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Late Miocene vegetation and climate of the Balkan region: palynology of the Beli Breg Coal Basin sediments

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Abstract: The results of palynological studies of Neogene freshwater deposits of the Beli Breg Graben (West Bulgaria) are presented. We analysed pollen and spores with the aim of obtaining data about the composition and structure of fossil vegetation and climate conditions. The main vegetation paleocommunities, which existed during the fossilization process, are characterized as mixed mesophytic and swamp forests, communities of aquatic plants, and herbaceous paleocoenoses. The climate data reconstructed by the Coexistence Approach indicate a warm temperate climate with mean annual temperatures around 16 °C and with mean temperature of at least 4 °C during the coldest month. With annual precipitation rates commonly above 1000 mm climatic conditions were overall humid, although partly seasonally drier conditions are evident from the data.

Key words: Pliocene, Late Miocene, Bulgaria, climate, vegetation, pollen analysis.

Introduction

The specific paleogeographical position of the Balkan Peninsula which was located between Tethys and Paratethys during the Neogene is important in terms of understanding the evolution of the recent flora and vegetation of this region. The territory of Bulgaria, with its numerous Miocene freshwater basins, appears as a key region to understand the Neogene evolution of the connection between Central and Eastern Europe and Asia Minor (Rögl 1998; Meulenkamp & Sissingh 2003), and the migration pathways and exchange routes for many plant and animal species. Apparently, this area plays a major role in the evolution and migration of the Mediterranean vegetation, in the survival of numerous Paleogene taxa in refugia, and in the processes of plant speciation (e.g. Palamarev 1989; Palamarev et al. 1999; Palamarev & Ivanov 1998, 2001, 2004). This region is also important for comprehending Neogene climate dynamics, the transition from greenhouse to icehouse climate, the appearance of arid habitats, and evolution of open landscapes.

During the last decade, palynological studies on the Neogene of the territory of Bulgaria have been undertaken to elucidate the evolution of vegetation and climate (e.g. Ivanov 1995, 1997a, 2003; Ivanov et al. 2002). The present paper provides an analysis of Late Miocene vegetation-climatic evolution based on the interpretation of palynological data in the area of the Beli Breg Coal Basin (West Bulgaria) using quantitative methods.

Notes on geological settings

The Beli Breg Coal Basin is located within a graben structure that is a part of the Sredna Gora tectonic unit in West Bulgaria, close to the village of Gaber, about 50 km west of Sofia (Fig. 1). It is a part of the so-called “Burrell fault zone” (Gochev et al. 1970), and in older literature it is also known as the Burrell Basin (e.g. Konjarov 1932). The Beli Breg Basin is an elongated NW–SE tending

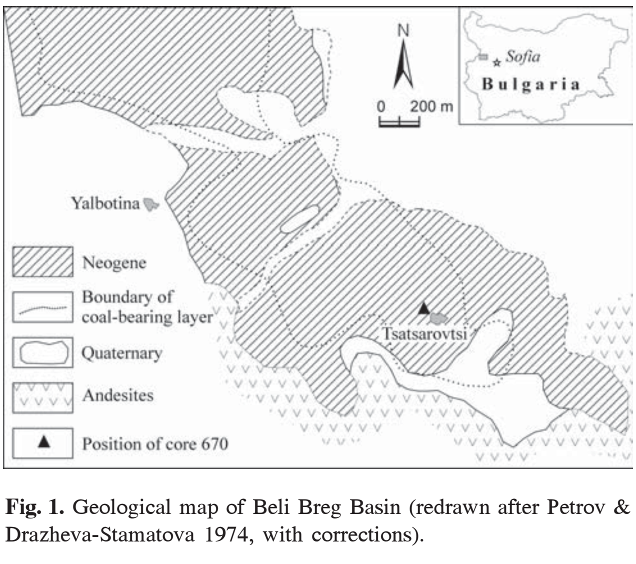

Fig. 1. Geological map of Beli Breg Basin (redrawn after Petrov & Drazheva-Stamatova 1974, with corrections).

structure, with a maximal length of ca. 9 km and a width of 2 to 5 km (Vatsev & Zdravkov 2004). It is surrounded by Jurassic (Polaten and Slivnitsa Formations: Ivanova et al. 2000; Ivanova & Koleva-Rekalova 2004) and Lower Cretaceous rocks as well as Upper Cretaceous volcano-clastic sediments and lavas with andesites, trachyandesites and tuffs. The Neogene sediments are represented by sandstones, carbonates, sandy clays and up to five browncoal seams, of which only one has a constant thickness and distribution within the basin.

The lithological subdivision of the sediments in the Beli Breg Basin is still controversial. Yovchev (1960) recognized 5 informal litostratigraphic units (horizons) in the basin: the first (from bottom to top) is represented by green sandy clays, sands and conglomerates (up to 50 m in thickness), the second (coal-bearing) is represented by a thick browncoal seam, and the III, IV, and V units lie on top of the above-mentioned units, and are represented mainly by unevenly distributed dark green and green clays and sandy clays.

Problems with the lithological subdivision arise from the fact that the basin is located in close proximity to the Sofia Basin, which is the main sedimentary structure in this region. There are two different approaches regarding the lithology of the sediments. The first one relies on the close geographical proximity to the Sofia Basin and applies the same lithostratigraphic units as defined by Kamenov & Kojumdgieva (1983) for the lithological sequence of the Sofia Basin to sediments from the Beli Breg, and other small basins in this area (e.g. Nikolov 1985; Zagorchev et al. 1995). This approach also suggests that all the small basins of the area were part of the Sofia Basin, or at least were connected to it in more or less precisely defined time slices. However, assigning lithostratigraphic units from the Sofia Basin to the Beli Breg Basin causes some inconsistencies, for example, according to Nikolov (1985), the coal-bearing horizon is an analogue of the Balsha Member belonging to the Gniljane Formation (Kamenov & Kojumdgieva 1983), while Zagorchev at al. (1995) recognized the same layer as the Lozenets Formation, and Palamarev (in Mai & Palamarev 1997) assigned these sediments from the Beli Breg Basin to the Noviiskar Formation (Kamenov & Kojumdgieva 1983).

