

# Late Miocene flora from SE Bulgaria: vegetation, landscape and climate reconstruction

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**Abstract.** The Neogene sediments of Southeast Bulgaria are poorly studied in terms of palaeobotany. This paper provides new data about the macro- and microflora from the upper undivided part of the Elhovo Formation (Toundzha Basin). Data from current palaeobotanical study contribute to the elucidation of evolution of the local and regional Late Miocene flora, vegetation patterns, palaeoecological peculiarities, and palaeogeography of the Balkan Peninsula. The taxonomic composition of the fossil flora includes 33 species identified as leaf imprints/charcoal remains, and 47 palynomorph taxa. On the basis of palaeoecological analysis we suggest the development of riparian forests, mesophytic and xeromesophytic forests, herbaceous and hydrophyllous communities. Calculations of the quantitative climate data indicate a warm temperate climate, with mean annual temperature of 14.4–15.8 °C and annual precipitation over 800 mm.

**Key words:** Bulgaria, climate reconstruction, Miocene, palaeobotany, palynology, Pliocene, sedimentology, vegetation

## Introduction

The Neogene sediments of Southeast Bulgaria are poorly studied in terms of palaeobotany. A brief review of the palaeobotanical studies in Bulgaria shows that most of the information about Neogene floras derives from localities situated in the western part of the country, while the eastern part is insufficiently studied yet (see Palamarev & al. 1999). Scarce information about the composition and character of the palaeoflora from the Toundzha Basin is available from some fragmentary data on the composition alone, originating from the upper undivided part of Elhovo Formation (Bozhinova 1991) and limited data on the macroflora of the Izgrev Member of the same Formation (Palamarev 1991; Mai & Palamarev 1997). Recently, studies of the fossil macroflora from the upper part of Elhovo Formation have been undertaken (Palamarev & Bozukov 2004) and are used in this paper for vegetation and climate reconstruction.

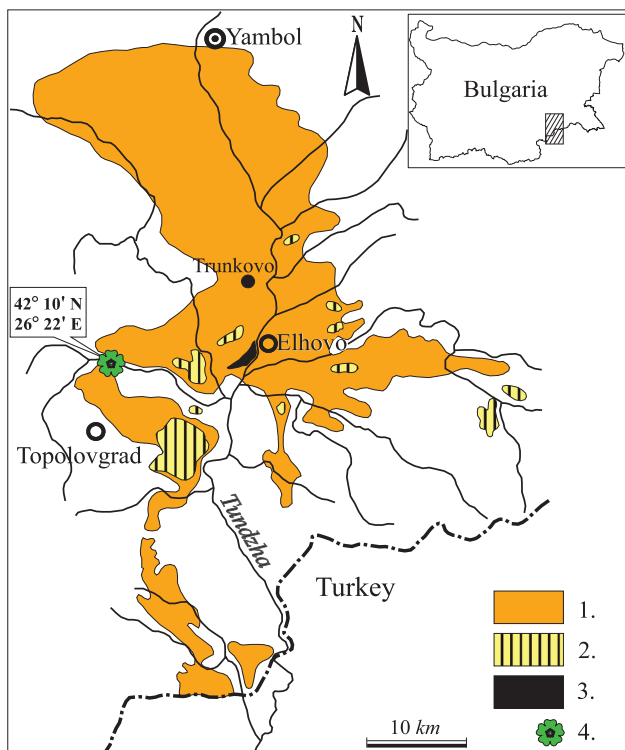
Palynological data about the Toundzha Basin are also scanty. Pollen analysis was applied to the clay sediments of Elhovo Formation for biostratigraphic purposes (Kojumdzieva & al. 1984), but the results were not published. Detailed palynological studies have been undertaken in the sediments of the Izgrev Member of Elhovo Formation, and the initial results were presented by Ivanov & Lazarova (2005).

## Location, geology and stratigraphy of the studied basin

Because of its geographic position, the sediment complex of the Toundzha Basin plays an important role in understanding and reconstruction of the palaeogeographical development during the Neogene of the entire southern half of the country (Kojumdzieva & al. 1984). That is why, data from this study contribute to the elucidation of the evolution of the local and regional Late Miocene flora, vegetation patterns, palaeo-

oecological peculiarities, and palaeogeography of the Balkan Peninsula.

The Neogene sediments of the Toundzha Basin are differentiated into the Elhovo Formation with its two members (Izgreve and Douganovo), and an undivided part (Fig. 1). Angelova & al. (1991) has described the infiltration limestone sediments of the Douganovo Member as the Prustnik Limestone Formation, and dated it to the Pleistocene.



**Fig. 1.** Geological map of the Toundzha Basin, SE Bulgaria (redrawn from Kojumdgieva & al. 1984).

Legend: 1. Elhovo Formation; 2. Douganovo Member of Elhovo Formation; 3. Izgreve Member of Elhovo Formation; 4. Outcrop near the bridge over river Sinapovska.

The Elhovo Formation is represented by alternating clays, sands, conglomerates and coal strata. They are entirely of continental origin and were deposited in alluvial, fluvial and lacustrine to marsh environments (Nakov & al. 2001). The thickness of the Elhovo Formation is ca. 150 m to 200 m, but locally it reaches up to 300 m (Kojumdgieva & al. 1984).

On the basis of a diatom analysis, Temniskova-Topalova & al. (1996) suggested Late Miocene (Pontian) as the age of the Izgreve Member of Elhovo Formation. That was confirmed by pollen analysis (Ivanov & Lazarova 2005). Remains of vertebrate fauna were discovered in the sediments from the up-

per part of the Elhovo Formation and the following species were identified: *Deinotherium giganteum* Kaup, *Tetralophodon longirostris* Kaup, *Anancus arvernensis* Croizet & Jobert, and *Zygodontodon borsoni* Hayes (Bakalov & Nikolov 1962; Kojumdgieva & al. 1984; Nikolov 1985). On the basis of these finds Kojumdgieva & al. (1984) assumed that the upper part of the Formation is Pontian-Pliocene, while the Elhovo Formation in general was formed in the Meotian-Early Pliocene time interval (according to the above-cited authors). The above-mentioned data invite the conclusion that the fossil flora probably dates to the transition from Late Pontian to Early Pliocene.

