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Original Article

Geology and woods of a new fossil forest from the Early Miocene of Gökçeada (Turkey)

Gökçeada'nın Erken Miyosen döneminden yeni bir fosil ormanın jeolojisi ve ağaçları

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ABSTRACT

In Gökçeada, metamorphic, sedimentary and volcanic rocks from the period covering the Paleozoic to the Upper Miocene periods have formed outcrops over time. A newly identified fossil forest site in Gökçeada covers an area of approximately 1.5 square kilometers of land situated near the coastline. Silicified trees in the area from the early Miocene period were observed to present three phases of pyroclastic deposition, namely: the complete silicification phase, the half silicification phase and the coal phase. The purpose of this study is to present the paleobiology and paleoecology of the wood flora and the geological formation of the fossil forest site, and to evaluate this information in terms of paleoclimatology. Sixteen (16) petrified pieces of wood thought to have originated from the upper slopes and found on the sea shore were collected, with three planes of thin sections taken from each one. A total of 12 types of woods were identified, as follows: three conifers (*Cupressinoxylon, Sequoioxylon* and *Pinoxylon*) and nine angiosperms (*Alnoxylon, Carpinoxylon, Ostryoxylon, Palmoxylon* type 1 and 2, *Fagoxylon, Quercoxylon* sect. *Ilex, Laurinoxylon* and *Platanoxylon*). The wood composition in Gökçeada is similar to that of the wood flora of the Miocene in Lesvos, showing the presence of riparian, well-drained lowland and coastal trees.

Keywords: Çanakkale, Early Miocene, Gökçeada, petrified wood, pyroclastics

ÖZ

Gökçeada'da metamorfik, tortul ve volkanik kayaçlar Paleozoyik'ten Üst Miyosen'e kadar uzanmaktadır. Silisleşmiş ağaçlar erken Miyosen döneminden olup üç farklı evreye sahip piroklastiklerde gözlenmiştir. Bu fazlar tam silisleşme fazı, yarım silisleşme fazı ve kömür fazıdır. Yeni fosil orman alanı yaklaşık 1.5 kilometrekarelik bir alanı kapsamakta ve deniz kıyısına yakın yerlerde bulunmaktadır. Çalışmanın amacı, bu fosil ormandaki ağaçları tespit etmek, fosil orman alanı oluşumu belirlemek ve paleoklimatolojik açıdan değerlendirmektir. Üst yamaçlardan deniz kıyısına taşınan 16 adet taşlaşmış ağaç parçası toplanmış ve her birinin üç yönünden ince kesitler alınmıştır. Toplam 12 farklı odun tipi tespit edilmiştir. Bunlar üç kozalaklı (*Cupressinoxylon, Sequoioxylon* ve *Pinoxylon*) ve dokuz angiosperm cinsidir (*Alnoxylon, Carpinoxylon, Ostryoxylon, Palmoxylon* tip 1 ve 2, *Fagoxylon, Quercoxylon sect. Ilex, Laurinoxylon* ve *Platanoxylon*). Gökçeada'daki ağaç bileşimi, Midilli Adası'nın Miyosen yaşlı ağaç florasına oldukça benzemektedir. Bu ağaç bileşimi nehir kıyısı, iyi drenajlı alçak kesim ve kıyıya yakın bir orman varlığını göstermektedir.

Anahtar Kelimeler: Çanakkale, Erken Miyosen, Gökçeada, piroklastik, silisleşmiş ağaç

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INTRODUCTION

Palaeobotany studies concerning petrified wood have revealed valuable information about forests dating back to the late Oligocene and the late Miocene forests as well as the climate of Turkey (e.g. Özgüven, 1971; Sayadi, 1973; Selmeier, 1990; Dernbach et al., 1996; Akkemik et al. 2009; Aytuğ and Şanlı, 1974; Eroskay and Aytug, 1982; Şanlı, 1982; Aras et al. 2003; Akkemik and Sakınç, 2013; Akkemik et al., 2016; Akkemik et al., 2017; Bayam et al., 2018). These studies showed that forests were composed of both conifers and broad-leaved trees. In riparian forests there were trees such as palmae,

Salix, Populus and *Liquidambar*, in swampy areas there were *Sequoia, Taxodium* and *Glyptostrobus*, and in well-drained lands, the forests were composed of *Pinus, Juniperus, Picea, Cedrus, Podocarpus*, *Quercus* (*ilex* type), *Acer, Ulmus, Zelkova, Prunus, Salix, and Fraxinus* etc. The resulting climate produced from this vegetation structure was a warm climate from the late Oligocene to the middle Miocene periods. The genera of *Taxodioxylon*, *Pinoxylon*, *Quercus* and *Alnus* were identified in the well-known fossil forests site, *Lesvos Petrified Forest* by Süss and Velitzelos (1994 a, b) and Velitzelos (1996, 1997).

A new petrified forest (fossil forest) site was found located on the island of Gökçeada, which is one of the larger islands in the Aegean Sea. Petrified wood can be found on both the soil surface and within the soil. Small and large wood pieces can be found in the material that has moved downwards from the upper slopes. The geology of the island was well-studied. Akartuna (1950) and Okut (1975) performed the first significant geological studies in Gökçeada, and these studies were used widely during the construction of geological maps. Following this, the characteristics of Tertiary volcanism in Gökçeada was investigated in detail by Ercan et al. (1995), Temel and Çiftçi (2002), Kesgin and Varol (2003), Varol and Baykal (2008), Koral et al. (2008), and at this point the island's 1/100000 scale geology map was published by Ilgar et al. (2008). More recently, Basaran et al. (2015 and 2016) studied Gökçeada's geopark potential, and Sarı et al. (2015) examined in detail the magmatic and volcanic rocks of Gökçeada.

The purpose of this study was to present the wood flora and formation of the fossil forest site, and to evaluate this data in terms of paleoclimatology.

MATERIALS AND METHODS

Gökçeada is an Aegean island, located at the entrance of Saros Bay to the north of the Aegean Sea, west of Gelibolu, and to the north of Lesvos (Figure 1). The fossil forest site is located on the south of the island. Silicified trees were found in an area up to 200 m above sea level. They were found in materials propelled along during the volcanic eruption and surfaced with the wear of the material above (Figure 2). A total of 16 samples were collected from the area. Preservation states were variable - while many of the samples were well-preserved, some were quite poorly preserved. However, most of the samples were of sufficient condition for identification.

For wood identification purposes, we took thin sections from three planes (the transverse section (TS) radial longitudinal section (RLS) and tangential longitudinal section (TLS)) from all specimens. Identification of the silicified woods was performed at the Tree-ring Research and Wood Anatomy Laboratory in the Forest Botany Department of the Faculty of Forestry, Istanbul University.

For identification, the wood anatomy reference book collection housed in the Forest Botany Department of the Faculty of Forestry, University of Istanbul were used (e.g. Jacquiot 1955; Greguss 1955; Greguss 1967; Barefoot and Hankins 1982; Fahn et al. 1986; Schweingruber 1990; Tidwell 1998; Eliçin 1977; Akkemik and Yaman, 2012). Additionally, an online database called InsideWood (http://insidewood.lib.nsc.edu), was another informative reference for wood identification. When using specific terminology, together with the aforementioned references, we followed the descriptions given in the IAWA Committee (1989) for hardwood identification and IAWA Committee (2004) for softwood identification wherever possible.