The other approach considers the Beli Breg Neogene Basin as isolated with its own specific lithostratigraphic units and geological history. From this point of view, Vatsev & Zdravkov (2004) introduced three official lithostratigraphic units (from bottom to top): the Nedelishte, Kaisiinitsa and Tranerska Formations. The Kaisiinitsa Formation, which includes the main coal seam with the III and IV units on top, established by Yovchev (1960), is the subject of our study.

The age of the sediments is also under discussion, and according to different authors it varies within a wide frame. Konjarov (1932) proposed a Pontian age for the sediments from the Beli Breg Basin, while Yovchev (1960) regarded them as Lower Pliocene (Dacian). The Pliocene age (Dacian–Romanian) was accepted by Zagorchev et al. (1995). Palamarev (1972) supposed the presence of Pontian sedimensts in the first and partly in the second horizon, but for clays on top of the main coal seam (III and IV units after Yovchev 1960) Palamarev & Kitanov (1988) accepted an Early Pliocene (Dacian) age, mainly on interpretations of the floristic composition. Nikolov (1985) determined the age of the coals as Pontian, based on the mammal record that indicates the MN13 mammal Zone. From the analysis of the diatom flora recorded in the succession, there is also evidence for a Pontian age (Ognjanova-Rumenova & Yaneva 2000).

Vatsev & Zdravkov (2004) attempted to summarize all available data and stated a Pontian to early Dacian age for the Kaisiinitsa Formation. In this study we will keep on this last proposed age frame until more detailed stratigraphic information becomes available from ongoing biostratigraphic (mammal fauna) and magnetostratigraphic studies.

Materials and methods

The sediments studied originate from core 670 (Fig. 1) drilled in the Beli Breg open cast mine (formerly known as the Bolshevik mine — see Palamarev 1972; Petrov & Drazheva-Stamatova 1974). The profile comprises browncoals (58.90–34.00 m and 33.60–26.00 m), grey clays (34.00–33.60 m), marly clays (26.00–13.00 m), interbedded with thin browncoal seams (at 15, 21, 23 and 26 m), and yellow clays up to the top of the core (13.00–0.50 m) with thin beds of green sandy clays (Fig. 2). The lignites are typical xylite-rich coals (Zdravkov & Kortenski 2003, 2004) containing weakly altered xylitic fragments (e.g. wood fragments at 42.0 and 44.0 m — Fig. 2) mixed with detritic material. The main coal seam is interbedded with carbonaceous and clay sediments, and in some layers (e.g. at 50.5, 52.5 and 57.5 m) numerous shells of freshwater molluscs occur.

The samples were processed according to the standard technique for disintegrating Cenozoic sediments. On the basis of pollen/spore counts a percentage pollen diagram was plotted (Fig. 3) showing the palynological record of the complete section. The percentage of each pollen taxon identified in the pollen spectra was calculated with respect to the total sum of aboreal (AP) and non-aboreal (NAP) pollen (AP + NAP = 100 %), with spores excluded. Local elements (L), such as spores, aquatic plants, were calculated on the basis of the sum AP + NAP + L = 100 %. Some samples did not provide enough pollen for a correct calculation of palynomorph percentages (or some were barren). In this case, the presence of pollen/spores is indicated with the symbol "**0**", not with a percentage proportion. This is done in order to present the complete palynomorph record for the studied section while at the same time avoiding erroneous interpretations from low quantities. For all the other samples, the quantities of taxa are illustrated on the diagram as bars responding to their percentage proportion in the pollen spectra.

To reconstruct paleoclimate from the palynological record of the Beli Breg Coal Basin, the Coexistence Ap-