## Material and methods

The flora-bearing sediments are exposed along the road from the Golyam Manastir village to the town of Topolovgrad, southwards of the bridge over river Sinapovska (Fig. 1). The locality lies in a small outcrop cut across by the road (Plate I, Figs 1–2). The excavated section comprises an alternating sequence of about 5 m of sandstone/sands and greenish-yellowish to beige-coloured silt-sandy clays. There are three layers of clayey sediments of irregular thickness, each about 0.40–0.50 m to 0.70–0.80 m thick, interbedded between 1.00 to 1.40 m with sandstone, and sands in the upper part of the section (Fig. 2). The section continues above with ca. 10 m of sands. The sands and sandstones are of irregular thickness, with slanted to crosswise layering. The sediments represent deltaic environment of deposition, with probable changes and cyclicity in the water level. These sediments belong to the upper undivided part of the Elhovo Formation (Kojumdgieva & al. 1984).

The fossil flora originates mainly from the first silt-sandy clay layer at the bottom of the section (Fig. 2). The second clayey layer shows irregular layering, without any well-preserved plant remains, and the third layer at the top of the section is significantly sandy in composition, without leaf imprints. The studied leaf imprints were preserved on 121 rock fragments. The taxonomic composition of the fossil macroflora was published by Palamarev & Bozukov (2004). In the present study we evaluate the macrofloristic data in terms of palaeoecology and palaeoclimate.

We have collected 18 samples for pollen analysis from the silt-clayey sediments. The samples were processed by standard treatment with HF, HCl, KOH, heavy liquid separation, and acetolysis. The fossil pollen in the studied sediments was very poor in terms of quantity and preservation, and was found mainly in the first layer, very scarcely in the second and totally absent in the third. Here we present the results from the pollen analysis of the first clay layer, where we were able to count a pollen sum of over 200 pollen grains from five pollen slides.

A sedimentological analysis was performed on the flora-bearing sediments (first clayey layer) in order to obtain additional information about the preservation of leaf imprints and taphonomic processes. The analysis was carried out on thin-sections of rock specimens using light microscopy.

The palaeobotanical data were analyzed in terms of palaeoclimate, using the Nearest Living Relative Approach. On the basis of the fossil macroflora and pollen data, we have reconstructed the climatic conditions

using the so-called Coexistence Approach (Mosbrugger & Utescher 1997), which is a recently developed technique for palaeoclimate reconstruction based on the philosophy of the nearest living relatives. For a given fossil flora, the Coexistence Approach (CA) method determines the nearest living relatives of the fossil taxa and their climatic tolerances and calculates the coexistence intervals (minimum and maximum values) for various climate parameters (for details see Mosbrugger & Utescher 1997) within which all living relatives of the fossil species can coexist. The Palaeoflora data base (Utescher & Mosbrugger 1990–2007) was used for identifying the living relatives and their climatic requirements. This coexistence interval is considered to represent a reasonable estimator of the past climate under which the fossil flora lived. The method was recently applied for climate reconstructions in Europe and Asia (e.g. Pross & al. 1998; Utescher & al. 2000; Bruch & Gabrielyan 2002; Bruch & Mosbrugger 2002; Ivanov & al. 2002; Bruch & Kovar-Eder 2003; Bruch & al. 2004, 2006; Mosbrugger & al. 2005; Ivanov & al. 2007; Utescher & al. 2007; Syabryaj & al. 2007).

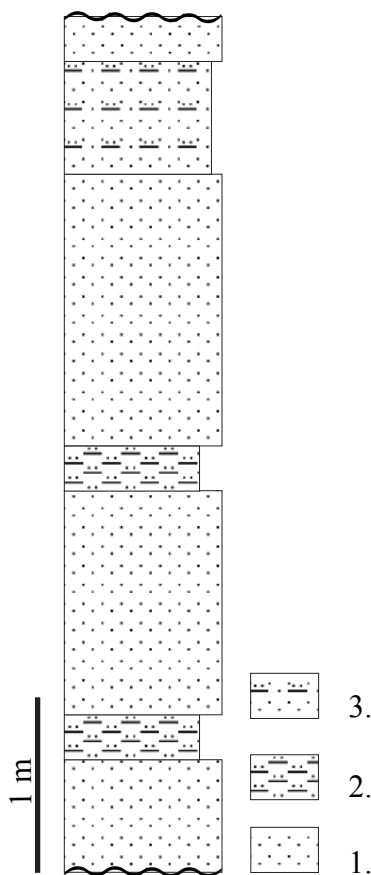
## Results and discussion

### Sedimentology of the host silt-sandy clays

Macroscopically, the clays show a very characteristic beige colouration with rare ochre patches and spots, irregularly pigmented by Fe-oxides and hydroxides. The rocks are massive and quite compact, but an indistinct parallel lamination (1.0–2.0 mm thick) can be recognized in some places. Under microscopic observation, they are predominantly composed of clay minerals. The clayey matrix is about 75–80 % and the clastic component ranges from 20 % to 25 %, respectively.

The matrix texture is very fine-grained: the clay particles are finer than 0.004 mm and their interfering colours in the thin sections (observed under polarizing light) are usually dark-grey to black. The main clay mineral is kaolinite. Some kaolinite crystals are bigger and worm-like in shape, supposedly of a late diagenetic origin.

The clastic constituents are presented by quartz grains, plagioclases, K-feldspars and muscovite flakes (Plate I, Figs 3–4). A clear bimodal distribution of the clastic components is visible, according to their size, shape and mineral composition. This fact proves that two different sources were responsible for their pres-



**Fig. 2.** Lithological column of the studied section. Legend: 1. Sands and sandstones; 2. Silty clays; 3. Sandy clays.

ence in the studied rock. Some of the particles, mainly quartz grains, are under 0.063 mm (silt fraction) in size and are subrounded to subangular in shape. The remaining components, mainly limpid (unaltered) plagioclases and K-feldspars, and seldom quartz, fall into the fine and medium sandy fractions (0.125–0.25 mm and 0.25–0.50 mm). Their shape is predominantly angular and they were transported to a short distance from a neighbouring provenance. The same rule applies to the muscovite. There are very fine-sized muscovite flakes and others that are visible macroscopically. Random spherical chalcedony fragments (sand-sized) have been identified too.

