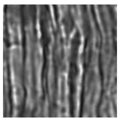
Vegetation and climate in the Miocene deposits of southern side of the Büyük Menderes Graben, Şahinali-2 core, SW Turkey

MEHMET SERKAN AKKİRAZ



Lower–Middle Miocene succession from the Şahinali coalfield (SW Turkey) was analyzed to reconstruct climate and vegetation. The sediments mainly represent a lacustrine facies and consist of a mudstone-marl dominated succession, including limited coarse-grained clastics. Results of microfloral and published macrofloral records have been considered. The main vegetation types were mixed mesophytic forest dominated by evergreen *Quercus* and coniferous forest consisting mainly of indeterminate Pinaceae, *Pinus* and Cupressaceae. In this belt riparian vegetation incorporates high proportions of *Alnus*, and less amounts of deciduous *Salix*, *Ulmus*, *Pterocarya*, *Carya*, *Platanus*, *Zelkova* and *Liquidambar*. Herbaceous components in the pollen spectra are in low frequencies, and consist of Poaceae, Brassicaceae, Chenopodiaceae, *Ephedra*, Asteraceae and Caryophyllaceae. Also three local pollen zones can be recognized based on the changes in relative abundances of palynomorphs. The micro- and published macrofloral records have been subjected to the Coexistence Approach method to obtain the palaeoclimate. Mean annual temperature is estimated to be over 14 °C and mean annual precipitation exceeds 1000 mm. In combination with other climate parameters (temperatures of warmest and coldest months, precipitation of the wettest, driest and warmest months), the data indicate very stable warm-temperate with high annual precipitation. Results of the Coexistence Approach using both sporomorph and leaf datasets are good in agreement, implying internal consistency in the method. Compared with modern meteorological records, surroundings of the Büyük Menderes Graben had similar temperature and higher precipitation during the Early–Middle Miocene. This study contributes to an understanding of the Miocene vegetation and climate evolution in southeastern Mediterranean area. • Keywords: Early–Middle Miocene, Büyük Menderes Graben, Southeastern Mediterranean, palynology, palaeoclimate.

AKKİRAZ, M.S. 2011. Vegetation and climate in the Miocene deposits of southern side of the Büyük Menderes Graben, Şahinali-2 core, SW Turkey. *Bulletin of Geosciences 86(4)*, 859–878 (9 figures, 3 tables). Czech Geological Survey, Prague. ISSN 1214-1119. Manuscript received March 18, 2011; accepted in revised form June 13, 2011; published online July 26, 2011; issued November 16, 2011.

Mehmet Serkan Akkiraz, Dumlupınar University, Department of Geological Engineering, Main Campus, 43270, Kütahya, Turkey; sakkiraz73@gmail.com, serkanakkiraz@dpu.edu.tr

Miocene lignite bearing-continental deposits from the western part of Turkey (southeastern Mediterranean Zone) are well known for their economic potential [*e.g.*, Manisa-Soma; Kütahya (Seyitömer and Tunçbilek); Çanakkale-Çan basins]; see Fig. 1A. A number of studies dealing with Cenozoic palynology and palaeobotany have been carried out in these areas (*e.g.*, Becker-Platen 1970; Benda 1971; Benda & Meulenkamp 1979, 1990; Mädler & Steffens 1979; Ediger 1990; Ediger *et al*. 1990; Akgün & Akyol 1999; Akgün *et al*. 2007; Yavuz-Işık 2007, 2008; Erdei *et al*. 2010; Akkiraz *et al*. 2011). The first palynological studies were made to solve the stratigraphy by means of form-generic names for most of pollen and spores (Akyol 1964, 1968; Nakoman 1965; Benda 1971; Benda & Meulenkamp 1979, 1990; Akgün & Akyol 1999). Recently, statistical methods have been applied to pollen samples in order to obtain reliable information about floral diversity, vegetation and climate (Akgün *et al*. 2007; Yavuz-Işık 2007, 2008; Kayseri & Akgün 2008; Akkiraz *et al*. 2011).

The most comprehensive published work on micro- and macrofloras of the Şahinali open cast mine (southern side of the Büyük Menderes Graben) was carried out by Gemici *et al*. (1993) who suggested Middle Miocene age (Fig. 1A, B). This age was palynologically confirmed by Akgün & Akyol (1999) as well. Palynoflora of Aydın–İncirliova, Köşk, Başçayır, Sarayköy and Hasköy areas in the northern part and those of in Aydın–Söke, Şahinali and Kuloğulları areas in the southern side of the Büyük Menderes Graben were investigated by Akgün & Akyol (1999) who suggested Early-Middle Miocene. Moreover, well preserved leaf flora from the Şahinali open cast mine was determined from the muddy sediments, and assigned to Serravallian by Mädler & Steffens (1979). Miocene sediments of the Söke Basin

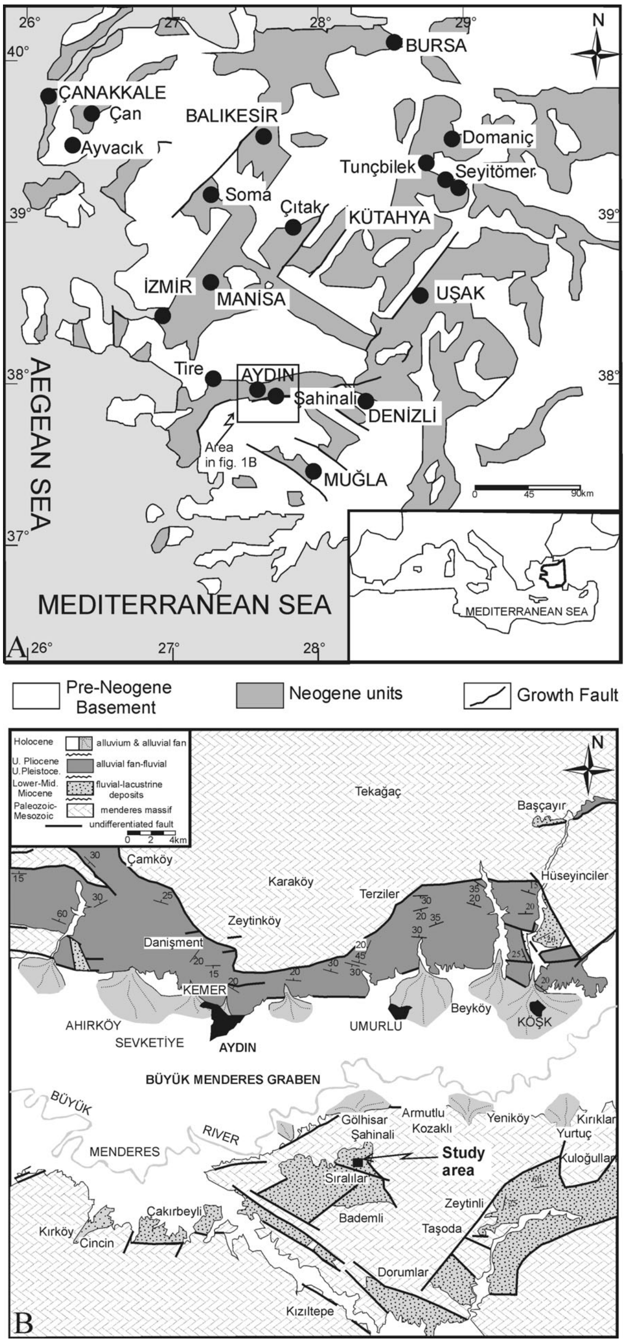


Figure 1. Map showing the lignite-bearing locations in western Turkey (A) and location of the studied Şahinali-2 core in the Şahinali open cast mine (B) (modified from Görür *et al*. 2009).

(Söke Formation) located about 70 km west of the current study area have similar lithologies to the Şahinali open cast mine and were dated as Early-Middle Miocene on the basis of mammal zone (MN4-6) (Gürer *et al*. (2009). Ünay & Göktaş (1999) described a well-preserved mammal fauna from the Söke and Dededağ Formations. The following fossil assemblages were determined from the Söke Formation indicating the Orleanian (late Early Miocene – MN-4) age: *Cricetodon* cf. *tobieni*, *Democricetodon* n. sp., *Megacricetodon* cf. *primitivus*, *Lartetomys* sp., *Spanocricetodon* sp., *Anomalomys* sp., *Glirulus* sp., *Debruijina* n. sp., *Albertona aegeensis* n. sp., *Schizogalerix* sp. from the Söke locality, and *Cricetodon* n. sp., *Megacricetodon primitivus*, *Anomalomys aliveriensis*, ?*Vasseuromys* sp., *Debruijnia* sp., *Schizogalerix* sp. from the Dededağ locality. Alçiçek (2010) studied the regional palaeogeography, stratigraphy and tectonism of the Neogene units in southwestern part of Turkey, and suggested middle Burdigalian-early Serravallian (Early–Middle Miocene) for the Söke Formation on the basis of mammal fauna studied by Becker-Platen (1970) and Gürer *et al*. (2009). Unfortunately, the age of lignite-bearing sediments in the northern and southern sides of the Büyük Menderes Graben is still a matter of debate and more precise dating is needed. Additionally, despite the fact that exploration and exploitation have been going on in the Şahinali open cast mine since 1960s, relatively limited information have been obtained on the flora, vegetation and palaeoclimate.

In this study the knowledge on the pollen flora has been enlarged by analysis of new samples from the Lower–Middle Miocene sequence of the Şahinali open cast mine. Also, the vegetation and palaeoclimate have been reconstructed independently by quantitative methods. Sediments of the present core represent a continuous stratigraphic sequence available for pollen studies in the Miocene of SW Turkey.

Studied area

Modern climate and vegetation

The Şahinali open cast mine located around 255 m a.s.l. lies between the Büyük Menderes Graben on the north and hills with elevations of 400–600 m a.s.l. on the south. Climate of the area is under influences of Mediterranean type. It is hot and dry in summers and warm and rainy in winters with an annual rainfall between 400 and 1000 mm (Kadıoğlu 2000) (Table 1).

The modern vegetation belongs to the region of Mediterranean pines, covered with *Pinus brutia*, *P. nigra*, *P. halepensis*. Mediterranean woodland (including xeric variety) consists of *Quercus ilex*, *Q. coccifera*, *Pistascia lentiscus*, *Olea europaea* var. *oleaster*, *Ceratonia siliqua*, *Nerium oleander*, *Ulmus glabra*, *Juniperus*, Poaceae and other herbs (Roberts & Wright 1993).

Geological setting and lithology of the Şahinali coalfield

During the Miocene western Turkey displayed a long-term trend of decreasing marine influence. Alpine tectonics

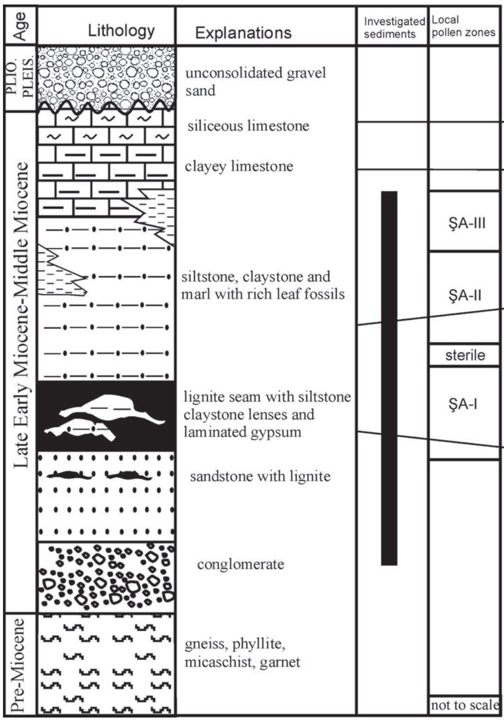


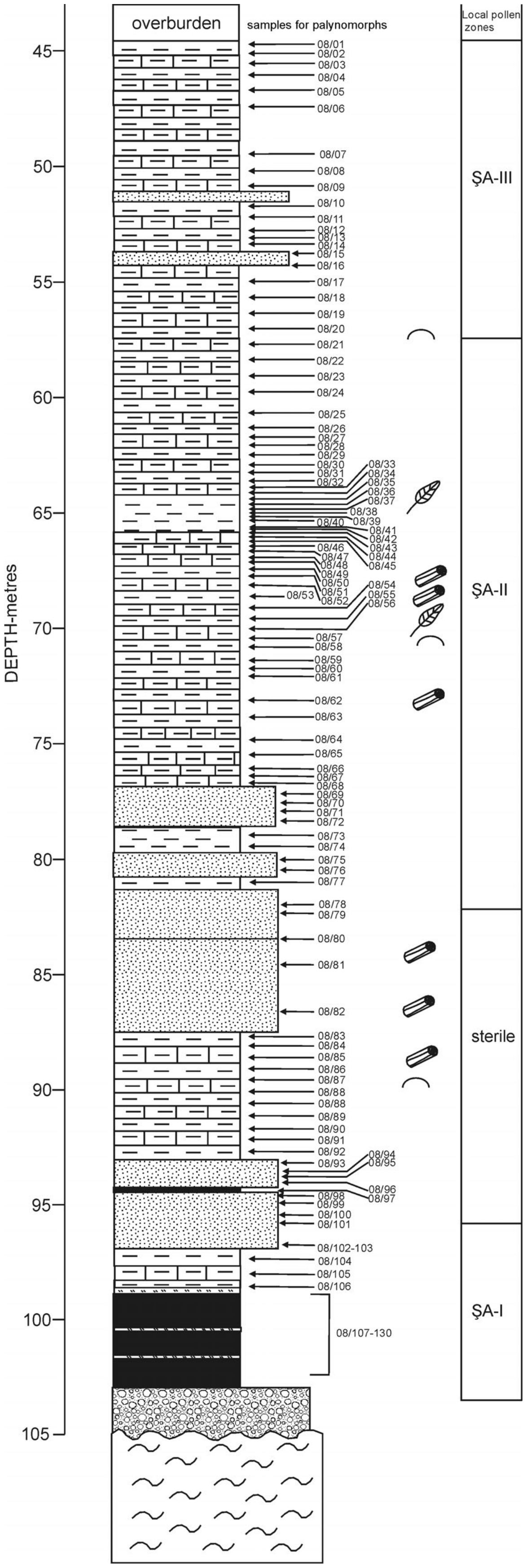
Figure 2. Şahinali open cast mine showing the position of the sequence (modified from Gemici *et al.* 1993).

