Turkish Journal of Botany

Volume 48 | Number 2 Article 4

3-19-2024

A new fossil wood species of Ziziphus from the Middle Miocene of Türkiye and its palaeoenvironmental evaluation

ÜNAL AKKEMİK
uakkemik@istanbul.edu.tr

ÖZLEM TOPRAK
ozlem.toprak@gop.edu.tr

Recommended Citation

AKKEMİK, ÜNAL and TOPRAK, ÖZLEM (2024) "A new fossil wood species of Ziziphus from the Middle Miocene of Türkiye and its palaeoenvironmental evaluation," *Turkish Journal of Botany*: Vol. 48: No. 2, Article 4. https://doi.org/10.55730/1300-008X.2798
Available at: https://journals.tubitak.gov.tr/botany/vol48/iss2/4

Turkish Journal of Botany
http://journals.tubitak.gov.tr/botany/
Research Article

Turk J Bot
(2024) 48: 91-104
© TÜBİTAK
doi:10.55730/1300-008X.2798

A new fossil wood species of *Ziziphus* from the Middle Miocene of Türkiye and its palaeoenvironmental evaluation

Ünal AKKEMİK[1,*], **Özlem TOPRAK**[2]
[1]Department of Forest Botany, Faculty of Forestry, Istanbul University, İstanbul, Turkiye
[2]Tokat Vocational School, Tokat Gaziosmanpaşa University , Tokat, Turkiye

Received: 10.09.2023 • **Accepted/Published Online:** 06.01.2024 • **Final Version:** 19.03.2024

Abstract: The purpose of this study is to describe a new fossil wood from the Middle Miocene of South Anatolia (Mersin) and to identify it and evaluate its palaeoenvironmental implications. Thin sections of transverse, tangential, and radial surfaces were examined and described using the terminology of the International Association of Wood Anatomists. The wood was determined to have characteristics of *Ziziphus* (Rhamnaceae). It is the first fossil wood of *Ziziphus* and is described as *Ziziphoxylon sayaz* Akkemik sp. nov. It is from the Middle Miocene Climate Optimum (MMCO), which is a relatively warm interval in the Miocene. Indistinct annual growth ring boundaries and wide rings indicate optimum growth site conditions during its life time. Furthermore, this fossil wood also supports the presence of shallow marine terrestrial areas in Mut Formation.

Key words: *Ziziphoxylon*, Mut Formation, palaeobotany, Middle Miocene Climate Optimum, MMCO

1. Introduction

Fossil woods from Miocene of Türkiye provide detailed information about the vegetation and climate of that time. There are many woods described from Early Miocene (e.g., Akkemik, 2021a,b,c; Akkemik et al., 2016, 2018, 2020), with fewer known from Middle Miocene (Akkemik et al., 2017; Güngör et al., 2019; Mantzouka et al., 2022) to Late Miocene (Akkemik and Acarca Bayam, 2019). These woods not only provide information about the diversity of the woody vegetation of the Miocene of Türkiye but also about the palaeoclimate of that era.

The Middle Miocene has an important epoch called the Middle Miocene Climate Optimum (MMCO) after the former climate optimum time called Middle Eocene Climate Optimum (MECO) represented with tropical woods such as *Palmoxylon sabaloides* Greguss (Akkemik et al., 2023), *Actinodaphnoxylon zileensis* Akkemik & Mantz. (Akkemik et al., 2021), and *Dichrostachyoxylon zirkelii* (Felix) Müller-Stoll & Mädel and *Laurinoxylon perseamimatus* Petrescu (Akkemik et al., 2023). MMCO covered the time interval of 16.9–14.7 Ma, and represented a relatively warm interval in the Miocene (Beerling et al., 2010; Ji et al., 2018; Steinthorsdottir et al., 2020). Global mean annual temperature during the MMCO was 5–6 °C warmer than present-day temperatures (Goldner et al., 2014; Hui et al., 2018). Böhme (2003), based on ectothermic vertebrates of Central Europe, indicated differences in seasonality of precipitation during MMCO with higher seasonality in precipitation, e.g., longer dry seasons. High seasonality promotes distinct growth ring boundaries in trees. Fossil trees in the middle Miocene of Gökçeada have distinct growth ring boundaries (Güngör et al., 2019) showing high seasonality.

Updating the world map of the Köppen-Geiger climate classification, Peel et al. (2007) stated that a monthly average temperature of 18 °C or higher in the coolest month of tropical climates, and hot temperatures throughout the year; yearly total precipitation is often abundant, and shows a seasonal rhythm, together with seasonal dryness to varying degree in some places. Trees in typical tropical conditions produce wide tree rings with mostly indistinct boundaries (e.g., Baas and Schweingruber, 1987). *Actinodaphnoxylon* trees from the Middle Eocene Climate Optimum (MECO) have very wide growth rings with indistinct boundaries and may be good indicators of tropical conditions (Akkemik et al., 2021). During the Early Miocene, trees produced distinct growth rings, indicating seasonality (e.g., Akkemik et al., 2018, Acarca-Bayam et al., 2018; Akkemik, 2021a,b,c). Additional samples of fossil wood from the Middle Miocene of Türkiye are needed to

* Correspondence: uakkemik@iuc.edu.tr

provide more data on growth ring features. The purpose of the present study is to describe and identify a new fossil wood from the middle Miocene of South Anatolia (Silifke-Mersin) and evaluate its growth conditions.

2. Geological setting

The study area is located in the Central Taurus Mountains, on the Silifke-O31 sheet, which is situated between Karaman Province in the north and Silifke District in the south (Figure 1). The study area includes rocks that were tectonically settled in the region and named Bozkır and Aladağ units by Özgül (1976), with Tertiary sedimentary rocks unconformably overlying them. Quaternary sediments overlie all these rocks (Figure 1).

The Bozkır Unit defined by Özgül (1976) includes block and allochthon units of different ages, types, and sizes. The Bozkır Unit, which has a Middle-Late Triassic-Late Cretaceous age range, consists of four lithostratigraphic units in the study area. These are Kuztepe limestone, Asartepe limestone, Mersin Ophiolite, and Mersin Ophiolitic mélange (Özgül, 1997). Only the carbonate rocks of the Çambaşı Formation belonging to the Aladağ Unit crop out in the region. Tertiary rocks consist of Derinçay, Mut, Köselerli, Dağpazarı, Tırtar, and Ballı formations, respectively (Figure 2).

Tanar and Gökçen (1990) stated that the Mut and Köselerli formations were deposited in shallow marine conditions. In addition to these two researchers, Özdoğan (1999) also acknowledged that the terrestrial rock units were transitional with marine rock units. However, the Mut Formation was deposited in reef and lagoon environments, while the Köselerli Formation was deposited in the basin slope and basin environment with the planktonic foraminifera it covers, and there is a transgressive flooding surface between the terrestrial and marine sediments (Atabey et al., 2000a, b). The tree fossils, which are the subject of this study, are found in these terrestrial areas. In the region, a shallowing phase occurred as a result of the seafloor uplift caused by tectonism and the related regression at the end of the Langhian and the beginning of the Serravallian. Claystone, limestone, beach pebbles and sandstone were deposited in the formed lagoon areas (Dağpazarı Formation). Depending on the small oscillations of the sea, some alluvial fan-delta deposits have progressed on these coastal deposits. A second transgression developed in the region after shallowing in the Lower Serravallian. Limestone and clayey limestone (Tırtar Formation) were deposited in the reef and back reef environments of the sea that invaded the region at the beginning of the Upper Serravallian, and Tortonian clayey limestone, marl (Ballı Formation) were deposited in the basin slope and basin environment. At the end of the Tortonian, a regressive phase developed again, and the Tırtar and Ballı formations were covered by Pliocene continental clastics (Atabey et al., 2000a, b) (Figure 2).