Most probably, the good preservation of the plant remnants was due to a relatively high rate of accumulation of the silt-sandy clayey material in which they were involved. As mentioned above, one of the clastic sources was situated close to the place of sedimentation. The material was rapidly compacted to a higher degree because of the pressure of the above-lying sediment load. Thus, the pore spaces of the sediments decreased and probably almost disappeared. The pore solutions (responsible for many alterations) did not move and the plant remnants remained in a very good state.

### Floristic and vegetational analysis

The analysis of the fossil flora is based on data from the ichnophytological and palynological methods. These two different palaeobotanical methods supplement each other when jointly applied, owing to the fact that the various plant organs have individual taphonomic peculiarities and storage capability. Macrofloristic records provide detailed information on the vegetation in close proximity to the palaeobasin, owing to the better storage capabilities. On the other hand, pollen analysis provides data on the vegetation in a considerably wider region due to the pollen's good capabilities for long-distance transport by wind and water. Thus, when the two above-mentioned methods are jointly applied, they provide a fuller floristic range and a more reliable reconstruction of the fossil coenoses.

The fossil flora identified during the macro- and micro-palaeobotanic studies generally comprised representatives of 38 families: 33 taxa from 16 families in the macroflora (Palamarev

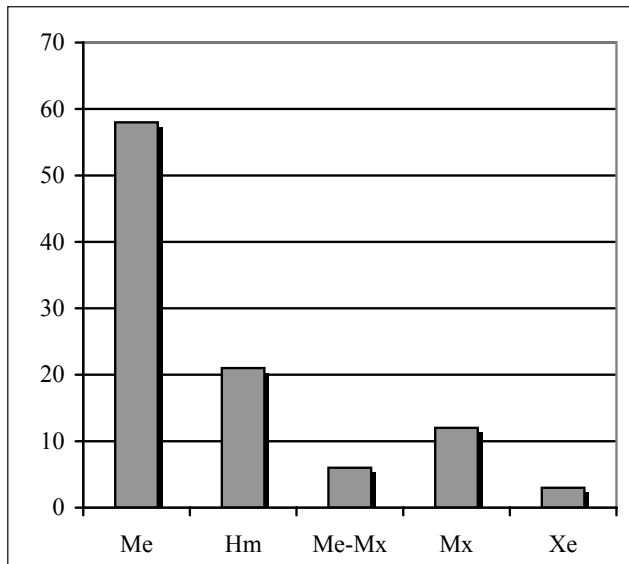
& Bozukov 2004) and 47 pollen types (Plates I–II) from 30 families (this study). Representatives of eight families have been simultaneously identified as leaf imprints and palynomorphs.

Within the macroflora, the following families showed the greatest species diversity: *Juglandaceae* (2), *Fagaceae* (3), *Salicaceae* (3), *Betulaceae* (3), *Fabaceae* (4), and *Lauraceae* (5). The species of the highest occurrence (the greatest number of leaf imprints) were: *Pterocarya paradisiaca* (Unger) Iljinsk., *Salix lavateri* A. Braun, *Quercus pliovariabilis* Kolak., *Q. kubinyi* (Kováts ex Ettingsh.) Czechtz, *Alnus gaudinii* (Heer) Knobl. & Kvaček, and *Lindera ovata* Kolak.

From palaeoecological viewpoint, the greatest share in the macroflora was claimed by the mesophytes (58%), followed by hygromesophytes (21%) (Fig. 3, Table I). The mesoxerophytic and xerophytic

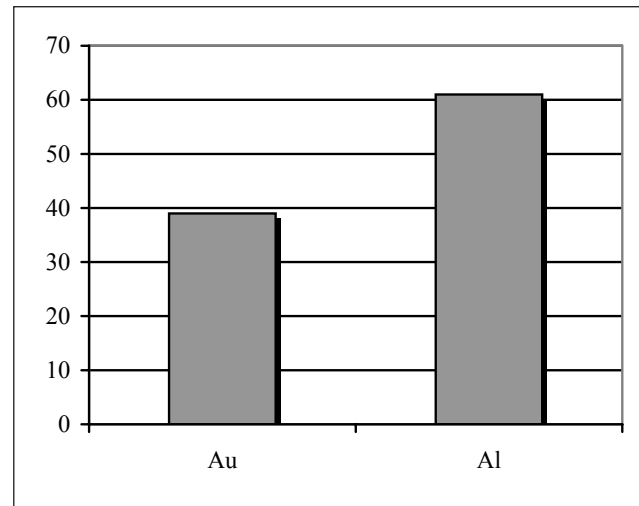
**Table 1.** Taxonomic composition of the macroflora from Toundzha Basin with the ecological and biological type of fossil taxa (after Palamarev & Bozukov 2004).

Taxa	Ecological type	Biological type
<i>Magnolia diana</i>	mesophyte	tree
<i>Actinodaphne cf. dolichophylla</i>	mesophyte to hygromesophyte	tree/shrub
<i>Daphnogene polymorpha</i>	mesophyte to hygromesophyte	tree/shrub
<i>Lindera ovata</i>	mesophyte	tree
<i>Litsea primigenia</i>	hygromesophyte	tree
<i>Ocotea euxina</i>	hygromesophyte	tree
<i>O. heeri</i>	hygromesophyte	tree
<i>Persea cf. pliocenica</i>	hygromesophyte	tree
<i>Quercus neriifolia</i>	mesophyte	tree
<i>Q. cf. kubinyi</i>	mesoxerophyte	tree
<i>Q. cf. pliovariabilis</i>	mesophyte	tree
<i>Alnus gaudinii</i>	mesophyte	tree
<i>A. rotundata</i>	mesophyte	tree
<i>Carpinus grandis</i>	mesophyte	tree
<i>Carya denticulata</i>	hygromesophyte	tree
<i>Pterocarya paradisiaca</i>	mesophyte	tree
<i>Gleditsia lyelliana</i>	hygromesophyte	tree/shrub
<i>Robinia regeli</i>	mesophyte	tree
<i>Sophora europaea</i>	mesophyte	tree
<i>Wisteria cf. falax</i>	mesophyte to hygromesophyte	liana
<i>Arbutus guriense</i>	mesoxerophyte to mesophyte	tree
<i>Styrax pseudoofficinale</i>	hygromesophyte	tree/shrub
<i>Acer sp.</i>		
<i>Liquidambar europaeum</i>	mesophyte	tree
<i>Sapindus falcifolius</i>	mesophyte	tree
<i>Ulmus pyramidalis</i>	mesophyte	tree
<i>Zelkova zelkovifolia</i>	mesophyte	tree
<i>Parrotia pristina</i>	mesophyte	tree
<i>Populus populina</i>	mesophyte	tree
<i>Salix cf. haidingeri</i>	mesophyte	tree/shrub
<i>Salix lavateri</i>	mesophyte	tree
<i>Rhamnus rectinervis</i>	mesoxerophyte to mesophyte	shrub
<i>Paliurus cf. favonii</i>	xerophyte	shrub
<i>Pistacia miocenica</i>	xerophyte	tree/shrub

