Late Oligocene–Early Miocene palaeoecology based on pollen data from the Kalkım-Gönen Basin (Northwest Turkey)

Sariye Duygu Üçbaş Durak* and Mehmet Serkan Akkiraz

Department of Geological Engineering, Dumlupınar University, 43100 Kütahya, Turkey

(Received 26 January 2016; final version received 28 April 2016)

Radiometric and palynological data of the Upper Oligocene–Lower Miocene Soma Formation from the Kalkım-Gönen Basin yield new results related to age and palynological contents. In this study, Upper Oligocene strata from the Danışment and Linfa areas and Lower Miocene strata from the Bengilere area were sampled palynologically and for radiometric dating. The Danışment assemblage, which is older than the Linfa assemblages, mainly contains coniferous and evergreen to deciduous mixed mesophytic forest elements. Relatively high quantities of the altitudinal plants Picea and Abies, indicate a cooler palaeoclimate. The Linfa associations mainly include coniferous and riparian elements. Pollen of the riparian plant Alnus and Taxodiaceae indicative for the swamp forest community was predominant, probably as a result of a high lake level. There is a hiatus during the Oligocene–Miocene transition, probably showing a non-depositional phase and sea-level fall indicating the Mi-1 glaciation event. Higher in the sequence, the Aquitanian Bengiler sediments include high amounts of coniferous forest elements as well as components indicative for the evergreen and deciduous mesophytic forest and also riparian forest and swamp forest. Due to presence of thermophilous taxa Reveesia, Mastixiaceae and Arecales, a warm and humid palaeoclimate is inferred according to quantitative analyses using the Coexistence Approach.

Keywords: Kalkım-Gönen Basin; Oligo–Miocene; palaeoclimate; radiometric dating; palynology

1. Introduction

North-western Anatolia has richly explored lignite and natural gas potential. In particular the Thrace Basin is well known since it mostly includes the Oligocene lignite-bearing deposits (e.g. Akgün et al., 2013; Akyol, 1971; Batı, 1996; Bozcu et al., 2015; Demirtaş, Bozcu, Koşun, & Akkiraz, 2015; Ediger, Batı, & Alișan, 1990; Görür & Okay, 1996; İslamoğlu et al., 2010; Less, Özcan, & Okay, 2011; Özcan et al., 2010; Sakınç, Yaltırak, & Oktay, 1999; Siyako & Huvaz, 2007, Figure 1). Geological studies indicated that the spread of Oligocene coaly sequences was thought to be only in the Thrace Basin. However, recent studies emphasised that these coaly Oligocene sequences reach to the northern part of the Biga Peninsula, south of the Thrace Basin (Akgün et al., 2013; İslamoğlu et al., 2010, Figure 1). Apart from the Thrace Basin, four lignite-bearing basins with a different sedimentary history may be distinguished on the Biga Peninsula, such as the Gökçeada Basin, the Lapseki-Biga Basin, the Çan Basin and the Kalkım-Gönen Basin (Figure 1). They represent individual NNE–SSW-trending basins of Oligocene to Miocene age and are mostly of lacustrine origin. Some parts of the Gökçeada, Thrace and Lapseki-Biga basins show some marine influences (Akgün et al., 2013; İslamoğlu et al., 2010). Previous data on fossils from the area and surroundings suggest sea-level decline from the late Rupelian to early Chattian (Akgün et al., 2013; Bozukov, Utescher, & Ivanov, 2009; İslamoğlu et al., 2010). Recent palynological studies, conducted on the Rupelian deposits, indicate that the sedimentation took place in a coastal environment marked by the presence of mangrove plants such as Avicennia, Pelliciera, Nypa and Acrostichum aurorum, dinoflagellate cysts and microforaminiferal linings (Akgün et al., 2013). Terrestrial conditions appeared in the Chattian with a dense forest being dominant (Akgün et al., 2013; İslamoğlu et al., 2010).

The filling of these basins mostly consists of clastic and pyroclastic rocks, including some lignites. Even the Oligocene (late Rupelian) coal exposures of the Gökçeada Basin, located on the western side of the Biga Peninsula, (Figure 1) may be correlated with the Thrace Basin since the palynomorph assemblages are more or less comparable. Both basins included high percentages of rotan palm Calamus (morpho-species Dicollopolis kockelii) peaking during the Chattian (Late Oligocene) as indicated by Batı (1996), Ediger et al. (1990), Akgün et al. (2013) and Demirtaş et al. (2015).

The coaly deposits of the Lapseki-Biga Basin outcrop well in a road-cut between Lapseki and Biga with the coordinates of 40°23′46″N, 26°50′31″E and 65 m a.s.l. (Akgün et al., 2013) shown in Figure 1. They were dated as Rupelian, according to mollusc fauna and palynological assemblage (Şevketiye palynoflora) (Akgün et al., 2013). The palaeoflora consists mainly of Lygodium, Castanea-Castanopsis, Engelhardia, Lepidocaryoidae,
Quercus, Juglandaceae and Pelliciera. This assemblage may be correlated with the palynological assemblage of the Thrace Basin since both include marine paly- nomorphs such as Pelliciera, Nypa and undifferentiated dinocysts. On the Biga Peninsula, the lignite-bearing terrestrial sediments expose well in the south-east of the Thrace Basin around Çan (called as the Çan Basin) (Figure 1). The deposits of the Çan Basin accumulated during the Early–Middle Miocene in a lacustrine environment (Bozcu et al., 2015; Ediger, 1990; Siyako, Bürkan, & Okay, 1989). Here, an initial palynological investigation was made by Ediger (1990) who examined 27 samples from the Çanakkale and Gönen areas, mainly determined the morpho-species Leiotrilites microadrenensis, Baculatisporites primarius, Laevigatosporites haardti, Pityosporites sp., Inaperturopollenites dubius, I. hiatus, I. polyformosus and I. emmaensis, and dated the sequence as late Burdigalian–middle Serravallian. This age was confirmed by radiometric data obtained from the volcanic rocks around Çanakkale, Balikesir and Bandırma (Ercan et al., 1990; Genç, 1998; Selim, Tüysüz, & Barka, 2006) (about 15–20 ma). Recent palynological studies indicated further species diversity (Bozcu et al., 2015). The main vegetation types include elements of coniferous forest, evergreen and deciduous mixed forest, as well as of riparian and swamp forests.

