H.L. Juss.

Species *Azadirachta* sp.

Locality: Institute of Petrified Wood and Mineral Resources, grid no.A4-2

This slide is from a small fragment on the surface of the gravel, probably *ex situ* mixed with gravels on the surface. The whole specimen was picked up for making thin sections.

Specimen Number: A4-2 (Figs. 4.66 - 4.67)

Preservation: The preservation of this specimen is excellent; cellular detail can be clearly seen in all sections.

Description

Growth ring boundaries intermediate between distinct and indistinct. Wood diffuse-porous.

Vessels 2 - 3 cells /mm^2. Vessel clusters common and varying in number and grouping pattern of clusters. Mostly 1 (sometimes 2 - 4) large vessels surrounded with a small cluster of vessels or clusters of vessels in between or to one side of large vessels; some 10 - 12 cells of approximately similar size grouped in one cluster. Most solitary vessels medium in size but some are large, t.d. (100 -) 130 - 240 µm (mean 154.8 µm), r.d. (90 - 100) 130 - 240 µm (mean 175.5 µm); the remaining small vessels with t.d. 20 - 100 µm (mean 55.9), r.d. (10 -) 20 - 90 (-110) µm (mean 46.8 µm). Vessel element length 200 - 500 (520) µm (mean 338.8 µm). Solitary vessels rounded in outline; perforations simple. Deposits often appear collected at the ends of vessel elements. Vessel elements always surrounded with ray cells in longitudinal sections.

Intervessel pits alternate, vestured, and small sized, about 4 - 6 µm in diameter. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell.

Paratracheal **axial parenchyma** vasicentric and occasionally apotracheal axial parenchyma present in irregular tangential bands about 10 - 14 cells wide, and some single long vertical parenchyma strands present in transverse section. In tangential section, 2 to 8 cells per parenchyma strand appearing close to vessel or in between ray and vessel regions.

Rays (1 - 3) 4 - 5 (6) seriate and non-storied, tangential height (100 -) 180 - 590 (740) µm (average 363.14 µm) and width (25 -) 50 - 105 µm (average 74.86 µm). Body ray cells procumbent with 1(2) rows of upright or square marginal cells.

Fibers thin to thick-walled. Non-septate fibers present.

Affinities

The main characters of this specimen are vessels being rather clustered but having mainly two different sizes, large and small, in the same clusters, and axial parenchyma sometimes arranged in single vertical strands in transverse section. In tangential section, 2 to 8 cells per parenchyma strand appear close to vessels or in between ray and vessel regions. Axial parenchyma is occasionally seemingly present in irregular tangential bands about 10 - 14 cells wide. Intervessel pits are alternate, perforation plates are simple, rays are non-storied heterocellular, and fibers non-septate. The features of vessels, rays, and parenchyma are quite different from those of other fossil specimens. These characters show very close similarity to the modern wood of *Azadirachta* in the family Meliaceae.

The genus *Melia* is closely related to *Azadirachta*, but differs in the absence of axial parenchyma bands (Ogata *et al., 2008*), which are present in *Azadirachta* and this fossil specimen. There are two species of *Azadirachta*, *A. indica* and *A. excelsa*, of which their features are very similar in vessel grouping and arrangement, (1 - 2) 3-multiseriate non-storied rays, and non-septate fibers.

Traumatic axial resin canals are occasionally present in this genus (Lemmens *et al*., 1995 and Ogata *et al., 2008*). *Azadirachta indica* is described as having helical thickenings in/and throughout the vessel element (InsideWood, 2004-onwards). However, helical thickenings were not observed in this fossil specimen and in the specimen of modern wood of *Azadirachta indica* (Fig 4.68) used for comparison. This may because of variation in the wood.

It is rather difficult to assign the fossil to either species because the fossil specimen shares characters with both species and modern wood of these two species is variable within the same species, e.g., some specimens of *A. indica* have 4 - 6 seriate rays, whereas rays are often 2 - 3 (rarely 4) seriate in other specimens. In *A. excelsa* (Figs. 4.69 - 4.70), some specimens have many vessel clusters present among the irregular bands, while others have solitary vessels present among the bands and not frequently.

I do not see definitive characters of one particular species; therefore, this specimen is identified as *Azadirachta* sp.

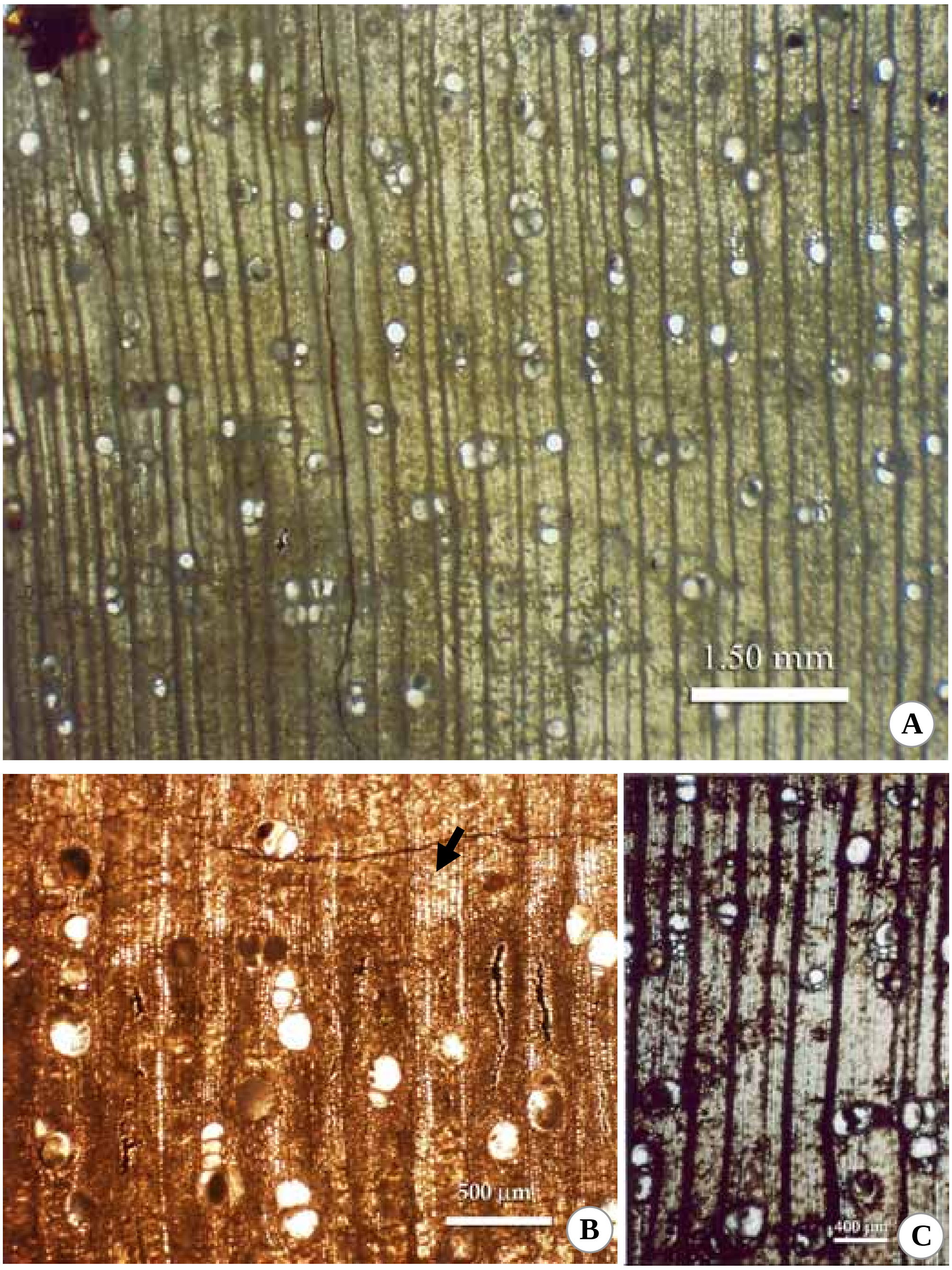


Figure 4.66 Thin section of A4-2. Transverse section. **A.** and **C.** Solitary and clusters of vessels are common. **B.** Irregular band of 10 - 16 cells axial parenchyma cells (arrow) and some radial multiples of 2 - 4 vessels.

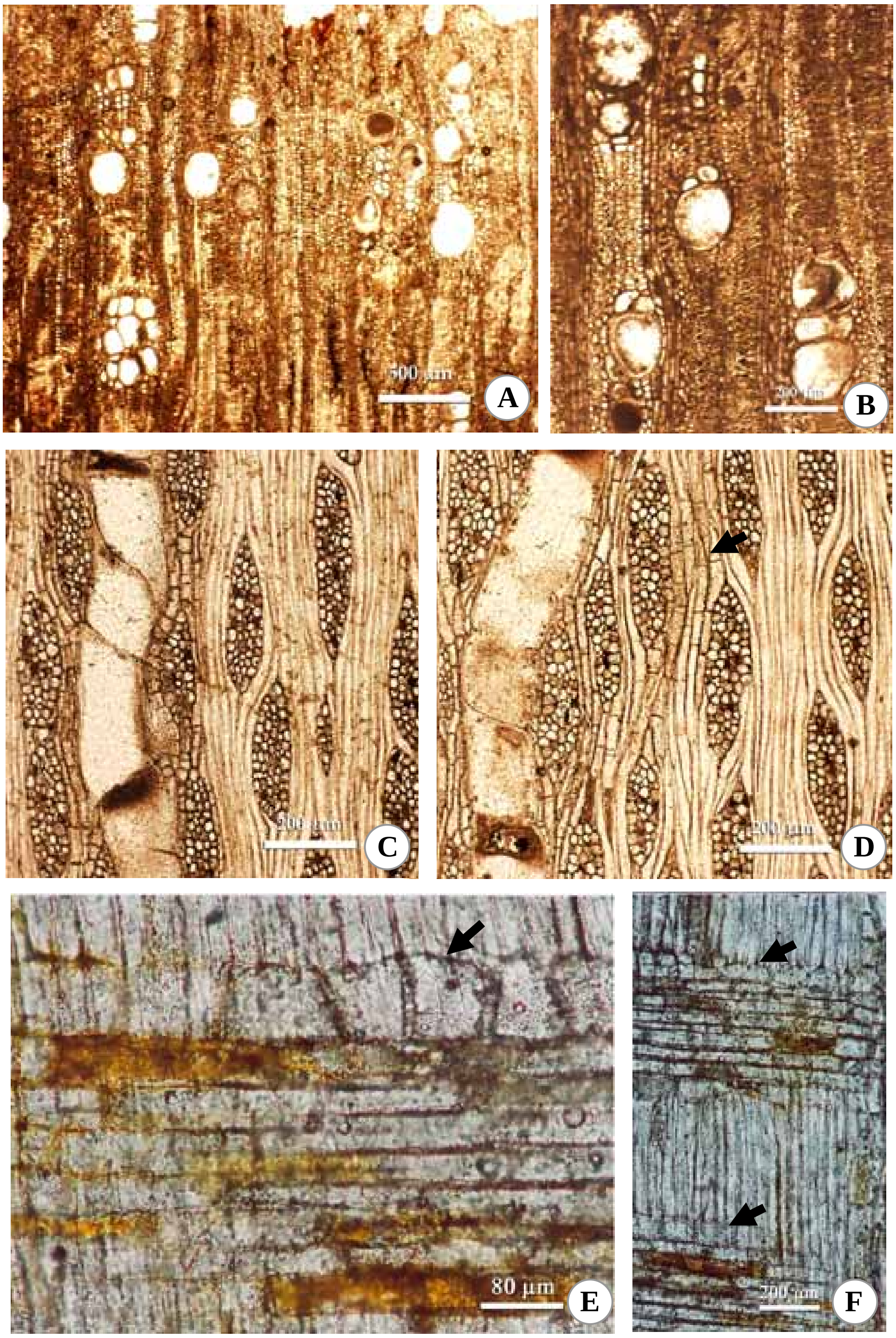


Figure 4.67 Thin section of A4-2. **A.** (Tv) Solitary and clustered vessels. **B.** (Tv) Vessels in clusters and in radial of multiples of 3. **C**. (Tg) Non-storied, (2) 4 - 6 seriate rays and non-septate fibers. **D.** (Tg) Parenchyma strands (arrow) **E.** and **F.** (R) Body ray cells procumbent with 1 row of square/upright marginal cells (arrows).

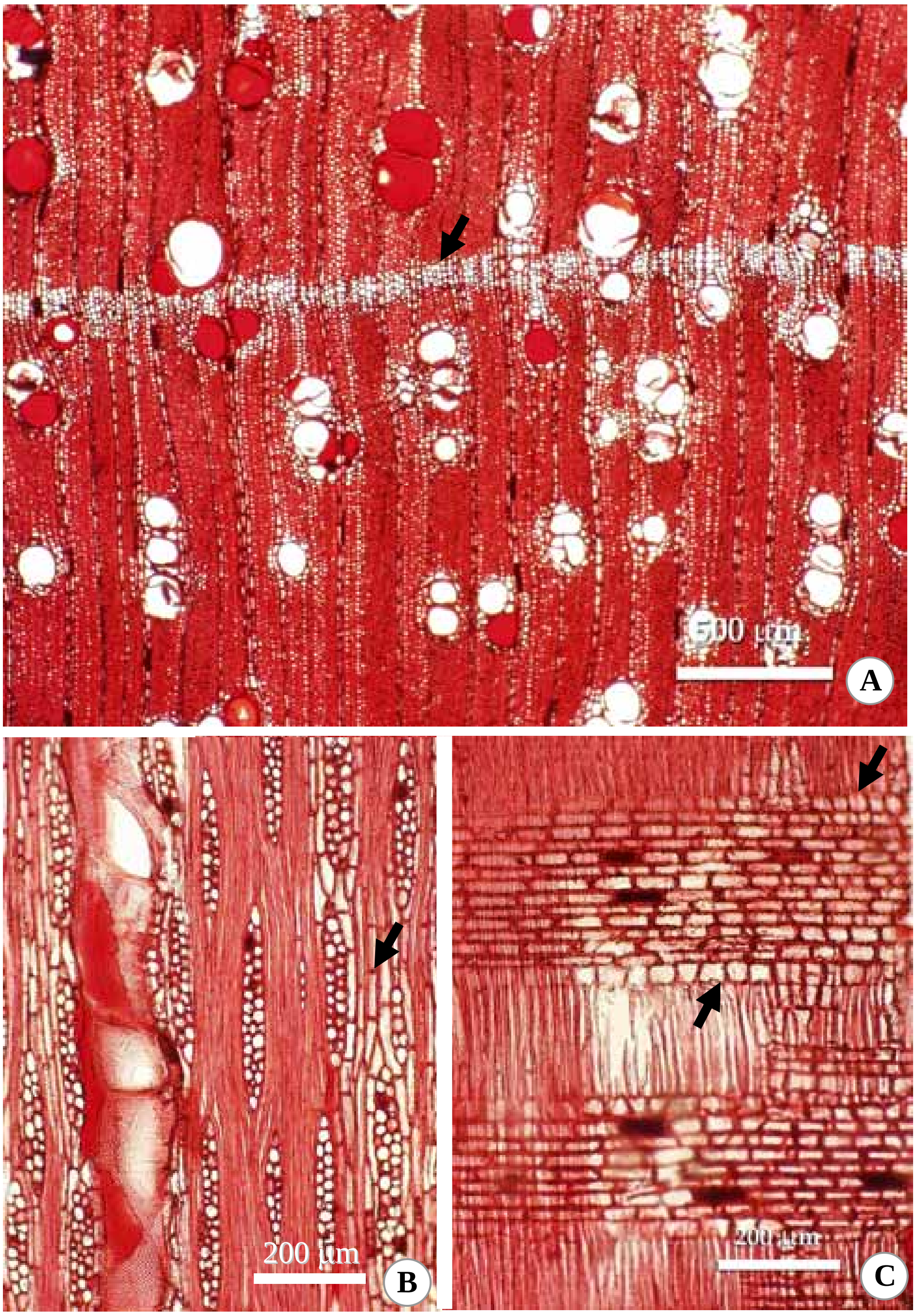


Figure 4.68 Thin section of *Azadirachta indica*. **A.** (Tv) Solitary vessels common and irregular band of 6 - 10 cells comprising axial parenchyma. **B.** (Tg) Non-storied and (1) 2 - 3 seriate rays. Non-septate fibers and parenchyma strands (arrow). **C.** (R) Body ray cells procumbent with 1 upper and 1 lower row of square/upright marginal cells (arrows).

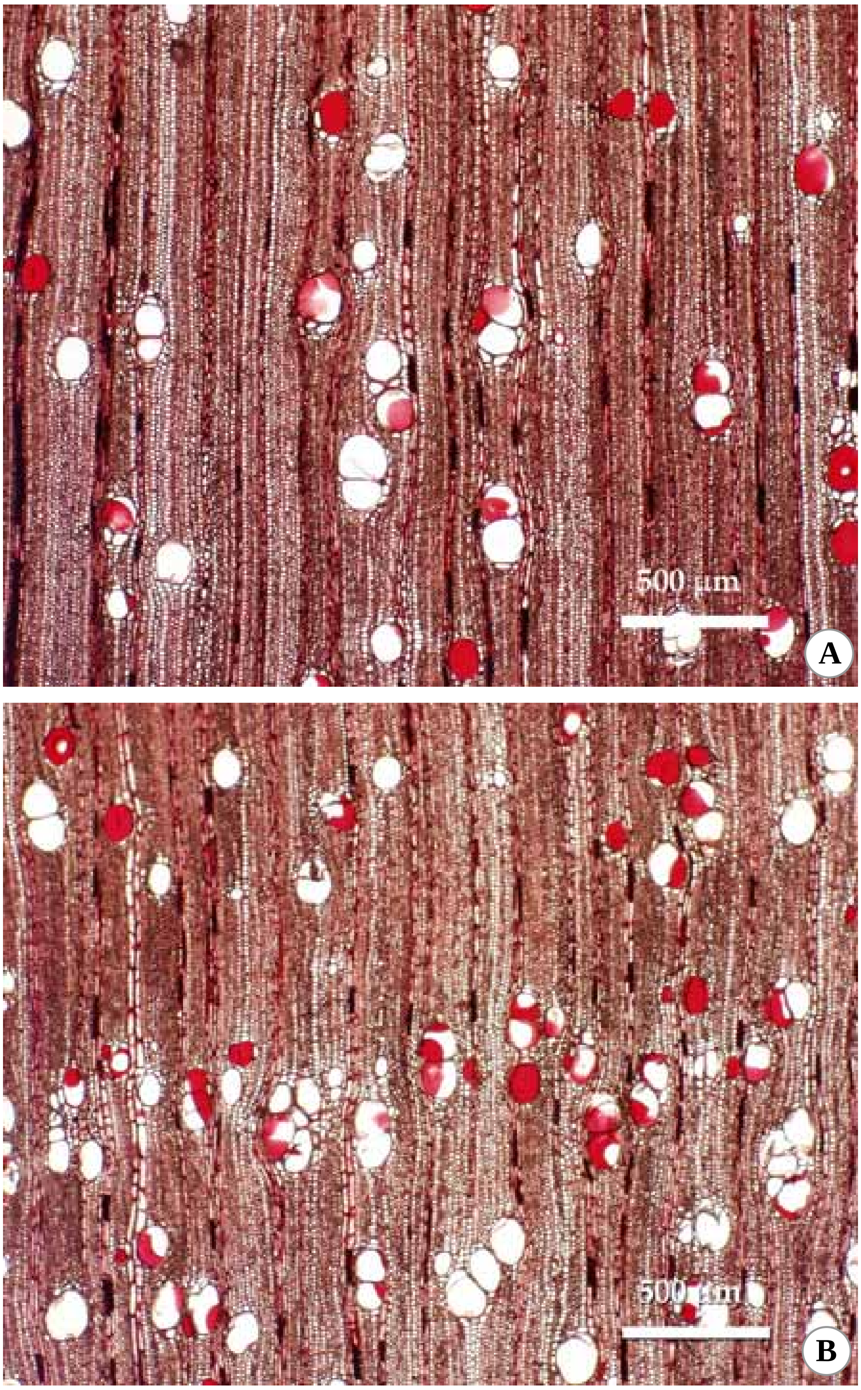


Figure 4.69 Thin section of *Azadirachta excelsa*. **A.** (Tv) Solitary vessels common, some in radial multiples and clusters. **B.** (Tv) Irregular band of axial parenchyma and vessel clusters.