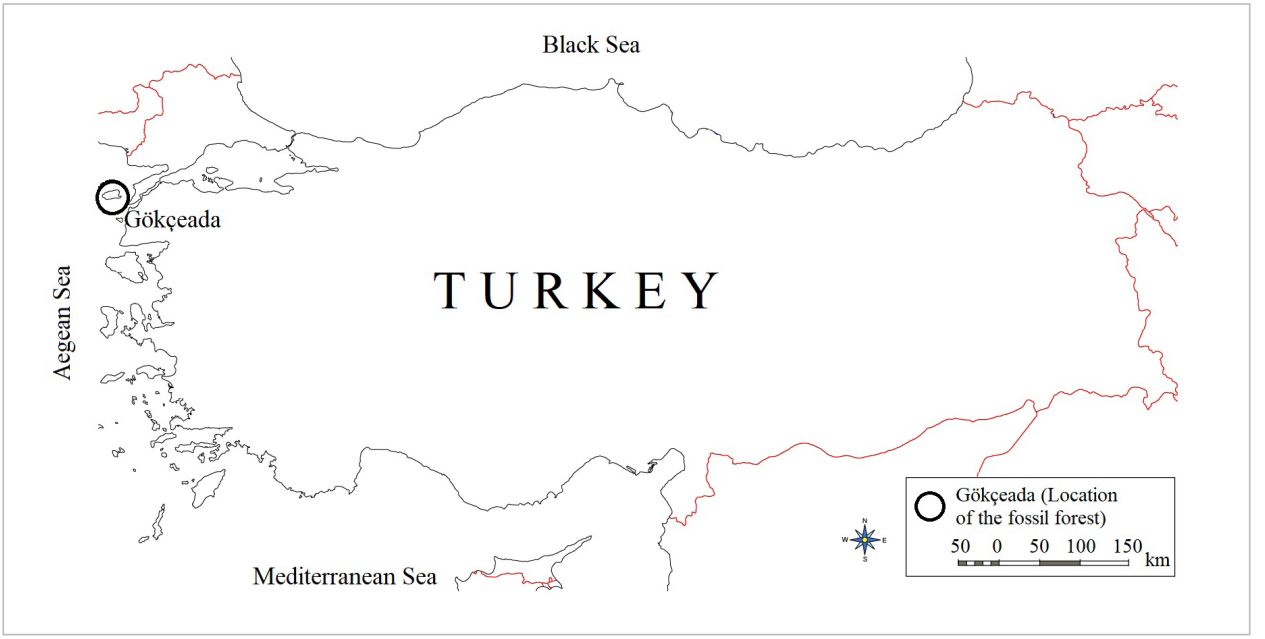

Figure 1. Location map of the study area

General Geology of Gökçeada

The general geology of Gökçeada was summarized based on the related reference (Akartuna, 1950; Okut, 1975; Akartuna and Atan, 1978; Ercan et al., 1995; Temel and Çiftçi, 2002; Kesgin and Varol, 2003; Varol and Baykal, 2008; Koral et al., 2008; Ilgar et al, 2008; Başaran et al., 2015, 2016; Sarı et al., 2015) as follows (Figure 3). The oldest unit in the study area is the Late Ediakaran/Early Paleozoic age Çamlıca Metamorphics, containing a sericite schist, a chlorite schist, slate and marble. This unit is located on Dağiçi Tepe on the north-west of Gökçeada and have fault outcrops. Çamlıca Metamorphites have been unconformably overlaid by the Early Eocene age Karaağaç formation. The Karaağaç Formation includes submarine fan deposits, rhyolitic lavas, sandstone, claystone marl alternations and formed outcrops between Gizli Liman and Mutludere in Gökçeada. These rhyolitic volcanic rocks, cutting across the Çamlıca metamorphites and intruding into the Karaağaç Formation, are the oldest volcanic units in the study area. These units were seen to be of columnar shape and composed of rhyolitic lava and tuffs (Temel and Çiftçi, 2002).

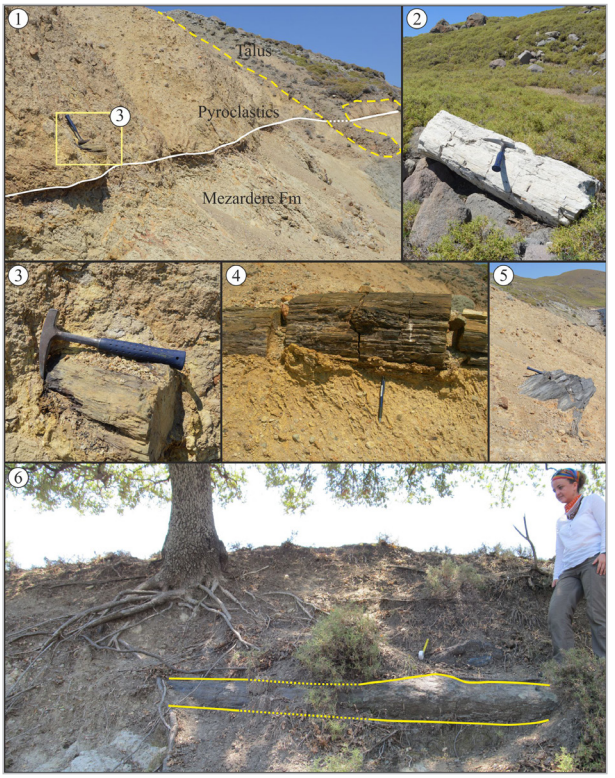

Figure 2. Some fossil wood in the field. 1-4) Petrified woods, 5) A wood sample, which has turned to coal, 6) A long petrified wood stem

The Middle Eocene age Koyunbaba Formation is composed of platform carbonates and overlies the Karaağaç Formation unconformably. This unit starts with conglomerate at its base and continues with conglomerate-sandstone-siltstone and marl alternations towards the top.

The Soğucak Formation conformably covers the Koyunbaba Formation and is characterized by an abundance of Nummulites sp. fossils (Varol and Baykal, 2008). This formation is composed of shallow marine carbonates. The Middle-Upper Eocene aged Ceylan Formation is composed of claystone-sandstone-shale intercalations and lies conformably on the Soğucak Formation. This formation has been conformably overlaid by the Early Oligocene age Mezardere Formation which is composed of conglomerate-sandstone-siltstone and marl alternations. Both the

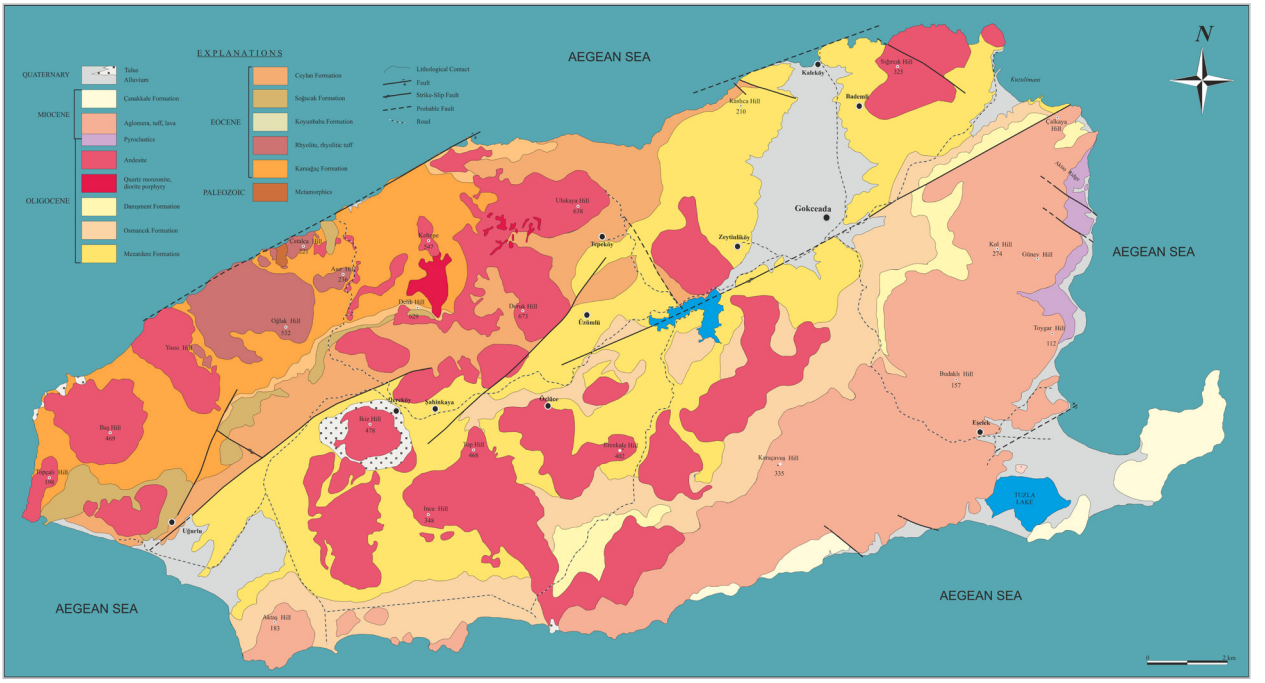

Figure 3. Geological map of the study area (Modified after Koral et al., 2008 and Sarı et al., 2015)

Ceylan and Mezardere sedimentary units are turbiditic deposits of a deep marine sedimentary environment. These units are cut by subvolcanics at different levels. The lower parts of these subvolcanics are identified as the Mutludere Intrusion, which consists of diorite-monzodorites (Sarı et al., 2015).

