# ไม้กลายเป็นหินสกุล *Agathoxylon* ในเส้นทางศึกษาธรรมชาติแหล่งซากดึกดำบรรพ์ไม้กลายเป็นหินภูปอ อำเภอคำม่วง จังหวัดกาฬสินธุ์ ประเทศไทย

# Petrified wood of the genus *Agathoxylon* on the nature trail at Phu Por fossil site, Kham Muang District, Kalasin Province, Thailand

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## บทคัดย่อ

การศึกษาเปรียบเทียบลักษณะทางกายวิภาคศาสตร์ของไม้กลายเป็นหินในมหายุคมีโซโซอิก ณ แหล่งซากดึกดำบรรพ์ไม้กลายเป็นหินภูปอ อำเภอคำม่วง จังหวัดกาฬสินธุ์ มีวัตถุประสงค์เพื่อจำแนกชนิดไม้กลายเป็นหินที่พบในเส้นทางศึกษาธรรมชาติ ซึ่งเป็นส่วนหนึ่งของการพัฒนาแหล่งซากดึกดำบรรพ์ให้กลายเป็นแหล่งอนุรักษ์ซากดึกดำบรรพ์และแหล่งท่องเที่ยวทางธรรมชาติของอุทยานธรณีกาฬสินธุ์ ตัวอย่างทั้งหมด 7 ตัวอย่าง ศึกษาด้วยวิธีการตัดแผ่นหินบาง เพื่อศึกษากายวิภาคของเนื้อไม้ พบไม้กลายเป็นหิน 1 สกุล คือ *Agathoxylon* พบวงปีชัดเจนและไม่พบวงปี ผนังเทรคีดบางและหนา หลุมผนังเซลล์ 1 – 2-seriate เซลล์เรย์ 1 – 2-seriate ปลายเซลล์เรียบ และมี cross-field pits แบบ araucarioid 4 – 12 รอยเว้า การตรวจสอบและวิเคราะห์วงปีของไม้กลายเป็นหินสกุล *Agathoxylon* ช่วยคาดการณ์สภาพอากาศบรรพกาลได้ พบว่าตัวอย่างที่ศึกษามีทั้งที่พบวงปีและไม่พบวงปี บ่งบอกว่าต้นไม้เหล่านี้ผ่านการเผชิญกับสภาพอากาศชื้นโดยมีฤดูแล้งสลับกันในช่วงกลางถึงปลายยุคจูแรสซิก หรือการแปรผันของวงปีอาจเกิดจากการแทนที่ที่ไม่สมบูรณ์ของแร่ธาตุระหว่างที่เกิดกระบวนการกลายเป็นหิน หรือจากผลกระทบอื่นๆ ทางธรณีวิทยา ในขณะที่การค้นพบไม้กลายเป็นหินสกุล *Xenoxylon* จากการศึกษาก่อนหน้าสนับสนุนสมมติฐานสภาพอากาศที่เย็นและเปียก การศึกษานี้อาจเป็นส่วนช่วยในการพัฒนาแหล่งซากดึกดำบรรพ์ไม้กลายเป็นหินภูปอให้เป็นแหล่งท่องเที่ยงเชิงอนุรักษ์ ส่งผลดีต่อเศรษฐกิจท้องถิ่น นอกจากนี้ยังช่วยเพิ่มคุณค่าการเรียนรู้และอุทยานธรณีกาฬสินธุ์ให้ได้รับการยอมรับในฐานะศูนย์กลางการท่องเที่ยวและการวิจัยระดับชาติและนานาชาติ

**คำสำคัญ:** *Agathoxylon*, ไม้กลายเป็นหิน, จูแรสซิก, กลุ่มหินโคราช, อุทยานธรณีกาฬสินธุ์

## Abstract

A comparative anatomy of the Mesozoic petrified wood was conducted at the Phu Por fossil site in Kham Muang District, Kalasin Province. The objective is to classify the petrified wood species found along the nature trails, contributing to the development of the Kalasin Geopark and conservation tourism or natural tourist attractions focused on Mesozoic-era petrified wood in Thailand. A total of seven samples were studied using the thin section technique, revealing the presence of one genus of petrified wood, *Agathoxylon. Agathoxylon* sp. is characterized by the presence or absence of growth rings, thin or thick-walled thacheis, 1 – 2-seriate alternate or opposite in radial walls, 1 – 2-seriate rays, and araucarioid cross-field pits.

Examining and analyzing the growth rings of petrified wood allows for paleoclimate predictions. It was found that the samples had both clear and unclear growth rings, suggesting these trees experienced humid weather with alternating short dry seasons during the middle to late Jurassic. The presence of *Agathoxylon* with growth rings implies a humid climate, while the discovery of *Xenoxylon* from previous studies supports a cool and wet climate hypothesis.

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Additionally, variations in growth rings may be due to incomplete mineral replacement during petrification or other geological processes. Developing Phu Por fossil site into an eco-tourism destination can significantly benefit the local economy. Furthermore, it will enhance the scientific and educational value of the site, contributing to Kalasin Geopark's recognition as a national and international tourist and research hub.

