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Some fossil conifer species descriptions from the Paleogene to Pliocene of Turkey and their evaluations

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Abstract
Until now, a considerable number of Miocene conifer trees has been determined using fossil wood identification. Some studies on fossil wood identifications have revealed the need to reconsider certain fossil wood species definitions. The present study aimed to re-analysis the conifer wood identifications (Cupressaceae), which were described as genus, and performed necessary revisions in the descriptions. All studies were conducted on thin sections used in former studies, and detailed investigations were performed. As result, *Cupressinoxylon pliocenica* Akkemik, 2019, *Glyptostroboxylon rudolphii* Dolezych & van der Burgh, 2004, and *Taxodioxylon gypsaceum* (Göppert) Kräusel, 1949, were described in Turkey. This study showed that these three fossil species had wider distribution areas and lived in a very wide time interval from mainly early Miocene to Pliocene in Turkey.

Keywords: *Cupressinoxylon pliocenica*, *Glyptostroboxylon rudolphii*, *Taxodioxylon gypsaceum*, Turkey, fossil species

1.Introduction

Petrified wood identifications in Turkey started in 1970s and increased in the first quarter of 21st century. A considerable number of petrified woods have been identified from the late Oligocene, Miocene, and Pliocene in Turkey.

The increased number of the palaeobotanical studies in Turkey showed the presence of a diverse conifer genera such as *Araucarioxylon, Pinuxylon, Lesbosoxylon, Cupressinoxylon, Taxodioxylon, Glyptostroboxylon, Sequoioxylon Juniperus, Taxoxylon* (Kayacık et al., 1995; Selmeier, 2001; Akkemik et al., 2005; Kutluk et al., 2012; Akkemik and Sakınç, 2013; Akkemik et al., 2009, 2016, 2017, 2019a,b, 2020; Acarca Bayam et al., 2018; Akkemik, 2019; Akkemik and Acarca Bayam, 2019; Güngör et al., 2019).

In some of the studies, the fossil species of these genera were identified such as *Sequoioxylon egemenii* Özgüven-Ertan, 1971 (Özgüven-Ertan, 1971), *Cupressinoxylon akdiki* Özgüven-Ertan, 1977 (Özgüven-Ertan, 1977), *Sequoioxylon gypsaceum* (Göppert) Greguss, 1967 (Özgüven-Ertan, 1981 (1983), *Taxodioxylon gypsaceum* (Göppert) Kräusel, 1949, *Glyptostroboxylon rudolphii* Dolezych & van der Burgh 2004 (Akkemik and Bayam, 2019), and *Cupressinoxylon pliocenica* Akkemik 2019 (Akkemik, 2019).

The most of the members of Cupressaceae were identified as genus level (e.g. Akkemik et al., 2009; Akkemik and Sakınç, 2013; Akkemik et al., 2017; Acarca Bayam et al., 2018; Akkemik et al., 2019a;

Güngör et al., 2019). In the fossil specimens, which were fossilized in good conditions, a revision may be done, and possible fossil species of these genera may be described. It may also be discussed their species diversity and distributions in geological times and geographic areas. Therefore, the purpose of the present study is to restudy the identifications of the fossil *Cupressinoxylon, Glyptostroboxylon, Sequoioxylon* and *Taxodioxylon* genera of Cupressaceae, and to describe their fossil species, whenever it is possible.

2.Material and Methods

While certain conifer woods were identified at the species level, some others were identified at the genus level (Table 1).

The present study focused on the some Cupressaceae woods identified at the genus level, and used thin sections of the fossil (petrified) woods utilized in the previous studies as materials, obtained from different locations from the west-central Anatolia to the European part of Turkey (Figure 1).

Studies were performed on the thin wood sections of *Cupressinoxylon, Glyptostroboxylon*, *Sequoioxylon* and *Taxodioxylon* (Kayacık et al., 1995; Akkemik et al., 2005; Akkemik et al., 2009; Akkemik et al., 2016; Acarca Bayam et al., 2018; Akkemik et al., 2019a; Güngör et al., 2019; Polat et al., 2019) (Table 1). For identification at the species level, the published descriptions given in the relevant discussion parts of the related species were used.