The Late Oligocene age Gökçeada Ignimbrite in the east and south part of the Island, is composed of pumice flows and lies uncomformably on the Mezardere Formation. The Early Miocene age Kesmekaya volcanics are covered by these pumice flows and composed of basaltic andesite, andesitic lava and pyroclastic rocks. The entire section is covered by the Upper Miocene age Çanakkale Formation in the study area (Figure 3).

RESULT AND DISCUSSION

Formation Pattern of the Fossil Forest

The fossil forest was analysed in the pyroclastics in the study area (Figure 2). This fossil forest was observed in three different levels within this unit. These phases are (1) the complete silicification phase, (2) the semi-silicification phase and (3) the coalification phases. These phases, observed within the same unit, indicated that the trees were the same age but were formed in different sedimentary environments in a short interval. The main volcanic activities of the Early Miocene period completely buried these forest after which, complete silisification occurred. These samples were clearly observed in the study area. Pyroclastic flow swept the majority of the forest towards the sea and some of this banked on the shore zone. The Semi-silicification and coalification phases also occurred in these banked forest units. Due to the tectonic uplift of the Island, burned out segments of forest were observed as coal fragments in cliffs and were rapidly eroded. This fossil forest, located in the east part of the study area, occurred within the Early Miocene age pyroclastic debris flow and Quaternary colluvial fan deposits.

Wood Flora of the Fossil Forest

Twelve different wood types of conifers and broad-leaved trees were identified (Table 1). All woods were catalogued by adding "xylon" at the end of the name such as *Alnoxylon, Pinoxylon*, *Fagaceoxylon* and *Seqoioxylon*. *Quercus* woods can be identified as section levels (sec. *Cerris*, sec. *Ilex*, sec. *Quercus*). In Gökçeada, *Quercus* woods were identified as *Quercoxylon* section *Ilex* (evergreen oaks) (Table 1). The name *Sequoioxylon* includes the genera *Sequoia, Sequoiadendron* and *Metasequoia*, due to having very similar wood features. The identification details and wood features were given for each wood type below.

Systematic palaeobotany

***Cupressinoxylon* (Cypress)**
Family CUPRESSACEAE Rich. ex Bartling 1830
Genus CUPRESSINOXYLON Göppert 1850

Material: Material no. 4.

Locality: East of Eşelek Village - Gökçeada, and near to the coastline.

Age: Early Miocene

Wood description: Tree-ring border distinct. Gradual transition from earlywood to latewood. No resin canal in cross section; axial parenchyma very common, and horizontal walls slightly nodular. Cross-field pitting cupressoid. 2-3 (1-4) pits per cross-field. Rays homogenous. Ray height 1-15 cells (mostly 6-7 cells), uniseriate or sometimes partly biseriate. Pitting on radial walls of tracheids uniseriate. Tracheidal pitting also common on the tangential walls (Plate I).

Discussion: The name of this type of wood was proposed as *Cupressinoxylon* by Bamford et al (2002). Due to having cupressoid type cross-field pits, gradual transition from earlywood to latewood, wood growth ring boundary distinct, 1-15 cells of ray height, abundant axial parenchyma cells, tracheidal pitting on tangential walls, and slightly nodular walls of axial parenchyma cells (Figueiral et al., 1999; Klusek, 2014; Pujana et al., 2014), wood identification leads us to *Cupressinoxylon*. Similar woods

Table 1. Woods identified and their sample numbers. The gymnosperms listed first and then angiosperms in the table

Sample No	Groups	Family	Identification
4	Gymnosperms	Cupressaceae	*Cupressinoxylon*
211p			*Sequoioxylon*
260		Pinaceae	*Pinoxylon*
3	Monocotyledonous	Araceae	*Palmoxylon* type 1
259			*Palmoxylon* type 2
231	Dicotyledonous	Betulaceae	*Alnoxylon*
1			*Carpinoxylon*
2			*Ostryoxylon*
257		Fagaceae	*Fagoxylon*
5e, 5ece2, 202			*Quercoxylon section Ilex*
1ok, 5, 261		Lauraceae	*Laurinoxylon*

were described from the early Miocene of central Anatolia as *Juniperus* by Akkemik et al. (2016). *Juniperus* woods have very low ray cells and a space between tracheids in cross-field (Akkemik et al., 2016). Today, the genus of *Cupressus* L. is represented by one species (*Cupressus sempervirens* L.) across the Mediterranean region, and is common in coastal areas.

***Sequoioxylon* (Redwood)**
Family CUPRESSACEAE Rich. ex Bartling 1830
Genus SEQUOIOXYLON Torrey 1923

Material: Material no. 211p.

Locality: East of Eşelek Village - Gökçeada, and on the coastline.

Age: Early Miocene

Wood description: Distinct tree-ring border with 2-13 rows of latewood tracheids. No resin canal in cross-section; axial parenchyma common, and horizontal walls generally smooth or slightly nodular. Rays homogenous in general, and there are rarely ray tracheids present. Cross-field pitting is taxodioid and rarely cupressoid. Ray height is 3-15 cells, uniseriate or rarely partly biseriate (Plate II).

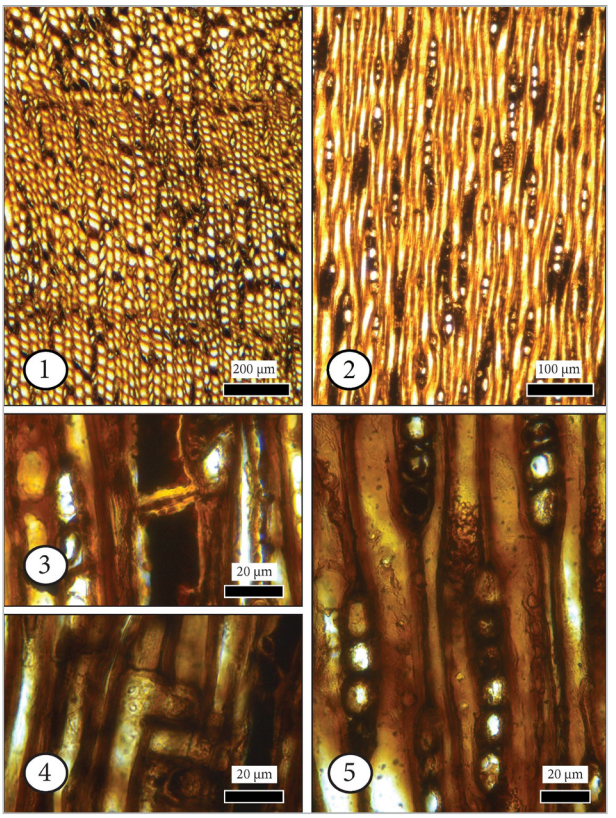

Plate I. *Cupressinoxylon* sections. 1) A transversal section with dense axial parenchyma, 2) Tangential section, 3) Slightly nodular end wall of axial parenchyma, 4) Cupressoid type cross-field pits, 5) Tracheidal pitting on tangential walls of tracheids

Discussion: This type of wood is very common in the European part of Turkey (Özgüven, 1971; Akkemik et al., 2005; Sakınç et al., 2007; Akkemik and Sakınç, 2013), in Çamlıdere (Akkemik et al., 2009), and in Kızılcahamam (Bayam et al, 2018). Today, this genus is extinct throughout Europe and Asia.