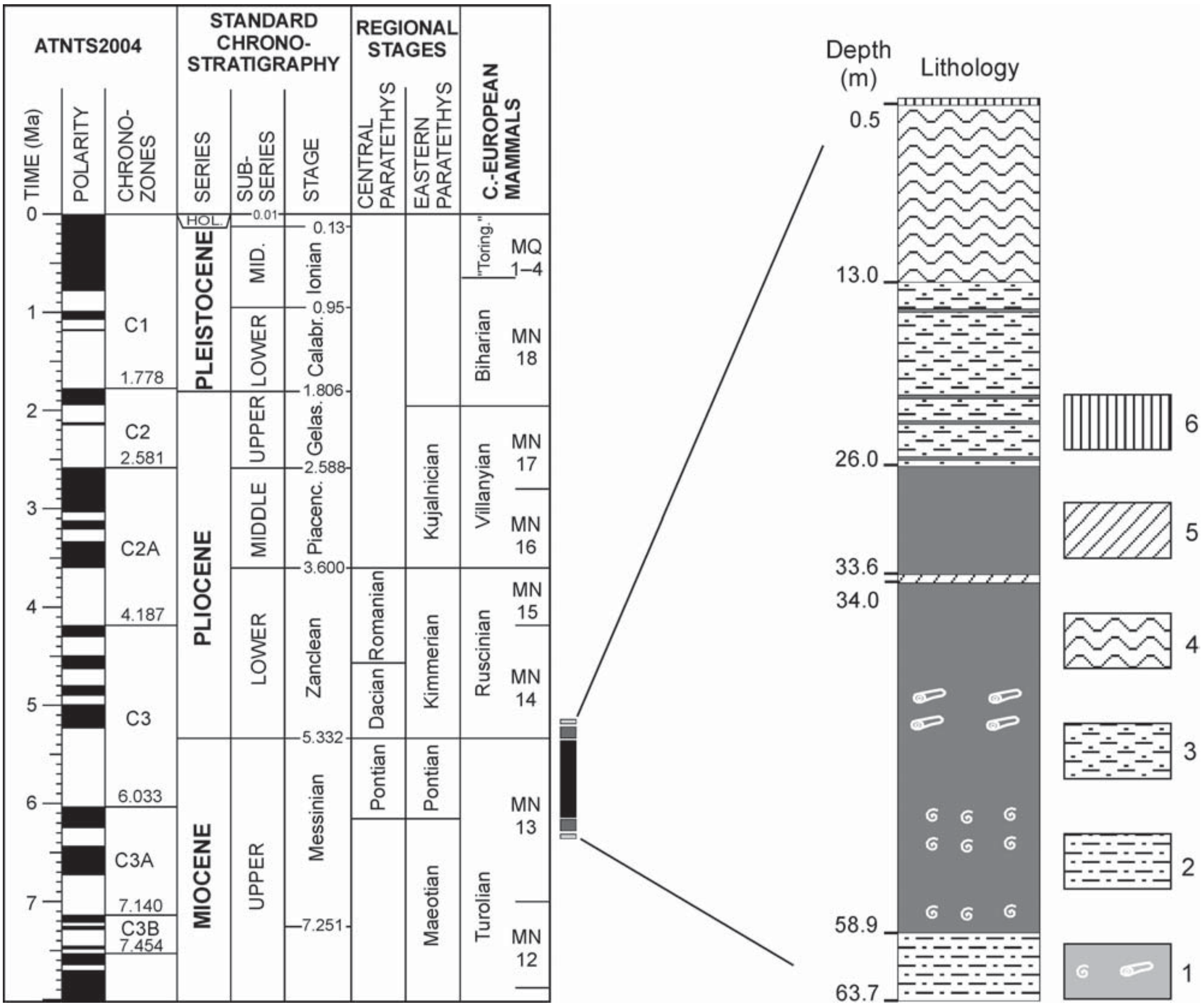

Fig. 2. Lithological column of core 670, Beli Breg Basin (redrawn after Petrov & Drazheva-Stamatova 1974, with corrections). **1** — Brown-coals with interbedded calcareous clays, shells, and wood fragments; **2** — Green clays; **3** — Marl clays; **4** — Yellow clays; **5** — Grey clay; **6** — Soil.

proach (CA) was applied (Mosbrugger 1995; Mosbrugger & Utescher 1997). This method uses the climate tolerances of all Nearest Living Relatives known for a given fossil flora to determine a coexistence interval for each considered climate variable which allows the majority of Nearest Living Relatives of a fossil flora to co-exist. The resulting intervals obtained for the different climate variables were then interpreted as the most probable ranges of paleoclimate parameters for the fossil flora analysed. The climatic resolution of the method and the significance of the results obtained mainly depend on the diversity of the fossil flora analysed, and on the taxonomic level of identification of Nearest Living Relatives for a given fossil taxon (Mosbrugger & Utescher 1997).

In the present study, five climatic parameters are considered and discussed below, namely mean annual temperature (MAT), mean temperature of the coldest month (CMT), mean temperature of the warmest month (WMT), mean annual precipitation (MAP), and mean monthly precipitation in the driest month (MMPdry). These are the parameters which most reliably represent changes in paleoclimatic conditions because their effect on plant distribution is most important. As shown by previous paleoclimate reconstructions for the Bulgarian Neogene, significant changes primarily involve mean annual temperature, temperature of the coldest month and mean annual precipitation, while temperatures of the warmest month are more constant and show smaller fluctuations (Ivanov et al. 2002).

For the analysis, 30 microfloras were selected providing climate data for 8 to 33 extant plant taxa at a mean diversity of 17 taxa. Fourteen samples were excluded because their diversity was below the limit of the method to produce reliable results (Mosbrugger & Utescher 1997). The climate data obtained for the different variables are summarized in Table 1.