Table 1. The restudied fossil conifer woods identified from the Cenozoic era of Turkey

Age	Identification	Code	Locality	Formation	Reference
Paleogene	*Sequoioxylon* Torrey 1923	USA01	Küçükler area in the west of the city of Banaz of the province of Uşak	-	Polat et al. (2019)
Early Miocene	*Cupressinoxylon* Göppert 1850	GOK04	East of Eşelek Village - Gökçeada, and near to the coastline.	Kesmekaya Volcanics	Güngör et al. (2019)
Early Miocene	*Sequoioxylon* Torrey 1923	GOK211	East of Eşelek Village - Gökçeada, and near to the coastline.	Kesmekaya Volcanics	Güngör et al. (2019)
Early Miocene	*Sequoioxylon* Torrey 1923	DUR02	Alaçam Village of the city of Dursunbey	Beke Formation	Akkemik et al. (2019a)
Early Miocene	*Sequoia* (D. Don.) Endlicher 1847	INO04	Beypazarı Inozu Valley	Hançili Formation	Acarca Bayam et al. (2018)
Early Miocene	*Sequoioxylon* Torrey 1923		European Part of Turkey (Thrace)	Hisarlı Dağ Volcanics	Akkemik & Sakınç (2013)
Early-Middle Miocene	*Sequoia* (D. Don.) Endlicher 1847	BUG20	the villages of Çamlıdere-Buğralar	Pazar Formation	Acarca Bayam et al. (2018)
Early-Middle Miocene	*Sequoia* (D. Don.) Endlicher 1847	SOG04	Kızılcahamam-Soğuksu	Pazar Formation	Acarca Bayam et al. (2018)
Early-Middle Miocene	*Taxodium* Richard 1810	BUG01	the villages of Çamlıdere-Buğralar	Pazar Formation	Acarca Bayam et al. (2018)
Early-Middle Miocene	*Taxodium* Richard 1810	CAM01	Ankara-Çamlıdere	Pazar Formation	Akkemik et al. (2009)
Early-Middle Miocene	*Sequoia* (D. Don.) Endlicher 1847	CAM2	Ankara-Çamlıdere	Pazar Formation	Akkemik et al. (2009)
Early-Middle Miocene	*Glyptostroboxylon* Conwentz	GUD02, GUD05	Ankara-Güdül	Pazar Formation	Akkemik et al. (2017)
Pliocene	*Sequoioxylon* Torrey 1923	CUK07	Çukurköy near Tunçbilek in the city of Tavşsnlı, Kütahya	Çokköy Formation	Akkemik et al. (2019a)

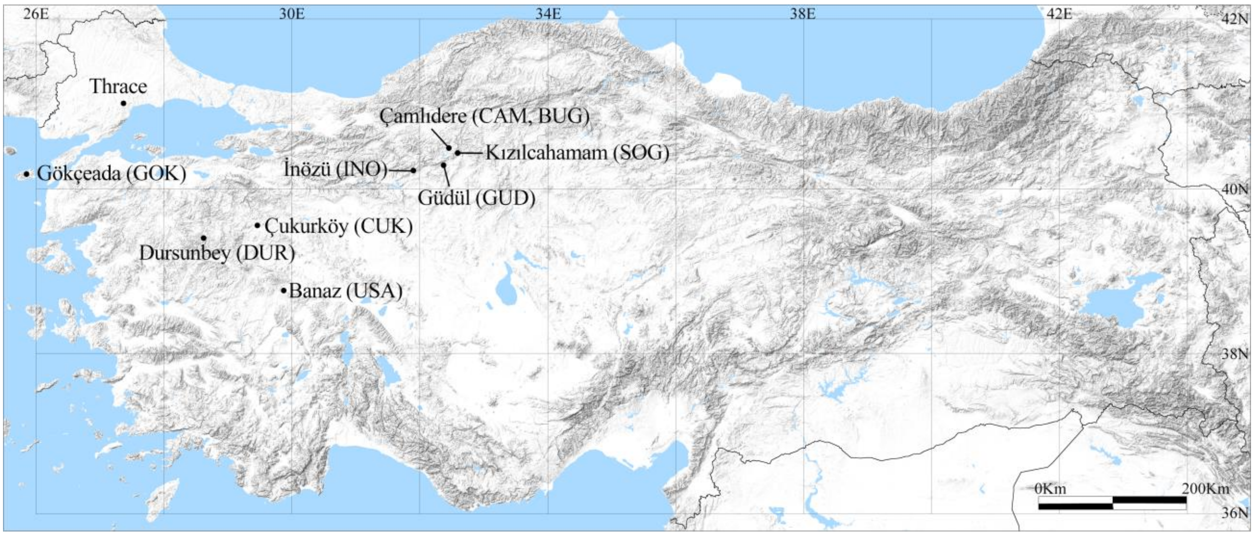

Figure 1. The location map of the revisited specimens in Turkey.

3.Systematic palaeobotany

In this study, the fossil species, *Cupressinoxylon pliocenica* Akkemik, 2019, *Glyptostroboxylon rudolphii* Dolezych & van der Burgh 2004, and *Taxodioxylon gypsaceum* (Göppert) Kräusel 1949, were identified.

