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More evidence of tropical conditions in the Middle Eocene Climatic Optimum (MECO) with new fossil woods from North-Central Türkiye

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Abstract: Fossil wood descriptions are among the most important indicators in understanding forest structures across geological ages. This study was carried out to obtain new findings about the Middle Eocene Climate Optimum (MECO) period of Anatolia with new samples collected from the Middle Eocene-aged fossil area near Amasya-Göynücek. The fossil area falls into the Göynücek Volcanics in the region. Transverse, radial, and tangential microscopic sections were taken from three new fossil wood samples, and all identifications were performed on these microscopic sections. As a result, the fossil species were identified as *Pinuxylon* cf. *P. tarnocziense*, cf. *Dichrostachyoxylon zirkelii*, and *Laurinoxylon perseamimatus* based on their wood anatomical features. In all three fossil woods, the growth rings are quite wide and their boundaries are indistinct. This indicates the existence of warm tropical conditions in the MECO period. On the other hand, the extant representatives of the angiosperm genera identified here are found in tropical-subtropical forests. Overall, more information was obtained about the forest structure and climate of tropical conditions in the MECO period of Anatolia.

Keywords: Middle Eocene Climate Optimum, *Pinuxylon tarnocziense*, *Dichrostachyoxylon zirkelii*, *Laurinoxylon perseamimatus*, petrified wood, Göynücek Volcanics

1. Introduction

Türkiye has a geologically active structure and has fossil records bearing the traces of different ages from Paleozoic to Pliocene. After the demonstration of evidence of spore-forming plants of Carboniferous age (Cleal et al., 2017), many studies were performed on fossil woods for different geological times such as the Middle Jurassic (Akkemik et al., 2022), Cretaceous (Kutluk et al., 2012; Akgün et al., 2019), Middle Eocene (Akgün et al., 2002; Akkiraz et al., 2006, 2008; Akkemik et al., 2021) Oligo-Miocene (e.g., Akgün et al., 2007; Akkemik and Sakınç, 2013; Akkemik et al., 2023), Miocene (e.g., Kayseri and Akgün, 2008; Acarca Bayam et al., 2018; Akkemik et al., 2018), and Pliocene (Akkemik, 2019). The increase in these studies based on fossil wood and pollen in recent years has provided important information about the climate and forest structure across geological ages. Zachos et al. (2008) and Burke et al. (2018) stated that there was a dramatic change in climate from the beginning to the end of the Cenozoic period. Fossil wood and pollen studies have also shown that there was a change in climate and forest structure from tropical conditions to Mediterranean conditions.

The presence of a tropical climate and forests in the Middle Eocene has also been supported by relevant fossil pollen data (Akgün et al., 2002; Akkiraz et al., 2008) and fossil wood findings (Akkemik et al., 2021). In this context, more fossils from any geological period have the potential to provide more evidence and information to understand the paleoenvironmental conditions. For example, *Actinodaphnoxylon zileensis* Akkemik & Mantzouka was the first identified fossil wood of the modern genus *Actinodaphne* Nees in the world. The genus *Actinodaphne* has 108 representatives from tropical and subtropical Asia to SW Pacific countries and islands (Hassler, 2004-2023). New findings from the region may reveal more about forest composition and climate in the Middle Eocene. In this context, the aim of this study is to provide more evidence for the existence of tropical forests in Anatolia within the Middle Eocene Climate Optimum (MECO) period. For this purpose, new species for the Middle Eocene of Türkiye were identified via fossil wood samples collected from the vicinity of Amasya-Göynücek.

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2. Geological setting

The study area is located in the Göynücek region (SW Amasya) of North Central Türkiye (Figure 1) and its geological age is Lutetian (Figures 1 and 2). The detailed geology of the area was studied by Koçbulut (2004) and Koçbulut et al. (2015) (Figure 2). The basement units along the Çekerek River Valley, whose exact age is pre-Permo-Triassic, are named the Turhal Metamorphics (Tekeli, 1981). The Turhal Metamorphics consist of phyllite, metavolcanics, micaschists, metadiabase, and metasedimentary rocks. The Ferhatkaya and Carcurum formations belonging to the Amasya Group, which show lateral and vertical transitions with each other, unconformably overlie the Turhal Metamorphics. Among these Upper Jurassic-Lower Cretaceous formations, the Ferhatkaya Formation consists of gray-white, massive or thick-layered limestones of partly brecciated texture, while the Carcurum Formation consists of cream-white limestones and clayey limestones with claystone interlayers in places.

The Upper Cretaceous Artova Ophiolitic Complex consisting of diabase, spilite, tuff-originated volcanics, metavolcanics, and serpentinites is deposited on the Carcurum Formation with a tectonic contact. Eocene rocks overlie the older units with an angular unconformity and are named the Çekerek Formation. The Lutetian-aged Çekerek Formation starts with conglomerate at the bottom and consists of conglomerate, sandstone, mudstone, claystone, marl, and limestone alternations. While the Çekerek Formation was deposited in a shallow marine clastic environment during the Eocene transgression, the Göynücek Volcanics were formed when basaltic and andesitic volcanism was active in different phases. The Göynücek Volcanics on the Çekerek Formation started with the *Nummulites* level at the base, continued to the upper volcano-sedimentary units, and ended with volcanics at the top.

On the Çekerek Formation, the Göynücek Volcanics include olivine basalt, basaltic andesite, basalt, agglomerate, and locally tuff-intercalated units that widely outcrop along the Çekerek River Valley to the southwest of Amasya and they were named by Özcan et al. (1980). The studied fossil woods are found at the bottom levels of the Göynücek Volcanics.

Terrestrial sediments consisting of Mio-Pliocene conglomerate, sandstone, and claystone alternations are named the Çerkeş Formation. These units overlie older units with an angular unconformity. Quaternary river terrace deposits, travertines, and alluviums unconformably overlie all these units.

3. Chronology

The radiometric data from the basaltic andesite of the Tokat area (or the Almus area sensu Göçmengil et al., 2018) suggest an age of 45.3 ± 3.1 Ma in contrast to an age of 41.8 ± 1.3 Ma by the K-Ar method (Platzman et al., 1994). The recent study by Göçmengil et al. (2018) gave an age of 40–41 Ma for our studied area. Therefore, our palaeobotanical findings are of great importance because they represent more paleoxylotomical evidence for the forest structure and climate in the MECO for Türkiye. Van der Boon et al. (2021) explained that volcanic activity increased around 40 Ma, very close to the peak warming phase of the MECO, and they deemed it a plausible major contributor to greenhouse warming during the MECO (Akkemik et al., 2021).

