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Woods of a Miocene Petrified Forest near Ankara, Turkey

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Introduction

Little is known about the palaeoecology of Turkey during the Tertiary since fossiliferous localities in both Thrace (European Turkey) and Anatolia (the Asian part of Turkey) have received few palaeobotanical investigations. Those studies have focused predominantly on evidence from macrofossils (Özgüven, 1971; Sayadi, 1973; Eroskay & Aytuğ, 1982; Şanlı, 1982; Selmeier, 1990; Gemici et al., 1991; Dernbach et al., 1996; Akkemik et al. 2005) rather than microfossils (Şanlı, 1982; Batı, 1996; Kayseri and Akgül, 2007).

In Thrace, to the northwest of Istanbul, the upper Oligocene Ağacı Lignite Quarry has yielded relatively abundant Tertiary fossil materials, indicating that the
vegetation was diverse in that period. Petrified wood provides evidence for forests composed of Pinus, Taxus, Juniperus, Juglans, Quercus, Salix (Aytuğ and Şanlı, 1974), and Sequoiioxylon (Akkemik et al., 2005). Upper Oligocene wood from the Northern Thrace Basin has revealed the presence of Sequoiioxylon (S. egemeni) (Özgüven, 1971) and Sequoiadendron giganteum (Aras et al., 2003). Further evidence for a taxodiaceous element to the vegetation comes from fossil wood assemblages in Miocene deposits around Küçük Çekmece Lake (NW Turkey), which indicates the sustained presence of *Taxodium* in the vegetation along with *Taxus* and *Alnus* (Selmeier, 2001).

In west central Anatolia, middle Miocene sediments around Kütahya have yielded abundant macro and microfossils. Over 70 species have been described from this region. Whereas *Glyptostrobus europeaus* was abundant in swamps, *Pinus* and *Quercus* formed a forest around the lake (Gemici et al., 1991). To the west, Suss and Velitzelos (1994a, 1994b) and Velitzelos (1996, 1997) described a petrified forest on Lesvos (Greece), which was composed of *Taxodiioxylon*, *Pinoxylon*, *Quercus*, and *Alnus*. Studies of Miocene fossil wood from the Ergene Basin of Thrace provide evidence for the presence of *Carya* and *Juglans* (Eroskay and Aytuğ, 1982). Kayseri and Akgün (2007) identified vegetation composed of relatively abundant (5%-14%) *Pinus* (silvestris-type), *Taxodiaceae*, *Nymphaeaceae*, *Myricaceae*, *Ulmus*, *Quercus*, *Cyrillaceae*, and *Chenopodiaceae* along with rarer elements (1%-4%) such as *Engelhardtia*, *Juglandaceae*, *Platycarya*, *Carya*, *Salix*, *Quercus* (henrici-type), *Fagaceae*, *Castanea*, *Oleaceae*, *Asteraceae* (Tubulifloreae-type), *Gleichenia*, *Sphagnaceae*, *Podocarpus*, *Cupressaceae*, *Seqouia*, *Ephedraceae*, *Sparganiaceae*, *Tilia*, *Alnus*. Cycadaceae and Umbelliferae have also been identified from Miocene lignites of Çorum and Sivas provinces, located in the northern part of inner Anatolia (Kayseri and Akgül, 2007).

Further insights into the Late Tertiary palaeoecology can be gleaned from the discovery of 2 new petrified forests that have recently been uncovered (Ulrich Dernbach; personal communication). The forest studied in this work is located 85 km northeast of Ankara, 10 km from the centre of Çamlıdere, and just south of the village of Pelitçik. The site is small, measuring ~400 m × ~250 m, and lies at 40°26’N 32°24’E, and at an altitude of 1100 m a.s.l. It is partially surrounded, on its southern and eastern sides, by the Çamlıdere Dam Lake (Figure 1). Numerous petrified trunks and stem material can be found lying on the surface (Figure 2).

During the Miocene, this forest grew on the Galatia volcanic mass (Yılmaz et al., 1981) at a palaeolatitude of 39°N (Meulenkamp and Sissingh, 2003). The prevailing climate was initially sub-tropical but gradually became more arid (Tankut et al., 1995). Tankut and co-workers studying the surrounding volcanics of the Çamlıdere fossil forest proposed an age range of 18.2-16.9 million years (Tankut et al., 1995).