**Keywords:** *Agathoxylon*, Petrified wood, Jurassic, Khorat Group, Kalasin Geopark

## Introduction

The discoveries of petrified wood in the Khorat Plateau of Thailand have been reported from several provinces in northeastern region. These provinces include Kalasin, Nakhon Ratchasima, Khon Kaen, Roi Et, Yasothon, Udon Thani, Mukdahan, and Sakon Nakhon. The petrified wood found includes *Agathoxylon saravanensis*, *Agathoxylon* sp., *Brachyoxylon boureauii*, *Brachyoxylon orientale*, *Brachyoxylon serrae*, and *Xenoxylon* sp. (Philippe *et al*., 2004, 2009, 2011; Boonchai *et al*., 2020).

In Kalasin Geopark, many significant fossil localities have been discovered. One of the richest and complete dinosaur fossil sites is the Phu Kum Khao which located in Sahatsakhan District. The site was developed to the Sirindhorn Museum, the biggest dinosaur museum in Northeastern of Thailand. Developed from the rich fossil site of Phu Kum Khao, this museum houses an extensive collection of dinosaur fossils, making it a key destination for researchers and visitors alike. Recently, one of the most outstanding fossil localities was discovered at Baan Din Chi, Kham Muang District, Kalasin Province. The site named Phu Noi fossil site, has yielded more than 5,000 dinosaur bones, including those of sauropods, theropods and ornithopods, as well as several vertebrate remains such as pterosaurs, crocodiles, turtles, bony fish, and freshwater sharks (Cuny *et al*., 2014; Tong *et al*., 2015; Martin *et al*., 2018; Samathi *et al*. 2019; Deesri *et al*., 2022; Manitkoon *et al*., 2023).

Another significant site within Kalasin Geopark is the Phu Por fossil site, located at Ban Kham Somboon, Na Bon Subdistrict, Kham Muang District, Kalasin Province. This site has yielded numerous petrified wood samples, with coordinates marking it at latitude 16° 55' 15.07" and longitude 103° 41' 1.42". The Phu Por fossil site adds to the diversity of paleontological finds in the geopark, showcasing the rich botanical history of the region. The petrified woods found here provide valuable information about the ancient forests that once covered this area, contributing to a deeper understanding of the region's geological past.

From the Phu Por fossil site, head northeast for about 10 minutes to reach the Phu Noi fossil site (Figure 1). The environment of both sites is characterized as mixed forest, or mixed deciduous forest, scattered in small patches in the northeastern region (Santisuk, 2006). These sparse forests feature trees with alternating tall, medium, and low trunks, interspersed with bamboo. The soil is derived from sedimentary rocks, and most trees shed their leaves in the dry season. However, during the rainy season, the comes alive with full foliage, creating a lush and vibrant landscape. These unique environmental conditions have contributed to the preservation of the region's remarkable fossil record.

Together, these sites form a network of significant paleontological resources within Kalasin Geopark. The Sirindhorn Museum, Phu Por fossil site, and Phu Noi fossil site not only highlight the area's rich fossil heritage but also contribute to the ongoing scientific research and public education efforts, making Kalasin Geopark a vital hub for understanding Thailand's ancient past.

Phu Por fossil site is bedded in the Phu Kradung Formation. The discovery of the petrified wood genus *Xenoxylon* in this location, for the first time in Thailand, indicates that the Phu Kradung Formation dates to the middle to late Jurassic. However, the exact dating of this formation remains debated (Boonchai *et al*., 2020). The physical characteristics of the rocks and the fossils indicate that the Phu Por fossil site was formed from swamps or rivers with meandering channel river and strong currents in the channel. The paleoclimate was relatively dry (Racey & Goodall, 2009). The Phu Kradung Formation consists of sedimentary rocks including siltstone, greenish-gray sandstone, mudstone, and mixed calcareous conglomerate. The thickness of this rock layer is approximately 1,000 meters. The formation contains mica minerals and calcrete layers interspersed with reddish-gray rocks (Department of Mineral Resources, 2007).

## Method

**1. Field work**

Petrified wood samples were collected from the Phu Por fossil site at a total of seven locations, with in-situ samples chosen for collection, as shown in Table 1. Sample 1 (mean sea level ~240 meters), comes from a point about 220 meters away from the tourist service point (mean sea level ~220 meters), with a petrified wood length of approximately 2.3 meters and a width of approximately 0.8 – 0.9 meters (Figure 1 - 2).

Samples 2 to 7 (mean sea level ~260 meters) come from a point about 420 meters away from the tourist service point. The lengths of the petrified woods for these samples were approximately 6, 5, 6, 5, 4, and 2 meters, respectively (the width could not be measured as it is buried in the rock layer). The petrified wood is arranged in a long row, with seven trees scattered and not aligned in the same direction (Figure 1 - 2).

**Tabel 1** Petrified woods used in the study were collected from the Phu Por petrified wood source at various locations.

| Fossil No. | Sample No. | Length (m) | Width (m) | Location |
|---|---|---|---|---|
| PP-19-9 | 1 | ~2.3 | ~0.80–0.9 | 16°55’18.3”N 103°40’56.6”E |
| PP-19-1 | 2 | ~6 | - | 16°55’18.0”N 103°41’04.2”E |
| PP-19-2 | 3 | ~5 | - | 16°55’18.0”N 103°41’04.2”E |
| PP-19-3 | 4 | ~6 | - | 16°55’18.2”N 103°41’04.0”E |
| PP-19-4 | 5 | ~5 | - | 16°55’17.9”N 103°41’03.7”E |
| PP-19-5 | 6 | ~4 | - | 16°55’17.9”N 103°41’03.6”E |
| PP-19-6 | 7 | ~2 | - | 16°55’17.8”N 103°41’03.4”E |

**2. Laboratory work**

**2.1 Sample preparation**

Petrified wood samples were prepared for study using the thin section method to analyze the anatomy of the wood. They were then examined under a compound light microscope and a stereo microscope at the Palaeontological Research and Education Center and the Department of Biology, Faculty of Science, Mahasarakham University.

