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# Miocene palynoflora of the Kocaçay and Cumaovası basins: a contribution to the synthesis of Miocene palynology, palaeoclimate, and palaeovegetation in western Turkey

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**Abstract:** Palynofloras of the Kocaçay and Cumaovası basins in western Turkey that belong to a time-span from the late Early to late Middle Miocene (the late Burdigalian–Serravallian) are studied and compared with published palynofloras of Europe and Turkey. Palynological data and numerical climatic results obtained by the coexistence approach indicate palaeoclimate changed from warm subtropical to temperate during the late Burdigalian–Serravallian. Moreover, the palaeoclimates of the Kocaçay and Cumaovası basins are compared with continental palaeoclimatic records of coal-bearing sediments in western Turkey and current temperatures in the İzmir region. According to this comparison, palaeoclimatic results of these basins and other localities in western Turkey show a distinct difference as a result of orographic change. The palaeovegetation in the Kocaçay and Cumaovası basins during the studied time-span was affected by palaeotopography and palaeoclimate. In these basins mixed mesophytic, coniferous forests, and swamp palaeovegetation generally predominated during the late Early–early Middle Miocene. The role of the herbaceous taxa increased at the end of the late Middle Miocene (the Serravallian) in the Kocaçay and Cumaovası basins. It is obvious from the palynomorph data of these basins that grassland palaeovegetation started to expand in the late Middle Miocene. Unlike in Central Europe, where late Burdigalian and Langhian represent a period of outstanding warmth, the so-called Mid-Miocene Climatic Optimum, cold month mean temperatures reconstructed in this study point to an ongoing cooling trend, already from the late Burdigalian onwards, possibly related to increasing terrestrial conditions in the study area.

**Key words:** Palynology, palaeoclimate, palaeovegetation, coexistence approach, western Turkey, Miocene

## 1. Introduction

The Neogene characterises a transitional stage between the greenhouse world of the Cretaceous/Paleogene and the Quaternary ice house situation (Bruch et al., 2006, 2007; Zachos et al., 2001, 2008; Yao et al., 2011). It is represented by palaeoclimatic change. Quite a number of studies in Europe and Turkey have investigated this climate change, both in the marine and terrestrial environments, in order to understand the causal relationships between palaeogeography, palaeorography, and palaeoclimate (e.g., Wolf, 1995; Utescher et al., 2000; Ivanov et al., 2002; Mosburgger et al., 2005; Bruch et al., 2006; Jiménez-Moreno, 2006; Akgün et al., 2007; Jiménez-Moreno and Suc, 2007; Jiménez-Moreno et al., 2005, 2007, 2008; Ivanov et al., 2002, 2007, 2011; Donders et al., 2009, Utescher et al., 2011; Kern et al., 2011).

Turkey is a transcontinental country more than 1600 km in length and 800 km in width. The orographic features of Turkey clearly reflect the geological structure of the territory. In western Turkey, the development of north–south trending (northeast–southwest and northwest–southeast) basins and east–west trending grabens has been attributed to 2 causes. It is suggested that north–south trending pre-Tortonian (the Early Miocene) basins were generated from a continuing post-Paleogene north–south compression and shortening of western Turkey (Şengör, 1987). The Tortonian structures are considered to originate from a north–south extensional regime (Seyitoğlu and Scott, 1991). The vast lake basins were formed during the Early–Middle Miocene and the Kocaçay and Cumaovası basins are 2 of them (Yağmurlu, 1986; Yağmurlu et al., 1988; Seyitoğlu and Scott, 1991; Emre, 1996; Koçyiğit et al., 1999; Yilmaz et al., 2000; Sözbilir, 2001, 2002; Bozkurt and Sözbilir, 2004; Emre and Sözbilir, 2007; Sözbilir et al., 2011).

Age evidence of the Kocaçay and Cumaovası basins has been obtained from the regional correlations in previous studies (i.e. Kaya et al., 2007; Sözbilir et al., 2011). Although there are a few samples in these basins that are suitable for palynological study, our study is important because the first detailed age interpretations of these basins are given in the present study. Palynological data of these

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basins are correlated with some published palynological studies in Turkey and Europe (Luttig and Steffens, 1976; Hochuli, 1978; Thiele-Pfeiffer, 1980; Akgün, 1986, 1993; Ediger, 1990; Nagy, 1990; Planderová, 1990; Gemici et al., 1991; Mai, 1991; Akgün et al., 1995, 2000a, 2000b, 2002, 2004, 2007; Ashraf and Mosbrugger, 1995, 1996; Akgün and Akyol, 1999; Karayigit et al., 1999, Stuchlik et al., 2001, 2002; Akgün and Kayseri, 2004; Ioakim et al., 2005; Jiménez-Moreno et al., 2005, 2007, 2008; Jiménez-Moreno, 2006; Kayseri et al., 2006; Jiménez-Moreno and Suc, 2007; Kayseri and Akgün, 2008). In addition, palaeoclimatic and palaeovegetational records of the Kocaçay and Cumaovası basins for the late Burdigalian–Serravallian are described in this study. Moreover, palaeoclimatic records of other regions in Turkey are evaluated to synthesise palaeoclimatic change during the Miocene. Quantitative palaeoclimatic results are compared with the central European climatic records.

**2. Materials and methods**

Ninety-five samples were collected from the claystones, mudstones, and lignite layers of the Dereköy and Vişneli formations in the Kocaçay basin (İzmir–Dereköy location) and the Çatalca and Yeniköy formations in the Cumaovası basin (İzmir–Çatalca, Yeniköy, and Gaziemir locations). The samples were treated with HCl, HF, KOH, and $HNO_3$ following standard procedures described by Kaiser and Ashraf (1974). The residue was sieved with a mesh size of 10 µm. Only 20 samples were suitable for qualitative and quantitative pollen analysis. All samples, residues, and slides are stored in Dokuz Eylül University, İzmir, Turkey. Although there are few samples that included the palynomorphs, the obtained palynological evidence of the Kocaçay and Cumaovası basins is important for the palaeoenvironmental and palaeoclimatic conditions and stratigraphy of western Anatolia. For this reason, a minimum of 100 (only 1 sample KG01/35) and a maximum of 250 individual palynomorphs per sample were counted in samples of these basins. Palynomorph identification was performed under an Olympus light microscope, usually at 40× magnification. The palynomorph diagram was prepared with Tiliagraph (2.0).

The palaeovegetation was represented by a complex mosaic because of the water availability, characteristics of the soils, orography, sea–land boundary, palaeoclimate, etc. (Jimenez-Moreno et al., 2007). The most important effect on the palaeovegetation, as in the present day, would be altitude, controlling both temperature and precipitation. For this reason, in most palynological studies on the Miocene (e.g., Suc, 1989; Jiménez-Moreno et al., 2005, 2007, 2008; Jiménez-Moreno, 2006; Jiménez-Moreno and Suc, 2007), the palaeovegetation would be organised in altitude belts, which have been compared with those found today in subtropical to temperate south-eastern China. Palaeovegetation during the Miocene in western Anatolia was affected by water availability, characteristics of the soils, orography, sea–land boundary, palaeoclimate, and precipitation. For example, the widespread graben tectonic in western Anatolia caused altitude differences (Sözbilir 2001, 2002, 2005). According to all palynostratigraphic explanations, in the pollen diagrams of Kocacay and Kemalpaşa basins, defining palynomorphs have been grouped into 8 different groups (coniferous, mixed mesophytic, lowland, riparian forests, swamp, freshwater and open vegetations, and cosmopolitan plants) based on ecological criteria in order to clearly visualise the composition of past vegetation. Percentages of *Pinus* and non-identified Pinaceae have been not excluded from the pollen sum of fossil spectra (Fauquette et al., 1998, 1999). These pollen grains of Pinaceae are often over-represented in the sediments due to their high production and over-abundance in air and water transport (Heusser, 1988; Cambom et al., 1997; Fauquette et al., 2007). Therefore, environmental assessment of the study areas is done by ignoring the abundance of Pinaceae.

Today, vegetation is characterised by very diverse trees in western Anatolia, which are subtropical, and Mediterranean elements in inner western Anatolia with warm-temperate latitude elements in the central part of western Anatolia. A richer and more diverse flora has been identified for the Miocene in Anatolia. For this purpose, sporomorphs of this study are grouped according to climatic requirements (megathermic "MEGA" (tropical), mega–mesothermic "MMT" (subtropical), mesothermic "MESO" (warm-temperate) and microthermic "MIC" elements (high-altitude elements) (Suc, 1989). Moreover, we benefited from published studies with a similar grouping (Jiménez-Moreno et al., 2005, 2007, 2008; Jiménez-Moreno, 2006; Jiménez-Moreno and Suc, 2007).

Quantitative palaeoclimate parameters were derived using the coexistence approach introduced by Mosbrugger and Utescher (1997). It is based on the assumption that Cenozoic plant taxa have similar climatic requirements as their nearest living relatives (NLRs). The aim of the coexistence approach is to find the intervals of various climate parameters for a given fossil flora in which a maximum number of NLRs of this flora can coexist; these coexistence intervals are considered as the best description of the palaeoclimatic situation under which the fossil flora had lived. The application of the coexistence approach is facilitated by computer programs (CLIMSTAT) and a database that contains the NLRs of more than 400 Cenozoic pollen and spore taxa (Mosbrugger and Utescher, 1997; Mosbrugger, 1999; Utescher and Mosbrugger, 2010) and a palaeoflora database (http://www.palaeoflora.de). Palynofloras of the Kocaçay and Cumaovası

basins were analysed by the coexistence approach. The climatic parameters discussed here are the mean annual temperature (MAT), mean temperature of coldest month (TCM), mean temperature of warmest month (TWM), and mean annual precipitation (MAP). In addition, the mean annual ranges of temperature are calculated as the difference between summer and winter temperatures (the mean annual ranges of temperature: MART = TWM – TCM (Mosbrugger and Utescher, 1997; Mosbrugger, 1999; Pross et al., 2001).

Numerical climatic values of the Cumaovası and Kocaçay basins are generally obtained using 10 taxa as was done in Western Eurasia (Utescher et al., 2007), China (Yao et al., 2011), and Bulgaria (Bozukov et al., 2009). Although using taxa numbers in the coexistence approach method is rare, climatic values of these basins are important for palaeoclimatic evolution of Europe and the palaeoclimatic changes in western Anatolia during the late Burdigalian–Langhian. Moreover, the coexistence approach values of the Büyük Menderes and Küçük Menderes Grabens were calculated by Akgün et al. (2007) and these results were used in the present study for the palaeoclimatic interpretation of western Anatolia.

## 3. Geological features of basins

### 3.1. The Kocaçay basin

This basin is a continental, fault-bounded SW–NE-oriented asymmetric basin of about 25-km length and 5-km width (Figures 1a, 1b, and 2). It is interpreted as a transtensional supradetachment basin of typical rhomboidal geometry that is determined by the configuration of the kinematically coupled low-angle/high-angle normal faults and strike-slip faults, which together make up the eastern margin of the basin (Sözbilir et al., 2004a). The basin is bounded to the west by the Bornova flysch zone and to the east by the metamorphic rocks of the Menderes Massif. One of the most distinctive characteristics of the basin is that sedimentation and tectonism are actively associated. Evidence for this includes the presence of intraformational angular unconformities and syndepositional folds and faults as well as several transgressions and regressions in the basin fill. The sedimentary fill consists of a thick (up to 1000 m) pile of deformed continental clastic/carbonate sediments and numerous thin coal seams. The sequence also includes several extrabasinal olistoliths derived from the underlying basement units. The olistoliths reach up to 500 m in diameter (Sözbilir et al., 2003). The oldest sedimentary unit in the Kocaçay basin is the Early–Middle Miocene Dereköy Formation (Figure 3), which comprises alternating sequences of alluvial and fluvial clastics that grade into lacustrine sediments, which are thickest towards the eastern margin of the basin. The first palaeontological record of this formation was obtained from the Kemalpaşa–Dereköy, Yukarıkızılca, and Dağkızılca areas in the Kocaçay basin by Saraç (2003). The author collected mammalian fossils from the Dereköy and Yukarıkızılca areas indicating an Early Miocene (*Microdryomys*, *Democricetodon*, *Eumyarion*, *Cricetodon*, *Anomalomys* cf. *aliverensis*, *Aliveria*, MN4) and from the Dağkızılca area indicating the Middle Miocene (Cricetodontinae, MN6–8) (Sickenberg et al., 1975; Saraç, 2003). Kaya et al. (2007) studied the Early Miocene stratigraphy of western Turkey and recorded 2 micromammalian faunas of the Early Miocene (MN3 and MN4 zones) in the Kemalpaşa Formation, which is correlated with the Dereköy Formation (Sözbilir et al., 2011; Kaya et al., 2007; see Figure 4 for location of the MN4 mammalian zone, UTM coordinate: 053985E/424405N). Micromammalian fauna of the MN3 zone comprised *Cricetodon kasapligili*, *Crisetodon* sp., *Megacricetondon* sp., *Sayimys* sp., Gliridae, Sciuridae, Insectivora, and Lagomorpha. Micromammalian fauna of the MN4 zone is characterised by *Aliveria* sp., *Anomalomys* cf. *aliveriensis*, *Cricetodon* sp., *Democricetodon* sp., *Eumyarion* sp., *Galerix* sp., *Megacricetondon* cf. *collongensis*, *Microdyromys* sp., Erinaceidae, and Lagomorpha. Additionally, the following fossil assemblages (foraminifers and ostracods) were recorded from the fine-grained interval of the Dereköy Formation (*Globorotalia obesa*, *Globigerinoides trilobus*, *Globoquadrina dehiscens*, *Globorotalia* cf. *menardii*, *Globigerinoides obliquus*, *Globorotalia scitula scitula*, *Orbulina universa*, and Indet. *Candonas*). These foraminifer and ostracod associations do not show a precise age. However, the co-occurrence of planktonic foraminifers and ostracods indicates a marine connection within the Kocaçay basin (Sözbilir et al., 2011). The Dereköy Formation is overlain by the Vişneli Formation, which is made up of alluvial fan conglomerates and sandstones at the bottom and grades into lacustrine mudstones, including lenses of tuffs of 13.8 ± 1 my in age, obtained by using $Ar^{40}/Ar^{39}$ radiometric dating (Sözbilir et al., 2005, 2011). The Pleistocene Kızılca Formation lies unconformably above the older Dereköy and Vişneli formations.