**Material and Methods**

Silicified wood material, collected from the site, represent stem parts that had been felled by a volcanic eruption. They were all situated in close proximity to one another with the 2 specimens described herein lying next to each other. The preservation of the material collected was variable with some specimens being well-preserved, and others less so.
Two specimens (CAM1-01 and CAM2-01) are representative of the 2 taxa (CAM1 and CAM2) present in this assemblage. They were thin sectioned along 3 planes, transverse section (TS), radial longitudinal section (RLS), and tangential longitudinal section (TLS), and were studied using a transmitted light microscope. Descriptions follow the terminology of the IAWA Committee (2004) wherever possible. Identifications were made following reference to well-described extant wood, preferably voucher specimens, housed in the Forest Botany Department, Faculty of Forestry, Istanbul University, and the University Utrecht Branch of the National Herbarium of the Netherlands along with comparisons with the literature (e.g. Jacquiot, 1955; Greguss, 1955; Greguss, 1967; Eliçin, 1977; Barefoot and Hankins, 1982; Fahn et al., 1986; Schweingruber, 1990, 1993; Tidwell, 1998). The fossil material described has been referred, rather than assigned, to modern taxa at this stage. More specimens need to be sectioned to validate identification as fossil conifer wood morphospecies are usually ill-defined (cf. Wheeler and Baas, 1998; Falcon-Lang and Cantrill, 2000) and both quantitative and qualitative anatomical characters can vary greatly throughout one tree.
Results

The descriptions are based on the anatomical characteristics of 2 pieces of silicified wood that represent the 2 taxa (CAM Types 1 and 2) present at this site. Their anatomical characters are summarised in Table 1 and illustrated in Figures 3 and 4.

**Cupressaceae**

*Taxodium* sp.

Representative specimen: CAM1-01

This specimen measures 8 cm diameter by 11 cm in length and displays ~30 growth rings.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>CAM Type 1</th>
<th>CAM Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen</td>
<td>CAM1-01</td>
<td>CAM2-01</td>
</tr>
<tr>
<td>Location</td>
<td>from region within the site of abundant fallen material</td>
<td>from the same area with CAM1-01</td>
</tr>
<tr>
<td>Preservation</td>
<td>silicified with good contrast locally</td>
<td>silicified with locally good contrast</td>
</tr>
</tbody>
</table>

**TS:**

- **Growth ring boundary**: indistinct, distinct
- **EW to LW transition**: gradual with narrow zone (1-2 rows) of LW, abrupt with wide zone (>10 rows) of LW.
- **Resin ducts**: absent, absent
- **Axial parenchyma**: solitary and rare, diffuse to tangentially zonate
- **Intercellular canals**: absent, absent

**TLS:**

- **Ray width (cells)**: uniseriate (part biseriate), uniseriate
- **Ray height (cells)**: 1-4(-10), 5-33
- **Helical thickenings**: absent, absent
- **Axial parenchyma end walls**: none observed, seemingly smooth

**RLS:**

- **Tracheidal pit arrangement**: 1-2(3), opposite, 1-3(4), opposite
- **Cross field pitting**: taxodioid horizontally, randomly arranged, cupressoid-taxodioid, horizontally arranged
- **No. pits per cross field**: 2-7, 1-6
- **Indentures**: absent, absent
- **Ray cells walls: end** smooth, smooth
  - **horizontal** smooth, smooth
- **Ray tracheids**: absent, absent