3. Materials and methods

The fossil wood described herein, measuring 43 cm in length and 35 cm in diameter, was collected from Kavaklı Village in the Silifke District of Mersin Province. Although the piece of wood looks like stem wood, the distinction between root or stem wood is difficult because of the indistinct growth ring boundaries and the presence of root pieces extending in two different directions at the base (Figure 3).

A small piece of the wood was selected for thin sectioning, and slides (about 30 μm thick) of transverse, tangential, and radial sections were prepared. Wood anatomy references (e.g. Fahn et al., 1986; Schweingruber, 1990; Akkemik and Yaman, 2012; InsideWood, 2004-onwards) were used for wood identification. All anatomical structures of the fossil wood were studied under a LEICA microscope (DM2500), and microphotographs were taken with a LEICA camera (DFC295). We followed the terminology suggested by IAWA Hardwood Committee (1989), as well as that used on the InsideWood web site (Wheeler, 2011; Wheeler et al., 2020).

We searched the hardwood database of InsideWood (2004-onwards) to identify the wood. In this key, we entered the representative number for each feature proposed by IAWA committee (1989) and the representative letter for the presence or absence for each feature, which is proposed in InsideWood: "p" present, "a" absent, "r" present required, and "e" absent required. For example, in "13r", "13" represents presence of simple perforation plate, and "r" indicates that this feature is required to be present in any suggested match (Wheeler, 2011, Wheeler et al., 2020). Thereafter, we examined the families, genera, and species suggested by the InsideWood search.

4. Results and discussion

4.1. Systematic palaeobotany

Class: MAGNOLIOPSIDA Cronquist et al., 1996

Order: Rosales Bercht. & J.Presl. 1820

Family: Rhamnaceae Juss 1809

Genus: ***Ziziphoxylon*** Akkemik gen. nom. nov

Species: *Ziziphoxylon sayaz* Akkemik sp. nov.

(Figure 3, Plates IV-V)

Etymology: Based on the Rule 12C in Latin nomenclature (Lapage et al, 1992), the first letters of the following words, including its region and fruit importance, were used in selecting the species epithet "*sayaz*": a fossil fruit wood from **S**outh **A**natolia, which is a **Y**ieldful **A**griculturally and **Z**estful. Because *Ziziphus* is economically important today, this epithet was selected for the fossil form of modern *Ziziphus* wood.

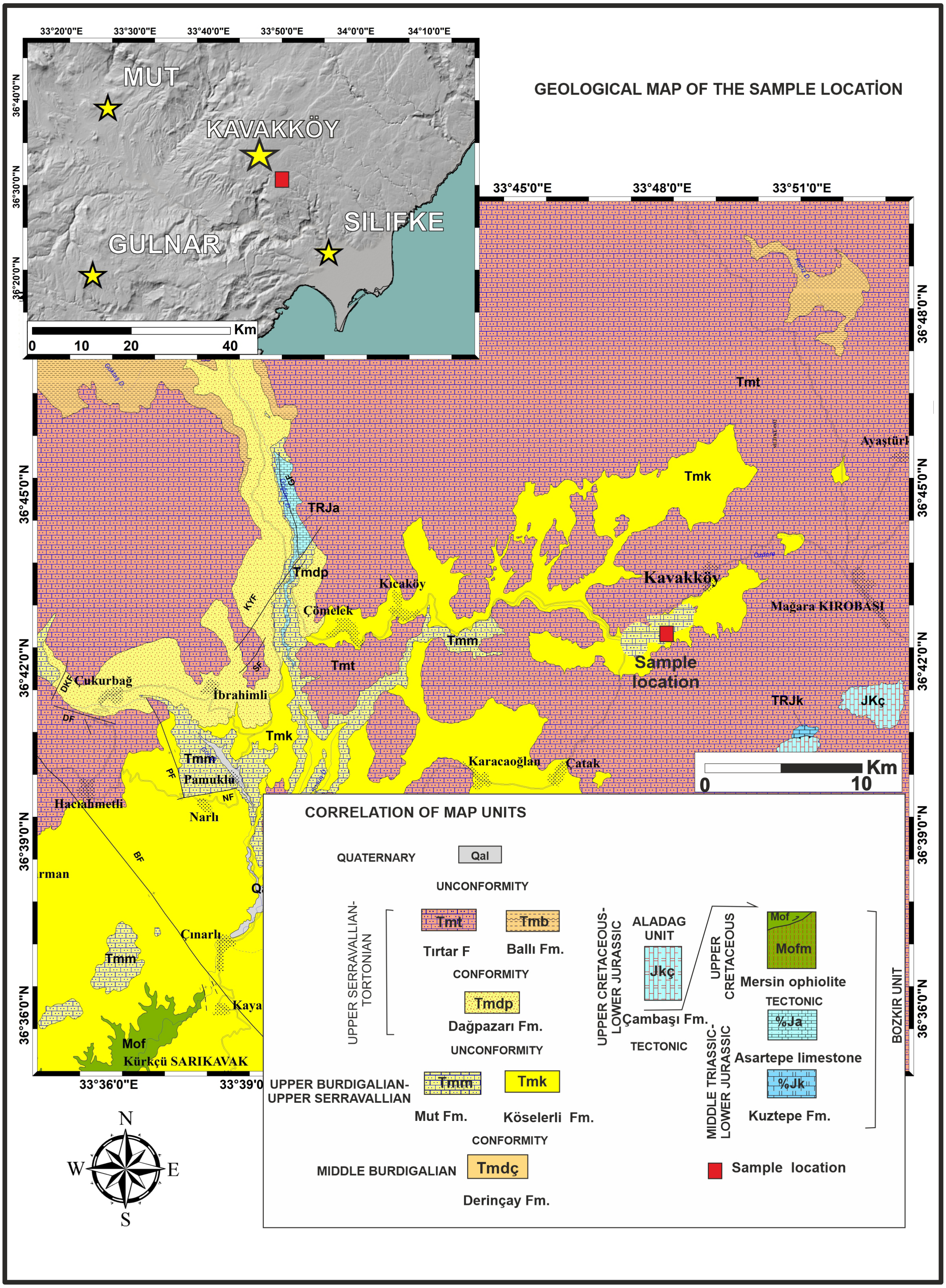

Figure 1. The geological map of Kavakköy (Silifke) region (modified from the MTA 1/100,000 map) and the location map of the studied area.