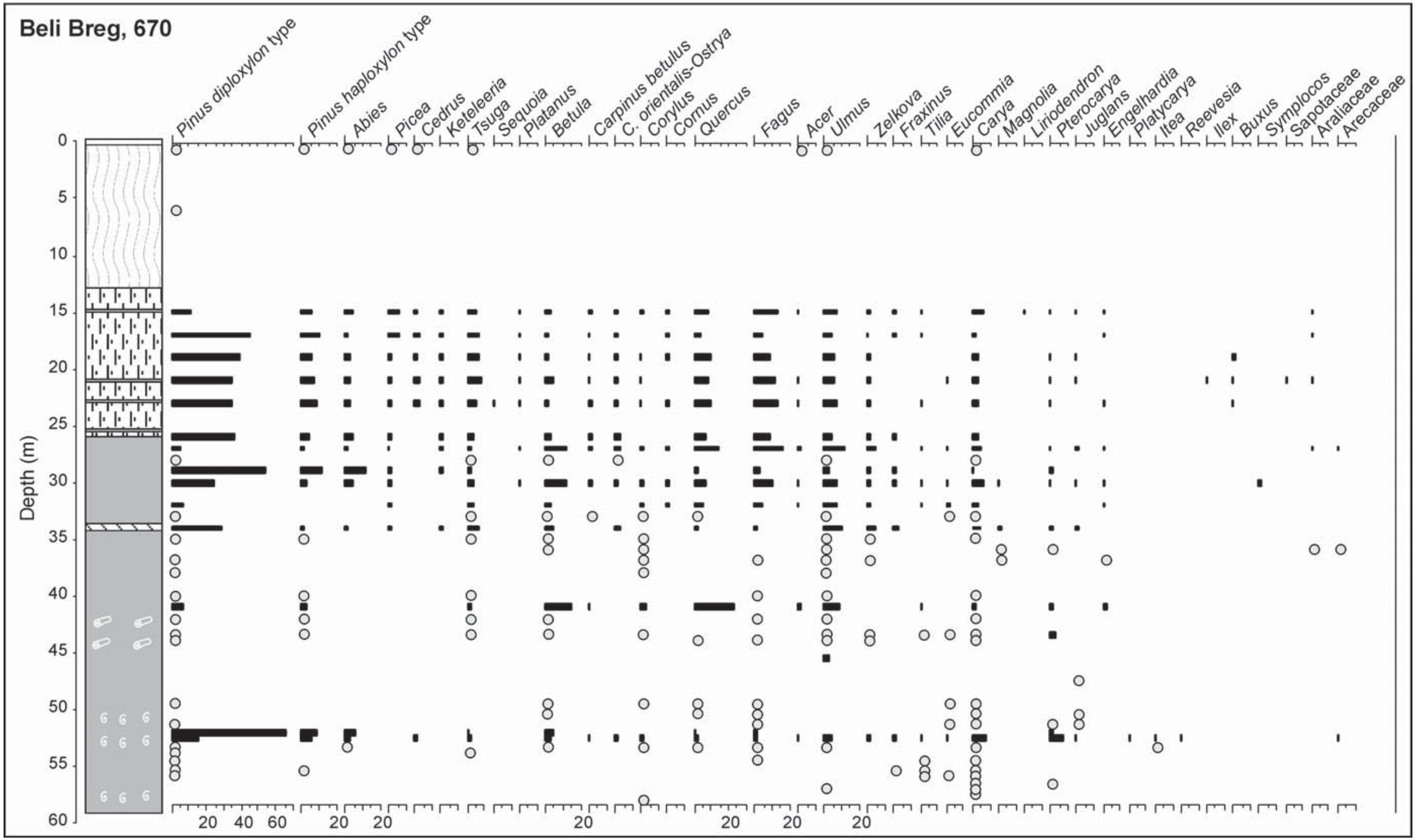

Fig. 3a. Pollen diagram of core 670. For the samples that do not contain enough pollen for percentage calculations the presence of registered pollen/spores is represented with the symbol **"0"**, not with the percent proportion. For all the other samples, the quantities of taxa are illustrated as bars corresponding to their percentage proportion in the pollen spectra.

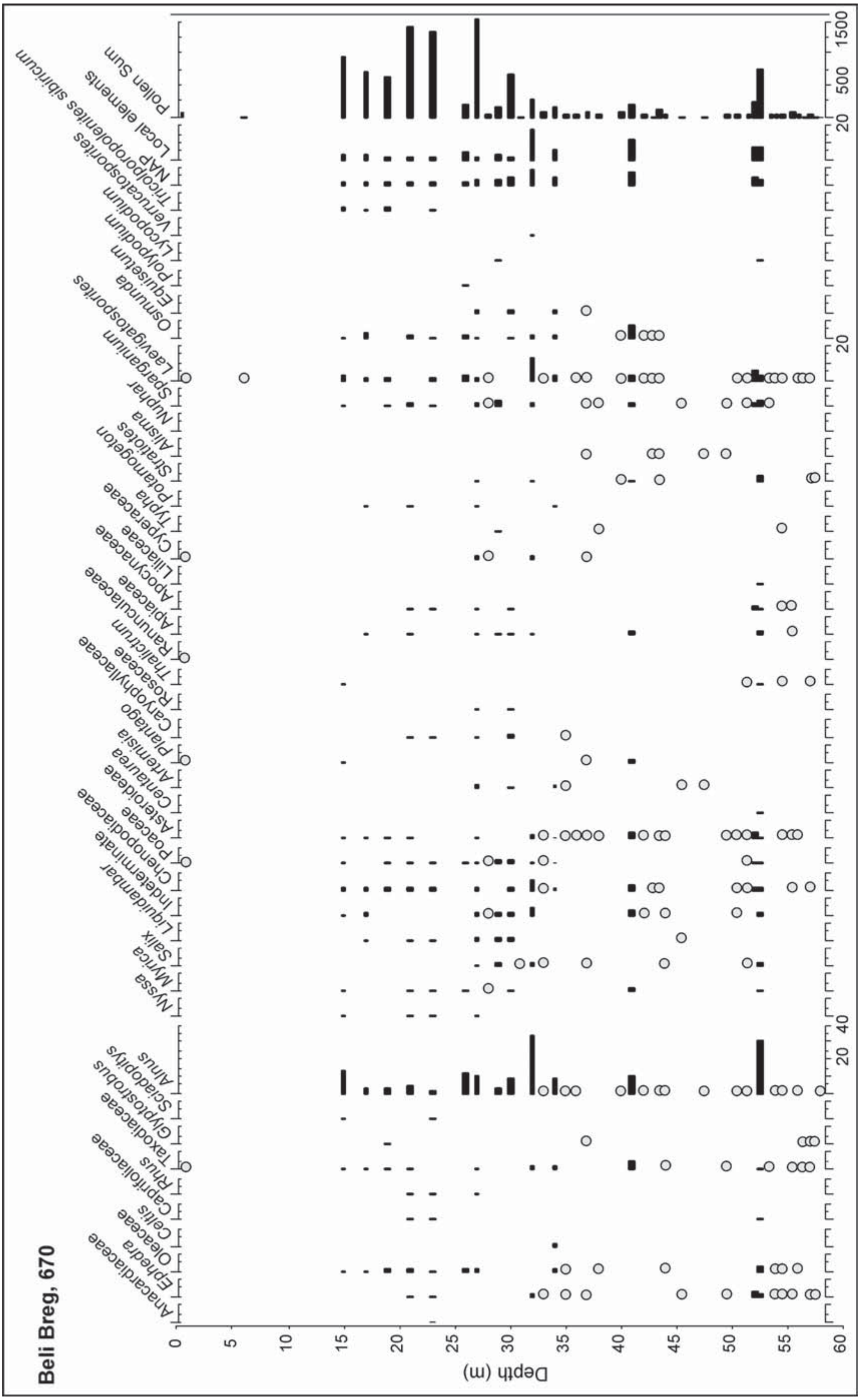

Fig. 3b. Pollen diagram of core 670 (*continued*).

Table 1: Climate data calculated for the single microfloras of core 670. Ntaxa — number of taxa contributing climate data; min/max — lower/upper limit of climate range. For samples with Ntaxa < 7 no data are given. Samples with Ntaxa ≥14 are highlighted in grey; for all these microfloras more specific climate data are obtained from the coexistence approach.