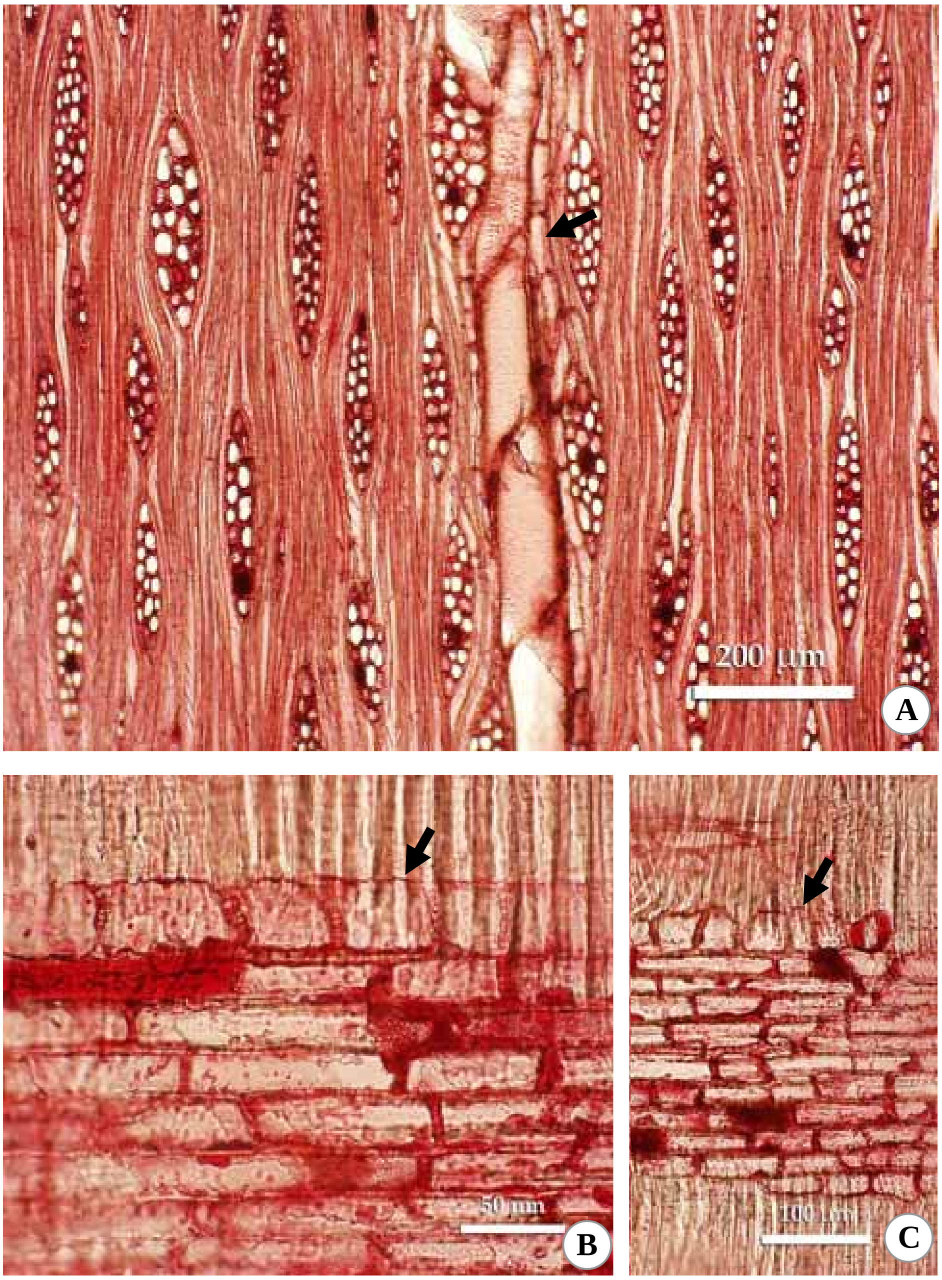


Figure 4.70 Thin section of *Azadirachta excelsa*. **A.** (Tg) (1 - 2) 3 - 4 seriate non-storied rays, non-septate fibers, and parenchyma strands (arrow). **B.** and. **C.** (R) Body ray cells procumbent with 1 row of square/upright marginal cells (arrows).

Family - (Angiosperm wood, family *incertae sedis*)

Genus - (Unidentified)

Species - (Unidentified)

Locality: Institute of Petrified Wood and Mineral Resources, grid no. D4

Specimen Number: D4 (Figs. 4.71 - 4.74)

Preservation: The specimen is poorly preserved and was highly compressed. It is roughly identify as dicotyledoneous wood from the presence of the vessels.

Description

Vessels and **parenchyma** compressed in irregular shape, cannot determine type or size.

Intervessel pits small, about 5 - 7 µm, usually alternate and some opposite.

Rays 2 - 4 seriate, non-storied, tangential height (325 - 600) 710 - 1,300 (1,500 - 1,625) µm (average 872.5 µm) and width 25 - 60 (75) µm (average 40.31µm), heterocellular consisting of procumbent body ray cells with 1 - 2 rows of upright and/or square marginal cells.

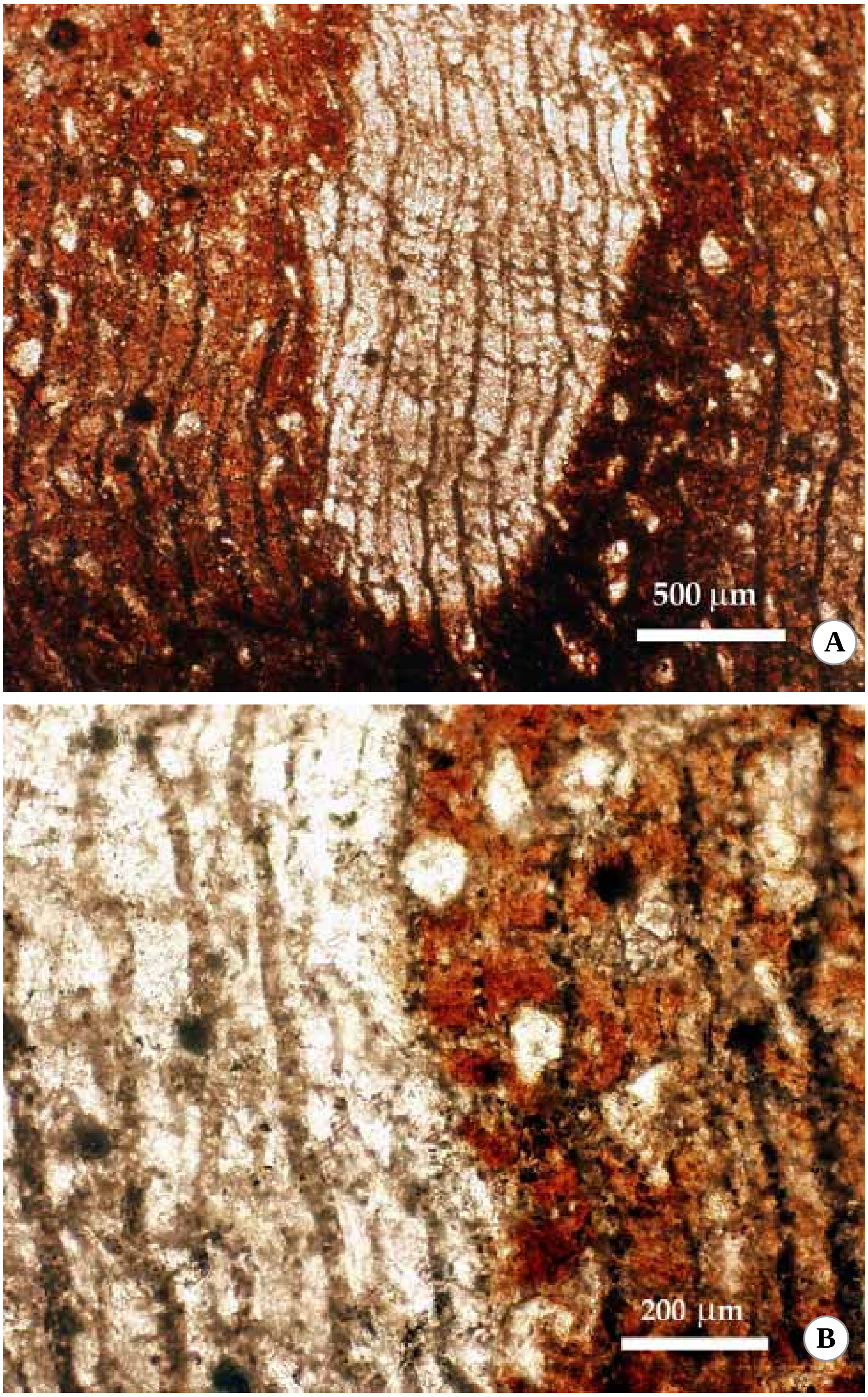


Figure 4.71 Thin section of fossil wood of D4 in transverse section. **A.** and **B.** Vessels and rays are highly compressed and distorted from the original shape.

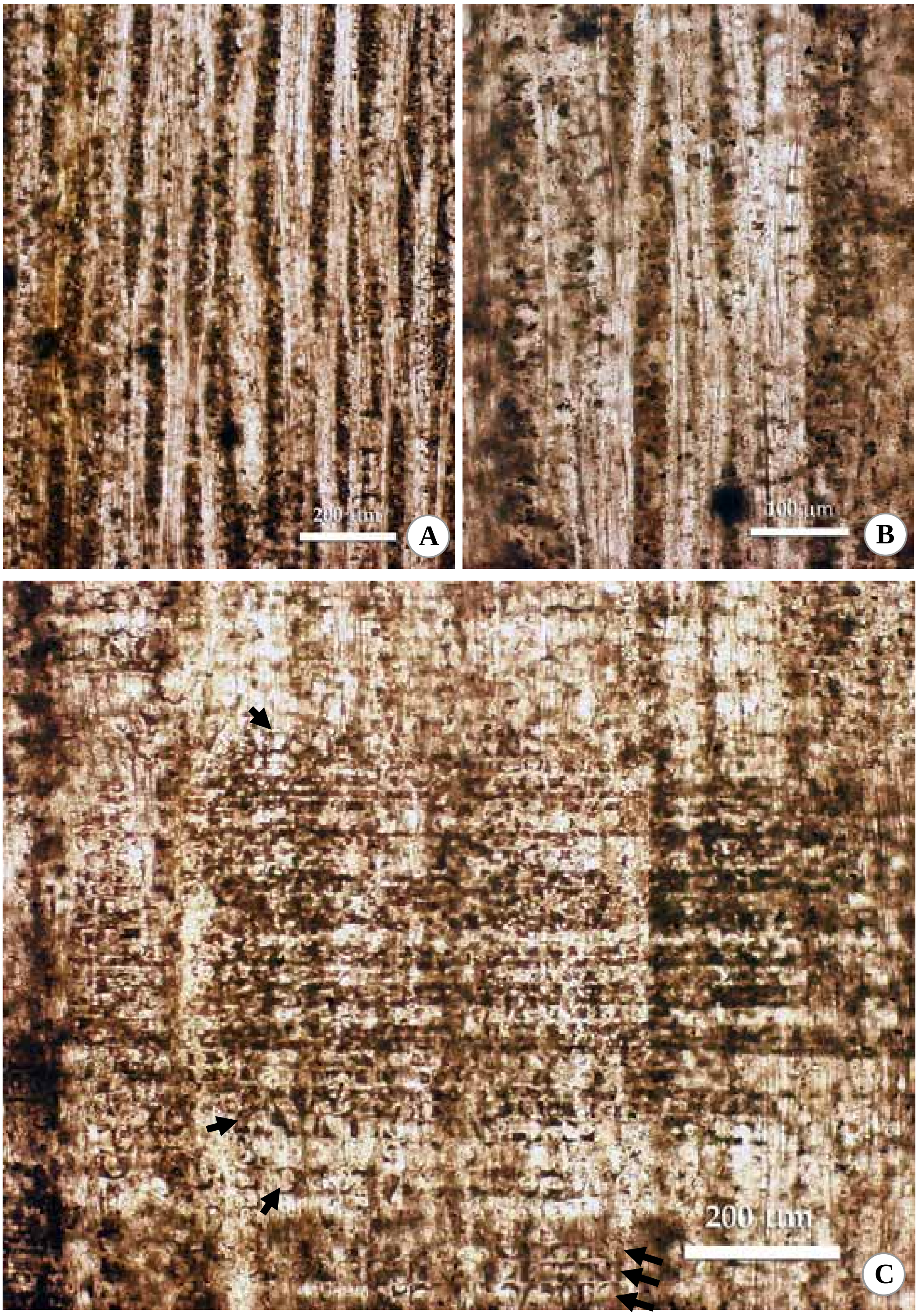


Figure 4.72 Thin section of fossil wood of D4. **A.** and **B.** (Tg) Non-storied and 2 - 4 seriate rays. Non-septate fibers. **C.** (R) Rays consisting of procumbent body ray cells with approximately 1 - 3 rows of upright and/or square marginal cells (arrows).

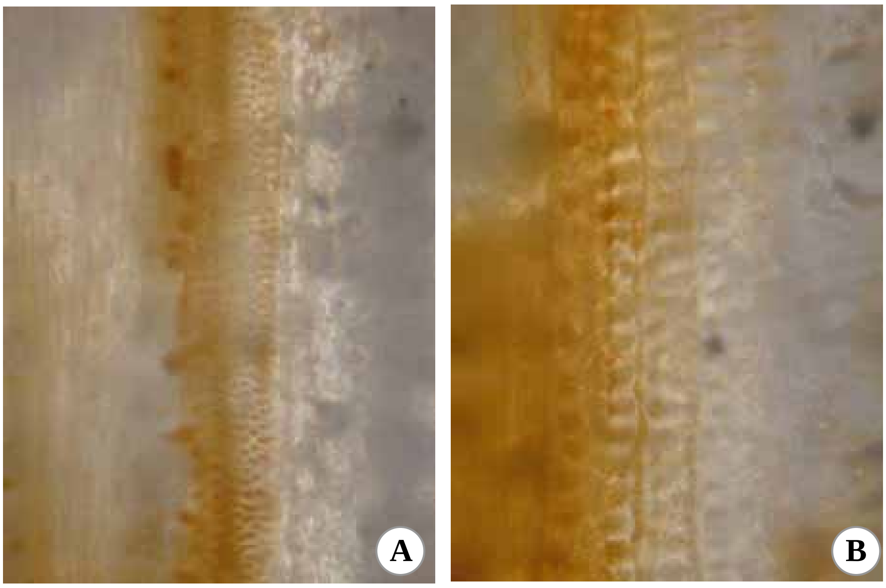


Figure 4.73 Thin section of fossil wood of D4. **A.** (Tg) and **B.** (Tg) Intervessel pits.

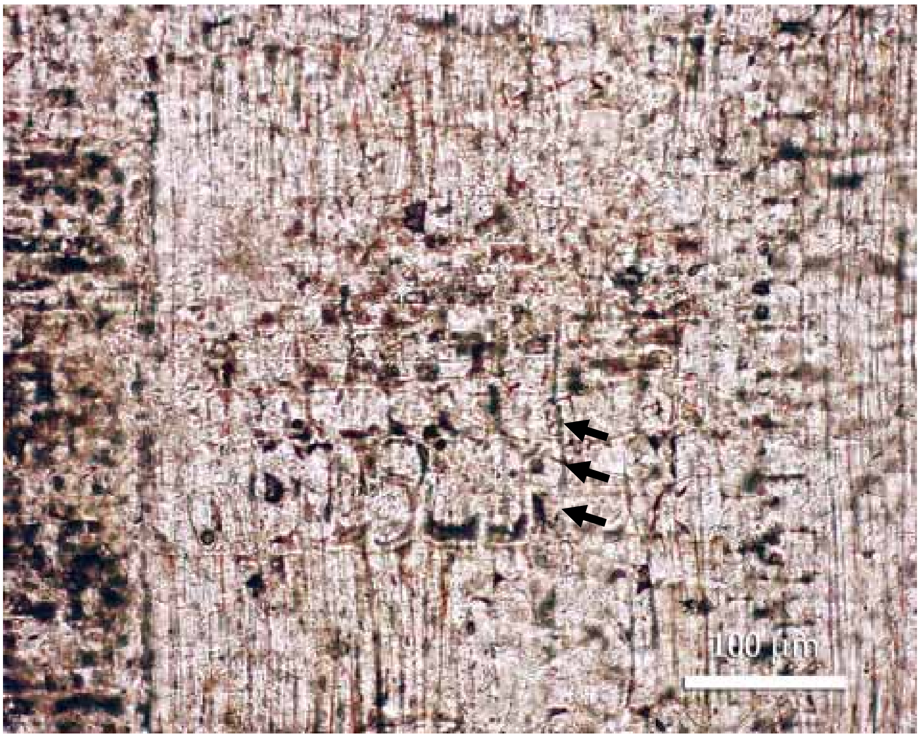


Figure 4.74 Thin section of fossil wood of D4 in radial section. Rays consisting of procumbent body ray cells with 3 rows of upright and/or square marginal cells (arrows).