Figure 1. Geological map of northwest Turkey. (a) Gökçeada Basin; (b) Lapseki-Biga Basin; (c) Çan Basin; (d) Kalkm-Gönen Basin (from Okay, Özcan, Cavazza, Okay, & Less, 2010).
the Soma Formation (Akçay, Dönmez, Ilgar, Duru, & Pehlivan, 2008; Duru, Pehlivan, Ilgar, Dönmez, & Akçay, 2007; Pehlivan et al., 2007). So we adopted this name for this study as well. According to many authors the volcanic activity occurred simultaneously with the sedimentation (Duru et al., 2007; Genç, 1998; Pehlivan et al., 2007).

This study presents first radiometric datings from surface sections of open pit mines of the Danişment and Linfa areas, a subsurface borehole in the Bengiler area, as well as palaeoecological characteristics based on the palynology of the Late Oligocene–Early Miocene Kalkım-Gönen Basin (Figure 2).

2. Stratigraphy

Pre-Cenozoic rocks crop out in NE–SW trending tectonic belts and comprise the İzmir-Ankara, Sakarya, Ezine zones and related ophiolitic rocks (Figure 2) (Akçay et al., 2008; Duru et al., 2007; Okay, Siyako, & Bürkan, 1990, 1991; Pehlivan et al., 2007). These basement rocks expose well between towns Danişment, Bengiler and Tütüncü (Figure 2). Upper Cretaceous and Oligocene deposits were largely eroded at the end of the Oligocene uplift (Okay et al., 1990). Cenozoic volcaniclastic deposits unconformably overlie these basement rocks, and constitute from bottom to top the Hallaçlar Volcanics, Sapçı Volcanics, Soma Formation, Ilyasbaşı Formation and Bayramiç Formation (Akçay et al., 2008; Duru et al., 2007; Pehlivan et al., 2007; Üçbaş, 2013). During the Oligo-Miocene, widespread and intense calc-alkaline magmatism prevailed. Huge amounts of andesite, dacite, rhyolite and acidic tuffs were deposited during the Middle Miocene (Ercan, Dinçel, & Günay, 1979). Pleistocene–Holocene alluvial deposits unconformably rest on these previous units (Figure 2).

The Soma Formation, constituting the main subject of this study, includes marl, mudstone, siltstone, agglomerate, tuff, tuffite, sandstone, limestone and lignite...
deposited in a lacustrine environment. These sediments outcrop well around Sebepli and Koyunerı (Figure 2). In this study, partial measured sections were taken and palynologically sampled from the Danişment and Linfa locations and Bengiler well (Figure 3). Samples were also collected from the volcano-clastic levels to assign a precise age using radiometric analyses. Detailed lithological properties of the lacustrine sections are presented below:

2.1. **DANİŞMENT SECTION (COORD: 39°52'13.19"N/27°37'58.56"E)**

In this locality, the sediments crop out in a road cut, and consist of incompetent whitish tuffs, tuffites, lignites and marl (Figure 3). The total thickness of the section is around 4 m including a lignite level of about 80 cm in thickness. The 40Ar/39Ar isotope data from the sample D-1 indicate 26.42 ± 0.13 Ma (Late Oligocene; Chattian) corresponding to the MP-26 mammal zone (Figure 3).

2.2. **Linfa section (Coord: 39°56'58.82"N/27°37'51.48"E)**

This section is located around 14-km north-east to the Danişment section (Figure 2). The thickness of this section is around 85 m (Figure 3). It starts with a gypsum-bearing marl of about 40-m thickness, and succeeded by a lignite seam (about 17 m thick) and greyish organic shale (about 20-m thick) which includes syn-sedimentary gypsum layers and poorly preserved leaf fossils. The amounts of gypsum in the lignites decrease from bottom to top of the sequence. Volcano-clastic deposits with lignite occur at the top of the sequence, attaining a thickness of about 7 m in total (Figure 3). Volcanic sample (Li-1) yields an 40Ar/39Ar age of 25.94 ± 0.16 Ma (Late Oligocene; Chattian) corresponding to the upper part of the MP-26 mammal zone.

2.3. **Bengiler section (Coord: 39°44'30.17"N/27°28'55.21"E)**

The youngest among the studied successions is the Bengiler sequence, dated as 22.26 ± 0.06 Ma (mid-

![Figure 3. Lithological aspects of the Danişment and Linfa sections and Bengiler well.](image-url)
Aquitanian; MN-1 mammal zone) corresponding to upper part of the sequence (Figure 3). Here, a borehole, with a total thickness of up to 167 m, was already drilled by a private company, Ege Mining, close to the village of Bengiler (Figure 2). The sequence of the profile starts with a thin agglomerate level, which is overlain by a lignite level of about 15 m in thickness (Figure 3). Thick volcanics, volcano-clastics and marls with lignites occur in higher stratigraphical levels. Leaf/plant fragments also occur within the volcanic levels.

3. Material and methods

3.1. Material

In this study, a total of 76 samples were collected from the following localities: 21 from the Linfa section, 4 from the Danisment section and 51 from the Bengiler drill core. With respect to palynomorph content 28 of 76 samples were productive (Figure 3). In order to obtain precise ages, three ash samples from volcano-clastic sediments (D-1, Li-1 and E-1) were collected as well and analysed using \(^{40}\text{Ar}/^{39}\text{Ar}\) radiometric dating, carried out by the Nevada Isotope Geochronology Laboratory (Figure 3). As regards several index minerals such as sanidine, plagioclase, biotite and amphibole, we obtained radiometric ages for the Linfa, Danisment and Bengiler deposits.

3.2. Methods

3.2.1. Preparation methods

The standard palynological processing (HCl, HF, HNO\(_3\) + KClO\(_3\) and KOH) was applied to the pollen samples to remove the carbonates and silicates, restore losing oxygen and remove materials sticking on spore and pollen. The organic residues were sieved by the use of an 8 \(\mu\)m mesh screen and 1–4 slides were prepared for the microscope examinations. Counting results were converted to relative pollen percentages using the ‘TILIA’ developed by Grimm (1994). Synthetic pollen diagrams for the sections were prepared according to palaeoecological criteria of selected taxa such as mega-thermic, meso-thermic, meso-micro-thermic and microthermic (Ivanov et al., 2012; Jiménez-Moreno et al., 2005; Suc, 1984) (Table 1 and Figure 7). Representative sporomorphs are illustrated in Plates 1 and 2, using an Olympus BX51 microscope and Dewinter Caliper Pro 4.1 camera at a 400×. At least 200 sporomorph grains for per sample were counted.