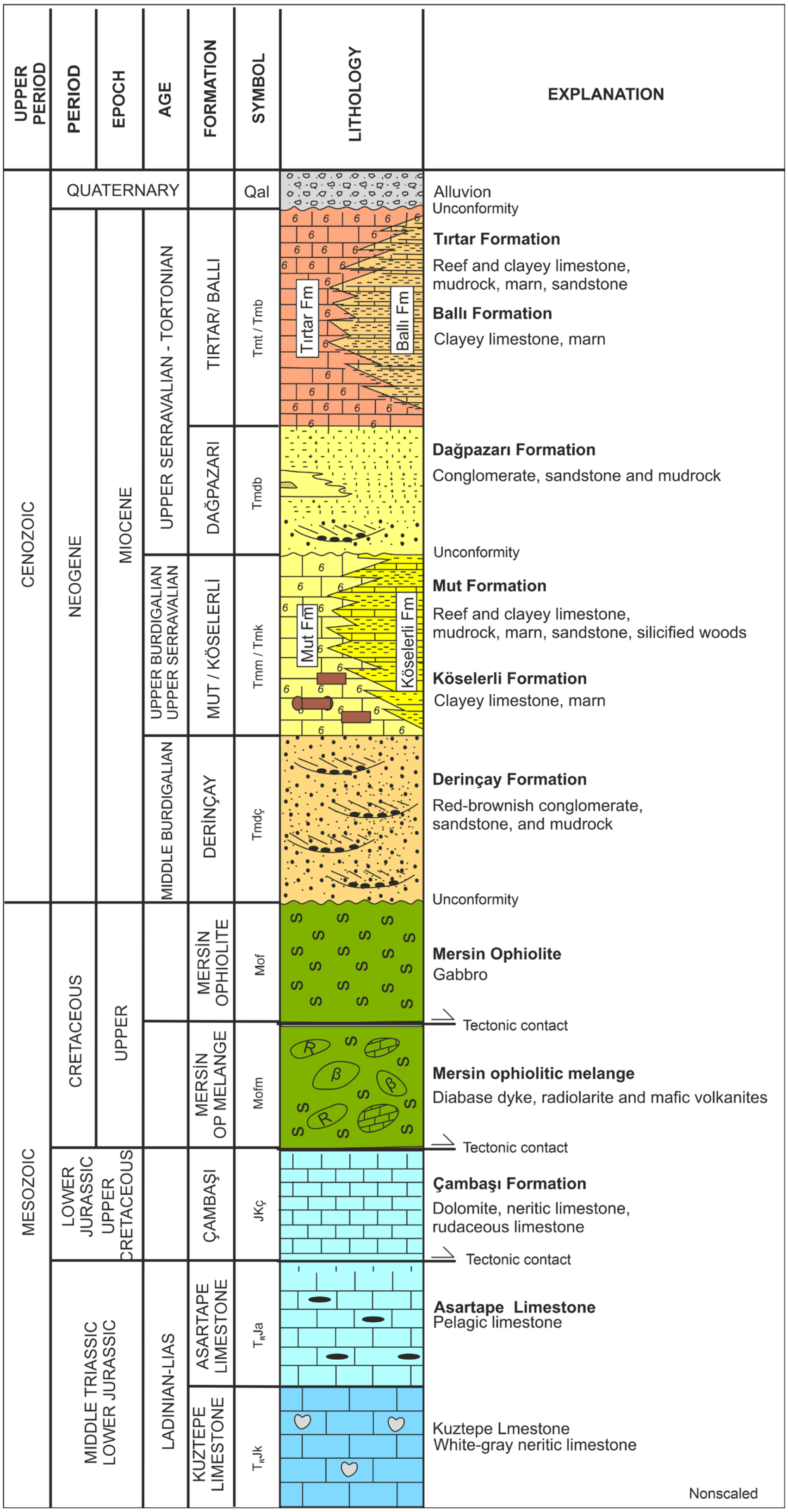

Figure 2. The generalized stratigraphic section of Kavakköy (Silifke)) region (modified from (Ilgar et al., 1996).

Figure 3. The studied fossil wood. Lower part of the wood looks like the root starting area. For wood identification, a wood sample was taken from the tip (stem wood) of the fossil wood.

Nomenclature: The fossil genus name *Zizyphoxylon* B.S.Trivedi & K.Srivastava was first used by Trivedi & Srivastava (1982). However, today the accepted name of living plants of the genus is *Ziziphus* Mill., 1754, and *Zizyphus* Adans, 1763 is an orthographic variant of *Ziziphus* (https://www.ipni.org/n/52402-3. According to the Vienne Code Article 61, only one orthographical variant of any one name is treated as validly published. Based on this discussion, and because of different use of the fossil *Zizyphoxylon* wood as *Ziziphoxylon* or *Zizyphoxylon*, we propose *Ziziphoxylon* Akkemik nom. nov. for fossil wood resembling modern *Ziziphus*.

Furthermore, we propose to use the fossil forms of the woods by adding the suffix "*xylon*", because the suffix "-*xylon*" is often used in generic names, indicating a similarity with the wood of the modern genus whose name is combined with that suffix. Because of having features in common with both *Ziziphus* and *Paliurus* woods, we prefer to use the suffix "*xylon*". Finally, after making a nomen novum to correct the fossil genus name as *Ziziphoxylon* and proposing to use the fossil forms with the suffix "*xylon*", we propose two new combinations: *Ziziphoxylon mandlaensis* (Trivedi & Srivastava, 1982) Akkemik, 2024 comb. nov. and *Ziziphoxylon oxyphylla* (Edgew., 1992) Akkemik, 2024 comb. nov.

Type locality: Kavak Village in the district of Silifke of the province of Mersin, Türkiye.

Holotype: A large sample and three thin sections from it with repository number ISTO-FW-00386).

Type stratigraphic horizon: Mut Formation

Geological age: Late Burdigalian-Late Serravallian.

Plant fossil name registry number for fossil genus: PFN003227

Plant fossil name registry number for fossil species: PFN003214

Repository: ISTO Herbarium Fossil Collection at the Department of Forest Botany, Faculty of Forestry, Istanbul University - Cerrahpasa, İstanbul, Türkiye.

Diagnosis: Growth ring boundaries indistinct. Wood diffuse-porous. Vessels rounded, solitary and in radial multiples of 2–3 (rarely up to 7) vessels, and sometimes clusters present. Number of vessels per square millimetre: 5–20. Perforation plates simple. Intervessel pits large. Axial parenchyma scanty paratracheal and vasicentric, and in one or two rows of marginal axial parenchyma. Libriform fibres nonseptate. Fibres thin- to thick-walled in regular radial rows. Rays predominantly uniseriate, sometimes partly biseriate, homocellular (all ray cells procumbent) and heterocellular, body ray cells procumbent with 1-2 rows of square and/or upright marginal cells, some rays with procumbent, square and upright cells mixed throughout the ray. Crystals present in both procumbent and square cells. Vessel-ray pits are small and numerous similar to intervessel pits.

Description: The description of the fossil wood was made based on the three microscopic sections, transverse, tangential, and radial as follows.

Transverse section: Growth ring boundaries indistinct to distinct, 1-2 rows of marginal axial parenchyma, with differences in vessel diameter near the marginal parenchyma bands, the growth ring boundaries very slightly visible microscopically (Figures 4A, 4B, 5A–5C). Wood diffuse-porous. Vessels solitary and n radial multiples of 2–3 or rarely up to 7 vessels. Vessel outline rounded. Libriform fibres thin- to thick-walled (Figures 5A–5E). Tangential diameter of vessels 106 (61–174) µm, radial diameters 141 (34–228) µm. Vessel frequency 13 (5–21) per square millimetre. Axial parenchyma in 1–2 rows of marginal parenchyma, scanty paratracheal, and vasicentric (Figures 5C–5E).

Tangential section: Rays predominantly uniseriate, partly biseriate, and mostly 10–20 cells high (max. 26 cells) (Figures 6A and 6B). Ray cells variable in size (Figure 6B), mostly large, square to rounded. Libriform fibres present. Axial parenchyma strands 1–4 or more cells (Figure 6C). Rays per millimetre 13–22. Crystals present in ray cells. Coloured deposits may be seen in some ray cells (Figure 6D). Vessel element length is 380 (115–671) µm.