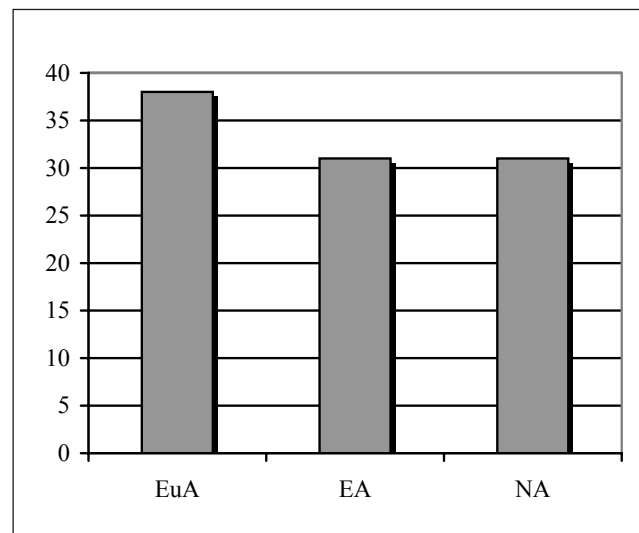


**Fig. 3.** Ratio between ecological groups in the fossil macroflora. Legend: Me – Mesophytes; Hm – Hygromesophytes; Me-Mx – Mesophytes to Mesoxerophytes; Mx – Mesoxerophytes; Xe – Xerophytes.

components showed the same percentage participation (21%). An interesting specificity of that flora was the correlation of allochthonous (61%) and autochthonous (39%) components (Fig. 4) (for definition of allochthonous and autochthonous elements see Mai 1995). Prevalence of allochthonous components usually marks the earlier floristic complexes. By this index, the researched flora is close to the flora from Melnik, the Sandanski Graben (Palamarev 1982; Palamarev & al. 2002). The high percentage of allochthonous elements was probably due, on the one hand, to the specificity of the taphonomic processes (fast burial of the plant material) and, on the other, to the specific origin of the plant material (species characteristic of the coastal and riparian forests). As compared to the other palaeocoenoses, coastal forest communities have more favourable storage opportunities, owing to their immediate proximity to the place of burial. On the other hand, the local palaeoclimatic conditions around the lakes and inflowing rivers ensured higher air humidity and a high ground water table, which helped them play the role of refugia for a number of species. This also explains the comparatively good representation of the East Asian and North American refugial-geographic elements (each by 31% – Fig. 5), while the Eurasian elements participated with 38% in the floristic composition. Vegetation analysis of Late Miocene/Pliocene floras from southern Europe (Kovar-Eder & al. 2006)



**Fig. 4.** Ratio between the autochthonous (Au) and allochthonous (Al) elements in the fossil macroflora.



**Fig. 5.** Ratio between the main refugial-geographic elements in the fossil macroflora. Legend: EuA – Eurasian; EA – East Asian; NA – North American.

reveals that the Balkan peninsula had the special status favourable for a longer persistence of taxa surviving from the Middle Miocene.

The following families showed the highest taxonomic diversity in the composition of the pollen flora: *Pinaceae* (6 pollen types), *Betulaceae* and *Asteraceae* (5 pollen types each), and *Fagaceae* (3 pollen types). Most families were represented by one pollen type each. Of the trees and shrubs, the greatest participation was claimed by the *Pinus diploxylon* type (13.5%), followed by *Alnus* (6.3%), *Betula* (1.8%), *Carpinus betulus* type (2.2%), *C. orientalis*\Ostrya type (3.6%), *Corylus* (2.7%), *Quercus* (3.1%), *Ulmus* (3.6%), and *Tilia* (1.4%). The pollen flora identified during our



studies characteristically showed a considerable pollen participation of herbaceous species and absence of representatives of spore plants. The herbaceous plants not only showed a high percentage participation (45.8%), but considerable taxonomic diversity too (Figs 6–7). The highest percentage of the herbaceous species was shown by: *Chenopodiaceae* (11.6%), *Asteroidaeae* (8.5%), *Poaceae* (7.1%), *Dipsacaceae* (5.4%), *Artemisia* (2.7%), *Apiaceae* (1.8%), and *Cichorioideae* (1.4%). Mention deserves the fact that the identified pollen of the family *Poaceae* could be assigned to