4. Material and methods

Fossil specimens were collected from the Lutetian-aged Göynücek Volcanics near Amasya-Göynücek in the Central Black Sea Region. Three fossil specimens taken for this purpose were brought to the Botany Herbarium (ISTO Herbarium) of the İstanbul University-Cerrahpaşa Faculty of Forestry's Department of Forestry and recorded as ISTO-FW-00343, ISTO-FW-00344, and ISTO-FW-00345 in the fossil specimen collection found there (Figure 3).

Three microscopic sections were taken from each fossil specimen. These sections were in transverse, tangential, and radial directions and allowed the same wood elements to be examined from different directions.

In the identification process, data from the website InsideWood (InsideWood, 2004-onwards) were used for comparison and appropriate references (IAWA Committee, 1989, 2004) were used for terminology. In the identification of the *Pinuxylon* type wood, appropriate references were used (Rössler, 1937; van der Burgh, 1964; Huard, 1966; Privé, 1972; van der Burgh, 1973; Dupéron and Dupéron-Laudoueneix, 1985; Yi, 2002; Yi et al., 2005; Jeong et al., 2012; Wang et al., 2017; Dolezych and Reinhardt, 2019; Akkemik et al., 2021). In the identification of *Dichrostachyoxylon* and for comparison with former descriptions, the descriptions of Sayadi (1973) and Selmeier (1990) were used. The descriptions of Petrescu (1978), InsideWood (2004-onwards), and recent studies from the region (e.g., Mantzouka et al., 2016; Akkemik et al., 2019) were used in identification of *Laurinoxylon*.

5. Results and discussion

5.1. Fossil wood descriptions

Within the scope of this study, three fossil woody plant species were defined. The first of these is a pine species (*Pinuxylon* cf. *P. tarnocziense*), which has also been described by Akkemik et al. (2021) from the area (Zile, Tokat), and the other two (cf. *Dichrostachyoxylon zirkelii* (Felix) Müller-Stoll & Mädel 1967 and *Laurinoxylon perseamimatus* Petrescu, 1978) are new species for the region.

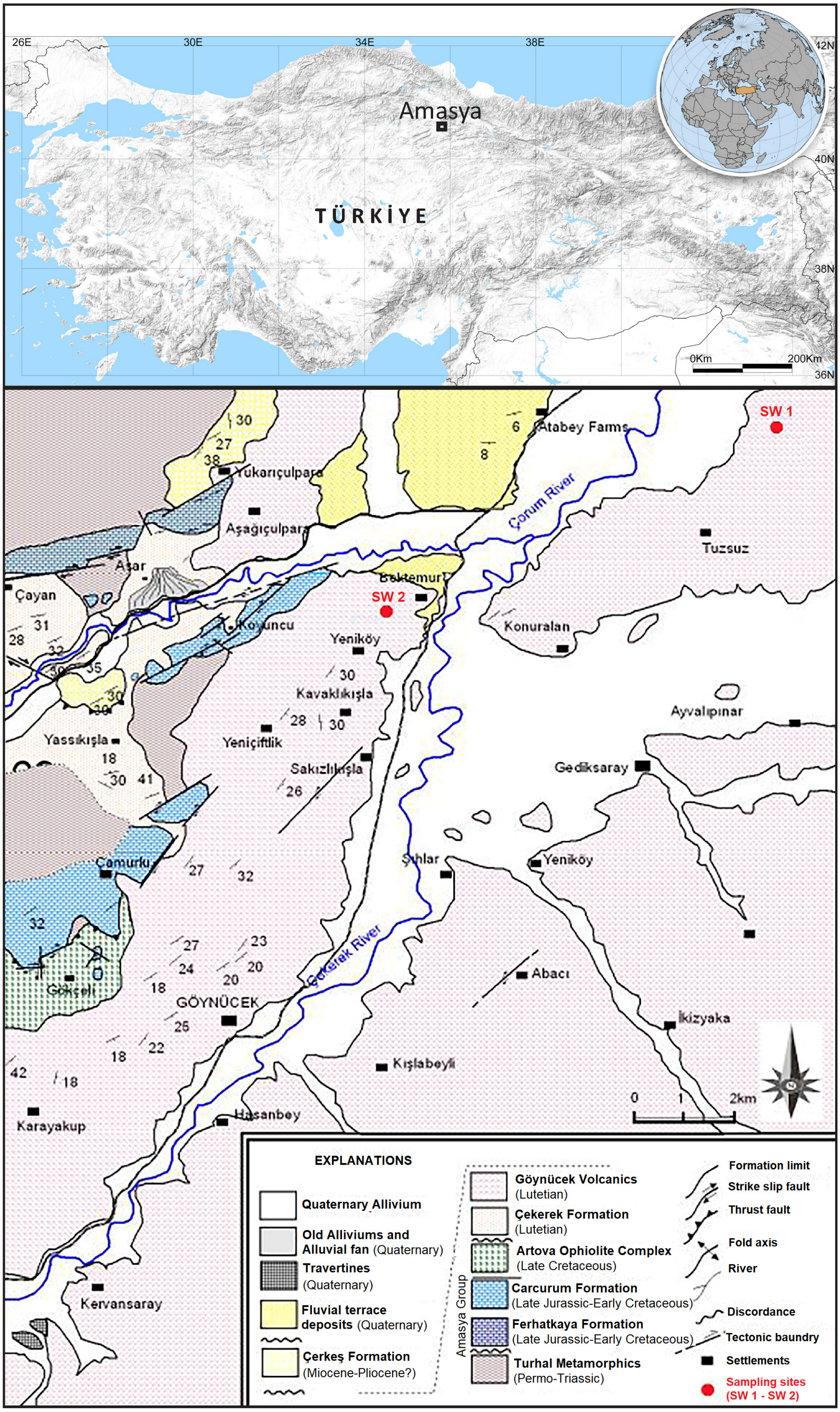

Figure 1. a) Location map of the study area. b) Geological map of the Göynücek (SW Amasya) region (modified from Koçbulut, 2004).