Radial section: Rays both homocellular and heterocellular. In homocellular rays, all ray cells are procumbent. In heterocellular rays, body ray cells

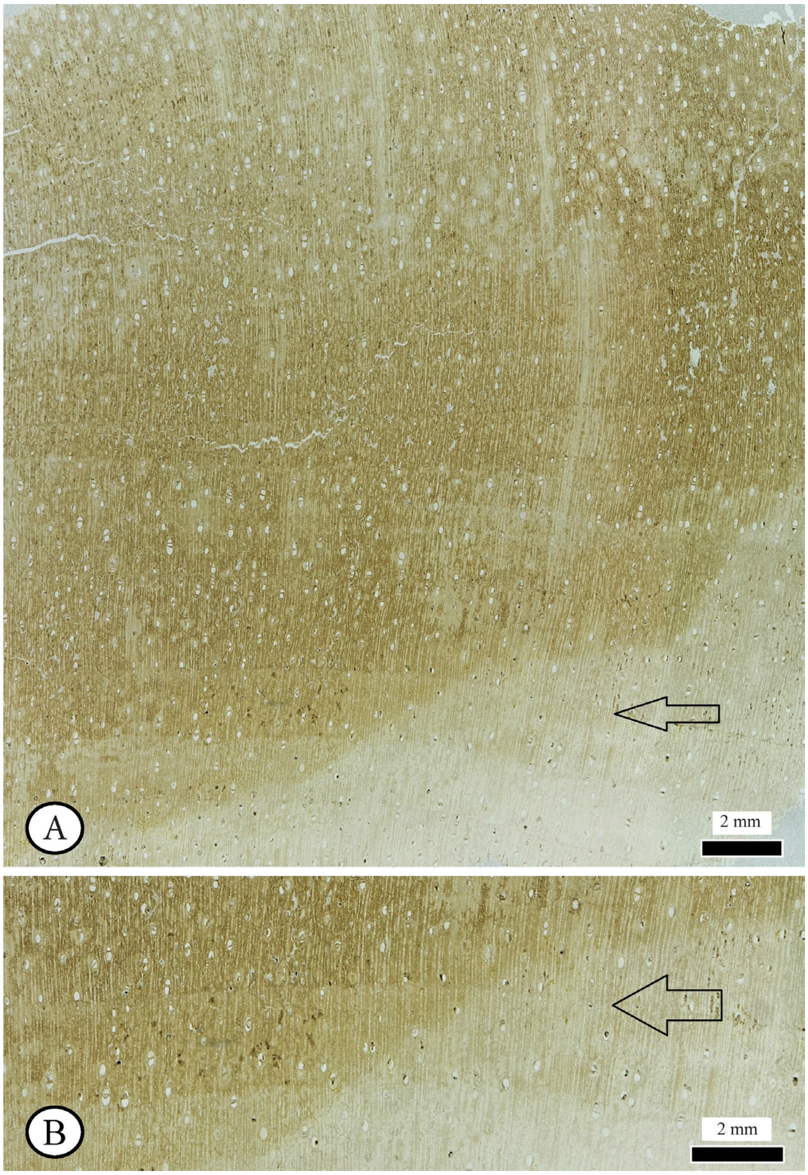

Figure 4. Indistinct growth ring boundaries of the fossil wood. The arrows show a slightly visible growth ring boundary having 1–2 rows of axial parenchyma.

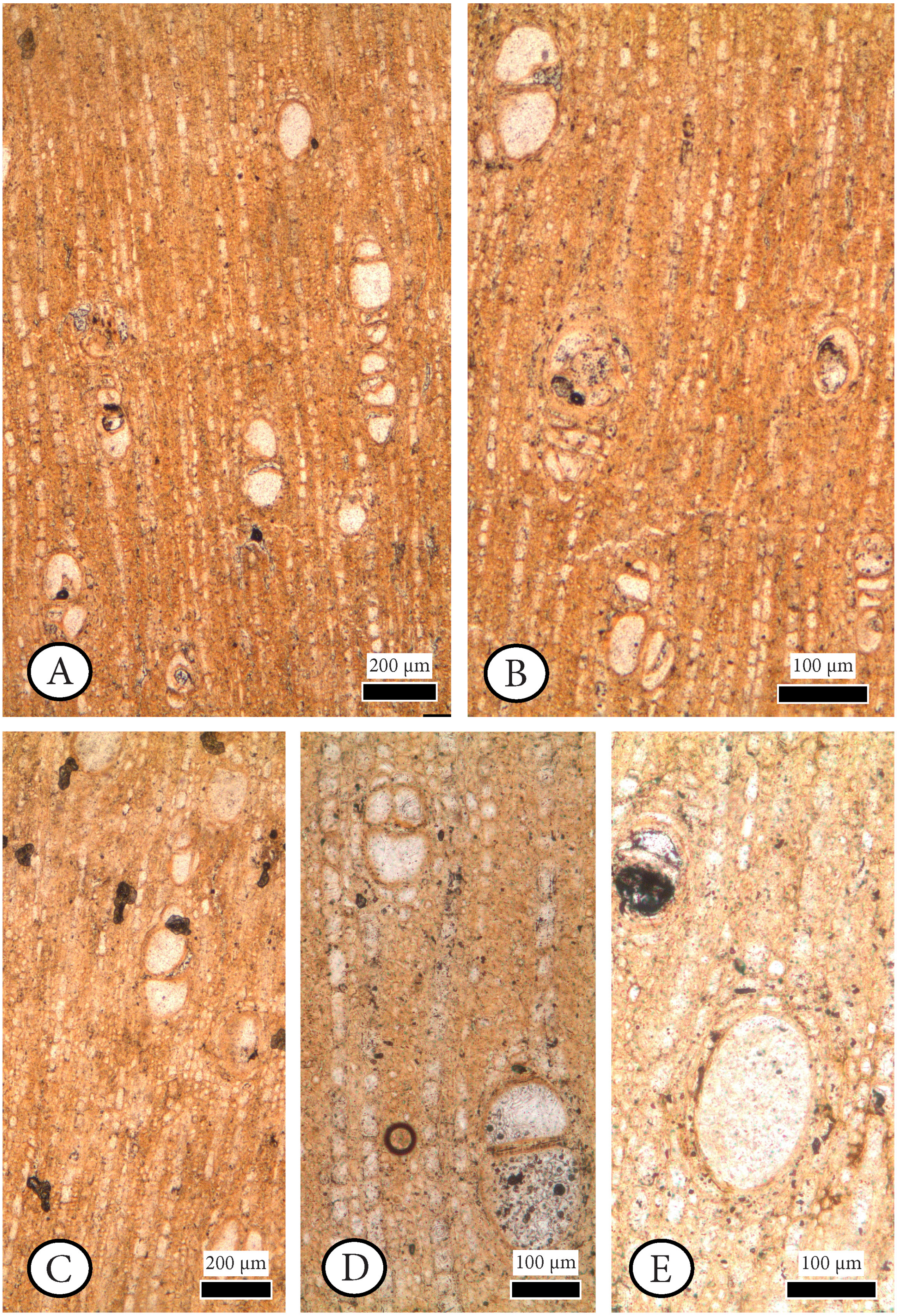

Figure 5. Transverse sections of *Ziziphoxylon sayaz* Akkemik sp. nov. A) Vessels solitary and in radial multiples; axial parenchyma band, B) A vessel cluster and radial multiples, C) Vasicentric axial parenchyma, D) Scanty paratracheal axial parenchyma, E) 1-2 rows of vasicentric axial parenchyma.