Depth (m)	Ntaxa	MATmin	MATmax	CMTmin	CMTmax	WMTmin	WMTmax	MAPmin	MAPmax	MMPdrymin	MMPdrymax
0.5	8	11.6	18.4	–0.3	12.5	19.4	28.6	373	1520	8	41
6	0										
13	0										
15	32	15.7	16.6	5	7	24.7	26.4	1096	1520	32	41
17	25	15.7	17.6	5	9.7	24.7	27.6	1069	1520	8	41
19	22	15.7	17.6	3.8	9.7	21.7	26.4	1096	1520	8	41
21	33	15.7	17.6	3.8	9.6	23.6	26.4	1096	1520	18	41
23	33	15.7	16.6	5	7	24.7	26.4	1096	1577	25	41
26	17	15.7	17.6	3.8	9.7	20.2	26.4	1096	1548	8	59
27	33	15.7	17.6	5	9.6	24.7	26.4	1096	1548	24	43
28	8	9.1	18.3	–2.7	10.9	19.3	27.6	402	1548	8	43
29	14	15.7	21.7	3.8	13.6	21.7	28.3	1096	1520	8	43
30	28	15.6	17.6	5	9.7	24.7	26.4	823	1548	9	59
31	0										
32	21	15.6	19.4	5	9.6	24.7	28.1	823	1520	9	43
33	10	9.4	17.6	–0.1	9.6	20.2	26.4	471	1548	8	45
34	19	15.7	18.3	3.8	10.9	21.7	27.6	1096	1520	8	24
35	9	9.4	21.9	–0.1	13.6	21.7	29.4	389	1724	8	45
36	8	13.3	24	–0.1	16.4	22.8	28.1	581	1682	5	59
37	8	15.6	21.9	5	13.6	24.7	28.5	823	1682	5	45
38	4										
40	7	4.4	21.9	–6.4	15.6	19.3	28.5	422	1724	8	59
41	18	15.6	17.6	5	9.7	24.7	26.4	823	1520	9	43
42	8	9.1	21.9	–2.7	15.6	19.3	28.5	373	1520	8	67
43	2										
43.5	13	10.6	19.4	–6.4	9.6	21.7	28.1	396	1724	9	59
44	8	9.1	21.9	–2.7	13.6	21.7	28.3	422	1520	8	59
45	0										
45.5	4										
47.5	1										
49.5	8	10.6	19.4	–0.1	9.6	20.2	28.3	422	1520	8	43
50.5	6	9.1	23.1	–2.7	17	19.3	28.3	422	1520	8	67
51.5	7	10.6	19.4	–6.5	9.6	21.7	28.5	422	1958	8	43
52	9	9.4	21.9	–0.1	15.6	21.7	28.3	422	1741	5	45
52.5	29	17.2	17.6	4.3	9.6	22.8	26.4	1187	1520	25	41
53.5	9	9.1	23.1	–0.1	16.7	21.7	28.3	422	1520	25	43
54	4										
54.5	7	9.4	20.8	–0.1	13.3	19.6	28.1	422	1724	8	45
55.5	7	9.4	20.8	–0.1	13.3	19.3	28.1	373	1724	8	45
56	5										
56.5	3										
57	4										
57.5	3										

Results and discussion

Plant diversity and vegetation

Core 670 had already been a subject of palynological studies by Petrov & Drazheva-Stamatova (1974). The authors identified and described 21 pollen taxa belonging to 14 genera, namely *Ephedra distachya* type, *Thalictrum* cf. *aquilegifolium* L., *Thalictrum* cf. *simplex* L., *Eucommia ulmoides* Oliv. foss., *Humulus* cf. *lupulus* L., *Pterocarya* cf. *insignis* Rehd. et Wils., *Pterocarya* sp., *Juglans cinerea* type, *Juglans regia* type, *Carya ovata* type, *Carya* sp.1, *Carya* sp.2, *Engelhardtia acerifolia* type, *Apocynum* cf. *venetum* L., *Periploca* cf. *graeca* L., *Plantago* cf. *lanceolata* L., *Alisma* cf. *plantago* L., *Typha* cf. *latifolia* L., *Typha* cf. *angustifolia* L., *Sparganium* sp., and *Stratiotes* cf. *aloides* L. In the present study we have re-analysed all samples from this core, including identification of all spores and pollen recorded and quantitative counts. As a result, more than 65 additional pollen and spore taxa were identified for the first time in the core section (see Fig. 3, and Figs. 4–7), and thus results are obtained allowing for conclusions with respect to vegetation and climate.

The recognized fossil spore and pollen flora in the course of this study on the Beli Breg Basin comprise plants from different taxonomic groups: pteridophytes, gymnosperms, and angiosperms. The latter produces the highest taxonomic diversity, namely about 70 % of the taxonomic composition of the flora. Pollen spectra from the lower part of the section (meaning from brown coals)

