In situ wood fossil from Gorontalo, Indonesia

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Abstract. Gorontalo, one of the provinces in Indonesia, has not been widely known for its potential of wood fossil. The anatomical structures observation and the age estimation were conducted on two specimens of wood fossils buried in Tohupo Village, Bongomeme District, Gorontalo. The anatomical features of wood fossils were observed through thin slices of the cross, radial, and tangential sections using a Carl Zeiss- Axio Imager-A1m microscope. The description of anatomical features referred to the IAWA (International Association of Wood Anatomists) list of microscopic features for hardwood identification. The age estimation of the wood fossils was based on Geological Map (scale 1: 100.000) of the Tilamuta sheet, Sulawesi. Based on anatomical structures observation, the species of wood fossils were identified as Hopenium sp. (merawan/hopea) and Shoreoxylon sp. (balau). The estimated age of wood fossils was 3.6 to 1.8 million years before the present (BP) (between the late Pliocene and Early Plistocene periods).

1. Introduction

The field of wood anatomy has a broad relationship. It can support other science branches, such as archeology, forensics, ethnology, dendrochronology, and paleobotany. The study of paleobotany is a science that includes aspects of plant fossils, reconstruction of taxonomy, and the history plant evolution [1].

Indonesia is famous not only for its diversity of tree species but also for its diversity of wood fossil species. To date, the abundance of wood fossils only benefits collectors and sellers for the sake of business and pleasure. Wood fossils, since more or less 20 years ago, have been traded in the western regions of Java [2]. Research on wood fossils is necessary because wood fossils are one of the historical relics of flora in Indonesia. The more intense the wood fossils commerce, the more scarce the wood fossils. In the meantime, their botanical identities are unknown. The botanical identity is important to explore the history of the distribution of tree species growing in the past era.

Research on wood fossils in Indonesia has been widely carried out both in the Dutch colonial era and afterward. It started in 1854 by Goppert, who examined wood fossils in Java [3]. Crie (1888) discovered wood fossil of Naucleoxylon spectabile (Rubiaceae) on Kendeng Mountain (in Java) [4], which was later revised by Krausel through his research into Dipterocarpxylon spectabile [5]. Den Berger revised Dipterocarpoxylon spectabile found by Krausel into Dryobalanoxylon spectability [6]. In 1958, Schweitzer found Vaticoxylon plioicaenicum and Shoreoxylon pulchrum in Jambi, Dipterocarpxylon javanicum in Indramayu and Dryobalanoxylon tobleri in Banten [7]. Sukiman reported the discovery of Shoreoxylon pachitanensis in Pacitan (East Java) [8]. Mandang and Martono reported that the species of wood fossils found in showroom in Ciampea, Leuwiliang, and Jasinga were dominated by Dipterocarpaceae, namely Anisopteroxylon, Dipterocarpxylon, Dryobalanoxylon, Hopeoxylon, Shoreoxylon, Parashoreoxylon, and Cotylelobioxylon [2]. Still, in the
Leuwiliang area, *Dryobalanoxylon bogorensis* were found by Srivastava and Kagemori [9]. A few years later, Mandang dan Kagemori [10] found *Dryobalanoxylon lunaris* in Maja-Lebak Regency (Banten). Andianto and Ismanto in 2017 found *Shoreoxylon* sp. (Meranti) and *Dryobalanoxylon* sp. (Kamper) in Jasginga (Bogor) and Curug Bitung (Lebak-Banten) [11]. *Dryobalanoxylon* sp. was found by Andianto et al. in 2018 in West Bangko-Merangin, Jambi [12]. Although there are many wood fossils discovered in Indonesia, there has not been much information on wood fossils originating from Sulawesi Island, especially from Gorontalo Province.

The distribution of wood fossils in Indonesia needs to be explored to obtain scientific data such as species, location of wood fossil existence, and geological age estimation. Gorontalo, one of the provinces in Indonesia, has not been widely known with the potential of wood fossil. This paper presents the botanical identity of wood fossils from this region and the estimation of its geological age.