Table 1. Climatic parameters of Early–Middle Miocene in the Şahinali open cast mine obtained by the CA compared with the modern ones (MAT: mean annual temperature, CMT: mean temperature of the coldest month, WMT: mean temperature of warmest month, MAP: mean annual precipitation, HMP: precipitation of the wettest month; LMP: precipitation of the direst month; WMP: precipitation of the warmest month).

Climate parameters	Early–Middle Miocene (Şahinali open cast mine)		Modern
	Leaf flora	Palynoflora	
MAT(°C)	14.4–15.4 °C *Quercus incana – Castanopsis chrysoph*	15.6–18.4 °C *Engelhardia – Cedrus*	14–18 °C
CMT (°C)	5.6–7.0 °C *Laurus* and *Fagus orientalis*	7.7–12.5 °C *Engelhardia – Cedrus*	7–8 °C
WMT (°C)	26.4–27.7 °C *Sapindus – Populus balsamifera*	24.7–28.1 °C *Engelhardia* – Cupressaceae	27–29 °C
MAP (mm)	1031–1171 mm *Myrica cerifera – Castanopsis chrysoph*	1003–1520 mm Arecoideae – Taxodiaceae	400–1000 mm
HMP (mm)	124–134 mm *Myrica cerifera – Populus balsamifera*	204–227 mm *Engelhardia – Pinus diploxylon* type	150–450 mm
LMP (mm)	10–11 mm *Populus balsamifera – Castanopsis chrysoph*	16–41 mm Podocarpaceae – *Cedrus*	0–20 mm
WMP (mm)	90–94 mm *Myrica cerifera – Populus balsamifera*	79–125 mm *Engelhardia – Pinus diploxylon* type	100–200 mm

were active during the Late Cretaceous and Early Cenozoic periods (Collins & Robertson 2003, Robertson *et al*. 2003), producing uplift of the Taurides. The convergence between the Africa and Eurasian plates led to the development of two distinct realms during the Miocene and Pliocene: The Mediterranean and Paratethys seas (Rögl 1998, Meulenkamp & Sissing 2003). Then lacustrine sediments were filled in most of the Miocene basins in western Turkey. Succession of the Büyük Menderes Graben is made up of Miocene–Quaternary terrestrial sediments. Numerous studies concerning the stratigraphy, sedimentology and tectonism were carried out in the graben (Şengör *et al.* 1985; Şengör 1987; Seyitoğlu & Scott 1991, 1992; Ünay *et al.* 1995; Emre & Sözbilir 1997; Akgün & Akyol 1999; Yılmaz *et al*. 2000; Gürer *et al*. 2001, 2009; Seyitoğlu *et al.* 2004; Koçyiğit 2005; Bozkurt & Mittwede 2005; Kaymakçı 2006; Alçiçek 2010).

The Şahinali coalfield (37° 46´ 12˝ N, 27° 55´ 48˝ E and 255 m alt.) is situated around 15 km southern part of the Büyük Menderes Graben, southeast of Aydın (Fig. 1A, B).

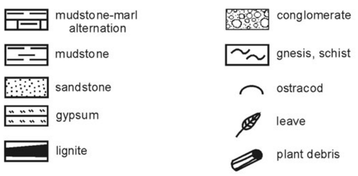


The Lower–Middle Miocene units were deposited in approximately 9 km length and 9 km width covering an area of over 81 km^2 extending in a NE-SW direction (Fig. 1B) and rest unconformably on crystalline schists and gneiss of the Menderes Massif (Bozkurt 1999, Bozkurt & Satır 2000, Bozkurt & Oberhändsli 2001, Koralay *et al*. 2004) (Fig. 2). According to the field observations and estimations, sediments were not subjected to a strong tectonism since dip and strike of bedding plane is almost horizontal (Fig. 3). Small-scale foldings and normal faults occurred in the sequence. Apart from conglomerates and sandstones at the base, the units appear relative uniform and homogeneous, and consist of fine-grained deposits, mudrock and marl alternation (Figs 2, 3). The most common components of the conglomerates include grains of the crystalline schist, gneiss and abundantly quartz derived from the basement. These coarse-grained clastics grade into sandstones which were covered by a lignite seam with 7–8 m on average thickness (Figs 2, 3). Thin to medium bedded gypsum levels occur both within the lignite seam and upper side of the lignite level. Gypsum levels may be weathering products of sulphide and carbonate minerals (Vassilev & Vassileva 1996) and may indicate that the sulphate content in waters was probably increased as a consequence of evaporation under dry conditions. Gypsum-bearing lignites then evolved into an alkaline lake since the sequence continued upward with sandstones, claystones and marl alternation, reaching to 100 m total thickness (Fig. 3). Marl dominated lithologies contain plant debris, leaves and ostracods (Fig. 3). The Miocene units end with clayey and siliceous limestones (Fig. 2) and are unconformably overlain by the Pliocene–Pleistocene unconsolidated coarse-grained sediments (Fig. 2).

Published flora

In addition to the palynoflora from the Şahinali coalfield, leaf flora from the same area has been evaluated. The well-preserved leaf fossils described by Mädler & Steffens (1979) and Gemici *et al*. (1993) were taken from the marl dominated lithologies above the main coal seam (Figs 2, 3).

Figure 3. Figure shows the depths at which samples were taken from the core.



Material and methods

Material

The Şahinali-2 core is located at the northeast of the coalfield (Fig. 1B) was drilled to a total depth of 105 metres by Aydın Lignite Company until they reached to the basement (Fig. 3). A total of 130 samples were collected for palynological purposes, at an average distance of 45 cm. But quantitative data are confined to 55 productive samples. No palynomorphs were found in 75 samples (*e.g.*, 08/03, 08/04, 08/42), possibly owing to environmental conditions inappropriate for pollen preservation (Fig. 3). Since samples between 08/121 and 08/125 included low amounts of spore and pollen, these samples were combined to sample (Figs 4, 6). Therefore, 51 samples were suitable for palynological counting (Fig. 4).

Preparation methods

For palynological studies, ten grams of each sample were treated with HCL-HF-Acetolysis according to standard procedures. The organic residue was sieved through an 8 µm mesh screen and 1–3 slides per sample of the >8 µm fraction were prepared for transmitted light microscopy. Pollen counts were carried out at a magnification of 400× using an Olympus microscope. Sporomorph contents of the samples are shown in a detailed palynological analytical diagram (Fig. 4). In this study, freshwater algae *Botryococcus* were not considered from the total sum used for calculating spore and pollen percentages, with a minimum of 200 grains of pollen and spores counted for all samples. In addition, a synthetic pollen diagram was plotted (Suc 1984, Jiménez-Moreno *et al*. 2005), in which pollen taxa have been arranged in 10 groups based on the ecological criteria (Fig. 5). Selected sporomorphs were photographed by the help of an Olympus BX51 microscope and Dewinter Caliper Pro 4.1 camera (Figs 7–9). TILIA software was used for calculating the pollen and spore records, and TILIAGRAPH was used for plotting the pollen diagram (Grimm 1994).

Method of palaeoclimate reconstruction

Palaeoclimate proxies are made on the basis of the Coexistence Approach (CA) (Mosbrugger & Utescher 1997), a computer-aided for quantitative terrestrial climate reconstructions during the Paleogene and the Neogene using plant fossils. According to this technique the climatic requirements of the fossil plant taxa are similar to those of their Nearest Living Relatives (NLRs). The resolution rises with the number of the taxa included in the analysis. In general, relatively high in floras about ten or more are climatically considered more valuable taxa. This technique is based on presence/absence of taxa instead of relative abundances. The aim of the CA is to establish the intervals of various climate parameters for a given fossil flora in which maximal number of NLRs of this flora can coexist; these coexistence intervals are regarded as the best description of palaeoclimate under which flora lived. The method is applied to a total of 46 samples (Fig. 6).

Table 2. Macrofloral list of Şahinali open cast mine with Nearest Living Relatives of the fossil taxa.

Fossil taxa	Nearest Living Relatives; bold: taxa reponsible for climate intervals
Alnus phocaeensis Sap. (= cf. *nepalensis* Don)	*Alnus* sp.
Acer sp.	*Acer* sp.
Betula subpubescens Goepp.	*Betula pubescens*
Carya serraefolia (Goepp.) Krä.	*Carya cordiformis*
cf. *Castanea kubinyi* Kov.	*Castanea* sp.
Castanopsis sp.	***Castanopsis chrysoph***
Cercis antiqua Sap.	*Cercis* sp.
Cinnamomophyllum scheuchzeri (Heer) Kr. & Weyl.	Lauraceae
Daphnogene polymorpha (A. Br.) Ettin.	*Daphnogene* sp.
Diospyros cf. *anceps*	*Diospyros* sp.
Diospyros sp.	*Diospyros* sp.
Fagus orientalis Lip.	***Fagus orientalis***
Fagus attenuata Goepp.	*Fagus ferruginea*
Fraxinus sp.	*Fraxinus* sp.
Glumophyllum sp.	Monocotyledoneae
Glyptostrobus europaeus (Brongn.) Heer	*Glyptostrobus pensilis*
Laurophyllum primigenium (Ung.) Kr. & Weyl. *in* Mad. & Steff.	Lauraceae
Laurus sp.	***Laurus* sp.**
Magnolia sp.	*Magnolia* sp.
Myrica lignitum (Ung.) Sap.	***Myrica cerifera***
Myrica cf. *pseudolignitum* Kr. & Weyl *in* Mad. & Steff.	*Myrica* sp.
Pinus pinastroides Unger	*Pinus* sp.
Pinus sp.	*Pinus* sp.
Populus cf. *latior* A.Br.	*Populus* sp.
Populus cf. *balsamoides* Goepp.	***Populus balsamifera***
Quercus goepperti Web.	***Quercus incana***
Quercus drymeja Ung.	*Quercus* sp.
Quercus mediterranea Unger	*Quercus ilex-coccifera* type
Quercus neriifolia (A. Br.)	*Quercus* sp.
Sapindus falcifolius A. Br.	***Sapindus* sp.**
cf. *Symplocos* sp.	*Symplocos* sp.
Tilia sp.	*Tilia* sp.

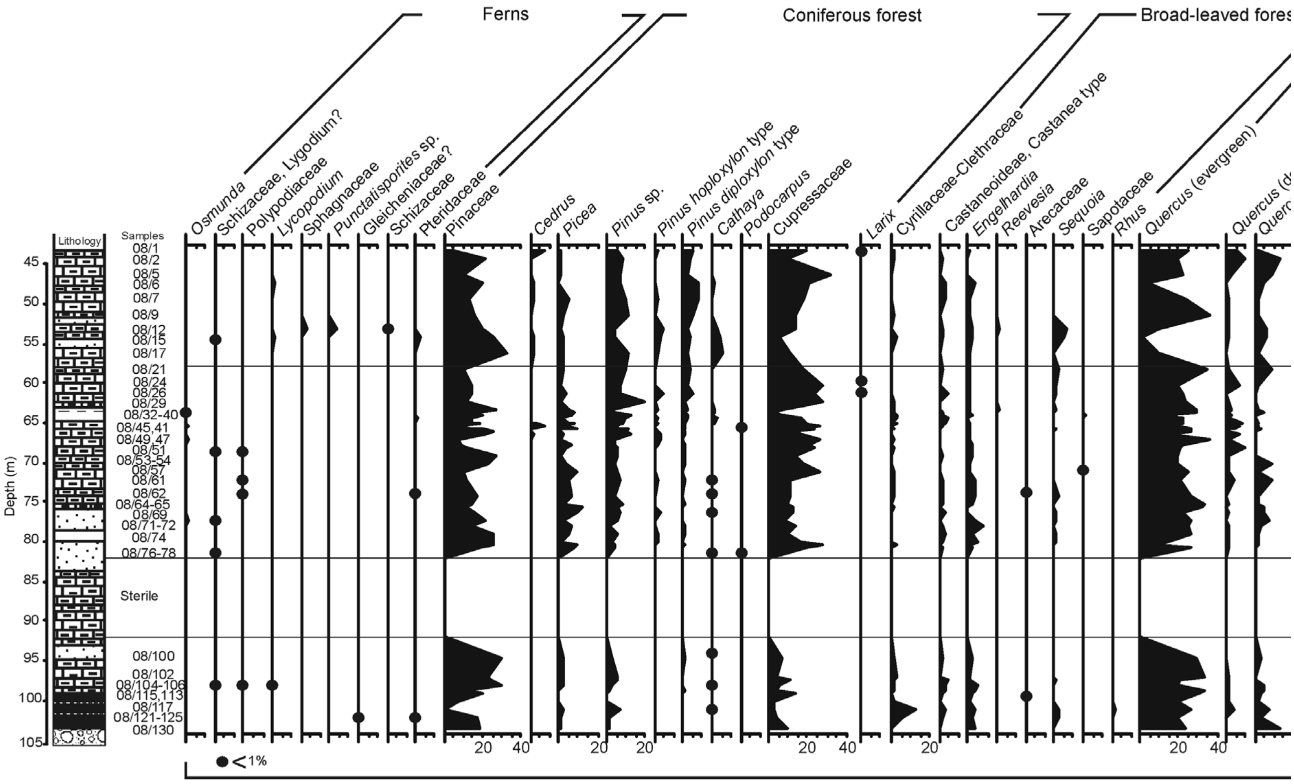


Figure 4. Pollen diagram of the Şahinali-2 core indicating percentages of floral components in samples.