Abbreviations of characteristics of petrified wood specimens used in table 4.1

(modified from Wheeler and Manchester, 2006)

GR growth rings, + = present, – = absent, +/– = both, I = indistinct.

POR porosity, D = diffuse-porous, S = semi-ring porous, R = ring porous.

VD vessel diameter VS = very small, S = small, M = medium, L = large

Tg = tangential (size)

TgM = mean tangential (diameter)

RdM = mean radial (diameter)

VMM vessels per square millimeter

MVL mean vessel element length.

PP perforation plate, SI = simple, SC = scalariform, M = multiple

IVP intervessel pit

AR arrangement of vessel pits, A = alternate, O = opposite, S = scalariform,

? = not observed.

AP axial parenchyma

A = absent, R = rare, D = diffuse, DA = diffuse-in-aggregates, B = banded, M = marginal, SP = scanty paratracheal, V = vasicentric, AF = aliform, C = confluent.

R ray RW = ray cells wide, RH = ray height

S = storied structure; s = storied, ns = non-storied

RC ray cellular composition, Ht = heterocellular, Ho = homocellular,

US = all square and upright cells,

M = mixed, upright, square, and procumbent cells throughout the ray.

SF septate fiber

FW fiber wall thickness, V_{Tn} = very thin, Tn = thin, Th = thick, V_{th} = very thick

D deposits in vessel lumina

C crystals, **–** = not observed, Cr = crystals in rays

Table 4.1 Summary of characteristics of petrified wood specimens. (See the previous page for explanation of abbreviations.)

Code	GR	POR	VD			VMM	MVL	PP	IVP		AP	R			RC	SF	FW	D	C
			Tg	TgM	RdM				AR	µm		RW	RH	S					
A4-1	I	D	S-M	104.2	142.0	5-8	240.00	SI	A	8-12	V,AF	1-(2)	240.83	ns	Ht	+	Tn-Tk		
A4-2	I/+	D	M-L	55.9*/154.8	46.8*/175.5	2-3	338.80	SI	A	4 -6	,M	(1-3)-4-5-(6)	363.14	ns	Ht	–	V_{Tn}		
A4-4	I	D	S-M	102.8	128.4	5-6	377.20	SI	A	2-3	DA,M	1-3	411.50	ns	Ht	–	Tn-Tk	+ +	
B5	-	D	S-L	177.2	185.5	1-3	188.40	SI	A	~4.8		(1)2-3(4)	232.33	ns	Hm	+	V_{Tn}		
C4	I	S	VS-M	87.6	128.4	4-7	215.52	SI	A	4 -5	B	1-2(3)	232.14	ns	Ht (Hm)	?	V_{Tn}?		
D4										5-7		2-4	872.5	ns	Ht	-			
F5-1	I	D	S-M	147.8	174.1	4-6	288.39	SI	A	4-6		(1)-2-(3)	259.00		Ht				
F5-2	I	D	S-M	100.6	156.1	2-5	254.72	SI	A	3-5.5	V,B	1-2	285.00	ns	Ht (Hm)	+?	V_{tk}	+	
G5	-	D	S-M	107.3	146.7	4-6	281.40	SI	A	4-5	?	1-2(3)	314.71		Ht/M	?	?	+	Cr
I2-1	-	D	S-M	113.8	195.9	5-6	198.85	SI	?	?	B	2-3	316.33	ns	Hm		V_{tk}		
I2-2	-	D	S-M(L)	127.7	195.0	3-5	322.29	SI	A	4-5	B	(1)-2-(3)	252.50		Hm		V_{tk}		
I2-3	-	D	S-M	89.3	153.0	3-4	272.83	SI	A	3-5	B	1-2	241.00	ns	Ht	–	Tk		

* Vessels in 2 size classes.

Table 4.1 (Continued)

Code	GR	POR	VD			VMM	MVL	PP	IVP		AP	R			RC	SF	FW	D	C
			Tg	TgM	RdM				AR	µm		RW	RH	S					
I6	I	D	M-L	167.9	233.4	2-5	275.1?	SI	A	7-10	V,B	(1)-2	318.60	ns					
L7	-	D	M	136.4	179.2	4-7	351.61	SI	A	3.12-5.28	V,B	1-2	349.00	ns			V_{tk}	+	
M1-1	I	S	(S)-M	126.7	194.7	3-8	321.33	SI	A	4. -5	V,B	1-2-(3)	482.67			+,–	$V_{(Tn)-tk-}$ Vtk		
M1-4	I	D	S-M	125.4	201.4	3-5	302.00	SI	A	3 -6	B	(1)2-3	328.85	ns	Hm (Ht)	–	Tn-Tk		
M7-1	I/-	D	M	144.1	157.0	3-6	305.94	SI	A,0	7.2-10.8	A,M	1-2	338.29	ns	Hm	–			
M7	I/-	D	S-M	115.2	157.6	2-6	314.56	SI	A	8-10	A,M	1-2	210.14	ns	Ht (Hm)	–	V_{tk}	+	
M8	-	D	M-L	138.5	211.2	6-10	125.00			3.2-4.4	V,B	1-3	275.00				V_{tk}		
N7-1	I/-	D	(VS)-S	68.0	76.8	2-3	322.33	SI	A	3.5-5	V,B	(1-2)3-4(5)	290.33		Ht		V_{tk}		
N7-3	-	D	S-M	104.0	144.0	7-9	276.67	SI	A	3-4	B,A	1-2(3)	239.57	ns	Ht (Hm)	–			
N8	-	D	(S)-M	121.2	149.2	6-9	303.53	SI	–	–	V	(1)-2-(3)			Ht (Hm)				Cr
O7	I	D	S-M	89.3	153.0	3-6	198.85	SI	A	3.5-5	A,C	(1)2-3	322.92	ns	Ht	–		+	

4.2 Geological Information from the Study Area

The sediment at the study area consists of different types of lithologies. They vary from alternating cross-bedded sandstone to sand-gravel conglomerate and limonitic gravel. Both unconsolidated and semi-consolidated sediments are found at the site. Colors vary from reddish orange to light tan (Fig. 4.75). Logs and many fragmentary pieces of petrified wood are commonly found in the gravels (Figs. 4.76 - 4.69). Some wood specimens are found embedded in sandstone (Fig. 4.76). However, other organs of plant fossil or animal fossils have been found. Fragments of wood are variable in size and subangular to subrounded. The surficial sediments have been disturbed as a result of human activities, including construction at the museum site. The large *in situ* petrified fossil logs are embedded at different vertical positions, but within about 4 meters of each other.

The physical information, e.g., measurement of each log, is presented in Table 4.1. The petrified logs are lying in different orientations with the base of each trunk pointing to a different direction (Fig. 4.70). Some specimens had been partly or wholly removed and cannot be measured for actual length and orientation. Photographs of the original trunks and sediments are shown for comparison with the more recent photographs in Fig. 4.71 - Fig. 4.72.

Figure 4.75 The section of sediment showing unconsolidated and semi-consolidated sand to gravel. Colors vary from reddish orange to light tan (photography was taken by Jintasakul in 2000).

Figure 4.76 Petrified log (arrow) is embedded in *ex situ* sandstone. The sandstone was removed from its original position elsewhere within the study area.

Figure 4.77 Petrified logs (arrows) and fragments are partly exposed on the surface of the study area, which consists of gravels, pebbles, and sands.

Figure 4.78 A. The recently photographed gravel bed at the western side of the study area, petrified wood is found both on the surface and deeper level (arrows). **B.** Large fragmented petrified logs are exposed at the deeper level, ~2 m depth, after sediments were partly dug out. An arrow with dotted line pointing to the position of **B.** within **A.**

Table 4.2 Information* on *in situ* embedded petrified logs.

No.	Specimen Code	Length m	Orientation	Diameter (cm)			Identification	Burial		Note
				Apical	Middle	Basal		in situ	Ex situ	
1	A5-1	?	-	-	-	-	*Terminalia* sp.	✓		The large fragments of a log were dug out from digging the pond and placed nearby.
2	B5	5.12	140˚W of N	20	55	50	*Canarium* sp.	✓		
3	F5-1	?	-	?	?	?	*Cynometroxylon holdeni*		✓	One of fragments was collected from the embedded specimen on surface
4	F5-2	?	-	?	?	?	*Cynometroxylon holdeni*	✓		The embedded specimen on surface
5	G5	3.10	135˚ E of N	35	100	56	*Mangiera?*	✓		
6	I6	?	-	-	-	-	*Careya* sp.		✓	*In situ* specimen was removed from the original site and later brought back
7	L7	5.85	15˚Wof N	?	60	?	*Irvingia* sp.	✓		The specimen is broken in fragments
8	M7-2	4	80˚Eof N	?	60	?	*Terminalia* sp.	✓		Original specimen was about 8m long (L-shaped), but approximately 3m of it was lost.
9	M8	7	45˚Wof N	50	100	120	*Cynometroxylon holdeni*	✓		

* The information in this table is base on recent data from 2006 after the museum was established. The original petrified logs were probably larger in size.

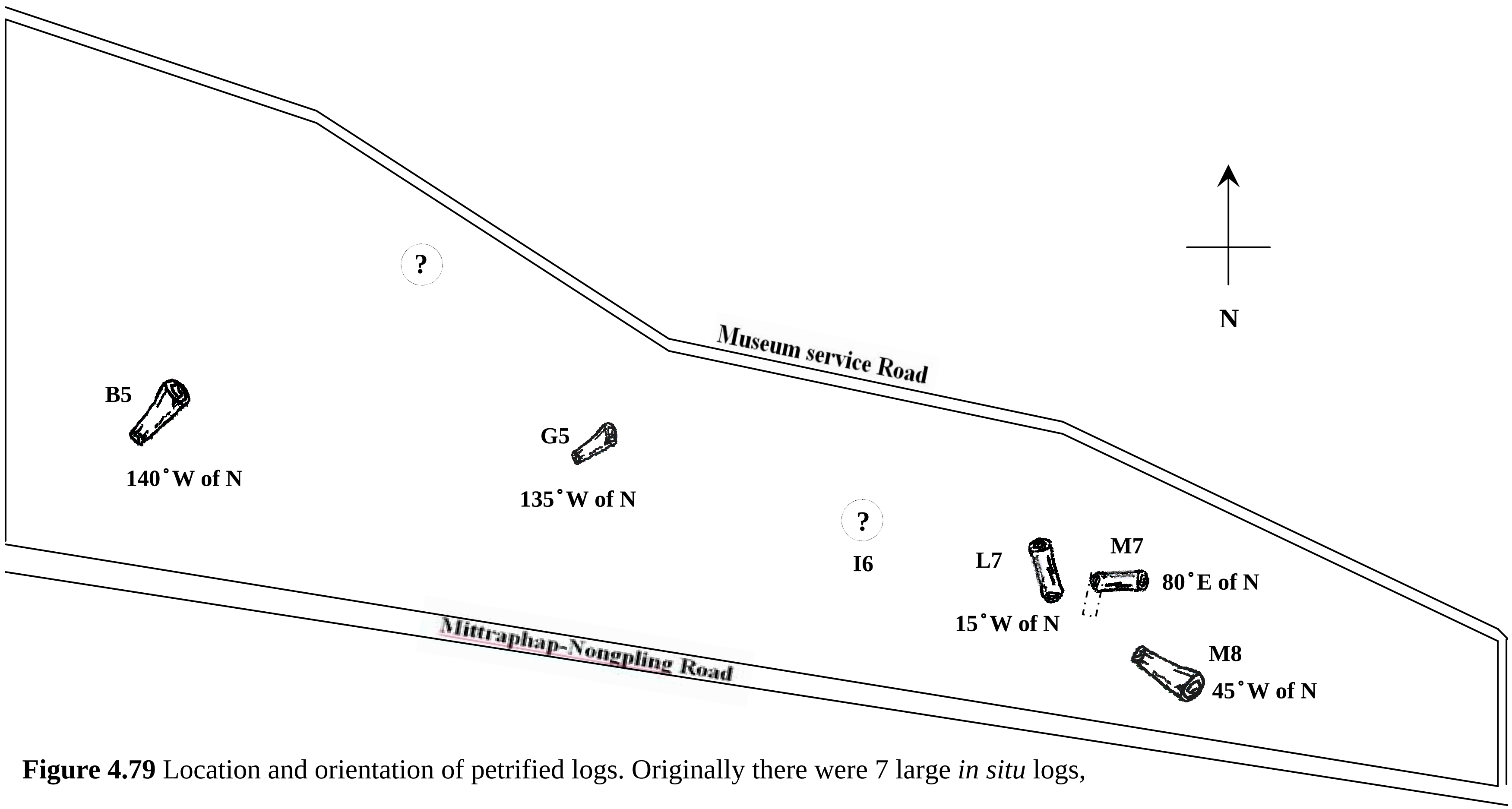


Figure 4.79 Location and orientation of petrified logs. Originally there were 7 large *in situ* logs, but only five could be measured as to orientation. Three meters of log in grid no. M7 were removed. The outline of the site was modified from the architecture map of the museum (2000).

Figure 4.80 Petrified logs from grid no. A5. **A.** The logs were removed during excavation of the pond and put on the adjacent sediments. Showing the pond (**B.**) and surrounding sediments (**C.**) where the logs and fragments were found (in red circles).

Figure 4.81 *In situ* petrified trunk from grid no. B5. **A.** The log in original sediments when first discovered (photograph by Jintasakul, 2000). **B.** The log lying in the pavilion no.1 after the museum was established; the photograph was taken in 2007, from the opposite direction of **A.**

Figure 4.82 *In situ* petrified trunk from grid no. F5. **A.** The embedded specimen (arrow) and surrounding area. **B.** Part of the log with many fragments (arrow) is exposed on the surface, but the log is mostly embedded in consolidated conglomerate sediments. **C.** The log surface partly broken into small fragments. The photographs were taken in 2006.

Figure 4.83 *In situ* petrified trunk from grid no. G5. **A.** The apex is much thinner than the base and sloping downward. **B.** The base of the trunk is partly eroded. **C.** Showing a side view of the trunk. The specimen is lying in pavilion no.3. The photographs were taken in April 2007.

Figure 4.84 *In situ* petrified trunk from grid no. L7. **A.** The location of the *in situ* log is next to pavilion no.6 and close to the fence within the institute area. **B.** Showing the size of the log. The photographs were taken in March 2007, from opposite directions.

Figure 4.85 *In situ* petrified trunk from grid no. M7. **A.** The original log, which broken in an L-shape (arrows) when it was first discovered (photograph by Jintasakul, 2000). **B.** The more recently fragmentary log remaining after some part had been stolen. It is lying in the pavilion no.6 after the institute was established; the photograph was taken in March 2007.

Figure 4.86 *In situ* petrified trunk from grid no. M8. **A.** The original log when it was first discovered (photograph by Jintasakul, 2000). **B.** The recently photographed log is lying in the pavilion no.7 after institute was established; the photo was taken in March 2006.

CHAPTER V

DISCUSSION AND CONCLUSIONS

5.1 Discussion

5.1.1 The systematics and comparative anatomy of fossil wood

It is rather difficult to determine all fossil wood to the species level because the wood of the same species can vary in its features depending on the environment in which the trees are growing, i.e., climate, soil type, etc. Also the species level of modern angiosperm trees are mainly considered by identification of flowers. However, besides fossil wood, no other plant organs, e.g., leaves, fruits, and seeds are found in my study area. The age of sediments at the site is from the Miocene to the Pleistocene. The fossil wood shows close resemblance to modern wood, and some are possibly the same taxon as an extant species. However, it is unknown whether the flowers of these fossil trees are exactly the same as flowers from the modern trees. As flowers are reproductive organs, there might have been more rapid adaptation than for wood because of biotic interactions or co-evolution between flowers and insect or other animal pollinators (Philippe, 2007, personal communication; Grote, 2008, personal communication).

In this research, if fossil wood shows very close similarities to a modern wood genus, it is given a modern generic name. If its characters are closer to those of other fossil wood specimens studied, then the previously published fossil genus or species name is used. The generic name for fossil wood often contains the Greek ending "*xylon*" which mean wood.

There are some differences in the terminology used in describing microscopic features of modern wood and fossil wood from previous literature, especially literature prior to the 1980s. This is another factor to be carefully checked in placing fossil wood at the species level. For example, microscopic descriptions of modern wood species are often given as averages, while those of fossil wood are given as ranges. In describing ray height, the number of ray cells but not the measurement in micrometers is presented in older literature, whereas in most current descriptions, the tangential height of rays in micrometers is given, but the number of ray cells in height is not mentioned.

Therefore, in this thesis I describe both the range and average of the features for checking with other literature on both modern wood and fossil wood.

5.1.2 The distribution of modern trees related to fossil wood

From the study on comparative anatomy of fossil wood, it is indicated that the fossil assemblage shares taxa with modern floras including those are found in the surrounding area. Although some trees species of Dipterocarpaceae, e.g., *Dipterocarpus obtusifolius*, are found within the museum area and are common in the Northeast, none of collected fossil wood specimens in this study are from the family Dipterocarpaceae. No monocotyledonous fossil wood was found at the study site, even though fossil palms were found from nearby areas within the institute.

5.1.2.1 Family Anacardiaceae

There are at least four genera, *Buchanania* Spreng., *Dracontomelon* Blume., *Pleiogynium* Engl., and *Mangifera* L., having characters similar to those of two fossil wood specimens from my study site. About 6 species, *B. arborescens, B.*

glabra, B. lanzan, B. reticulate, B. sessiflolia, and *B. siamensis* are found today in Thailand (The Forest Herbarium, 2001). *B. lanzan* and *B. siamensis* are often found in dry dipterocarp forest. They are also common in Nakhon Ratchasima, especially in Suranaree subdistrict where there is a village whose name includes the local Thai name of the tree *B. lanzan* that grows around there. Only one species of *Dracontromelon*, *Dracontomelon dao*, is found in Thailand. It is commonly in everygreen forests by streams and tropical rain forest of Thailand (Chayamarit, 1994; Santisuk, 2006). There is no report of *Pleiogynium* in Thailand; however, it is distributed from northeast Australia to the Philippines and is found in rain forests (Association of Societies for Growing Australian Plants [ASGAP], 2007).

Mangifera consists of 60 species distributed from India, through Southeast Asia, to New Guinea (Ogata *et al.*, 2008). In Thailand, about 17 species or subspecies are listed as follows: *M. caesia, M. caloneura, M. camptosperma, M. cochinchinensis, M. duperreana, M. flava, M. foetida, M.gedebe, M. gracilipes, M. griffithii, M. indica, M. lagenifera, M. longipes, M. odorata, M. pentandra, M. quadrifida* var. *quadrifida and M.* var. *longipetiolata, M. sylvatica* (The Forest Herbarium, 2001). *Mangifera* spp. can be found in mixed deciduous, dry evergreen, and lower montane forests of Thailand (Santisuk, 2006). They are often cultivated in gardens.