### 3.2. The Cumaovası basin

This basin, formerly known as the Çubukludağ graben, is located at the western end of the Gediz and Küçük Menderes grabens in the west Anatolian extensional province. It is a 5–17-km-wide and 35-km-long, NNE-trending, asymmetric shaped basin that was formed under the control of strike-slip and oblique-slip normal faults (Uzel and Sözbilir, 2008). The basement units consist of Palaeozoic–Mesozoic metamorphic rocks of the Menderes Massif and Upper Cretaceous–Palaeocene rocks from the Bornova Mélange. The Menderes Massif and tectonically overlying Bornova Mélange are disconformably overlain

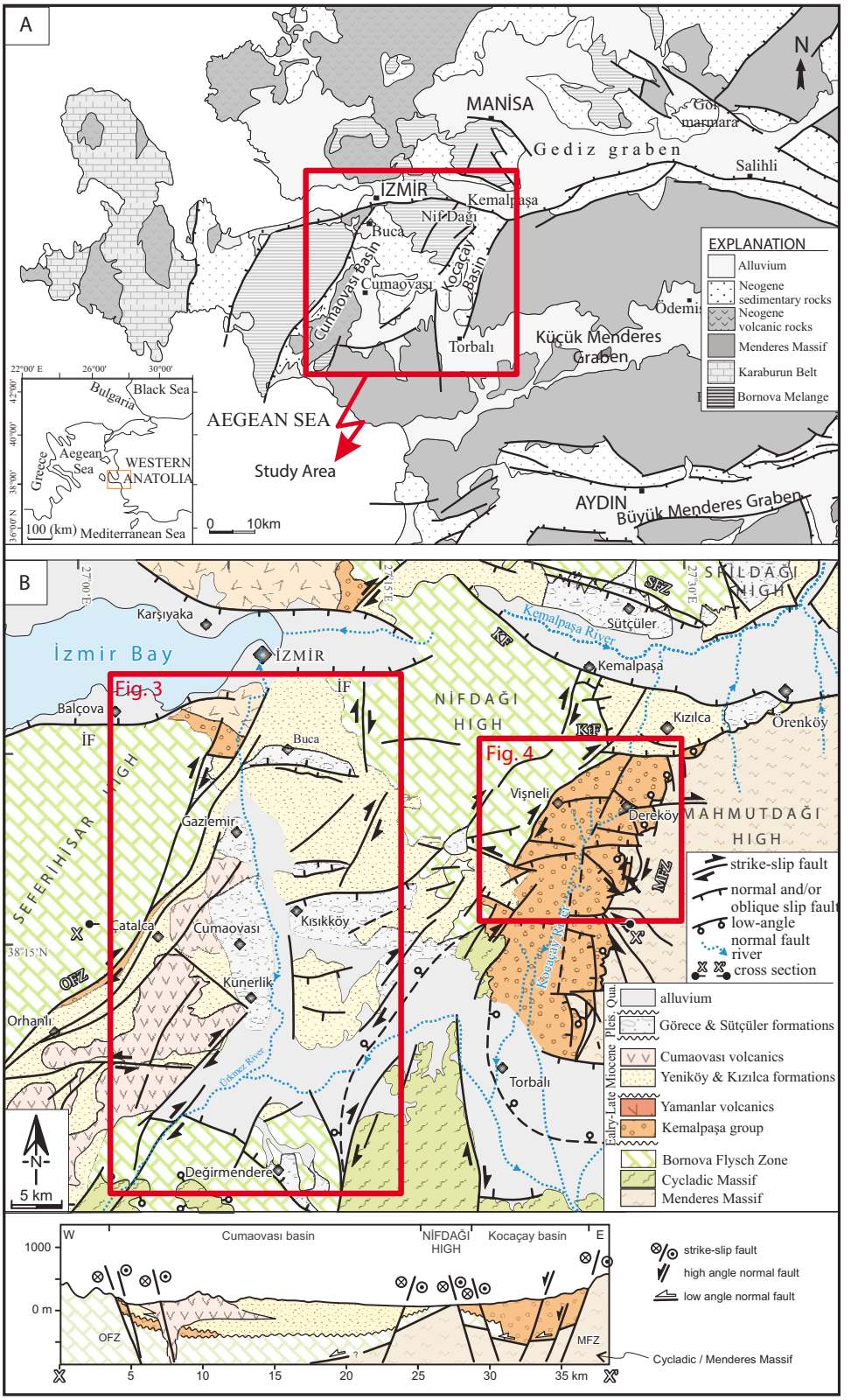



**Figure 1.** a) Regional map showing the Late Cenozoic basins of western Anatolia. b) simplified geological map of the Cumaovası and Kocacay basins. MFZ, Mahmutdağı Fault Zone; SFZ, Spildağı Fault Zone; KF, Kemalpaşa Fault; KTF, Kalkancatepe Fault; OFZ, Orhanlı Fault Zone (Sözbilir et al., 2011).

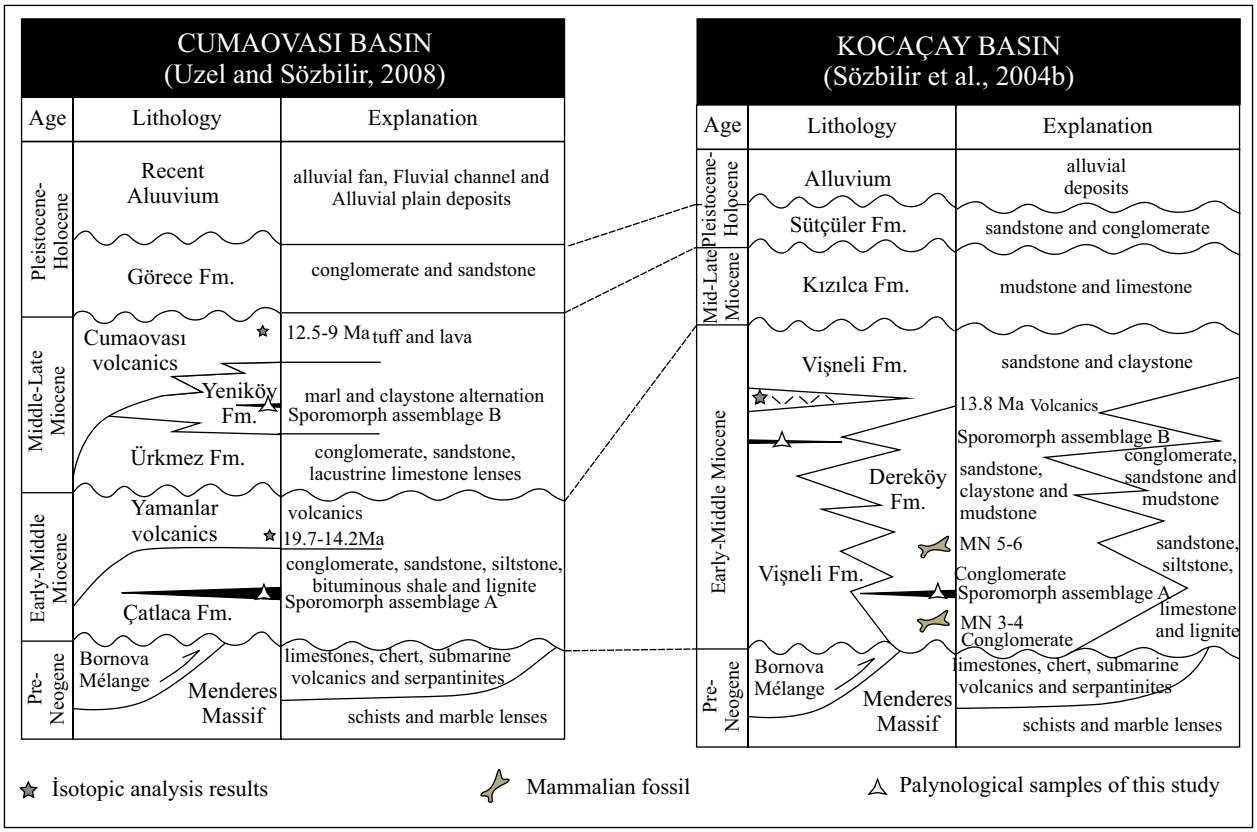



**Figure 2.** Generalised lithostratigraphic columnar sections of the Cumaovası and Kocaçay basins in western Turkey.

by Neogene volcano-sedimentary successions. The lower part of the Neogene sequence, the Çatalca Formation, is composed of thin-to-thick bedded conglomerates, sandstones, siltstones, and shale alternations including lignite lenses (Figure 4). The Çatalca Formation is interpreted as a lacustrine fan delta facies and dated as the Early–Middle Miocene based on regional stratigraphic correlation (Akartuna, 1962; Kaya, 1979, 1981; Genç et al., 2001; Sözbilir et al., 2004b). In the north of the study area, the fine-grained clastics of the Çatalca Formation are intercalated with lavas and tuffs of the Karaburun volcanics. Radiometric datings on the lavas yield ages ranging from about 12.5 Ma to 9 Ma (Yilmaz, 1997). The middle part of the sequence, the Ürkmez Formation (Eşder and Şimşek 1975; Genç et al., 2001), is dominated by red conglomerate and sandstone alternating with lacustrine limestone lenses of latest Middle (?)–Late Miocene (Genç et al., 2001; Uzel and Sözbilir, 2008). These clastics are interbedded with lacustrine limestones of the Yeniköy Formation consisting of sandstones, mudstones, and claystones alternating with thin lignite seams. Upward, the sequence is dominated by thin-to-medium–bedded lacustrine limestones and green laminated claystone alternations, which are interbedded with pyroclastic rocks of the Cumaovası volcanics (Eşder and Şimşek, 1975; Özgenç, 1978; Genç et al., 2001) (Figures 1a, 1b, and 2).

## 4. Palynological assemblages

In total, 42 genera and 59 species were identified in the lignite-bearing sediments from the Çatalca and Yeniköy formations in the Cumaovası basin and the Dereköy and Vişneli Formations in the Kocaçay basin. The relative percentages are given in palynological diagrams (Figures 5–7). The relative abundance of sporomorphs was classified as follows: classifying more than 15% as highly abundant, 5% to 14% as abundant, 1% to 4% as sparse, and less than 1% as rare. Two sporomorph assemblages, A and B, were defined in this study and botanical names are used for identification (Table 1).

Sporomorph assemblage A of the late Early–early Middle Miocene (the Burdigalian–Langhian) is recognised from the lower coal seams in the Çatalca Formation (sample numbers 35, 39, 42, and 44) and the Dereköy Formation (sample numbers 6 and 7). This assemblage is represented by highly abundant Polypodiaceae, *Pinus haploxylon* type, Cupressaceae, *Quercus*, and Cyrillaceae; by abundant *Ulmus*, *Castanea*, Sparganiaceae, and Oleaceae; and by sparse or rare occurrences of

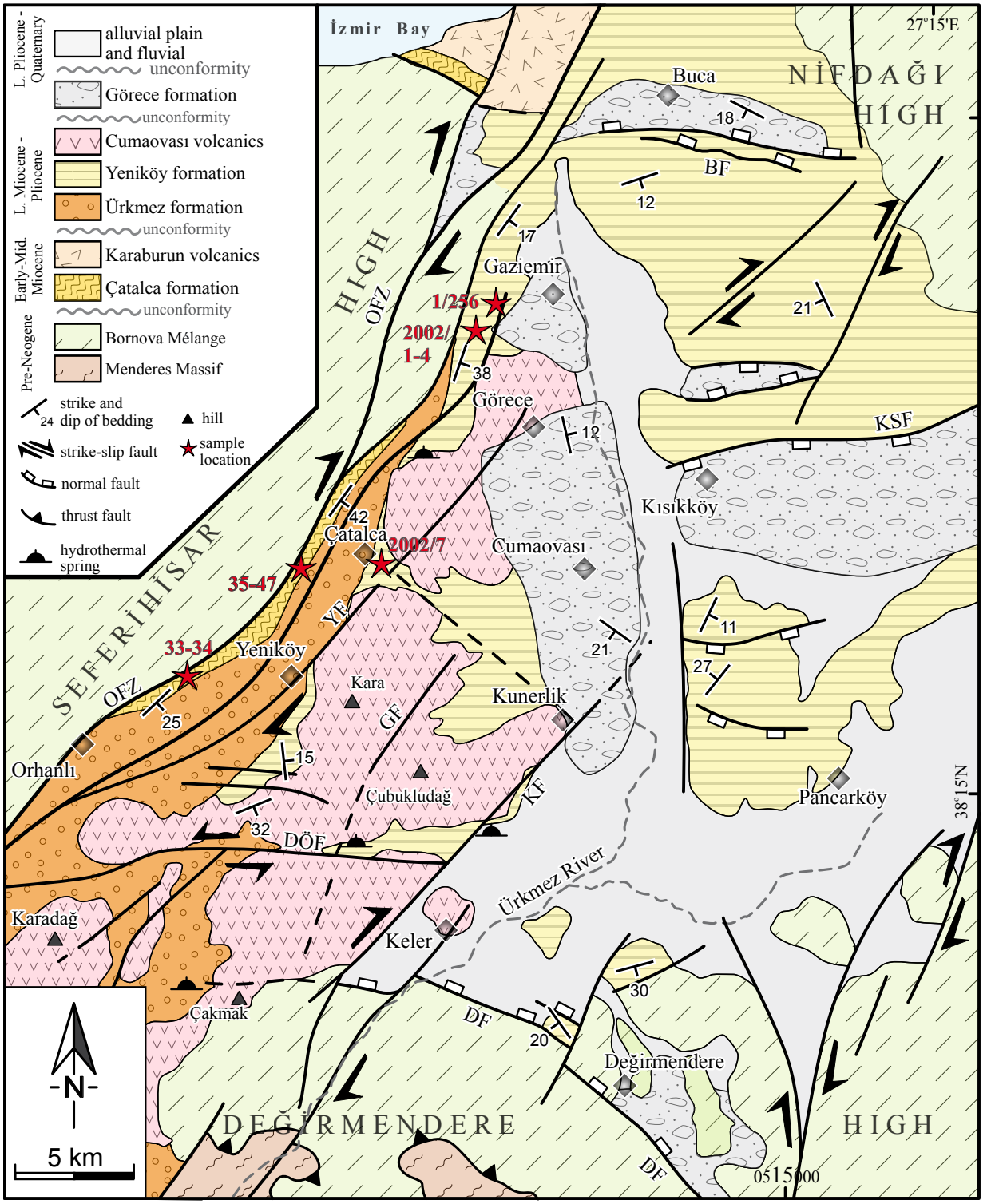



**Figure 3.** Detailed geological map of Cumaovası Basin (Uzel & Sözblir, 2008). Locations of palyological samples are also indicated. See Figure 1 for location of the map.