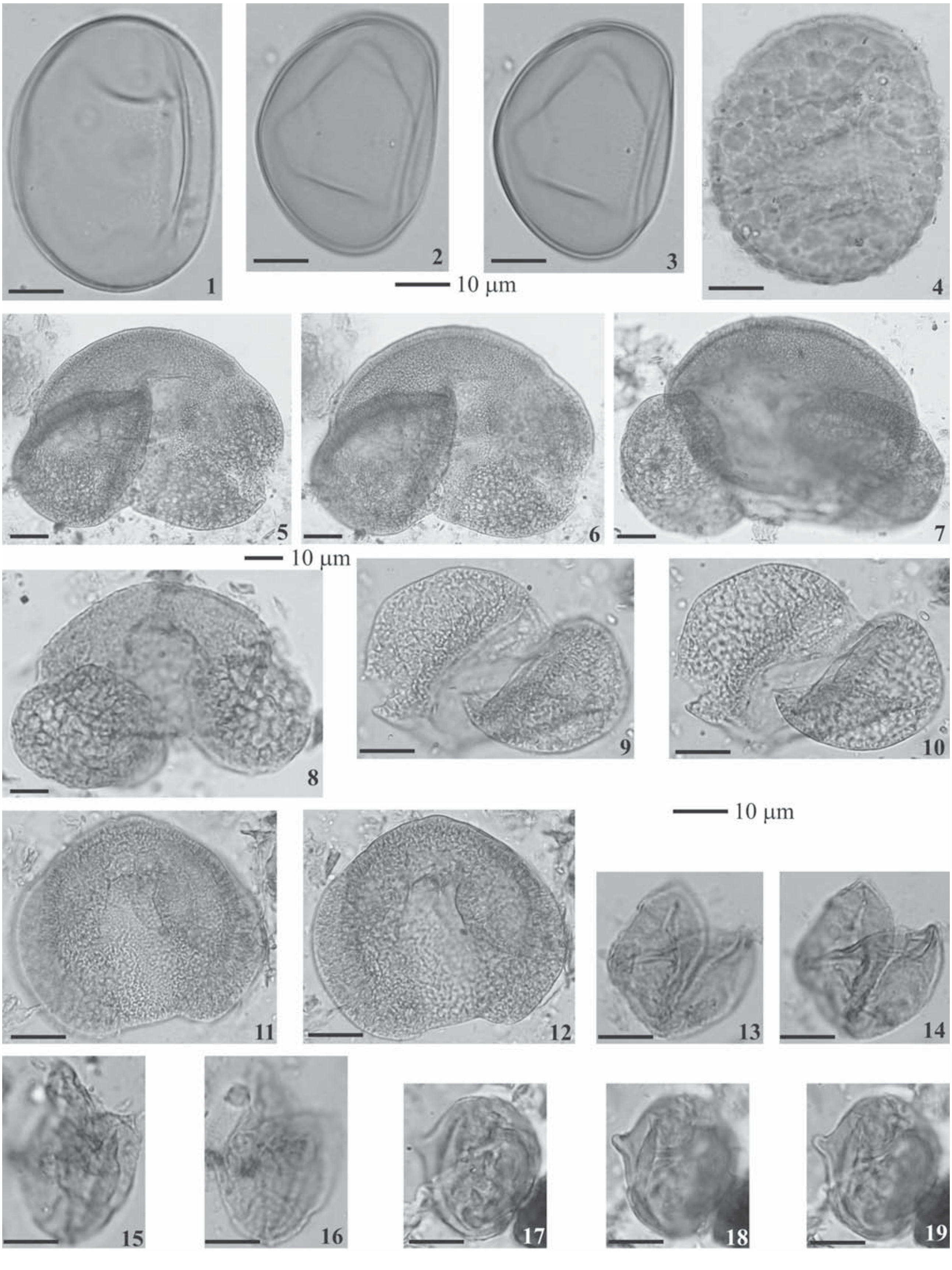

Fig. 4. **1–3** — *Laevigatosporites* sp. (cf. Thelypteridaceae, cf. Polypodiaceae); **4** — *Verrucatosporites* sp. (Polypodiaceae, cf. Davaliaceae); **5–7** — *Abies*; **8** — *Keteleeria*; **9, 10** — cf. *Cathaya*; **11, 12** — *Cedrus*; **13, 14** — Taxodiaceae; **15, 16** — cf. *Glyptostrobus*; **17–19** — *Sequoia.*

were very poor in fossil palynomorphs, and only few samples (41.0, 52.0, 52.5 m) provided enough grains for pollen counts. In the samples with a lower pollen content (Fig. 3a,b) *Tsuga*, *Betula*, *Corylus*, *Quercus*, *Fagus*, *Ulmus,* and *Carya* (Figs. 4, 5, and 6) occur most commonly, and in rarer cases also *Zelkova*, *Tilia*, *Eucommia*, *Pterocarya*, *Juglans*, *Ephedra*, and Oleaceae. Most of these are components of mesophytic forests. Taxodiaceae, *Alnus*, and *Salix* originate from wetland vegetation, Chenopodiaceae, Asteraceae, and *Artemisia* (Fig. 7) from herbaceous communities. The results obtained from studies on the composition and environmental conditions of the coal formation (Zdravkov & Kortenski 2003, 2004) suggest oxygen-rich conditions during the deposition of the peat (oxygenated upper layer of the peat). This assumption explains the low content (or even lack) of palynomorphs in the coal samples studied, because their exine is sensitive and can easily be destroyed in oxygen-rich environments. The low quantity of palynomorphs from coal-bearing sediments restricts us to confirm the conclusion of Zdravkov & Kortenski (2003, 2004) that coals were deposited in an environment with predominantly herbaceous vegetation mixed with woody plants and with limited development of open-water surfaces within the mire.

The upper part of the core (mostly clayey sediments) provides more complete pollen spectra permitting quantitative calculations and thus providing data not only for the taxonomic composition of fossil vegetation, but also for the quantitative participation of individual pollen taxa. Thus, the vegetation reconstruction presented herein is largely based on these samples.

Quercus, *Fagus*, *Carya* and *Ulmus* are most abundant among all the angiosperm pollen recorded, especially in the upper part of the profile (Fig. 3a,b). The percentage proportions of most taxa vary in narrow ranges, mainly between 1–5 % and the pollen of *Betula*, *Corylus*, *Carpinus*, *Ostrya*, *Eucommia*, *Zelkova*, *Fraxinus*, *Tilia*, *Acer*, *Engelhardia*, *Pterocarya*, *Juglans*, etc. is more abundant (Figs. 5, 6, and 7).

The mosaic character of the vegetation, composed of different plant associations, grew in the hinterland and lowlands — these were mainly deciduous mixed mesophytic forest types with evergreen components. Thermophillous taxa are of comparatively minor importance in these plant communities — only small quantities of paleotropical elements are recorded in the pollen spectra studied. The dominant taxa in mesophytic forest paleocoenoses (which formed the zonal vegetation) were *Quercus*, *Fagus*, *Carya*, and *Ulmus*, accompanied by *Betula*, *Carpinus*, *Ostrya*, *Corylus*, *Zelkova*, *Fraxinus*, *Eucommia*, *Acer*, *Juglans*, *Engelhardia*, *Tilia*, *Buxus*, *Ilex*, etc. The taxonomic diversity of these forests was due mainly to floristic elements growing in temperate and/or warm-temperate climatic conditions, while the subtropical elements (like *Engelhardia*, *Platycarya*, *Symplocos*, Sapotaceae, Arecaceae etc.) appeared in low quantity in the pollen spectra. Macrofloristic studies in the Beli Breg coal mine (Palamarev & Kitanov 1988; Palamarev et al. 2002) point out the importance of Fagaceae-species, which formed the forest canopy, and an undergrowth of evergreen shrubs such as *Buxus*, *Ilex* and *Daphne*.