**2.2 Classification of petrified wood**

For the anatomical study, the dichotomous key of Philippe and Bamford (2008) was used to identify the scientific names of petrified wood, The anatomical features were compared using the IAWA List of microscopic features for softwood identification. Significant characteristics for identification growth rings, tracheid, helical thickenings in tracheids, axial parenchyma, ray composition, cross-field pitting, ray size, intercellular canals, and mineral inclusions (IAWA Committee, 2004). The description of petrified wood followed Boura *et al*. (2021).

The measurement of the size of the important characteristics used to classify a wand as a stone is based on the following IAWA criteria:

1) Ray cell length is measured in micrometers (μm). The size is measured from a radial section to the tangential, by randomly selecting from an array of not less than 25 cells and then finding the mean (Mean), standard deviation (SD), and range (Range).

2) The length of the ray cell is divided into four sizes: very short (up to 4 cells), medium (5 – 15 cells), long (16 – 30 cells), and very long (more than 30 cells).

3) Tracheids are measured in micrometers and divided into three sizes: short (less than 3000 μm), medium (3000 – 5000 μm), and long (more than 5000 μm) (IAWA Committee, 2004).

## Results

**1. Systematic paleontology**

Seven petrified wood samples used in the study collected from the Phu Por fossil site and belong to the middle to late Jurassic, Phu Kradung Formation. All samples underwent a detailed examination of the anatomy of petrified wood using a light microscope. They can be classified, as shown in Table 2, and the taxonomic order of petrified wood from the Phu Por fossil site was determined as follows:

Araucariaceae Henkel & W. Hochstetter, 1865

*Agathoxylon* Hartig, 1848

*Agathoxylon* sp.

**2. Descriptions**

Growth ring boundaries are distinct (Figure 3a) or absent (Figure 3b). Tracheids thin-walled, circular to oval in cross-section outline and 14.4 – 37.5 μm (mean 25 μm) in tangential diameter (Table 2).

Tracheids pits in radial walls 1-seriate (Figure 3d), 1-2-seriate (Figure 3e, 3f, 3g) (very rarely 2-seriate, alternate (Figure 3h)), circular to oval in outline and 14.6 - 22.3 μm (mean 18.9 μm) in vertical diameter. Radial pits in chains of contiguous are slightly flattened pits, rarely somewhat distant (Table 2).

Ray is 1-seriate, completely composed of parenchyma, 30 – 183 μm (mean 81.5 μm) high, relatively low with only 1 – 8 cells (mean three cells); rays are oval or elliptical in tangential section, both vertical and horizontal end walls of ray parenchyma cells are smooth (Figure 3c) (Table 2).

Araucarioid cross-field, pits bordered, with included apertures, more than 5 per cross-field, arranged in mostly two alternate rows, with a tendency for crowding (Figure 3i, 3j) (Table 2).

Helical thickenings on tracheid walls, axial parenchyma, intercellular canals, resin canals and crystals were unobserved.

The described petrified wood can have indistinct or absent growth ring boundaries, whereas *Agathoxylon* typically has well-defined growth rings. The dimensions and wall thickness of tracheids can vary, with the described petrified wood generally exhibiting a narrower range. The described petrified wood features more than five pits per cross-field, often arranged in two rows. Additionally, the rays in the described petrified wood have fewer cells and a smaller overall height compared to *Agathoxylon*. These differences may result from geological changes or the petrification process.