The following palaeoclimate climate parameters are considered: MAT – mean annual temperature (°C); CMT – mean temperature of thecoldest month (°C); WMT – mean temperature of the warmest month (°C); MAP – mean annual precipitation (mm); HMP – precipitation of the wettest month (mm); LMP – precipitation of the direst month (mm); WMP – precipitation of the warmest month (mm). Also leaf flora has been subjected to the CA method to obtain quantitative palaeoclimate data, and the results are correlated with the climate records from palynological data (Table 1).

Results

Pollen flora

A total of 62 sporomorph taxa were identified and major floral components are indicated in Fig. 4 (Ivanov *et al.* 2002, Jiménez-Moreno *et al.* 2007). Diversity and percentages of spores are low, but the number of pollen and their quantities are high. Most of the taxa are recorded in low frequencies, but a few are abundant.

The detailed pollen diagram indicates high percentages of pollen grains of indeterminate Pinaceae, *Pinus,* Cupressaceae (mainly morpho-genus *Inaperturopollenites* and pollen grains of *Cupressacites*), evergreen *Quercus* and *Alnus* (Fig. 4). Indeterminate Pinaceae are constant and well represented in the diagram (up to 33%). They are followed by low frequencies of other coniferous forest elements: *Pinus*, *Cedrus*, *Picea*, *Pinus diploxylon* type, *P. haploxylon* type, *Podocarpus*, *Larix* and *Cathaya*. Cupressaceae are comparatively in less quantities in the lower side of the succession where they do not exceed 12%, but abundant in the higher stratigraphic levels. Among the broad-leaved forest elements evergreen *Engelhardia* and deciduous *Castanea* type constantly occur. Mixed mesophytic forest elements evergreen and deciduous *Quercus* and *Fagus* occur regularly. Evergreen *Quercus* are represented by high percentages and constantly more abundant than deciduous *Quercus*. Riparian vegetation element *Alnus* makes a peak reaching to 40% in the lower part, but decreases to the upper part. The pollen grains of *Ulmus*, *Pterocarya*, *Carya*, *Platanus* and *Zelkova* occur in low percentages, even below 1%. Some taxa such as *Cedrus*, *Cathaya*, *Larix*, *Reevesia*, *Sequoia*, Sapotaceae, *Carpinus*, *Parrotia persica*, Oleaceae, *Betula*, *Ilex*, *Ostrya*, *Phillyrea*, *Cycas*, *Tilia*, *Salix*, *Liquidambar* and Nyssaceae occur in low percentages and discontinuously. Herbaceous plants (Cyperaceae, *Sparganium*, Asteraceae, Chenopodiaceae, *Ephedra*, Caryophyllaceae and Brassicaceae) are represented by minor quantities throughout the diagram.

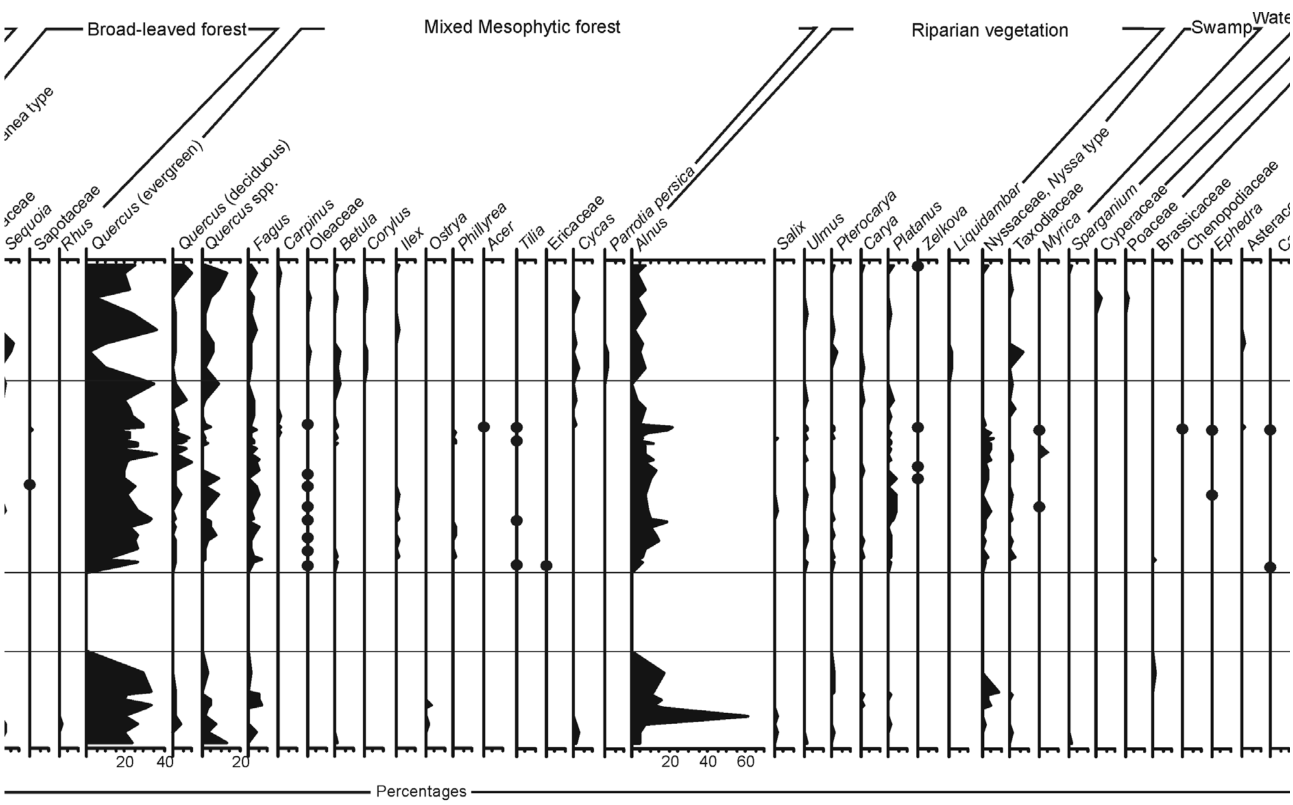


Figure 4 – continued

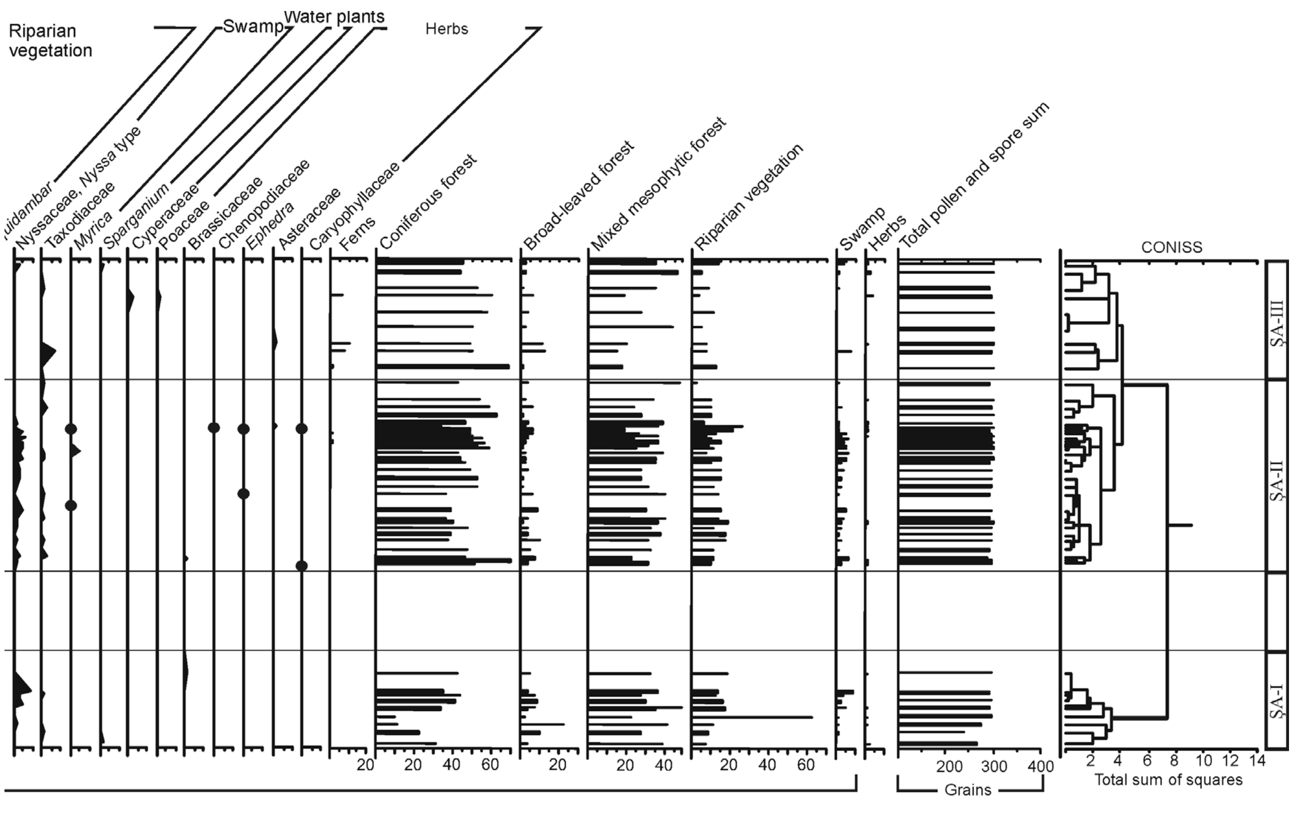


Figure 4 – continued

Table 3. Coexistence intervals of individual samples from palynoflora.

Samples	Number of taxa	MAT (°C)	CMT (°C)	WMT (°C)	MAP (mm)	HMP (mm)	LMP (mm)	WMP (mm)
08/01 (top)	12	15.6–18.4	5.0–12.5	24.7–28.1	823–1520	204–227	8–41	79–125
08/06	10	15.6–18.4	5.0–12.5	24.7–28.3	823–1577	204–227	5–41	79–125
08/07	10	15.6–18.4	5.0–12.5	24.7–28.3	823–1577	204–227	8–41	79–125
08/09	11	15.6–21.3	5.0–13.3	24.7–28.3	823–1595	204–227	8–54	79–125
08/12	13	15.6–21.3	5.0–17.0	24.7–28.3	823–1520	204–227	5–54	79–125
08/15	16	15.6–18.4	5.0–12.5	24.7–28.1	823–1520	204–227	5–41	79–125
08/17	13	15.6–18.4	5.0–12.5	24.7–28.1	823–1574	204–227	8–41	79–125
08/21	11	15.6–21.3	5.0–13.3	24.7–28.1	823–1520	204–227	8–43	79–125
08/24	11	15.6–21.3	5.0–13.3	24.7–28.1	823–1520	204–227	8–43	79–125
08/26	13	15.6–21.7	5.0–15.6	24.7–28.1	823–1520	204–227	5–43	79–125
08/29	10	15.6–21.3	5.0–13.3	24.7–28.3	823–1520	204–227	8–54	79–125
08/32	14	15.6–20.8	5.0–13.3	24.7–28.1	823–1520	204–227	9–45	79–125
08/33	16	15.6–18.4	5.0–12.5	24.7–28.1	823–1574	204–227	8–41	79–125
08/34	11	15.6–20.8	5.0–13.3	24.7–28.1	823–1574	204–227	9–43	79–125
t08/35	13	15.6–20.8	5.0–12.5	24.7–28.1	823–1520	204–227	9–41	79–125
08/36	15	15.6–18.4	5.0–12.5	24.7–28.1	823–1574	204–227	8–41	79–125
08/37	14	15.6–18.4	5.0–12.5	24.7–28.1	823–1574	204–227	9–41	79–125
08/38	13	15.6–18.4	5.0–12.5	24.7–28.1	823–1574	204–227	9–41	79–125
08/39	10	15.6–21.3	5.0–13.3	24.7–28.3	823–1595	204–227	8–54	79–125
08/40	12	15.6–18.4	5.0–12.5	24.7–28.1	823–1520	204–245	8–41	79–154
08/41	12	15.6–18.4	5.0–12.5	24.7–28.1	823–1577	204–245	16–41	79–125
08/45	10	15.6–18.4	5.0–12.5	24.7–28.3	823–1577	204–227	8–41	79–125
08/47	10	15.6–21.7	5.0–15.6	24.7–28.1	823–1520	204–245	5–43	79–180
08/49	10	15.6–18.4	5.0–12.5	24.7–28.3	823–1520	204–227	8–41	79–125
08/51	10	15.6–21.3	5.0–13.3	24.7–28.3	823–1595	204–227	8–54	79–125
08/53	10	15.6–21.3	5.0–13.3	24.7–28.3	823–1595	204–227	8–54	79–125
08/57	10	15.6–21.3	5.0–13.3	24.7–28.3	823–1613	204–353	8–54	79–163
08/61	10	15.6–21.3	5.0–13.3	24.7–28.3	823–1520	204–227	8–54	79–125
08/62	13	15.6–21.3	7.7–13.3	24.7–28.3	1003–1520	204–245	8–45	79–163
08/64	10	15.6–20.8	5.0–13.3	24.7–28.1	823–1520	204–227	9–54	79–125
08/71	10	15.6–23.1	5.0–13.3	24.7–28.3	823–1520	204–245	5–59	79–180
08/72	10	15.6–21.3	5.0–13.3	24.7–28.3	823–1520	204–245	8–54	79–125
08/74	11	15.6–20.8	5.0–13.3	24.7–28.1	823–1520	204–245	9–43	79–125
08/76	12	15.6–21.3	5.0–13.3	24.7–28.3	823–1520	204–245	16–67	79–154
08/77	10	15.6–18.4	5.0–12.5	24.7–28.1	823–1520	204–227	9–41	79–125
08/78	10	15.6–23.1	5.0–12.5	24.7–28.3	823–1520	204–353	9–41	79–154
08/100	10	15.6–21.7	5.0–13.3	24.7–28.1	823–1574	204–227	5–43	79–125
08/102	10	15.6–23.1	5.0–12.5	24.7–28.3	823–1595	204–353	9–67	79–154
08/104	11	15.6–21.3	5.0–13.3	24.7–28.1	823–1520	204–245	8–43	79–154
08/105	10	15.6–23.1	5.0–13.3	24.7–28.3	823–1595	204–353	9–67	79–180
08/106	11	15.6–21.3	5.0–13.3	24.7–28.3	823–1520	204–227	8–54	79–125
08/113	11	15.6–21.7	7.7–15.6	24.7–28.1	1003–1574	204–323	5–43	79–180
08/115	10	15.6–23.1	5.0–13.3	24.7–28.3	823–1520	204–353	5–59	79–180
08/117	10	15.6–21.7	5.0–15.6	24.7–28.1	823–1520	204–245	5–43	79–180
08/121–125	11	15.6–21.3	5.0–15.6	24.7–28.3	823–1595	204–353	8–67	79–154
08/130 (base)	12	15.6–18.4	5.0–12.5	24.7–28.1	823–1520	204–227	9–41	79–125