Order PINALES Gorozhankin, 1904
Family CUPRESSACEAE Gray, 1822
Genus *CUPRESSINOXYLON* (Goeppert) emend. Dolezych 2005
***Cupressinoxylon pliocenica* Akkemik, 2019**

Formation: Kesmekaya Volcanics. The detailed geology of the area was given by Güngör et al. (2019).
Age: Early Miocene
Locality: East of Eşelek Village - Gökçeada, and near to the coastline.
Sample code: GOK04
Diagnosis: The wood anatomical characteristics of *Cupressinoxylon* given by Güngör et al. (2019) were restudied here and the diagnosis were designed as follows: Growth ring border distinct with 1-5 rows of radially flattened latewood tracheids, transition from earlywood to the latewood gradual. Tracheids polygonal, irregularly shaped or slightly circular. Normal axial and horizontal resin canals absent. Axial parenchyma common, diffuses, short diffuse-in-aggregate and marginal; dark content very common in axial parenchyma cells (Figure 2: A-B). Rays predominantly uniseriate and very rarely and partly biseriate, ray heights 3-13 (1-23) cells (Figure 2:C). Rays homogenous, end walls of ray cells commonly smooth, 2-3 (1-4) cupressoid type of cross-field pits present (Figure 2: D and G). Tracheidal pits on radial walls predominantly uniseriate, rarely partly biseriate (Figure 2: E). Tracheidal pits also common on tangential walls of tracheids. End walls of axial parenchyma smooth in general (Figure 2: F).

Discussion: *Cupressinoxylon* is one of the most common genera identified from Cretaceous to Pliocene, and, until now, more than 130 fossil species were described (Vaudois and Prive, 1971; Özgüven-Ertan, 1977; Duperon-Laudoueneix, M., 1979; Nishida, 1984, 1988; Bamford et al., 2002; Herbst et al., 2007; Philippe and Bamford, 2008; Martínez, 2010; Klusek 2014; Bodnar et al. 2015; Pujana et al., 2014, 2015; Akkemik, 2019).