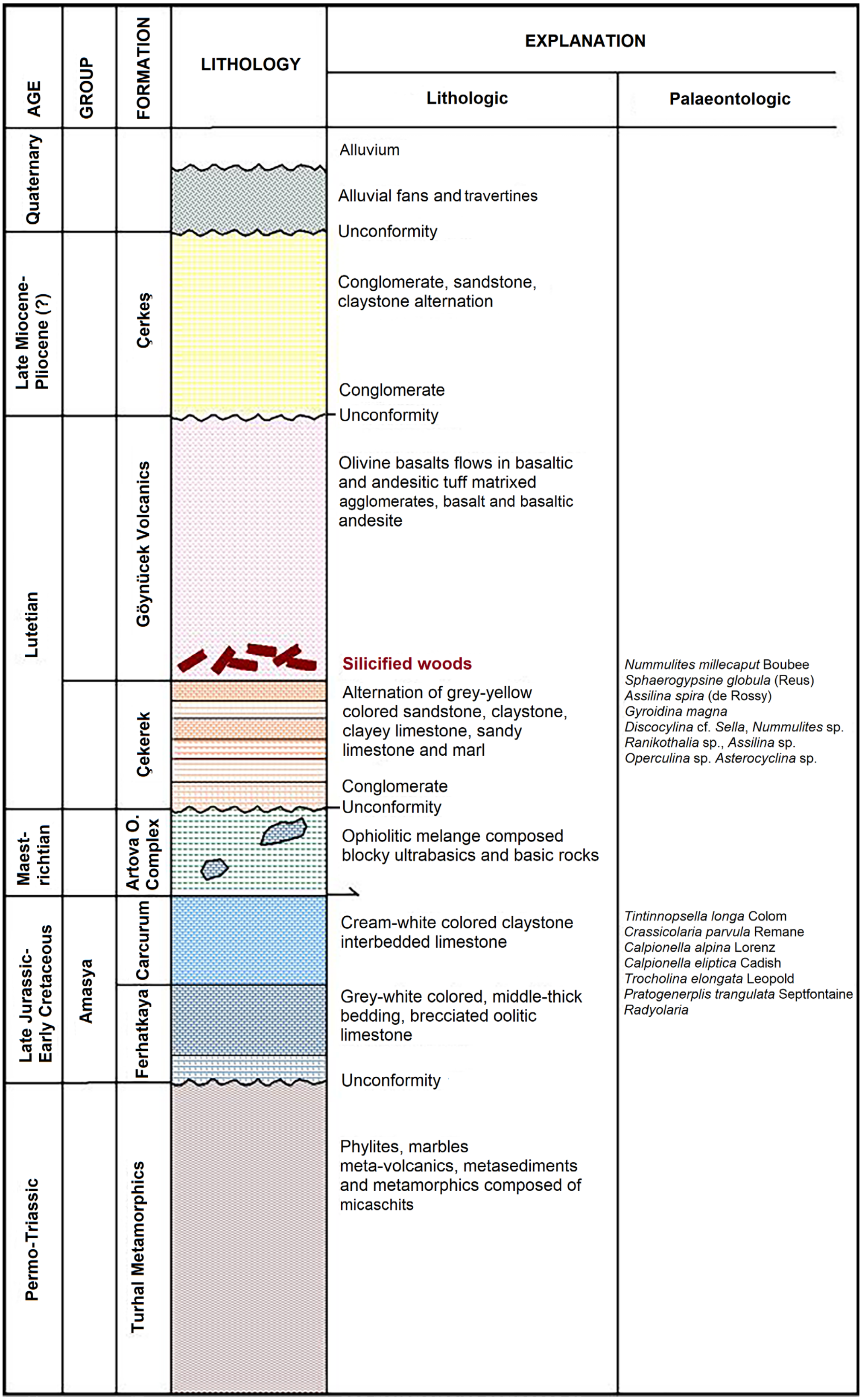

Figure 2. Generalized stratigraphic section of the *Göynücek (SW Amasya) region* (modified from Koçbulut et al., 2015).

Figure 3. The collected and studied fossil wood samples.

Family: PINACEAE Sprengel ex Rudolphi, 1830
Genus: *PINUXYLON* Gothan, 1905
***Pinuxylon* cf. *P. tarnocziense* (Tuzśon, 1901) Greguss, 1954**

Specimen code: ISTO-FW-00345.

Repository: Fossil Wood Collection of the ISTO Herbarium of the Department of Forest Botany, Faculty of Forestry, İstanbul University-Cerrahpaşa, İstanbul, Türkiye.

Locality: Göynücek-Amasya.

Age: Middle Eocene.

Horizon: Göynücek Volcanics.

Description: Wood description was made based on three sections, transverse, tangential, and radial, as follows.

Transverse section (TS): In the wood, the growth ring boundary is indistinct or slightly visible, transition from earlywood to latewood is gradual, and intraannual fluctuations are common. Shapes of tracheids are rectangular, slightly hexagonal, and circular. Axial resin canals are common, with thin-walled epithelial cells (Figure 4a). They are present mostly in transition and latewood zones. Axial resin canals are seen in late earlywood; they are solitary and sometimes in tangential rows. Subsidiary parenchyma cells are present around resin canals (Figure 4b).

Tangential longitudinal section (TLS): Fusiform rays including radial resin canals are common and generally 2–3-seriate, and rays are predominantly uniseriate, some of them partly biseriate. Radial resin canals have thin-walled epithelial cells, as well. Height of uniseriate rays up to 17 cells, height of fusiform rays mostly 12–14 cells (Figure 4c) and up to 30 cells.

Radial longitudinal section (RLS): Rays are heterocellular. Ray tracheids present, 1 (rarely 2–3)-seriate, smooth, and sinusoidal and indistinctly dentate walled (Figure 4d). End walls of axial parenchyma around resin canals smooth (Figure 4e). Tracheid pitting in radial walls of earlywood uniseriate, rarely partly biseriate (Figure 4f). Ray cells occasionally pitted. Cross-field pitting pinoid in 1(–2) row of usually 1–2(–4) per cross-field and wider. End walls of ray parenchyma cells smooth with no indentures observed (Figure 4g).

Comparison and affinities: Mantzouka et al. (2019) stated that the presence of axial and radial resin canals with thin-walled epithelial cells, pinoid type of cross-field pitting, ray tracheids smooth or dentate horizontally, and end walls of ray parenchyma cells were the wood anatomical features of *Pinuxylon*. The pine woods are separated into two main groups as haploxylon and diploxylon pines. Due to having these features, our wood belongs to *Pinuxylon*. Mantzouka et al. (2019) also indicated that while the haploxylon *Pinuxylon* has smooth horizontal walls of ray tracheids, diploxylon specimens have mainly dentate ray tracheids. Due to having smooth horizontal walls together with slightly dentate ones, our wood belongs to the diploxylon group of pines.