***Pinoxylon* (Pine)**
Family PINACEAE Sprengel ex F. Rudolphi, 1830
Genus PINOXYLON Knowlton 1900

Material: Material no. 260.

Locality: East of Eşelek Village - Gökçeada, and on the coastline.

Age: Early Miocene

Wood description: Growth ring boundaries distinct, and a gradual transition from earlywood to latewood. Longitudinal resin canals visible with thin-walled epithelial cells. Tracheid pitting in radial walls in earlywood uniseriate. Latewood tracheids thick-walled, and no helical thickening. No axial parenchyma observed. Rays are heterogeneous and those without horizontal resin canals, exclusively uniseriate, rays with resin canals partly multiseriate. Ray tracheid present, but walls not

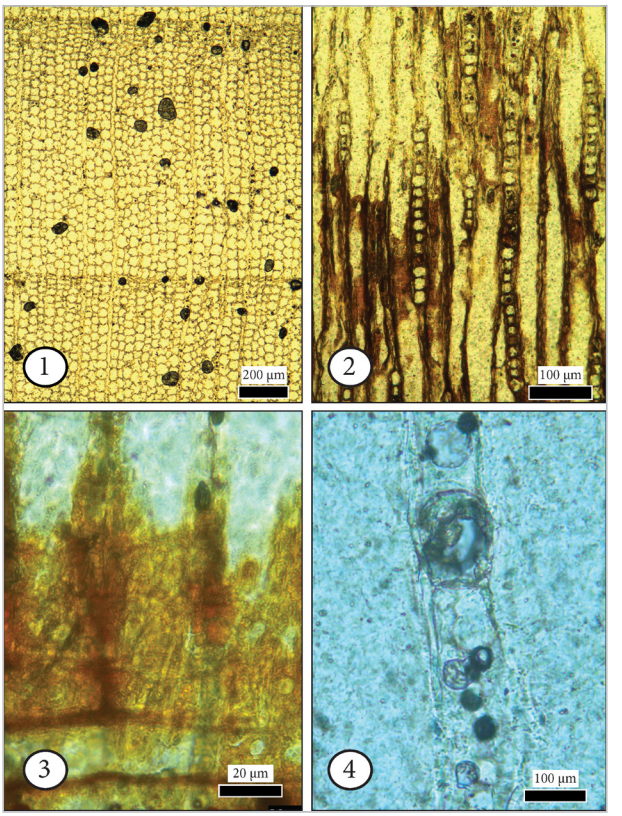

Plate II. *Sequoioxylon* sections. 1) Transversal section without resin canal, 2) Tangential section with high rays, 3) Taxodioid type cross-field pits on radial section, 4) Smooth end wall of axial parenchyma

visible clearly on the section. Pinoid type of cross-field pits distinct, and two pits per cross-field observed in general. Ray height 1-12 cells (Plate III).

Discussion: This type of wood was identified from Early Miocene of Central Anatolia (Akkemik et al., 2016; Bayam et al., 2018) and in Lesvos (Velitzelos and Zouros, 1997). Vertical resin canals, heterogenous rays with ray tracheids and horizontal resin canals, and pinoid type of cross-field pits are the clear features of pine woods. All these features were observed in the petrified wood, and then it was identified as *Pinoxylon*. Today, it is represented by 5 different 2-needle species in Turkey. Pinoid type cross-field pits may be used in identification of the modern species by using the key given in Akkemik and Yaman (2012). The fossil wood is rather similar to the modern *Pinus pinea* L. with their cross-field pits, therefore this wood may be named *Pinus* cf. *pinea*.

***Palmoxylon* (Palms)**
Family ARECACEAE Schultz Sch. 1832
Genus PALMOXYLON Schenk 1882

Material: Material no.s. 3 and 259.

Locality: East of Eşelek Village - Gökçeada, and on the coastline.

Age: Early Miocene

Wood description of type 1 (Sample No: 3): The wood is made up of small vascular bundles, measuring around 200-300 µm in diameter, scattered in loosely packed parenchymatous ground tissue. They comprise 4-8 wider and around 100 µm in length, closely spaced metaxylem vessels together with more small ones. The shapes of the metaxylem vessels are clearly ellipsoid (Plate IV).

Wood description of type 2 (Sample No: 259): The wood has small vascular bundles, measuring less than 200-250 µm in diameter. They are distributed throughout the parenchymatous ground tissue through the wood. They comprise numerous, small (less than 50 µm in diameter) closely spaced metaxylem vessels together with smaller ones. The shapes of the metaxylem vessels are clearly circular (Plate V).

Discussion: This type of monocotyledon wood was identified from Seben Fossil Forest in Bolu for the first time (Akkemik et al., 2016). It is also found in Lesvos island (Zouros et al., 2004). These two types of wood are different from the wood found in Seben Fossil Forest, which had 2-4 vessels in each vascular bundle found (Akkemik et al., 2016). The modern palm wood in Turkey is *Phoenix theophrasti*, and mostly restricted to the southwest Anatolia (Boydak, 1983, 1985). This identification may be

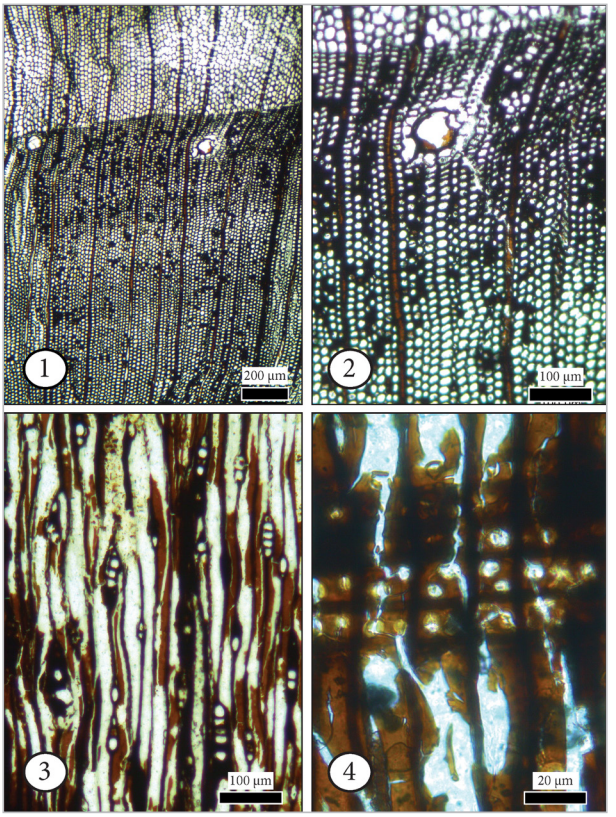

Plate III. *Pinoxylon* sections. 1-2) Transversal sections with resin canal, 3) Tangential section with horizontal resin canal, 4) Heterocelluler rays with pinoid (slightly windows-like)

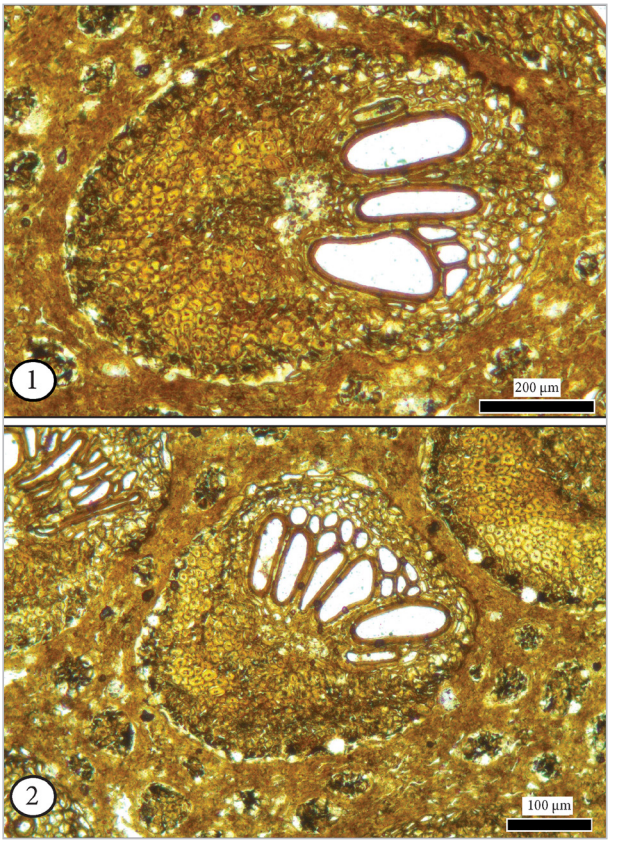

Plate IV. *Palmoxylon* type 1. 1) Transversal section of the wood, 2) Vascular bundle with elipsoid vessels elements

considered as an indicator genus for paleoclimatic evolution of the early Miocene of Gökçeada.