5.1.2.2 Family Burseraceae

Burseraceae consists of about 17 genera and 500 species, including trees and shrubs. Their distribution is mostly in the tropics. Leenhouts reported in 1956 that about 8 genera and 108 species occurred in the Malesian region (Ogata *et al.*, 2008).

The genus *Canarium* L. consists of about 100 species spreaded in tropical Africa, Madagascar, and Southeast Asia to the western Pacific and northern Australia (Ogata *et al.*, 2008). In Thailand, at least 12 species of *Canarium* are listed (The Forest Herbarium, 2001). *Canarium subulatum* (syn. *C. kerrii*) has been reported from the institute area and SUT (TISIR, 2001; Chomko, 1999). *C. subulatum* is also found in dry dipterocarp and lower montane rain forests of Thailand (Phengklai and Khamsai, 1985; Santisuk, 2006).

5.1.2.3 Family Combretaceae

The genus *Terminalia* L. consists of about 200 species distributed in the tropics (Ogata *et al.*, 2008). In Thailand, at least 16 species are found, *T. alata, T. bellirica, T. calamansanai, T. cambodiana, T. catappa, T. chebula, T. citrina, T. foetidissima, T. franchetii* var. *tomentosa, T. glaucifolia, T. harmandii, T. mucronata, T. myriocarpa, T. pedicellata, T. pierrei,* and *T. triptera* (The Forest Herbarium, 2001). The species are commonly found in mixed deciduous forest, and, in northeastern Thailand, are *T. alata, T. chebula, T. bellirica, T. mucronata,* and *T. triptera*. However, *T. triptera* and *T. pierrei* are also found in dry evergreen forest (Santisuk, 2006).

5.1.2.4 Family Irvingiaceae

Irvingia F.Muell. consists of 4 species, three of them from tropical Africa (Ogata *et al.*, 2008). Only one species, *Irvingia malayana* Oliv. ex A. W. Benn. (syn. *Irvingia oliveri* Pierre), is found in Thailand throughout the country. The trees particularly occur in dry dipterocarp forest, but also in dry evergreen forest and in tropical rain forest at altitudes below 300m In addition, they can be found in the lowlands of Indochina, Malaya, Sumatra, and Borneo (Ogata *et al.*, 2008; Phengklai, 1981; Santisuk, 2006; The Forest Herbarium, 2001). They are also commonly found in the institute area and SUT (TISIR, n.d.; Chomko, 1999).

5.1.2.5 Family Lecythidaceae

The genus *Careya* Roxb. consists of four species extending from India eastward through Thailand and Indo-China to New Guinea and New Britain (Prakash and Tripathi, 1972). *Careya* is distributed from Afghanistan, India, Andaman Islands, Nepal, and Sri Lanka, to Southeast Asia, Laos, Cambodia, Vietnam, Thailand, Peninsular Malaysia, , Borneo, Sumatra, and Java, as well as in Africa (Benyasuta, 2003; Sosef, Hong, and Prawirohatmodjo, 1998). *Careya* is sometimes seggregated in Barringtoniaceae (Takhtajan, 1997). There are two species of *Careya* in Thailand: *C. herbacea* and *C. arborea* (syn. *C. sphaerica*) (The Forest Herbarium, 2001). *C. arborea* is dispersed in mixed deciduous forest and dry deciduous forest throughout the country (Phengklai and Khamsai, 1985).

5.1.2.6 Family Leguminosae (Subfamily Caesalpinoideae)

The genus *Cynometra* L. consists of 150 species of trees and shrubs in the world. About 60 species are distributed in tropical regions (Larsen *et al.*, 1984; Ogata *et al*., 2008). Approximately 5 species: *C. cauliflora, C. craibii, C. iripa, C. malaccensis,* and *C. ramiflora* are found in Thailand: *Cynometra ramiflora* and *C. iripa* commonly grows along the tidal areas and mangroves, being dispersed in beach forests or other littoral communities. *C. ramiflora* sometimes grows inland and is rarely found above 400 m altitude (Larsen *et al.*, 1984; Chayamarit, 1986). *C. craibii* is found in evergreen forest along streams at low altitudes, whereas *C. malaccensis* can be found in evergreen forest including tropical rain forest (up to 1300m in the Malay Peninsula) and mangrove forest. *C. cauliflora* is recognized as cultivated on the Asiatic mainland and the type is from Indonesia (Larsen *et al*., 1984;

Santisuk, 2006).

5.1.2.7 Family Leguminosae (Subfamily Papilionoideae)

The genus *Millettia* Wight & Arn.consists of approximately 323 species in the world and about 150 species in the tropical to subtropical regions of Asia and America (The Bay Science Foundation. Inc., 2008; Ogata *et al.*, 2008). At least 16 species of *Millettia* are found in Thailand. They are *M. brandisiana, M. caerulea, M. decipiens, M. extensa, M. glaucescens, M. kangensis, M. kityana, M. latiflora, M. leucantha*, (var. *leucantha* and *buteoides*), *M. macrostachya* (var. *macrostachya* and *tecta*), *M. pachycarpa, M. peguensis, M. pulchra, M. sericea, M. utilis,* and *M. xylocarpa* (The Forest Herbarium, 2001). *Millettia* spp. are often found in mixed deciduous forest (Santisuk, 2006).

5.1.2.7 Family Meliaceae

The genus *Azadirachta* A. Juss. consists of 2 species, *A. excelsa* (Jack) Jacobs and *A. indica* A. Juss. *A. excelsa* is native to Peninsular Malaysia, Sumatra, Borneo, Sulawesi, the Aru Islands, New Guinea, and the Philippines. *A. indica* is thought to be native to the dry forest areas of the Indo-Pakistan subcontinent and possibly also to Myanmar. It is widely cultivated and sometimes occurs naturalized throughout India, Pakistan, Sri Lanka, Thailand, and Indonesia (Lemmens, Soerianegara, and Wong, 1995). Both species are found in Thailand (The Forest Herbarium, 2001). *A. indica* var. *siamensis* are commonly found in mixed deciduous forest (Santisuk, 2006) and can be seen very commonly in northeast Thailand. So far no fossil wood of this genus has been recorded before. *Azadirachta indica* is growing in the study area.

5.1.3 Paleoclimate

As for anatomical features of these fossil wood specimens, most are diffuse ring porous, similar to the porosity of modern wood of living trees in Thailand. Only one specimen is semi-ring porous. This indicates that the climate in each season is not so different throughout the year. The paleoflora shows close resemblance with modern tree species of mixed deciduous forest, some of dry dipterocarp forest, commonly found in Suranaree subdistrict, Nakhon Ratchasima, and some flora from dry evergreen forests. This indicates that the paleoclimate corresponds to the Recent climate in Nakhon Ratchasima, but the humidity was higher than at present. The paleoclimate was the tropical wet and dry (Aw) and tropical monsoon (Am) according to the Köppen climate classification (Jintasakul, 2008, personal communication).

The fossil species are similar to modern floras tree species commonly found in mixed deciduous, dry dipterocarp, and dry evergreen forests. Among the fossils, the specimens showing close resemblance to modern wood of *Cynometra* are the highest in number. The genus *Cynometra* is usually found in evergreen forest, especially in the peninsula of Thailand. Although some species of *Cynometra* commonly grow in the littoral communities of Thailand, there is no evidence of close proximity of the sea at my study site, the depositional environment being that of a braided river. The distribution of modern trees related to the fossil flora is shown in Table 5.1.

Table 5.1 Distribution of modern taxa related to the fossils (Chayamarit, 1986; Larsen *et al.*, 1984; Phengklai and Khamsai, 1985; Santisuk, 2006).

Family	Fossil wood	Modern relatives	Forest type
Anacardiaceae	*indet.*	*Buchanania*	DD[1]
		Dracontomelon	TR[2]
		Pleiogynium	TR
	cf. *Mangiferoxylon* sp.1 cf. *Mangiferoxylon* sp.2	*Mangifera*	MD[3], DE[4] (LMrf[5])
Burseraceae	*Canarium*	*Canarium* sp.	MD, DE (LMrf), DD
Combretaceae	*Terminalia* sp.1	*Terminalia*	MD, DE, DD
	Terminalia sp. 2	*Terminalia*	
Irvingiaceae	*Irvingia*	*Irvingia*	DD, DE, TR
Leguminosae	*Cynometroxylon holdeni* *Cynometroxylon* sp. cf. *Cynometroxylon* cf. *Cynometroxylon*	*Cynometra*	EF[6]: TR,MG[7],BF[8]
	cf. *Millettia* sp. 1 cf. *Millettia* sp. 2	*Millettia*	MD
	cf. *Pterocarpus*	*Pterocarpus*	MD, DD
Lecythidaceae	*Careya*	*Careya*	MD, DD
Meliaceae	*Azadirachta*	*Azadirachta* sp.	MD, DD

[1] DD = Dry Dipterocarp forest
[2] TR = Tropical rain forest
[3] MD = Mixed deciduous forest
[4] DE = Dry evergreen forest
[5] LMrf = Lower montane rain forest (~ 1,000 m -1,900 m above sea level)
[6] EF = Evergreen forest
[7] MG = Mangrove forest
[8] BF = Beach forest

5.1.4 Geology of the study area and petrification

The study area was greatly disturbed by human activities from the past: about 7-8 meters of the surface sediments were all removed and two large *in situ* petrified logs disappeared. Therefore the results of this research are mainly based on the present study and on some previous available data. The information on the direction of river flow cannot be concluded from this study. However, the different orientations of five large petrified trunks indicate the strength of flowing water, which was probably from overbank flooding or very strong river flow.

Many petrified logs and fragments were discovered at another area in Chaimongkon subdistrict, about one kilometer from the study site. The surficial sediments were dug out to about 20 m in depth and petrified wood fragments were exposed. Most logs were carried out with the removed soil to another area. However, the original stratigraphic layers, where a large petrified log is embedded, can be seen from the wall. Sediments of that area and the study site are similar and consist of sand, gravel, and pebbles, which indicate characters of sediments from a braided stream system similar with stratigraphic sediments of the “Donjek type model” (Moore, 2008, personal communication; Miall, 1978).

The trees were possibly carried by strong water current and finally buried by the sediments from strong sudden flooding and later became petrified at the study site due to the alkaline solution rather than hydrothermal solution, which can be observed from the rich $CaCO_3$ underground water of that area.

From microscopic features of fossil wood, it is shown that most specimens were not compressed. This implies that the buried sediments above the fossils were not so high. Therefore, they were probably not in a free oxygen condition, but low oxygen. Some strange features seemingly like fungi appear in some vessels.

No trace of catastrophic burning, mentioned by Bunopas *et al.* in 2002 and 2003, was observed on petrified trunks either outside or inside the wood by during microscope studies.

5.2 Conclusions

The paleoflora in the study area shows very close resemblances to the modern flora commonly growing in northeastern Thailand, especially in Suranaree subdistrict, including the area of the Research Institute of Petrified Wood and Mineral Resources and Suranaree University of Technology. The number of fossil tree species occurring at the study site suggests that a rather high diversity of trees was growing in the area at the time of deposition.

The paleoecosystem in that time was dominated by mixed deciduous, some dry dipterocarp, and dry evergreen forest near braided stream system. The weather was warm and the climate was tropical wet and dry (Aw) and tropical monsoon (Am) similar as the Recent, but it was possibly little more humid and less hot because of the ancient river passed there. The logs were carried and embedded in the sediments by strong flooding, and the sediments of the upper section are mixed because of reworking. No trace of burning was observed from petrified trunks in this site.

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APPENDICES

APPENDIX A

LIST OF MODERN WOOD SLIDES FROM FOREST PRODUCTS RESEARCH CENTER USING FOR COMPARATIVE ANATOMY WITH PETRIFIED WOOD

Family	Scientific name	Slide number	Note
Anacardiaceae	*Anacardium excelsum*	FRI 559	
	Buchanania latiflora	FRI 573 (Thailand)	
	Buchanania sp.	- (New slide, Thailand)	
	Dracontamelon dao		
	Dracontamelon mangiferum	FRI 1505; FRI 570	Yala, Thailand; New Guinea
	Mangifera altissima	FRI 563 (Philippines)	
	Mangifera caloneura	- (New slide, Thailand)	
	Mangifera camptosperma	FRI 561	
	Mangifera indica	- (New slide, Thailand)	
Annonaceae	*Polyalthia cerasoides*	FRI 71 (Thailand)	
Burseraceae	*Canarium indicum*	FRI 374	
Burseraceae	*Canarium kerrii*	FRI 377 and FRI 352 (Thailand)	syn. *C. subulatum*, *C. venosum*
	Canarium schweinfurthii	FRI 1354 (Africa)	
	Canarium venosum	FRI 355 and other new slides, TH	syn. *C. subulatum*, *C. kerrii*

Family	Scientific name	Slide number	Note
Burseraceae	*Dacryodes buettneri*	FRI 372 (West of Africa)	
	Garuga pinnata	FRI 347	
	Protium serratum	FRI 345, FRI 346 (Thailand)	
Combretaceae	*Combretum quadrangulare*	FRI 884	
	Terminalia arjuna	FRI 1300 (Thailand)	
	Terminalia alata	FRI 878 (Thailand)	syn. *T. tomentosa*
	Terminalia amazonia	FRI 1202 (Brazil)	
	Terminalia belerica	- (New slide, Thailand)	
	Terminalia brassii	FRI 1012 (New Guinea)	
Combretaceae	*Terminalia chebula*	FRI 879 (Thailand)	
	Terminalia citrine	FRI 874 (Thailand)	
	Terminalia citrine	FRI 1319 (India)	
	Terminalia comintana	FRI 1301 (Philippine)	
	Terminalia paniculata	FRI 1303 (South-west of India)	

Family	Scientific name	Slide number	Note
	Terminalia sumatrana	FRI 870 (North of Borneo)	
	Terminalia superba	FRI 1244 (West of Africa)	Tropical forest
	Terminalia tomentosa	FRI 876 (Burma)	Syn. *T. alata*
Irvingiaceae	*Irivingia malayana*	- (New slide, Thailand)	
Leguminosae	*Afzelia xylocarpa*	FRI 696 (Thailand)	
	Cynometra anata	FRI 651 (America)	
	Cynometra ramiflora	FRI 1150 (Thailand)	
	Cynometra polyandra	FRI 678 (India)	
	Cassia bakeriana	FRI 683 (Thailand)	
	Cassia fistula	FRI 590 (Thailand)	
	Cassia garrettina	FRI 685 (Thailand)	
	Cassia siamea	FRI 593 (Thailand)	
	Pahudia cochinchinensis	FRI 598 and FRI 633 (Indochina)	
Leguminosae	*Pahudia rhomboidea*	FRI 667 (Indochina)	

Family	Scientific name	Slide number	Note
Leguminosae (Papilionoideae)	*Millettia calfra*	FRI 731 (Africa)	
	Millettia leucantha	FRI 610 (Thailand)	
	Millettia versicolor	FRI 1142 (Africa)	
	Pterocarpus indicus	FRI 601 (Thailand)	
	Pterocarpus macrocarpus	FRI 607 (Thailand)	
Lecythidaceae	*Barringtonia* sp.	FRI 919 (Thailand)	
	Barringtonia acutangula	FRI 920	
Lytharaceae	*Lagerstroemia flisreginae*	- (New slide, Thailand)	
Meliaceae	*Amoora polystachya*	FRI 429 (Thailand)	*Amoora* = syn. *Agalia* probably the corrected name is *Aphanamixis polystachya*
Meliaceae	*Azadirachta indicus*	- New slide, Thailand	
	Azadirachta excelsa	- New slide, Thailand	

APPENDIX B

DESCRIPTION OF INDIVIDUAL PETRIFIED WOOD SPECIMENS

Family Combretaceae R. Br.

Genus *Terminalia* L.

Species *Terminalia* sp. 1

Locality: Museum of Petrified Wood and Mineral Resources, grid no. M1

Specimen number: M7-1 (Figs. 4.26 - 4.28)

Preservation: The specimen is well preserved in radial and tangential section, but the cross section is not well preserved, especially fibers. Parenchyma and vessels are rather clear.

Description

Growth ring boundaries indistinct. Wood diffuse-porous.

Vessels 3-6/mm^2. Vessels usually medium sized, t.d. 100 - 180 µm (mean 144.1 µm), r.d. 100 - 200 µm (mean 157 µm). Vessels predominantly solitary and some are in radial multiples of 2 - 3 or 4. Vessel element length (100) 150 - 480 (540) µm (mean 305.94 µm). Dark and brownish deposits appearing in some vessel elements; perforation plates simple; intervessel pits alternate or opposite in some areas, medium to large, 7.20 - 10.80 µm in diameter.

Axial parenchyma lozenge aliform with short wing-like extensions; axial parenchyma in marginal or in seemingly marginal bands.

Rays 1 - 2 seriate (mostly = 1), non-storied, all cells procumbent, tangential height (90 - 150) 200 - 580 (760) µm (average 338.29 µm) and width 15 - 50 µm. Dark deposits in lumina of ray cells.

Fibers nonseptate, thickness of wall cannot be determined because of not well preserved in transverse section.

Family Combretaceae

Genus *Terminalia* L.

Species *Terminalia* sp. 2

Locality: Museum of Petrified Wood and Mineral Resources, grid no. M7

Specimen Number: M7-2 (Figs. B1 - B3)

Preservation: The specimen is well preserved in radial and tangential sections, but the cross section is not well preserved, especially fibers. Parenchyma and vessels are rather clear.

Description

Growth ring boundaries absent. Wood diffuse-porous.

Vessels 2 - 6 /mm^2. Vessels small to medium, t.d. 80 - 150 µm (mean 115.2 µm), r.d. 90 - 210 µm (mean 157.6 µm). Vessels solitary about 60 - 70% and some in radial multiples of 2 - 3, very rarely 4 and 5. Solitary vessel outline round to oval (mostly oval). Vessel element length (130 - 170) 220 - 540 µm (mean 341.56 µm). Perforations simple; intervessel pits alternate, vestured, and medium sized, 8 - 10 µm in diameter. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. In cross section, yellowish brown and dark deposits appear to completely fill some vessel lumina, and in longitudinal sections, deposits often appearing collected at the end of vessel elements.

Axial parenchyma aliform; lozenge to short wing-aliform. Axial parenchyma in marginal or in seemingly marginal bands.

Rays 1-2 seriate (mostly 1), rays 7 - 21 cells high, tangential height (110 - 120) 145 - 300 (355 - 445) µm (average 210.14 µm) and width 19.2 - 36 µm, non storied. Parenchyma strands, 5 - 8 cells, present especially close to vessels.