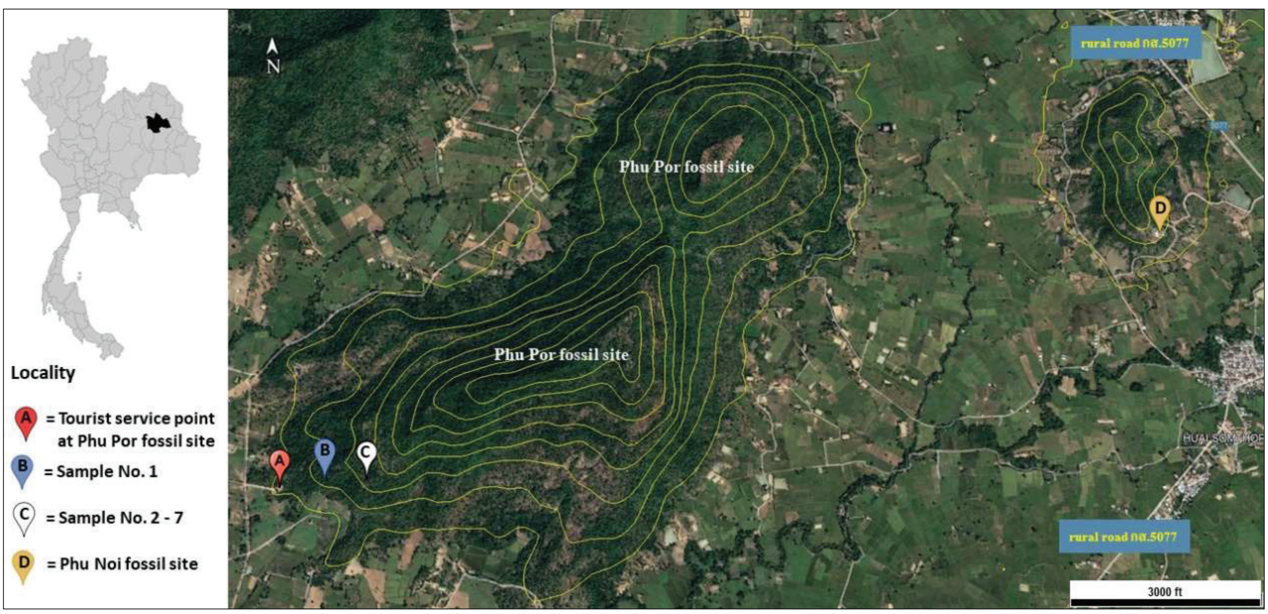


**Figure 1** Map showing the location of Phu Por and Phu Noi fossil sites Kham Muang District, Kalasin Province, Thailand. Note: white A = Tourist service point at Phu Por fossil site, B = Sample No.1, C = Sample No. 2 – 7 and D= Phu Noi fossil site – Scale bars: 3000 ft. (Google Earth Pro, 2022)