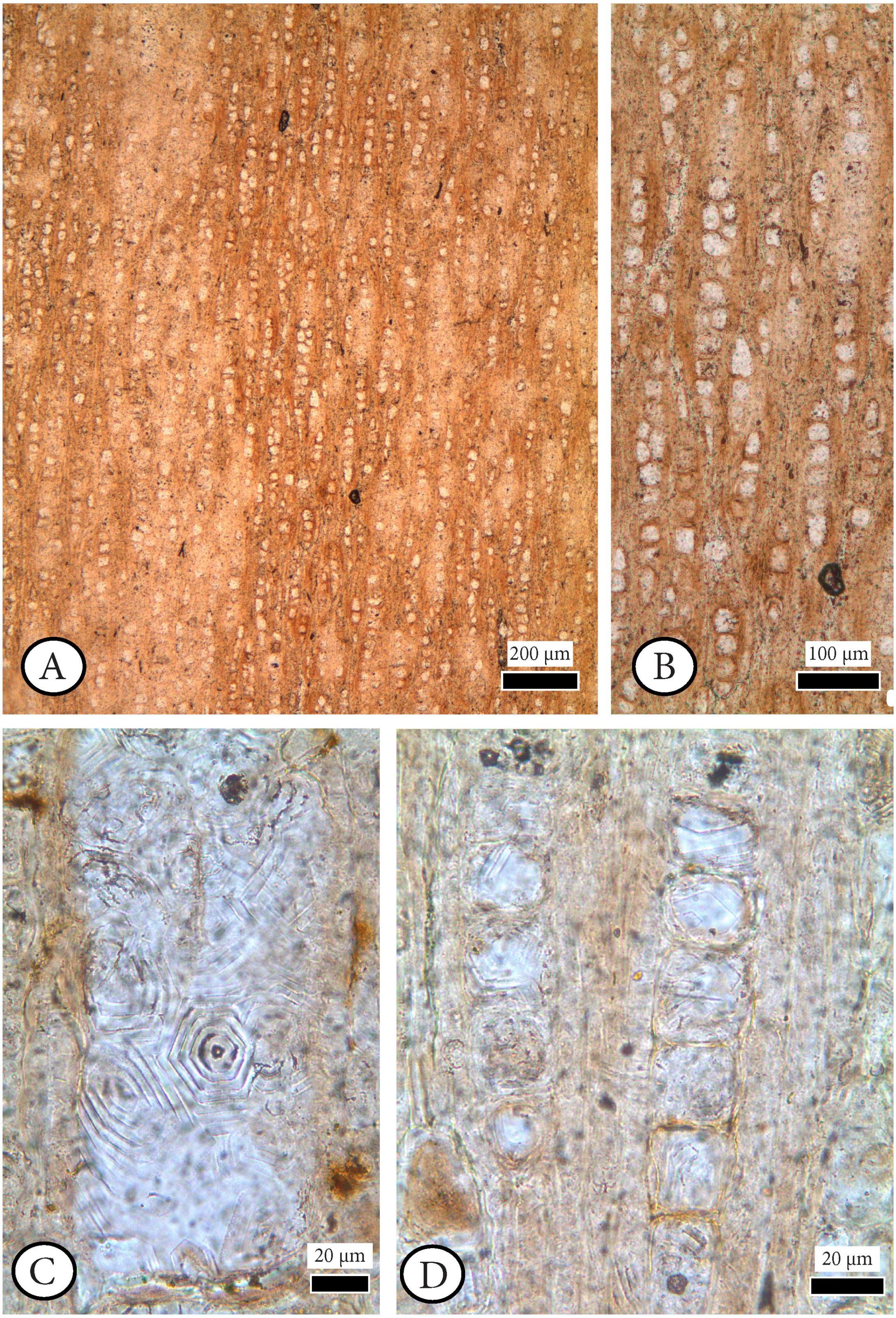

Figure 6. Tangential sections of *Ziziphoxylon sayaz* Akkemik sp. nov. A-B) Predominantly uniseriate and sometimes partly biseriate rays, C) Mineralization within the vessel and axial parenchyma strands around the vessel, D) Crystals in ray cells.

procumbent with one row of upright and/or mostly square marginal cells, and rays with procumbent and square cells mixed throughout the ray or one row square cells (Figures 7A, 7D, 7F). Perforation plates simple (Figures 6B and 6C). Crystals and coloured materials are present in rays (Figures 7E and 7F). Intervessel pits medium to large, 9 (7–12) µm in diameter.

Identification: The IAWA features of 2p 3e 5r 6a 8a 9e 12a 13r 14e 47p 59e 77e 78p 79p 80a 81a 82a 83a 84a 85a 86a 87a 88a 89p 90a 92p 96p 98e 99e 104p 106p 110e 111e 112e 113e 114e 118e 119e 120e 121e 122e 124e 125e 126e 127e 128e 129e 130e 131e 132e 133e 134e 135e 136p 144a 149e 150e 151e 152e 153e 154e 155e 156e 157e 158e 159e were entered in the website of InsideWood with 1 allowable mismatch, and the following results were obtained.

The combination of diffuse porous wood, 5–20 of vessels per square millimetre, uniseriate rays, homocellular and heterocellular rays, 1–4 or more cells per parenchyma strands, presence of scanty paratracheal, vasicentric and marginal axial parenchyma cells, occurs in some woods of the Sapindaceae, Combretaceae, Oxalidaceae, Anacardiaceae, and Rhamnaceae.

Because marginal parenchyma is absent from *Conocarpus* (Combretaceae), *Sarcotheca* (Oxalidaceae), many Sapindaceae and Anacardiaceae genera (InsideWood, 2004-onwards), our wood differs from all these similar woods. Klaassen (1999) reviewed the woods of Sapindaceae and stated that all woods have homocellular and weakly heterocellular rays. In the present fossil wood, heterocellular rays are common. Furthermore, rays in the present fossil wood are clearly larger than those of most Sapindaceae. Another similar wood, *Anogeissus acuminate* (Roxb. ex DC.) Guillaum. & Perr. (Combretaceae) differs from our wood in having diffuse axial canals in wood. Due to having different combinations of wood features in Anacardiaceae such as larger rays 4–10 seriate, presence of axial canals, 1–3 seriate of rays, and different types of axial parenchyma, our wood differs from the woods of Anacardiaceae.

Within these woods, the closest affinities were found with the taxa of the family Rhamnaceae (Metcalfe and Chalk, 1950). Within Rhamnaceae, Suessenguth (1953) proposed four tribes: Zizipheae, Rhamneae, Gouanieae, and Colletieae. The features of the fossil wood are similar to the tribe of Zizipheae. Schirarend (1991) divided the tribe Zizipheae into three main groups based on wood features. In group 1, the growth ring boundary is distinct or indistinct, rays predominantly uniseriate, rays heterogeneous to homogeneous. In this group, there are three genera, *Paliurus*, *Ziziphus*, and *Sarcomphalus*. *Sarcomphalus* differs in having larger rays 4–10 seriate and much higher vessel number per square millimetre. Thus, this fossil wood is closer to *Paliurus* and *Ziziphus*. In the website of InsideWood (Wheeler, 2011), the species name *Paliurus spina-christii* Mill. is given as *Ziziphus spina-christii* (L.) Desf. According to Schweingruber (1990), in *Paliurus* and *Ziziphus*, wood features are very similar and they cannot be differentiated on the basis of wood anatomy. However, in *Paliurus*, vessels are somewhat wider and wood is diffuse to semiring-porous (Akkemik and Yaman, 2012). According to InsideWood criteria (InsideWood, 2004-onwards), the closest wood to our fossil wood is *Ziziphus jujuba* Mill. with one mismatch of the feature 2 (growth ring boundary indistinct). In *Ziziphus jujuba*, the growth ring boundary is mostly distinct. However, indistinct growth ring boundaries are a common feature in the modern tropical species of *Ziziphus* (InsideWood, 2004-onwards).

In conclusion, the features of diffuse porous wood, simple perforation plates, medium or large sizes of pits, predominantly uniseriate rays, presence of diffuse, scanty paratracheal, vasicentric and seemingly marginal axial parenchyma, rays with cells all procumbent or with 1–2 rows of marginal square cells, or with intermixed square and procumbent cells, and presence of crystals are the same in both modern *Ziziphus* and the fossil wood. Based on these similarities, we consider this fossil wood to be *Ziziphoxylon*, which is the fossil form of *Ziziphus*.