3.2.2. Methods for palaeoclimate reconstruction

Quantitative palaeoclimate data are reconstructed using the ‘Coexistence Approach’ method developed by Mosbrugger and Utescher (1997) and Utescher et al. (2014). This technique is based on the assumption that climate conditions of a fossil flora corresponds, with the climatic range in which most nearest living relative(s) (NLRs) known for the fossil assemblage can coexist. A computer-aided program, CLIMSTAT, was used to obtain quantitative palaeoclimate data. The quantitative data of mean annual temperature (MAT), mean temperature of the warmest month (WMT), mean temperature of the coldest month (CMT), mean annual precipitation (MAP), precipitation of the wettest month (HMP), precipitation of the driest month (LMP) and precipitation of the warmest month (WMP) were calculated. According to the original description of the method the significance of the results obtained depends on the number of taxa considered in the analysis. Therefore, samples with less than 10 taxa with known NLRs and corresponding climate data-sets were excluded from the analysis (Mosbrugger & Utescher, 1997; Utescher et al., 2014).

4. Palynological data

4.1. Chattian (Late Oligocene)

4.1.1. Pollen results from Danisment

The Danisment pollen flora determined from all samples includes 31 taxa, 29 belong to pollen and 2 belong to spores (Figure 4(a)). The samples are dominated coniferous and evergreen to deciduous mixed mesophytic forest taxa, typically characterised by undifferentiated Pinaceae (30% on average), Picea (7% on average), Fagus (5% on average) and Carpinus (5% on average). taxa such as Cupressaceae, Pinus haploxylon type, Abies, Keteleeria, Cathaya, Cedrus and Podocarpus are represented by minor amounts. Diversity and percentages of spores are in negligible quantities and include Schizaceae and Polypodiaceae/Thelypteridaceae (<1%). There is a striking increase in abundance of the deciduous Castanea type, reaching a maximum of 14.8% at sample 09/44. On the other hand, the percentages of the deciduous plants Carpinus and Fagus gradually decrease along the section (Figure 4(a)). Plants such as Engelhardia and Araliaceae are extremely rare or absent. The swamp forest is represented by low percentages of Taxodiaceae, Nyssa and Myrica. It is also clear that evergreen Quercus stepwise decreases from the lower to the upper part (change between 1.2 and 5.4%). The values of Quercus spp. increase in the same direction. Riparian plants such as Alnus, Ulmus, Pterocarya, Carya and Salix occur in low percentages (Figure 4(a)).

4.1.2. Pollen results from Linfa

Five of 21 samples collected from the top of the sequence were investigated for palynological examinations (Figure 4(b)). We identified 43 sporomorph taxa in total, belonging to 17 families, 21 genera and 3 species. Counting results indicate that the amounts of coniferous and riparian plants occur in high quantities. The abundance of evergreen and deciduous mixed mesophytic forest elements is less important. Percentages of spores,
swamp forest taxa, aquatics and herbs are in negligible quantities (Figure 4(b)). The palynological assemblages may be divided into two local pollen phases according to quantitative changes in pollen percentages.

| Table 1. Palaeoecologic characteristics of taxa recorded from all sections. |
|---------------------------------------------------------------|
| **Mega-mesothermic elements**                                  |
| Mastixiaceae                                                   | x |
| Araliaceae                                                     | x |
| Areceae                                                        | x |
| Cyrtllaceae-Clethraceae                                        | x |
| Engelhardia                                                    | x |
| Magnolia                                                       | x |
| Myrica type                                                    | x |
| Reevesia                                                       | x |
| Sapotaceae                                                     | x |
| **Mesothermic elements**                                       |
| Acer                                                           | x |
| Alnus                                                          | x |
| Betula                                                         | x |
| Carraea                                                        | x |
| Carpinus                                                       | x |
| Fagus                                                          | x |
| Castanea type                                                  | x |
| Hedera                                                         | x |
| Ilex                                                           | x |
| Juglans                                                        | x |
| Nyssa                                                          | x |
| Oleaceae                                                       | x |
| Ostrya                                                         | x |
| Platanus/Salix                                                 | x |
| Pterocarya                                                     | x |
| deciduous Quercus                                              | x |
| Ulmus                                                          | x |
| Zelkova                                                        | x |
| Liriodendron                                                   | x |
| **Meso-microthermic elements**                                 |
| Cedrus                                                         | x |
| Sciadpitopollenites                                            | x |
| Keteleeria                                                     | x |
| **Microthermic elements**                                      |
| Abies                                                          | x |
| Picea                                                          | x |
| Evergreen Quercus                                              | x |
| Pinus, inderteminated Pinaceae, Podocarpaceae                  | x |
| Cathaya                                                        | x |
| Cupressaceae                                                   | x |
| Xerophyte plants                                               |
| Phillyrea                                                       | x |
| Rhus                                                           | x |
| **Herbs**                                                      |
| Asteraceae                                                     | x |
| Brassicaceae                                                   | x |
| Caryophyllaceae                                                | x |
| Chenopodiaceae                                                 | x |
| Ericaceae                                                      | x |
| Ephedra                                                        | x |
| Poaceae                                                        | x |
| Sparganiaceae                                                  | x |
| **Algae**                                                      |
| Botryococcus                                                   | x |

4.1.2.1. Local pollen zone Li-1 (83.10–83.50 m of the measured section; samples 09/66–68). This zone is marked by predominance of riparian plants, principally *Alnus* (30% on average) and *Salix* (16% at sample 09/
Figure 4. Pollen diagrams indicating the percentages for each sample. (a) Danişment pollen flora. (b) Lüleba pollen flora.
66) (Figure 4(b)), with additional members of *Ulmus*, *Ostrya*, *Zelkova* and *Carya* in minor quantities. The amounts of *Salix* diminish from the lower part to the top of the zone (Figure 4(b)). The *Castanea* type attains highest value at the lower part of the zone (10.8% at sample 09/67), and decreases throughout its upper part. The percentages of undifferentiated Pinaceae range from 6.6 to 15.6%. Moreover, *Engelhardia* (1–5.2%), evergreen *Quercus* (2.6–5.8%), *Quercus* spp., (0.4–14.8%), *Taxodiaceae* (3.8% on average), *Oleaceae* (0.2–2.3%) and *Cyrillaceae*–*Clethraceae* (0.2–2.1%) are reported. *Myrica*, *Sapotaceae*, *Araliaceae*, *Fagaceae* and *Monoleio-trites minimus* (unknown botanical affinity) are represented by values of less than 1%.