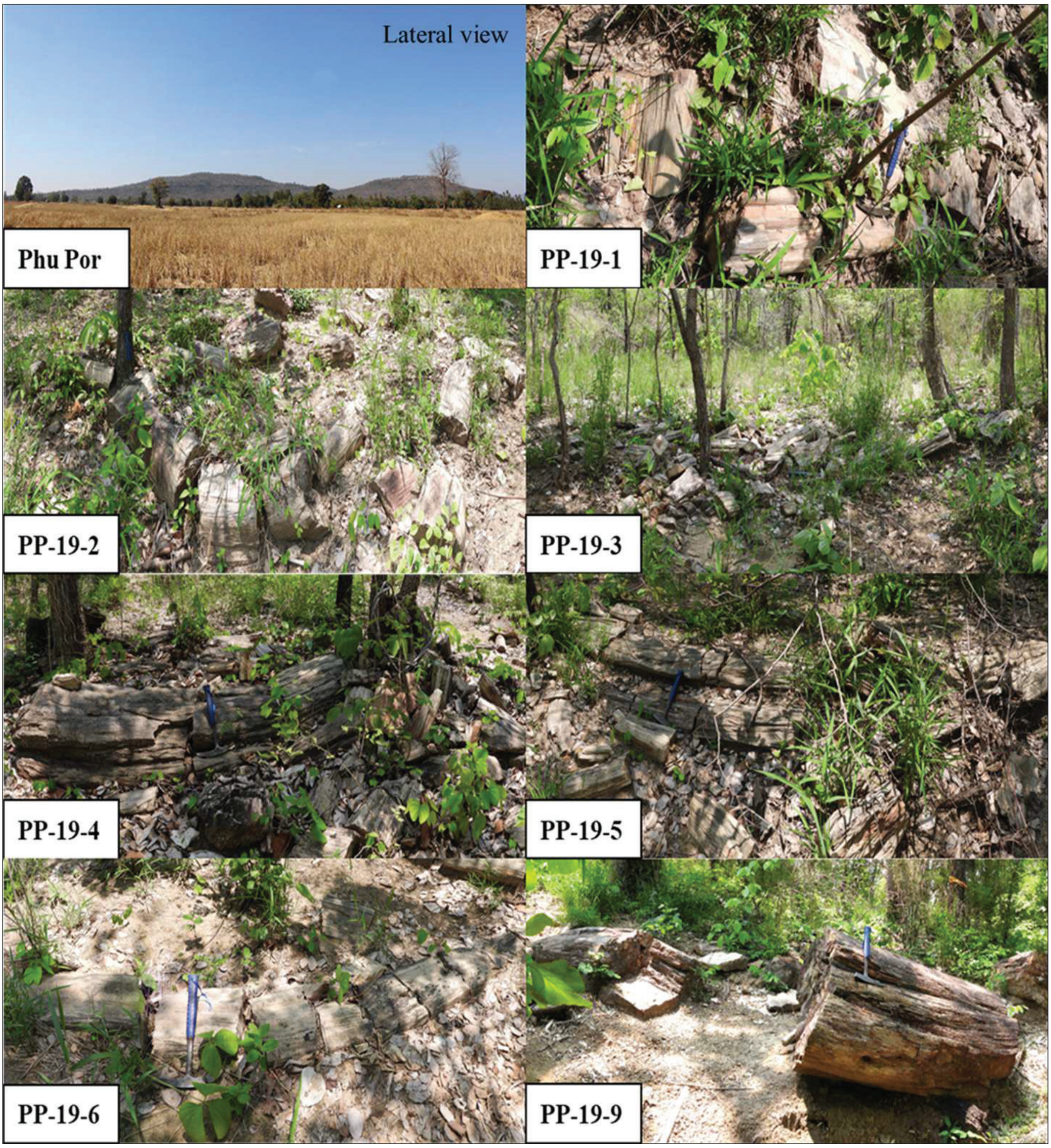


**Figure 2** Petrified woods used in the study were collected from the Phu Por fossil site.

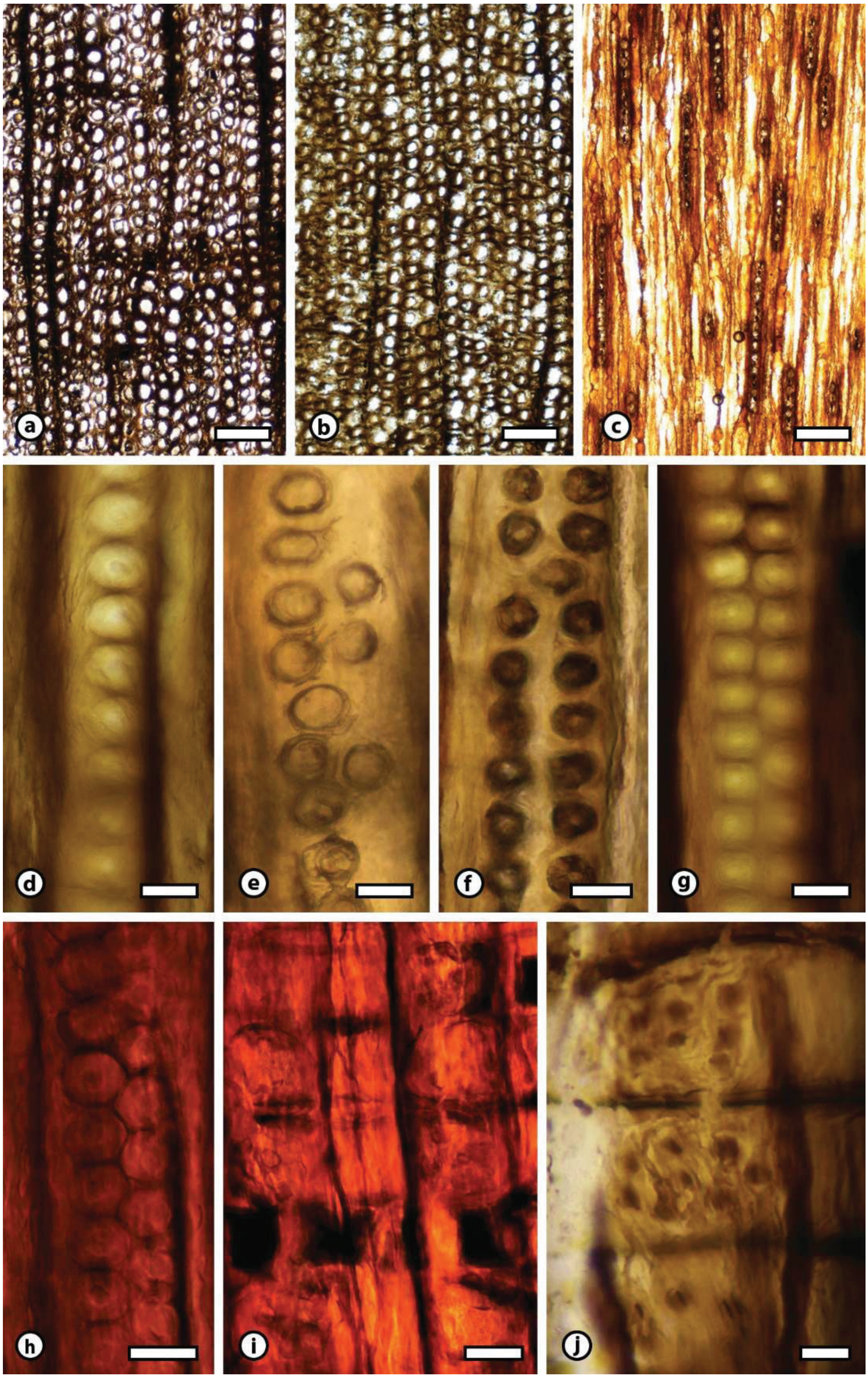


**Figure 3** Wood anatomy of *Agathoxylon* sp. (PP-19-1, PP-19-2, PP-19-3, PP-19-5, PP-19-9) from Phu Por fossil site Kalasin Province, Thailand. a: Transverse section showing distinct growth ring. – b: Growth ring absent. – c: Tangential section showing 1-seriate rays. – d: Radial section showing 1-seriate. – e, f: Radial section showing 1 – 2-seriate rays. – g: Radial section showing opposite 2-seriate rays. – h: Radial section showing alternate 2-seriate rays. – i, j: Radial section showing araucarioid cross-field. – Scale bars of 19 = 10 μm; 13, 14, 15, 16, 17 & 18 = 20 μm; of 10, 11 & 12 = 200 μm.

**Table 2** Comparative anatomy of petrified wood used to study from the Phu Por fossil site. Abbreviation: GR, growth rings; Tg TP, tangential tracheid pitting; Rd TP, radial tracheid pitting; Ax Pa, axial parenchyma; CFP, cross-field pits; R, Resin canals; P, present; A, absent.