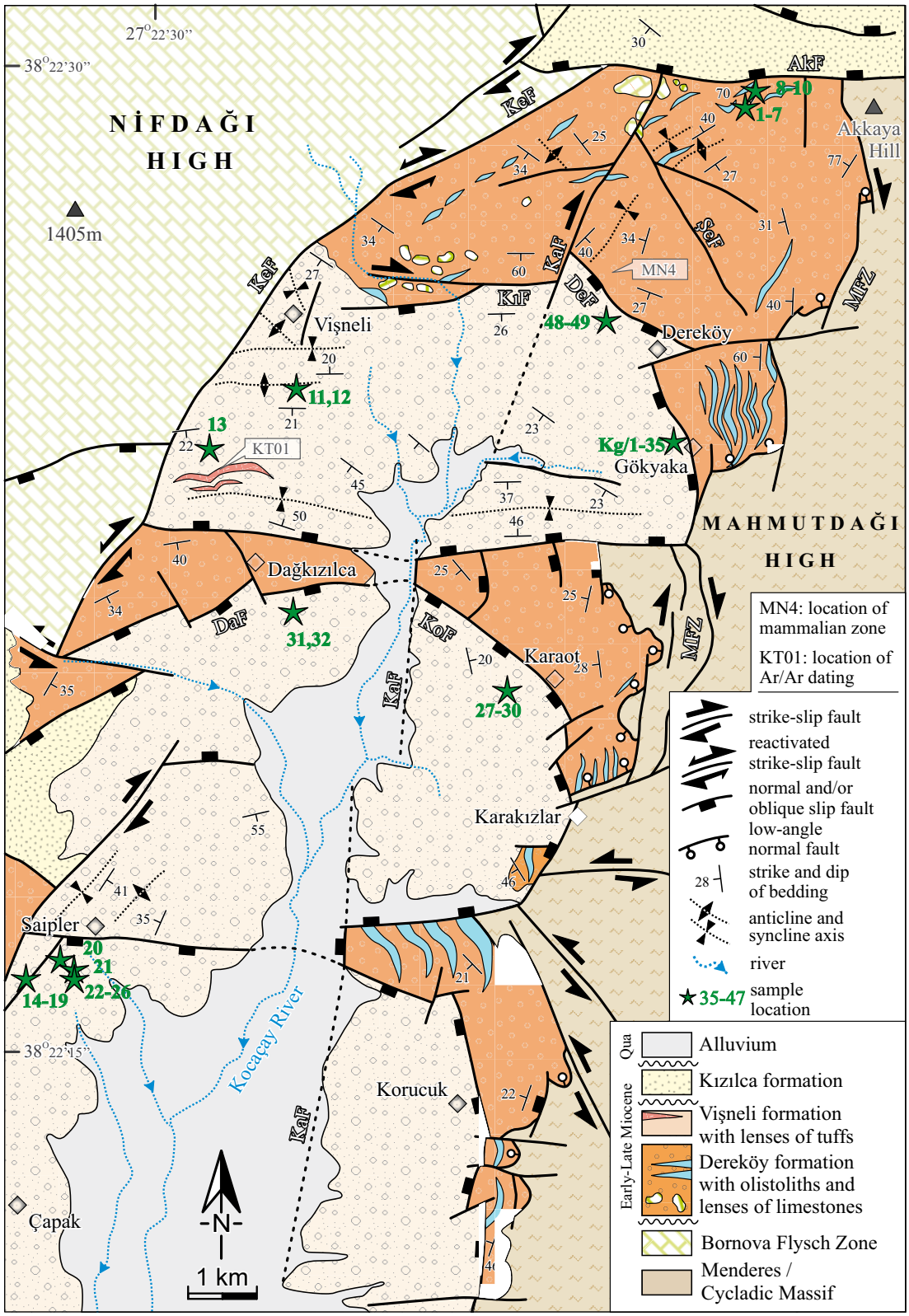
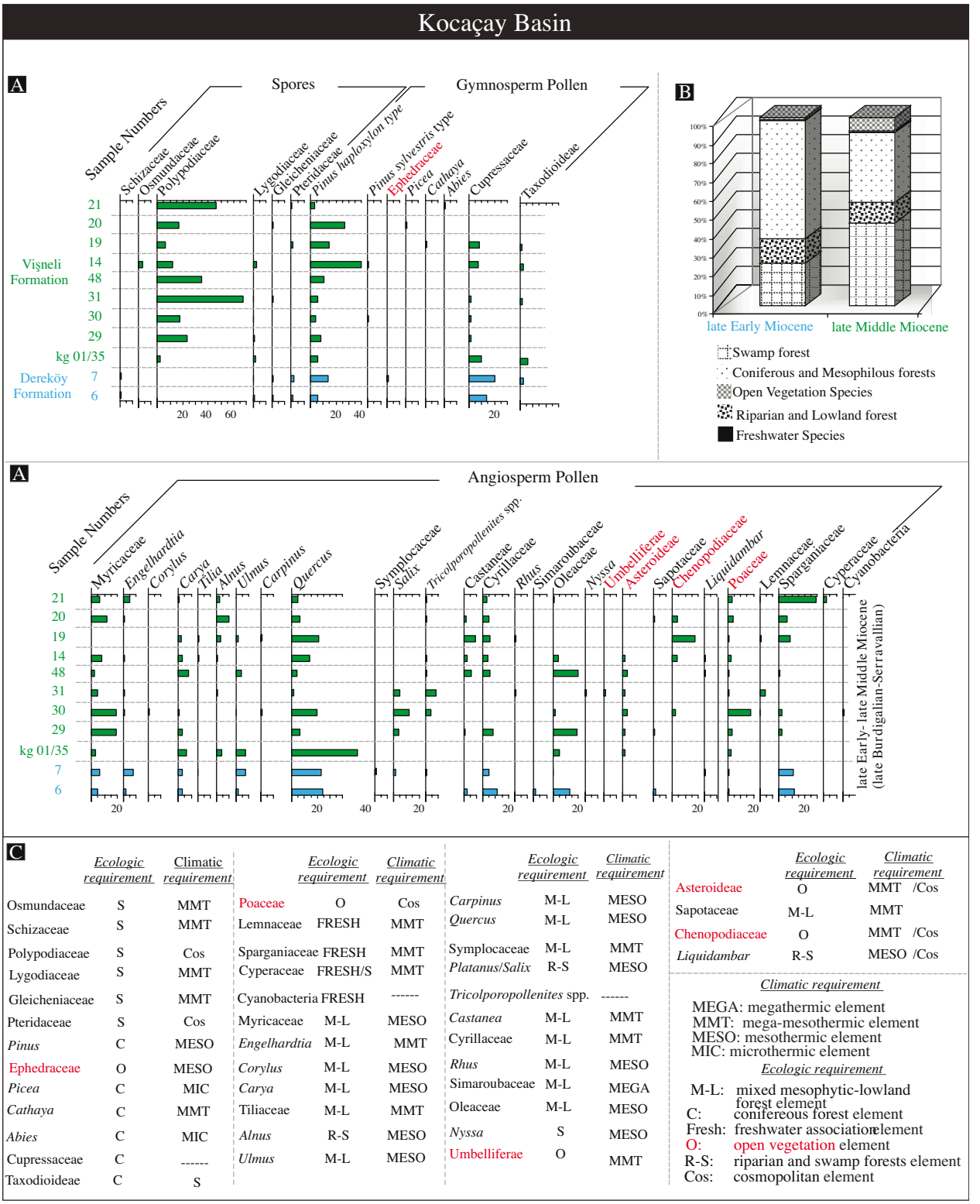



**Figure 4.** Detailed geological map of Kocacay Basin (Sözbilir et al., 2011). Locations of palyological samples are also indicated. MFZ, Mahmutdağı Fault Zone; KoF, Karaot Fault; KeF, Kesmedağı Fault; Kıf, Kızılkaya Fault; AkF, Akkayatepe Fault; ReF, Rekeroluk Fault; DaF, Dereköy Fault; DaF Dagkızılca Fault; KaF, Karabeldere Fault. See Figure 1 for location of the map.




C

| | Ecologic requirement | Climatic requirement |
|---|---|---|
| Osmundaceae | S | MMT |
| Schizaceae | S | MMT |
| Polypodiaceae | S | Cos |
| Lygodiaceae | S | MMT |
| Gleicheniaceae | S | MMT |
| Pteridaceae | S | Cos |
| *Pinus* | C | MESO |
| Ephedraceae | O | MESO |
| *Picea* | C | MIC |
| *Cathaya* | C | MMT |
| *Abies* | C | MIC |
| Cupressaceae | C | ------ |
| Taxodioideae | C | S |

| | Ecologic requirement | Climatic requirement |
|---|---|---|
| Poaceae | O | Cos |
| Lemnaceae | FRESH | MMT |
| Sparganiaceae | FRESH | MMT |
| Cyperaceae | FRESH/S | MMT |
| Cyanobacteria | FRESH | ------ |
| Myricaceae | M-L | MESO |
| *Engelhardtia* | M-L | MMT |
| *Corylus* | M-L | MESO |
| *Carya* | M-L | MESO |
| Tiliaceae | M-L | MMT |
| *Alnus* | R-S | MESO |
| *Ulmus* | M-L | MESO |

| | Ecologic requirement | Climatic requirement |
|---|---|---|
| *Carpinus* | M-L | MESO |
| *Quercus* | M-L | MESO |
| Symplocaceae | M-L | MMT |
| *Platanus/Salix* | R-S | MESO |
| *Tricolporopollenites* spp. | ------ | |
| *Castanea* | M-L | MMT |
| Cyrillaceae | M-L | MMT |
| *Rhus* | M-L | MESO |
| Simaroubaceae | M-L | MEGA |
| Oleaceae | M-L | MESO |
| *Nyssa* | S | MESO |
| Umbelliferae | O | MMT |

| | Ecologic requirement | Climatic requirement |
|---|---|---|
| Asteroideae | O | MMT /Cos |
| Sapotaceae | M-L | MMT |
| Chenopodiaceae | O | MMT /Cos |
| *Liquidambar* | R-S | MESO /Cos |

*Climatic requirement*

MEGA: megathermic element
MMT: mega-mesothermic element
MESO: mesothermic element
MIC: microthermic element

*Ecologic requirement*

M-L: mixed mesophytic-lowland forest element
C: conifereous forest element
Fresh: freshwater association element
O: open vegetation element
R-S: riparian and swamp forests element
Cos: cosmopolitan element

**Figure 5.** a) Pollen diagram of lignite samples in the Kocaçay basin, b) pollen diagram based on the percentage of palaeovegetational distribution during the late Early–Middle Miocene, c) ecological and climatic requirements of defining sporomorphs of the Kocaçay basin (samples are not classified as temporal).

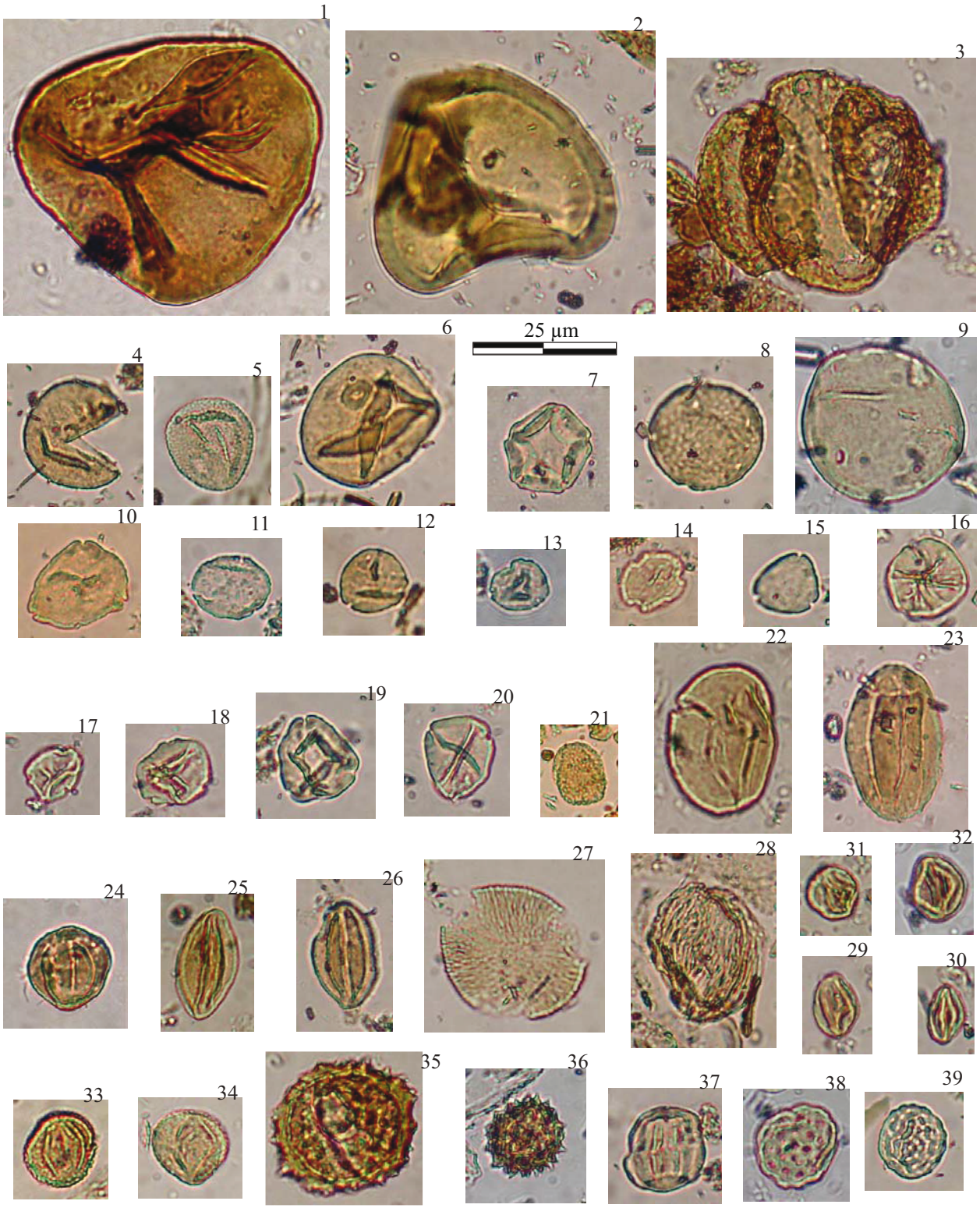
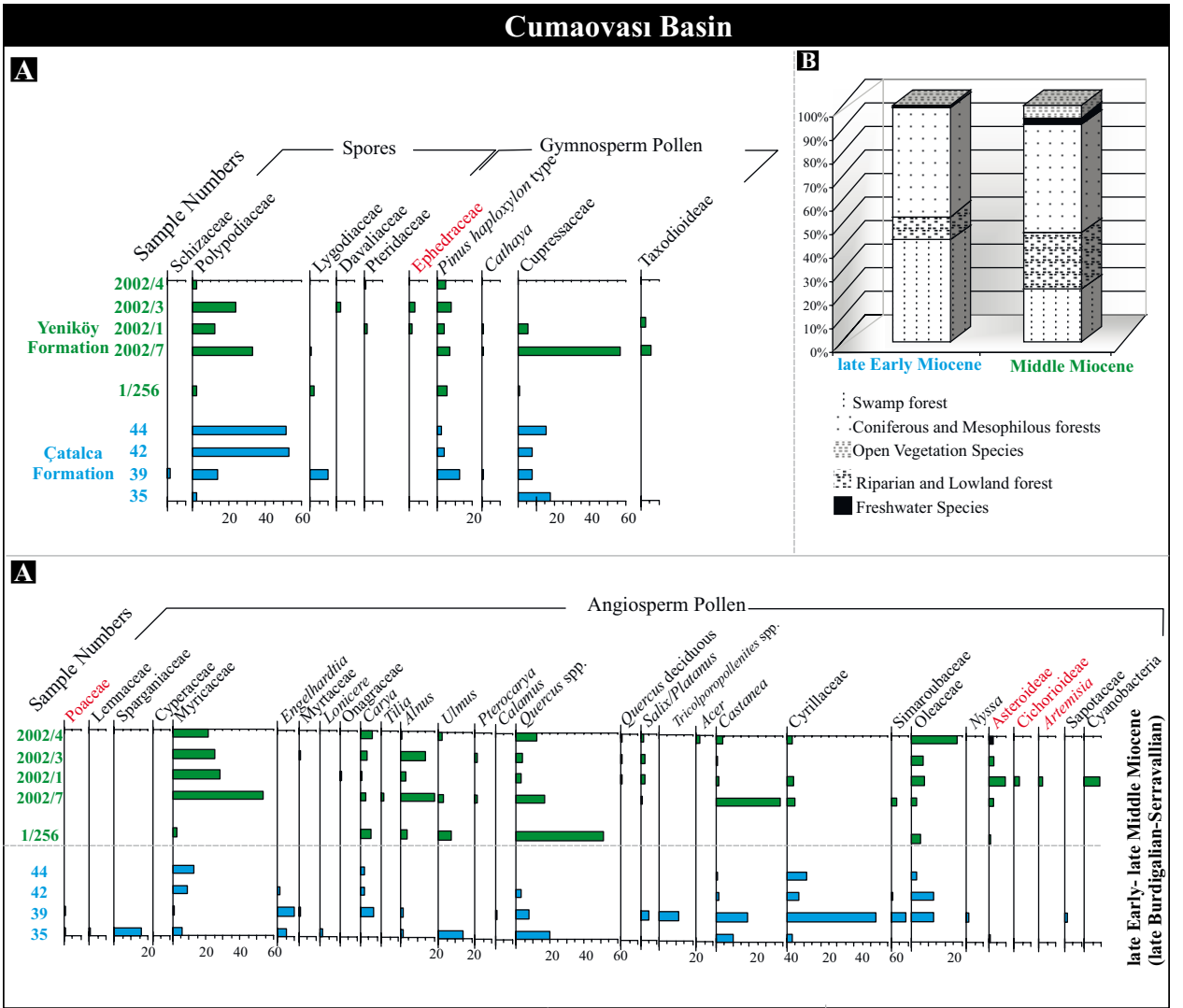