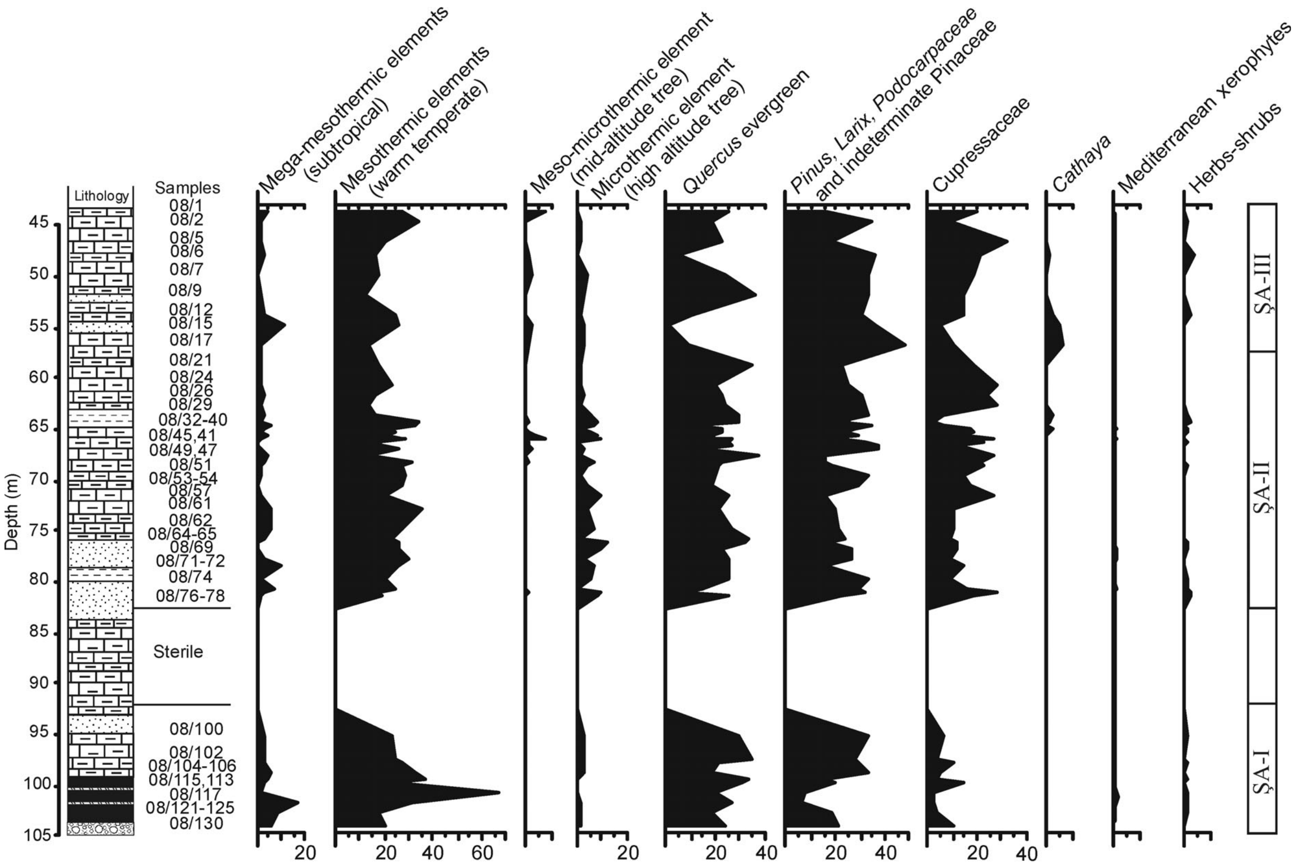


Figure 5. Synthetic pollen diagram. Pollen taxa have been grouped on the basis of ecological criteria (according Suc 1984, Jiménez-Moreno *et al.* 2005): Mega-mesothermic elements (subtropical): Taxodiaceae, *Engelhardia, Myrica*, Sapotaceae, *Castanea-Castanopsis* type, Cyrillaceae-Clethraceae, *Reevesia*, Arecaceae; *Cathaya*; Mesothermic elements (warm temperate): deciduous *Quercus, Carya, Pterocarya,* Oleaceae, *Carpinus*, *Ostrya, Parrotia persica, Zelkova, Ulmus, Tilia, Acer, Liquidambar, Alnus, Salix, Platanus, Nyssa, Ilex, Betula, Sequoia* and *Fagus*; *Pinus*, *Larix*, Podocarpaceae and indeterminate Pinaceae; Meso-microthermic element (cool temperate): *Cedrus*; Microthermic element (cool): *Picea*; Mediterranean xerophytes: *Rhus* and *Phillyrea*; Evergreen *Quercus*; Cupressaceae; Herbs-shrubs: Poaceae, Amaranthaceae-Chenopodiaceae, Asteraceae, *Ephedra*, Cyperaceae, *Sparganium*, Brassicaceae and Caryophyllaceae.

According to quantitative changes in certain sporomorphs, the pollen diagram has been divided into three pollen phases (= local pollen zones) which are corroborated by CONISS clustering via TILIA 2.0 (Fig. 4). However, due to lack of pollen grains, there is a gap in the pollen diagram between 82.15 and 95.2 m (samples 08/79–99).

Local pollen zone ŞA-I (core depth 95.2–103.04 m; samples 08/100–130)

This zone is characterized by the highest average content of *Alnus,* represented mainly by values from 5 to 12%, with a maximum of 62.5% at 100.25 m (sample 08/115), and Cyrillaceae-Clethraceae*,* represented mainly by values from 1 to 5%, occasionally higher (13.46% at 101.2 m; sample 08/117). Indeterminate Pinaceae are characterized with higher values of 0 to 30%, and tend to increase towards the upper part of the zone. Evergreen oaks (*Quercus*, range 25.2–35%) abundantly occur. Cupressaceae appear regularly with values of 2.5 to 12%. *Picea* is represented with the values range from 0 to 3.8%. Nyssaceae reach to the highest occurrence about 9.6% at 97.50 m (sample 08/102). Spores are represented by scarce grains of Schizaeceae, Gleicheniaceae?, Polypodiaceae, Pteridaceae and *Lycopodium* (Fig. 5). Open vegetation elements, Brassicaceae, are found in minor quantities. Low percentages of *Rhus* and *Ostrya* occur in this zone.

Local pollen zone ŞA-II (core depth 57.43–82.15 m; samples 08/21–08/78)

The diversities and percentages of spores slightly increase in this zone. Indeterminate Pinaceae have more or less similar percentages in fluctuating abundances (Fig. 5). The pollen of *Cedrus*, *Larix*, *Pinus haploxylon* type, *Podocarpus, Reevesia*, Sapotaceae, Oleaceae, *Phillyrea*, *Acer*, *Tilia*, *Ilex*, *Zelkova*, Chenopodiaceae, *Ephedra*, Asteraceae and Caryophyllaceae appear in low amounts. The pollen