2. Materials and methods

Two specimens of wood fossils were excavated from the wall of the hill (Figure 1) in Tohupo village, Bongomeme District, Gorontalo Regency (Figure 2). Each specimen was cut into small blocks (2x2x4 cm$^2$) using a diamond wheel. Furthermore, the specimen was rubbed using carborundum powder and mounted in glass slide using Canada balsam until getting a thin section. Thin sections of the fossil woods were prepared in three planes/sections, i.e., transverse, tangential, and radial, by standard techniques for the study of anatomical characters. Every plane was made in three repetitions. The sections were studied and photographed under a high-power Olympus microscope. Microscopic observation of wood fossils was undertaken under a light microscope to identify the name of species. The anatomical nomenclature description and measurements followed the IAWA (International Association of Wood Anatomist) list of microscopic features for hardwood identification [13]. The anatomical features of wood fossils were furthermore compared to anatomical features database of the authentic modern wood collection in the Xylarium Bogoriense. The mineral contents in wood fossils were analyzed using X-ray Diffraction (XRD) and X-Ray Fluorescence (XRF).

![Figure 1](image1.jpg)

*Figure 1. The location of wood fossil on the wall of the hill in the Tohupo Village.*

Coordinate points of the location were taken for estimating geological age of wood fossils through analysis of sediment formation using the geological map of Tilamuta sheet-Sulawesi (scale 1:100,000) (Figure 3) and the International Chronostratigraphic Chart (Figure 4). A geological map contains stratigraphical rock formation with estimated information on its age. The wood fossil buried in the rock layers was assumed to have the same age as the rock layer. The rock layers on the map are described in several different colors. Each color contained in the map informs rock formations and estimated age. Furthermore, the color information on the map is adjusted to the color on the graph map of the estimated age of the fossils.
Figure 2. The map of Gorontalo Province area (the location of wood fossil discovery is shown in red arrow).

Figure 3. Geological map of Tilamuta quadrangle, Sulawesi and wood fossil site [14].
3. Results and discussion

3.1. Description area

Gorontalo Province has an area of 12,435.00 km² with a topography that is generally hilly, located in the northern part of Sulawesi Island with coordinates 0°19′00″-1°57′00″ LU (North Latitude) and 121° 23′ 00″-125° 14′ 00″ BT (East Longitude). The province is flanked by Gorontalo Bay (Tomini Bay) in the south and the Sulawesi Sea in the north (Figure 2). Its location, which is close to the equator, causes the Gorontalo area to be generally quite hot. September estimates the temperature in this region to be 22.8°C, while the maximum temperature occurs in October with an estimated temperature of 33.5°C [16].

Two pieces of wood fossils were found in the area of Tohupo Village, Bongomeme Subdistrict, Gorontalo Regency with location coordinates are (N): 00° 34,1' 63'' and (E): 122° 51’ 64''. The location characteristics are in the form of a hill wall where beneath it flows the Bongomeme River (Figure 2). On the other side of the corner, there is a community plantation area. The existence of wood fossils still stuck on the cliff wall, which was a layer of yellow and gray rock. Different colors show differences in the mineral content contained in the second layer of rock. At the edge of the cliff, a continuous rock layer indicated that a normal fault occurred in the area. Wood fossils standing out on...
the hill wall each had a length of about 1 m in diameter around 0.5 meters. The yellow rock layer is tuffsand, while the ash-colored rocks are tuffaceous sandstones. Different colors show differences in the mineral content contained in these two rocks.

3.2. Wood fossil identification

The anatomical structure of the microscopic cross-section of wood fossil samples is presented in Figure 5 and Figure 6. The comparison of anatomical features between *Hopenium* sp. and *Shoreoxylon* is presented in Table 1, while the observing results of the anatomical structure of wood fossil specimens obtained anatomical features as follows:

3.2.1. Specimen 1. Vessel: diffuse porous (5); simple perforation plate (13), alternate inter-vessel pits (22); tyloses common in a vessel (56). Fiber: thin to thick cell-wall fiber (69). Parenchyma: axial parenchyma diffuse-in-aggregate (77), axial parenchyma vasicentric (79), and confluen (83). Rays: ray width 1 to 3 cells (97), larger rays commonly four to ten seriates (98); body ray cells procumbent with one row of upright and/or marginal square cells (106); body ray cells procumbent with mostly 2-4 rows of upright and/or marginal square cells (107). Inter cellular canals: axial canals in long tangential lines (127). Mineral inclusion: prismatic crystals in upright and/or square ray cells (137), in procumbent ray cells (138), in radial alignment in procumbent ray cells (139), and prismatic crystals in chambered axial parenchyma cells (142). The anatomical features of merawan including diffuse porosity, tend to be grouped and generally contain tyloses, axial parenchyma vasicentric, confluent form, axial canal in tangential lines [17, 18]. The anatomical characteristics of wood fossil specimen 1 are similar to anatomical characteristics of the modern wood of merawan (*Hopea sp.*). The nomenclature for the wood fossil of Hopea sp. is *Hopenium* sp.