Homogeneous rays consisting of homocellular rays, all ray cells procumbent.

Fibers nonseptate and very thick-walled.

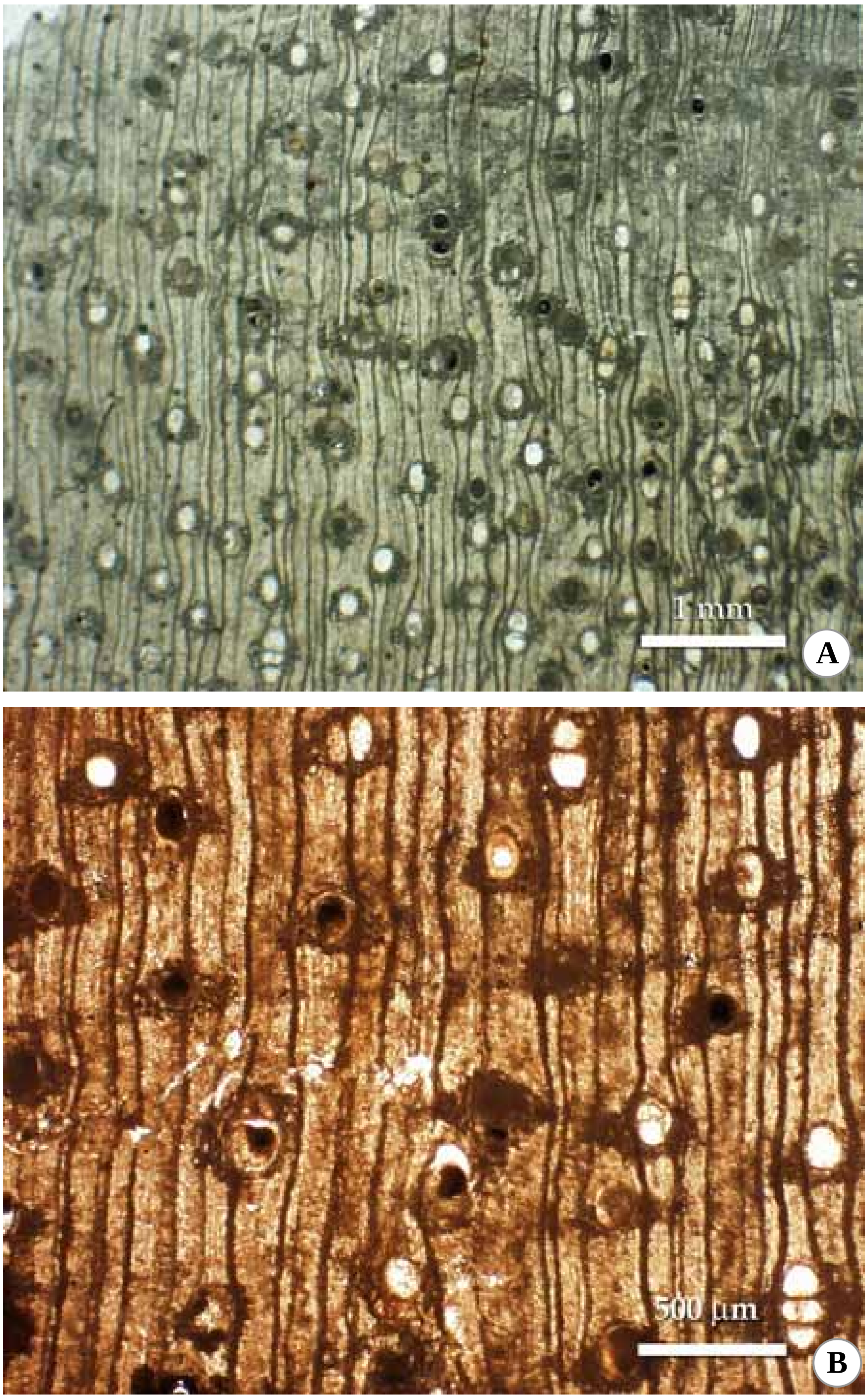

Figure B1 Thin section of fossil wood M7-2 in transverse section. **A.** Diffuse porous wood. Vessels mostly solitary and occasionally in radial multiples of 2 - 4. **B.** Axial parenchyma lozenge to short wing-aliform and in marginal or in seemingly marginal bands.

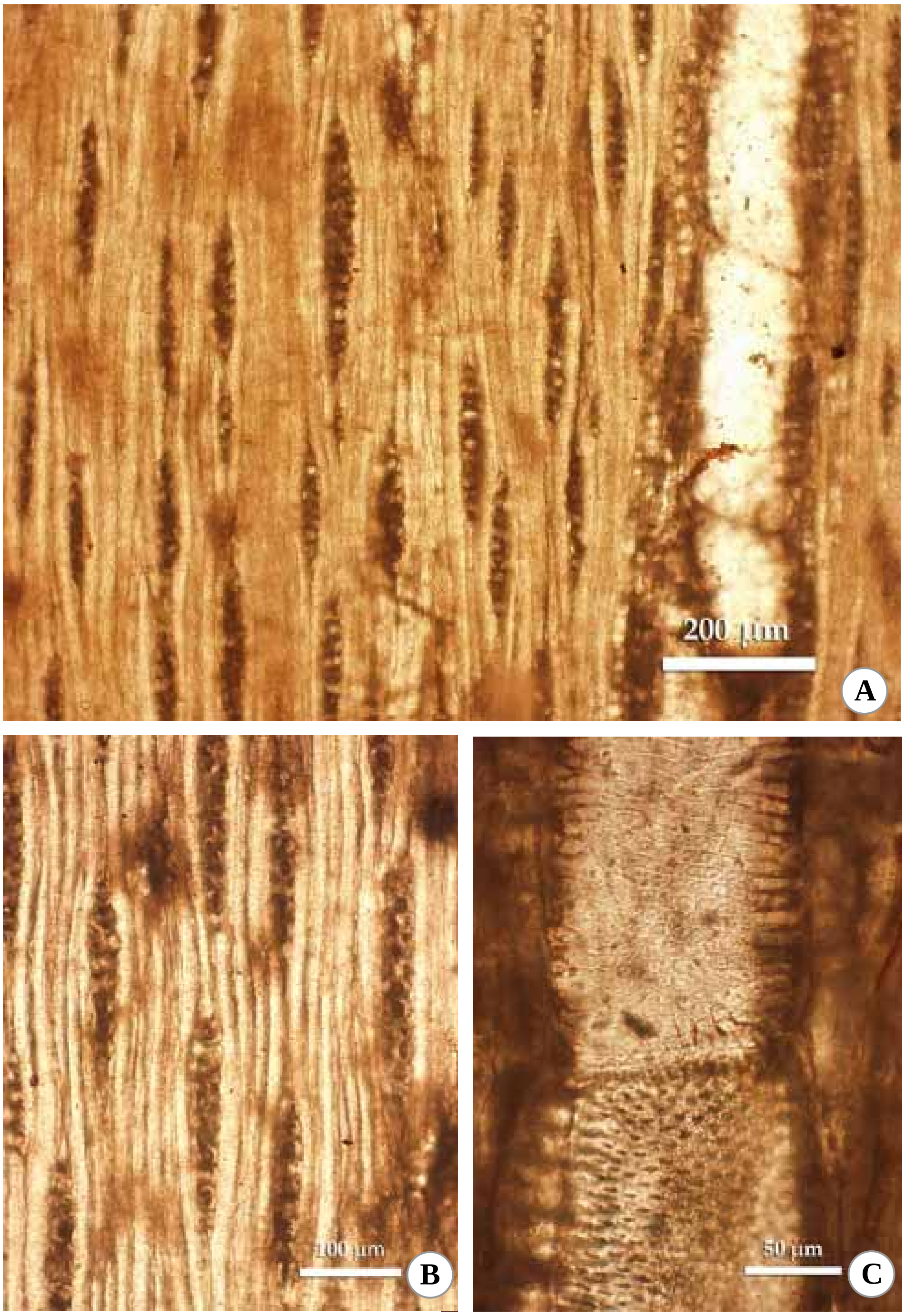

Figure B2 Thin section of fossil wood M7-2. **A.** and **B.** (Tg) Non-storied, 1 - 2 seriate rays and non-septate fibers. **C.** (Tg) Alternate intervessel pitting can be observed from vessels wall.

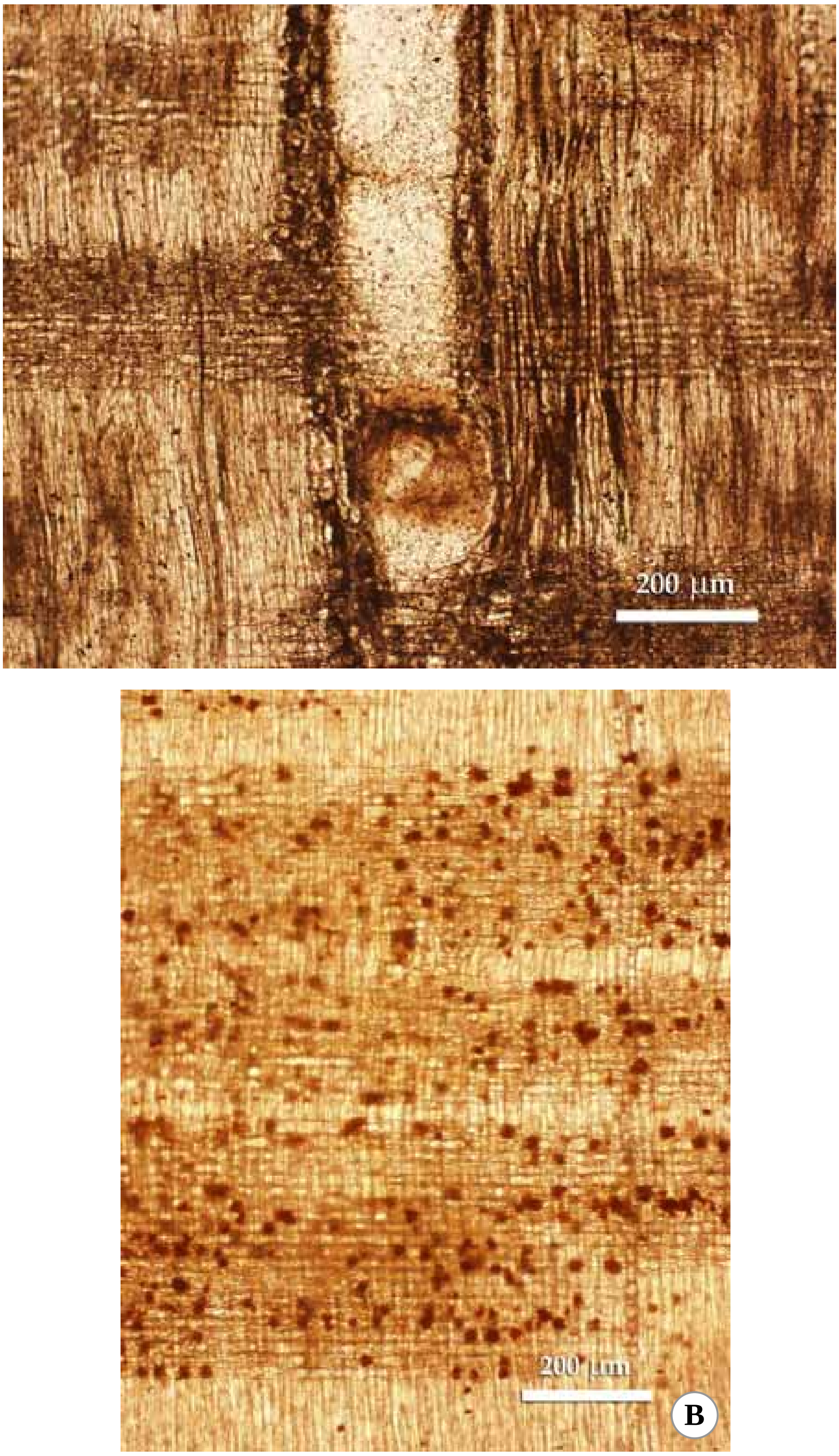

Figure B3 Thin section of fossil wood M7-2 in radial section. **A.** and **B.** Homogeneous rays consisting of homocellular rays, all cells procumbent.

Family Leguminosae Juss.

Genus *Cynometroxylon* Chowdhury and Ghosh, 1946

Species *Cynometroxylon holdeni* (Gupta) Prakash and Bande, 1980

Locality: Museum of Petrified Wood and Mineral Resources, grid no. F5

This specimen was collected from a moderate sized log fragment, with the main trunk still embedded *in situ* in the surface of the sediment.

Specimen number: F5-1 (Figs. 4.36 - 4.37)

Preservation: The specimen is well preserved. Although fibers are not very clear in cross section, they can be described. Other cell types are clearly seen in all sections

Description

Growth ring boundaries indistinct. Wood diffuse-porous.

Vessels 4 - 6 /mm^2. Vessels usually medium and few small sized t.d., 90 - 200 µm (mean 147.8 µm), r.d. (100) 130 - 230 µm (mean 174.1 µm), solitary as well as in radial multiples of 2, or sometimes 3 or 4. Solitary vessel outlines mostly round and some oval with brownish or black deposits in lumina.

Vessel element length 105 - 450 µm (mean 288.39 µm). Simple perforation plates. **Intervessel pits** alternate, vestured, and small, 4 - 6 µm in diameter. Vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cell.

Paratracheal **axial parenchyma** vasicentric and banded 2 - 6 cells in width. Bands of parenchyma alternating with thicker bands (~7 - 17 cells wide) of fibers and partially or wholly encircling the vessels. In tangential section, the banded parenchyma appears as inclining ripples.

Rays (1) 2 (3) seriate and 7 - 26 cells high, tangential height (120) 150 - 350

(475) µm (average 259 µm) and width (15-20) 25 - 45 (55) µm. Ray heterocellular; body ray cells procumbent with one row of upright and/or square marginal cells. Rays occasionally irregularly storied, some non-storied, and a few storied, all present in the same specimen.

Fibers very thick-walled, non-septate and libriform (pits in fiber walls can be seen in some areas).

Family Leguminosae

Genus *Cynometroxylon* Chowdhury and Ghosh, 1946

Species *Cynometroxylon holdeni* (Gupta) Prakash and Bande, 1980

Locality: Museum of Petrified Wood and Mineral Resources, grid no. F5

This specimen is a small fragment on the ground close to the *in situ* log fragment in the surface of the sediment

Specimen Number: F5-2 (Figs. B4 - B5)

Preservation: The specimen is very well preserved, can be clearly seen in all sections**.**

Description

Growth ring boundaries absent. Wood diffuse-porous.

Vessels 2-5 /mm^2. Vessels small to medium sized, t.d. (50 - 60) 70 - 150 µm (mean 100.6 µm), r.d. 90 - 210 µm (mean 156.1 µm). Vessels solitary or some in radial multiples of 2 - 3, rarely 4, and few 5 - 6. Solitary vessel outline oval to elliptic. Vessel element length (120) 125 - 350 (450) µm (mean 254.72 µm). Perforation simple; **intervessel pits** alternate, vestured, and minute to small sized (usually small), about 3 - 5.5 µm in diameter. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. In cross section, yellowish brown and dark deposits appearing to completely fill some vessel lumina, and, in longitudinal sections, deposits often appearing collected at the end of vessel elements.

Axial parenchyma vasicentric and banded ~ 3 - 7 cells wide, alternating with the slightly wider bands of fibers. Occasionally, some parenchyma bands bifurcating and joining with each other. Axial parenchyma in marginal or in seemingly marginal bands.

Rays 1 - 2 seriate, (3 - 6) 9 - 28 cells high, and non-storied. Tangential height varies from (90, 100) 135 - 445 (520, 610) μm (average 285 μm) and width 14.4 - 36 μm. Rays heterocellular; body ray cells procumbent with 1 row of upright or square marginal cells.

Fibers non-septate, thick to very thick-walled.

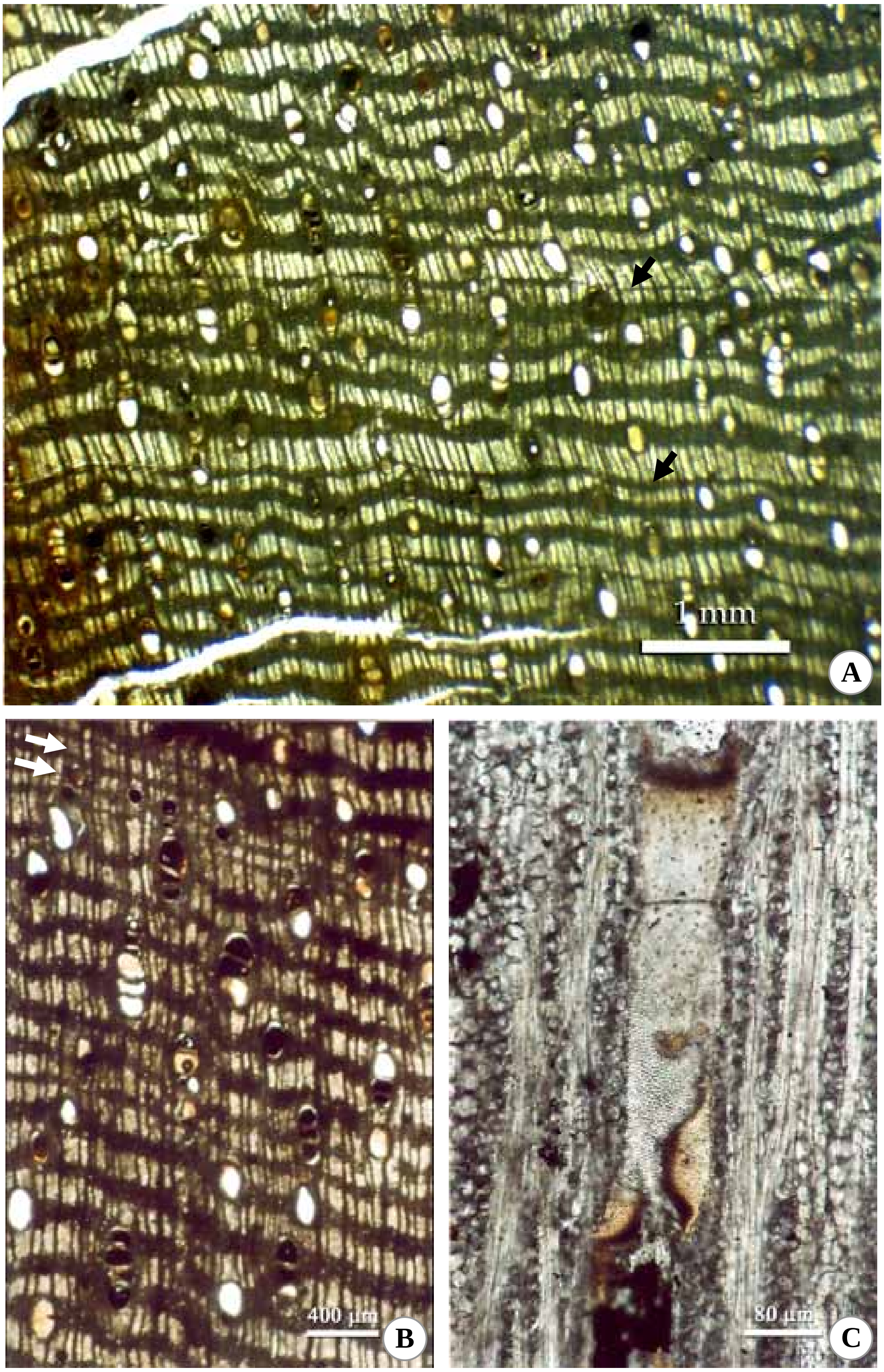

Figure B4 Fossil wood of F5-2. **A.** and **B.** (Tn) Axial parenchyma bands ~3 - 7 cells wide and marginal bands (arrows).Vessels solitary and in radial multiples of 2 - 4 (-6). **C.** (Tg) Non-storied, 1 - 2 seriate rays and alternate intervessel pits.