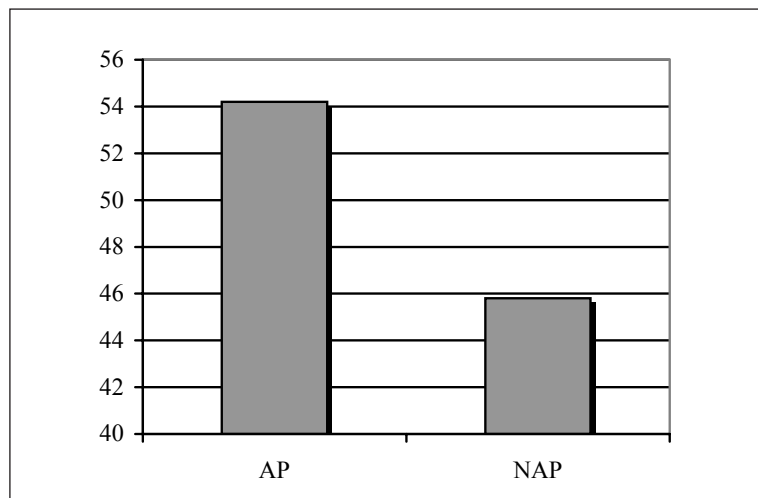
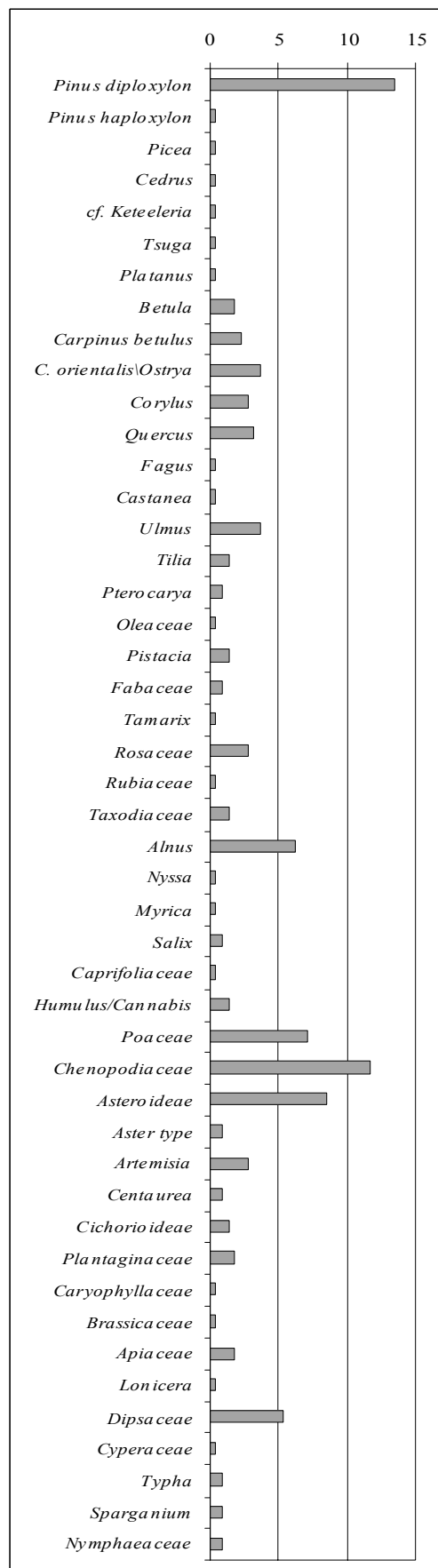


Fig. 6. Ratio between trees and shrubs (AP) and herbs (NAP) in the fossil pollen flora.

two types. The first type comprised pollen grains of smaller size (33–45  $\mu\text{m}$  – Plate II, Figs 24–25) and is close to the pollen of the recent wild grasses. The second type comprises pollen grains of larger size (52–59  $\mu\text{m}$ ), with an exine 1.0–1.5  $\mu\text{m}$  thick and a well-outlined annulus (Plate II, Figs 26–27). Similar in size is the pollen of the cultivated cereals (*Triticum* and *Secale*), but the fossil pollen found by us had a thinner exine, a finer annulus and fine-grained ornamentation (Plate II, Figs 26–27). These characteristics distinguish it markedly from *Triticum* and *Secale* and reject the possibility of sample contamination with contemporary pollen. That type of pollen has shown closest proximity to the pollen of subfamily *Bambusoideae*, and in particular to the genera *Bambusa* Schreber, *Oryza* L. and *Dendrocalamus* C.G. Nees. (according to Stuchlik 1964). Worobiec & Worobiec (2005) maintain that in terms of morphology it is closest to the pollen of the contemporary genus *Arundinaria* Michx. The same authors regard the Neogene bamboo plants as components of swamp and riparian forests, similar to the contemporary *Arundinaria gigantea* and *A. tecta* in the southeastern part of North America.

Fig. 7. Percentage proportion of the fossil pollen found in the sediments from the studied section.



The composition of the identified macro- and microflora allowed to distinguish the following main plant communities:

**Mixed mesophytic forests** composed of representatives of *Magnolia*, *Lindera*, *Daphnogene*, *Ocotea*, *Quercus*, *Carya*, *Acer*, *Ulmus*, *Zelkova*, *Corylus*, *Fagus*, *Castanea*, *Tilia*, *Wisteria*;

**Riparian forests** with the participation of the genera *Salix*, *Populus*, *Pterocarya*, *Liquidambar*, *Alnus*, *Rhamnus*, *Nyssa*, *Myrica*, *Bambusoideae*;

**Xeromesophytic woody and shrub communities** of *Robinia*, *Arbutus*, *Paliurus*, *Pistacia*, *Parotia*, *Oleaceae*;

**Herbaceous communities** mainly composed of representatives of the following families and genera: *Chenopodiaceae*, *Asteraceae*, *Artemisia*, *Centaurea*, *Plantaginaceae*, *Caryophyllaceae*, *Brassicaceae*, *Apiaceae*, *Poaceae*, *Dipsaceae*;

**Hydrophyllous vegetation** composed of representatives of *Typha*, *Sparganium*, *Cyperaceae*, *Nymphaeaceae*.

Data on the quantitative participation of fossil species in the composition of the macroflora put forth the representatives of the riparian valley palaeocoenoses represented by the greatest number of leaf imprints. This is due, on the one hand, to the better storage capabilities (distribution along a water basin) and, on the other, to the comparatively limited distribution of the mesophytic forest palaeocoenoses. Spatially, mesophytic forests were closely connected with the riparian and coastal forests by occupying humid habitats in the depressions of the relief, without forming a fully-developed mesophytic forest belt.