There is only one validly published fossil species with similarity to *Ziziphus*, *Zizyphoxylon mandlaensis* Trivedi & Srivastava (1982) from the Tertiary (probably early Eocene) of Mandla district in India (Trivedi and Srivastava, 1982). However, Trivedi and Srivastava (1982), indicated three more fossil Rhamnaceae woods as *Ziziphus intertrappea* (referred to Chitaley et al., 1970), *Rhamnoxylon intertrappa* (Chitaley and Kate, 1972), and *Ziziphus eocenum* (refered to Upadhye and Patil, 1979) from the same region and formation. Two of these fossil species (*Zizyphus intertrappa* and *Zizyphus eocenus*) were published as abstracts in Proceedings of the Indian Science Congress Part 3: 337 in 1970, and the third one (*Rhamnoxylon intertrappea* referred to Chitaley and Kate, 1972) was also published as an abstract in Indian Science Congress Association Proceedings in 59 (3): 340, 1972. These three fossil species have no valid descriptions and photographs. Guleria (1992) stated that "*Detailed account of fossil woods of Zizyphus intertrappea (Chitaley et al., 1970) and Z. eocenus (Upadhye & Patil, 1979) is not available. Their published records are in the form of abstracts without photographs. Even after two decades their details have not been published till this date. So these records seem questionable and are not being taken into account. It is therefore suggested that such records should be overlooked to avoid further confusion and unnecessary repetition in literature, unless they are validly published*". Therefore, these three fossil species of Rhamnaceae were not included in InsideWood (2004-onwards).

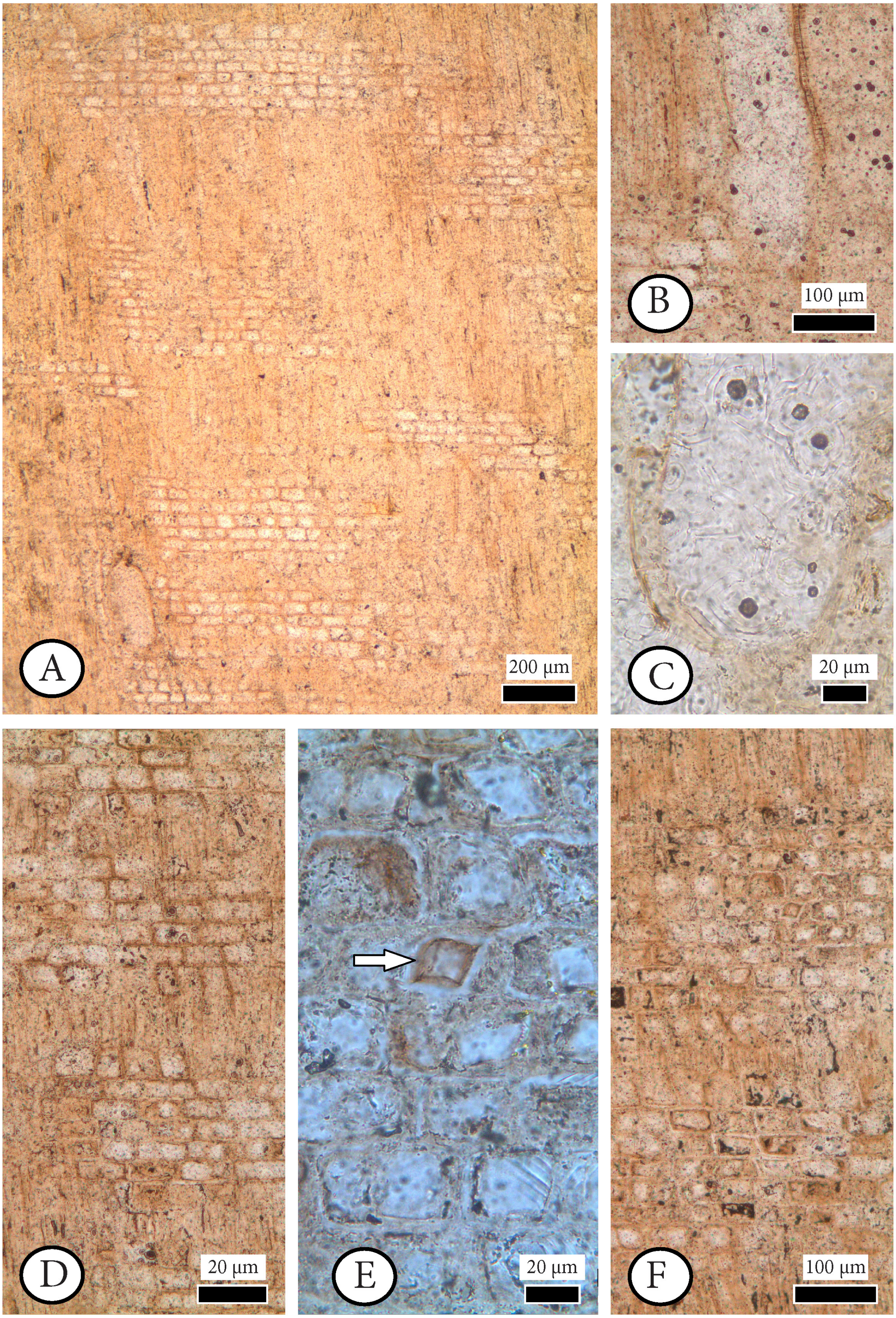

Figure 7. Radial sections of *Ziziphoxylon sayaz* Akkemik sp. nov. A) Homocellular and slightly heterocellular rays, B-C) Simple perforation plates, D) Heterocellular rays, E-F) Crystal (arrow) and dark materials (star) in ray cells, and a mixed type of procumbent and square ray cells.

We compared our fossil wood with *Zizyphus oxyphylla* Edgew., probably Pliocene, from Rajasthan (Northern India) (Guleria, 1992), and *Zizyphoxylon mandlaensis*, and prepared an identification key for the three fossil *Ziziphus* woods (by using the proposed Latin names in this study) as follows:

1A. Wood semiring porous.

Ziziphoxylon oxyphylla **(Edgew.) Akkemik**

1B. Wood diffuse porous.

2A. Wood with paratracheal vasicentric axial parenchyma as 2–4 cells thick layer around the vessels; ray tissue heterocellular, ray cells upright and procumbent.

Ziziphoxylon mandlaensis **(Trivedi & Srivastava) Akkemik**

2B. Paratracheal vasicentric axial parenchyma is in 1–2 cells layer, irregular, or partly 2–3 seriate around the vessels, scanty paratracheal parenchyma present; ray tissue homocellular and heterocellular, cells in heterocellular rays mostly square and/or upright and body ray cells procumbent, and mixed of procumbent and square cells through the ray.

Ziziphoxylon sayaz **Akkemik sp. nov.**

Based on these differences given in the identification key, we described our fossil wood as a new fossil species as *Ziziphoxylon sayaz* Akkemik sp. nov. from the middle Miocene of South Anatolia.

4.2. Comparison with the nearest modern species, Ziziphus jujuba

Today, the genus *Ziziphus* is represented with more than 80 species of deciduous and evergreen shrubs, climbers, and trees found across the Old World tropics, subtropics, and warmer temperate regions (Cahen et al. 2021; POWO 2023). Within the species of the genus, our fossil wood has the closest features to *Ziziphus jujuba*, except for mostly indistinct growth ring (InsideWood, 2004-onwards; Table 1). This species is most probably native to South Asia and called Chinese date (POWO, 2023).