A high percentage of *Pinus* pollen is present and dominates all the pollen spectra. *P. diploxylon* prevails over *P. haploxylon* (including *Cathaya* — Fig. 4.9,10). It should also be mentioned that conifer pollen, mainly *Pinus*, can be particularly abundant, presumably because of the capacity of saccate pollen for a long-distance transport. The other gymnosperms (*Picea*, *Abies*, *Tsuga*, *Keteleeria*) are represented in small quantities, usually about 3–5 %. Thus their presence testifies to the existence of mid- and/or high-altitude forests (composed by *Tsuga*, *Cedrus*, *Cathaya*, *Abies*, *Picea* and some flowering plants) that were also important in the regional vegetation.

Swampy and marshy elements are comparatively scarce in the pollen spectra. Taxodiaceae is poorly presented in all the pollen spectra, commonly reaching less than 2 %. While macroremains of *Glyptostrobus* (branches with leaves or cones) are very common in the clayey sediments (see Palamarev & Kitanov 1988; Palamarev et al. 2002), pollen that can be identified as the *Glyptostrobus* type is very rare. The same is true for *Sequoia* pollen (Fig. 4.15–19) and, in rarer cases, also for *Sciadopitys*, *Nyssa*, *Myrica*, and *Salix*. Only *Alnus* reaches higher percentages (up to 10–15 %) suggesting the domination of these trees in flooded forests (Fig. 3a,b). Some pteridophytes appeared as undergrowth of these communities or in partly open places, for example, *Osmunda* and *Laevigatosporites* (cf. Thelypteridaceae, Ivanov 1997b; Barthel 1976). *Pterocarya*, *Platanus*, *Liquidambar* and *Itea* were part of these plant communities or of riparian forests closely connected to the swamp. From the pollen spectra originating in clay sediments (meaning a high stand of the water table and a lake environment) we can conclude that the distribution of this vegetation type was limited to the shore-side of the lake or some small marshy ponds, respectively.

Aquatic plants were more or less closely connected to swamp areas, but they are poorly represented in the pollen spectra and their spatial distribution was limited, as is obvious from their low percentage proportion (e.g. *Nuphar*, *Potamogeton*, *Typha*, *Sparganium*, *Alisma*, *Stratiotes* (Fig. 5.5–6; Fig. 7.12–15) and other inhabitants of open water and shoreline). The presence of algae (*Pediastrum*, *Botryococcus*, and cysts of unknown algae Fig. 7.16–23) indicates open water conditions.

Pollen of trees and shrubs dominate the pollen spectra, while herbs are represented in small quantity, thus testifying to the dominance of forest-type vegetation in the areas surrounding the paleo-lake. Herbs (mainly Poaceae, Chenopodiaceae, *Artemisia*, Caryophyllaceae, Polygalaceae, Apiaceae, and Asteraceae — Fig. 7.4, 6–11) do not exceed 6–7 % NAP (Fig. 3). Because of the absence of significant changes in the frequency of herbs it is not possible to draw conclusions about the dynamics of this vegetation type. Probably open landscapes and herbaceous communities had only a limited distribution and did not play a significant role in the vegetation structure. Mesoxerophytic shrubs and forests (*Ephedra*, *Olea*, *Celtis*, *Rhus*, *Quercus ilex-coccifera* type, *Carpinus orientalis/*