4.1.2.2. Local pollen Li-2 (83.50–84.05 m of the measured section; samples 09/69–70). This zone is characterised by higher mean values of *Alnus* (about 20%), *Cupressaceae* (about 16%), undifferentiated Pinaceae (about 9%), evergreen *Quercus* (about 8%) and *Taxodiaceae* (about 5%). Here *Taxodiaceae* slightly increase up to 9% at sample 09/70. The riparian plant *Zelkova* appears here, represented by values from 1.8 to 4.2%, with minor quantities of *Ulmus* and *Carya*. The amounts of *Cyrillaceae*–*Clethraceae* and *Castanea* type diminish here (<1%). Herbaceous plants belonging to the Chenopodiaceae appear in negligible quantities (Figure 4(b)).

4.2. Aquitanian (Early Miocene)

4.2.1. Pollen results from Bengiler

Nineteen of 50 palynological samples yielded a considerable amount of diverse and well preserved palynomorphs. The other samples were either bereft of pollen or had a meagre pollen concentration. We identified 54 sporomorph taxa in total that belong to 20 families, 29 genera and 1 species (Figure 5). Spores such as *Osmunda* and *Polypodiaceae*/*Thelypteridaceae* from the coaly samples from the lower and upper parts of the core were common (Figure 5). However, they occur in small quantities or even are absent from clayey and volcanic levels in the middle part of the core. Undifferentiated Pinaceae and *Cupressaceae* (coniferous forest), *Castanea* type, evergreen *Quercus* and *Quercus* spp., (evergreen and deciduous mesophytic forest), *Alnus* (riparian forest) and *Taxodiaceae* (swamp forest) frequently occur along the sequence. Three different zones may be distinguished on the basis of sporomorph percentages (Figure 5).

4.2.1.1. Local pollen B-1 (149.75–164.60 m of the core; samples 09/195–224). This pollen zone from the lignite samples at the base of the core is recognised by an augmentation of spores such as *Osmunda* (12% on average) and *Polypodiaceae*/*Thelypteridaceae* (6% on average), conifers such as undifferentiated Pinaceae (15% on average), an element of the evergreen and
Figure 6. Coexistence intervals obtained from the palynoﬂoras of the Danișment section (a), Linfa section (b) and Bengiler well (c).
deciduous mixed forest such as *Quercus* spp., (10% on average) and the riparian plant *Alnus* (13% on average) (Figure 5). Among the coniferous forest elements, other conifers such as Cupressaceae are also important, and exhibit some fluctuations along the zone. *Castanea* type and *Quercus* spp. are the most abundant in the evergreen and deciduous mixed mesophytic forest assemblage which also includes lower amounts of *Engelhardia*, *Cyrillaceae–Clethraceae* and evergreen *Quercus* showing remarkable oscillations. The percentages of evergreen

*Quercus* continue to increase slightly in the upper part of the zone and attain a maximum value of 19.8% at 150.8 m (sample 09/196). Aquatic plants belonging to Sparganiaceae appear in this zone but are scarce (range 0–2%).

4.2.1.2. Local pollen B-2 (67.70–148.80 m of the core; samples 09/186–193). The samples of this succeeding zone correspond to the clastic and volcano-clastic parts of the sequence (Figure 5). The values of main pollen
Figure 7. Synthetic pollen diagrams of Danişment, Linfa and Bengiler. Pollen taxa are grouped on the basis of ecological criteria (Table 1) (acc. Jiménez-Moreno et al., 2005; Suc, 1984).

Plate 2. Fossil palynomorphs from all sections with sample numbers and local pollen zones indicated. Photomicrographs are the same scale (see 25 μm bar). (1) Zelkova, sample 09/70; Linfa assemblages; Li-2 zone, (2) Carpinus, sample 09/43; Danişment assemblage, (3) Pterocarya, sample 09/66; Linfa assemblages; Li-1 zone, (4) Alnus, sample 09/70; Linfa assemblages; Li-2 zone, (5) Revenzia, sample 09/185; Bengiler assemblages; B-3 zone, (6) evergreen Quercus, sample 09/191; Bengiler assemblages; B-2 zone, (7) deciduous Quercus, sample 09/216; Bengiler assemblages; B-1 zone, (8) Salix, sample 09/66; Linfa assemblages; Li-1 zone, (9) Castanea type, sample 09/67; Linfa assemblages; Li-1 zone, (10) Cyrillacea-Clethraceae, sample 09/67; Linfa assemblages; Li-1 zone, (11) Oleaceae, sample 09/190; Bengiler assemblages; B-2 zone, (12) Nyssa, sample 09/196; Bengiler assemblages; B-1 zone, (13) Fagus, sample 09/191; Bengiler assemblages; B-2 zone, (14) Ilex, sample 09/185; Bengiler assemblages; B-3 zone, (15) Ericaceae, sample 09/187; Bengiler assemblages; B-2 zone, (16) Chenopodiaceae, sample 09/70; Linfa assemblages; Li-2 zone and (17) Botryococcus, sample 09/193; Bengiler assemblages; B-2 zone.

| Age (Ma) | Epoch | Age | Mem. Zone | Studied section |
|----------|-------|-----|-----------|----------------|
| 20       | Miocene | Burdigalian | MN3 | 09/172 |
| 20.43    | E      | Aquitanian | MN2 | 09/170 |
| 23.03    | L      | Chattian | MN1 | 09/170 |
| 28.45    | Oligocene | Rupelian | MP24 | 09/170 |
| 30       |        |        | MP25 | 09/170 |
|          |        |        | MP26 | 09/170 |
|          |        |        | MP27 | 09/170 |
|          |        |        | MP30 | 09/170 |

Geodinamica Acta 305
types such as undifferentiated Pinaceae, Castanea, Quercus spp., Alnus and Taxodiaceae are comparable with values of the B-1 zone. However, there is an explicit differentiation between the B1 and B-2 zones. Polypodiaceae/Thelypteridaceae are reported at lower percentages in this zone. Additionally Osmunda totally disappears. The Cupressaceae gradually increase in abundance, having two peaks of 27.4% at 123.8 m (sample 09/187) and 20.8% at 138.2 m (sample 09/188). Also, the following palynomorphs appear here in low quantities: Lygodium, Pteridaceae, Podocarpus, Picea, Coniferae, Sapotaceae, Carpinus, Oleaceae, Phillyrea, Ilex, Carya, Poaceae, Polygonacea, Brassicaceae, Scrophulariaceae, Liriodendron, Juglans, and Botryococcus. The deciduous plant Fagus appears at the base of this zone and increases in abundance having a peak of 11.8% at 148.2 m (sample 09/191) and drops gradually towards the top. Similarly, evergreen Quercus has its maxima in the same zone as well. The freshwater algae Botryococcus only occurs in sample 09/190 reaching a maximum value of 6% at 148.85 m.