| Taxa | No. | GR | R | Rd TP | Tg TP | Ray height | CFP (pits) | Ax Pa |
|---|---|---|---|---|---|---|---|---|
| *Agathoxylon* sp. | PP-19-1 | A | A | 1-2 seriate, opposite | A | 5-12 (x=8) | araucarioid 5-12, 1-3 rows, alternate, opposite | A |
| *Agathoxylon* sp. | PP-19-2 | A | A | uniseriate, 1-2-seriate | A | 1-15 (x=5) | araucarioid 4- >6, 1-2 rows, alternate | A |
| *Agathoxylon* sp. | PP-19-3 | P | A | 1-2 seriate, alternate | A | 2-11 (x=5) | araucarioid 6-8, 2-4 rows, alternate, opposite | A |
| *Agathoxylon* sp. | PP-19-4 | P | A | 1-2 seriate, opposite, alternate | A | 2-35 (x=10) | araucarioid 4-7, 2 rows, alternate | A |
| *Agathoxylon* sp. | PP-19-5 | A | A | 1-2 seriate, opposite | A | 2-11 (x=7) | araucarioid 4-7(10), 1-3 rows, alternate | A |
| Gymnosperm (cf. *Agathoxylon* sp.) | PP-19-6 | A | A | 1-2 seriate, opposite, alternate | A | - | araucarioid >6, 2 rows, alternate | A |
| *Agathoxylon* sp. | PP-19-9 | A | A | 1-2 seriate, alternate, opposite | A | 6-26 (x=11) | araucarioid >6, 2 rows, alternate | A |

## Discussion

### 1. *Agathoxylon* distributions

*Agathoxylon* is a gymnosperm in the family Araucariaceae. First discovered by Hartig in 1848, *Agathoxylon* is the most commonly accepted name (Philippe, 2011). It dates from the Middle Jurassic Period (168-165 million years ago) to the Miocene Epoch (23 – 5.3 million years ago). The current genus closest to *Agathoxylon* is *Agathis*, a pine tree that diverged from the southern hemisphere. The distribution range of *Agathis* covers New Zealand and western Fiji to the Malay Islands and Sumatra. This genus is an example of allopatric speciation, where species evolve in different geographic areas, leading to plants with varying physical characteristics in diverse environments (Whitmore & Page, 1980). It is hypothesized that *Agathis* expanded its distribution range, originating from two central Gondwana, and successfully spread to outcompete wild flowering plants (Whitmore & Page, 1980).

*Agathoxylon*, a form genus of fossil wood, has a noTable presence in Southeast Asia. In the Lower Mekong Basin, which spans parts of Thailand, Laos, and Cambodia, this discovery is instrumental in developing hypotheses about the ancient courses of the Mekong River and understanding the region's paleoenvironment (Carling *et al*., 2017). *Agathoxylon* have been discovered in Mesozoic and Quaternary. In Thailand, large petrified trunks of *Agathoxylon* have been found in the northeast and northern regions. During the Mesozoic Era, giant gymnosperm trees, including *Agathoxylon*, were prevalent. These findings highlight the significant role of *Agathoxylon* in the region's paleobotanical record (Benyasuta, 2003; Boonchai, 2008; Boonchai *et al*., 2020).

The extensive temporal range of *Agathoxylon*, from the Middle Jurassic to the Miocene, highlights its ecological success and resilience. This makes it an important subject of further education for understanding the factors contributing to the longevity and adaptability of plant species over geological time scales (Kloster & Gnaedinger, 2018)

### 2. Paleoclimate

Examining and analyzing the growth rings of petrified wood allows for paleoclimate predictions. It was found that the petrified wood samples labeled PP-19-3 and PP-19-4 had clear growth rings (Figure 3a) (Table 2). These trees represent wood formed at the end of a short dry season, as evidenced by the fewer tracheid cells growing with thick cell walls. As sugar availability increases later in the season, narrower cells with thick walls, known as latewood, are produced. This is different from the beginning of the season when tracheid undergo many cell divisions and have thin cell walls. Thus, sugar availability in the cambium affects wood formation during the growing season. Initially, low sugar levels lead to slow wall deposition, resulting in the production of large cells with thin walls, known as earlywood. It may be predicted that each year there was relatively humid weather and alternating periods of short dry seasons (Cartenì *et al*., 2018).

In contrast, petrified woods PP-19-1, PP-19-2, PP-19-5 and PP-19-6 had nebulous or absent growth rings (Figure 3b) (Table 2). The discovery of plants of the same genus in one area, some with growth rings and some without, can be attributed to the varying availability of water sources, which affects tree growth differently.

Another hypothesis is that some of the petrified woods in the present work, where growth rings were not found, grew at the foot of mountains or near water sources, resulting in thin cell walls in the wood. In contrast, some petrified woods with growth rings presumably grew in areas with higher elevations or on mountaintops, where they received less water for growth, resulting in thick cell walls (Carlquist, 2013; Zhou *et al*., 2022). The domination of *Agathoxylon* with growth rings at Phu Por fossil site may suggest the humid climate with low seasonality during the middle to late Jurassic. Additionally, in the case of petrified woods, this variation may occur due to the incomplete replacement of minerals during the petrification process or other geological processes that affect the visibility of growth rings.

This hypothesis is consistent with the discovery of *Xenoxylon* in the Phu Por fossil site (Boonchai *et al*., 2020), The presence of *Xenoxylon*, typically indicative of mid- to high-paleolatitudes and cooler or wetter climates (Philippe *et al*., 2013), in Southeast Asia supports the hypothesis of temporary southward expansions of cooler climate conditions during the Mesozoic. This aligns with similar occurrences in southern China and Vietnam, contributing to the broader understanding of Mesozoic paleoclimate and biogeographical patterns (Boureau, 1950; Vozenin-Serra & Privé-Gill, 1991; Philippe *et al*., 2009; Oh *et al*., 2015). *Xenoxylon* distribution is limited to the area of Laurasia, in the high paleo-latitude range of the northern hemisphere. However, during the middle to late Jurassic, the weather in the southern hemisphere was likely getting colder (Oh *et al*., 2015).