The charcoalified fossil wood of *Hopenium pondicherriensis* from the district of Tamil-India, had wood anatomy characteristics: simple perforation plate, alternate inter-vessel pits, parenchyma intermingled with vasicentric tracheid, aprotachae parenchyma in the form of tangential bands, and seriate rays of 2-6. In contrast, the multiseterate rays consist of procumbent, vertical gum canals vertical, circular, arranged in tangential rows [19]. There are differences and similarities of wood anatomy characteristics between *Hopenium pondicherriensis* and *Hopenium* sp. (species in this study). These can be caused by different origin location and species difference.

3.2.2. Specimen 2. Vessel: diffuse porous (5); simple perforation plate (13), alternate inter-vessel pits (22); tylosis common in vessel (56). Fiber: thin to thick cell-wall fiber (69). Parenchyma: axial parenchyma diffuse (76), axial parenchyma diffuse-in-aggregate (77), axial parenchyma scanty paratracheal (78), aliform (80), confluen (83). Rays: ray width 1 to 3 cells (97), larger rays commonly four to ten seriates (98); body ray cells procumbent with one row of upright and/or marginal square cells (106); body ray cells procumbent with mostly 2-4 rows of upright and/or marginal square cells (107). Inter cellular canals: axial canals in long tangential lines (127). Mineral inclusion: prismatic crystals in upright and/or square ray cells (137), in procumbent ray cells (138), in radial alignment in procumbent ray cells (139), and prismatic crystals in chambered axial parenchyma cells (142).

The anatomical features of wood fossil specimen 2 were similar to the anatomical features of balau wood (*Shorea* sp.). The anatomical characteristics of balau wood included diffuse porosity, and contained many tyloses, parenchyma diffuse-in-aggregate, aliform to confluent, and axial canal in long tangential lines [17,18].

The predominant differences between *merawan* and *balau* species can be identified from the presence of mineral inclusion, i.e., crystals. In *merawan*, crystals were found in the ray and parenchyma cells, while in *balau*, the crystals were only found in parenchyma cells. As stated by Sudo in Soerianegara et al. [20], *merawan* wood (*Hopea sp.*) not only have prismatic crystals in chambered axial parenchyma cells, but also have crystals in upright ray cells, procumbent, and radial alignment in procumbent ray cells. The nomenclature for the wood fossil of *Shorea* sp. is *Shoreoxylon* sp.
Transverse                                  Radial                                 Tangential

Figure 5. Microscopic features of merawan wood fossil (Hopenium sp.).

Transverse                                Radial

Figure 6. Microscopic features of balau wood fossil (Shoreoxylon sp.).

Based on wood species collection data in Xylarium Bogoriense, merawan and balau wood species originated from Celebes island, but there was no specific information about the name of the province. Species of wood fossils found in Gorontalo province clarifies that merawan (Hopea sp.) and balau (Shorea sp.) have grown in Gorontalo since million years ago. Both merawan and balau modern species do not grow anymore in Gorontalo now. It shows that there is an extinction of merawan and balau species in Gorontalo Province.

3.3. Mineral content

According to the test result of XRD and XRF, the mineral contents of the wood fossil were mostly Quartz (SiO$_2$); Graphite (C) or Diamond (a type of carbon allotrope), Zaherite (AL$_{12}$(SO$_4$)$_5$(OH)$_{26}$), Albite, disordered (Na (Si$_3$AL)O$_8$). Calcium Sodium Alumosilicate (CaO.65 NaO.35 (Al1.65 Si$_2$.35 O$_8$)), Magnesium Vanadium Molybdenum Oxide (Mg$_2$.5 V Mo O$_8$). It shows that the chemical elements contained in both wood fossils were no longer carbon, so the estimated age could not be analyzed using the Carbon Dating method.