4.2.1.3. Local pollen B-3 (62.85–64.00 m of the core; samples 09/177–185). The values of Osmunda increase extremely, and exceed 40% at 61.95 m (sample 09/191) and 44.8% at 64.0 m (sample 09/181). Ulmus and Salix accompany Alnus in low percentages (<1%). The curve of swamp elements belonging to Taxodiaceae attains maximum values of 14.8% in sample 09/185 at 67.5 m, and declines towards the top (Figure 5). The evergreen tree Engelhardtia displays low amounts (2% on average) in fluctuating abundances.

5. Palaeovegetation

5.1. Chattian (Late Oligocene)

All sequences of the Oligo-Miocene Soma Formation were accumulated in lacustrine environments. The palynological assemblage of Danişment indicates a forest vegetation cover including coniferous forest and evergreen and deciduous mixed forest (Figure 4(a)). The coniferous forest biome consists mainly of undifferentiated Pinaceae, Cupressaceae, Picea and Pinus haploxylon type and minor amounts of Abies, Keteleeria, Cedrus, Podocarpus and Pinus diploxylon type. The microthermic (e.g. psycrophile) plants Abies, Cedrus and Picea inhabited high altitude palaeotopography with cooler climate conditions (Figures 4(a) and 7). The common occurrence of conifers also shows that the mountain area encircled the depositional area in which sparsely hygrophytic forest assemblages comprising Alnus, Taxodiaceae, Nyssa and Myrica were included. The evergreen and deciduous mixed mesophytic forest forming the zonal vegetation is characterised by relatively high percentages of Castanea, Quercus spp., Fagus, Carpinus, minor amounts of mega-mesothermic Araliaceae and Engelhardtia, and mesothermic Juglans. Swamp, herbaceous and aquatic plants occurred in minor quantities. The undergrowth was made up of ferns such as

![Figure 8. Means for each palaeoclimate parameter by section as obtained from overlapping coexistence intervals.](image-url)
Polypodiaceae/Thelypteridaceae and Schizaceae. The palynological assemblages from the Danişment and Linfa sections are very similar in terms of diversities and percentages of sporomorphs. However, there are some disparities in the concentrations that may be related to several factors such as vegetation cover, climate and different ages of the sections.

The major vegetation types of Linfa were coniferous forest, evergreen and deciduous mixed forest, as well as riparian forest (Figures 4(b) and 7). Swamp forest, aquatic and herbaceous plants played a minor role. Compared to the Danişment palynoflora, the values of the coniferous forest elements such as undifferentiated Pinaceae decreased. A perceptible decrease in the percentages of *Picea* is also noticeable. All pollen spectra show that alderwood (*Alnus*), consistently represented in high percentages, was the main element in the riparian and/or swamp environments, along with minor contributions of *Ulmus*, *Zelkova*, *Ostrya*, *Pterocarya*, *Salix* and *Carya*. Some taxa such as the microthermic *Abies* and mesothermic *Keteeleria*, *Fagus* and *Carpinus* were reported from Danişment (Figure 7), but they are absent from Linfa. Evergreen and deciduous mixed forest, which attains more or less comparable values to those of Danişment, developed beyond swamp environment, and is characterised by the dominance of *Engelhardia*, *Castanea*, evergreen *Quercus* and *Quercus* spp. There are also some differences regarding the percentages between the Li-1 and Li-2 zones. The Li-1 zone included relatively high amounts of *Castanea* and *Alnus* with minor occurrence of Oleaceae and *Salix*. Compared to the Li-1 zone, the Li-2 zone is characterised by predominance of Taxodiaceae (swamp forest) probably related to a rising lake level. The riparian plant *Alnus* was still abundant together with *Zelkova*.

5.2. **Aquitanian (Early Miocene)**

Percentages of the plant groups recognised from the Bengiler core (Aquitanian) are similar to those from the Danişment and Linfa sections ( Chattian). The assemblages mainly consisted of coniferous forest, evergreen and deciduous mixed forest and riparian forest plants (Figure 5). Swamp forest had relatively lower importance. Aquatic and herbaceous plants occurred in minor quantities. These data indicate that similar palaeoenvironments existed during Late Oligocene and Early Miocene. However, some crucial sporomorphs enable us to make the distinction between the zones. For instance, the spores such as *Osmunda* and Polypodiaceae/Thelypteridaceae frequently occurred in coaly levels located at the lower B-1 zone and the upper parts (B-3 zone) of the core (Figure 5), whereas they are present in small quantities in the B-2 zone. High percentages of *Osmunda* and Polypodiaceae/Thelypteridaceae together with *Alnus* indicate the existence of peat forming swamp vegetation. Their decrease in the B-2 zone may be related to a decay of the swamp or lower water levels. The green algae *Botryococcus* highlights the existence of open water setting in which it received higher precipitation during the deposition of volcano-clastic and fine grained sediments, and occurs in low frequency in the B-2 zone, but does not exist in the Chattian (Danişment and Linfa) (Figure 4). Changes in the percentages of Taxodiaceae and *Alnus* should be associated with fluctuations of the water level (Figure 5). Low percentages of *Cyrillaceae-Clethracaceae*, *Myrica* and *Nyssa* are also recorded in this environment. Undifferentiated Pinaceae and Cupressaceae in the distinguished zones were dominant within the coniferous forest. However, the frequent occurrence of *Fagus* and rare occurrence of *Picea* in the B-2 zone indicate a mountain area. Evergreen and deciduous plants such as *Engelhardia*, *Castanea*, evergreen *Quercus* and *Quercus* spp., were also common. Riverine plants included *Alnus*, *Ulmus*, *Pterocarya*, *Carya* and *Salix*. Herbaceous plants were extremely rare and constituted *Ephedra*, Poaceae, Polygalaceae, Brassiaceae and Caryophyllaceae. There are occurrences of mega-mesothermal taxa such as Mastixiaceae, Arecales and *Reveesia*, which were not recorded at Danişment and Linfa (Figures 4 and 7).

6. **Palaeoclimate**

The ‘Coexistence Approach’ method was applied to the sporomorph associations to reconstruct palaeoclimate quantitatively (Mosbrugger & Utescher, 1997). The quantitative results for all palynofloras including more than ten fossil taxa are given in Figures 6 and 8.