Palynological data support the fragmentary character of the mesophytic forests: their representatives showed the lowest values and low participation in the pollen spectra. They considerably differ from the data on the mixed mesophytic forests that had existed during sediments deposition in the Izgrev Member and formed the zonal vegetation (Ivanov & Lazarova 2005). During that period of the vegetation development, dominants in the forest vegetation were: *Quercus* and *Ulmus*, with the participation of *Betula*, *Carya*, *Carpinus*, *Corylus*, *Acer*, *Juglans*, *Engelhardia*, *Tilia*, etc. Floristic elements with warm temperate climate distribution were of main importance, with the presence of some thermophilous species, such as: *Engelhardia*, *Platycarya*, cf. *Castanopsis*, *Corylopsis* (cf. Ivanov & Lazarova 2005). The identified pol-

len of *Pinus*, *Tsuga*, *Cedrus*, *Keteleeria*, and *Picea* presumes mountainous forest communities. Their percentage participation, however, was low, which gives rise to assumptions that such type of palaeocoenoses was distributed in the high parts of comparatively distant mountains (PalaeoRhodopes, PalaeoBalkan Range), while the identified pollen probably resulted from long-distance transport. Xeromesophytic to xerophytic vegetation also claimed an important part in the formation of the palaeolandscape. Its representatives were distributed on dry and eroded terrains and stony slopes. The mesic-subxeric open woodland was also recognized in Northern Greece during the Late Miocene/Pliocene. They were represented by sclerophyllous oaks, cupressoids, pines and other elements that formed shrub-like sclerophyllous woodland on drier substrates (Kovar-Eder & al. 2006).

Palynological data testifies to a wide distribution of herbaceous palaeocoenoses (NAP = 48.2%). There were probably at least two types of plant communities: mesophyllous herbaceous communities inhabiting wet habitats along the palaeobasin of the wet prairies type (Hofmann & Zetter 2005), and xerophytic herbs of steppe character distributed on dry terrains. The palaeocarpological data provided by Palamarev (1991) also testified to the distribution of xerophytic herbaceous communities composed of representatives of *Polycnemum*, *Chenopodium*, *Arenaria*, and *Portulaca*. The author assumed that they had formed communities of a semi-steppe type on open and eroded terrains. The palynological data provided by Popescu (2006) from the southwestern part of the Black Sea (hole 380A) registered an increase of the herbaceous component and the steppe/forest index (SFI) in the Late Miocene-Pliocene. These data corresponded to the high NAP values established in the present study. A sharp increase and high values of the herbaceous component were established for the high levels of the sections from the Late Miocene-Pliocene sediments of the Karlovo Basin (Ivanov & Slavomirova unpubl.). All this testified to a large-scale change in the vegetation during that time period, which was probably of climatogenic origin.

### Palaeoclimate reconstruction

Analysis of the macro- and microfloristic data provided information on the probable climatic conditions during the sedimentation process. The floristic data have been analysed with the help of the Coexistence

Approach method (Mosbrugger & Utescher 1997). The following four climatic indices have been reconstructed: MAT – Mean Annual Temperature, CMMT – Coldest Month Mean Temperature, WMMT – Warmest Month Mean Temperature, MAP – Mean Annual Precipitation. These four parameters of the climate are of major importance for plant distribution and appear as determining factors of the ecological and physiological character of the plant communities. They are also best developed in terms of methodology (see Bruch & Mosbrugger 2002; Ivanov & al. 2002). The contemporary climatic conditions in the region (according to the Yambol Climatic Station) are the following: MAT 12.2°C, CMMT 0.9°C, WMMT 22.7°C, and MAP 541 mm (Velev 1997).

The calculated values of the various palaeoclimatic indices on the basis of the fossil macroflora (Fig. 8, Table 2) have shown the annual temperatures within the range 14.4–15.8°C, winter temperatures 3.7–5.8°C, summer temperatures 25.6–26.4°C, and the annual precipitation 961–1179 mm. These values are by several degrees higher than the contemporary temperature values in the region, and the precipitation is considerably higher than presently. The values calculated on the basis of palynological data have shown wider CA-intervals: MAT 13.6–18.4°C, CMMT 2.4–9.4°C, WMMT 22.8–26.1°C, and MAP 740–1206 mm (Fig. 8, Table II). The wider coexistence intervals obtained from the palynological data are explained with the lower taxonomic resolution of the pollen analysis. The wider interval of annual precipitation (740–1206 mm) might reflect diversity of the climatic conditions on a larger territory, including drier habitats.

The conclusion generally is that the results of the macro- and microfloristic analysis show a high degree of compatibility, which enhances the reliability of the obtained quantitative values about the palaeoclimate. They correspond to the palaeoecological analysis of the flora, which presumes vegetation development under the condition of a warm temperate up to subtropical climate, with a distinctive dry period. Quantitative climate calculations for Late Miocene (Messinian)

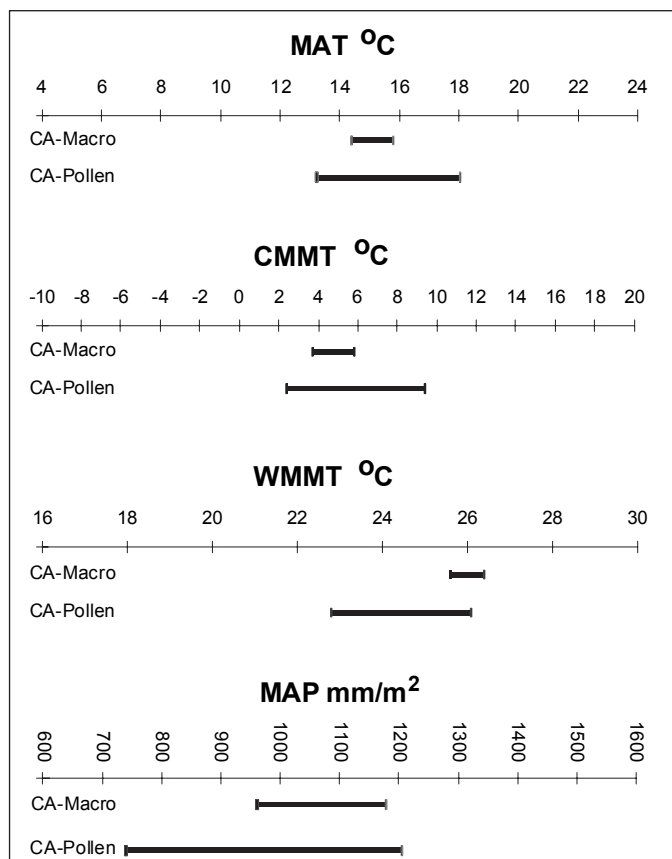


Fig. 8. Coexistence intervals derived from the fossil macroflora (CA Macro) and pollen flora (CA Pollen).  
Legend: MAT – Mean Annual Temperature; CMMT – Coldest-Month Mean Temperature; WMMT – Warmest-Month Mean Temperature; MAP – Mean Annual Precipitation.