Table 1. Wood features and identifications of representatives of the 2 taxa present (CAM Type1 and CAM Type 2). LW: Latewood, EW: Earlywood, TS: Transversal Section, TLS: Tangential Section, RLS: Radial Section
Figure 3. CAM01-01 ‘Taxodium’. 1. TS showing narrow growth rings with indistinct boundaries. Scale bar 1 mm. 2. Narrow latewood zone and 3 vascular traces, TS; scale bar 1 mm. 3. Vascular trace running at ~45° to the main axis showing vascular strand (vs), TS; scale bar 1 mm. 4. Vascular trace running parallel to the main axis showing vascular strand and surrounding parenchymatous cells, TS; scale bar 250 μm. 5. RLS of 2 short rays; scale bar, 100 μm. 6. TLS of short rays; scale bar, 250 μm. 7. Vascular strand in TLS showing spiral thickening; scale bar, 25 μm. 8. RLS showing biseriate and opposite tracheidal pitting; scale bar, 100 μm. 9. RLS showing cross field pitting; scale bar, 100 μm.
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Figure 4. CAM02-01 ‘Sequoia’. 1 and 2. TS showing wide growth rings with distinct boundaries; scale bar, 1 mm. 3. TS showing wide zone of thick walled late wood tracheids with reduced radial diameters; scale bar 250 μm. 4. Rays and axial parenchyma, RLS; scale bar 100 μm. 5. Biseriate and triseriate tracheidal pitting, RLS; scale bar 100 μm. 6. Horizontally aligned cross field pits, RLS; scale bar 50 μm. 7. Axial parenchyma, RLS; scale bar 100 μm. 8. Short, part-biseriate rays, TLS; scale bar 100 μm. 9. TLS showing uniseriate ray size and distribution scale bar 250 μm.
Transverse section: Growth ring boundaries indistinct (Figure 3.1). Transition from earlywood to latewood gradual with narrow zone (1-3, rarely more) of thin walled, latewood tracheids (Figure 3.1-3.2). Axial parenchyma diffuse and rare. Resin canals absent. About 20 vascular traces (probably leaf traces) present (Figure 3.1-3.4), in no obvious arrangement, with a central vascular strand (Figure 3.2-3.4), surrounded by parenchymatous tissue, running parallel to the longitudinal axis (Figure 3.2-3.4) or at an angle (e.g. 45°; Figure 3.2-3.3) or running perpendicular to the axis (not shown) and passing through at least 2 growth rings.

Tangential section: Rays uniseriate and very low (1-4 cells) to rarely moderate (up to 10 cells) in height (Figure 3.6). Tracheidal pitting rare, uniseriate and non-contiguous or biseriate and contiguous. Helical thickening absent. Vascular traces composed of elongated cells with wall ornamentation and/or spiral thickening (Figure 3.7).

Radial section: Tracheid pitting generally uniseriate or biseriate (rarely triseriate) and opposite (Figure 3.8). Rays low (Figure 3.5). Three to seven seemingly taxodioid pits per cross field both horizontally and randomly (Figure 3.9). Ray tracheids absent. Ray parenchyma walls smooth.

Cupressaceae

‘Sequoia’ sp.

Representative specimen: CAM2-01

This specimen measures 5 cm diameter by 14 cm in length and displays ~20 growth rings.

Transverse section: Growth ring boundaries distinct (Figure 4.1-4.3). Transition from earlywood to latewood abrupt with a thick zone (>10 cells) of latewood tracheids with reduced radial diameters (Figure 4.1-4.3). Axial parenchyma diffuse to tangentially zonate (Figure 4.1, 4.3). Resin canals absent. Vascular traces absent. Crushing of the early wood tracheids present in some growth rings.

Tangential section: Rays uniseriate and (low) medium to high (5-33 cells) (Figure 4.9), rarely part-biseriate (Figure 4.8). Tracheidal pitting rare, non-contiguous uniseriate, and loosely biseriate and opposite. Helical thickening absent. Axial parenchyma in strands with brown contents present in each cell and smooth horizontal end walls.

Radial section: Tracheid pitting generally uniseriate in the latewood and bi- and triseriate, and opposite in the earlywood (Figure 4.5). Ray (low) medium to high (Figure 4.4). One to six cupressoid-taxodioid pits per cross field, horizontally arranged (Figure 4.6). Ray tracheids absent. Ray parenchyma walls smooth. Axial parenchyma cells with (brown) contents (Figure 4.4, 4.7).