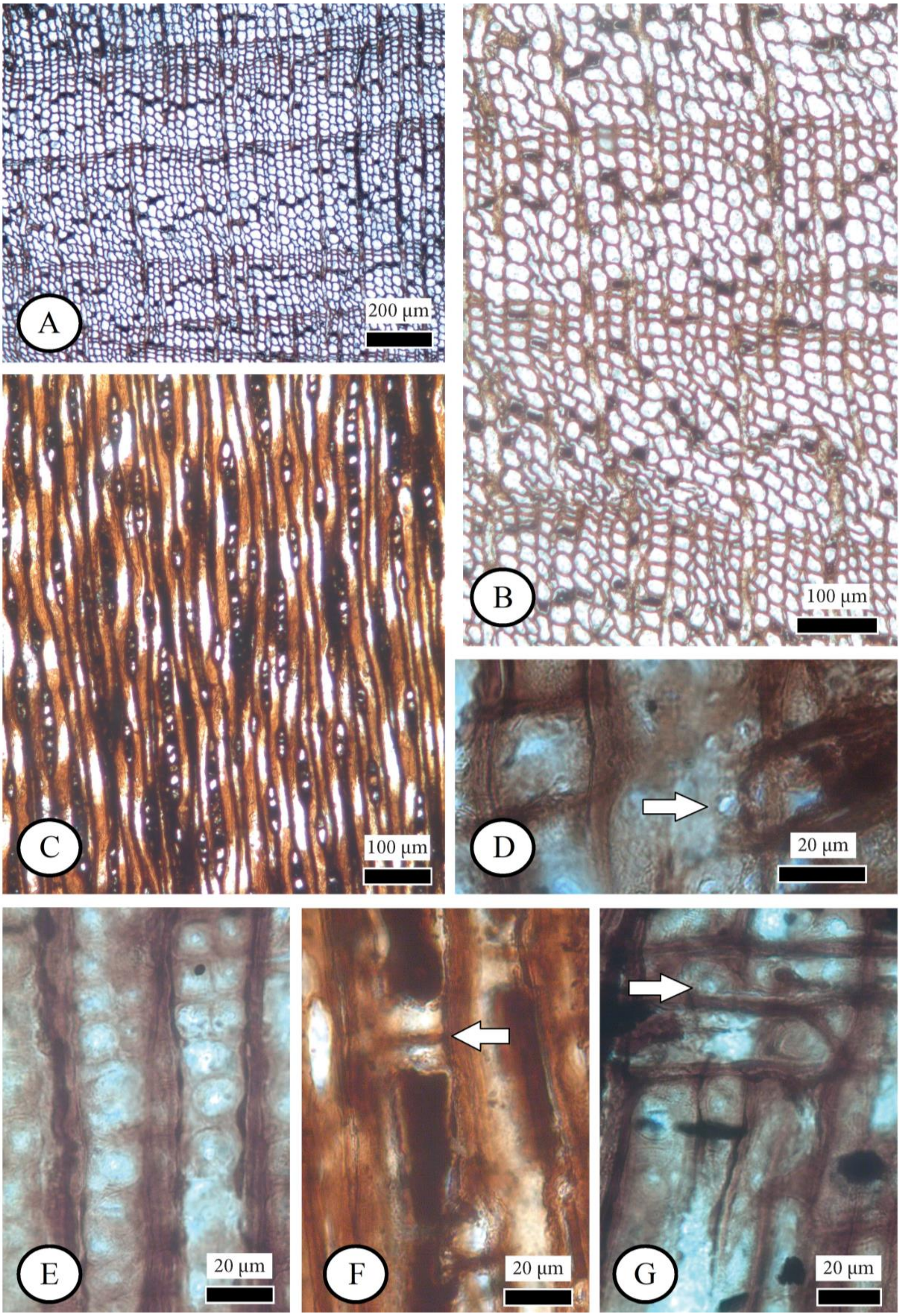

Figure 2. The thin sections of *Cupressinoxylon pliocenica*. A-B) Transversal sections with dense axial parenchyma and without resin canal, C) Tangential section, D) Cupressoid type cross-field pits (arrow), E) Generally uniseriate tracheidal pits on radial surface and rarely biseriate pits, F) Almost smooth horizontal-walled axial parenchyma (arrow), G) A radial section and cupressoid type cross-field pits (arrow).

After the species of *Cupressinoxylon* were revised by Dolezych-Mikolai (2005) and Klusek (2014), the latest species of the fossil genus was described by Akkemik (2019) as *Cupressinoxylon pliocenica* from the Pliocene of the north-central Anatolia (Çankırı-Çerkeş-Yıprak Village). The studied *Cupressinoxylon* specimen was compared first with this fossil species (Table 2).

Table 2. Comparison *Cupressinoxylon pliocenica* Akkemik (Akkemik, 2019) and the re-studied *Cupressinoxylon*.

Features	***Cupressinoxylon pliocenica* (Akkemik, 2019)**	***The studied Cupressinoxylon specimen***
Growth ring	Growth ring boundaries distinct. Transition from earlywood to latewood gradual.	Growth ring border distinct, transition from earlywood to latewood indistinct.
Tracheids	Tracheid pitting in radial walls in earlywood predominantly uniseriate. Intercellular spaces throughout the wood in transversal section observed. Latewood tracheids thick-walled.	Tracheid pitting in radial walls uniseriate and rounded; Intercellular spaces present. Latewood tracheids thick-walled.
Rays	Number of pits per cross-field 2 to 4 (mostly 2), and their angle about 45^0 or more. Average ray height 5-15 cells. Max ray height 34 cells.	Number of pits per cross-field 2-3 (1-4), Average ray height 3-10 (1-23) cells.
Axial parenchyma	Axial parenchyma common. End walls of axial parenchyma cells smooth and nodular.	Axial parenchyma present and abundant. End walls of axial parenchyma cells smooth and nodular.

Based on the strong similarities between the studied *Cupressinoxylon* specimen and *Cupressinoxylon pliocenica*, it was described as *Cupressinoxylon pliocenica* (Table 2). At present, the genus *Cupressus* is represented with a common species called Mediterranean cypress (*C. sempervirens* L.), and it distributes throughout the Mediterranean basin. Akkemik (2019) suggested that *C. pliocenica* has close wood characteristics to this modern species, *C. sempervirens*. The results at the present study showed also that the new *Cupressinoxylon* wood was also close to the modern species. It may be suggested that *Cupressinoxylon* has a long history from early Miocene to the present in Anatolia, and showed mostly stable wood anatomical features through the Neogene.

Genus *GLYPTOSTROBOXYLON* Conwentz, 1884 emend. Dolezych & Van der Burgh 2004

***Glyptostroboxylon rudolphii* Dolezych & van der Burgh 2004**

Formation: Pazar Formation. The detailed geology of the area was given by Akkemik et al. (2017).
Age: Early-Middle Miocene.
Locality: Near the city of Güdül.
Sample code: GUD06.
Diagnosis: Wood anatomical characteristics were given based on new observations and Akkemik et al. (2017) as follows. Diagnosis of the wood showed the following features: Growth rings generally distinct with 1-3 rows of flattened latewood tracheids. Transition from earlywood to latewood gradual and indistinct. Earlywood zone is distinctly wider than latewood zone. Normal axial and horizontal resin canals absent. Tracheids generally polygonal and hexagonal in outline in transverse section. Axial parenchyma presents, tangentially zonate and diffuse (Figure 3: A). Rays predominantly uniseriate, rarely biseriate, height of rays 2-5 (1-11) cells (Figure 3: B). End walls of axial parenchyma thin and slightly dentate or smooth (Figure 3: C). Helical thickenings absent. Horizontal and tangential end walls of ray cells smooth (unpitted), and ray tracheids absent. Cross-field pits predominantly glyptostroboid and rarely taxodioid, and number of pits 2-6 per cross-field (Figure 3: D). Tracheidal pitting on radial walls circular in outline, and 1-3 seriate, and crassulae present (Figure 3: E-F).