***Alnoxylon* (Alder)**
Family BETULACEAE Gray 1822
Genus ALNOXYLON Felix 1884

Material: Material no. 231.

Locality: East of Eşelek Village - Gökçeada, and on the coastline.

Age: Early Miocene

Wood description: Growth ring boundary generally distinct. Wood diffuse porous, and vessels arranged in no specific pattern, solitary or commonly in radial multiples of 2-4 or more. Solitary vessel outline angular. Perforation plate scalariform with 10-30 bars. Intervessel pits opposite and small. No helical thickening observed. Mean tangential diameter of vessel lumina 50-100 µm in earlywood and less than 50 µm in latewood. 40-100 vessels per square mm. Rays were exclusively uniseriate and all rays procumbent. Aggregate rays visible. Ray number per square mm more than 12. Maximum ray height could not be observed (Plate VI).

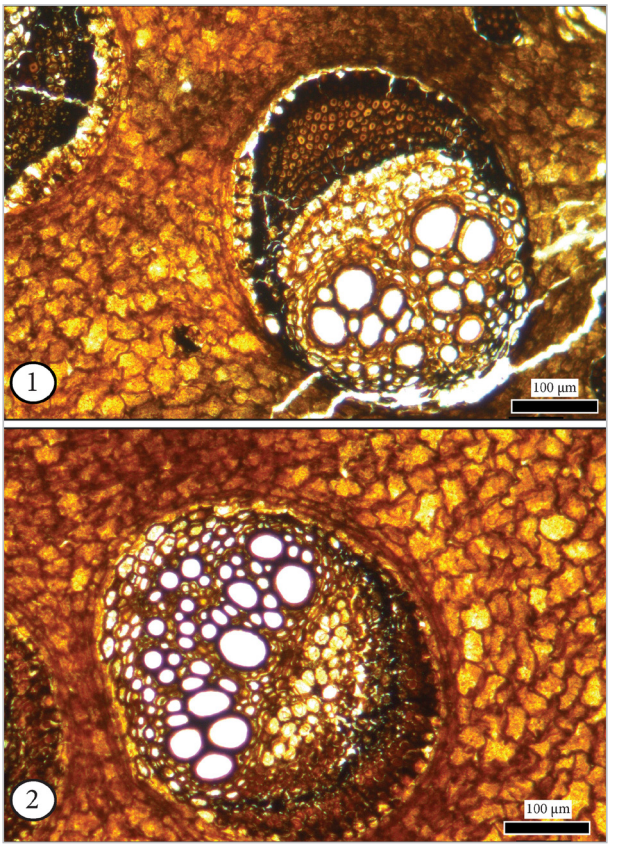

Plate V. *Palmoxylon* type 2. 1) Transversal section of the wood, 2) Vascular bundle with rounded vessels elements

Discussion: Features such as vessel diffuse porous, aggregate rays, vessels in radial rows of up to 4 or more, scalariform perforation plates (with 20-30 bars) are the characteristics for *Alnus* wood (Akkemik and Yaman,2012). We determined all these features on the wood. *Alnoxylon* was also determined by Selmeier (2001) from the middle to the late Miocene of North West Anatolia. Selmeier and Velitzelos (2000) described *Alnoxylon* from the early Miocene of Lesvos Island and from Oligocene volcanic series of Thrace, NE Greece. This genus was one of the most common trees in riparian vegetation during Miocene (Denk et al, 2017a; Güner et al., 2017). Today, the genus *Alnus* is represented by two species in Turkey, *Alnus glutinosa* (L.) Gaertn. and *Alnus orientalis* Decne. They are the main elements of riparian vegetation.

***Carpinoxylon* (Hornbeam)**
Family BETULACEAE Gray 1822
Genus CARPINOXYLON Vater 1884

Material: Material no. 1.

Locality: East of Eşelek Village - Gökçeada, and on the coastline.

Age: Early Miocene

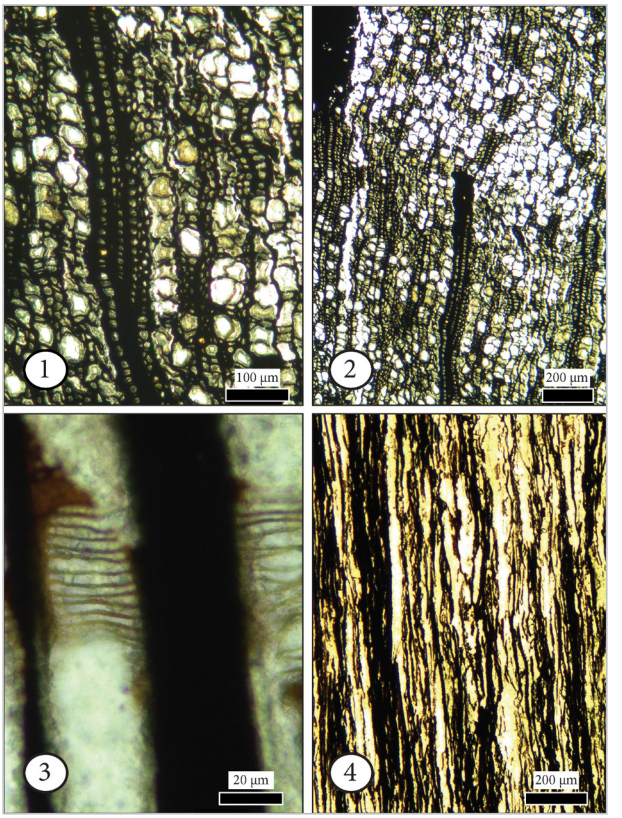

Plate VI. *Alnoxylon* sections. 1-2) Transveral section with aggregate rays, 3) Scalarifom perforation plates, 3) *Tangential section of the wood*

Wood description: Growth ring boundaries indistinct. Wood diffuse porous and vessels arranged in radial multiples, and generally in a dendritic pattern. Radial clusters of vessels very common and solitary vessels rather rare. Perforation plate simple. Fibers thick-walled. Axial parenchyma commonly apotracheal diffuse and diffuse-in-aggregate, and in narrow and short tangential bands. Ray width 1-3 seriate, and in some rays, one to four rows of square marginal cells present. Rays per millimeter more than 12, and ray height 1-30 cells (Plate VII).

Discussion: *Carpinus* wood has growth rings having distinct or indistinct boundary, diffuse porous and vessels in radial multiples, simple or scalarifom perforation (with 2-3 bars), and aggregate rays (Akkemik and Yaman, 2012). In the fossil wood, similar features were observed. However, clearly indistinct growth ring boundary, dendritic arrangement of vessels and lower rate of aggregate rays are small changes from the modern represantatives. This genus is represented by two species in Turkey - *Carpinus orientalis* Mill. and *Capinus betulus* L. in the humid and well-drained lowlands and upland forests.