**3. Boosting eco-tourism**

The petrified wood at Phu Por fossil site is extraordinary, with abundant specimens scattered throughout the mountain area. Studying this wood offers numerous benefits, such as creating job opportunities and boosting the local economy. This can expand career options and distribute income to nearby communities.

Developing Phu Por fossil site into an eco-tourism destination can further promote Kalasin Province as a national geopark. This transformation can attract tourists, researchers, and students, enhancing appreciation for natural history and geological conservation. Historically, while Mesozoic Era petrified wood has been studied in Thailand, there hasn't been a site developed for conservation tourism. Establishing Phu Por as a destination can fill this gap, providing a place for scientific research and education while boosting eco-tourism. This dual focus on preservation and tourism can protect the area's natural heritage and contribute to sustainable economic growth.

## Abbreviation

PP: Phu Por fossil site.

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## References

Benyasuta, P. (2003). *Petrified wood of northeastern Thailand and its implication on biodiversity and the ecosystem during the Cenozoic Era* [Ph.D. dissertation, Suranaree University of Technology].

Boonchai, N. (2008). *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* [Master's thesis, Suranaree University of Technology].

Boonchai, N., Suteethorn, S., Sereeprasirt, W., & Philippe, M. (2020). *Xenoxylon*, a boreal fossil wood in the Mesozoic redbeds of Southeast Asia: Potential for the stratigraphy of the Khorat group and the palinspatic reconstruction of Southeast Asia. *Journal of Asian Earth Sciences*, *189*, Article 104153. https://doi.org/10.1016/j.jseaes.2019.104153

Boura, A., Bamford, M., & Philippe, M. (2021). Promoting a standardized description of fossil tracheidoxyls. *Review of Palaeobotany and Palynology*, *295*, Article 104525. https://doi.org/10.1016/j.revpalbo.2021.104525

Boureau, É. (1950). *Contribution à l'étude paléoxylologique de l'Indochine: I. Présence du Xenoxylon latiporosum Cramer, Gothan, dans le lias du Centre-Annam. II. Présence du Ficoxylon saurinii n. sp. dans le terrain rouge du Cambodge*. Imprimerie française d'outre-mer.

Carling, P., Boonchai, N., Philippe, M., & Meshkova, L. (2017). A preliminary investigation of fossil wood from Lower Mekong Basin of southeast Asia. *Global Geology*, *20*(3), 2–14. https://doi.org/10.3969/j.issn.1673-9736.2017.03.01

Carlquist, S. (2013). *Comparative wood anatomy: Systematic, ecological, and evolutionary aspects of dicotyledon wood*. Springer.

Cartenì, F., Deslauriers, A., Rossi, S., Morin, H., De Micco, V., Mazzoleni, S., & Giannino, F. (2018). The physiological mechanisms behind the earlywood-to-latewood transition: A process-based modeling approach. *Frontiers in Plant Science*, *9*, Article 991. https://doi.org/10.3389/fpls.2018.00991

Cuny, G., Liard, R., Deesri, U., Liard, T., Khamha, S., & Suteethorn, V. (2014). Shark faunas from the Late Jurassic—Early Cretaceous of northeastern Thailand. *Paläontologische Zeitschrift*, *88*(3), 309–328. https://doi.org/10.1007/s12542-013-0203-1

Deesri, U., Suteethorn, V., Suteethorn, S., Sila, S., Manitkoon, S., & Cuny, G. (2022, November 7-11). *A disarticulated skeleton of a hybodont shark from the Jurassic of Thailand* [Conference presentation]. The 6th International Palaeontological Congress, Khon Kaen, Thailand.

Department of Mineral Resources. (2007). *Geology of Thailand* [in Thai]. Ministry of Natural Resources and Environment.

Google Earth Pro. (2022). *Phu Por fossil site, 16°55'16.66"N, 103°40'48.98"E, elevation 3,000 ft* [Digital map]. Retrieved May 15, 2024, from Google Earth Pro software.

IAWA Committee. (2004). IAWA list of microscopic features for softwood identification. *IAWA Journal*, *25*(1), 1–70. https://doi.org/10.1163/22941932-02501001

Kloster, A. C., & Gnaedinger, S. C. (2018). Coniferous wood of *Agathoxylon* from the La Matilde Formation (Middle Jurassic), Santa Cruz, Argentina. *Journal of Paleontology*, *92*(4), 546–567. https://doi.org/10.1017/jpa.2018.10

Manitkoon, S., Deesri, U., Khalloufi, B., Nonsrirach, T., Suteethorn, V., Chanthasit, P., Boonla, W., & Buffetaut, E. (2023). A new basal neornithischian dinosaur from the Phu Kradung Formation (Upper Jurassic) of northeastern Thailand. *Diversity*, *15*(7), Article 851. https://doi.org/10.3390/d15070851

Martin, J. E., Suteethorn, S., Lauprasert, K., Tong, H., Buffetaut, E., Liard, R., Salaviale, C., Deesri, U., Suteethorn, V., & Claude, J. (2018). A new freshwater teleosaurid from the Jurassic of northeastern Thailand. *Journal of Vertebrate Paleontology*, *38*(6), Article e1549059. https://doi.org/10.1080/02724634.2018.1549059