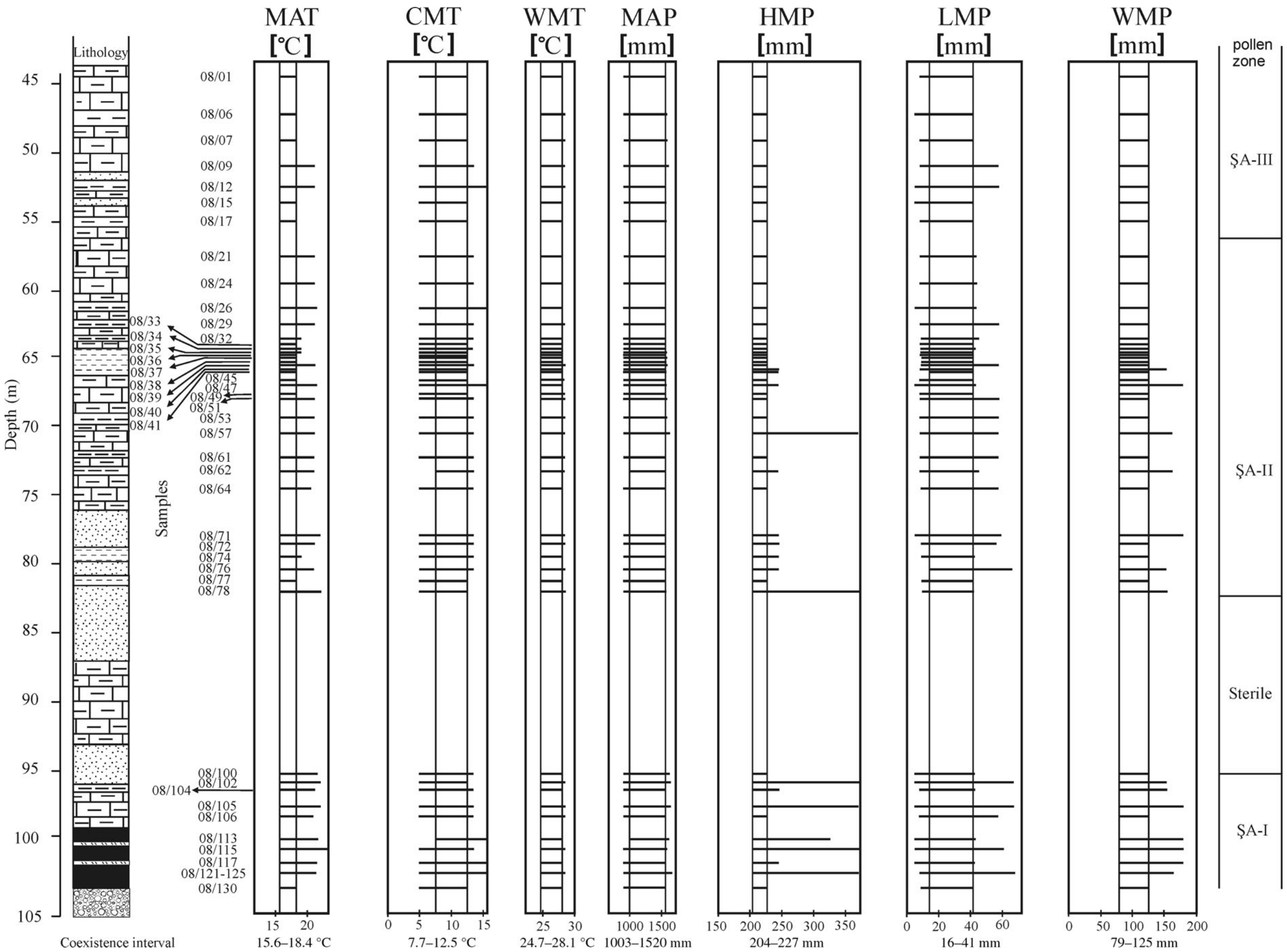


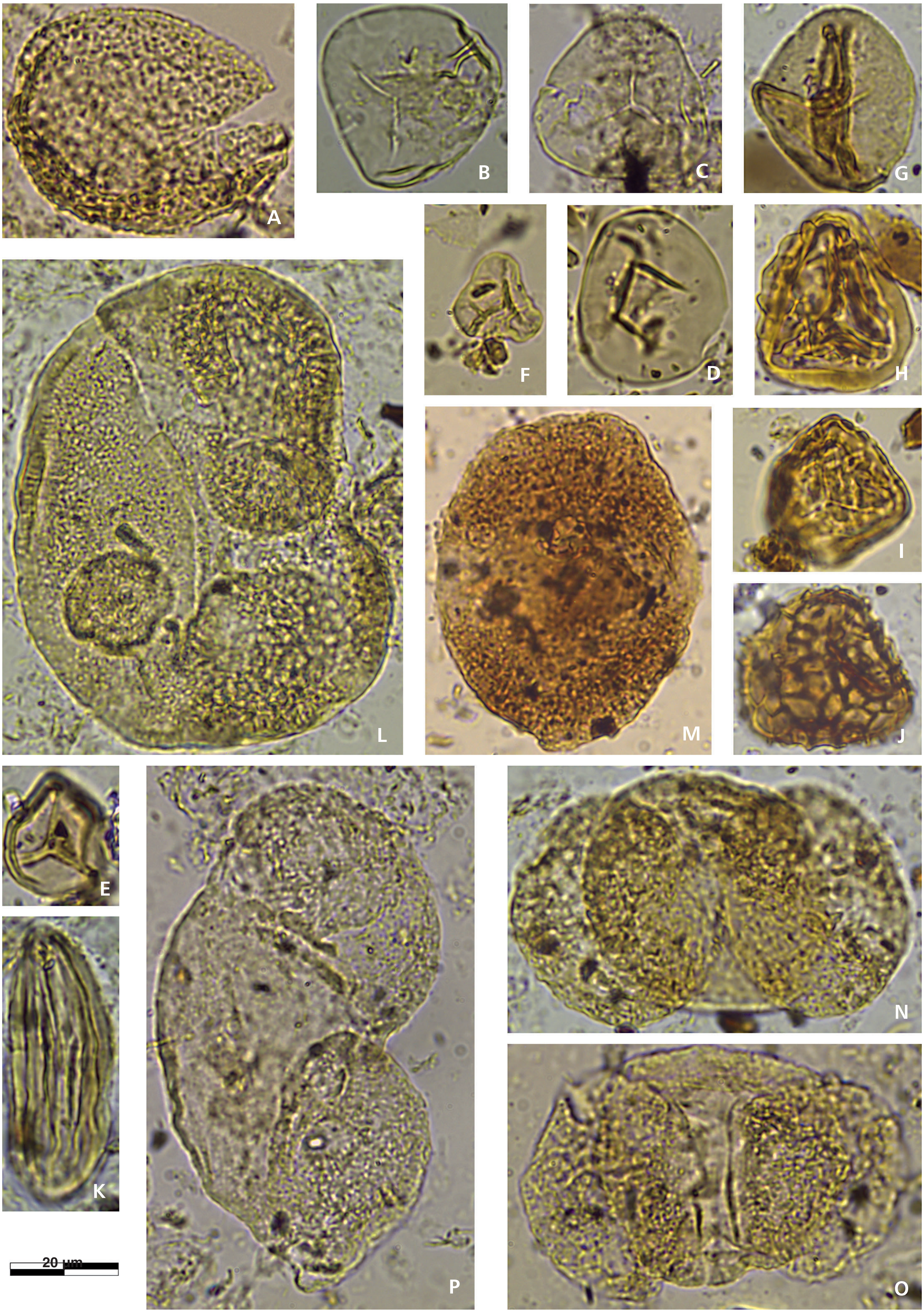
Figure 6. Coexistence intervals of each sample from the Şahinali palynoflora.

of *Picea*, *Pinus*, *Pinus diploxylon* type, deciduous *Quercus*, *Platanus* and Taxodiaceae have slightly increased. *Picea* is mainly represented by the values of 2.5 to 12.5%, and has maximum values of 12.6% at 76.16 m (sample 08/69). The curve of *Pinu*s reaches a peak of 20.02% at 62.5 m (sample 08/29). *Pinus diploxylon* type has slightly increased along the zone 2. The percentages of the Cupressaceae rise significantly upwards, reaching up to 25–28% at 80.78 m (sample 08/77). Whereas the percentages of *Alnus* mark a slight tendency to decrease and values of 7–8% are most common, occasionally up to 21% at 63.8 m (sample 08/33). Also Cyrillaceae-Clethraceae decrease and values range from 1 to 2%. Herbs such as Caryophyllaceae, Chenopodiaceae, Brassiacaceae, *Ephedra* and Poaceae are rarely observed or even single grains recorded.

Local pollen zone ŞA-III (core depth 42.84–57.43 m; samples 08/01–08/17)

The highest percentages of the ferns are recorded in this zone. *Lycopodium* reaches up to 2% at 53.75 m and 47.4 m (samples 08/15 and 08/06). Sphagnaceae and unknown botanical affinity of *Punctatisporites* sp. also reach

Figure 7. Each illustration is accompanied by its name, sample number, depth of the Şahinali-2 core and local pollen zones. Scale bar 20 µm for all photographs. • A – *Osmunda*, sample 08-38; depth 65.0 m; ŞA-II. • B, C – *Lygodium*; B – sample 08-51; depth 67,5 m; ŞA-II, C – sample 08-72; depth 78.10 m; ŞA-II. • D – Polypodiaceae, sample 08-130; depth 103.85 m; ŞA-I. • E – Sphagnaceae, sample 08-12; depth 53.25 m; ŞA-III. • F – Gleicheniaceae?, sample 08-130; depth 103.85 m; ŞA-I. • G – *Punctatisporites* sp., sample 08-12; depth 53.25 m; ŞA-III. • H, I – Pteridaceae; H – sample 08-15; depth 53.75 m; ŞA-III, I – sample 08-130; depth 103.85 m; ŞA-I. • J – *Lycopodium* sample 08-06; depth 47.40 m; ŞA-I. • K – *Ephedra,* sample 08-62; depth 74.4 m; ŞA-II. • L – *Picea*, sample 08-69; depth 76.1 m; ŞA-II. • M – *Pinus haploxylon* type, sample 08-17; depth 56.2 m; ŞA-I. • N, O – *Pinus diploxylon* type; N – sample 08-09; depth 50.95 m; ŞA-III, O – sample 08-07; depth 49.10 m; ŞA-III. • P – *Pinus* spp.; sample 08-69; depth 76.1 m; ŞA-II.


A
B
C
G
F
D
H
L
M
I
J
E
K
P
N
O
20 µm

up to 4.8% and 4.9% at 53.25 m, respectively (sample 08/12). Pteridaceae make a peak, percentage values of 3.8% at 53.75 m (sample 08/15). The pollen of *Corylus*, *Parrotia persica*, *Liquidambar*, Cyperaceae and Poaceae appear in minor quantities. Indeterminate Pinaceae achieve their highest percentages of 32.8% at 56.18 m (sample 08/17). The pollen of *Picea*, *Alnus* and *Platanus* mark a slight tendency to decrease, whereas *Pinus*, *Pinus diploxylon* type and *Cathaya* have increased. Taxodiaceae reach their maximum values, 7.1% at 53.75 m (08/15 sample). Compared to other local zones, Nyssaceae are represented by low percentages. The highest percentages of *Sequoia,* around 6% at 53.25 m (sample 08/12), were recorded in this zone.

The three local zones are very similar in having major tree genera indeterminate Pinaceae, evergreen *Quercus*, *Pinus*, Cupressaceae and *Alnus*. Even though there were some fluctuations in the three zones, the main types remained the same. It indicates that evergreen and deciduous mixed mesophytic and coniferous forest assemblages were dominant during the Early–Middle Miocene.

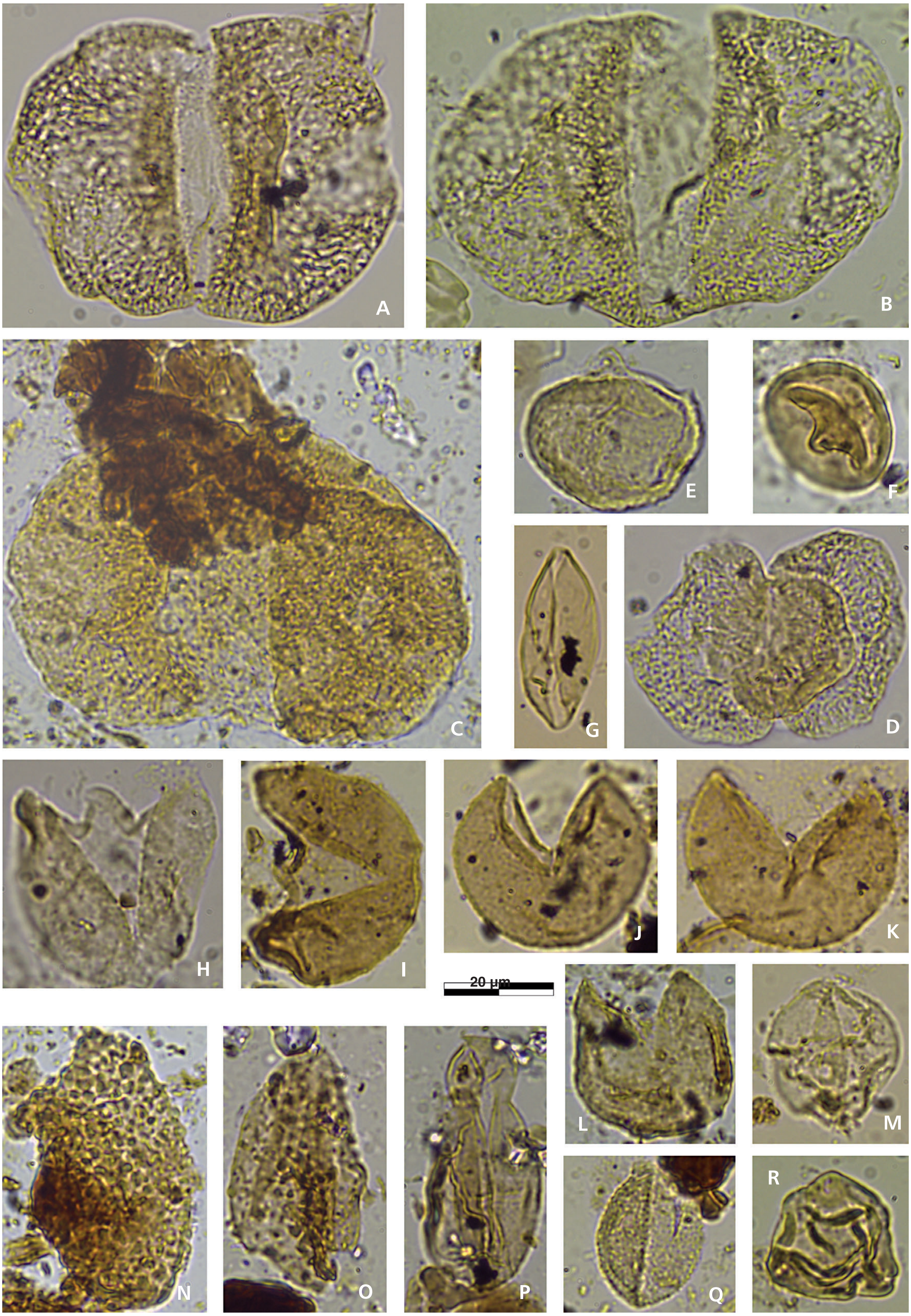
Leaf flora

Mädler & Steffens (1979) and Gemici *et al*. (1993) described 32 taxa (Table 2) from the marl-dominated lithologies above the main coal seam corresponding to local pollen zones ŞA-II and ŞA-III (Fig. 3). The assemblage predominantly includes high quantities of *Laurus*, *Cinnamomophyllum*, *Myrica*, evergreen oaks (*Quercus mediterranea* and *Q. drymeja*), and alder (*Alnus*) (Madler & Steffens 1979). Evergreen *Quercus* and *Alnus* are predominantly found in the palynological data as well. Subtropical climate was suggested on the basis of thermophilous elements such as *Cercis*, *Laurus* and evergreen *Quercus*. Also Gemici *et al*. (1993) indicated that mixed mesophytic forest assemblage was dominated by oaks. Pinaceae constantly occurred in all strata. Swamp vegetation was represented by *Glyptostrobus europaeus* and *Myrica lignitum*.