***Ostryoxylon* (Hophornbeam)**
Family BETULACEAE Gray 1822
Genus OSTRYOXYLON Ü. Akkemik 2018

Material: Material no. 2.

Locality: East of Eşelek Village - Gökçeada, and on the coastline.
Age: Early Miocene

Wood description: Growth ring boundaries distinct with 1-2 rows of marginal fiber cells. Wood diffuse-porous, and vessels arranged in radial multiples 2-4 or more (up to 13 vessels). Perforation plates simple and intervessel pits mostly alternate. Mean tangential diameter of vessel lumina less than 50 µm. Vessel frequency 50-100 per square mm. Helical thickening on vessels very common. Axial parenchyma present and diffuse. Rays width 1-4 seriate, and aggregate rays present. Rays heterocellular; body ray cells procumbent with mostly 1-4 rows of upright and / or square marginal cells. Rays per mm were more than 12. Maximum ray height up to 71 cells (Plate VIII).

Discussion: In spite of the fossil wood of *Ostrya* being very similar to that of *Carpinus*, the presence of helical thickening in *Ostrya* wood is the main difference between these two genera. This type of wood may have procumbent or heterocellular rays, simple or scalariform perforation plates, 1-3 seriate or 4-to 10 seriate of rays together with helical thickening in vessels (Suzuki and Watari, 1994; Jeong et al., 2009). Because our wood has very similar features to those of the fossil wood *Ostrya*, we have identified this wood as *Ostryoxylon*. This is the first description of this fossil-genus in Turkey. The modern representative of this genus is *Ostrya carpinifolia* Scop. in Turkey, and grows in well-drained

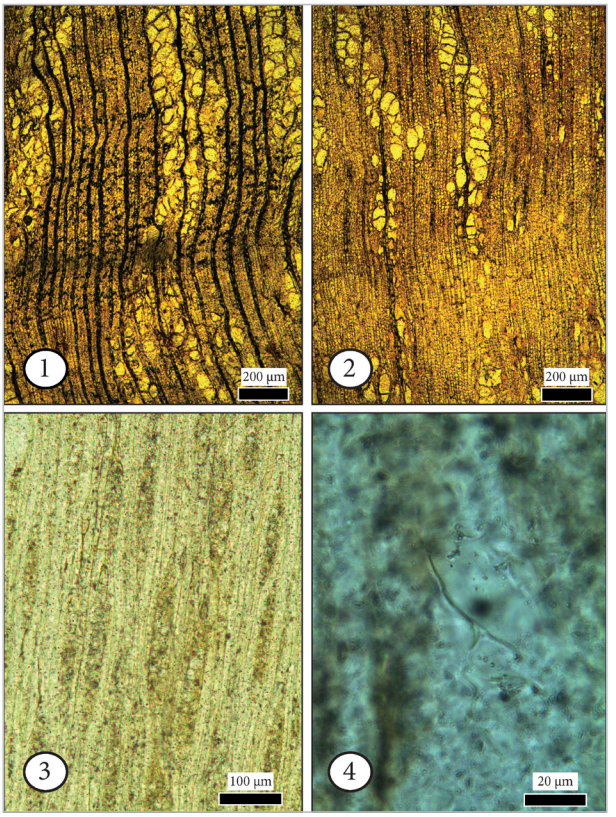

Plate VII. *Carpinoxylon* sections. 1-2) Transversal sections of the wood, 3) Rays in tangential section, 4) Simple perforation plate

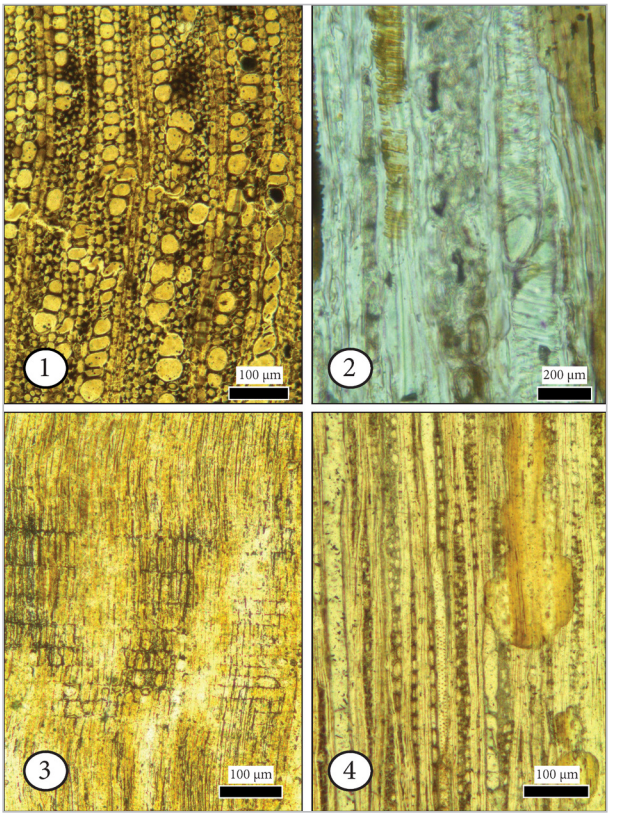

Plate VIII. *Ostroyoxylon* sections. 1) Transversal section, 2) Simple perforation plates and helical thickening on the walls of vessels, 3) Heterocellular rays, 4) Rays in tangential section

upland forests in the Mediterranean region and lowland and upland forest of Black Sea region of Turkey.

***Fagoxylon* (Beech)**
Family FAGACEAE Dumort. 1829
Genus FAGOXYLON Stopes and Fujli 1910

Material: Material no. 257.

Locality: East of Eşelek Village - Gökçeada, and on the coastline.

Age: Early Miocene

Wood description: Growth ring boundary distinct. In the border of growth ring, vessel number decreases and thick-walled fibers increase. Wood diffuse to semi-ring porous. Pores frequent and more than 100 per square mm. Vessels solitary and clustered. Intervessel pits opposite and alternate. Perforation plate mostly simple, rarely scalariform. Mean tangential diameter of vessel lumina around 50 µm. No helical thickening observed. Axial parenchyma commonly apotracheal diffuse and diffuse-in-aggregate. Rays uniseriate to multiseriate. Width of multiseriate rays more than 10 cells. All ray cells procumbent. Rays per millimeter 4-12, and height of multiseriate rays more than 1 mm (Plate IX).

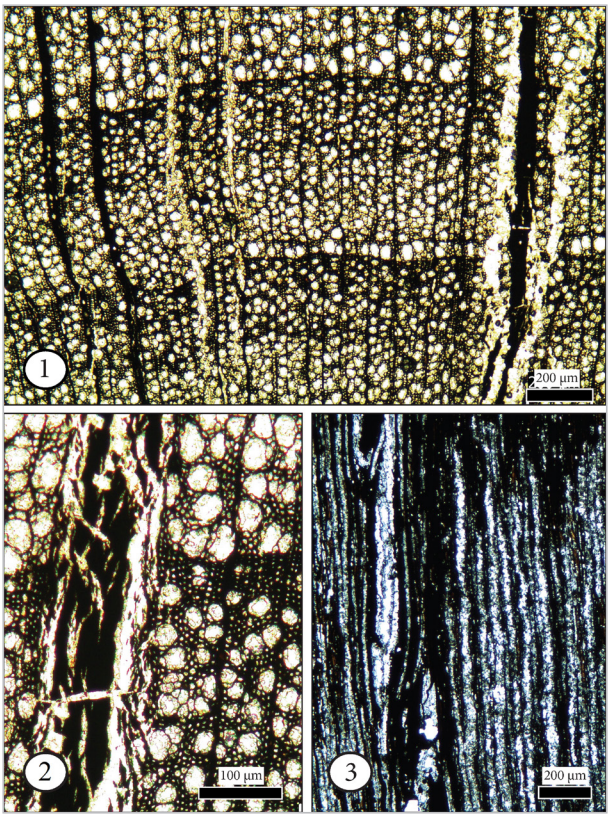

Plate IX. *Fagoxylon* sections. 1-2) Transversal section with narrow and very wide rays. Wood semi-ring porous, 3) Tangential section of the wood

Discussion: *Fagoxylon* was described in Turkey for the first time. The presence of distinct annual ring boundary, diffuse porous, distribution of 1-3 seriate and more than 10 seriate of rays through wood, and long rays (>1 mm) showed the features of the wood of *Fagus*. Leaves and other macrofossils of the genus *Fagus* were identified by Denk et al. (2017a) and Güner et al. (2017) from a different region of Turkey. This was a common genus in the early Miocene forests (Denk et al., 2017a; Güner et al., 2017). Today, this genus is represented by two species (*Fagus orientalis* Lipsky and *F. sylvatica* L.) in the lowland and upland humid forest sites of Turkey.