**Figure 6.** Spores and pollen of the sporomorph assemblages of study areas (1, 2. Schizaeaceae; 3. *Pinus haploxylon* type; 4. Taxodioideae; 5. Sparganiaceae; 6. Poaceae; 7. *Alnus*; 8. *Ulmus*; 9. *Carya*; 10. Myricaceae; 11–14. Juglandaceae; 15. *Engelhardia*; 16–20. *Platycarya*; 21. *Calamus*; 22–24. *Quercus*; 25, 26. Fagaceae; 27, 28. *Acer*; 29, 30. *Castanea*; 31, 32. Cyrillaceae; 33, 34. Oleaceae; 35, 36 Asteroideae–Tubuliflorae type; 37. Sapotaceae; 38, 39. Chenopodiaceae).




C

| | Ecologic requirement | Climatic requirement |
|---|---|---|
| Schizaceae | S | MMT |
| Polypodiaceae | S | Cos |
| Lygodiaceae | S | MMT |
| Davaliaceae | M-L | MMT |
| Pteridaceae | S | Cos |
| *Pinus* | C | MESO |
| Ephedraceae | O | MESO |
| *Cathaya* | C | MMT |
| *Abies* | C | MIC |
| Cupressaceae | C | ------ |
| Myrtaceae | M-L | MMT |
| *Lonicere* | M-L | MMT |
| Taxodioideae | C | S |

| | Ecologic requirement | Climatic requirement |
|---|---|---|
| Poaceae | O | Cos |
| Lemnaceae | FRESH | MMT |
| Sparganiaceae | FRESH | MMT |
| Cyperaceae | FRESH/S | MMT |
| Cyanobacteria | FRESH | ------ |
| Myricaceae | M-L | MESO |
| *Engelhardtia* | M-L | MMT |
| *Carya* | M-L | MESO |
| *Tilia* | M-L | MMT |
| *Almus* | R-S | MESO |
| *Ulmus* | M-L | MESO |
| *Calamus* | M-L | MMT |

| | Ecologic requirement | Climatic requirement |
|---|---|---|
| *Quercus* | M-L | MESO |
| *Quercus* deciduous | M-L | MESO |
| *Platanus/Salix* | R-S | MESO |
| *Tricolporopollenites* spp. | | ------ |
| *Castanea* | M-L | MMT |
| Cyrillaceae | M-L | MMT |
| Simaroubaceae | M-L | MEGA |
| Oleaceae | M-L | MESO |
| Asteroideae | O | MMT |
| Sapotaceae | M-L | MMT |
| Cichorioideae | O | MMT |
| *Artemisia* | O | MMT |
| Onagraceae | M-L | MMT |

***Climatic requirement***

MEGA: megathermic element
MMT: mega-mesothermic element
MESO: mesothermic element
MIC: microthermic element

***Ecologic requirement***

M-L: mixed mesophytic -lowland forests element
C: conifereous forest element
Fresh: freshwater association element
O: open vegetation element
R-S: riparian and swamp forests element
Cos: cosmopolitan element

**Figure 7.** a) Pollen diagram of the Cumaovası basin, b) pollen diagram based on the percentage of palaeovegetational distribution during the Early–Middle Miocene, c) ecological and climatic requirements of defining sporomorphs of the Cumaovası basin (samples are not classified as temporal).

Schizaeaceae (*Leiotriletes microadriennis* and *L. maxoides maximus*), Gleicheniaceae, Poaceae, Lemnaceae, Myricaceae, *Engelhardia*, *Carya*, *Lonicera*, *Tilia*, *Alnus*, *Carpinus*, *Platanus*, *Salix*, Sapotaceae, *Liquidambar*, and Asteroideae–Tubuliflorae type. Moreover, pollen taxa such as *Calamus*, *Engelhardia* (*Momipites punctatus* and *M. quietus*), Icacinaceae (*Compositoipollenites minimus*), and *Carya (Subtriporopollenites anulatus nanus)* are rare in assemblage A (Table 1; Figures 5 and 6).

Sporomorph assemblage B of the late Middle Miocene (the Serravallian) is defined from samples of lignite layers in the upper part of the Yeniköy Formation (sample numbers Çatalca 2002/7, 1/256, Seydiköy–2002/1, 3, and 4) and the Vişneli Formation (samples number KG–1/35, 14, 19–21, 29–31, and 48). Polypodiaceae, *Pinus haploxylon* type, Cupressaceae, Sparganiaceae, Myricaceae, *Engelhardia*, *Alnus*, *Quercus*, *Tricolporopollenites* sp., and *Castanea* have a high frequency in the samples. Representatives of Schizaeaceae, *Abies*, Poaceae, *Carya*, *Ulmus*, Cyrillaceae, Myrtaceae, and Oleaceae occur almost regularly in small amounts (Figure 6). Asteroideae–Tubuliflorae type and Cichorioideae–Liguliflorae type, Chenopodiaceae, *Artemisia*, *Platanus*, *Salix*, *Pterocarya*, *Tilia*, Sparganiaceae, Lemnaceae, Cycadaceae, *Carpinus* Schizaeaceae, and Cyanobacteria occurred in low frequencies (Figures 5–7). Palynoflora of sporomorph assemblage B differs from the palynoflora of sporomorph assemblage A, due to the presence of herb taxa in assemblage B that are observed more abundantly than in assemblage A (Table 1).

### 4.1. Correlation with European and Turkish Miocene palynofloras

Palynofloras of the Early and Middle Miocene have been defined in a wide range of previous studies (e.g., Benda, 1971a, 1971b; Akgün, 1986, 1993; Akgün and Akyol, 1987, 1992, 1999; Benda and Meunlenkamp, 1990; Ediger, 1990; Gemici et al., 1991; Akgün et al., 1995, 2000a, 2000b, 2002, 2004, 2007; Karayigit et al., 1999; Akgün and Kayseri, 2004; Kayseri et al., 2006; Yavuz-Işık, 2007; Kayseri and Akgün, 2008). Age evidence of lignite layers in this study area is obtained by correlation with previous palynological studies in Turkey and Europe.

#### 4.1.1. The Early Miocene

In Turkey, there are several palynological studies from the Early Miocene in the Kale–Tavas region (the Aquitanian), Ankara–Çayırhan, Çanakkale–Çan, İzmir–Sabuncubeli, Balıkesir–Bigadiç, Ören–Kultak, and Samsun–Havza regions (the latest Burdigalian). In Europe, there are numerous palynological studies of the Early Miocene such as Germany, Hungary, Poland, Czech and Slovak Republics, and Greece (i.e. Hochuli, 1978; Thiele-Pfeiffer, 1980; Planderová, 1990; Ashraf and Mosbrugger, 1995, 1996; Stuchlik et al., 2001, 2002; Ioakim et al., 2005; Jiménez-Moreno et al., 2005, 2007, 2008; Jiménez-Moreno, 2006; Jiménez-Moreno and Suc, 2007).

In Turkey, Benda (1971a, 1971b) and Benda and Muelenkamp (1990) recorded pioneering palynological studies of the Late Oligocene–Early Miocene, and the Kale sporomorph assemblage was defined in these studies. This assemblage is of Chattian, which was characterised by Myricaceae, *Engelhardia*, *Quercus*, Cyrillaceae, Oleaceae, and Cupressaceae. Later, Akgün and Sözbilir (2001) documented palynomorph assemblages of the Kale–Tavas region. Palynomorph assemblage 1 of the Aquitanian was characterised by Schizaeaceae, Myricaceae, *Plicatopollis plicatus* (Juglandaceae), *Quercus*, Cyrillaceae, Oleaceae, and *Carya* (Akgün and Sözbilir, 2001). Akgün et al. (2007) and Kayseri and Akgün (2008) studied the palaeoclimatic evolution of the Miocene in central Anatolia. According to these studies, the Balıkesir–Bigadiç and Samsun–Havza sporomorph assemblages of the Early Miocene (the latest Burdigalian) are contained less abundantly and various spore families such as Davaliaceae, Schizaeaceae, Osmundaceae, Gleicheniaceae. *Quercus*, *Ulmus*, *Podocarpus*, *Cathaya*, Taxodioideae, *Cupressaceae*, Sparganiaceae, Myricaceae, *Engelhardia*, *Carya*, *Platanus/Salix*, *Castanea*, Cyrillaceae, *Nyssa*, Sapotaceae, Poaceae, Lemnaceae, Juglandaceae, *Pterocarya*, Simarubaceae, Myrtaceae, *Reveesia*, *Alnus*, *Carpinus*, and Fagaceae accompany these spore species. Kayseri et al. (2007) studied the late Burdigalian–Langhian in Turkey and defined Kultak palynoflora, which is equivalent to the MN5–6 boundary. This palynoflora is characterised by Osmundaceae, *Ulmus*, *Picea*–Pinaceae, *Cathaya*, *Cupressaceae*, *Castanea*, Cyrillaceae, Oleaceae, Poaceae, *Alnus*, *Carya*, *Engelhardia*, *Quercus*, *Platanus/Salix*, and Myricaceae. Palynofloras of Çanakkale–Çan and Balıkesir–Gönen regions are dated the late Burdigalian–? Serravallian by Ediger (1990). Gymnosperms in palynospectra of the Çan and Gönen regions are observed in high percentage. *Alnus*, *Castanea*, Cyrillaceae, *Quercus*, and *Leoitriletes microadriennis* diverse fungal spore species are accompanied by gymnosperm pollen in these regions. Samples of the upper lignite seams from the Çoraklar Formation in the Ankara–Beypazarı (Çayırhan) region (Central Anatolia) were studied palynologically by Güngör (1991) and palynoflora of the latest Burdigalian is defined. This palynoflora is represented by *Nyssa*, Myricaceae, *Alnus*, *Platanus*, and *Salix*. During the late Burdigalian, palynoflora of coal and claystones samples in the İzmir–Sabuncubeli region (MN3a mammalian zone) was characterised by Sparganiaceae, Schizaeaceae, *Engelhardia*, Myricaceae, *Castanea*, Cyrillaceae, *Carya*, *Quercus*, *Ulmus*, and *Pinus* (Kayseri et al., 2007).