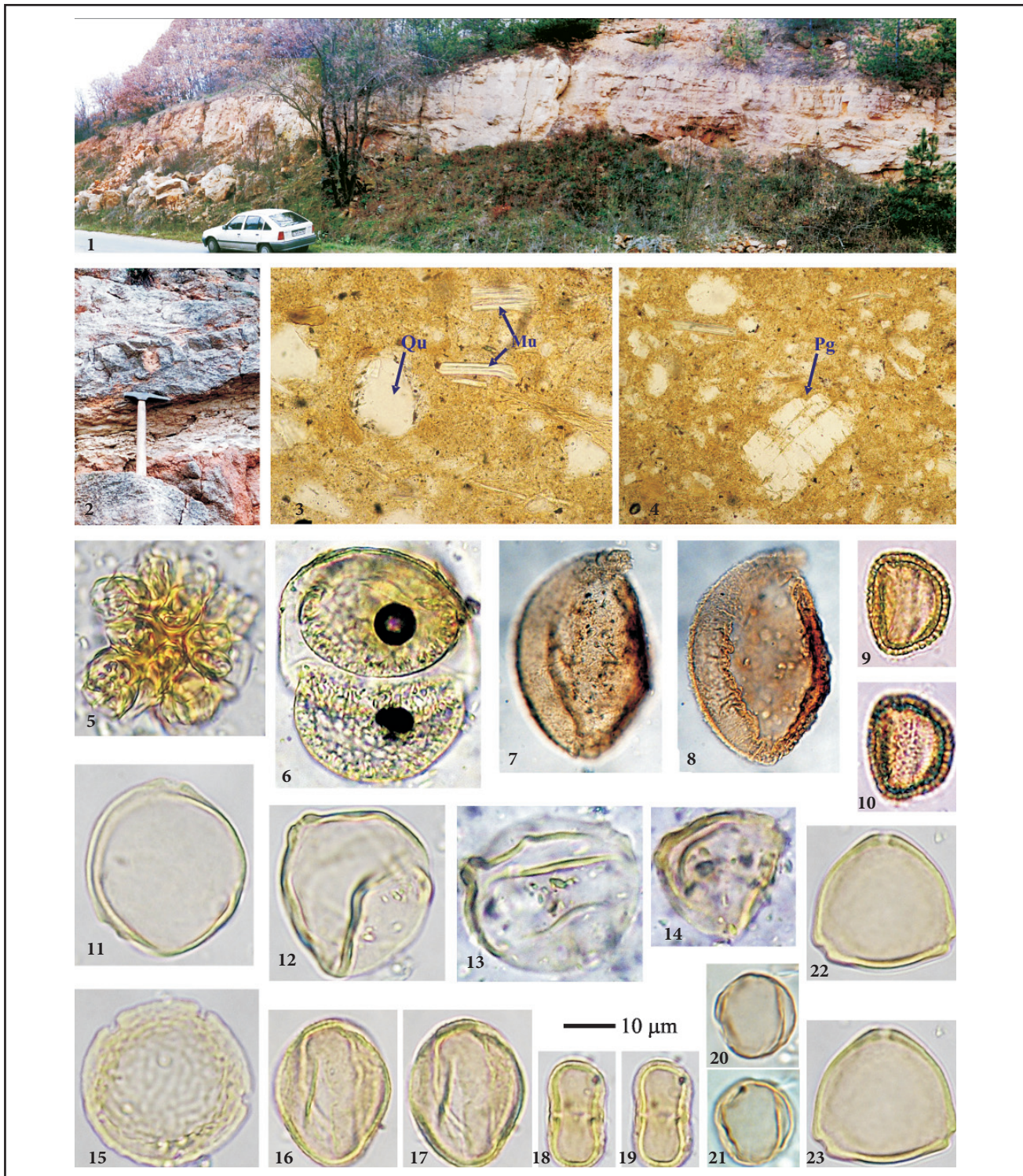
Table 2. Climate parameters for the flora of Toundzha Basin derived from the macro- and microfloristic record. The taxa responsible for the minimum and maximum values are listed.

Climate parameter	Min	Max	Left border set by:	Right border set by:
<b>Macroflora</b>				
MAT	14,4	15,8	<i>Persea</i> sp.	<i>Parrotia persica</i>
CMMT	3,7	5,8	<i>Persea</i> sp.	<i>Pterocaria fraxinifolia</i>
WMMT	25,6	26,4	<i>Persea</i> sp.	<i>Acer campestre</i>
MAP	961	1179	<i>Litsea</i> sp.	<i>Quercus sect. cerris</i>
<b>Pollen flora</b>				
MAT	13,6	18,4	<i>Pistacia therebinthus</i>	<i>Cedrus</i> sp.
CMMT	2,4	9,4	cf. <i>Keteleeria</i> sp.	<i>Cedrus</i> sp.
WMMT	22,8	26,1	<i>Cedrus</i> sp.	<i>Quercus ilex-coccifera</i> type
MAP	740	1206	<i>Fagus</i> sp.	<i>Platanus</i> sp.

Vegora macroflora (Northern Greece) show similar climate values, but a little bit lower temperatures, especially for the winter temperatures: MAT 13.3–14.6°C; CMMT 0.4–4.5°C; WMMT 23.8–24.6°C; and MAP 897–1018 mm (Kvacek & al. 2002, 2004).



## Plate I



**Figs 1–2.** Photographs of the river Sinapovska outcrop:

1, Panoramic view; 2, Part of the studied section and fossil-bearing layer.