***Quercoxylon* section *Ilex* (Evergreen oak)**
Family FAGACEAE Dumort. 1829
Genus QUERCOXYLON Hofmann 1929 Section ILEX

Material: Material nos. 5e, 5ece2, and 202.

Locality: East of Eşelek Village - Gökçeada, and on the coastline.

Age: Early Miocene

Wood description: Growth ring boundaries mostly distinct or indistinct, and wood diffuse porous. Transition from earlywood vessels to latewood indistinct, and from one ring to the next. Vessels exclusively solitary, these solitary vessels are rounded, and walls of vessels are thick. Perforation plate simple. Mean tangential diameter of vessel lumina 100-200 µm in earlywood, and 50-100 µm in the latewood, and 5-20 vessels per square mm. Axial parenchyma commonly diffuse, in narrow and short tangential bands and scanty paratracheal. Rays in two distinct sizes, uniseriate and multiseriate (more than 10-seriate and extremely broad). In multiseriate rays, height more than 1 mm. All ray cells procumbent, and 4-12 rays per millimeter. Tyloses common in vessels of earlywood (Plate X).

Discussion: The former studies showed that evergreen sclerophyllous oaks (*Quercus* section *Ilex*) of Turkey belong to a wider Eurasian group of evergreen oaks (Denk & Grimm, 2009; Denk & Grimm, 2010; Hubert et al., 2014; Hipp et al., 2015). This type of wood is rather common in the early Miocene through Turkey (Akkemik et al., 2016; Bayam et al., 2018). Today, Turkey is represented by three evergreen oak species. They are *Quercus coccifera*, which is a common macchie element, *Q. ilex* which is a rare macchie element growing throughout the coastal areas of Black, Aegean and the Mediterranean Seas, and *Q. aucheri*, which is an endemic species growing locally in southwestern Turkey and the Greek island of Kos.

***Laurinoxylon* (Laurel)**
Family LAURACEAE Juss. 1789
Genus LAURINOXYLON Felix 1890

Material: Material nos. 1ok, 5, and 261.

Locality: East of Eşelek Village - Gökçeada, and on the coastline.

Age: Early Miocene

Wood description: Growth ring boundaries distinct, marked by thick-walled latewood fibres. Vessel diffuse-porous, and arranged in no specific pattern, solitary, and radial multiples of 2-3 vessels. Perforation plates simple. Intervessel pits alternate and small-sized (4-7 µm). Shape of the alternate pits polygonal. Mean tangential diameter of vessel lumina 50-100 µm and the number of vessels per square mm 20-40. Axial parenchyma was scanty paratracheal, and strand length 1 to 4 cells. Ray width 1 to 3 cells, and body ray cells procumbent with one row of upright and/or square marginal cells. 4-12 rays per mm. Oil cells commonly present, and associated with ray parenchyma (Plate XI).

Discussion: *Laurinoxylon* including the the genera, *Laurus* and *Ocotea* is one of the most common wood types in the Miocene time. Many different woods of this morphogenus have been identified (Prakash et al., 1971; van der Burgh et al., 1973; Iamandei and Iamandei, 1997; Cevallos-Ferriz et al., 2016; Jud and Dunham, 2017). The presence of oil and/or mucilage cells in rays, diffuse porous, distinct boundary of growth ring, 1-3 seriate of ray cells, vasicentric type of axial parenchyma are the typical features of *Laurinoxylon*. We observed all of these features. Güner et al. (2017) and Denk et al. (2017a) identified Laucaceae type leaves from western and central Turkey as well. Today, only one genus and species of Lauraceae, *Laurus nobilis* L., represents the family in Turkey. This species grows in the warm, humid and semi-humid lowland areas throughout coastal Turkey.

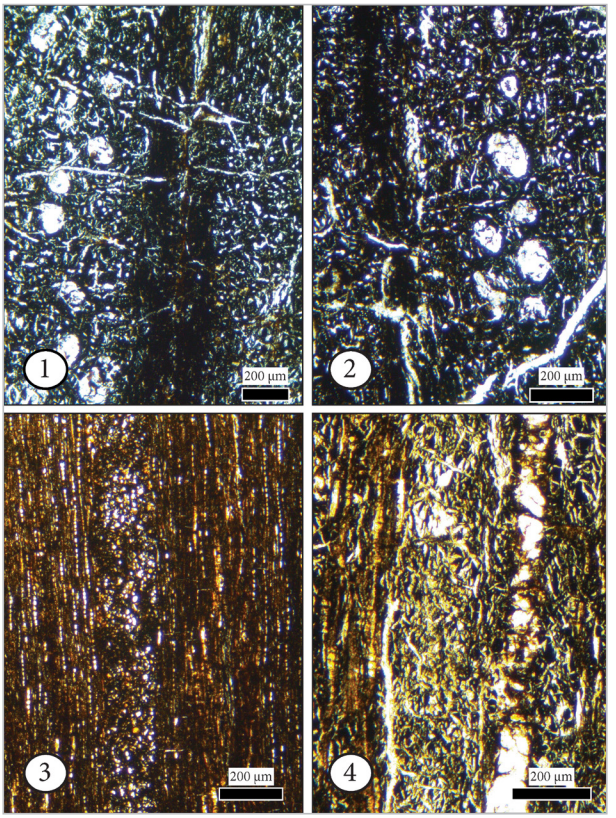

Plate X. *Quercoxylon* sect. Ilex sections. 1-2) Transversal sections, 3) Tangential section with narrow and very wide rays, 4) Vessel with simple perforation plate

***Platanoxylon* (Plane)**
Family PLATANACEAE T. Lestib. 1826
Genus PLATANOXYLON E. Hofmann 1952

Material: Material no. 258.

Locality: East of Eşelek Village - Gökçeada, and on the coastline.

Age: Early Miocene

Wood description: Growth rings boundary distinct, marked by distended rays and by thick-walled and radially flattened latewood fibers. Wood diffuse-porous, and vessels arranged in no specific pattern, and generally solitary and rarely in radial multiples. Shape of the solitary vessel outline angular. Perforation plates both simple and scalariform. Scalariform perforation plates mostly with 10-20 bars. Intervessel pits opposite. Vessel diameter 50-100 µm. Vessel frequency 40-100 per square mm. Axial parenchyma diffuse-in-aggregates and scanty paratracheal. All ray cells procumbent (homocellular). Rays distended at growth ring boundaries, and mostly multiseriate, larger rays commonly both 4- to 10-seriate and > 10-seriate. Ray height generally more than 1 mm. Prismatic crystals common in procumbent ray cells (Plate XII).