Many different fossil species of *Pinuxylon* were described in the world (e.g., Rössler, 1937; van der Burgh, 1964; Huard, 1966; Privé, 1972; van der Burgh, 1973; Dupéron and Dupéron-Laudoueneix, 1985; Yi, 2002; Yi et al., 2005; Jeong et al., 2012; Wang et al., 2017; Dolezych and Reinhardt, 2019). Among these woods, Akkemik et al. (2021) identified *Pinuxylon* cf. *P. tarnocziense* from the

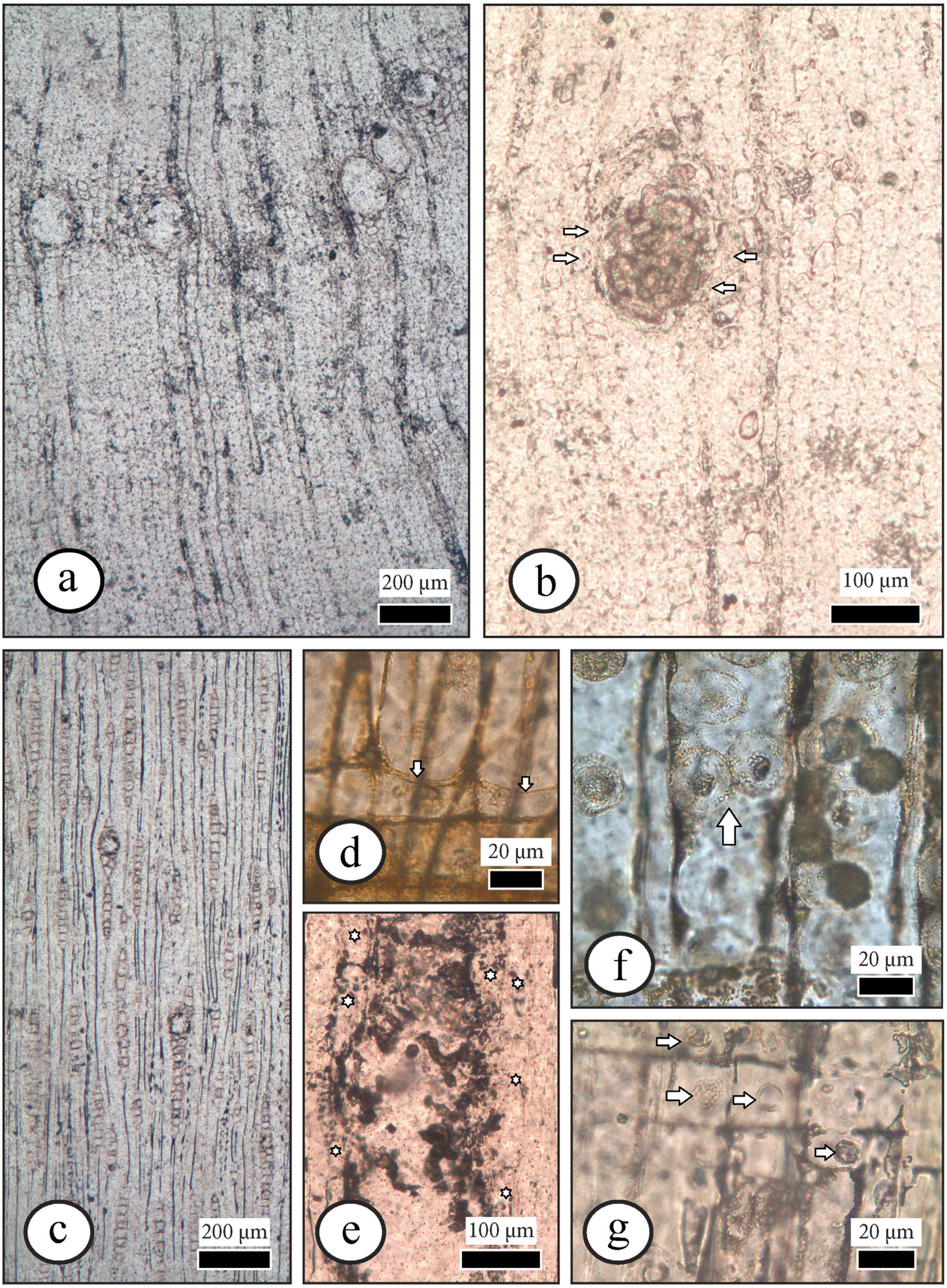

Figure 4. Wood anatomical features of *Pinuxylon* cf. *P. tarnocziense*. a, b) Transverse section with indistinct growth ring boundary and axial resin canals with subsidiary parenchyma cells (arrows); c) tangential section with horizontal resin canal; d) smooth-walled ray tracheids (arrows) and pinoid type cross-field pits; e) axial parenchyma cells around resin canal (stars); f) partly biseriate bordered pits on radial wall of tracheid (arrow); g) pinoid-type cross-field pits (arrows) and uniseriate bordered pits on radial wall of tracheids.

same geological area (Çekerek Formation). These fossil pine woods (the present pine wood and cf. *P. tarnocziense* by Akkemik et al., 2021) have nearly the same wood features. Due to having very similar wood features, we identified it as *Pinuxylon* cf. *P. tarnocziense* from the same geological area, and so the extent of its distribution is widened.

Family: FABACEAE Lindl., 1836

Genus: *DICHROSTACHYOXYLON* Müller-Stoll and Mädel 1967

Species: cf. *Dichrostachyoxylon zirkelii* (Felix) Müller-Stoll & Mädel 1967

Specimen code: ISTO-FW-00344.

Repository: Fossil Wood Collection of the ISTO Herbarium of the Department of Forest Botany, Faculty of Forestry, İstanbul University-Cerrahpaşa, İstanbul, Türkiye.

Locality: Göynücek-Amasya.

Age: Middle Eocene.

Horizon: Göynücek Volcanics.

Description: Wood description was made based on three sections, transverse, tangential, and radial, as follows.