In Europe, palynoflora compositions change from region to region because of the palaeogeographic and palaeoclimatic condition for the Early–Middle Miocene. However, general palynostratigraphic evidence of the Early Miocene indicates similarity. The Egerian microflora of the

**Table 1.** Sporomorph list of the Cumaovası and Kocaçay basins.

| **SPOROMORPHS** | |
|---|---|
| **SPORES** | |
| *Baculatisporites primarius* | Osmundaceae, *Osmunda* type |
| *Verrucatosporites* sp. | Polypodiaceae, Davaliaceae |
| *Trilites solidus* | Lygodiaceae (Schizaceae) |
| *Leiotriletes maxoides minoris* | Lygodiaceae, *Lygodium* type (Schizaceae) |
| *Leiotriletes maxoides maximus* | Lygodiaceae, *Lygodium* type (Schizaceae) |
| *Gleicheniidites* sp. | Gleicheniaceae |
| *Cingulatisporites macrospeciosus* | Pteridaceae |
| *Laevigatosporites haardti* | Polypodiaceae |
| **GYMNOSPERM POLLEN** | |
| *Ephedripites* sp. | *Ephedra* |
| *Pityosporites microalatus* | Pinaceae, *Pinus haploxylon* type |
| *Pityosporites* cf. *alatus* | *Picea* |
| *Pityosporites labdacus* | *Pinus - sylvestris* type |
| *Cathayapollis* sp. | *Cathaya* |
| *Abiespollenites absolutus* | *Abies* |
| *Cycadopites* sp. | *Cycas* |
| *Inaperturopollenites hiatus* | Taxodioideae |
| *Inaperturopollenites dubius* | Cupressaceae |
| *Cupressacites cuspidataeaformis* | Cupressaceae |
| **ANGIOSPERM POLLEN** | |
| **Monocotyledoneae** | |
| *Monoporopollenites gramineoides* | Poaceae |
| *Echigraminidites moravicus* | Lemnaceae |
| *Sparganiaceaepollenites polygonalis* | Sparganiaceae |
| *Sparganiaceaepollenites neogenicus* | Sparganiaceae, *Sparganium* type |
| *Cyperaceaepollis* sp. | Cyperaceae |
| **Dicotyledoneae** | |
| *Triatriopollenites rurensis* | Myricaceae |
| *Triatriopollenites bituitus* | Myricaceae |
| *Triatriopollenites exelsus* | Myricaceae |
| *Triatriopollenites myricoides* | Myricaceae |
| *Triatriopollenites pseudorurensis* | Myricaceae |
| *Triatriopollenites* sp. | Myricaceae sp. |
| *Plicatopollis plicatus* | Juglandaceae |
| *Momipites punctatus* | Juglandaceae, Engelhardia type |
| *Triatriopollenites coryphaeus* | Myricaceae |
| *Compositoipollenites minimus* | Icacinaceae |

**Table 1.** (continued).

| | |
|---|---|
| *Myrtaceidites mesenosus* | Myrtaceae |
| *Triporopolenites coryloides* | Betulaceae, *Corylus* type |
| *Lonicerapollis* sp. | Caprifoliaceae, *Lonicera* type |
| *Corsinipollenites occulis noctis* | Oenotheraceae (Onagraceae) |
| *Suptriporopollenites simplex* | Juglandaceae, *Carya* type |
| *Subtriporopollenites anulatus* | Juglandaceae, *Carya* type |
| *Suptriporopollenites constans* | Juglandaceae, *Carya* type |
| *Intratriporopollenites instructus* | Tiliaceae, *Tilia* type |
| *Polyvestibulopollenites verus* | Betulaceae, *Alnus* type |
| *Polyporopollenites undulosus* | Ulmaceae, *Ulmus* type |
| *Polyporopollenites stellatus* | Juglandaceae, *Pterocarya* type |
| *Polyporopollenites carpinoides* | Betulaceae, *Carpinus* type |
| *Dicolpopolis kalewensis* | Arecaceae, *Calamus* type |
| *Tricolpopollenites henrici* | *Quercus* |
| *Tricolpopollenites microhenrici* | *Quercus* |
| *Tricolporopollenites pudicus* | *Quercus* |
| *Tricolpopollenites asper* | *Quercus* |
| *Quercopollenites robur* | *Quercus robur* type |
| *Tricolpopollenites densus* | *Quercus* sp. |
| *Porocolpopollenites* sp. | Symplocaceae |
| *Tricolpopollenites retiformis* | Salicaceae, *Salix* type |
| *Tricolpopollenites liblarensis* | Fagaceae |
| *Aceripollenites striatus* | Aceraceae, *Acer* type |
| *Tricolpopollenites* sp. | Unknown |
| *Tricolporopollenites cingulum* | Fagaceae, Castaneoideae, *Castanea* type |
| *Tricolporopollenites megaexactus* | Clethraceae, Cyrillaceae |
| *Tricolporopollenites pseudocingulum* | Anacardiaceae, *Rhus* type |
| *Tricolporopollenites pacatus* | Simaroubaceae |
| *Tricolporopollenites microreticulatus* | Oleaceae |
| *Tricolporopollenites krutschi* | Nyssaceae, *Nyssa* type |
| *Umbelliferoipollenites* sp. | Apiaceae, (=Umbelliferae) |
| *Tricolporopollenites* sp. | Asteraceae (=Compositae), Asteroideae, Tubuliflorae type |
| *Tricolporopollenites* sp. | Asteraceae (=Compositae), Cichorioideae, Liguliflorae type |
| *Tricolporopollenites* sp. | Asteraceae (=Compositae), *Artemisia* type |
| *Tricolporopollenites* sp. | Unknown |
| *Tetracolporopollenites folliformis* | Sapotaceae |
| *Tetracolporopollenites* sp. | (cf. Sapotaceae) |
| *Polycolpopollenites* sp. | Unknown |
| *Periporopollenites multiporatus* | Caryophyllales (=Centrospermae), Chenopodiaceae |
| *Periporopollenites stigmosus* | Hamamelidales, Altingiaceae, *Liquidambar* type |
| **Nonpollen palynomorph** | |
| *Sigmopollis pseudosetarius* | Cyanobacteria |

Central Paratethys (Slovakia, Germany) is characterised by a lower percentage of some tropical–subtropical flora elements such as *Palmae*, *Calamus*, Myrtaceae, and *Cathaya*, and by the decrease in Paleogene elements in microflora like *Hippophae*, *Eucalyptus*, Elaeagnaceae, Juglandaceae, and *Cicatricosisporites chattensis*. The Eggenburgian microflora includes Anacardiaceae, *Ulmus*, *Carpinus*, Betulaceae, *Castanea*, Araliaceae, *Quercus*, Schizaeaceae, Myricaceae, Cyrillaceae, Simarubaceae, *Nyssa*, Sapotaceae, *Engelhardia*, and *Carya* (Hochuli, 1978; Planderová, 1990; Stuchlik et al., 2001, 2002; Kvaček et al., 2006; Kováčová and Sitár 2007; Doláková and Kováčová 2008; Doláková et al., 2011; Kováčová et al., 2011). Palynological results of the Mesohellenic Trench and Aliveri basin in Greece around the eastern Mediterranean basin were represented by *Platycarya*, *Engelhardia*, *Myrica*, Sapindaceae, *Quercus*, *Ilex*, *Lauraceae*, *Olea*, and *Pistacia*. Herbaceous elements such as Ephedraceae, Amaranthaceae–Chenopodiaceae, Asteroideae–Tubuliflorae type, and Poaceae are recorded abundantly in eastern and western Mediterranean basins (Ioakim et al., 2005; Jiménez-Moreno and Suc, 2007).

All palynological studies in Europe and Turkey indicate that palynofloras of the Aquitanian are characterised by some taxa (i.e. *Hippophae*, *Calamus*) recorded in low percentages or sporadic in samples of the Oligocene. Furthermore, proportions of the megathermic and meso–megathermic elements (Simaroubaceae, Sapotaceae, *Engelhardia*, Cyrillaceae, and *Castanea*) tend to increase at the end of the Early Miocene (the Burdigalian) and early Middle Miocene (Langhian). Additionally, other taxa of the entire Miocene, which include *Quercus*, Fagaceae, *Carya*, *Alnus*, *Castanea*, and Oleaceae, are recorded in high percentages (Figures 5 and 7). In our palynoflora of assemblage A (the late Early Miocene–early Middle Miocene), *Calamus* and megathermic and meso–megathermic taxa (Schizaeaceae, Sapotaceae, *Engelhardia*, Cyrillaceae, *Castanea*) are observed. Moreover, herb taxa are in low percentages in the palynospectra of assemblage A. Our palynoflora resemble the other palynofloras of the late Burdigalian–Langhian in Turkey and Europe. In addition, palynostratigraphic interpretation of the Kocaçay and Cumaovası basins is consistent with the previous paleontological records in western Turkey.

**4.1.2. The Middle Miocene**

There are many palynological studies of the early Middle Miocene (Langhian) in Europe (e.g., Germany (Hochuli, 1978; Ashraf and Mosbrugger, 1995, 1996; Bruch et al., 2004), Bulgaria (Ivanov et al., 2002, 2007, 2011), Greece (Reigel et al., 1989; Ioakim et al., 2005), Spain (Jiménez-Moreno and Suc, 2007), France (Jiménez-Moreno and Suc, 2007), the Slovak Republic, Poland, and Hungary (Planderová, 1990; Wazynska, 1998; Stuchlik et al., 2001, 2002; Jiménez-Moreno, 2006; Kvaček et al., 2006; Kováčová and Sitár, 2007; Doláková and Kováčová, 2008; Doláková et al., 2011; Kováčová et al., 2011). In addition, sediments of the Langhian–Serravallian are widespread in Turkey. Most of the palynological records are obtained from sediments of the Serravallian (Manisa–Soma; Büyük Menderes Graben–Şahinali, Nazilli–Hasköy, Köşk–Kızılcayer, Sarayköy–Sazak, and Aydın–İncirliova; Çankırı–Çorum basin; Sivas basin) (Akgün and Akyol, 1987, 1999; Kayseri and Akgün, 2008). Conversely, there is a limited number of palynological data sets in western Turkey for the Langhian (Kuloğulları and Başçayır areas in western Turkey) (Kayseri et al., 2007).

Akgün and Akyol (1999) determined the early Middle Miocene (Langhian) palynoflora in the Kuloğulları and Başçayır areas (Büyük Menderes Graben). According to the authors, this palynoflora is characterised by the abundance of Taxodioidea, Cupressaceae, *Alnus*, *Quercus*, Cyrillaceae, *Castanea*, and rare Gleicheniaceae, Schizaeaceae, Pteridaceae, Osmundaceae, Juglandaceae (*Triatriopollenites plicatus*), Myricaceae, *Tilia*, *Nyssa*, *Ilex*, *Pterocarya*, and Sapotaceae. In the palynospectra of the Serravallian in western Turkey, *Alnus*, *Quercus*, *Castanea*, Cyrillaceae, *Carya*, *Ulmus*, Oleaceae, Myricaceae, *Tilia*, Fagaceae, Nyssaceae, and Sparganiaceae were recorded (Akgün, 1986; Akgün and Akyol, 1987, 1992, 1999). The latest Middle Miocene (the late Serravallian) palynoflora of the Büyük Menderes Graben deposits (Nazilli–Hasköy, Köşk–Kızılcayer, and Sarayköy–Sazak) is characterised by abundant Taxodioideae, *Quercus*, *Alnus*, *Pinus* (*dipoxylon* type), and herbaceous pollen flora such as Asteroideae–Tubuliflorae and Ligulifloreae types, Poaceae, Umbelliferae, and Chenopodiaceae. Akgün et al. (2000a, 2000b) and Kayseri and Akgün (2008) studied the early–middle Tortonian palynofloras of the Sivas–Hafik and Vasıltepe regions. The authors emphasised the increasing percentage of herbaceous pollen from the late Serravallian to Tortonian and this increase is an important indication of the Late Miocene in Turkey.

The lower Badenian (the Langhian) of Slovakia, France, Spain, Bulgaria, Czech Republic, Greece, and Hungary is characterised by the regular occurrence and abundance of megathermic and meso–megathermic taxa (*Palmae*, Schizaeaceae, Sapotaceae, *Reevesia*, Theaceae, Araliaceae, *Engelhardia*, Myrtaceae, *Platycarya*, *Castanea*, *Avicennia*, *Itea*, and Cyrillaceae) (Nagy and Kókey, 1991; Nagy, 1999; Jiménez-Moreno et al., 2005; Jiménez-Moreno, 2006). The upper Badenian (the Serravallian) of these countries is represented by *Castanea*, *Ulmus*, Myricaceae, *Carya*, *Pterocarya*, Oleaceae, *Abies*, *Sequoia*, *Juglans*, *Tilia*, *Alnus*, *Acer*, *Carpinus*, *Betula*, *Fagus*, *Corylus*, *Quercus*, *Tsuga*, *Ulmus*, *Zelkova*, *Buxus*, *Rhus*, Chenopodiaceae, Asteroideae–Tubuliflorae, Cichorioideae–Liguliflorae types, and *Artemisia* (Planderová, 1990; Planderová et al.,

1992; Stuchlik et al., 2001, 2002; Medeanic, 2002; Ioakim et al., 2005; Jiménez-Moreno, 2006; Kováčová and Sitár, 2007; Kvaček et al., 2007 Doláková and Kováčová, 2008; Doláková et al., 2011; Kováčová et al., 2011). Palynofloras of Europe indicate variations due to palaeoenvironmental and palaeoclimatic conditions. However, the common feature of these palynofloras is abundance of thermophilous plants during the Burdigalian–Langhian, and abundance and diversity of herb taxa during the Serravallian.

According to all the palynological data of Turkey and Europe, percentages of certain spores and pollen (i.e. Schizaeaceae, *Engelhardia*, *Palmae*, Juglandaceae) that are abundantly observed in Oligocene–Early Miocene and percentages of these sporomorphs decrease throughout the Middle Miocene (from the Burdigalian to Serravallian). Furthermore, other angiosperm and gymnosperm pollen (e.g., *Pinus*, *Quercus*, *Castaneae*) are determined in high percentages. As well as in certain regions of Europe and Turkey, herbaceous pollen taxa (Asteroideae–Tubuliflorae type, Poaceae, Chenopodiaceae, Ephedraceae, and Umbelliferae) increased from the late Middle Miocene (Serravallian) to Late Miocene (Tortonian) and temperate elements were also abundant due to climatic changes. At the same time, percentages of megathermic and meso–megathermic taxa (i.e. Sapotaceae, Cyrillaceae, and *Engelhardia*) decreased during the Serravallian–Tortonian. Cenozoic spores and pollen are defined by low percentages in the content of the sporomorph assemblage B of the late Middle Miocene and percentages of herbaceous pollen are observed increasing (from 1% to 8%) in some samples (14; 19–21; 29–31; 48; 2002–1, 3, 4, 7) of the Kocaçay and Cumaovası basins (Figures 5 and 7). The sporomorph content of assemblage B resembles the palynoflora of Serravallian in Turkey and parts of Europe. According to the paleontological data of western Turkey, this age interpretation of assemblage B is supported by the previous age determination.

**5. Palaeovegetational and palaeoclimatic reconstruction of the Kocaçay and Cumaovası basins**

Here we show a summary of the Neogene vegetation dynamics from the Kocaçay and Cumaovası basins. Five palaeovegetational groups, namely riparian and lowland forest, swamp forest, open vegetation, coniferous and mesophilous forest, and freshwater, are separated for the vegetation interpretations (Hochuli, 1978; Thiele-Pfeiffer, 1980; Planderová, 1990; Ashraf and Mosbrugger, 1995, 1996; Stuchlik et al., 2001, 2002; Ivanov et al., 2002; Jiménez-Moreno et al., 2005, 2007, 2008; Jiménez-Moreno, 2006; Kvaček et al., 2006; Ivanov et al., 2007; Jiménez-Moreno and Suc, 2007; Kováčová and Sitár, 2007; Doláková and Kováčová, 2008; Doláková et al., 2011; Kováčová et al., 2011) (Figures 5–8).