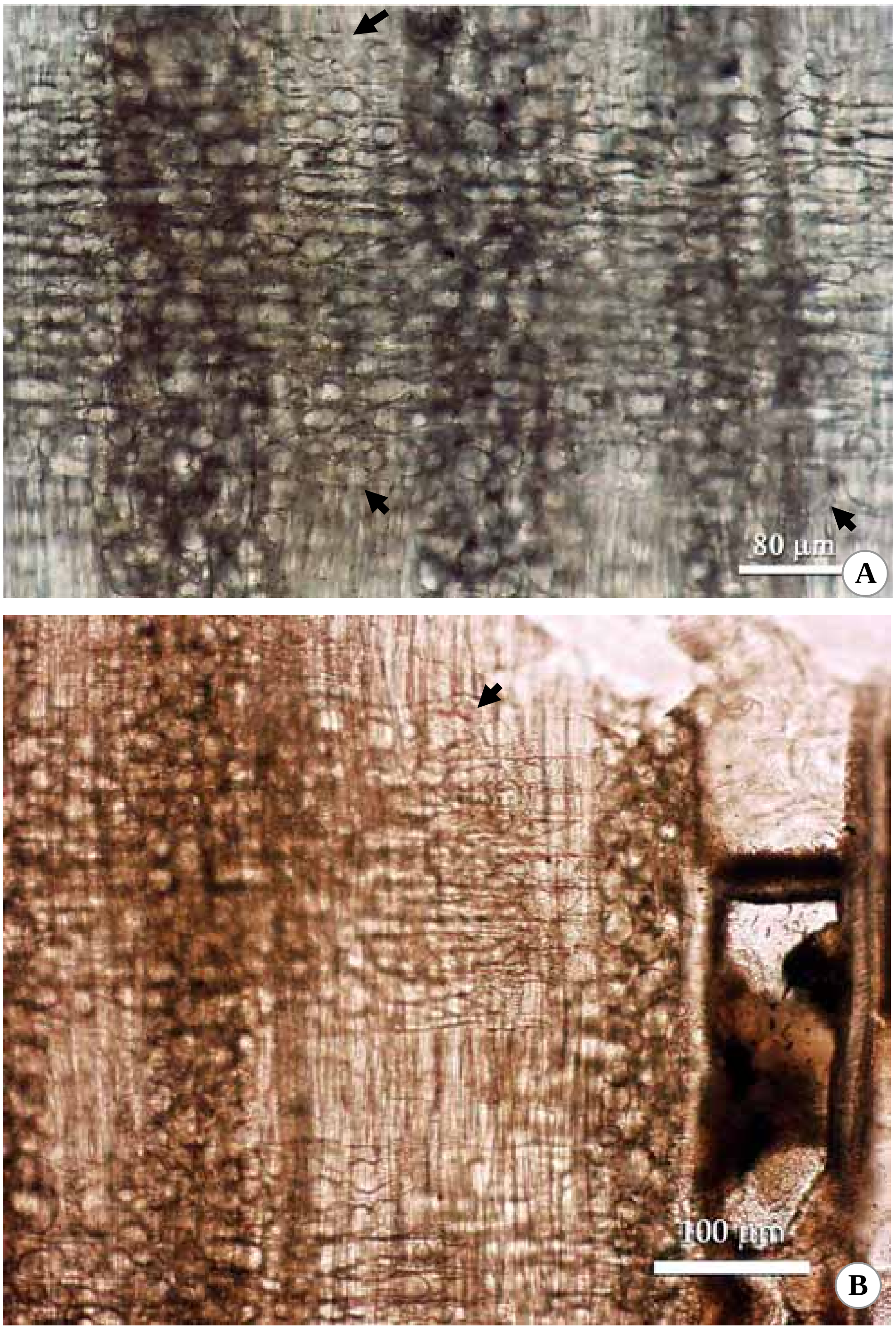

Figure B5 Fossil wood of F5-2 in radial section. **A. & B.** Body ray cells procumbent with one row of upright and/or square marginal cells (arrows).

Family Leguminosae

Genus *Cynometroxylon* Chowdhury and Ghosh, 1946

Species *Cynometroxylon holdeni* (Gupta) Prakash and Bande, 1980

Locality: Museum of Petrified Wood and Mineral Resources, grid no. I2

Specimen number: I2-2 (Figs. B6 - B8)

Preservation: The preservation is fair. Fibers in cross section are not well preserved, but can be seen clearly enough to describe in some areas.

Description

Growth ring boundaries indistinct. Wood diffuse-porous.

Vessels 3 - 5 /mm^2. Vessels small to medium sized, t.d. (60) 80 - 180 (210) µm (mean 127.7 µm), r.d. 100 - 280 µm (mean 195 µm). Vessels mostly solitary, some are in radial multiples of 2 - 3 (4); very rarely vessels in radial multiples irregularly attached together in a tangential line (Fig. B6 - B). Solitary vessel outline oval to elliptic.Vessel element length (140) 200 - 470 µm (mean 322.29 µm). Perforation plates simple. Vessels more often present in between banded parenchyma than among bands of fibers. Deposits appearing to fill a few vessels lumina.

Intervessel pits alternate, vestured, and small, 4 - 5 µm in diameter. Vessel-ray pits with distinct boarders; similar to intervessel pits in size and shape throughout the ray cells.

Paratracheal axial **parenchyma** vasicentric and banded 3 - 9 cells wide alternating with bands of fiber; usually fiber bands thicker, but occasionally very broad banded parenchyma occuring. Many chambered parenchyma cells present in tangential section, sometimes causing difficulty in distinguishing the tips of long ray cells and short parenchyma cells when they are close together. Three to five cells per parenchyma strand. Prismatic crystals present in chambered axial parenchyma cells.

Rays (1) 2 (rarely 3) seriate, 6 - 22 cells high, and non-storied. Tangential height (115) 165 - 335 (400, 430) µm (average 252.2 µm) and width 15 - 45 (55) µm. Rays heterocellular; body ray cells procumbent with one row of upright and/or square marginal cells.

Fibers non-septate, very thick walled, and banded about 5 - 19 cells in vertical lines.

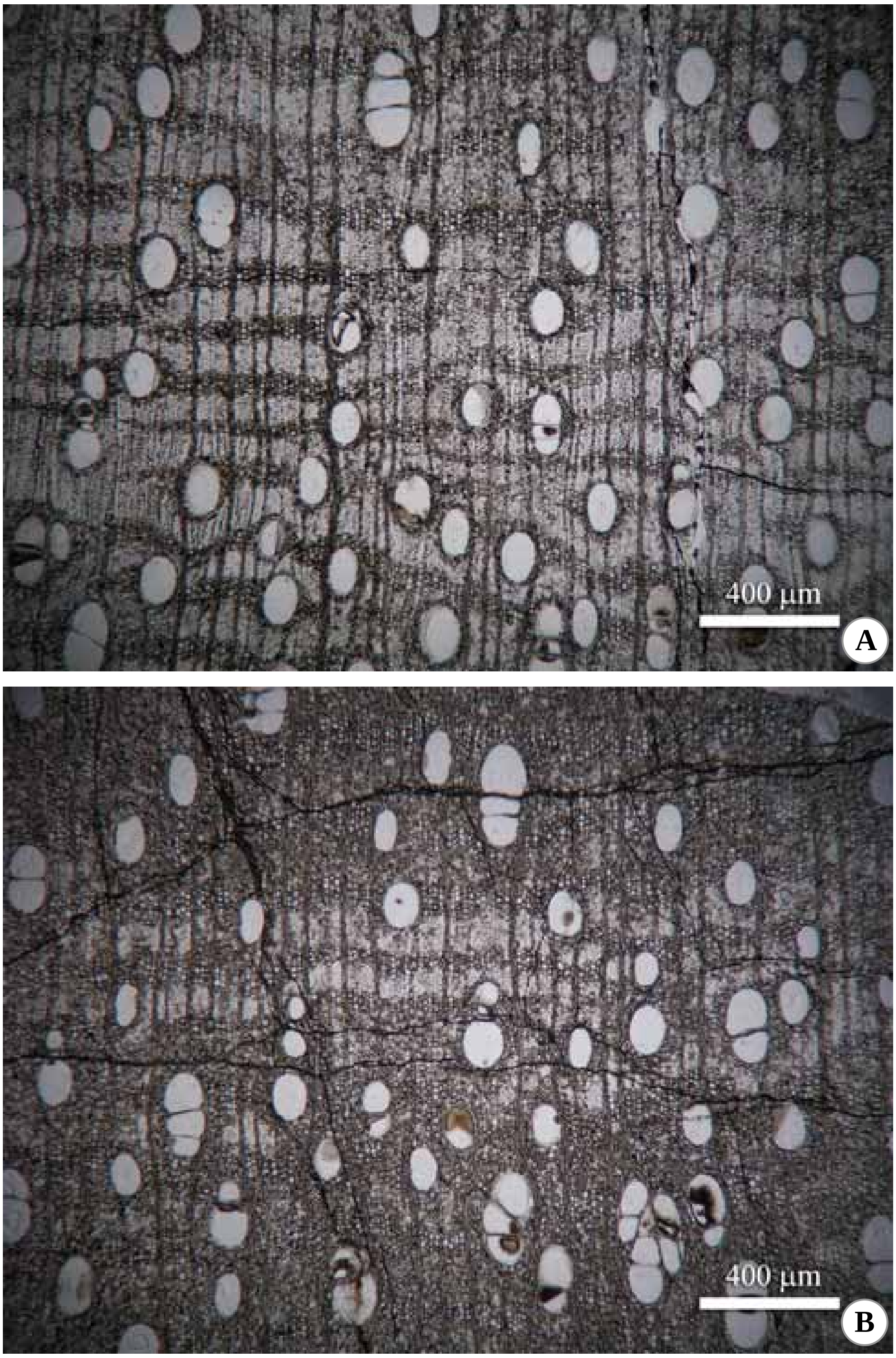

Figure B6 Thin section of fossil wood I2-2 in transverse section. **A.** Vessels solitary and in radial multiples of 2-3. Axial parenchyma banded**. B.** A few vessels present in clusters.

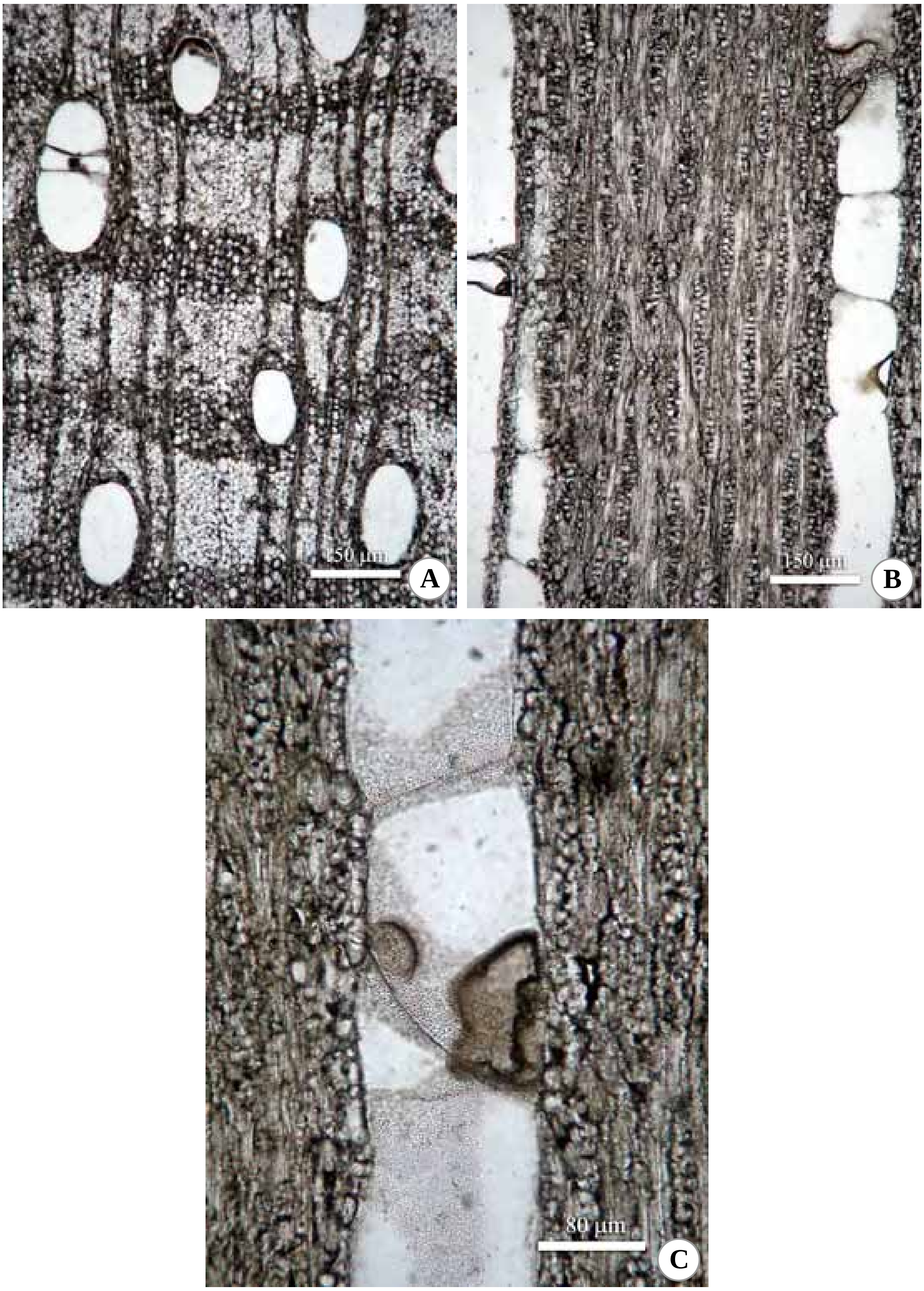

Figure B7 Thin section of fossil wood I2-2. **A.** (Tn) Banded parenchyma and fibers very thick walled. **B.** (Tg) Rays often biseriate and non-storied. **C.** (Tg) Alternate intervessel pits.

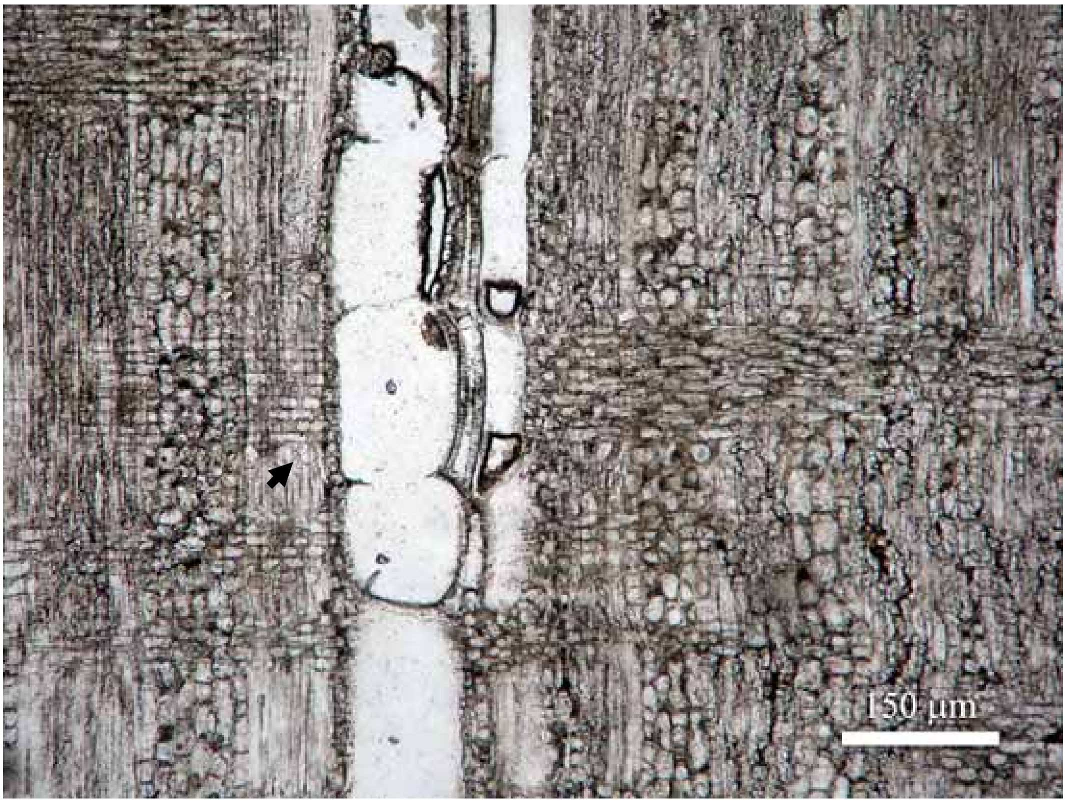

Figure B8 Thin section of fossil wood I2-2 in radial section. Rays consisting of procumbent body ray cells with one row of upright and/or square marginal cells (arrow).

Family Leguminosae

Genus *Cynometroxylon* Chowdhury and Ghosh, 1946

Species *Cynometroxylon holdeni* (Gupta) Prakash and Bande, 1980

Locality: Museum of Petrified Wood and Mineral Resources, grid no. I2

Specimen number: I2-3 (Figs. 4.30 - 4.32 and Figs. B9A - B)

Preservation: The specimen is very well preserved, especially the radial and tangential sections which are excellent. All sections can be clearly seen.

Description

Growth ring boundaries indistinct. Wood diffuse-porous.