Transverse section (TS): In the wood, the growth ring boundary is indistinct, growth rings are very wide, and intraannual density fluctuations can be seen in the wood. Vessels are solitary and in radial multiples of 2 or 3, outline of the vessels circular to oval, 8–20 vessels per square millimeter. Tangential diameter of solitary vessels 103 (77–137) µm and their radial diameter is 150 (112–193) µm. Vessel tangential diameter of radial multiples of 2 is 114 (72–150) µm and their radial diameter is 118 (75–171) µm. As for the vessel diameters of radial multiples of 3, the tangential diameter is 113 (52–183) µm and radial diameter is 90 (30–182) µm. Dark material is common in vessel cells. Axial parenchyma paratracheal vasicentric, with a tendency to be lozenge-aliform, and all parenchyma cells differ from the ground tissue by dark contents. Fiber lumina is almost completely or nearly closed (Figures 5a–5c).

Tangential longitudinal section (TLS): Ray width 1–2(–3) cells, ray height not over 1 mm, 14–17 rays/mm. Vascular or vasicentric tracheids occur in association with vessel elements. Because of bad fossilization, we could not observe helical thickening. Intervessel pits alternate. No septate fibers are present and fibers are very thick-walled. There is no change in the thickness of the fibers between latewood and earlywood (Figure 5d).

Radial longitudinal section (RLS): All rays procumbent. Perforation plates simple (Figures 5e and 5f). Intervessel pits alternate, 6.5 (5–9) µm.

Comparison and affinities: The wood features, including diffuse porosity and predominantly low number of vessels with paratracheal vasicentric axial parenchyma, simple perforation plates, and mostly homocellular rays, are features of the woods of the family Fabaceae (Wheeler, 2011). Our wood has features closer to *Dichrostachyoxylon zirkelii* identified from İstanbul (Selmeier, 1990) and Antalya (Sayadi, 1973), as given in the Table.

All features indicated in the Table show close similarity of wood anatomical characteristics in vessels, fibers, rays, and axial parenchyma in all woods. The only difference is the indistinct growth ring boundary in the Middle Eocene wood and distinct growth ring boundaries in Miocene woods. This is not a sufficient feature for a new species description because the growth ring boundary indicates the growing site conditions, and depending on seasonality, it may change. In tropical conditions, due to continuous cambial activity, the growth ring boundary is generally indistinct. In temperate zones, because of clear seasonal changes, the growth ring boundary is distinct. Therefore, the feature of "indistinct growth ring boundary" reflects the tropical conditions. As a result, based on these features, we identified this wood as cf. *Dichrostachyoxylon zirkelii* (Felix) Müller-Stoll & Mädel 1967.

Family LAURACEAE Juss., 1789

Genus *LAURINOXYLON* Felix, 1890

***Laurinoxylon perseamimatus* Petrescu, 1978**

Specimen code: ISTO-FW-00343.

Repository: Fossil Wood Collection of the ISTO Herbarium of the Department of Forest Botany, Faculty of Forestry, İstanbul University-Cerrahpaşa, İstanbul, Türkiye.

Locality: Göynücek-Amasya.

Age: Middle Eocene.

Horizon: Göynücek Volcanics.

Description: Wood description was made based on three sections, transverse, tangential, and radial, as follows.

Transverse section (TS): Growth ring boundaries are indistinct. Vessels diffuse-porous and arranged in no specific pattern, solitary, mostly in radial multiples of 2–3 vessels. Outline of the vessels circular to oval. Vessel tangential diameter of solitary vessels 124 (92–164) µm and radial diameter 177 (133–214) µm. Vessel tangential diameter of radial multiples of 2 is 115 (50–176) µm and their radial diameter is 143 (83–198) µm. As for vessel diameters of radial multiples of 3, tangential diameter is 116 (57–181) µm and radial diameter is 110 (51–170) µm. The number of vessels per square millimeter is approximately 20–40. Axial parenchyma very rare and slightly scanty paratracheal (Figures 6a and 6b).

Tangential longitudinal section (TLS): Rays 1–3-seriate. Longer rays more than 1 mm. Ray density is 9–13 rays/mm tangentially. Oil cells are relatively common and associated with only ray parenchyma cells. Oil cells are larger and rounded at the tip or inside of rays. Septate fibers common (Figures 6c–6f).