6.1. **Late Oligocene**

Quantitative palaeoclimate data of the Linfa and Danişment sections provide similar values regarding all parameters calculated (Figure 6(a) and (b)). For the Danişment section, on the basis of *Engelhardia* (left border) and *Juglans cinerea* as the NLR of *Juglanspollenites verus* (right border), the MAT, CMT, WMT, MAP, HMP and WMP coexistence intervals ranged from 13.8 to 16.7 °C, 3.1 to 5.6 °C, 20.6 to 27.7 °C, 740 to 1262 mm, 150 to 154 mm and 79 to 107 mm, respectively. The values for the LMP are between 18 and 71 mm, determined by *Juglans cinerea* (left border) and *Olea* (right border) (Figure 6(a)).

Using *Engelhardia* and *Sciadopitys verticilata* (fossil taxon *Sciadopityspollenites crassus*), the intervals for the MAT and CMT of the Linfa section are considerably narrow, and changed from 13.8 to 14.0 °C and 3.1 to 3.7 °C, respectively (Figure 6 (b)). The WMT calculated leads to an interval between 23.6 and 24.3 °C on the basis of *Sapotaceae* and *Sciadopitys verticilata*. The coexistence intervals for the MAP range from 740 to 932 mm, determined by *Engelhardia* and *Ephedra*, but a second coexistence interval from 1300 to 1356 mm, on the basis of *Sciadopitys verticilata* and *Phillyrea*, also occurs. This discrepancy may be related to palaeogeographic organisation leading to development of plant
communities under different climate conditions. The coexistence interval for the HMP is 150–154 mm, delimited by *Engelhardia* and *Juglans cinerea*. For the LMP, coexistence interval ranges from 25 to 45 mm on the basis of *Sciadopitys verticilata* and *Ephedra*. Calculations for the WMP are between 115 and 224 mm, delimited by *Sciadopitys verticilata* and Chenopodiaceae. During the deposition of the Linfa sediments, the climate was slightly warmer than during the deposition of Danışment sediments which included relatively high amounts of altitudinal plants *Picea, Abies* and *Cedrus*, and minor quantities of mega-mesothermic plants such as *Engelhardia* and *Araliaceae* (Figure 7). Mega-mesothermic plants such as *Taxodiaceae* and *Engelhardia* clearly increased and *Sapotaceae* appeared in the Linfa sediments. High *Alnus* (20% on average) together with *Taxodiaceae*, *Zelkova* and *Salix* in the Linfa assemblages may also be explained by a high rainfall in mild climate. However, this warming was minor and had no strong impact on the vegetation.

### 6.2. Early Miocene

For the Bengiler core, 8 of 19 samples were suitable for the quantitative climatic analysis (Figure 6(c)). Values of all palaeoclimate parameters defined here are higher than the values of Danışment and Linfa. The MAT values are between 15.7 and 20.5 °C, delimited by Mastixiaceae and *Phillyrea*. The calculated CMT ranges from 9.6 to 13.3 °C according to Mastixiaceae and *Liriodendron*. Based on the *Sapotaceae* and *Quercus*, the WMT values change between 23.6 and 28.3 °C. The calculated MAP ranges from 1096 (Mastixiaceae) to 1356 mm (*Phillyrea*). But an interval between 800 and 932 mm (*Reveesia* and *Ephedra*) also occurs. According to Cycadaceae and *Ephedra*, the HMP values change from 187 to 200 mm. Calculated LMP values range from 32 to 45 according to *Liriodendron* and *Ephedra* (Figure 6(c)). The WMP coexistence interval is constantly 118–221 mm (left border: *Reveesia*; right border: Cycadaceae). There is a remarkable case on the palaeoclimate values that the lower boundaries of the MAT, CMT, HMP and LMP slightly increased in the Aquitanian (Figures 6 and 8). This may indicate a warming trend from the Chattian to Aquitanian. This result is confirmed by presence of mega-mesothermal taxa such as *Reveesia*, *Liriodendron*, *Sapotaceae* and *Araliaceae*, not present in the Chattian (Figure 7). However, it should be taken into consideration that a hiatus existed in our successions comprising the end of the Chattian and earliest Aquitanian (persisting on 2.2 My). This may point out a non-depositional phase associated with the Mi-1 glaciation event (Miller, 1991). On the other hand, Bozuks, Palamarev, and Petkova (2008) propounded a warming in the Late Oligocene and a cooling during the Oligo–Miocene transition. Mosbrugger, Utescher, and Dilcher (2005) asserted a temperature peak from the Lower Rhine Basin in the latest Chattian corresponding to Late Oligocene warming according to the marine oxygen record (Zachos, Pagani, Sloan, Thomas, & Billups, 2001). The authors point out that there was a short-term cooling in the earliest Aquitanian. Larsson, Vajda, and Dybkjaer (2010) claimed that there was a cooling period at the Oligo–Miocene transition as well. In contrast, a warming trend was suggested for the Late Oligocene and Early Miocene from various basins of Turkey on the basis of palynofloras (Akgün, Kayseri, & Akkiraz, 2007). Our palaeoclimate data indicate that relatively cool conditions existed at the time of deposition of the Danışment sediments ( Chattian) since they included different kinds of altitudinal plants such as *Picea*, *Abies*, *Keteleeria*, *Cedrus*, *Podocarpus* and *Fagus* thriving in mountain areas. Minor amounts of mire forest elements such as *Nyssa*, *Taxodiaceae* and *Myrica*, and riparian plants such as *Alnus* and *Ulmus* may indicate a relatively small extension of wetlands, possibly due to reduced rainfall. These results may be linked to the fact that eustatic sea-level was low at that time, due to globally cooler conditions leading to the growth of the Antarctic glaciers (Haq, Hardenbol, & Vail, 1987). Palaeoclimate became slightly warmer during the deposition of the Linfa sediments which include warmth loving plants such as *Engelhardia*, *Sapotaceae* and *Araliaceae*. Compared to the Danışment assemblage, the palynological associations constituted high amounts of *Alnus* and *Taxodiaceae* thriving in the swamp and levees. After a hiatus including the later Chattian and earliest Aquitanian, the Bengiler sediments deposited in a warm and humid environment as proven by quantitative palaeoclimate data and the high amounts of warmth-loving plants. Also, mega-mesothermic plants such as *Mastixiaceae*, *Reveesia* and *Arecaceae* appeared here.

### 7. Conclusions

The results of the present study can be summarised as follows:

1. According to 
   
   40Ar/39Ar data, two outcrop sections from the Danışment and Linfa areas, and a borehole from the Bengiler area yield Late Oligocene and Early Miocene ages, respectively.

2. The Danışment assemblage represents the lowermost part of the Late Oligocene (‘mid-Chattian’) and contains high quantities of coniferous and evergreen and deciduous mixed mesophytic forest elements. It includes relatively high quantities of pollen of microthermic plants such as *Picea* and *Abies*, and minor amounts of meso-megathermic elements such as *Engelhardia* and *Araliaceae*. This is probably related to several factors such as, global cooling and high palaeotopography.