Oh, C., Philippe, M., & Kim, K. (2015). *Xenoxylon* synecology and palaeoclimatic implications for the Mesozoic of Eurasia. *Acta Palaeontologica Polonica*, *60*(1), 245–256. https://doi.org/10.4202/app.00040.2013

Philippe, M. (2011). How many species of *Araucarioxylon*? *Comptes Rendus Palevol*, *10*(2–3), 201–208. https://doi.org/10.1016/j.crpv.2011.01.001

Philippe, M., & Bamford, M. K. (2008). A key to morphogenera used for Mesozoic conifer-like woods. *Review of Palaeobotany and Palynology*, *148*(2–4), 184–207. https://doi.org/10.1016/j.revpalbo.2007.08.003

Philippe, M., Daviero-Gomez, V., & Suteethorn, V. (2009). Silhouette and palaeoecology of Mesozoic trees in Thailand. In E. Buffetaut, G. Cuny, V. Suteethorn, & H. Tong (Eds.), *Mesozoic terrestrial ecosystems of Thailand* (Geological Society, London, Special Publications, Vol. 315, pp. 85–96). Geological Society of London. https://doi.org/10.1144/SP315.6

Philippe, M., Jiang, H.-R., Kim, K., Oh, C., Gromyko, D., Harland, M., Paik, I. S., & Thévenard, F. (2009). Structure and diversity of the Mesozoic wood genus *Xenoxylon* in Far East Asia: Implications for terrestrial palaeoclimates. *Lethaia*, *42*(4), 393–406. https://doi.org/10.1111/j.1502-3931.2009.00167.x

Philippe, M., Suteethorn, V., & Buffetaut, É. (2011). Révision de *Brachyoxylon rotnaense* Mathiesen, description de *B. serrae* n. sp. et conséquences pour la stratigraphie du Crétacé inférieur d'Asie du Sud-Est [Revision of *Brachyoxylon rotnaense* Mathiesen, description of *B. serrae* n. sp. and consequences for the stratigraphy of the Lower Cretaceous of Southeast Asia]. *Geodiversitas*, *33*(1), 25–32. https://doi.org/10.5252/g2011n1a2

Philippe, M., Suteethorn, V., Lutat, P., Buffetaut, E., Cavin, L., Cuny, G., & Barale, G. (2004). Stratigraphical and palaeobiogeographical significance of fossil wood from the Mesozoic Khorat Group of Thailand. *Geological Magazine*, *141*(3), 319–328. https://doi.org/10.1017/S001675680400891X

Philippe, M., Thévenard, F., Nosova, N., Kim, K., & Naugolnykh, S. (2013). Systematics of a palaeoecologically significant boreal Mesozoic fossil wood genus, *Xenoxylon* Gothan. *Review of Palaeobotany and Palynology*, *193*, 128–140. https://doi.org/10.1016/j.revpalbo.2013.01.004

Racey, A., & Goodall, J. G. (2009). Palynology and stratigraphy of the Mesozoic Khorat Group red bed sequences from Thailand. In E. Buffetaut, G. Cuny, V. Suteethorn, & H. Tong (Eds.), *Mesozoic terrestrial ecosystems of Thailand* (Geological Society, London, Special Publications, Vol. 315, pp. 69–83). Geological Society of London. https://doi.org/10.1144/SP315.5

Samathi, A., Chanthasit, P., & Sander, P. M. (2019). A review of theropod dinosaurs from the Late Jurassic to mid-Cretaceous of Southeast Asia. *Annales de Paléontologie*, *105*(3), 201–215. https://doi.org/10.1016/j.annpal.2019.07.001

Santisuk, T. (2006). *Forests of Thailand* [in Thai]. Forest and Plant Conservation Research Office, Department of National Parks, Wildlife and Plant Conservation.

Tong, H., Naksri, W., Buffetaut, E., Suteethorn, V., Suteethorn, S., Deesri, U., Sila, S., Chanthasit, P., & Claude, J. (2015). A new primitive eucryptodiran turtle from the Upper Jurassic Phu Kradung Formation of the Khorat Plateau, NE Thailand. *Geological Magazine*, *152*(1), 166–175. https://doi.org/10.1017/S001675681400049X

Vozenin-Serra, C., & Privé-Gill, C. (1991). Les terrasses alluviales pléistocènes du Mékong (Cambodge). I–Bois silicifiés homoxylés récoltés entre Stung-Treng et Snoul [The Pleistocene alluvial terraces of the Mekong (Cambodia). I–Silicified homoxylous woods collected between Stung-Treng and Snoul]. *Review of Palaeobotany and Palynology*, *67*(1–2), 115–132. https://doi.org/10.1016/0034-6667(91)90029-H

Whitmore, T. C., & Page, C. N. (1980). Evolutionary implications of the distribution and ecology of the tropical conifer *Agathis*. *New Phytologist*, *84*(2), 407–416. https://doi.org/10.1111/j.1469-8137.1980.tb04763.x

Zhou, Y., Yi, Y., Liu, H., Song, J., Jia, W., & Zhang, S. (2022). Altitudinal trends in climate change result in radial growth variation of *Pinus yunnanensis* at an arid-hot valley of southwest China. *Dendrochronologia*, *71*, Article 125914. https://doi.org/10.1016/j.dendro.2021.125914