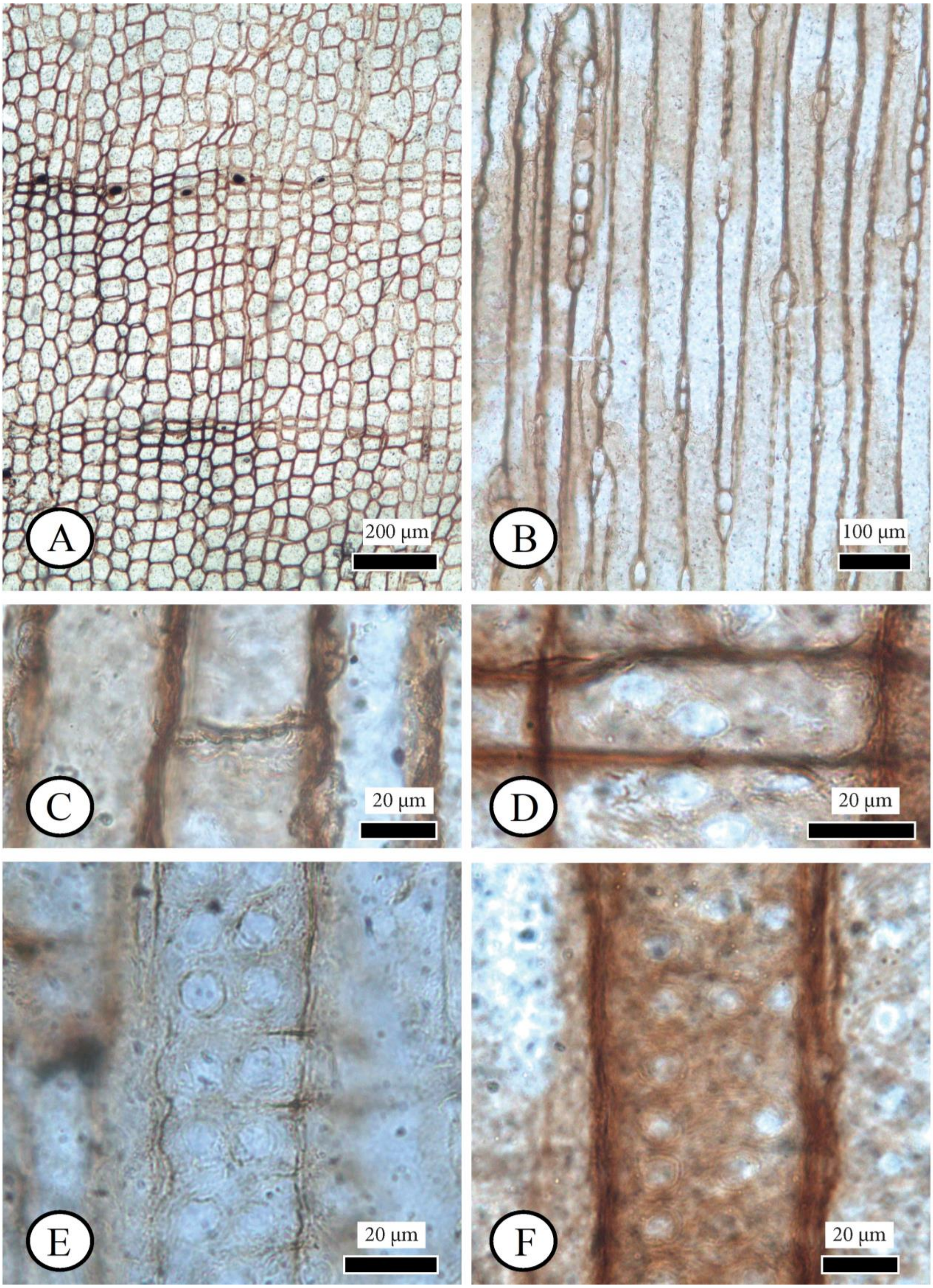

Figure 3. The thin sections of *Glyptostroboxylon rudolphii*. A) Transversal section with 1-2 rows of flattened latewood tracheids, and without resin canals, B) Tangential section, C) Axial parenchyma with smooth end walls, D) Glyptostroboid type cross-field pits, E-F) 2-3 rows of tracheidal pits of radial surface.