According to Mustoe [21], after silica, calcium carbonate is the most common form of wood petrifaction. Carbonate minerals are divided into calcite and dolomite. Dolomite has infrequently been reported as a component of carbonate-mineralized wood. Mg is highly water-soluble in most near-surface terrestrial and lacustrine environments. Therefore, dolomitized wood is most likely to occur in wood buried in marine or brackish water sediments. Fractures in the wood are commonly filled with crystalline quartz precipitated during a later phase of mineralization. Based on the results of this research, the most common of mineral contents of wood fossils was Quartz (SiO$_2$). It means that both
hopenium sp. and shoreoxylon sp. from Gorontalo is Dolomite wood buried in marine or brackish water sediments.

### Table 1. The comparison of anatomical features between Hopenium sp. and Shoreoxylon sp.

| No. | Anatomical features          | Hopenium sp.                  | Shoreoxylon sp.               |
|-----|------------------------------|-------------------------------|------------------------------|
| 1.  | Vessels                      |                               |                              |
| 2.  | Porosity                     | diffuse-porous (5)            | diffuse-porous (5)           |
| 3.  | Perforation plates           | simple (13)                   | simple (13)                  |
| 4.  | Arrangement of intervessel pits | alternate (22)              | alternate (22)               |
| 5.  | Tyloses and deposits in vessels | tyloses common (56)         | tyloses common (56)          |
| 6.  | Fiber wall thickness         | fibers thin-to thick-walled (69) | fibers thin-to thick-walled (69) |
| 7.  | Axial parenchyma             |                               |                              |
| 8.  | Apotracheal                  | diffuse-in-aggregates (77)    | diffuse-in-aggregates (77)   |
| 9.  | Paratracheal                 | vasicentric (79)              |                              |
| 10. | Paratracheal                 | confluent (83)                | confluent (83)               |
| 11. | Paratracheal                 | aliform (80)                  |                              |
| 12. | Paratracheal                 | scanty (78)                   |                              |
| 13. | Rays                         |                               |                              |
| 14. | Width                        | 1 to 3 cells (97)             | 1 to 3 cells (97)            |
| 15. | Width                        | larger rays commonly four to ten seriates (98) | larger rays commonly four to ten seriates (98) |
| 16. | Cellular composition         | body ray cells procumbent with one row of upright and/or marginal square cells (106) | body ray cells procumbent with one row of upright and/or marginal square cells (106) |
| 17. | Cellular composition         | body ray cells procumbent with mostly square cells (107) | body ray cells procumbent with mostly square cells (107) |
| 18. | Intercellular canals         | axial canals in long tangential lines (127) | axial canals in long tangential lines (127) |
| 19. | Mineral inclusions           | prisms crystals in upright and/or square ray cells (137) | -                            |
| 20. | Prismatic crystals           | prisms crystals in procumbent ray cells (138) | -                            |
| 21. | Prismatic crystals           | prisms crystals in radial alignment in procumbent ray cells (139) | -                            |
| 22. | Prismatic crystals           | prisms crystals in chambered axial parenchyma cells (142) | prisms crystals in chambered axial parenchyma cells (142) |

Note: numbers in brackets are IAWA codes for anatomy features.

#### 3.4. Geological age

The location area of wood fossils excavation was in Tohupo Village. It was in the Pinogu Volcanic Rock Formation (TQpv) in the form of agglomerates, tuffs, andesite-basal lava. This formation was in the age of the late Pliocene and early Plistocene rocks. Furthermore, based on the graphical chart of the estimated age of the fossils (International Chronostratigraphic Chart), the age of rock layers, in the late Pliocene and early Plistocene, is between 3.6 to 1.8 million before present (BP). Therefore, the age of wood fossils (hopenium sp. and shoreoxylon sp.) were estimated between 3.6 to 1.8 million BP. The Pliocene era (5 to 1.8 million BP) was marked by the decreasing number of plants due to cold weather. In comparison, the Plistocene epoch (1.8 to 0.01 million BP) was characterized by several glaciations (ice age), which covered most of Europe, North America, North Asia, the Alps, the Himalayas and Cherpathia [22]. The research of Hopenium sp. was also conducted in India, in which the age of Hopenium sp. varied from Miocene to Pliocene [19].
4. Conclusion
Identification results based on anatomical characteristics indicated that a sample of a wood fossil found in the village of Tohupu, Bongomeme Subdistrict, Gorontalo Province, was a Hopenium sp. (merawan/hopea) and Shoreoxylon sp. (balau). The age of wood fossils (hopenium sp. and shoreoxylon sp.) were estimated between 3.6 and 1.8 million years before the present (between the late Pliocene and early Plistocene).

5. References
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