Palaeovegetation

On the basis of palynomorphs and leaves, it is possible to draw a general picture of the different vegetation units surrounding of Şahinali open cast mine for the whole sequence. In the area, forested environments should have covered much of the landscape for the time of deposition of sediments, as coniferous forest and evergreen to deciduous mixed mesophytic forests were dominant in the succession (Fig. 4). Broad-leaved forest and riparian vegetation elements are of secondary importance. Ferns, herbaceous plants and swamp elements occur in minor amounts (Fig. 4). In the assemblages evergreen *Quercus* and coniferous forest Cupressaceae were widespread. In contrast, lower percentages of mesothermic elements with contributions by deciduous *Quercus*, Oleaceae, *Acer*, *Tilia* and *Betula* were recorded. Their limited occurrence indicates lowlands and mid-altitude upland environments that also permit the growth of *Fagus, Carpinus* and *Ilex*. In these forests some thermophilous evergreen broad-leaved plants such as Arecaceae, *Engelhardia* and *Reevesia* survived. Evergreen and deciduous mixed forest assemblages are well evidenced by macrofloral records of *Laurus*, *Laurophyllum*, sclerophyllous oaks (*Quercus mediterranea* and *Q. drymeja*), *Carya serraefolia, Castanea kubinyii*, *Betula subpubescens*, *Diospyros* cf. *anceps*. *Diospyros* sp., *Magnolia* sp., *Symplocos* sp., *Fraxinus* sp., *Acer* sp., *Tilia* sp., and certain species of *Fagus* (*e.g*., *F. attenuata* and *F. orientalis*) (Table 2) and microfloral records of Cyrillaceae-Clethraceae, *Engelhardia*, *Castanea*, Sapotaceae, deciduous *Quercus*, *Fagus*, *Carpinus*, *Betula*, *Parrotia persica*, *Ostrya* and *Acer* (Fig. 4). Also, the palaeo-lake was surrounded by dense hydrophilous trees such as *Alnus* (both micro- and macrofloras), *Salix*, Nyssaceae, Taxodiaceae, *Myrica*, *Liquidambar* (microfloral record) and the azonal element *Populus balsamifera* as NLR of *P. balsamoides* (macrofloral record). *Alnu*s, as a component of wetland forest community presents changing percentages from the lower side to the top of the succession (Fig. 4). The azonal elements *Glyptostrobus europaeus* and *Myrica lignitum* and evergreen broad-leaved plants *Daphnogene* may also have been part of the wetland gallery forest. The understorey vegetation was composed of different kinds of ferns in low quantities. The pollen of hygrophilous plants like sedges (Cyperaceae) and cattails (*Sparganium*) are poorly presented in the pollen spectra. Herbaceous plants including Poaceae, Chenopodiaceae, Brassicaceae, Caryophyllaceae, *Ephedra* and Asteraceae played a minor role in the assemblage due to their limited distribution. According to Strömberg *et al*. (2007), open habitats developed in

Figure 8. A, B – *Cathaya*; A – sample 08-76; depth 80.4 m; ŞA-II, B – sample 08-69; depth 76.1 m; ŞA-II. • C – *Cedrus*, sample 08-01; depth 42.85 m; ŞA-III. • D – *Podocarpus*, sample 08-76; depth 80.4 m; ŞA-II. • E, F – *Sequoia*, sample 08-62; depth 74.8 m; ŞA-II. • G – *Cycas* sample 08-24; depth 59.75 m; ŞA-II. • H, I – Taxodiaceae; H – sample 08-62; depth 74.8 m; ŞA-II, I – sample 08-21; depth 57.45 m; ŞA-II. • J–L – Cupressaceae; J, K – sample 08-21; depth 57.45 m; ŞA-II, L – sample 08-09; depth 50.95 m; ŞA-III. • M – Poaceae, sample 08-115; depth 100.25 m; ŞA-I. • N, O – *Liriodendron*; N – sample 08-06; depth 47.40 m; ŞA-III, O – sample 08-121; depth 102.2 m; ŞA-I. • P – Cyperaceae, sample 08-06; depth 47.40 m; ŞA-III. • Q – Sparganiaceae, sample 08-117; depth 101.2 m; ŞA-I. • R – *Myrica*, sample 08-47; depth 66.8 m; ŞA-II.


A
B
C
E
F
G
D
H
I
J
K
20 µm
L
M
N
O
P
Q
R

Asia Minor (Turkey) beginning already in the Early Miocene based on phytolith studies. But, analyses of Anatolian pollen profiles document an increasing abundance of open vegetation taxa only during the Tortonian (Benda *et al.* 1974, Akgün & Akyol 1999, Akgün *et al.* 2000, Akgün *et al.* 2007, Kayseri & Akgün 2008, Akkiraz *et al.* 2011). This may indicate a general reduction in tree cover and predominance of open-habitat grasses throughout the Miocene in Turkey. Low quantities of herbaceous plants indicate that open areas were not widespread in the Şahinali area during the Early–Middle Miocene.

On more elevated parts, mid-high altitude elements are confirmed by high quantities of indeterminate Pinaceae and low amounts of *Cedrus*, *Picea*, *Podocarpus*, *Larix* and *Cathaya*. However, low quantities of these taxa represented in the pollen records during the Early–Middle Miocene may be interpreted as owing to low altitude of the surrounding mountains or distance of a mountain range. In other words, although palaeogeographic reorganizations took place in global scale, Miocene tectonic movements had no significant influences since the floras included low amounts of high altitude conifers and sediments are more or less uniform and almost horizontally layered. Indeterminate Pinaceae are abundant probably due to capacity of saccate pollen for long-distance transport (Suc & Drivaliari 1991).

Altogether, changes in quantitative values of individual pollen taxa permit us to distinguish three stages in the development of the fossil vegetation. The first includes pollen spectra from 95.2 to 103.04 m corresponding to local pollen zone ŞA-I and is characterized by flooded forests related to high water table (Nyssaceae and *Alnus*) and comparatively low quantities of conifers and herbs. Also mesothermic elements are dominant (Fig. 5).

The second stage (57.43 to 82.15 m) is mainly characterized by higher percentages of conifers, and accompanied by a slight increase in the abundance of mixed mesophytic forests. Swamp and riparian elements have more or less similar percentages. However, during the pollen zones ŞA-II and ŞA-III, an increase of *Larix*, *Corylus*, *Betula* and *Ephedra* has been observed. The group of mesothermic elements is predominant during the ŞA-II (Fig. 5). In contrast, the group of meso-microthermic and microthermic elements slightly increases. Pollen of *Cedrus* and *Picea* attain higher values.

In the third stage (42.84 to 57.43 m), a reduction in proportion of *Alnu*s and Nyssaceae has been observed that may indicate a decrease of flooded settings. Compared to the previous pollen zones, high quantities and biodiversities of spores occur in third stage.

In general, the plant taxa found at Şahinali open cast mine are similar to those found today in southeastern Mediterranean region with woodland xeric variety of *Quercus,* pines, *Olea europaea* var. *oleaster*, *Ceratonia siliqua*, *Nerium oleander*, *Ulmus glabra*, *Juniperus*, Poaceae and other herbs (Roberts & Wright 1993).

Palaeoclimate evolution using the CA method

In this section, quantitative palaeoclimate data from the CA based on micro- and macrofloras are presented and correlated with palaeovegetation.

For microflora, the individual analyses of all samples provide information about possible brief climate modifications within the studied interval. As the resolution and the reliability of the resulting coexistence intervals increase with the number of taxa included in the analysis, some samples with lower than 10 taxa were not included in the climate calculations (Bruch & Mosbrugger 2002, Bruch & Zhilin 2007) (Table 3).

The climate parameters have been determined for 46 individual palynofloral assemblages from samples 08/01 to 08/130 (Fig. 6 and Table 3). Although some samples have yielded wider coexistence intervals than others, all coexistence intervals from the 46 samples overlap. However, the coexistence intervals are mostly similar for each sample and give no indication for climate changes from ŞA-I to

Figure 9. A, B – *Engelhardia*; A – sample 08-53; depth 68.80 m; ŞA-II, B – sample 08-115; depth 100.25 m; ŞA-I. • C – *Reveesia*, sample 08-12; depth 53.25 m; ŞA-III. • D – *Carya*, sample 08-76; depth 80.4 m; ŞA-II. • E – *Tilia*, sample 08-41; depth 65.35 m; ŞA-II. • F, G – *Betula*; F – sample 08-15; depth 53.75 m; ŞA-III, G – sample 08-76; depth 80.4 m; ŞA-II. • H – *Alnus*, sample 08-76; depth 80.4 m; ŞA-II. • I – *Zelkova*, sample 08-38; depth 65.0 m; ŞA-II. • J – *Ulmus*, sample 08-62; depth 74.8 m; ŞA-II. • K – *Pterocarya*, sample 08-57; depth 70.85 m; ŞA-II. • L, M – *Corylus*; L – sample 08-12; depth 53.25 m; ŞA-III, M – sample 08-104; depth 98.0 m; ŞA-I. • N, O – *Quercus* spp.; N – sample 08-07; depth 49.10 m; ŞA-III, O – sample 08-21; depth 57.45 m; ŞA-II. • P–R – evergreen *Quercus*; P – sample 08-26; depth 61.30 m; ŞA-II, Q – sample 08-09; depth 50.95 m; ŞA-III, R – sample 08-40; depth 65.10 m; ŞA-II. • S, T – *Platanus*, sample 08-62; depth 74.8 m; ŞA-II. • U, V – *Salix*; U – sample 08-45; depth 66.2 m; ŞA-II, V – sample 08-115; depth 100.25 m; ŞA-I. • W – Oleaceae, sample 08-45; depth 66.2 m; ŞA-II. • X – *Rhus*, sample 08-117; depth 101.2 m; ŞA-I. • Y, Z – deciduos *Quercus*; Y – sample 08-62; depth 74.8 m; ŞA-II, Z – sample 08-69; depth 76.1 m; ŞA-II. • AA, BB – Oleaceae; AA – sample 08-47; depth 66.80 m; ŞA-II, BB – sample 08-49; depth 67.1 m; ŞA-II. • CC, DD – *Phillyrea*; CC – sample 08-38; depth 65.0 m; ŞA-II, DD – sample 08-69; depth 76.1 m; ŞA-II. • EE, FF – *Castanea*, sample 08-117; depth 101.2 m; ŞA-I. • GG – *Parrotia persica*, sample 08-15; depth 53.75 m; ŞA-III. • HH – *Fagus*, sample 08-49; depth 67.1 m; ŞA-II. • II, JJ – *Nyssa*; II – sample 08-38; depth 65.0 m; ŞA-II, JJ – sample 08-76; depth 80.4 m; ŞA-II. • KK – *Acer*, sample 08-106; depth 98.75 m; ŞA-I. • LL – Chenopodiaceae, sample 08-76; depth 80.4 m; ŞA-II. • MM, NN – Caryophyllaceae; MM – sample 08-76; depth 80.4 m; ŞA-II, NN – sample 08-78; depth 81.2 m; ŞA-II. • OO – *Ilex*, sample 08-01; depth 42.85 m; ŞA-III. • PP – Sapotaceae, sample 08-12; depth 53.25 m; ŞA-III.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB
CC
DD
EE
FF
GG
HH
II
JJ
KK
LL
MM
NN
OO
PP
20 µm

ŞA-III. Using the combined samples, the values obtained are 15.6 to 18.4 °C for MAT, 7.7 to 12.5 °C for CMT, 24.7 to 28.1 °C for WMT, 1003 to 1520 mm for MAP, 204 to 227 mm for HMP, 16 to 41 for LMP, and 79 to 125 mm for WMP (Table 1). Although some samples yield wider coexistence intervals, the climate analysis of most of the samples points to a rather constant climate.

The macroflora analyzed from the same area (Madler & Steffens 1979, Gemici *et al*. 1993) contains a total of 32 taxa, 17 of which were used for calculating the coexistence intervals (Table 2). The values obtained 14.4 to 15.4 °C for MAT, 5.6 to 7 °C for the CMT, 26.4 to 27.7 °C for WMT, 1031 to 1171 mm for MAP, 124 to 134 mm for HMP, 10 to 11 mm for LMP, and 90 to 94 mm WMP (Table 1).

Comparing the quantitative palaeoclimate data from palynofloras and leaf flora, in general the coexistence intervals from these two datasets are close to each other and mostly overlap, although the taxa that border the coexistence intervals in the two data sets are different (Table 1). Both datasets are good in agreement, implying internal consistency in the method. In general, the CA on the basis of palynoflora yields wider coexistence intervals than on leaf floras (Mosbrugger & Utescher 1997, Liang *et al*. 2003). This is believed to be related to the fact that NLRs of Paleogene and Neogene palynomorphs are frequently determined only as family whereas nearest living relatives of Paleogene and Neogene leaves are more reliably identified to specific and generic level.

Indeed, large quantities of evergreen *Quercus* in the pollen records imply that the palaeoclimate may have been warm with mild winters. In the assemblages, subtropical element, *Nyssa*, occur steadily in minor percentages throughout the pollen record. In contrast, the mixture of deciduous elements (deciduous *Quercus*, *Alnus*, *Betula*, *Carpinus*, *Carya*, *Corylus*, *Platycarya*, *Ulmus*) in the pollen assemblage would tend to suggest a more temperate climate with a cold season. This conflict may be interpreted by palaeogeographic elevation which permitted to develop the vegetation from basin (palaeo-lake) to upland environment or climate cooling. However, several thermophilous plants such as Cyrillaceae-Clethraceae, *Engelhardia*, *Reveesia*, Arecaceae, Sapotaceae, Taxodiaceae and *Myrica* lived at low elevations. Meso-microthermic element *Cedrus* indicates the establishment of drier and cooler episodes. According to mesothermic element *Ostrya,* it is an evidence of the existence of drier and sunny biotop. Also Mediterranean plant evergreen *Quercus* may indicate in certain seasonality in precipitation or xerophilous azonal vegetation type (Utescher *et al*. 2007, Jiménez-Moreno *et al*. 2008). Therefore, it can be assumed the vegetational development in the Early–Middle Miocene of the Şahinali open cast mine is independent from climate. All climate variables appear to be consistent and indicate warm-temperate and humid climate.

As indicated in the palaeovegetation chapter, herbaceous communities such as Poaceae, Chenopodiaceae, Brassicaceae, Caryophyllaceae, *Ephedra* and Asteraceae had limited a distribution. With regard to *Ephedra*, its presence indicates aridity that may be supported by LMP (10–11 mm) based on leaf flora. Today, *Ephedra* grows in arid and semiarid areas. On the other hand, abundances of herbaceous taxa were reported in southeastern Mediterranean area by Ivanov *et al*. (2002, 2007) and Jiménez-Moreno *et al*. (2007) who pointed out drier climate. However, minority of herbaceous plants defined in this study points to the absence of prevalent dry conditions.

Modern climate the mean values of Aydın surrounding can be comparable with the fossil ones. Precipitation estimates of Early–Middle Miocene seem to be higher than today (Table 1). However, it should be considered that palaeoclimate and precipitation values may vary considerably over short distances, especially if there is mountainous relief near the basin. Overall, the floral records suggest that throughout the studied time-interval the palaeoclimate was of a relatively stable warm-temperate and summer-moist type. Sandy and muddy beds in the Şahinali sequence may imply hillwash owing to high annual rainfall and streams.