Radial longitudinal section (RLS): Rays heterocellular

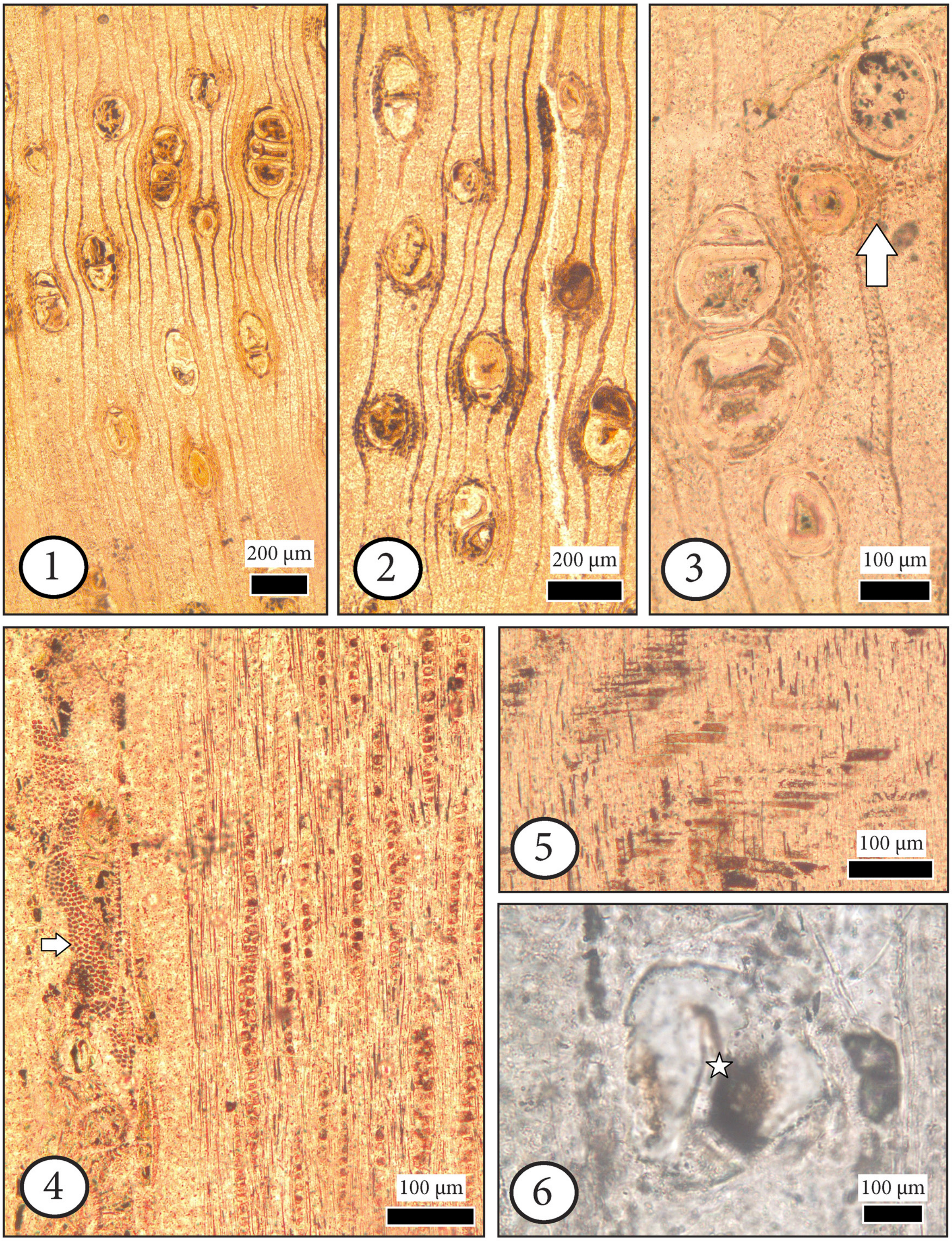

Figure 5. Wood features of cf. *Dichrostachyoxylon zirkelii*. a, b) Transverse section with diffuse to semi-ring porous vessels and vasicentric axial parenchyma; c) vasicentric and lozenge-aliform axial parenchyma (arrow); d) alternate arrangement of pits on the wall of vessel (arrow) and 1–3-rays; e) homocellular rays in radial section; f) simple perforation plate (star).

Table. Comparison of the fossil woods identified as *Dichrostachyoxylon zirkelii* in Türkiye.

Locality	Tokat (this study)	Antalya (Sayadi, 1973)	**İstanbul (Selmeier, 1990)**
Age	Middle Eocene	Miocene	Sarmatian (Middle Miocene)
Growth rings	Indistinct	Present	Present
Vessels	Diffuse to semi-ring, porous, solitary (45%), 2–3	Semi-ring porous, solitary (72%) and 2–3	Semi-ring porous, solitary (43%) and 2–3
Vessel diameter in earlywood	103 (77–137) µm	128 (106–158) µm	164 (107–230) µm
Vessel diameter in latewood		80 µm	49–101 µm
Pits	Alternate, 6.5 (5–9) µm	Alternate, 4–6 µm	Alternate, ca. 5 µm
Perforation plate	Simple	Simple	Simple
Vessels per square millimeter	8–20	8–10	11 (5–19)
Dark content	Present	Present	Present
Fibers	Not septate	Not septate	Not septate
Tracheids	Present	--	Present
Axial parenchyma	Paratracheal vasicentric, partly confluent, tendency to aliform, brown-dark contents	Paratracheal vasicentric, partly confluent, tendency to aliform, brown-dark contents	Paratracheal vasicentric, partly confluent, tendency to aliform, brown-dark contents
Ray composition	All ray cells procumbent	Homogeneous (all ray cells procumbent)	All ray cells procumbent
Ray width	1–2(–3)	(1-) 2-3 (-4)	(1–)2–3
Ray height	Less than 1 mm	Less than 0.5 mm	Less than 1 mm
Rays per mm	14–17	17–20	9–11(–14)
Prismatic crystals	–	–	Present

including body ray cells procumbent with one row of oil cells. Perforation plates are simple. Intervessel pits alternate and are large, 14 (9–23) µm. Strand length of axial parenchyma 5–8 or more (Figures 6g–6j).

Comparison and affinities: The wood of *Laurinoxylon* is described based on the following features: wood diffuse-porous; growth ring boundaries generally distinct; marginal axial parenchyma absent; oil and/or mucilage cells present in ray, axial parenchyma, and/or among fibers; ray cells 1–3-seriate; and diffuse, scanty paratracheal or vasicentric type of axial parenchyma (Mantzouka et al., 2016). The studied specimen has diffuse-porous wood; indistinct growth ring boundary; absence of marginal axial parenchyma, oil, and/or mucilage cells only in rays; 1–3-seriate rays; and rare, diffuse, and scanty paratracheal of axial parenchyma. These features led us to the genus *Laurinoxylon*. Mantzouka et al. (2016) grouped the fossil species of *Laurinoxylon*, and later Akkemik et al. (2019) prepared an identification key for the fossil species of *Laurinoxylon*. Based on the grouping by Mantzouka et al. (2016), our wood belongs to Type 1, which has oil and mucilage cells associated only with ray parenchyma cells. In this group, 1–3-seriate rays, simple perforation plates, and indistinct or absent growth ring boundaries belong to two fossil species, *Laurinoxylon perseamimatus* Petrescu, 1978 and *Laurinoxylon ehrendorferi* Berger, 1953, in the identification key (Akkemik et al., 2019). In our wood, axial parenchyma is very rare or absent; therefore, our fossil wood is closer to *Laurinoxylon perseamimatus* Petrescu, 1978. On the other hand, in *Laurinoxylon ehrendorferi*, axial parenchyma is very common. As a result, we identified our wood as *Laurinoxylon perseamimatus*. This type of fossil wood was described first by Petrescu (1978) from the Middle Oligocene of Romania. Thus, the age of this type of fossil wood dates back to the tropical conditions of the Middle Eocene.