Comparison of the fossil species with the modern *Ziziphus jujuba* showed that they are very similar to each other. Except for the mostly indistinct growth ring boundaries, all the other features are the same or similar. Du et al. (2022) explained that *Ziziphus jujuba* diverged from other Rosales species around 79.9 Ma, and two interspecific groups of sour jujube diverged around 55.86 Ma. Due to these similarities, we can suggest that our fossil wood from MMCO might be one of the interspecific taxa under *Ziziphus jujuba* or a different species.

4.3. Palaeoenvironment of the fossil species

Growth ring boundaries are indistinct in root woods and especially in evergreen woody plants that grow in warm-tropical conditions with low seasonality (e.g., Tarelkin et al., 2016). Some species may have both distinct and indistinct growth ring boundaries because of different environments. In the fossil wood described above, presence of wider growth rings and their indistinct boundaries may be considered an indicator for tropical warm conditions with even temperature and precipitation throughout the year. In the Middle Miocene Climate Optimum (MMCO), optimal growing conditions were likely present (Böhme, 2003; Beerling et al., 2010; Ji et al., 2018; Steinthorsdottir et al., 2020). Böhme (2003) suggested that "*Combining herpetological, palaeobotanical and bauxite formation data, it can be concluded that the Miocene Climatic Optimum in Central Europe ranged from about 18 to 14.0–13.5 Ma (Ottnangian to Early/Middle Badenian) and was characterized by a high mean annual temperature (MAT) exceeding 17.4 °C to at least 20–22 °C. A period of high precipitation during the Ottnangian and Karpatian was followed by a period with stronger seasonality in precipitation (up to six dry months) in the Lower Badenian*". Even if the fossil wood is a part of root wood, its very wide rings and wider vessels still may indicate optimum growth site conditions.

Denk et al. (2022) identified *Ziziphus paradisica*, an evergreen/deciduous angiosperm, from 18–20 Ma years ago (Aquitanian to early Burdigalian) of West Anatolia (Soma-Manisa), and they interpreted its vegetation as VU0 (steppe-like meadows with shrubs and/or small trees scattered or in groups)-VU5a (well-drained hot lowland forest). Both these Early Miocene (Denk et al., 2022) and Middle Miocene conditions (this study) may be considered the adaptation of the *Ziziphus* species to different conditions during geological times with probably different species. Today, there are about 80 species of the *Ziziphus* and they grow in different conditions, from dry Mediterranean areas (e.g., *Ziziphus lotus* L.) to the tropical conditions (POWO, 2023) and vary in growth ring boundaries (InsideWood, 2004-onwards).

5. Conclusion

Fossil woods from Türkiye reveal a rich diversity of woody species, particularly during Miocene time. This study describes a new fossil species, *Ziziphoxylon sayaz* Akkemik sp. nov. for Türkiye. By making a nomen novum with this study, we propose using *Ziziphoxylon* for all fossil forms of the woods of *Ziziphus*. Wood anatomical features of the fossil wood showed the presence of optimum growth site conditions, which were warmer temperatures, high water availability, and low seasonality during the MMCO in South Anatolia. In conclusion, new fossil woods from different regions of Türkiye may provide further evidence to enhance our understanding of woody plant diversity, growth site conditions, and climate during geological times.

Table 1. Comparison of modern *Ziziphus jujuba* with fossil *Ziziphoxylon sayaz* Akkemik sp. nov. The features are very similar to each other with some small differences.

Features	***Ziziphus jujuba* Mill.** (Schweingruber, 1990; InsideWood, 2004-onwards)	***Ziziphoxylon sayaz* Akkemik sp. nov.** (This study)
Growth ring	Growth ring boundaries are distinct. Marginal axial parenchyma bands present.	Growth ring boundaries are indistinct, due to presence of 1–2 rows of marginal axial parenchyma band, and differences in vessel diameter around the marginal parenchyma band, growth ring boundary very slightly visible.
Vessels	Wood diffuse-porous. Vessels diameter 50–200 µm, solitary and in short or long radial multiples. 5–40 vessels per square millimetre. Vessel outline rounded. Vessel element lengths ≤350 µm or 350–800 µm.	Wood diffuse-porous. Vessels diameters 50–200 µm, solitary and in radial multiple of 2–3 or rarely up to 7 vessels. 5–20 vessels per square millimetre. Vessel outline rounded. Vessel element length is 380 (115–671) µm.
Fibres	Fibres thin- to thick-walled in regular radial rows. Libriform fibres present.	Fibres thin- to thick-walled, and libriform fibres present
Axial parenchyma	Axial parenchyma diffuse, scanty paratracheal, vasicentric, confluent, and marginal.	All these types of the axial parenchyma present in the fossil wood.
Rays	Rays predominantly uniseriate, partly biseriate, height up to 25 (40) cells. Ray cells are large, square to rounded. Rays homocellular to slightly heterocellular. Ray cells are generally short rectangular, procumbent, one to four rows of square to upright marginal cells or mixed. Rays per millimetre 4–12 or ≥12.	Rays predominantly uniseriate, partly biseriate, mostly 10–20 cells high (max. 26 cells). Ray cells are large, square to rounded. Rays are both homocellular and heterocellular. Body ray cells procumbent with one row of square to upright marginal cells or mixed. Rays per millimetre 13–22.
Intervessel pits	Intervessel pits crowded, alternate, medium to large. Shapes of the intervessel pits are polygonal.	All these features are present in the fossil wood.
Mineral inclusions	Crystals common in central and outer ray cells; some cells containing crystals are enlarged.	Crystals present in central and outer ray cells.

Acknowledgments
We thank Mehmet Ali Oral for taking the microscopic sections and Ömer Faruk İlter for providing the sample and his help in the field work. The corresponding author was supported by the Research Fund of Istanbul University-Cerrahpaşa, Project number: FBA-2021-35698.

References

Akkemik Ü, Acarca Bayam NN. (2019). The first Glyptostroboxylon and Taxodioxylon descriptions from the late Miocene of Turkey. Fossil Imprint 75 (2): 268–280.

Akkemik Ü, Mantzouka D, Tunç U, Koçbulut F. (2021). The first paleoxylotomical evidence from the Mid-Eocene Climate Optimum from Turkey. Review Palaeobotany and Palynology 285: 104356.

Akkemik Ü. (2021a). A new fossil Cedrus species from the early Miocene of northwestern Turkey and its possible affinities. Palaeoworld. 30 (4): 746-756

Akkemik Ü. (2021b). A new species of Juniperoxylon from the early Miocene of Northwestern Turkey. Acta Palaeontologia Romaniae, 17 (1): 15-26.

Akkemik Ü. (2021c). A re-examination of the angiosperm wood record from the early and middle Miocene of Turkey, and new species descriptions. Acta Palaeobotanica. 61 (1): 42-94

Akkemik Ü, Arslan M, Poole I, Tosun S, Köse N et al. (2016). Silicified woods from two previously undescribed early Miocene forest sites near Seben, northwest Turkey. Review of Palaeobotany and Palynology, 235:31–50. https://doi.org/10.1016/j.revpalbo.2016.09.012

Akkemik Ü, Atıcı G, Poole I, Çobankaya M. (2018). Three new silicified woods from a newly discovered earliest Miocene forest site in the Haymana Basin (Ankara, Turkey). Review of Palaeobotany and Palynology, 254: 49 – 64.

Akkemik Ü, Iamandei S, Iamandei E, Koçbulut F, Güner HT et al. (2023). Wood and leaf remains of palms with affinities to Sabal Adans., from the middle Eocene of Turkey. Turkish Journal of Botany, 47: 50-60, doi:10.55730/1300-008X.2743

Akkemik Ü, Koçbulut F, Toprak Ö, Tunç U. (2023). More evidence of tropical conditions in the Middle Eocene Climatic Optimum (MECO) with new fossil woods from North-Central Türkiye. Turkish Journal of Earth Science, 32: 880-893, doi:10.55730/1300-0985.1880

Akkemik Ü, Mantzouka D, Kıran Yıldırım D. (2020). The first report of Lesbosoxylon from the early –middle Miocene of eastern Anatolia. Geodiversitas, 42 (23): 427-441.