Discussion: Three species of *Glyptostroboxylon* were described (Süss and Velitzelos, 1997; Teodoridis and Sakala, 2008; Dolezych, 2011; Akkemik et al., 2017; Akkemik and Acarca Bayam, 2019). The following identification key was prepared for these three fossil species:

1A. Radial tracheidal wall pits uniseriate and no crassulae formation; 1-2 glyptostroboid type of pits per cross-field > ***Glyptostroboxylon tenerum* (Kraus) Conwentz 1884**
1B. Radial tracheidal wall pits uni- to triseriate and, if biseriate, crassulae presents
   2A. Tracheids are very small; intercellular spaces between tracheids and rays present; horizontal walls of rays in the crossing area strongly thickened with tangential walls > ***Glyptostroboxylon microtracheidale* Süss & Velitzelos 1997**
   2B. Tracheids not small; tracheidal pitting on radial walls up to triseriate; 1-4 glyptostroboid type of pits per cross-field > ***Glyptostroboxylon rudolphii* Dolezych &van der Burgh 2004**

According to the identification key, the fossil *Glyptostroboxylon* from Güdül should be *G. rudolphii* due to having tracheidal pits up to triseriate, crassulae formation, and wider tracheids. Moreover, the fossil wood sample SOG04, identified as *Sequoia* (Acarca Bayam et al., 2018) from the same geologic formation (Pazar formation), has also glyptostroboid cross-field pits together with taxodioid pits and smooth end wall of axial parenchyma and indistinct transition from earlywood to latewood, and one to five rows of latewood tracheids. According to the identification key, this fossil wood may be *Glyptostroboxylon rudolphii*.

Further, this fossil species was identified from the late Miocene fossil woods found in the east Galatian Volcanic Province (Akkemik and Acarca Bayam, 2019) and from the mid-late Miocene of Kütahya in central Turkey (Akkemik et al., 2019a). Finally, this fossil species had a wide distribution area during the early-middle Miocene to the late Miocene in the swamp areas of central Turkey. Today, this genus and its swamp conditions are completely extinct from Turkey.

Genus *TAXODIOXYLON* Hartig 1848 emend. Gothan 1905

***Taxodioxylon gypsaceum* (Göppert) Kräusel 1949**

(Syn: *Sequoioxylon gypsaceum* (Göppert) Greguss 1967)

The samples identified as *Sequoioxylon* given below (Table 3) were re-analyzed and compared with the most related species, *Taxodioxylon (=Sequoioxylon) gypsaceum*.

Diagnosis: The wood features were summarized based on the results of the related studies (Table 3) and new observations: Growth ring boundary distinct with 2-10 radially flattened latewood tracheids, transition from earlywood to latewood mostly abrupt and clear latewood zone presents. Tracheid cells generally polygonal and sometimes rounded. Axial parenchyma diffuses and zonate. Resin and intercellular canals absent. (Figure 4: A). Rays uniseriate, rarely partly biseriate, ray height 1-32 cells (Figure 4: B). End walls of axial parenchyma smooth and slightly nodular (Figure 4: C). Rays homogenous, cross-field pits taxodioid, 2-4 pits per cross-fields (Figure 4: D). Ray tracheids absent or partly present, end and horizontal walls of rays smooth. Tracheidal ray pits 1-3 seriate, opposite, and crassulae presents (Figure 4: E).

Discussion: The comparison of the wood characteristics of *Taxodioxylon gypsaceum* (Greguss, 1967; Özgüven-Ertan 1981 (1983); Dolezych, 2011; Iamandei et al., 2013; Koutecký and Sakala, 2015; Akkemik et al., 2019a; Akkemik, 2019) with the specimens identified as *Sequoioxylon* and *Taxodioxylon* showed that all these woods are close to each other, and they should be belonging to *Taxodioxylon gypsaceum*.

Table 3. *Sequoioxylon* identification and their comparison with *Taxodioxylon gypsaceum.* All these woods showed most stable wood characteristics from Paleocene to Pliocene.