3. The Linfa assemblages were mainly characterised by elements of the coniferous forest and by riparian taxa, and the occurrences of warmth-loving
elements such as Araliaceae, Cyrillaceae–Clethraceae, Engelhardia, Sapotaceae and Taxodiaceae.

(4) The Lower Miocene strata from the Bengiler area contain abundant of coniferous forest elements, evergreen and deciduous mixed forest and riparian forest taxa indicating a warm and humid palaeoclimate. Counting results indicate that there is no significant change in the percentages between the Linfa and Bengiler communities. However, the climate reconstruction suggests that the Aquitanian (Bengiler flora) tends to be warmer and wetter compared to the Chattian Linfa flora. This should be related to minor occurrences of mega-mesothermic taxa such as Mastixiaceae, Arecales and Reveesia that were used in the palaeoclimate reconstruction. However, our record has a gap comprising the latest Oligocene–earliest Miocene, possibly related to a global cooling (i.e. Mi-1 glaciation) and erosional phase. If the Mi-1 cooling affected this continental area, it should have been of short duration, and did not affect the vegetation cover.

(5) According to radiometric dating, both Linfa and Bengiler florals correlate with a sea-level highstand and represent warm parts of the climate cycles.

Acknowledgements
We thank Funda Akgün who helped with the identification of palynomorphs. We also thank the employees of the Nevada Isotope Geochronology Laboratory for help with 40Ar/39Ar dating. The authors thank to Dr Torsten Utescher, and an anonymous referee Geochronology Laboratory for help with 40Ar/39Ar dating. palynomorphs. We also thank the employees of the Nevada Isotope Geochronology Laboratory for help with 40Ar/39Ar dating. We thank Funda Akgün who helped with the identification of palynomorphs. We also thank the employees of the Nevada Isotope Geochronology Laboratory for help with 40Ar/39Ar dating.

Disclosure statement
No potential conflict of interest was reported by the authors.

Funding
This study was supported by research project from Dokuz Eylul University, BAP – 2009.KB. FEN.021.

ORCID
Mehmet Serkan Akkiraz http://orcid.org/0000-0002-1853-0304

References
Akcay, E., Dönmez, M., Ilgar, A., Duru, M., & Pehlivian, S. (2008). 1:100.000 ölçekli Türkiye jeoloji haritaları-Bandırma-H19 paftası (1:100.000 scaled geological maps of Turkey- Bandırma-H19 sheet). Maden Tekiti ve Arama Enstitüsü Dergisi, 103, 1–26.

Akgün, F., Akkiraz, M. S., Üçbaş, S. D., Bozcu, M., Kapan-Yeşilyurt, S., & Bozcu, A. (2013). Oligocene vegetation and climate characteristics in North-west Turkey: data from the South-western part of the Thrace basin. Turkish Journal of Earth Sciences, 22, 277–303.

Akgün, F., Kayseri, M. Ş., & Akkiraz, M. S. (2007). Palaeoclimatic evolution and vegetational changes during the Late Oligocene–Miocene period in Western and Central Anatolia (Turkey). Palaeogeography, Palaeoclimatology, Palaeoecology, 253, 56–90.

Akyol, E. (1971). Microflora de Oligocene inférieur recollée dans un sondage près d’Aviccoru, Sile-Istanbul. Pollen et Spores, 13, 117–133.

Bah, Z. (1996). Palynostratigraphy and coal petrography of the Upper Oligocene lignites of the Northern Thrace Basin, NW Turkey (PhD thesis). Middle East Technical University, Ankara, Turkey. Unpublished.

Bozcu, M., Akgün, F., Gürdal, G., Bozcu, A., Kapan Yeşilyurt, S., Karaca, O., & Akkiraz, M. S. (2015). Evolution of Can-Ötli (Çanakkale-NW Turkey) Lignite Basin: Sedimentology, petrology, palynology and lignite characterization. International Journal of Sediment Research, 30, 197–203.

Bozkov, V., Palamarev, E., & Petkova, A. (2008). The fossil macroflora of the Vulche Pole Molasse Formation (SE Bulgaria). Phytologia Balcanica, 14, 173–184.

Bozkov, V., Utescher, T., & Ivanov, Dimiter (2009). Late Eocene to early Miocene climate and vegetation of Bulgaria. Review of Palaeobotany and Palynology, 153, 360–374.

Demirtas, F., Bozcu, M., Koşun, E., & Akkiraz, M. S. (2015). Petrography and palynology of Late Oligocene and Middle Miocene coals in the Gelibolu peninsula, NW Turkey. Turkish Journal of Earth Sciences, 24, 383–397.

Duru, M., Pehlivian, S., Ilgar, A., Dönmez, M., & Akçay, A. E. (2007). 1:100.000 ölçekli Türkiye jeoloji haritaları-Ayvalık-İI paftası (1:100.000 scaled geological maps of Turkey-Ayvalık-İI sheet). Maden Tekiti ve Arama Enstitüsü Dergisi, 98, 1–36.

Ediger, V. S. (1990). Paleopalynology of coal bearing Miocene sedimentary rocks associate with volcanics of the Biga Peninsula (NW Turkey) and the effect of volcanism on vegetation. Neues Jahrbuch für Geologie und Palaontologie. Abhandl, 180, 259–277.

Ediger, V. Ş., Batı, Z., & Alışan, C. (1990). Paleopalynology and palaeoecology of Calamites-like disulcate pollen grains. Review of Palaeobotany and Palynology: 62, 97–105.

Ercan, T., Dinçel, A., & Güny, E. (1979). Uşak volkanikleriinin petrolojisi ve plaka tektoniği açısından Ege Bölgesi’ndeki yeri (Petrology of Uşak volcanites and their importance in terms of plate tectonics in the Aegean region). Türkiye Jeleoloji Bilişen, 22, 185–198.

Ercan, T., Ergül, E., Akçören, F., Çetin, A., Granit, S., & Asu-tay, J. (1990). Balikesir-Bandırma jeolojisi, Tersiyer volkanojenik ve batıda Ege Bölgesi’ndeki yeri (Geology of Balikesir-Bandırma, Petrology of Tertiary volcanism and its regional spreading). Maden Tekiti ve Arama Enstitüsü Dergisi, 110, 113–130.