5.2. Paleoecology in the Middle Eocene

Eocene units are represented by the Çekerek Formation and Göynücek Volcanics in the provinces of Amasya and Tokat. The clay, sandstone, claystones, and clayey limestone and marl levels of the Çekerek Formation contain some larger foraminifera such as *Nummulites millecaput* Baubee, *Assilina spira* (de Rossy), *Discocyclina* cf. *sella*, and *Operculina* sp. Microfossil assemblages, generally composed of hyaline forms, indicate a shallow-water vegetated environment. The land part of the environment was represented by the fossil woods and fossil pollen

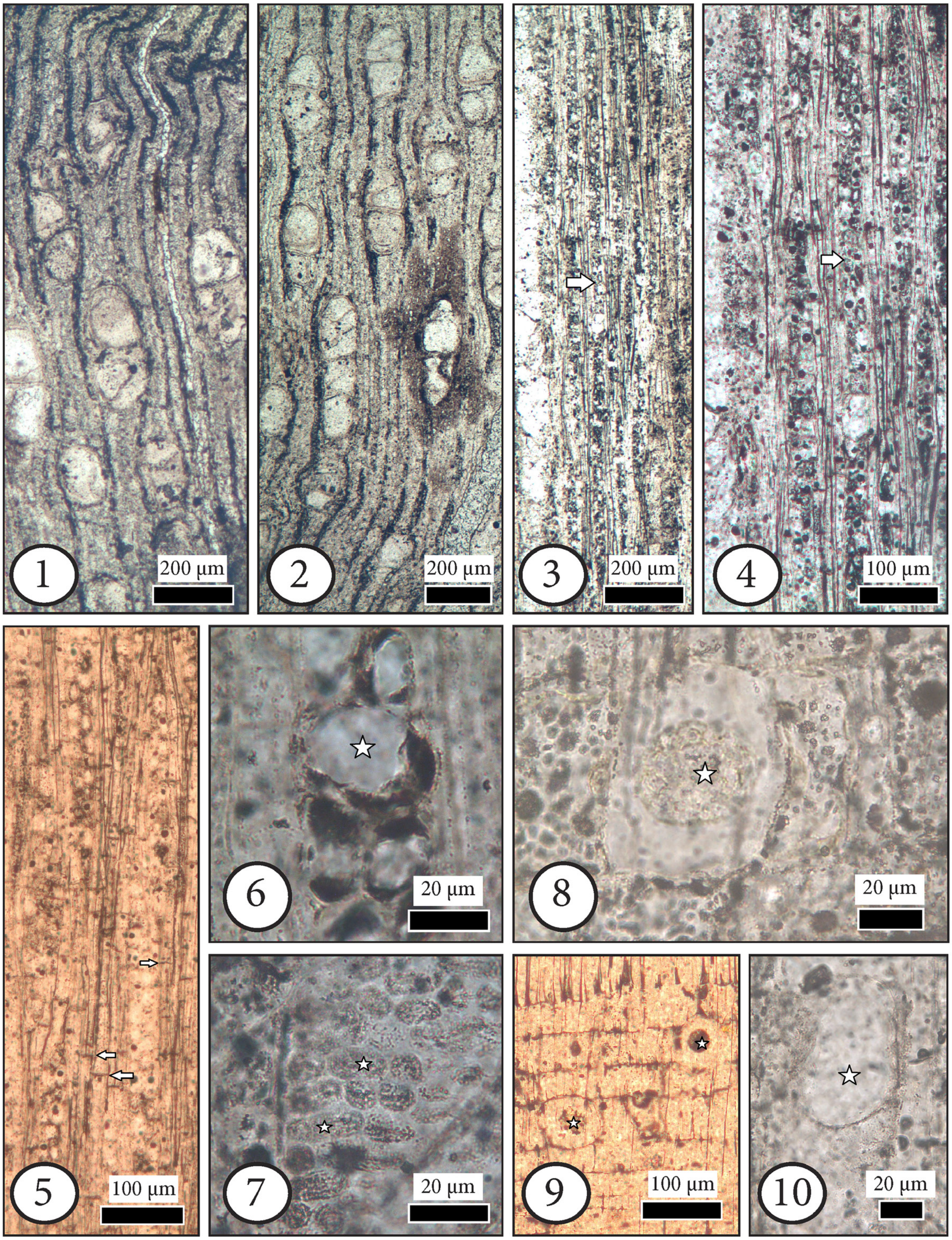

Figure 6. Wood features of *Laurinoxylon perseamimatus.* a, b) Transverse sections with diffuse porous vessels solitary and mainly in radial multiples of 2–3 vessels, and indistinct growth ring boundaries; c, d) tangential sections with 1–3 rows of rays and some longer rays of more than 1 mm (arrows); e) septate fibers (arrows); f) oil and mucilage cells associated with rays (arrow); g) alternate and medium/large-sized pits on the radial wall of vessel (stars); h) one row of oil and mucilage cells associated with a ray (star); i) oil and mucilage cells within ray (stars); j) simple perforation plate (star).

data. It is known that volcanism was active in the region during the Middle Eocene period. With the beginning of precipitation of pyroclastics formed by volcanism, the trees in the region were moved to the marine environment. It is thought that silicification took place in these trees, which were moved by ongoing volcanism. The described trees are known to characterize a tropical and warm climate in the region (Privé, 1970; Selmeier, 1990; Akkemik et al., 2021; PROSEA, 2023). In these climatic conditions, the effect of the Eocene shallow sea was present.

With this study, the species of cf. *Dichrostachyoxylon zirkelii*, *Laurinoxylon perseamimatus*, and *Pinuxylon* cf. *P. tarnocziense* were identified. These species are generally representatives of warm and rainy tropical forests (Boyer, 1987). It can be suggested that there was a shallow sea in the region during the Eocene period, and accordingly, warm tropical climate conditions prevailed in the terrestrial environment.

Today, tropical forests are the forests between the Tropics of Cancer and Capricorn in the world. The tropical forests are divided into three types as follows: 1) tropical and subtropical moist broadleaf forests, 2) tropical and subtropical dry broadleaf forests, and 3) tropical and subtropical coniferous forests (Olson and Dinerstein, 1998). The identified fossil woods, including *Actinodaphnoxylon zileensis* by Akkemik et al. (2021), cf. *Dichrostachyoxylon zirkelii*, *Laurinoxylon perseamimatus*, and *Pinuxylon* cf. *P. tarnocziense*, are representatives of warm and rainy tropical forests. The modern representatives of the identified genera are *Actinodaphne, Dichrostachys*, and tropical Lauraceae species, and they are mainly present in tropical and subtropical conditions. Zachos et al. (2008) suggested that Earth's climate has changed from the Eocene to the present and ice-free temperatures were around 8–10 °C in the time of the MECO. From fossil pollen records in the Yozgat basin (Türkiye), based on 64 genera and 136 palynoflora species of Middle-?Late Eocene age, and using the coexistence approach method, Akkiraz et al. (2008) suggested that the Middle-?Late Eocene formations in Central Anatolia were represented by mangrove swamp with contributions by *Nypa*, *Pelliciera*, *Avicennia*, *Diporites iszkaszentgyörgyi*, and dinoflagellate cysts, which reflect warm climatic conditions, and the region during the Middle-?Early Eocene had a megathermal zone (mean annual temperature of 24.8–25 °C) and megatherm/mesotherm intermediate zone (mean annual temperature of 23.1–24.8 °C near the coast), whereas mesothermic (mean annual temperature of 16.5–23.1 °C) conditions prevailed in the montane region. Regarding fossil woods, two pieces of evidence of the tropical conditions are 1) the species of the identified trees and 2) the growth ring features, which have indistinct boundaries and intraannual fluctuations (Figure 7). These three woods typically showed these two types of evidence and, therefore, they contributed more evidence for tropical conditions in the MECO.