Features	***Sequoioxylon* Polat et al. (2019)**	***Sequoioxylon* Akkemik and Sakınç (2013)**	***Sequoioxylon* Kayacık et al., (1995); Akkemik et al. (2005)**	***Sequoioxylon* Akkemik et al. (2019b).**	***Sequoioxylon* Güngör et al. (2019)**	***Sequoia* Akkemik et al. (2009)**	***Sequoioxylon* Akkemik et al. (2019b)**	***Taxodioxylon (Sequoioxylon) gypsaceum* Greguss (1967); Özgüven-Ertan (1981 (1983)); Dolezych (2011); Iamandei et al. (2013); Koutecký and Sakala (2015); Biondi and Brungiapaglia (1991)**
Locality /Code	Uşak-Banaz (USA)	Thrace	North of Istanbul (Thrace)	Dursunbey (DUR02)	Gökçeada (GOK211)	Çamlıdere (CAM2-01)	Çukurköy (CUK07)	-
Age	Paleocene	Mid-Late Oligocene	Late Oligocene	Early Miocene	Early Miocene	Early-Middle Miocene	Pliocene	-
Formation	-	Danişmen-Osmancık Formation	Danişment-Çöpköy Formation	Beke Formation	Kesmekaya Volcanics	Pazar Formation	Çokköy Formation	
Growth ring boundary	Distinct	Distinct	Distinct	Distinct	Distinct	Distinct	Distinct	Distinct
Earlywood to latewood transition	abrupt with wide zone (2-15 rows) of LW	abrupt with wide zone (2-10 rows) of LW	abrupt with wide zone (2-10 rows) of LW	abrupt with wide zone (2-11 rows) of LW	Gradual and abrupt with wide zone (2-13 rows) of LW	abrupt with wide zone (>10 rows) of LW	abrupt with wide zone (2-22 rows) of LW	Abrupt with wide zone of LW
Resin canal	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Axial parenchyma	Diffuse to tangentially zonate	Diffuse to tangentially zonate	Diffuse to tangentially zonate	Diffuse to tangentially zonate	Diffuse to tangentially zonate	Diffuse to tangentially zonate	Diffuse to tangentially zonate	Diffuse to tangentially zonate
End walls of axial parenchyma	Seemingly smooth	Smooth, slightly nodular	Smooth, slightly nodular	Seemingly smooth	Smooth, slightly nodular	Seemingly smooth	Seemingly smooth	Smooth, slightly nodular
Intercellular canals		Absent	Absent	Absent	Absent	Absent	Absent	Absent
Ray width	Uniseriate	Uniseriate	Uniseriate	Uniseriate	Uniseriate, rarely partly biseriate	Uniseriate	Uniseriate	Uniseriate, rarely partly biseriate
Ray height	5-40	5-33	2-61	2-31	3-35	5-33	2-31	1-33
Helical thickening	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Tracheidal pit arrangement	Uni-biseriate, opposite	1-3 (-4), opposite	Uni-biseriate, opposite	1-2 (-3), opposite	1-2 (-3), opposite	1-3 (-4), opposite	1-2 (-3), opposite	1-3
Cross-field pitting	?	2-6	2-8	2-5	2-5	1-6	2-5	1-5
Ray cell end walls	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Ray cell horizontal walls	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Ray tracheids	Absent	Absent	Partly present	Absent	Absent	Absent	Absent	Absent