In the Kocaçay basin, among the middle and low altitudes, the pollen of *Pinus haploxylon* type, *Cathaya*, *Carya*, *Tilia*, *Carpinus* (representing the coniferous and mixed mesophytic forests, 63%), and the plants of the Cyrillaceae and Myricaceae families (representing wet shrubs and brushwood peat bog) dominated during the late Early–early Middle Miocene. Swamp (22.5%) and riparian (13%) forests dominated the peat-producing communities. Megathermic and meso–megathermic taxa (tropical elements), which are represented by Lygodiaceae, Gleicheniaceae, *Castanea*, Cyrillaceae, *Engelhardia*, and Sapotaceae, are abundantly observed in this basin. Moreover, temperate elements (*Pinus haploxylon* type, *Carpinus*, *Ulmus*, and *Quercus*) accompany the megathermic and meso–megathermic taxa. During the late Burdigalian–Langhian in the Kocaçay basin, the climate was warm within the ranges of subtropical conditions based on plant association (Figures 5 and 8). During the late Middle Miocene (Serravallian), the riparian (11%) and swamp (44%) forest elements were abundant in samples (e.g., samples 18–20) of the Kocaçay basin (*Alnus*, *Ulmus*, and *Pterocarya*). The coniferous and mixed mesophytic forests elements (37%) were abundant. In addition, herbaceous pollen (especially Chenopodiaceae, Poaceae, Asteroideae–Tubuliflorae type, and Umbelliferae) were abundantly observed (7%) in the Kocaçay basin. During the late Middle Miocene in the Kocaçay basin, due to the disappearance of megathermic and meso–megathermic taxa (Lygodiaceae, Gleicheniaceae, and Sapotaceae) and presence of the abundant mesothermic taxa and temperate climate indicator plants (*Pinus haploxylon* type, *Alnus*, *Ulmus*, *Carya*, and *Quercus*), the palaeoclimate was generally temperate and humid (Figures 5 and 8).

In the Cumaovası basin during the late Early and early Middle Miocene (late Burdigalian–Langhian) vegetation cover was characterised by swamp forests (43%), consisting mostly of Cupressaceae, *Nyssa*, and Myricaceae, with numerous ferns (Polypodiaceae) in the undergrowth, coniferous (*Pinus haploxylon* type), and mixed mesophytic forests (Sapotaceae, Oleaceae, Cyrillaceae, *Castanea*, Fagaceae, *Quercus*, Arecaceae–*Calamus*, *Carya*, and Myrtaceae) (46%). Riparian forest (*Alnus*, *Ulmus*, *Platanus*, and *Salix*) is rarely observed (10%). Spore and pollen association throughout the late Early Miocene–early Middle Miocene in the Cumaovası basin evidenced the conditions favouring the development of rich and abundant vegetation in a warm subtropical climate (Figures 7 and 8). The meso–megathermic taxa are rarely encountered in Cumaovası basin samples of the late Middle Miocene: Sapotaceae and Arecaceae–*Calamus* (Calamoid palm). The mesothermic elements (*Cathaya*, Cupressaceae, *Carya*, *Lonicera*, *Alnus*, *Carpinus*, *Quercus*, Oleaceae, and Nyssaceae) are abundant and taxonomically

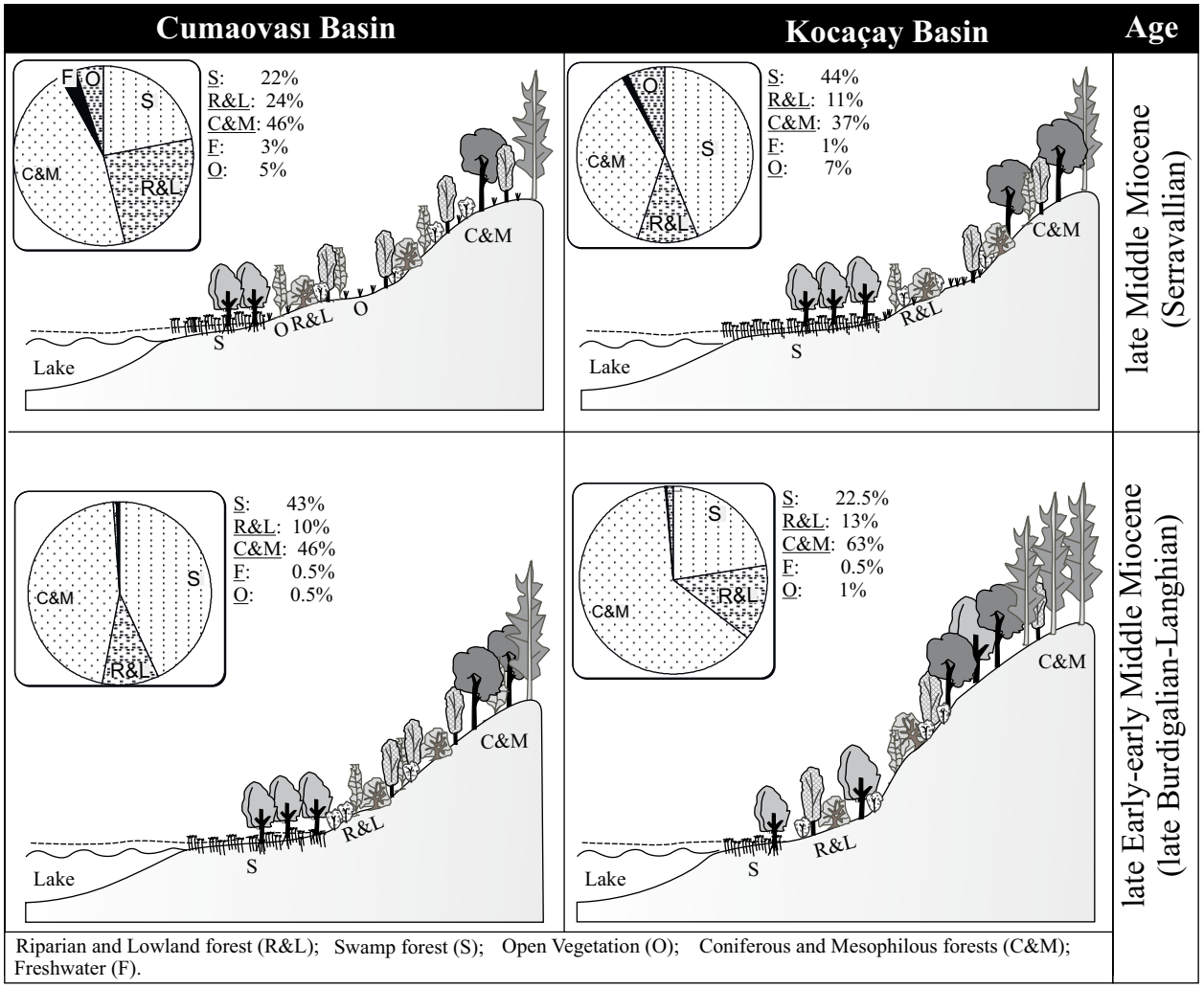



**Figure 8.** Palaeovegetational reconstruction of the Kocaçay and Cumaovası basins from the Early to late Middle Miocene based on the palynofloras.

varied. The percentage of riparian forest increased from the late Early and late Middle Miocene (from 10% to 24%). The freshwater elements (Sparganiaceae and Cyanobacteria) appeared relatively abundant only at this time. Moreover, the amount of herbaceous plants in open vegetation areas, such as Asteroideae–Tubuliflorae and Liguliflorae types, *Artemisia*, Umbelliferae, and Ephedraceae, gradually increased (from 0.5% to 5%). The megathermic and meso–megathermic taxa in the Cumaovası palynospectra were characterised by one taxon (Sapotaceae) and the mesothermic elements were abundantly represented and taxonomically varied (Myricaceae, *Engelhardia*, Myrtaceae, Symplocaceae, *Castanea*, Anacardiaceae, and Cyrillaceae). The temperate elements (*Abies*, *Picea*, Cupressaceae, *Carya*, *Quercus*, *Alnus*, Oleaceae, and *Ulmus*) were observed less commonly (Figures 7 and 8). In the late Middle Miocene, the palaeoclimate was temperate in the Cumaovası basin.

The number of grassland species (Asteroideae–Tubuliflorae type and Liguliflorae, *Artemisia*, Umbelliferae, and Ephedraceae) increased in the Cumaovası (from 0.5% to 5%) and Kocaçay (from 1% to 7%) basins during the late Early–late Middle Miocene. This increase could be explained by palaeovegetational change because of orographic and/or palaeoclimatic change. However, expansion of open areas due to the increasing grassland species in these basins is not as in eastern Anatolia (i.e. 10% for the Late Miocene (Tortonian) and 15%–30% for the Plio-Pleistocene) (Akgün et al., 2007; Kayseri and Akgün, 2008; Akgün and Kayseri, 2012) in the Miocene because the graben system prevented the occurrence of open areas in western Anatolia (e.g., Kocaçay and Cumaovası basins, Büyük Menderes Graben, Küçük Menderes Graben). For this reason, the change in percentage from 0.5%–1% to 5%–7% could be evaluated as expansion of open areas in the Cumaovası and

Kocaçay basins from the late Burdigalian to Serravallian. Mammalian fossil records in western Anatolia also support the treeless palaeoenvironment in the late Middle Miocene (Kaya and Mayda, 2011).

### 5.1. Coexistence approach

Numerical climatic values are calculated by applying the coexistence approach (Mosbrugger and Utescher, 1997) (Table 2). Palaeoclimate records can be plotted for the Kocaçay and Cumaovası basins in western Turkey for the late Early (late Burdigalian)-early Middle Miocene (Langhian) and late Middle Miocene (Serravallian). Although time resolution of these records is limited, trends and minor changes in the climate in both basins are reflected. Additionally, according to palaeoclimatic results of this study, Küçük Menderes Graben (İzmir–Tire region) and Büyük Menderes Graben (Aydın–Başçayır, Aydın–Kuloğullar, Aydın–İncirliova, lower and upper coal seams of Aydın–Hasköy, Aydın–Köşk, Aydın–Söke, and Aydın–Şahinali regions) are correlated with each other and a palaeoclimatic interpretation of western Turkey from the late Early Miocene (late Burdigalian) to late Middle Miocene (Serravallian) is constituted (Akgün and Akyol, 1999; Akgün et al., 2007; Kayseri and Akgün, 2008, 2010).

#### 5.1.1. Temperature parameters

In the Burdigalian–Langhian the lower mean annual temperature (MAT) values are observed from the Büyük Menderes Graben (average values of 13–17 °C) and the MAT values in the Küçük Menderes Graben are around the (19 °C). In the Kocaçay and Cumaovası basins, the MAT values varied between 17 and 18 °C (except for the Yeniköy 44 sample: 15.2 °C). During the Serravallian the lower MAT values are recorded from the Büyük Menderes Graben (average values of 9–15 °C) and in the Kocaçay and Cumaovası basins the MAT values increase (average values of 15–19 °C). Based on these data, from south (Büyük Menderes Graben) to north (Kocaçay and Cumaovası basins) the MAT values slowly increase in both the Burdigalian–Langhian and Serravallian (Table 2). The MAT values during the same time interval (e.g., Serravallian) indicate the differences region to region and this palaeoclimatic variation could be related to different orographic condition in western Anatolia. Furthermore, palaeoclimatic values decrease from late Early Miocene to late Middle Miocene and this decline could be related to palaeotopographic and/or palaeoclimatic changing from Langhian to Serravallian, which is globally observed (e.g., Mosburgger et al., 2005; Ivanov et al., 2011; Utescher et al., 2011).

The winter temperatures (TCM) also display a spatial differentiation with relatively high temperature in the Küçük Menderes Graben, and Cumaovası and Kocaçay basins (average values of 7–10 °C) and low ones in the Büyük Menderes Graben (average values of 1–7 °C) during the Burdigalian–Langhian. The TCM values in the Serravallian increase from the Büyük Menderes Graben (average values of (–0.8)–7 °C) to the Kocaçay and Cumaovası basins (average values of 1–10 °C). Distinct differences for the MAT and TCM are shown during the Burdigalian–Serravallian as a result of orographic or/and palaeoenvironmental differences (Table 2; Figures 9–11).

The summer temperature (TWM) does not show an obvious differentiation through the Burdigalian–Serravallian in the Büyük and Küçük Menderes Grabens, and Kocaçay and Cumaovası basins. Most samples reveal similar values around 24–27 °C (Table 2).

In the late Burdigalian the TCM values of western Turkey resemble those of Central Europe and values obtained for both regions are very high because of the onset of the Middle Miocene Climatic Optimum (Mosburgger et al., 2005; Ivanov et al., 2011; Kern et al., 2011; Utescher et al., 2011). In the Langhian, these high TCM values continue in Central Europe. However, in western Turkey during this time, decreasing TCM values are shown. This cooling from the Burdigalian to Langhian could be related to the expansion of terrestrial conditions in western Turkey during this time interval (Popov et al., 2004). In the early Serravallian, the TCM values similar to the values of the Langhian in Central Europe and from the Serravalian to Tortonian these values decrease (Mosbrugger et al., 2005). Nevertheless, in western Turkey from the Langhian to Serravallian, reduction of the TCM and MAT values continues (Table 1; Figure 9). The ongoing cooling in the Serravallian could be related to the continuing extension of terrestrial conditions in western Turkey and global cooling in the late Middle Miocene (Popov et al., 2004).