The 2 specimens are characterised by the lack of resin ducts, generally uniseriate rays, uniseriate and multiseriate opposite tracheidal pitting, axial parenchyma with smooth end walls (when observable), taxodioid-cupressoid cross field pitting, smooth tangential walls of the ray cells, which are characteristic of the taxodiaceous genera of the Cupressaceae. Taxodiaceous woods generally lack true resin canals, lack indentures in the horizontal walls of the ray parenchyma, and have taxodioid type cross-field pits (Visscher et al. 2003) – a character combination also observed in the fossil CAM1-01 specimens. These CAM1 specimens can be distinguished from the CAM2 specimens, represented by CAM2-01 by the presence of distinct growth rings with abrupt transition from late- to earlywood, seemingly tangentially zonate parenchyma and the presence of high rays, which are absent in CAM1-01, and the presence of vascular strands in CAM1-01. In comparisons with taxodiaceous woods, CAM1-01 exhibits closest similarity to modern Taxodium and CAM2-01 to modern Sequoia and have thus been referred to these modern genera.

Discussion

Today Turkey is a meeting point of 3 phytogeographical regions, namely the Euro-Siberian, Mediterranean, and Irano-Turanian regions, which reflects differences in climate, geology, topography, soils, and floristic diversity (Çolak and Rotherham, 2006). The Euro-Siberian region is characterised by deciduous forests growing under a relatively humid climate. The Mediterranean vegetation is predominantly sclerophyllous with maquis dominated by evergreen shrubs covering much of the land below 1200 m that gives way to coniferous forests at higher elevations. The vegetation of the Irano-Turanian phytogeographic region is less well known; however, over the Anatolia plateau, oak scrub dominates, giving way to pine forests in the north, west, and south. Today the native forests found in this region are composed of Quercus pubescens and Juniperus at lower elevations (700-1000 m), Pinus nigra at mid-elevations (1000-1400 m), and Pinus sylvestris and Abies
bornmuelleriana at elevations above 1400 m - a taxa combination commonly found in other arid parts of Turkey. The prevailing climate is continental with 565 mm annual precipitation and a mean annual temperature of 9.9 °C. According to the Thornthwaite Method (Çepel, 1988), the climate is generally humid with a summer dry period and a very cold winter season.

The Petrified Forest of Çamlıdere of west Central Anatolia lay at a palaeolatitude of 39°N during the Lower Miocene (Meulenkamp and Sissingh, 2003). Bruch et al. (2006) describes a mean annual temperature of between 16 and 17 °C with a cold month mean of 5-7 °C and a warm month mean of 26-27 °C, and a total annual precipitation of 500-1000 mm. Although these climate parameters can not be applied directly to Turkey, as it lies outside the area of data cover (Bruch et al., 2006), it can provide a general idea of conditions in this part of Europe during the later Miocene.

Taxodiaceous conifers (Cupressaceae) were an important component of the vegetation of this region for several million years during the Palaeogene. Evidence for this comes from deposits ranging from Eocene to late Miocene in age (Özgüven, 1971; Gemici et al., 1991; Suss and Velitzelos 1994a, 1994b; Kayacik et al., 1995; Batı, 1996; Selmeier 2001; Aras et al., 2003; Akkemik et al., 2005; Kayseri and Akgün, 2007). This is not surprising since both Taxodium and Sequoia have a long fossil history and were common elements in the forests of Europe, Asia, and America forming a subcosmopolitan distribution up to about 5 million years ago. Interestingly, the monospecific Sequoia, which today is restricted to a narrow range along the Pacific coast, is one of the few conifers that can vegetatively reproduce. Following a major environmental disturbance (e.g. fire), regeneration can occur from the stump, or even roots, and thus allowing it to survive and maintain dominance in an ecologically dynamic habitat. This ability may explain the dominance of Sequoia in the volcanic environment of Çamlıdere. Taxodium, restricted to the southern part of North America, occupies flood prone areas and its presence in the Miocene Petrified Forest of Çamlıdere may indicate that inundated regions were present in an otherwise Sequoia-dominated forest.

Conclusion

This study aims to highlight the excellent preservation of a newly discovered petrified forest from Çamlıdere in Central Anatolia (Turkey). The trees are preserved as a result of volcanic activity that took place during the lower Miocene. Preliminary studies indicate that the forest was composed predominantly of Taxodium with few Sequoias. Juniperus has also been found from the same area (Akkemik et al., 2008) along with Cupressus and more evidence for Juniperus from neighbouring areas (Ulrich Dernbach: personal communication). With further studies of the site and fossils found in the region, both here and at other localities around Ankara, a more complete reconstruction of ecology of this region will be possible.

Acknowledgement

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