Akkemik Ü, Mantzouka D, Tunç U, Koçbulut F (2021). The first paleoxylotomical evidence from the Mid-Eocene Climate Optimum from Turkey. Review of Palaeobotany and Palynology 285. https:// doi.org/10.1016/j.revpalbo.2020.104356

Atabey E, Atabey N, Hakyemez A, İslamoğlu Y, Sözer Ş et al. (2000a). Mut-Karaman arası Miyosen havzasının litostratigrafisi ve sedimantolojisi (Orta Toroslar). Maden Tetkik ve Arama Dergisi 122, 53-72 (in Turkish).

Atabey E, Atabey N, Sözeri Ş, İslamoğlu Y, Hakyemez A et al. (2000b). Mut (İçel)-Karaman arası Miyosen istifinin litostratigrafisi, kronostratigrafisi ve istif stratigrafik yorumu. Maden Tetkik ve Arama Genel Müdürlüğü Rapor No: 10312, Ankara (in Turkish).

Baas P, Schweingruber FH. (1987). Ecological Trends in the Wood Anatomy of Trees, Shurbs and Climbers From Europe, IAWA Bul. n.s. 8: 245-274

Beerling DJ, Fox A, Anderson CW. (2010). Quantitative uncertainty analyses of ancient atmospheric CO2 estimates from fossil leaves. American Journal of Science, 309 (9) (2010), pp. 775-787, 10.2475/09.2009.01

Böhme M. (2003). The Miocene Climatic Optimum: evidence from ectothermic vertebrates of Central Europe. Palaeogeography, Palaeoclimatology, Palaeoecology 195: 389-401.

Cahen D, Rickenback J, Utteridge TMA. (2021). A revision of Ziziphus (Rhamnaceae) in Borneo. Kew Bulletin 76(4): 767 – 804.

Du S, Hu X, Yang X, Yu W, Wang Z. (2022). Genetic diversity and population dynamic of Ziziphus jujuba var. spinosa (Bunge) Hu ex H. F. Chow in Central China. Ecology and Evolution, 12, e9101. https://doi.org/10.1002/ece3.9101

Fahn A, Werker E, Baas P. (1986). Wood anatomy and identification and shrubs from Israel and adjacent regions. Jerusalem, Israel, ISBN 965-208-073.

Goldner A, Herold N, Huber M. (2014). The challenge of simulating the warmth of the mid-Miocene climatic optimum in CESM1. Climate of the Past, 2014; 10 (2) 523-536. 10.5194/cp-10-523-2014

Guleria JS. (1992). A semiring porous fossil wood of Ziziphus from the Late Tertiary of Rajasthan. Palaeobotanist 39 (3): 303-308.

Güngör Y, Akkemik Ü, Kasapçi C, Başaran E. (2019). Geology and woods of a new fossil forest from the early Miocene of Gökçeada (Turkey) – Forestist. 69 (1): 22-34.

Hui Z, Zhang J, Ma Z, Li X, Peng T et al. (2018). Global warming and rainfall: lessons from an analysis of Mid-Miocene climate data. Palaeogeography, Palaeoclimatology, Palaeoecology, 512 (2018), pp. 106-117, 10.1016/j.palaeo.2018.10.025

IAWA Committee. (1989). IAWA List of Microscopic Features for Hardwood Identification (Eds. EA Wheeler, P Baas and PE Gasson), IAWA Bull. n.s. 10: 219-332.

Ilgar A, Esirtgen T, Demirkaya S. (1996). 1/100000 ölçekli Silifke 0-31 MTA raporu. Rapor no. 233 (in Turkish).

InsideWood. (2004-onwards). https://insidewood.lib.ncsu.edu/search?1 Published on the Internet.

Ji S, Nie J, Lechler A, Huntington KW, Heitmann EO et al. (2018). A symmetrical CO2 peak and asymmetrical climate change during the middle Miocene. Earth and Planetary Science Letters, 499 (2018), pp. 134-144, 10.1016/j.epsl.2018.07.011

Lapage SP, Sneath PHA, Lessel EF, Skerman VBD, Seeliger HPR et al. (1992). International Code of Nomenclature of Bacteria. Washington (DC): ASM Press.

Mantzouka D, Akkemik Ü, Güngör Y. (2022). Miocene Cupressinoxylon from Gökçeada (Imbros), Turkey with Protophytobia cambium mining and the study of ecological signals anatomy. PeerJ 10:e14212 doi:10.7717/peerj.14212

Metcalfe CR, Chalk L. (1950). Anatomy of the Dicotyledons. Clarendon Press, Oxford.

Özgül N. (1976). Toroslar'ın bazı temel jeoloji özellikleri. Türkiye Jeoloji Kurumu Bülteni 19, 65-78 (in Turkish).

Özgül N. (1997). Bozkır-Hadim-Taşkent (Orta Toroslar'ın kuzey kesimi) dolayında yer alan tektono-stratigrafik birliklerin stratigrafisi. Maden Tetkik ve Arama Dergisi 119, 113-174 (in Turkish).

Peel MC, Finlayson BL, McMahon TA. (2007). Hydrology and Earth System Sciences Updated world map of the Koppen-Geiger climate classification. Hydrology and Earth System Sciences, 11: 1633–1644.

POWO. (2023). Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. Available at: 'https://powo.science.kew.org/'.

Schirarend C. (1991). The systematic wood anatomy of the Rhamnaceae Juss. (Rhamnales) I.Tribe Zizipheae. IAWA Bulletin n.s. 12 (4): 359-388.Steinthorsdottir M, Coxall HK, de Boer AM, Huber M, Barbolini N, Bradshaw CD et al. (2021). The Miocene: the future of the past. Paleoceanography and Paleoclimatology, 36 (4) (2021). 10.1029/2020pa004037

Stoll HM, Guitian J, Hernandez-Almeida I, Mejia LM, Phelps S et al. (2019). Upregulation of phytoplankton carbon concentrating mechanisms during low CO2 glacial periods and implications for the phytoplankton pCO2 proxy. Quaternary Science Reviews, 208 (2019), pp. 1-20. 10.1016/j.quascirev.2019.01.012

Suessenguth K (1953). Rhamnaceae. In: A. Engler & K. Prantl, Die natiirlichen Pflanzenfamilien. ed. 2, 2Od. Duncker & Humblot, Berlin.

Tanar Ü, Gökçen N. (1990). Mut-Ermenek Tersiyer istifinin stratigrafisi ve paleontolojisi. Maden Tetkik ve Arama Dergisi 110, 175-180 (in Turkish).

Tarelkin Y, Delvaux C, Ridder MD, Berkani TE, Canniere CD et al. (2016). Growth-ring distinctness and boundary anatomy variability in tropical trees. IAWA Journal 37 (2): 274-294.

Trivedi BS, Srivastava K. (1982). Zizyphoxylon mandlaensis gen. et sp. nov. from the Deccan Intertrappean beds of Mandla District in MP (India). J. Ind. Bot. Soc. 61: 212--215.

Wheeler EA. (2011). InsideWood – A Web Resource for Hardwood Identification. IAWA Journal 32 (2): 199-211.

Wheeler EA, Gasson PE, Baas P. (2020). Using the InsideWood Web Site: Potentials and Pitfalls. IAWA Journal 41 (4): 412-462.