#### 5.1.2. Precipitation parameters

The mean annual precipitation (MAP) values show a humid climate with the mean annual rainfall exceeding 1000 mm during the Burdigalian–Langhian in the Kocaçay and Cumaovası basins (Table 2; Figures 9–11). However, in the Büyük and Küçük Menderes Grabens during this time it is less humid than in these basins. For instance, generally the lower boundary of the precipitation in the Büyük Menderes Graben is 700 mm (Table 2). From the Burdigalian–Langhian to Serravallian, the MAP values do not show any distinct differences in the Kocaçay and Cumaovası basins. However, the Kocaçay basin is more humid than the Cumaovası basin during the Middle Miocene. In the Serravallian, the Büyük Menderes Graben is less humid than the other region (the lower boundaries of the MAP coexistence ranges are 400–700 mm) (Table 2). Precipitation of the Miocene in the İzmir region is fairly high but precipitation of today is low (570 mm; http://www.mgm.gov.tr/veridegerlendirme). This difference in precipitation, palaeotopographic change, and palaeoclimatic condition could cause the vegetation

**Table 2.** Coexistence approach values of the Cumaovası and Kocaçay basins and Büyük Menderes and Küçük Menderes Grabens.

| AGE | LOCATION | SAMPLE NO. | MAT max | Average MAT | MAT min | TCM min | Average TCM | TCM max | TWM min | Average TWM | TWM max | MART | MAP min | Average MAP | MAP max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Late Early and early Middle Miocene (late Burdigalian–Langhian)* | Kocaçay basin | DEREKÖY 6 (10 taxa) | 13.5 | 17.4 | 21.3 | 1.8 | 7.55 | 13.3 | 25.4 | 26.75 | 28.1 | 19.2 | 1183 | 1351.5 | 1520 |
| | | DEREKÖY 7 (15 taxa) | 15.6 | 18.2 | 20.8 | 5 | 9.15 | 13.3 | 25.4 | 26.75 | 28.1 | 17.6 | 1183 | 1269 | 1355 |
| | Cumaovası basin | YENİKÖY 33 (10 taxa) | 15.6 | 18.65 | 21.7 | 5 | 10.3 | 15.6 | 24.7 | 26.4 | 28.1 | 16.1 | 823 | 1171.5 | 1520 |
| | | YENİKÖY 39 (10 taxa) | 15.6 | 18.45 | 21.3 | 5 | 9.15 | 13.3 | 24.7 | 26.4 | 28.1 | 17.25 | 1122 | 1348 | 1574 |
| | | YENİKÖY 42 (10 taxa) | 15.6 | 18.45 | 21.3 | 5 | 9.15 | 13.3 | 24.7 | 26.4 | 28.1 | 17.25 | 823 | 1171.5 | 1520 |
| | | YENİKÖY 44 (10 taxa) | 9.1 | 15.2 | 21.3 | -2.7 | 5.3 | 13.3 | 21.6 | 24.85 | 28.1 | 19.55 | 473 | 996.5 | 1520 |
| *Late Early and early Middle Miocene (late Burdigalian-Langhian)* | Büyük Menderes Graben (Akgün et al., 2007) | BAŞÇAYIR 1 | 12.9 | 17.3 | 21.7 | 0.9 | 8.25 | 15.6 | 23.6 | 25.85 | 28.1 | 17.6 | 735 | 1154.5 | 1574 |
| | | BAŞÇAYIR 3 | 8.7 | 15.2 | 21.7 | -3.9 | 5.85 | 15.6 | 21.6 | 24.85 | 28.1 | 19 | 735 | 1154.5 | 1574 |
| | | BAŞÇAYIR 6 | 6.6 | 13.95 | 21.3 | -10.6 | 1.35 | 13.3 | 21.6 | 24.85 | 28.1 | 23.5 | 735 | 1154.5 | 1574 |
| | | KULOĞULLARI 1 | 9.1 | 15.2 | 21.3 | -2.7 | 5.3 | 13.3 | 21.6 | 24.85 | 28.1 | 19.55 | 735 | 1127.5 | 1520 |
| | | KULOĞULLARI 4 | 12.9 | 17.1 | 21.3 | 0.9 | 1 | 1.1 | 23.6 | 25.85 | 28.1 | 24.85 | 735 | 1127.5 | 1520 |
| | | KULOĞULLARI 5 | 12.6 | 16.7 | 20.8 | 0.9 | 7.1 | 13.3 | 23.6 | 25.85 | 28.1 | 18.75 | 1122 | 1321 | 1520 |
| | | KULOĞULLARI 6 | 12.9 | 17.1 | 21.3 | 0.9 | 7.1 | 13.3 | 23.6 | 25.85 | 28.1 | 18.75 | 473 | 996.5 | 1520 |
| | | KULOĞULLARI 8 | 9.4 | 15.35 | 21.3 | -0.1 | 6.6 | 13.3 | 21.7 | 24.9 | 28.1 | 18.3 | 473 | 996.5 | 1520 |
| | | KULOĞULLARI 10 | 13.5 | 17.4 | 21.3 | 1.8 | 7.55 | 13.3 | 25.4 | 26.75 | 28.1 | 19.2 | 1183 | 1351.5 | 1520 |
| | | KULOĞULLARI 13 | 12.9 | 17.1 | 21.3 | 0.9 | 1 | 1.1 | 23.6 | 25.85 | 28.1 | 24.85 | 735 | 1127.5 | 1520 |
| | | KULOĞULLARI 15 | 9.1 | 15.2 | 21.3 | -2.7 | 5.3 | 13.3 | 21.6 | 24.85 | 28.1 | 19.55 | 735 | 1127.5 | 1520 |
| | | KULOĞULLARI 17 | 12.9 | 16.85 | 20.8 | 0.9 | 7.1 | 13.3 | 23.6 | 25.85 | 28.1 | 18.75 | 735 | 1127.5 | 1520 |
| | | KULOĞULLARI 20 | 9.1 | 15.4 | 21.7 | -2.7 | 6.45 | 15.6 | 21.6 | 24.85 | 28.1 | 18.4 | 735 | 1127.5 | 1520 |
| | | KULOĞULLARI 21 | 12.9 | 17.1 | 21.3 | 0.9 | 7.1 | 13.3 | 23.6 | 25.85 | 28.1 | 18.75 | 735 | 1127.5 | 1520 |
| | | KULOĞULLARI 22 | 6.6 | 13.95 | 21.3 | -10.9 | 1.2 | 13.3 | 21.6 | 24.85 | 28.1 | 23.65 | 374 | 974 | 1574 |
| | Küçük Menderes Graben (Akgün et al., 2007) | İZMİR-TİRE | 16.5 | 19 | 21.5 | 5 | 9.15 | 13.3 | 27.3 | 27.7 | 28.1 | 18.55 | 887 | 1203.5 | 1520 |
| *Late Middle Miocene (Serravallian)* | Cumaovası basin | ÇATALCA 2002/7 (12 taxa) | 16.5 | 18.65 | 20.8 | 5.5 | 9.4 | 13.3 | 27.3 | 27.7 | 28.1 | 18.3 | 1122 | 1348 | 1574 |
| | | SEY 02-1 (11 taxa) | 16.5 | 18.9 | 21.3 | 5.5 | 9.4 | 13.3 | 27.3 | 27.7 | 28.1 | 18.3 | 887 | 1230.5 | 1574 |
| | | SEY 02-3 (10 taxa) | 11.3 | 16.3 | 21.3 | 0.1 | 6.7 | 13.3 | 21.7 | 24.9 | 28.1 | 18.2 | 520 | 1066.5 | 1613 |
| | | SEY 02-4 (10 taxa) | 8.7 | 15 | 21.3 | -3.9 | 4.7 | 13.3 | 21.6 | 24.95 | 28.3 | 20.25 | 735 | 1174 | 1613 |
| | | YE1/256 (10 taxa) | 9.1 | 15.2 | 21.3 | -2.7 | 5.3 | 13.3 | 21.6 | 24.85 | 28.1 | 19.55 | 735 | 1127.5 | 1520 |
| | | KG 01-35 (10 taxa) | 15.6 | 18.45 | 21.3 | 5 | 9.15 | 13.3 | 24.7 | 26.4 | 28.1 | 17.25 | 1122 | 1348 | 1574 |
| | Kocaçay basin | YENİKÖY 14 (14 taxa) | 15.6 | 18.2 | 20.8 | -2.7 | -0.8 | 1.1 | 24.7 | 26.4 | 28.1 | 27.2 | 1122 | 1321 | 1520 |
| | | YENİKÖY 19 (10 taxa) | 15.6 | 18.2 | 20.8 | 5 | 9.15 | 13.3 | 24.7 | 26.4 | 28.1 | 17.25 | 823 | 1171.5 | 1520 |
| | | YENİKÖY 20 (10 taxa) | 17 | 19.6 | 22.2 | 6.2 | 9.75 | 13.3 | 26.5 | 27.5 | 28.5 | 17.75 | 1183 | 1252.5 | 1322 |
| | | YENİKÖY 21 (10 taxa) | 6.6 | 13.95 | 21.3 | -10.9 | 1.2 | 13.3 | 21.6 | 25.1 | 28.6 | 23.9 | 373 | 993 | 1613 |
| | | YENİKÖY 29 (12 taxa) | 13.6 | 17.45 | 21.3 | 1.8 | 7.55 | 13.3 | 23.6 | 25.85 | 28.1 | 18.3 | 1122 | 1321 | 1520 |
| | | YENİKÖY 30 (17 taxa) | 15.6 | 18.35 | 21.1 | -2.8 | -0.85 | 1.1 | 24.7 | 26.4 | 28.1 | 27.25 | 1122 | 1238.5 | 1355 |
| | | YENİKÖY 31 (10 taxa) | 15.6 | 18.65 | 21.7 | 5 | 10.3 | 15.6 | 25.4 | 26.75 | 28.1 | 16.45 | 1183 | 1378.5 | 1574 |
| | | YENİKÖY 48 (10 taxa) | 12.9 | 17.1 | 21.3 | 0.9 | 7.1 | 13.3 | 23.6 | 25.85 | 28.1 | 18.75 | 735 | 1174 | 1613 |

**Table 2.** (continued).

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AYDIN-İNCİRLİOVA 2 | 9.1 | 9.95 | 10.8 | -2.7 | -0.8 | 1.1 | 18.7 | 19.5 | 20.3 | 20.3 | 735 | 1127.5 | 1520 |
| | | AYDIN-İNCİRLİOVA 3 | 9.3 | 15.3 | 21.3 | -2.8 | 5.25 | 13.3 | 21.6 | 24.95 | 28.3 | 19.7 | 1122 | 1367.5 | 1613 |
| | | HASKÖY LOWER COAL 11 | 8.7 | 16.3 | 23.9 | -3.9 | 6.4 | 16.7 | 21.6 | 24.95 | 28.3 | 18.55 | 473 | 1165 | 1857 |
| | | HASKÖY LOWER COAL 18 | 9.1 | 14.95 | 20.8 | -2.7 | 5.3 | 13.3 | 21.6 | 24.85 | 28.1 | 19.55 | 735 | 1127.5 | 1520 |
| *Late Middle Miocene (Serravallian)* | Büyük Menderes Graben (Akgün et al., 2007) | HASKÖY LOWER COAL 19 | 8.7 | 15.2 | 21.7 | -3.9 | 5.85 | 15.6 | 21.6 | 24.85 | 28.1 | 19 | 735 | 1154.5 | 1574 |
| | | HASKÖY LOWER COAL 20 | 9.1 | 15.2 | 21.3 | -2.7 | 5.3 | 13.3 | 21.6 | 24.85 | 28.1 | 19.55 | 473 | 996.5 | 1520 |
| | | HASKÖY LOWER COAL 25 | 9.1 | 9.95 | 10.8 | -2.7 | -0.8 | 1.1 | 21.6 | 24.85 | 28.1 | 25.65 | 735 | 1127.5 | 1520 |
| | | HASKÖY LOWER COAL 26 | 9.1 | 9.95 | 10.8 | -2.7 | -0.8 | 1.1 | 21.7 | 24.9 | 28.1 | 25.7 | 473 | 996.5 | 1520 |
| | | HASKÖY LOWER COAL 33 | 8.7 | 15.2 | 21.7 | -3.9 | 5.85 | 15.6 | 21.6 | 24.85 | 28.1 | 19 | 473 | 1023.5 | 1574 |
| | | HASKÖY LOWER COAL 40 | 9.1 | 16.5 | 23.9 | -2.7 | 7 | 16.7 | 21.6 | 25.5 | 29.4 | 18.5 | 473 | 996.5 | 1520 |
| | | HASKÖY LOWER COAL 41 | 9.1 | 15.4 | 21.7 | -2.7 | 6.45 | 15.6 | 21.6 | 24.85 | 28.1 | 18.4 | 473 | 996.5 | 1520 |
| | | HASKÖY LOWER COAL 42 | 9.1 | 15.2 | 21.3 | -2.7 | 5.3 | 13.3 | 21.6 | 24.85 | 28.1 | 19.55 | 735 | 1127.5 | 1520 |
| | | HASKÖY LOWER COAL 43 | 6.6 | 13.95 | 21.3 | -10.9 | 1.2 | 13.3 | 21.6 | 24.85 | 28.1 | 23.65 | 374 | 974 | 1574 |
| | | HASKÖY LOWER COAL 44 | 0.2 | 12.05 | 23.9 | -16.6 | 1.4 | 19.4 | 16.3 | 22.3 | 28.3 | 20.9 | 233 | 1048.5 | 1864 |
| | | KÖŞK LOWER COAL 1 | 3.4 | 12.55 | 21.7 | -10.9 | 2.35 | 15.6 | 18.7 | 23.4 | 28.1 | 21.05 | 735 | 1154.5 | 1574 |
| | | KÖŞK LOWER COAL 4 | 9.1 | 15.4 | 21.7 | -2.7 | 6.45 | 15.6 | 21.6 | 24.85 | 28.1 | 18.4 | 473 | 996.5 | 1520 |
| | | SÖKE 3 | 9.3 | 15.5 | 21.7 | -2.8 | 6.4 | 15.6 | 21.6 | 24.85 | 28.1 | 18.45 | 1122 | 1348 | 1574 |
| | | SÖKE 6 | 9.1 | 15.2 | 21.3 | -2.7 | 5.3 | 13.3 | 21.6 | 24.85 | 28.1 | 19.55 | 473 | 996.5 | 1520 |
| | | SÖKE 8 | 9.4 | 15.55 | 21.7 | -0.1 | 7.75 | 15.6 | 18.8 | 23.45 | 28.1 | 15.7 | 735 | 1127.5 | 1520 |
| | | SÖKE 12 | 8.7 | 14.75 | 20.8 | -3.9 | 4.7 | 13.3 | 21.6 | 24.85 | 28.1 | 20.15 | 735 | 1154.5 | 1574 |
| | | ŞAHİNALİ 1 | 12.9 | 17.1 | 21.3 | 0.9 | 7.1 | 13.3 | 23.6 | 26.1 | 28.6 | 19 | 735 | 1127.5 | 1520 |
| | | ŞAHİNALİ 2 | 9.1 | 14.95 | 20.8 | -2.7 | 5.3 | 13.3 | 21.6 | 24.85 | 28.1 | 19.55 | 735 | 1127.5 | 1520 |
| | | ŞAHİNALİ 3 | 9.1 | 14.95 | 20.8 | -2.7 | 5.3 | 13.3 | 21.6 | 24.85 | 28.1 | 19.55 | 735 | 1127.5 | 1520 |