Vessels 3 - 4 /mm^2. Vessels small to medium sized, t.d. (40 - 50) 70 - 150 µm (mean 89.3 µm), r.d. 90 - 200 µm (mean 153 µm). Vessels mostly solitary, some in radial multiples of 2 - 3 (4). Solitary vessel outline usually oval. Vessels more often present in between banded parenchyma than among bands of fibers. Vessel element length (60, 100) 165 - 400 (450 - 460) µm (mean 272.83 µm). Perforation plates simple. Many roughly rounded objects, probably fungi, present (Fig. B9A - B).

Intervessel pits alternate, vestured, and minute to small, 3 - 5 µm in diameter. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cells.

Axial parenchyma banded (3) 4 - 6 (7) cells wide, alternating with thicker fiber bands of 6 - 24 cells in transverse section. Occasionally parenchyma bands bifurcating and then joining other bands on upper and lower sides. Four to eight or > 8 cells / parenchyma strand.

Rays 1 - 2 seriate and 5 - 21 cells high, varying in tangential height 80 - 440 (570) µm (average 241 µm) and width (10) 15 - 35 µm. Ray non-storied or some irregularly storied. The terminal cell of some rays, or sometimes the cell wall, contacting the cell of another ray; under 40X or 100X magnification appearing like one long ray. Rays heterocellular; body ray cells procumbent with mostly one row of upright and/or square marginal cells.

Fibers thick-walled and non-septate.

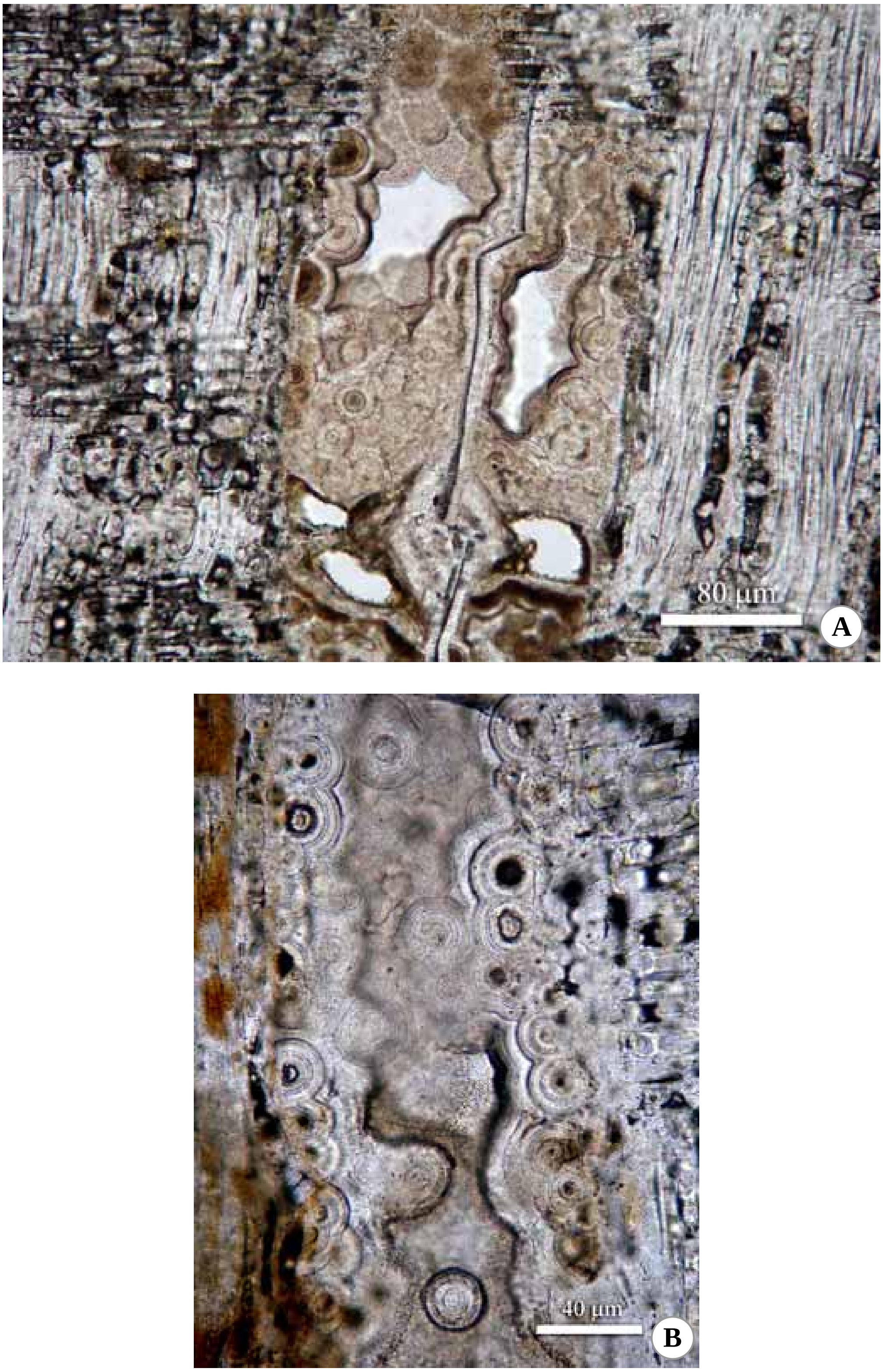

Figure B9 A. and **B.** Thin section of fossil wood I2-3 in radial section, showing brownish multilayer rounded objects, probably fungi, present.

Family Leguminosae.

Genus *Cynometroxylon* Chowdhury and Ghosh, 1946

Species *Cynometroxylon holdeni* (Gupta) Prakash and Bande, 1980

Locality: Museum of Petrified Wood and Mineral Resources, grid no. M1

Specimen number: M1-4 (Figs. B10 - B13)

Preservation: The specimen is rather well preserved; details can be seen clearly in all sections.

Description

Growth ring boundaries indistinct. Wood diffuse-porous.

Vessels 3-5 /mm^2. Vessels solitary as well as in radial multiples of 2 - 3 (5), a few in clusters of 3 vessels. Vessels seem more commonly present among fiber bands than parenchyma bands. Solitary vessel outlines circular to oval (most oval). Vessels medium or some small sized, t.d. 60 - 190 µm (mean 125.4 µm), r.d. 90 - 280 µm (mean 201.4 µm). Some tetragonal, hexagonal, and polygonal shapes as crystals appearing in vessel lumina.

Vessel element length (150) 190 - 420 (480) µm (mean 302 µm). Perforation plates simple. **Intervessel pits** alternate, minute to small sized 3 - 6 µm. Shape of alternate pits polygonal. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell.

Axial parenchyma banded, commonly ~ 4 - 7 cells wide. Bands of parenchyma alternating with thicker bands of fibers. Parenchyma in continuous tangential lines wider than rays.

Rays commonly 2 -3 seriate (very rarely 1 or 4 seriate), (7) 12 - 21 (28) cells high; tangential height 200 - 400 (580) µm (average 328.85 µm) and width (25) 30 -

35 µm. Rays mixed non-storied, irregularly storied, and storied present in the same specimen. Rays heterocellular consisting of all ray cells procumbent and/or body ray cells procumbent with one row of upright marginal cells.

Fibers (thin)-thick-very thick-walled (usually very thick) and non-septate.

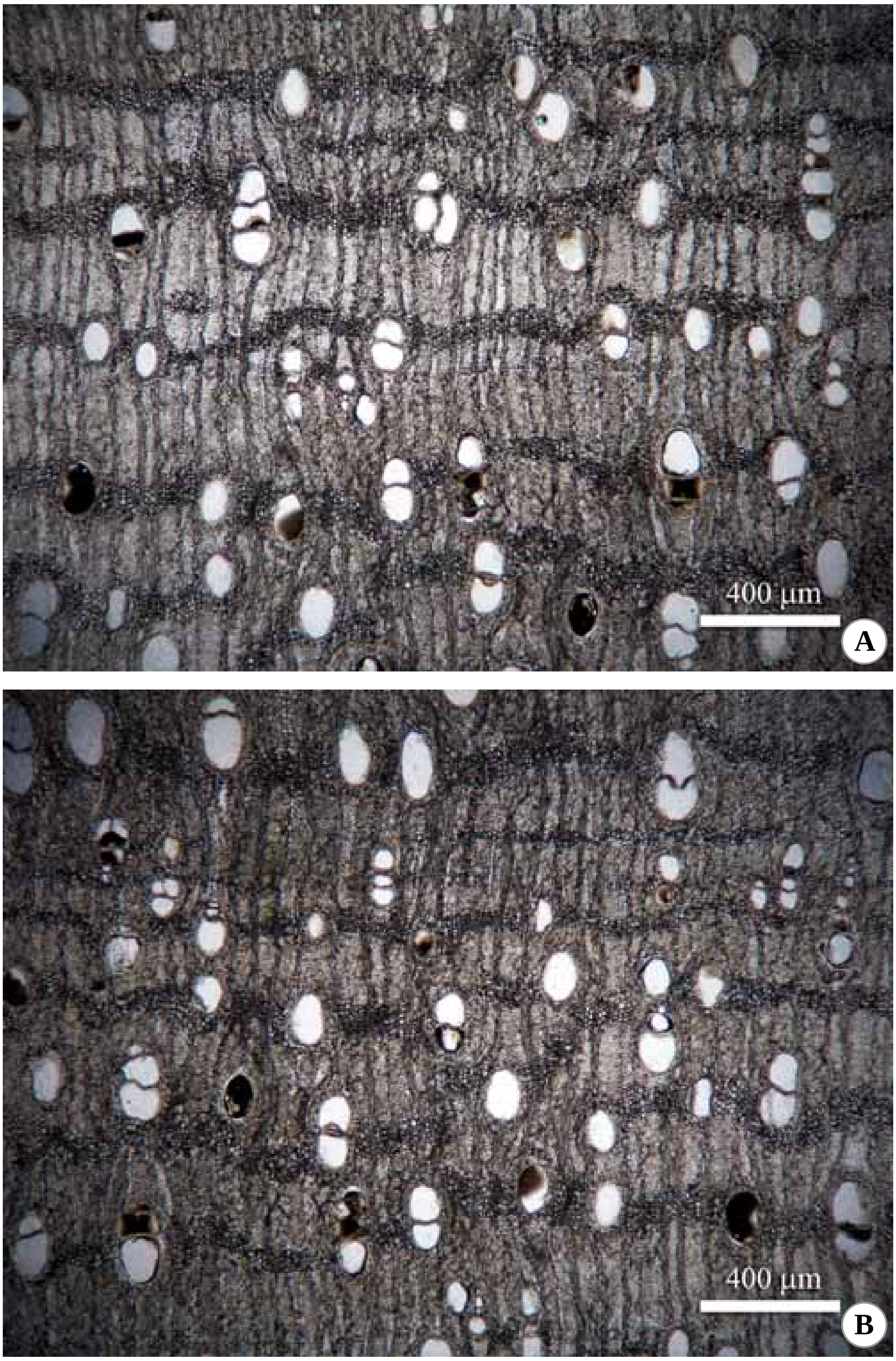

Figure B10 Fossil wood of M1-4 in transverse section. **A.** and **B.** Banded parenchyma alternating with fiber bands. Vessels solitary and in radial multiples of 2 - 3 (- 6), rarely in clusters of 3. Vessels in narrow bands smaller than those in boarder.

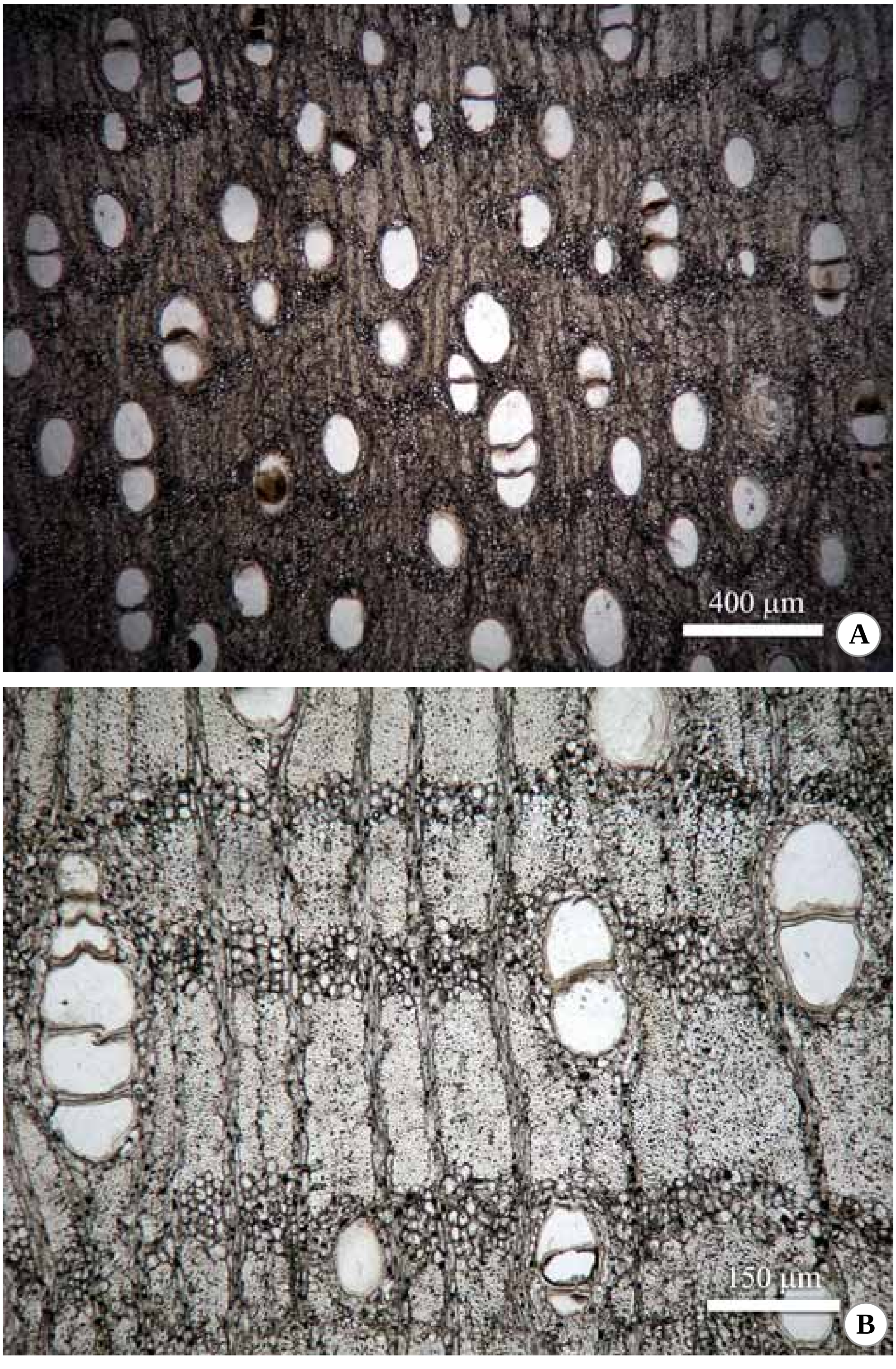

Figure B11 Fossil wood of M1-4 in transverse section. **A.** Axial parenchyma confluent and banded. **B.** Vessels rarely in radial multiples of 6, and fibers very thick-walled.

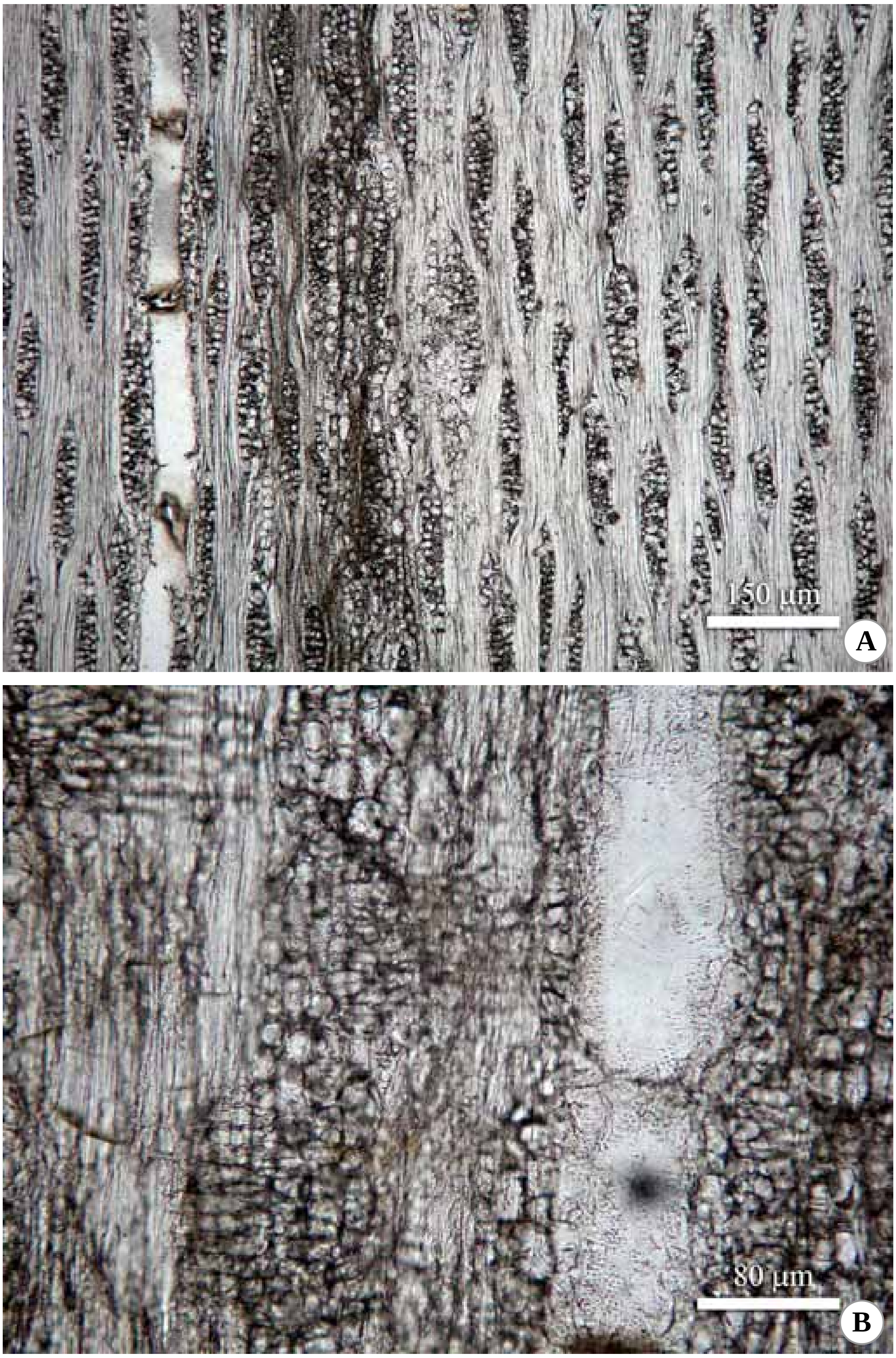

Figure B12 Fossil wood of M1-4 in transverse section. **A.** Non-storied and 2-3 seriate rays, non-septate fibers. **B.** Vessel-ray pitting.