Genç, Y. (1998). Başçakta-Akdağmadeni (Yozgat) Zn-Pb-Cu sulfide deposit: an example of metamorphosed sulphide deposit in the Akdağmadeni massif. Third International Turkish Geology Symposium Abstracts book, Ankara, p. 69.

Görür, N., & Okay, A.İ. (1996). Fore-arc origin of the Thrace Basin, northwest Turkey. Geologische Rundschau, 85, 662–668.

Grimm, E. (1994). TILLA and TILLIGRAPH pollen diagramming program. Springfield, IL: Illinois State Museum.

Haq, B., Hardenbol, J., & Vai, P. (1987). Chronology of fluctuating sea levels since the Triassic. Science, 233, 1156–1167.
Ismailoğlu, Y., Harzhauser, M., Gross, M., Jiménez-Moreno, G., Coric, S., Kroh, A., … Van Der Made, J. (2010). From Tethys to Eastern Paratethys: Oligocene depositional environments, paleoecology and paleobiogeography of the Thrace Basin (NW Turkey). *International Journal of Earth Sciences*, 99, 183–200.

Ivanov, D., Utescher, T., Ashraf, A., Mosbrugger, V., Bozukov, V., Djorgova, N., & Slavomirova, E. (2012). Late Miocene palaeoclimate and ecosystem dynamics in southwestern Bulgaria – A study based on pollen data from the Gotse-Delchev Basin. *Turkish Journal of Earth Sciences*, 21, 187–211.

Jiménez-Moreno, G., Rodriguez-Tovar, F. J., Pardo-Iguzquiza, E., Fauquette, S., Suc, J.-P., & Müller, P. (2005). High-resolution palynological analysis in late early-middle Miocene core from the Pannonian Basin, Hungary: Climatic changes, astronomical forcing and eustatic fluctuations in the Central Paratethys. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 216, 73–97.

Larsson, L. M., Vajda, V., & Dybkjær, K. (2010). Vegetation and climate in the latest Oligocene-earliest Miocene in Jylland, Denmark. *Review of Palaeobotany and Palynology*, 159, 166–176.

Less, G. Y., Özcan, E., & Okay, A. (2011). Stratigraphy and larger Foraminifera of the Middle Eocene to Lower Oligocene shallow-marine and olistostromal units in the northern and eastern parts of the Thrace Basin, NW Turkey. *Turkish Journal of Earth Sciences*, 20, 793–845.

Miller, M. (1991). High-angle origin of the currently low-angle Badwater Turtleback fault, Death Valley, California. *Geology*, 19, 372–375.

Mosbrugger, V., & Utescher, T. (1997). The coexistence approach – a method for quantitative reconstructions of Tertiary terrestrial palaeoclimatic data using plant fossils. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 134, 61–86.

Mosbrugger, V., Utescher, T., & Dilcher, D. L. (2005). Cenozoic continental climatic evolution of Central Europe. *Proceedings of the National Academy of Sciences*, 102, 14964–14969.

Nebert, K. (1978). Linyit içeren Soma Neojen Bölgesi, Batt Anadolu. *Maden Tetkik ve Araına Enstitüsü Dergisi*, 90, 20–69.

Okay, A., Siyako, M., & Bürkan, K. A. (1990). Biga Yarımadası’nın jeolojisi ve tektonik evrimi (Geology and tectonic evolution of the Biga peninsula). *Türkiye Petrol Jeolojisi Derneği Bülteni*, Turkish Association of Petroleum Geologists, 2, 83–121.

Okay, A., Siyako, M., & Bürkan, K. A. (1991). Geology and tectonic evolution of the Biga Peninsula, northwest Turkey. *Bulletin of the Technical University of Istanbul*, 44, 191–256.

Okay, A., Özcan, E., Cavazza, W., Okay, N., & Less, G. Y. (2010). Basement types, Lower Eocene Series, Upper Eocene Olistostromes and the Initiation of the Southern Thrace Basin, NW Turkey. *Turkish Journal of Earth Sciences*, 19, 1–25.

Özcan, E., Less, G. Y., Okay, A., Baldi-Beka, M., Kollanyi, K., & Yilmaz, İ. Ö. (2010). Stratigraphy and larger foraminifera of the Eocene shallow-marine and olistostromal units of the southern part of the Thrace Basin, NW Turkey. *Turkish Journal of Earth Sciences*, 19, 27–77.

Pehlivan, S., Duru, M., Dönmez, M., İlgar, A., Akçay, E., Erdogan, K., & Özver, D. (2007). 1:100.000 ölçekli Türkiye jeoloji haritaları Bandırma-H19 (1:100.000 scaled geological maps of Turkey-Bandırma-H19 sheet). *Maden Tetkik ve Araına Enstitüsü Dergisi*, 96, 1–40.

Saknç, M., Yaltırak, C., & Oktay, F. Y. (1999). Palaeogeographic evolution of the Thrace Neogene Basin and the Tethys Paratethys relations at northwestern Turkey (Thrace). *Palaeogeography Palaeoclimatology Palaeoecology*, 153, 17–40.

Selim, H. H., Tiüysüz, O., & Barka, A. A. (2006). Güney Marmara Bölümünün Neotektonikleri (Neotectonics of southern Marmara). *İstanbul Teknik Üniversitesi Dergisi*, 5, 151–160.

Siyako, M., Bürkan, K. A., & Okay, A. (1989). Biga ve Gıbelolu Yarımadasının tersiyer jeolojisi ve hidrokarbon olanakları (Tertiary Geology and Hydrocarbon Potential of the Biga and Gıbelolu peninsulas). *Türkiye Petrol Jeolojisi Derneği Bülteni*, 1, 183–200.

Siyako, M., & Huvaz, O. (2007). Eocene stratigraphic evolution of the Thrace Basin, Turkey. *Sedimentary Geology*, 198, 75–91.

Suc, J.-P. (1984). Origin and evolution of the Mediterranean vegetation and climate in Europe. *Nature*, 307, 429–432.

Üçbaş, S. D. (2013). *Palyonofı, palaeocology and palynofacies of the Oligo-Miocene sediments outcropping in the Yenice-Kalkan (Canakkale) basin* (Msc thesis, 195 pp.). Dumlupınar University, Kütahya.

Utescher, T., Bruch, A. A., Erdei, B., François, L., Ivanov, D., Jacques, F. M., B., … Spicer, R. A. (2014). The coexistence approach – Theoretical background and practical considerations of using plant fossils for climate quantification. *Palaeogeography Palaeoclimatology Palaeoecology*, 410, 58–73.

Zachos, J., Pagani, M., Sloan, L., Thomas, E., & Billups, K. (2001). Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science*, 292, 686–693.