Comparison with floras of neighboring areas

Floral data from the Miocene deposits in western Turkey provide valuable information for possible correlation.

Micro- and macrofloristic studies on the Miocene sediments of Kütahya area (Seyitömer and Tunçbilek sub-basins) were made by Nebert (1962), Mädler & Steffens (1979), Yavuz-Işık (2007) and Akkiraz *et al*. (2011) (Fig. 1A). In the Seyitömer Sub-basin, there are several common and widespread taxa, such as conifers, undeterminable Pinaceae, *Pinus Picea, Cedrus* and Cupressaceae, deciduous broad-leaved forest element *Castanea-Castanopsis* and mixed mesophytic forest element evergreen *Quercus.* The Seyitömer palynoflora appears to resemble local pollen zones ŞA-II and ŞA-III of the Şahinali palynoflora due to abundances of above mentioned taxa, but differs in the rich occurrence of ferns such as Polypodiaceae and *Osmunda*.

Palynoflora of the Tunçbilek Sub-basin was first examined by Akkiraz *et al.* (2011) who determined high quantities of *Alnus*, Arecaceae, undeterminable Pinaceae, Cupressaceae, Polypodiaceae and *Osmunda*. Abundances of *Alnus* in the ŞA-I and Tunçbilek palynoflora are concordant, but it is difficult to correlate in detail.

The Early–Middle Miocene fossil assemblage from the Kütahya area (Seyitömer and Tunçbilek sub-basins) described by Nebert (1962) and Madler & Steffens (1979) is species-poorer in the leaf record. The following leaf flora was determined: *Laurophyllum pirimigenium*, *Fraxinus, Diospyros brachysepala*, *Fagus attenuate*, *Myric*a *lignitum, Sciadopits tertiaria Taxodium dubium*, Taxodiaceae, *Glyptostrobus*, Lauraceae, *Engelhardia*, *Zelkova* and *Nerium*. In the Kütahya area, the absence of *Populus* and *Sapindus* is remarkable. However, the floras of the Kütahya and Şahinali areas share the presence and sometimes abundance of *Myric*a *lignitum*, *Fagus attenuate* and *Glyptostrobus*.

The Early–Middle Miocene pollen flora of the İzmir-Tire area (Fig. 1A) is dominated by Polypodiaceae, *Pteris*, Pinaceae, Cupressaceae, Taxodiaceae, Myricaceae, *Engelhardia Castanea*, evergreen *Quercus*, Oleaceae *Alnus*, *Ulmus* and *Carya* (Emre *et al*. 2011). Local zone ŞA-I of the Şahinali palynoflora is comparable with the Tire palynoflora, but smaller amounts of ferns, Polypodiaceae and *Pteris*, riparian elements such *Ulmus* and *Carya* were recorded in the Şahinali palynoflora.

Macroflora of the Tire area was studied by Gemici *et al*. (1992). A limited number of leaves are shared with the macroflora of the Şahinali area: *Pinus*, *Fagus orientalis*, *Quercus goepperti*, cf. *Q. neriifolia*, *Acer* and *Fraxinus*, *Daphnogene polymorpha*, *Populus latior*, and *Sapindus falcifolius*.

Middle Miocene microflora of the Manisa-Çıtak area (Fig. 1A) was studied by Akgün & Akyol (1987) who indicated high proportions of Polypodiaceae and riparian element *Alnus*. In assemblage, deciduous *Castanea,* evergreen *Engelhardia* and mixed mesophytic forest element *Quercus* constantly occurred but in low amounts. Local zone ŞA-I of the Şahinali palynoflora can be correlated with the Manisa-Çıtak palynoflora.

Gemici *et al*. (1991) described rich micro- and macrofloras of the Soma area (Fig. 1A). Local pollen zones ŞA-II and ŞA-III of the Şahinali palynoflora are comparable with the Soma palynoflora that is mainly characterized by Polypodiaceae, Taxodiaceae, Pinaceae, *Engelhardia*, *Quercus* and *Castanea* and Cyrillaceae-Clethraceae.

Macroflora of the Soma area shares even more taxa with Şahinali. Nothworthy are *Pinus*, *Quercus drymeja*, *Q. mediterranea*, *Laurophyllum primigenium, Daphnogene polymorpha*, *Cinnamophyllum scheuchzeri*, *Magnolia*, *Sapindus falcifolius*, *Carya serraefolia*, *Myrica lignitum*, *M. pseudolignitum*, *Glyptostrobus europaeus* and *Tilia*. On the other hand, some elements such as *Fagus orientalis, F. attenuata*, *Populus* cf. *balsamoides*, *P.* cf. *latior*, *Quercus goepperti* and *Q. neriifolia* in the Şahinali area were not recorded in the Soma area.

These studies of the micro- and macrofloras from the Miocene lacustrine sediments in western Turkey (Nebert 1962, Madler & Steffens 1979, Akgün & Akyol 1987, Gemici *et al*. 1991, Akgün *et al*. 2007, Yavuz-Işık 2007, Akkiraz *et al*. 2011) show a flora dominated by evergreen and deciduous mixed plant assemblages and coniferous elements indicative of vegetation that is qualitatively very similar to the floras of the Şahinali area. This is indicative for the homogeneity of the floral composition in western Anatolia.

Also, micro- and macrofloras in the Şahinali coalfield and above-mentioned locations contain limited herbaceous component. Although open herbaceous formations in southern Mediterranean area are known since the Burdigalian (Suc *et al*. 1995a, b; Jiménez-Moreno 2005; Strömber *et al*. 2007), herbaceous plant communities in western Turkey had a very restricted distribution above mentioned areas where the open environments had not developed.

Conclusions

Palynomorphs recovered from the Şahinali coalfield and previous records of leaves revealed a rich and diverse flora. Our results show that during the Early–Middle Miocene the foothills of the area were mainly covered with dense coniferous forest taxa (*e.g*., indeterminate Pinaceae, Cupressaceae and *Pinus*), evergreen *Quercu*s and *Alnus*. Herbs, shrubs and water plants had limited distribution at the time of the deposition. Three local pollen zones are recognized according to relative abundances of sporomorphs. The assemblage of local pollen zone ŞA-I is dominated by flooded forests and relatively low percentages of conifers and herbs. Local pollen zone ŞA-II is represented by high percentages of pines and low percentages of mixed mesophytic, swamp and riparian elements. A reduction of flooded settings is observed in the local pollen zone ŞA-III evidenced by a drop of riparian elements. The palaeoclimate predicted by coexistence analysis based on leave and palynoflora suggests that MAT ranged from 14.4 to 18.4 °C, CMT from 5.6 to 12.5 °C, WMT from 24.7 to 28.1 °C, MAP from 1003 to 1520 mm, HMP from 124 to 227 mm, LMP from 10 to 41 mm and WMP from 79 to 125 mm. Annual precipitation estimated was higher than today. Together with the high percentages of mesothermic elements and low amounts of mega-mesothermic elements the data suggest a warm-temperate climate under the existence of evergreen and deciduous mixed forest assemblages during the Early–Middle Miocene in western Turkey.

Acknowledgments

This study was supported by a research grant from the Scientific and Technical Research Council of Turkey (TÜBİTAK Grant Code 106Y104). Special thanks go to Funda Akgün for her valuable contributions during the identification of palynomorphs. The assistance of Oğuz Mülayim and Sariye Duygu Üçbaş are appreciated who took part in the field works. I would also like to thank

Vasilis Teodoridis and Angela Bruch for their constructive reviews. Comments and useful criticism of these people helped improving an earlier version of this manuscript considerably.

References

AKGÜN, F. & AKYOL, E. 1987. Akhisar (Çıtak) çevresi kömürlerinin palinolojik incelemesi. *Türkiye Jeoloji Bülteni 30*, 35–50.

AKGÜN, F. & AKYOL, E. 1999. Palynostratigraphy of the coal-bearing Neogene deposits graben in Büyük Menderes Western Anatolia. *Geobios 32(3)*, 367–383. DOI 10.1016/S0016-6995(99)80013-8

AKGÜN, F., KAYA, T., FORSTEN, A. & ATALAY, Z. 2000. Biostratigraphic data (Mammalia and Palynology) from the Upper Miocene İncesu Formation at Düzyayla (Hafik Sivas, Central Anatolia). *Turkish Journal of Earth Sciences 9*, 57–67.

AKGÜN, F., KAYSERİ, M.S. & AKKİRAZ, M.S. 2007. Paleoclimatic evolution and vegetational changes during the Late Oligocene–Miocene period in Western and Central Anatolia (Turkey). *Palaeogeography, Palaeoclimatology, Palaeoecology 253*, 56–90. DOI 10.1016/j.palaeo.2007.03.034

AKKİRAZ, M.S., AKGÜN, F., UTESCHER, T., WILDE, V., BRUCH, A.A., MOSBRUGGER, V. & ÜÇBAS, S.D. 2011. Palaeoflora and climate of lignite-bearing Lower-Middle Miocene sediments in Seyitömer and Tunçbilek subbasins, Kütahya Province, Northwest Turkey. *Turkish Journal of Earth Sciences.* DOI 10.3906/yer-1007-45

AKYOL, E. 1964. Türkiye Tersiyer kömürleri palinolojik etüdlerine dair başlangıç. *Maden Tetkik ve Arama Enstitüsü Dergisi 63*, 29–42.

AKYOL, E. 1968. Gelik civarındaki Sulu ve şüpheli Sulu damarlarının palinolojik korelasyonu. *Türkiye Jeoloji Kurumu Bülteni 11*, 30–39.

ALÇİÇEK, H. 2010. Stratigraphic correlation of the Neogene basins in southwestern Anatolia: Regional palaeogeographical, palaeoclimatic and tectonic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology 291*, 297–318. DOI 10.1016/j.palaeo.2010.03.002

BECKER-PLATEN, J.D. 1970. Lithostratigraphische Unterschungen im Kanozoikum Südwest Anatoliens (Türkei) – Kanozoikum und Braunkohlen der Turkei. *Beihhefte zum Geologischen Jahrbuch 97*, 1–244.

BENDA, L. 1971. Grundzüge einer pollenanalytischen Gliederung des türkischen Jungtertiärs (Känozoikum und Braunkohle der Türkei) 4. *Beihhefte zum Geologischen Jahrbuch 113*, 1–46.

BENDA, L., INNOCENTI, F., MAZZUOLI, R., RADIACATI, F. & STEFFENS, P. 1974. Stratigraphic and radiometric data of the Neogene in northwest Turkey (Cenozoic and Lignites in Turkey, 16). *Zeitschrift der Deutschen Geologischen Gesellschaft 125*, 183–193.

BENDA, L. & MEULENKAMP, J.E. 1979. Biostratigraphic correlations in the Eastern Mediterranean Neogene. 5. Calibration of sporomorph associations, marine microfossils and mammal zones, marine and continental stages and the radiometric scale. *Annales géologiques des Pays Helleniques (hors série) 1*, 61–70.

BENDA, L. & MEULENKAMP, J.E. 1990. Biostratigraphic correlations in the Eastern Mediterranean Neogene. *Newsletter on Stratigraphy 23(1)*, 1–10.

BOZKURT, E. 1999. Menderes Massif: A review and comparison with the Cyclades, 103–111. *In* PAPANIKOLAUO, D. & SASSI, F.P. (eds) *Palaeozoic Geodynamic Domains and TheirAlpidic Evolution in the Tethys. Special Publications of the Geological Society of Greece. IGCP Project No 276, Newsletter, No. 6.*

BOZKURT, E. & MITTWEDE, S.K. 2005. Introduction: Evolution of continental extensional tectonics of western Turkey. *Geodinamica Acta 18*, 153–165. DOI 10.3166/ga.18.153–165.

BOZKURT, E. & OBERHÄNSLI, R. 2001. Menderes Massif (western Turkey): structural, metamorphic and magmatic evolution – a synthesis. *International Journal of Earth Sciences 89*, 679–708. DOI 10.1007/s005310000173

BOZKURT, E. & SATIR, M. 2000. The southern Menderes Massif (western Turkey): geochronology and exhumation history. *Geological Journal 35*, 285–296. DOI 10.1002/gj.849

BRUCH, A. & MOSBRUGGER, V. 2002. Palaeoclimate versus vegetation reconstruction – palynological investigations on the Oligocene sequence of the Sava Basin, Slovenia. *Review of Palaeobotany and Palynology 122*, 117–141. DOI 10.1016/S0034-6667(02)00106-9

BRUCH, A. & ZHILIN, S.G. 2007. Early Miocene climate of Central Eurasia – evidence from Aquitanian floras of Kazakhstan. *Palaeogeography, Palaeoclimatology, Palaeoecology 248*, 32–48. DOI 10.1016/j.palaeo.2006.11.014

COLLINS, A.S. & ROBERTSON, A.H.F. 2003. Kinematic evidence for Late Mesozoic–Miocene emplacement of the Lycian Allochthon over the Western Anatolide Belt, SW Turkey. *Geological Journal 38*, 295–310. DOI 10.1002/gj.957

EDİGER, V.S. 1990. Paleopalynology of coal-bearing Miocene sedimentary rocks associated with volcanics of the Biga Peninsula (NW Turkey) and the effect of volcanism on vegetation. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 180*, 259–277.