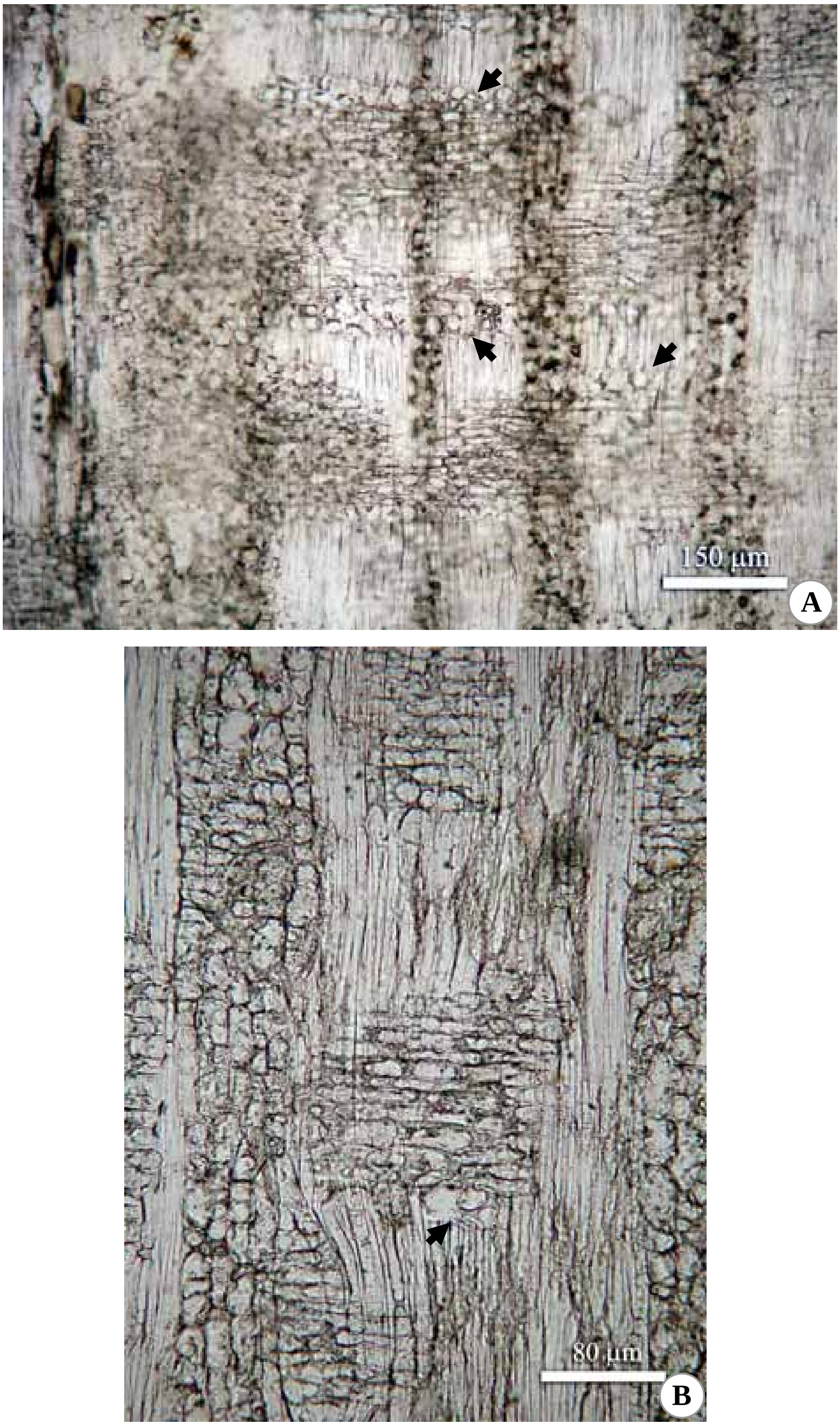

Figure B13 Fossil wood of M1-4 in radial section. **A.** and **B.** Body ray cells procumbent with one row of square marginal cells (arrows).

Family Leguminosae

Genus *Cynometroxylon* Chowdhury and Ghosh, 1946

Species *Cynometroxylon holdeni* (Gupta) Prakash and Bande, 1980

Locality: Museum of Petrified Wood and Mineral Resources, grid no. M8

Specimen Number: M8 (=NRRU 60) (Figs. B14-B16)

Preservation: The specimen is very well preserved in transverse section, moderate in radial section, but very poorly preserved in tangential section.

Note: This slide and museum slide number NRRU-60 are from the same specimen; therefore, intervessel pits and some organ in tangential sections, i.e., vessel element length and rays size, which cannot be seen or clearly observed in M8, were measured from NRRU-60 instead.

Description

Growth ring boundaries indistinct or absent. Wood diffuse-porous.

Vessels 6 - 10 /mm^2. Vessels usually medium to large, a very few small, sized, t.d. 80 - 180 µm (mean 138.5 µm), r.d. (60) 130 - 280 µm (mean 211.2 µm). Vessels solitary ~ 55% and some in radial multiple of 2 - 4 (often 2 - 3), rarely 4, and very rarely in clusters. Solitary vessel outline oval. Vessel element length (60) 80 - 180 µm (mean 125 µm). Perforation simple; intervessel pits alternate, vestured, minute to small sized, 3.20 - 4.40 µm in diameter. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. In cross section, yellowish brown and dark deposits appearing to partly fill some vessel lumina and in longitudinal sections, deposits often appearing collected at the end of vessel elements, but not often (only in some cells) and not thick. Hexagonal shape objects observed in vessel lumina.

Axial parenchyma vasicentric; banded parenchyma ~ 3 - 7 cells wide, alternating with the thicker fiber bands. Axial parenchyma in marginal or in seemingly marginal bands.

Rays 1-3 seriate, tangential height 100 - 360 (430 - 485) µm (average 275 µm) and width (12 - 17) 19 - 33 (36 - 43) µm. Most rays with all ray cells procumbent; a few rays with body ray cells procumbent with 1 (very rarely 2 or 4) row of upright or square marginal cells.

Fiber very thick-walled and non-septate.

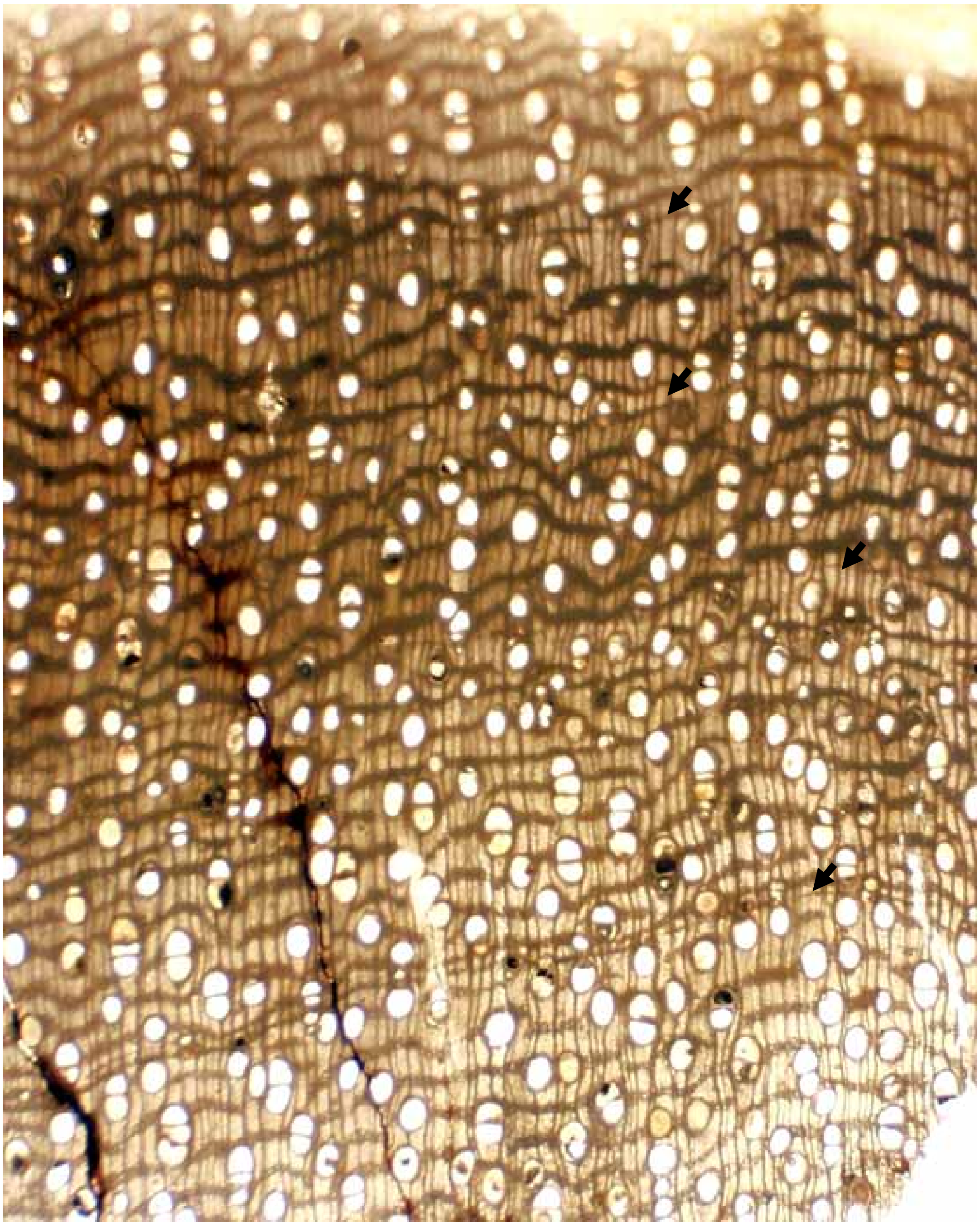

Figure B14 Thin section of M8 in transverse section, showing vessel distribution, wood diffuse-porous; axial parenchyma bands with parenchyma in seemingly marginal bands (arrows).

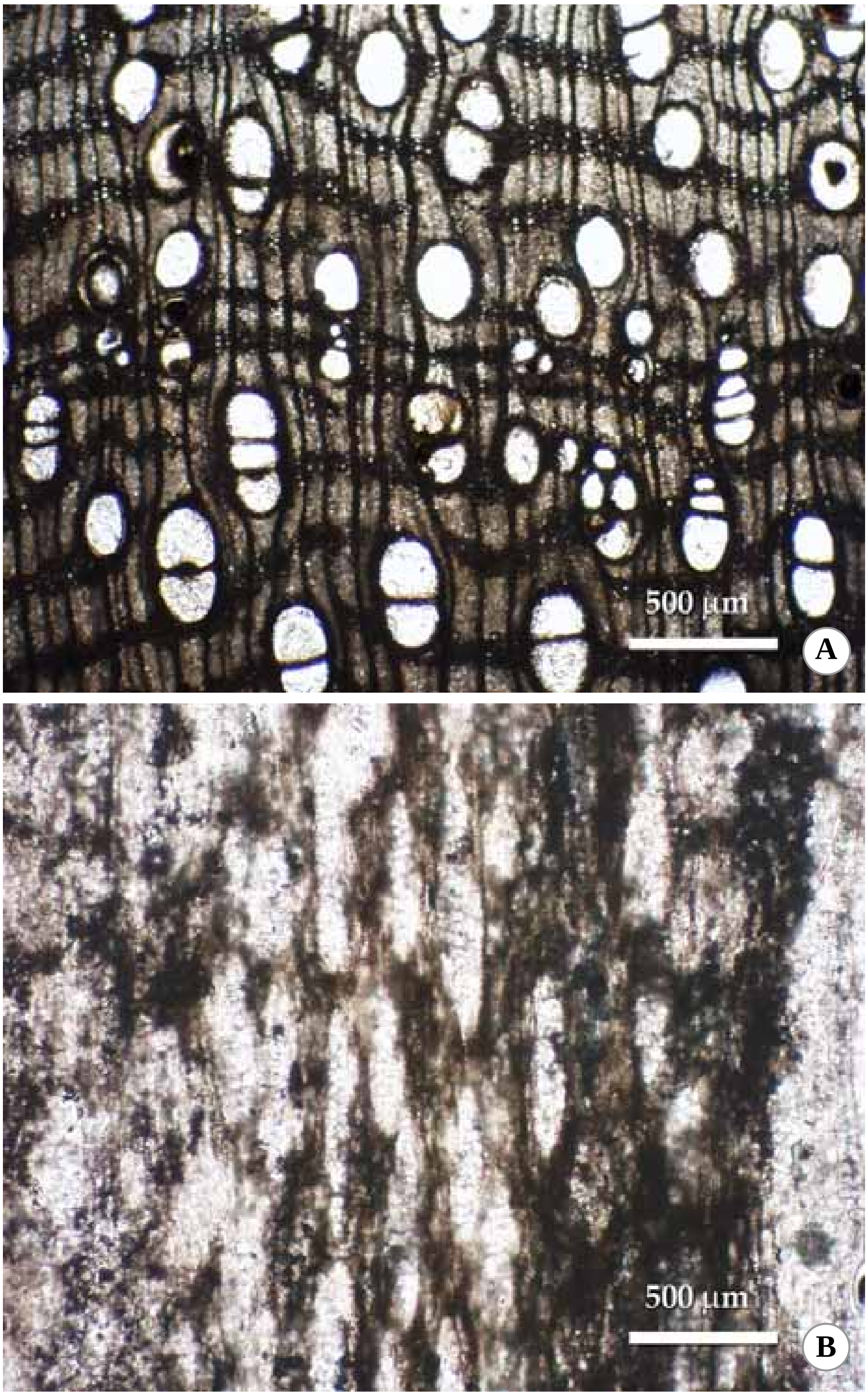

Figure B15 Thin section of M8. **A.** (Tn) Vessels solitary, in radial multiples of 2 - 3, or a few in clusters; axial parenchyma bands 3 - 7 cells wide. **B.** (Tg) Non-storied and 2 - 3 seriate rays.

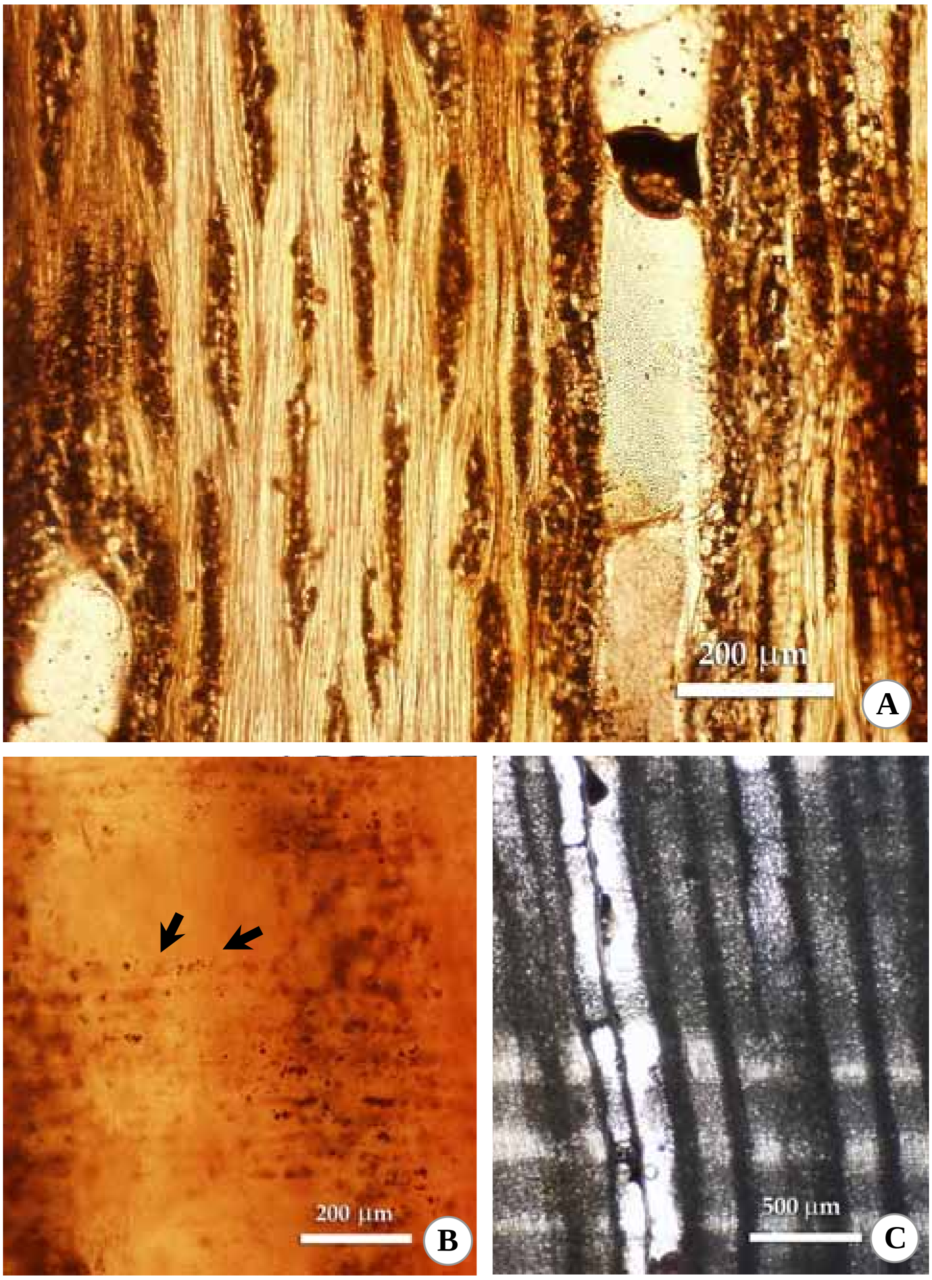

Figure B16 Thin section of slide no. NRRU-60 (A and B). **A.** (Tg) Non-storied and 1 - 3 seriate rays, non-septate fibers, alternate intervessel pits, and deposits appearing to collect at the ends of vessel elements. **B.** (R) Body ray cells procumbent with one row of square/upright marginal cells (arrow).**C.** (R) Thin section of slide no. M8 showing vessels elements and pattern of rays.

CURRICULUM VITAE

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Brief about works:

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