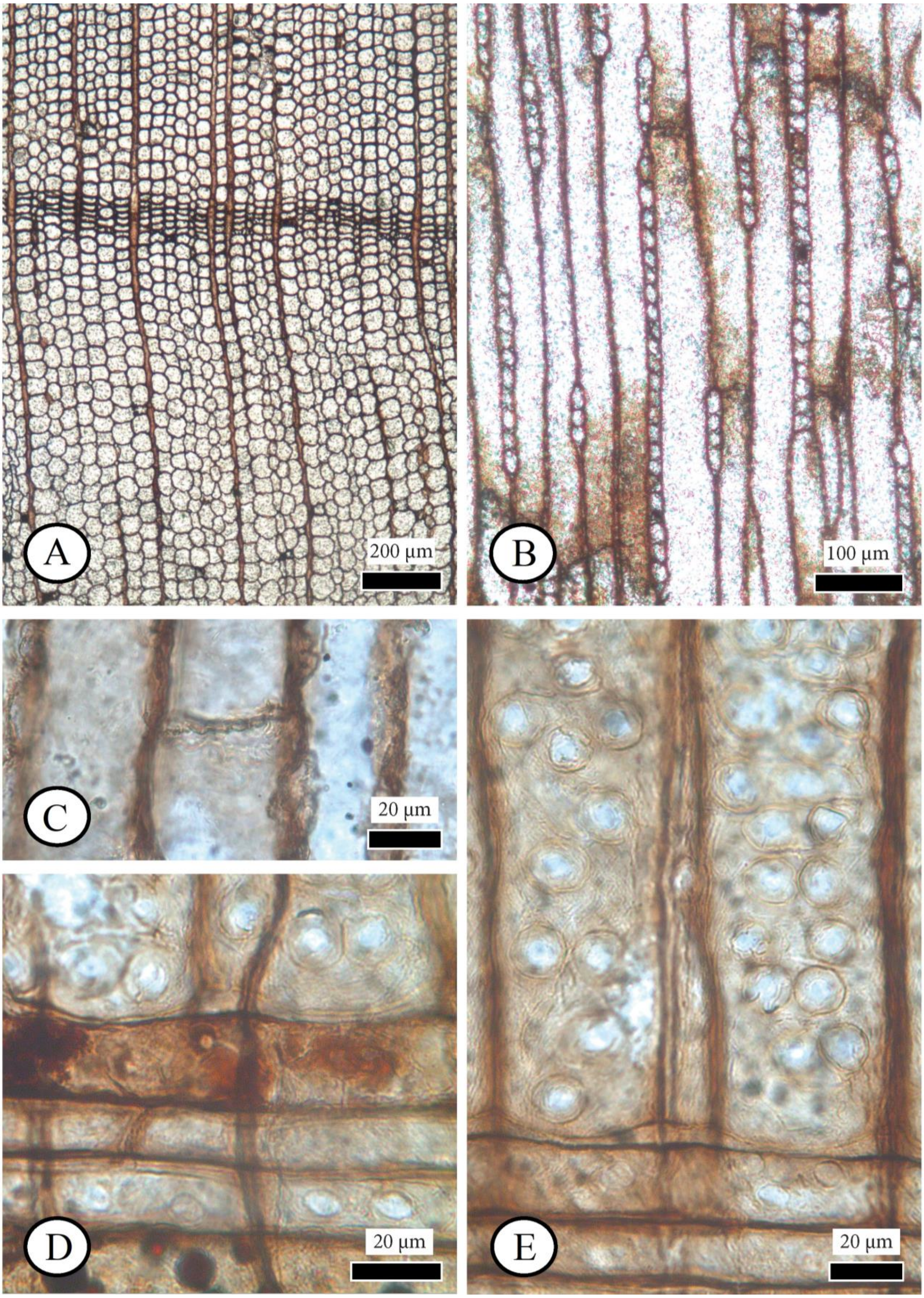

Figure 4. The thin sections of *Taxodioxylon gypsaceum*. A) Transversal section with axial parenchyma and without axial resin canals, B) Long uniseriate rays in tangential section, C) A slightly nodular end wall of axial parenchyma, D) Taxodioid type of cross-field pits, E) 2-3 seriate of pits on radial walls of tracheids.

Based on the recent discussion on the names of *Taxodioxylon* and *Sequoioxylon* (Blokhina et al., 2010; Tian et al., 2018), I prefer to use the name *Taxodioxylon*, as I used in my recent studies (Akkemik, 2019 and Akkemik et al., 2019a). The results showed that *T. gypsaceum* was identified from different time periods from Paleogene to Pliocene. It may be suggested that it was one of the most common fossil tree species in Cenozoic era of Turkey.

Until now, two *Sequoioxylon* species, *Sequoioxylon egemenii* (Özgüven-Ertan, 1971), and *S. gypsaceum* (now *Taxodioxylon gypsaceum*) (Özgüven-Ertan, 1981[1983]; Akkemik, 2019) were identified in Turkey. In *S.egemenii*, differently from *S. gypsaceum*, traumatic resin canals sometimes present and end walls of axial parenchyma predominantly smooth.

The identification showed that *Taxodioxylon gypsaceum* was the most common fossil species, and covered a huge area in Anatolia and its environs.

4.Discussion and Conclusion

The identified fossil species, *Glyptostroboxylon rudolphii*, is a typical element of swamp forests. Its modern representative, *Glyptostrobus pensilis* grows in the swamp and riparian conditions of Vietnam and South China (Eckenwalder 2009; Farjon 2010). This genus had different species and very wide areas in Miocene throughout Europe and Asia, but today restricted to very local swamp areas in China and Vietnam.

The identified fossil species, *Taxodioxylon gypsaceum*, is a member of riparian, well drained and warm to cool conditions. Its modern representative is mainly *Sequoia sempervirens* and grows in lowland riparian conditions of California shores generally below 300 m (Bannister and Neuner, 2001). This fossil species is the most common tree throughout Europe and Asia from Oligocene to Pliocene, and completely extinct from Europe and Asia in Pliocene.

This study and numerous palaeobotanical studies (e.g. Akgün et al. 2007; Akkiraz, 2011; Akkiraz et al., 2012; Velitzelos et al. 2014; Akkemik et al, 2016; Bouchal et al. 2016, 2017; Güner et al. 2017; Denk et al. 2017; Acarca Bayam et al. 2018) also suggested that swamp, riparian and warm-temperate conditions around the swamps and riparian areas were common in early Miocene to Pliocene in Turkey. Today in Turkey, riparian conditions are most common but swam conditions are very restricted.

The identified fossil species, *Cupressinoxylon pliocenica* from Gökçeada, where is an Aegean Island may indicate the presence of Mediterranean climate conditions. This fossil species was identified from the Pliocene time of north-central Anatolia for the first time, and this is the second wood of this fossil species. Denk et al. (2019) stated that "*There was a globally averaged climate curves (cooler Burdigalian, warmer Langhian) and it was not necessarily seen in local floras. Thus, tropical plant groups might have gone through bottlenecks prior to mid-Miocene warming.*" For that reason, *Cupressinoxylon* and the other swamp species might have been growth in different regions or times of the early Miocene.

This result may also suggest that *Cupressinoxylon pliocenica* growth not only in Pliocene but also in the early Miocene. Today, only one species, *Cupressus sempervirens*, grows through the Mediterranean basin, and the fossil species may be suggested as the potential ancestor of this modern species, thanks to the close similarities.

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