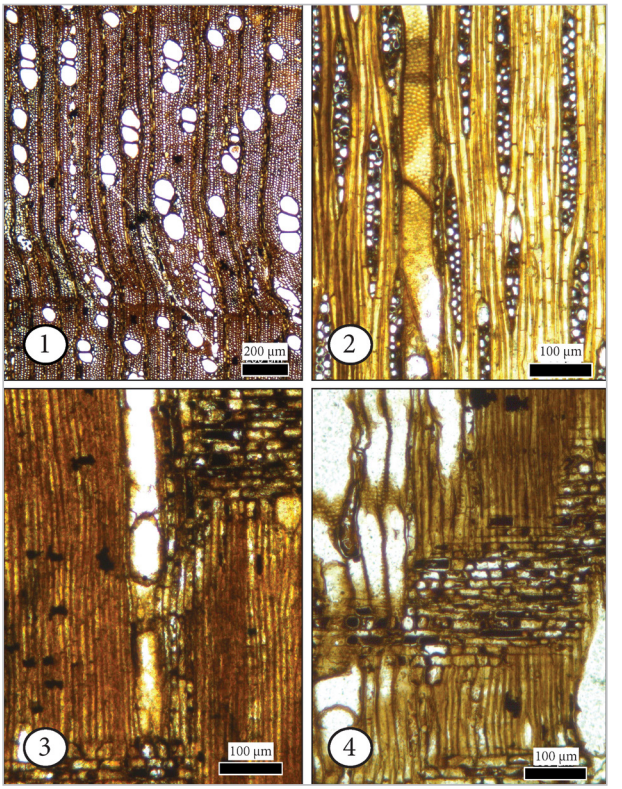

Plate XI. *Laurinoxylon* sections. 1) Transversal section with diffuse porous, 2) Tangential section with 1-3 rows of rays, 3-4) Heterocellular rays with oil cells on the borders, and simple perforation plates

Discussion: Wood of *Platanus* is rather similar to that of *Fagus* (Akkemik and Yaman, 2012). Woods of both of these two genera were described in this study. In *Platanoxylon*, the features are (1) rays distended at growth ring boundaries, (2) rays densely multiseriate (>10 seriate), (3) vessels exclusively solitary (90% or more), (4) perforation plates predominantly scalarifom, and (5) prismatic crystals common in rays. In contrast, *Fagoxylon* has (1) different sizes of rays, (2) no prismatic crystals in rays, (3) both simple and scalariform perforation plates. This type of wood, *Platanoxylon*, was described for the first time in Turkey. Today, *Platanus orientalis* L. is the unique plane species in the Mediterranean Basin. The fossil plane described here may be the ancestor of the present species.

Paleoclimatology of the Fossil Forest

The petrified wood materials collected from the coastline were materials which had moved from the upper areas to the shoreline. It was possible to evauate a total of 12 wood types, belonging to different vegetation units defined by Denk et al. (2017a,b,c), as evidence of this movement (Table 2).

Among the 12 different wood types, *Pinoxylon* and *Cupressinoxylon* may be considered as members of well-drained (lowland and) upland conifer forests. *Sequoioxylon* may be a member of a swamp, riparian or well drained lowland forest type. *Palmoxylon* woods may be seen as plants indicating subtropical, humid forest and, swamp or riparian vegetation. Two types of palm woods are members of these types of forests together with *Alnoxylon* and *Platanoxylon* (Table 2).

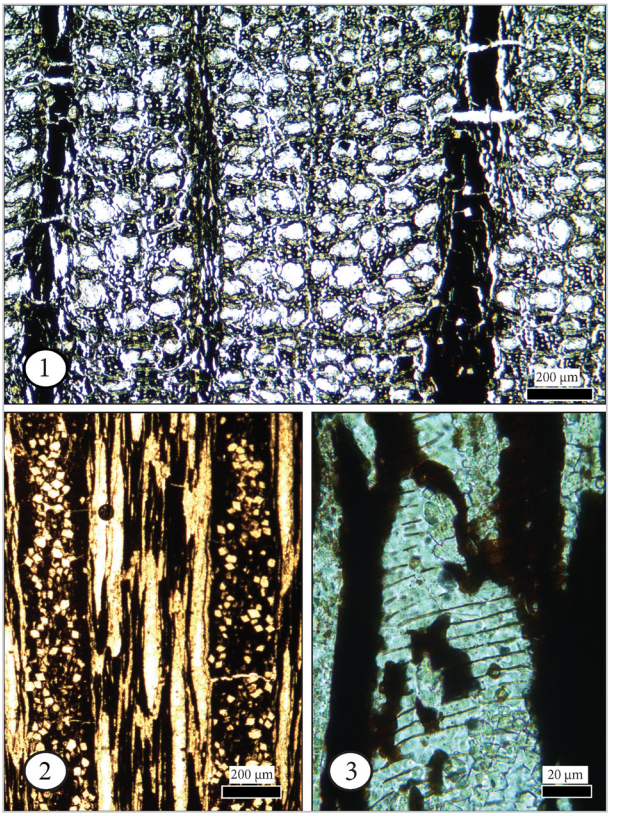

Plate XII. *Platanoxylon* setions. 1) Transversal section with wide rays and diffuse porous, 2) Wide rays with prismatic crystals, 3) Scalariform perforation plate

Finally, we can conclude that the following wood genera might be members of a forest from the lowlands to the uplands in the early Miocene of Gökçeada: *Palmoxylon, Sequoioxylon, Alnoxylon, Platanoxylon, Laurinoxylon, Cupressinoxylon, Quercoxylon* section *Ilex, Pinoxylon, Carpinoxylon, Ostryoxylon,* and *Fagoxylon*. Very similar results to the petrified woods of the Island Lesvos (Velitzelos et al., 2014) were obtained. *Sequoioxylon* (known as *Taxodioxylon gypsacum* in Lesvos), *Palmoxylon, Fagoxylon, Alnoxylon, Laurinoxylon* and *Quercuxylon* section *Ilex* were also identified from the island of Lesvos.

Within this wood vegetation the presence of palm trees may indicate that the climate in Gökçeada was both subtropical (warm and humid) and mountainous. The early Miocene palaeobotany studies on macrofossils (Denk et al., 2017a,b,c; Güner et al., 2017), microfossils (Akgün et al., 2007; Akkiraz et al., 2011), and petrified woods (Akkemik et al., 2005; Akkemik et al., 2009; Akkemik and Sakınç, 2013; Akkemik et al., 2016 and 2017; Bayam et al., 2018) revealed that the climate during the early Miocene period was subtropical warm and humid. The results from this study also supported the presence of a similar climate type in Gökçeada.

CONCLUSION

Petrified wood materials revealed a very rich wood flora in Gökçeada with 12 types of different woods (*Palmoxylon type 1 and type 2, Sequoioxylon, Alnoxylon, Platanoxylon, Laurinoxylon,*

Table 2. The genera identified and their vegetation units

Identification	Vegetation Unit*
Pinoxylon	VU0, VU3-VU7
Cupressinoxylon	VU5, VU7
Sequoioxylon	VU3, VU4, VU5
Palmoxylon type 1	VU0, VU4
Palmoxylon type 2	VU0, VU4
Alnoxylon	VU3, VU4
Carpinoxylon	VU5
Ostryoxylon	VU5
Fagoxylon	VU5, VU6
Quercoxylon section Ilex	VU5, VU6, VU7
Laurinoxylon	VU4, VU5
Platanoxylon	VU4

*From Denk (2017) and Güner et al (2017): Vegetation Unit (VU) 0: Subtropical, moist or dry light forest. VU 1: Aquatic. VU 2: Bogs, wet meadows. VU 3: Swamp forest. VU 4: Riparian forest. VU 5: Well-drained lowland forest (VU5a - *Quercus drymeja*, Fagaceae gen. et spec. indet. various, VU5b - edaphically and aspect wise dry forest). VU 6: Well-drained upland forest (*Fagus-Cathaya*). VU 7: Well-drained (lowland and) upland conifer forest including hammocks

Quercoxylon section *Ilex, Pinoxylon, Cupressinoxylon, Carpinoxylon, Ostryoxylon* and *Fagoxylon)*. Knowledge on the early Miocene flora and climate of Aegean Basin was increased with these findings, and we can conclude that the climate and the wood flora of Gökçeada are rather similar to those of Lesvos - which had a subtropical warm and humid climate. Due to having a rich fossil wood flora, the fossil forest in Gökçeada should be protected, and considered as a geosite. Furthermore, the area should then become a designated tourism route after protecting the petrified woods.

Peer-review: Externally peer-reviewed.

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