**Figs 3–4.** Photographs of the thin sections of the flora-bearing layer:

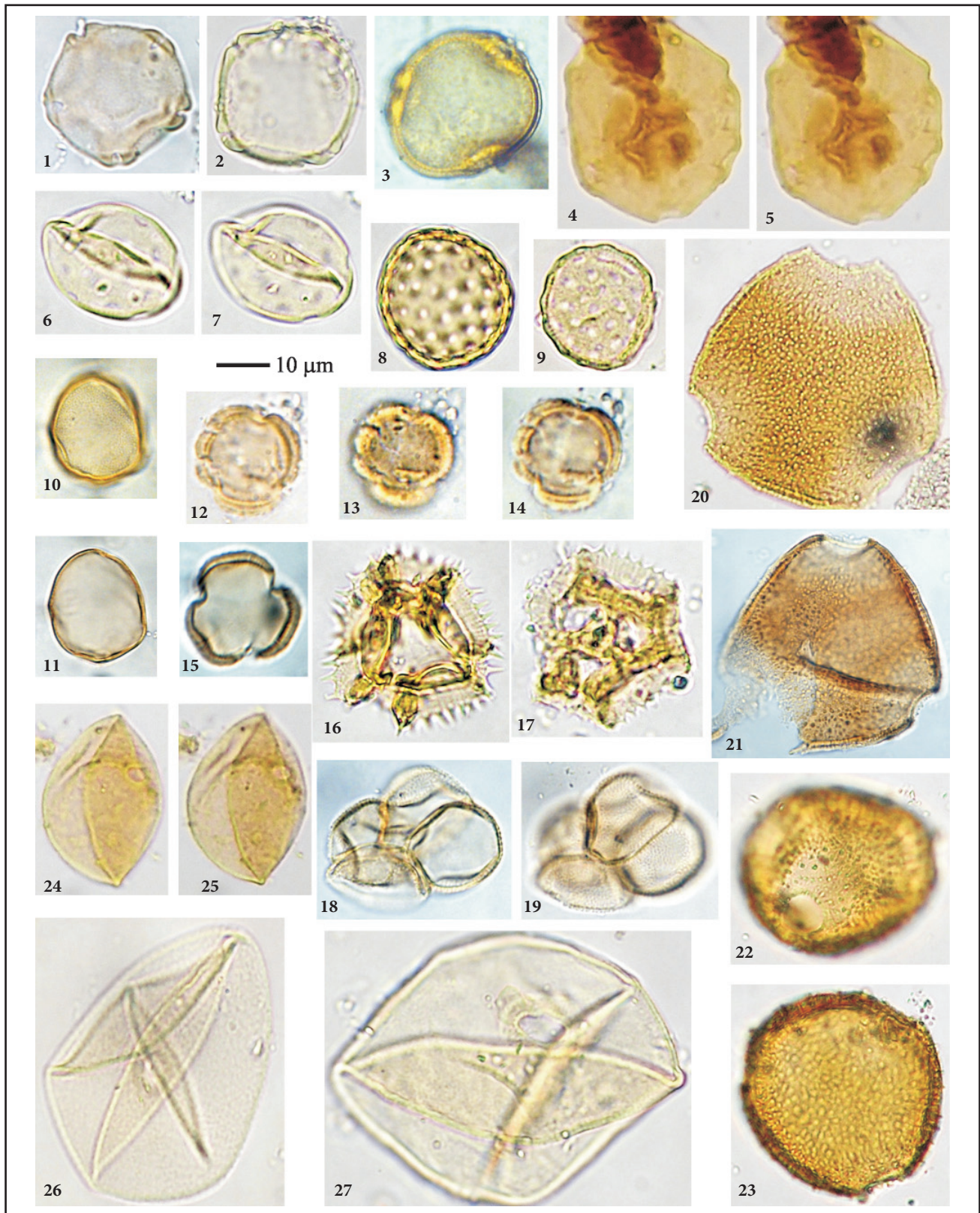
3, Thin section with quartz grains (Qu) and muscovite (Mu); 4, Thin section with plagioclases (Pg).

**Figs 5–23.** Photographs of the fossil pollen:

5, *Botryococcus* sp.; 6, *Pinus diploxylon* type; 7–8, *Tsuga* sp.; 9–10, *Platanus*; 11–12, *Carpinus orientalis*\ *Ostrya* type; 13, *Carpinus betulus* type; 14, *Betula*; 15, *Ulmus*; 16–17, *Quercus*; 18–19, *Apiaceae*; 20–21, *Rosaceae*; 22–23, *Corylus*.



## Plate II



Figs 1–27. Photographs of the fossil pollen:  
 1–2, *Alnus*; 3, *Tilia*; 4–5, *Pterocarya*; 6–7, *Plantaginaceae* (*Plantago* sp.); 8–9, *Chenopodiaceae*; 10–11, *Humulus/Cannabis* type; 12–15, *Artemisia*; 16–17, *Cichorioideae*; 18–19, *Typha*; 20–23, *Dipsacaceae*; 24–25, *Poaceae*; 26–27, *Poaceae* (*Bambusoideae*).

## Conclusion

Changes in the Late Pontian relief evoked by the neotectonic activity in the Late Miocene and Pliocene (Zagorčev 1992) had induced a considerable horizontal and vertical fragmentation of the vegetation. These changes, combined with the global changes of the Earth climate, had led to notable modification of the character of the plant cover. An analysis of the palaeofloristic composition has testified to the presence of fragments of hygromesophytic and mesophytic Middle Miocene and Volhynian vegetation in the composition of the Late Pontian vegetation (Palamarev & al. 1999). Its palaeocoenoses had probably survived in the river valleys and humid zones in close proximity to the studied water basin. They were the last remnants of the former zonal vegetation of semilaurel type, which formed the contemporary mesophytic forests during the Pliocene and Pleistocene (Palamarev & al. 1999). Palynological data testifies to a wide distribution of herbaceous palaeocoenoses of two types: mesophyllous herbaceous communities inhabiting wet habitats along the palaeobasin, and xerophytic herbs of steppe character distributed on dry terrains. The last ones were recognised also by palaeocarpological analysis (Palamarev 1991).

The results of palaeoecological analysis of the flora and the quantitative data on the palaeoclimate have shown that the climate in the Toundzha Basin in the period of sediment accumulation in the upper undivided part of the Elhovo Formation was warm temperate to subtropical, with an annual temperature within the range 14.4–15.8 °C, winter temperatures of 3.7–5.8 °C, summer temperatures within the range 25.6–26.4 °C, and the annual precipitation in the frame 961–1179 mm.

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