Privé (1970) stated that, regarding temperatures in the Miocene when the fossil trees of *Dichrostachys* were alive, the annual average temperature was 15–25 °C, while the minimum annual precipitation was 250–700 mm. The values of temperature and precipitation were higher in the Middle Eocene as also indicated by Akkiraz et al. (2008). This may be evidence of differences between generally distinct growth ring boundaries in the Miocene woods of *Dichrostachyoxylon zirkelii* (Selmeier, 1990) and generally indistinct growth ring boundaries in the Middle Eocene woods of this fossil species (this study).

On the other hand, tropical and subtropical warm conditions continued up to the Middle Miocene in Türkiye (Güner et al., 2017; Akkemik et al., 2023) with dry bottlenecks (Biltekin, 2018; Denk et al., 2019). In the Early Miocene, the taxonomic compositions of forests suggest that laurel trees were the major group on well-drained soils with ecotones between laurel forest and broadleaf deciduous forest biomes (Denk et al., 2019). Different genera and species of Lauraceae such as *Actinodaphnoxylon zileensis* (Akkemik et al., 2021) and *Laurinoxylon perseamimatus* (this study) from the Middle Eocene and *Lauroxylon thomasii* (Akkemik et al., 2019), *Laurinoxylon litseoides* (Akkemik et al., 2019; Akkemik, 2021), *Cryptocaryoxylon grandoleaceum* (Akkemik, 2021), and *Cryptocaryoxylon irregularis* (Akkemik et al., 2022) from the Early-Middle Miocene indicate that laurel biomass continued at least to the Middle Miocene in Türkiye with different genera and species. Today, this family is represented by only one species (*Laurus nobilis* L.) in the eastern Mediterranean basin. It grows in lowland, humid, and well-soil conditions of the Mediterranean basin. Alessi et al. (2018) indicated that *Laurus* populations grow in the areas receiving abundant precipitation throughout the year or in areas buffering the summer aridity with rich soils having nutrients and moisture.

6. Conclusion

With this study, two more tropical/subtropical woods (cf. *Dichrostachyoxylon zirkelii* and *Laurinoxylon perseamimatus*) were identified together with a pine wood (*Pinuxylon* cf. *P. tarnocziense*) from the region. The new woods supported the presence of tropical conditions with their indistinct growth ring boundaries and very wide growth rings. With these wood features, we may conclude that tropical and subtropical moist broadleaf forests together with tropical and subtropical coniferous forests composed of pine trees were present in the study area during the Middle Miocene. Our findings suggest that further studies would make more contributions to our knowledge of Middle Eocene forest compositions and paleoenvironments.

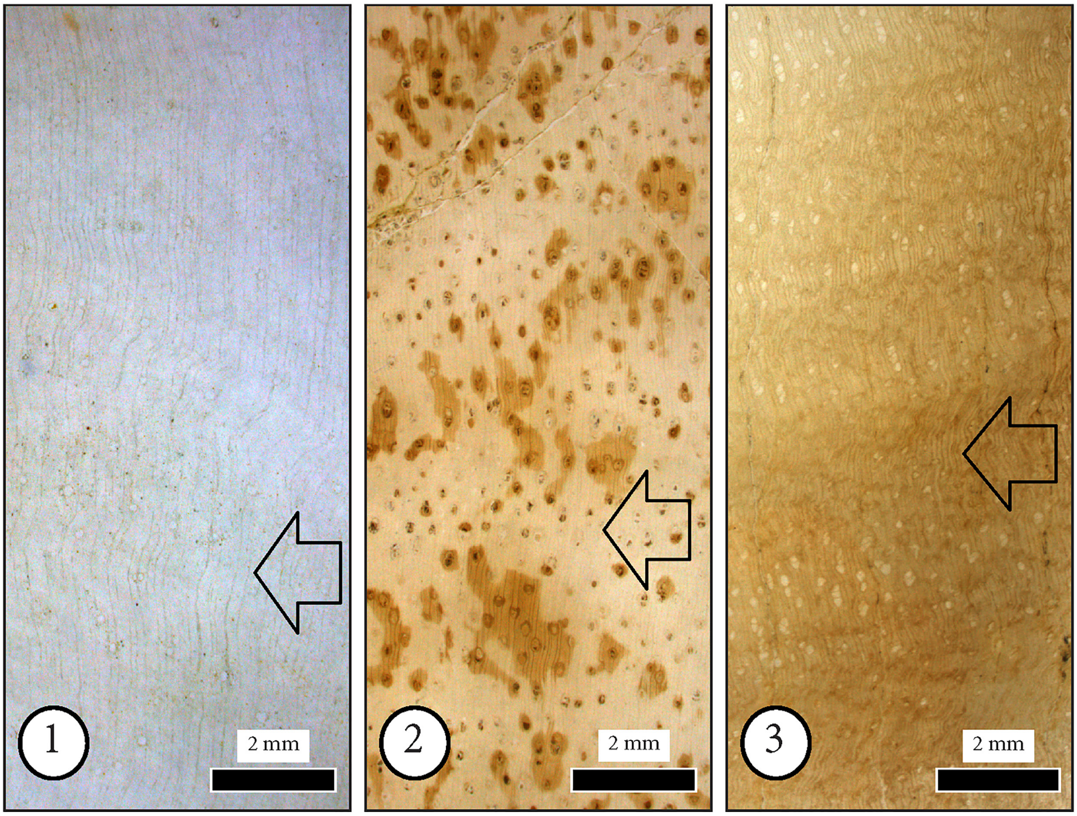

Figure 7. Indistinct growth ring boundaries of the three identified species. a) *Pinuxylon* cf. *P. tarnocziense*, b) cf. *Dichrostachyoxylon zirkelii*, c) *Laurinoxylon perseamimatus.* Arrows show intraannual fluctuations within the growth ring.

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