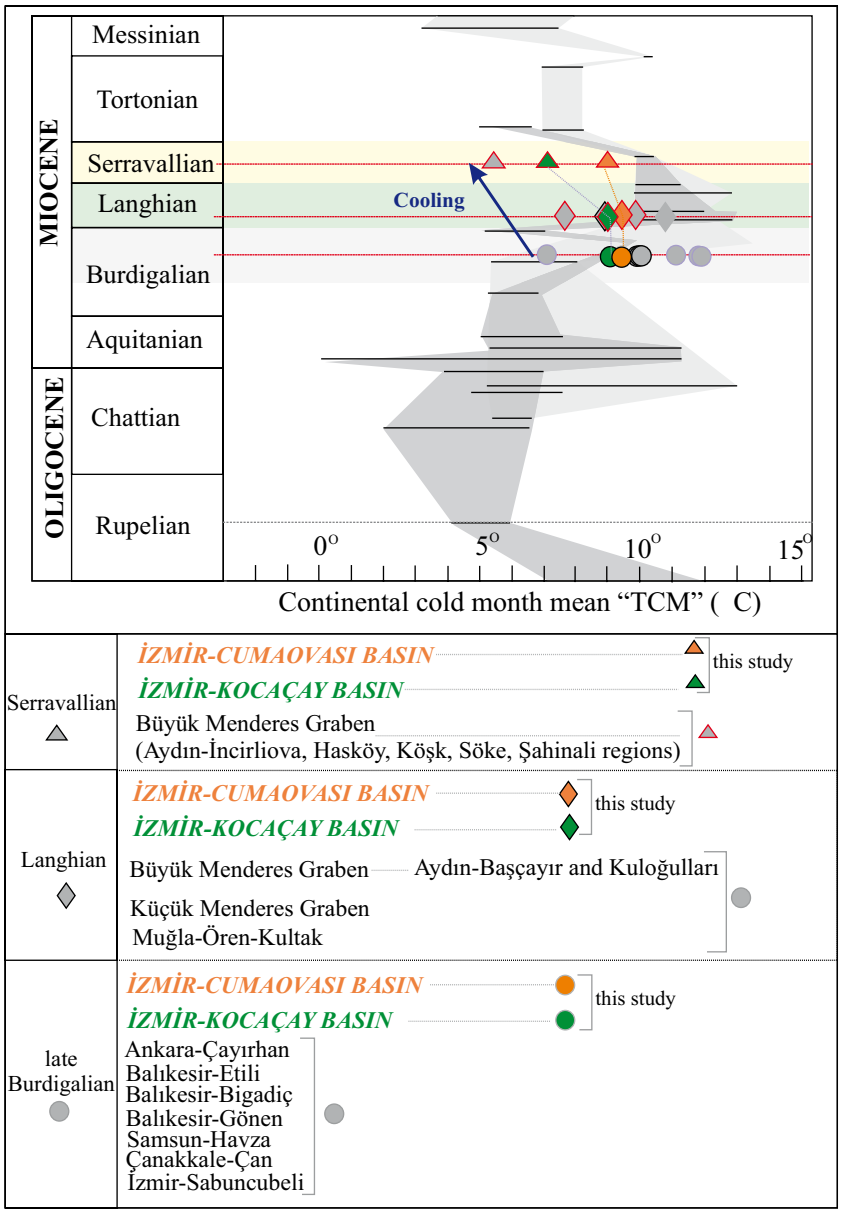



**Figure 9.** Continental temperature curves (TCM) for central Europe during the Oligo–Miocene (Mosburgger et al., 2005; Utescher et al., 2011) and TCM temperature values of Turkey (rhombus symbolises the average values of TCM of the Langhian, triangle indicates the average values of TCM of the Serravallian, and the circle symbolises the average values of TCM of the late Burdigalian).

change from the Miocene to today. The palaeovegetation of the Miocene is characterised by conifers and mixed mesophytic forests in highland areas and swamp forest in lowland areas. Today, these forests are not observed in the İzmir–Kemalpaşa region and instead a shrub plant community is widespread, because of the palaeoclimate and human impact (Koçman, 1989).

In Europe, marine sediments were widespread during the Burdigalian–Langhian (Popov et al., 2004) and maritime palaeoclimate conditions are recorded. In western Anatolia, different from the Burdigalian, terrestrial conditions in the Langhian are expanded (Menderes high) (Rögl 1999; Popov et al., 2004). These terrestrial conditions could have affected the palaeoclimatic conditions, and decreasing of the CMT values starts during the Langhian in western Anatolia. Differences in the mean annual range of the temperature values (MART) are indicative for continental climate conditions and/or seasonality

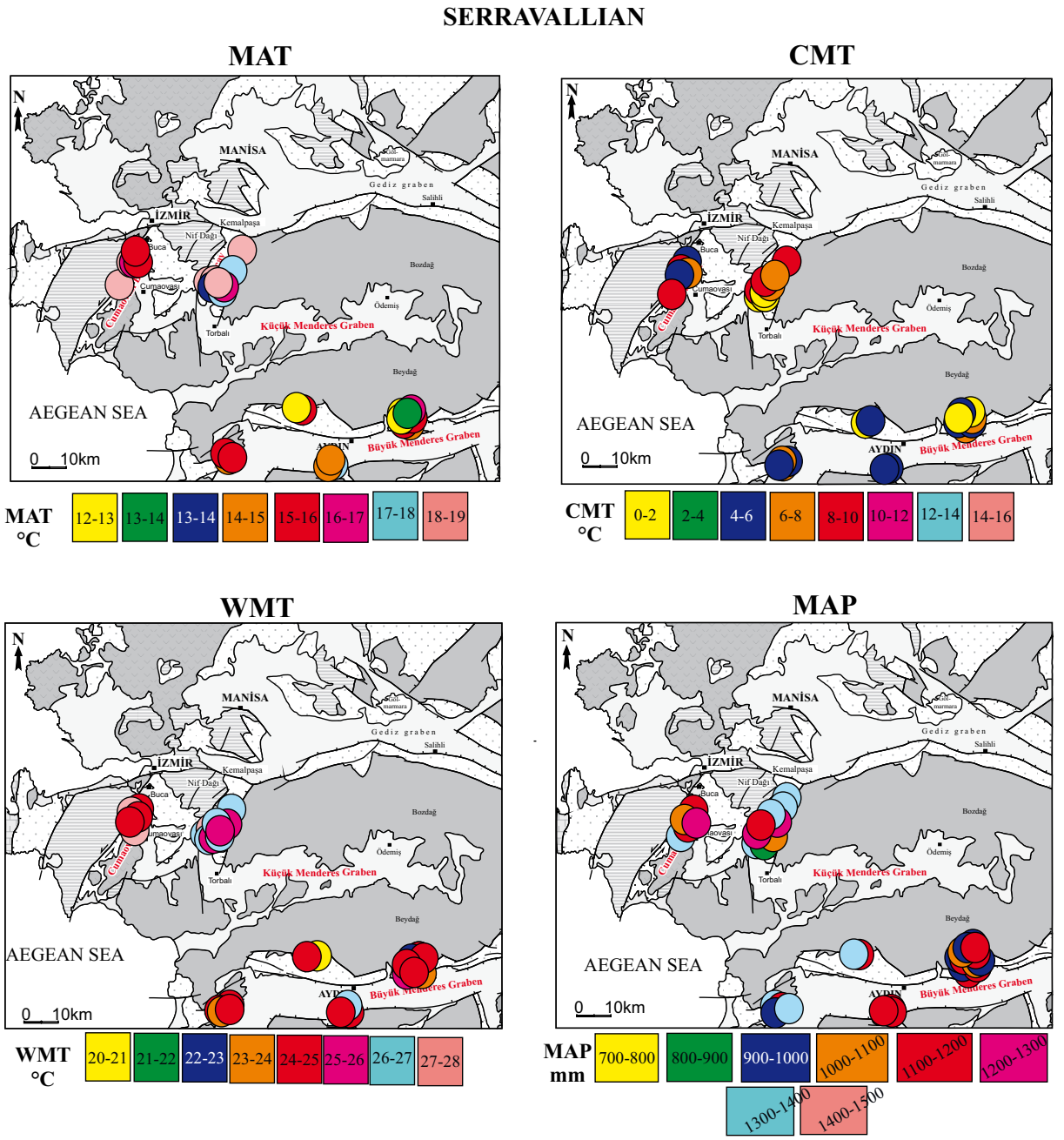



**Figure 10.** Simplified geological map of central western Anatolia (Genç et al., 2001) and average MAT, CMT, WMT, and MAP values of the Burdigalian–Langhian.

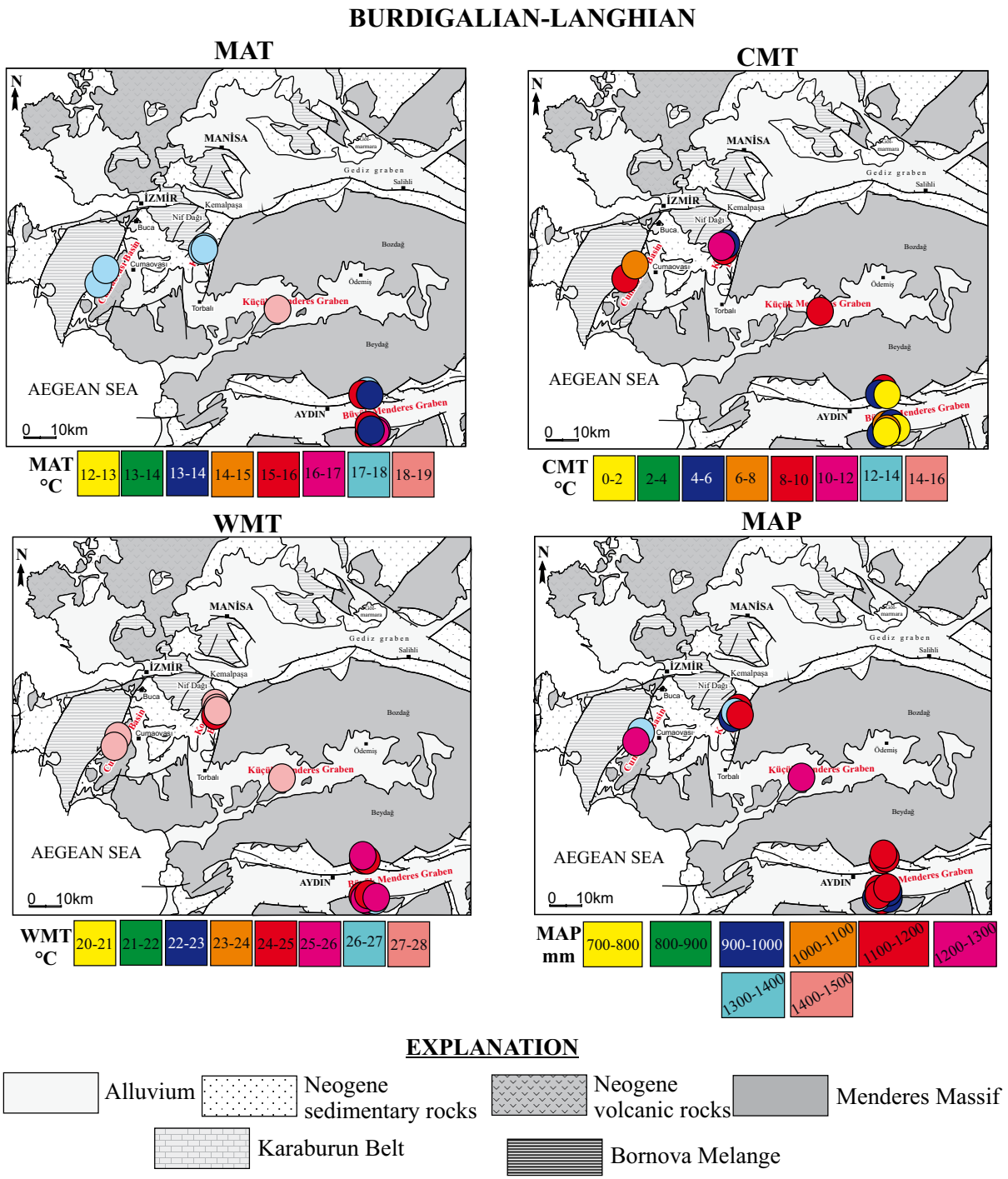



**Figure 11.** Simplified geological map of central western Anatolia (Genç et al., 2001) and average MAT, CMT, WMT, and MAP values of the Serravallian.

(Bruch et al., 2004; Yao et al., 2011). The MART values are between 17 and 27 °C during the Burdigalian–Serravallian in the Kocaçay and Cumaovası basins, thus showing a high seasonality (warmer summers and colder winters). As a result, high seasonality in western Turkey could be related to the influence of the continental climate (Table 2; Figures 9–11) (Yao et al., 2011).

This study contains the first palynological, palaeovegetational, and palaeoclimatic findings of the İzmir region and sporomoprhs of the Early–Middle

Miocene are for the first time identified from the lignite-bearing sediments in the Cumaovası and Kocaçay basins (İzmir–Cumaovası and Kemalpaşa regions). Two sporomorph assemblages (A and B) are recorded in both basins. Assemblage A of the late Early–early Middle Miocene is recorded from the lower lignite seams in the Çatalca and Dereköy formations. Sporomorph assemblage B of the late Middle Miocene (Serravallian) is defined from samples of lignite layers in the upper part of the Vişneli and Yeniköy formations. The palynofloras of these formations have been compared with the published palynofloras of the late Early–Late Middle Miocene in Europe and Turkey.

The microfloras cover a time-span from the late Early to late Middle Miocene. Throughout this time interval, the palaeoclimate changed from warm subtropical to temperate according to the palynoflora and numerical climatic values. These values of the Cumaovası and Kocaçay basins are compared with continental palaeoclimatic records from western Turkey (Büyük Menderes and Küçük Menderes Grabens). Orographic differences in western Anatolia affected the palaeoclimate during the late Burdigalian–Serravallian. From south to north the MAT values increase in both the Burdigalian–Langhian and Serravallian. From south to north the MAT and CMT values increase in both the Burdigalian–Langhian and Serravallian. Clear differences in the MAT and TCM values indicate orographic or palaeoenvironmental differences during the Burdigalian–Serravallian. The MAP values do not show any distinct differences between the Kocaçay and Cumaovası basins during the Burdigalian to Serravallian. Nevertheless, the Kocaçay basin is more humid than the Cumaovası basin during the Middle Miocene. In the Serravallian, the Büyük Menderes Graben is less humid than the other regions.

In the late Burdigalian the TCM values of Turkey and Central Europe are very high because of the Middle Miocene Climatic Optimum period. During the Langhian, these high TCM values continue in Central Europe, while decreasing TCM values are seen in Turkey. This cooling from the Burdigalian to Langhian could be related to the expansion of terrestrial conditions in Turkey. In the Serravallian, the TCM values of Central Europe were higher than those in western Turkey and the decline in the TCM values continues in Turkey from the Langhian to Serravallian. The ongoing cooling in the Serravallian could be related to continuing extension of terrestrial conditions in Turkey and a cooling period in the late Middle Miocene.

Palaeovegetation of the Cumaovası basin from the late Early to Middle Miocene is represented by coniferous and mixed mesophytic forests. Riparian forest elements tended to increase, while swamp forest elements seemed to decrease in the palynofloras of the Cumaovası basin. The general characteristic of the palaeovegetation in the Kocaçay basin during same interval is the presence of swamp, coniferous, and mixed mesophytic forests. Swamp forest elements show a rising tendency while the percentage of coniferous and mixed mesophytic forest elements tends to decrease in the Kocaçay palynoflora. Abundance of herb species increases towards the late Middle Miocene in the Kocaçay and Cumaovası basins.

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