EDİGER, V.S., BATI, Z. & ALİŞAN, C. 1990. Palaeopalynology and paleoecology of *Calamus*-like disulcate pollen grains. *Review of Palaeobotany and Palynology 62*, 97–105. DOI 10.1016/0034-6667(90)90019-F

EMRE, T. & SÖZBİLİR, H. 1997. Field evidence for metamorphic core complex, detachment faulting and accomodation faults in the Gediz and Büyük Menderes Grabens, western Anatolia. *Proceedings IESCA 1995(1)*, 73–94.

EMRE, T., TAVLAN, T., AKKİRAZ, M.S. & İSİNTEK, İ. 2011. Stratigraphy, sedimentology and palynology of the Neogene-Pleistocene(?) rocks around Akçaţehir-Tire-İzmir (Küçük Menderes Graben, Western Anatolia). *Turkish Journal of Earth Sciences 20*, 27–56. DOI 10.3906/yer-1001-30

ERDEI, B., AKGÜN, F. & LUMAGA, M.R.B. 2010. *Pseudodioon akyoli* gen. et sp. nov., an extinct member of Cycadales from the Turkish Miocene. *Plant Systematics and Evolution 285(1–2)*, 33–49. DOI 10.1007/s00606-009-0253-x

GEMİCİ, Y., AKYOL, E. & AKGÜN, F. 1993. Macro and micro fossil flora of the Şahinali (Aydın) Neogene Basin. *Turkish Journal of Botany 17*, 91–106.

GEMİCİ, Y., AKYOL, E., AKGÜN, F. & SEÇMEN, O. 1991. Soma kömür havzası fosil makro ve mikroflorası. *Maden Tetkik ve Arama Dergisi 11*, 161–178.

Gemİcİ, Y., Yilmazer, Ç. & Akgün, F. 1992. Macro and micro fossil flora of the Akçaştehir (Tire-İzmir) Neogene Basin. *Turkish Journal of Botany 16*, 383–393.

Gürer, A., Bozcu, M., Yilmaz, K. & Yilmaz, Y. 2001. Neogene basin development around Söke-Kuşadası (western Anatolia) and its bearing on tectonic development of the Aegean region. *Geodinamica Acta 14*, 57–69. DOI 10.1016/S0985-3111(00)01059-7

Gürer, O.F., Sarica-Filoreau, N., Özburan, M., Sangu, E. & Doğan, B. 2009. Progressive development of the Büyük Menderes Graben based on new data, western Turkey. *Geological Magazine 146(5)*, 652–673. DOI 10.1017/S0016756809006359

Grimm, E. 1994. *TILIA and TILIAGRAPH Pollen Diagramming Program*. Illinois State Museum, Springfield, IL.

Ivanov, D., Ashraf, A.R. & Mosbrugger, V. 2007. Late Oligocene and Miocene climate and vegetation in the Eastern Paratethys area (northeast Bulgaria), based on pollen data. *Palaeogeography, Palaeoclimatology, Palaeoecology 255*, 342–360. DOI 10.1016/j.palaeo.2007.08.003

Ivanov, D., Ashraf, A.R., Mosbrugger, V. & Palmarev, E. 2002. Palynological evidence for Miocene climate change in the Forecarpathian Basin (Central Paratethys, NW Bulgaria). *Palaeogeography, Palaeoclimatology, Palaeoecology 178*, 19–37. DOI 10.1016/S0031-0182(01)00365-0

Jiménez-Moreno, G. 2005. *Utilización del análisis polínico para la reconstrucción de la vegetación, clima y paleoaltitudes a lo largo de arco alpino europeo durante el Mioceno (21–8 m.a.).* 318 pp. Ph.D. thesis, Universidad de Granada, Granada, Spain.

Jiménez-Moreno, G., Mandic, O., Harzhauser, M., Pavelić, D. & Vranjković, A. 2008. Vegetation and climate dynamics during the early Middle Miocene from Lake Sinj (Dinaride Lake System, SE Croatia). *Review of Palaeobotany and Palynology 152*, 237–245. DOI 10.1016/j.revpalbo.2008.05.005

Jiménez-Moreno, G., Popescu, S.M., Ivanov, D. & Suc, J.P. 2007. Neogene flora, vegetation and climate dynamics in southeastern Europe and the northeastern Mediterranean, 503–516. *In* Williams, M., Haywood, A.M., Gregory, F.J. & Schmidt, D.N. (eds) *Deep-time perspectives on climate change: Marrying the signal from computer models and biological proxies. The Micropalaeontological Society, Special Publications.* The Geological Society of London, London.

Jiménez-Moreno, G., Rodriguez-Tovar, F.J., Pardo-Iguzquiza, E., Fauquette, S., Suc, J.-P. & Muller, 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(1)*, 73–97. DOI 10.1016/j.palaeo.2004.10.007

Kadioğlu, M. 2000. Regional variability of seasonal precipitation over Turkey. *International Journal of Climatology 20*, 1743–1760. DOI 10.1002/1097-0088(20001130)20:14<1743 ::AID-JOC584>3.0.CO;2-G

Kaymakçi, N. 2006. Kinematic development and paleostress analysis of Denizli basin (W Turkey): implications of spatial variation of relative paleostress magnitudes and orientations. *Journal of Asian Earth Sciences 27*, 207–222. DOI 10.1016/j.jseaes.2005.03.003

Kayserİ, M.S. & Akgün, F. 2008. Palynostratigraphic, palaeovegetational and palaeoclimatic investigations on the Miocene deposits in Central Anatolia (Çorum Region and Sivas Basin). *Turkish Journal of Earth Sciences 17*, 361–403.

Koçyİğİt, A. 2005. The Denizli graben-horst system and the eastern limit of western Anatolian continental extension: basin fill, structure, deformational mode, throw amount and episodic evolutionary history, SW Turkey. *Geodinamica Acta 18(3–4)*, 167–208. DOI 10.3166/ga.18.167–208

Koralay, O.E., Dora, O.Ö., Chen, F., Satir, M. & Candan, O. 2004. Geochemistry and geochronology of orthogneisses in the Derbent (Alaşehir) Area, eastern part of the Ödemiş-Kiraz Submassif, Menderes Massif: Pan-African Magmatic Activity. *Turkish Journal of Earth Sciences 13*, 37–61.

Liang, M.M., Bruch, A., Collinson, M., Mosbrugger, V., Li, C.S., Sun, Q.G. & Hilton, J. 2003. Testing the climatic estimates from different palaeobotanical methods: an example from the Middle Miocene Shanwang flora of China. *Palaeogeography, Palaeoclimatology, Palaeoecology 198*, 279–301. DOI 10.1016/S0031-0182(03)00471-1

Mädler, K. & Steffens, P. 1979. Neue Blattfloren aus dem Oligozän, Neogen und Pleistozän der Türkei. *Geologisches Jahrbuch 33*, 3–33.

Meulenkamp, J.E. & Sissingh, W. 2003. Tertiary palaeogeography and tectonostratigraphic evolution of the Northern and Southern Peri-Tethys platforms and the intermediate domains of the African-Eurasian convergent plate boundary zone. *Palaeogeography, Palaeoclimatology, Palaeoecology 196*, 209–228. DOI 10.1016/S0031-0182(03)00319-5

Mosbrugger, V. & Utescher, T. 1997. The coexistence approach – a method for quantitative reconstruction of Tertiary terrestrial palaeoclimate using plant fossils. *Palaeogeography, Palaeoclimatology, Palaeoecology 134*, 61–86. DOI 10.1016/S0031-0182(96)00154-X

Nakoman, E. 1965. Etude palynologique de quelques échantillons de lignite provenant du bassin de Thrace (Turquie). *Annales de la Société Géologique du Nord 84*, 298–302.

Nebert, K. 1962. Serpantin kitleleri arasına sıkışmış bir Neojen blokuna misal olmak üzere Alabarda (Tavşanlı) linyit bölgesi. *Maden Tetkik ve Arama Enstitüsü Dergisi 58*, 31–37.

Roberts, N. & Wright, Jr. H.E. 1993. Vegetation, lake-level, and climatic history of the Near East and Southwest Asia, 194–220. *In* Wright, Jr. H.E., Kutzbach, J.E., Web III, T., Ruddiman, W.F., Street-Perrot, F.A. & Bartlein, P.J. (eds) *Global Climates Since the Last Glacial maximum*. University of Minnesota Press, USA.

Robertson, A.H.F., Poisson, A. & Akinci, O. 2003. Developments in research concerning Mesozoic–Tertiary Tethys and neotectonics in the Isparta Angle, SW Turkey. *Geological Journal 38*, 195–234. DOI 10.1002/gj.953

Rögl, V.F. 1998. Palaeogeographic considerations for Mediterranean and Paratethys seaways (Oligocene to Miocene). *Annalen des Naturhistorischen Museums in Wien 99A*, 279–310.

Seyİtoğlu, G., Işik, V. & Çemen, İ. 2004.Complete Tertiary exhumation history of the Menderes Massif, western Turkey: an alternative working hypothesis. *Terra Nova 16*, 358–363. DOI 10.1111/j.1365-3121.2004.00574.x

Seyitoğlu, G. & Scott, B. 1991. Late Cenozoic crustal extension and basin formation in west Turkey. *Geological Magazine 128*, 155–166. DOI 10.1017/S0016756800018343

Seyitoğlu, G. & Scott, B. 1992. The age of the Büyük Menderes graben (west Turkey) and its tectonic implications. *Geological Magazine 129*, 239–242. DOI 10.1017/S001675680000830X

Strömberg, C.A.E., Werdelin, L., Friis, E.M. & Saraç, G. 2007. The spread of grass-dominated habitats in Turkey and surrounding areas during the Cenozoic: Phytolith evidence. *Palaeogeography, Palaeoclimatology, Palaeoecology 250*, 18–49. DOI 10.1016/j.palaeo.2007.02.012

Suc, J.P. 1984. Origin and evolution of the Mediterranean vegetation and climate in Europe. *Nature 307(5950)*, 429–432. DOI 10.1038/307429a0

Suc, J.P., Bertini, A., Combourieu-Nebout, N., Diniz, F., Leroy, S., Russo-Ermolli, E., Zheng, Z., Bessais, E. & Ferrier, J. 1995a. Structure of West Mediterranean vegetation and climate since 5.3 Ma. *Acta Zoologica Cracoviense 38*, 3–16.

Suc, J.-P., Diniz, F., Leroy, S., Poumot, C., Bertini, A., Dupont, L., Clet, M., Bessais, E., Zheng, Z., Fauquette, S. & Ferrier, J. 1995b. Zanclean (~ Brunssumian) to early Piacenzian (~ early-middle Reuverian) climate from 4° to 54° north latitude (West Africa, West Europe and West Mediterranean areas). *Mededelingen Rijks Geologische Dienst 52*, 43–56.

Suc, J.P. & Drivaliari, A. 1991. Transport of bisaccate coniferous fossil pollen grains to coastal sediments: An example from the earliest Pliocene Orbria (Languedoc, southern France). *Review of Palaeobotany and Palynology 70*, 247–253. DOI 10.1016/0034-6667(91)90006-O

Şengör, A.M.C. 1987. Cross faults and differential stretching in their hanging walls in regions of low-angle normal faulting: examples from western Turkey, 575–589. *In* Coward, M.J., Dewey, J.F. & Hancock, P.L. (eds) *Continental extensional tectonics. Geological Society of London, Special Publication 28*.

Şengör, A.M.C., Görür, N. & Şaroğlu, F. 1985. Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study, 227–264. *In* Biddle, K.T. & Christie-Blick, N. (eds) *Strike-slip deformation, basin formation and sedimentation. Society of Economic Paleontologists and Mineralogists, Special Publication 37.*

Utescher, T., Djordjevic-Milutinovic, D., Bruch, A. & Mosbrugger, V. 2007. Palaeoclimate and vegetation change in Serbia during the last 30 Ma. *Palaeogeography, Palaeoclimatology, Palaeoecology 253*, 141–152. DOI 10.1016/j.palaeo.2007.03.037

Ünay, E. & Göktaş, F. 1999. Söke çevresi (Aydın) Geç Erken Miyosen ve Kuvaterner yaşlı küçük memelileri: Ön Sonuçlar. *Türkiye Jeoloji Bülteni 42(2)*, 99–114.

Ünay, E., Göktaş, F., Hakyemez, M., Avşar, M. & Şan, O. 1995. Büyük Menderes Grabeni'nin kuzey kenarındaki çökellerin Arvicolidae (Rodentia, Mammalia) faunasına dayalı olarak yaşlandırılması. *Türkiye Jeoloji Bülteni 38*, 63–68.

Vassilev, S.V. & Vassileva, C.G. 1996. Mineralogy of combustion wastes from coal-fired power stations. *Fuel Processing Technology 47(3)*, 261–280. DOI 10.1016/0378-3820(96)01016-8

Yavuz-Işık, N. 2007. Pollen analysis of coal-bearing Miocene sedimentary rocks from the Seyitömer Basin (Kütahya), Western Anatolia. *Geobios 40*, 701–708. DOI 10.1016/j.geobios.2006.11.006

Yavuz-Işık, N. 2008. Vegetational and climatic investigations in the Early Miocene lacustrine deposits of the Güvem Basin (Galatean Volcanic Province), NW Central Anatolia, Turkey. *Review of Palaeobotany and Palynology 150*, 130–139. DOI 10.1016/j.revpalbo.2008.02.001

Yilmaz, Y., Genç, Ş.C., Gürer, Ö.F., Bozcu, M., Yilmaz, K., Karacik, Z., Altunkaynak, Ş. & Elmas, A. 2000. When did the western Anatolian grabens begin to develop?, 353–384. *In* Bozkurt, E., Winchester, J.A. & Piper, J.D.A. (eds) *Tectonics and Magmatism in Turkey and the Surrounding Area. Geological Society of London, Special Publication 173*.