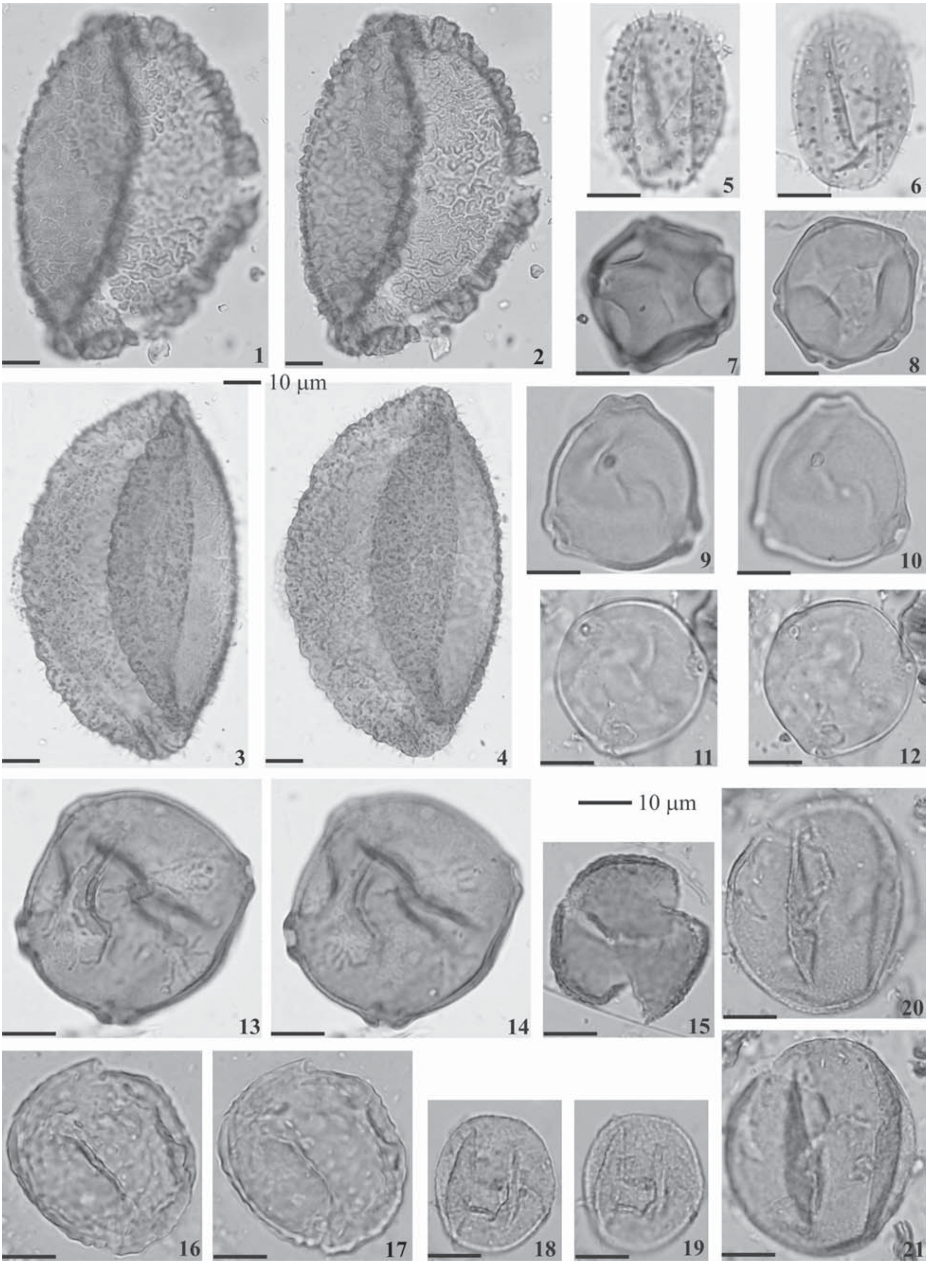

Fig. 5. **1, 2** — *Tsuga canadensis* type; **3, 4** — *Tsuga heterophylla* type; **5, 6** — *Nuphar*; **7, 8** — *Alnus*; **9, 10** — *Betula*; **11, 12** — *Carpinus orientalis/Ostrya* type; **13, 14** — *Carpinus betulus* type; **15** — *Quercus* — polar view; **16, 17** — *Ulmus*; **18, 19** — *Quercus*; **20, 21** — *Fagus*.

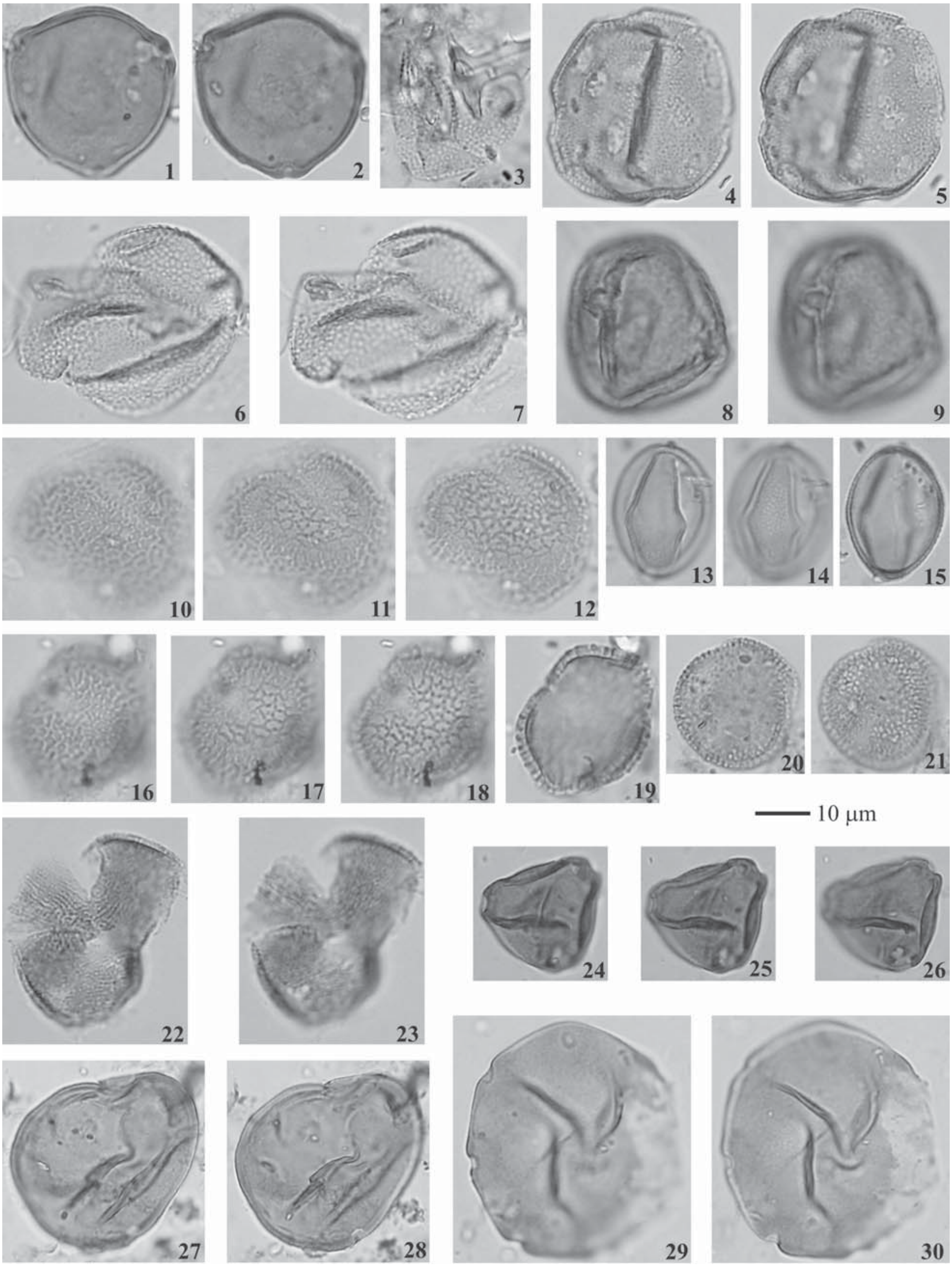

Fig. 6. 1, 2 — *Corylus*; **3** — Hamamelidaceae (cf. *Hamamelis*); **4, 5** — *Liquidambar*; **6, 7** — Hamamelidaceae (cf. *Parrotia*); **8, 9** — *Nyssa*; **10–12** — *Olea*; **13–15** — cf. Rosaceae; **16–19** — Oleaceae; **20, 21** — *Platanus*; **22, 23** — *Acer*; **24–26** — Juglandaceae (cf. *Platycarya*); **27, 28** — *Carya*; **29, 30** — *Pterocarya.*

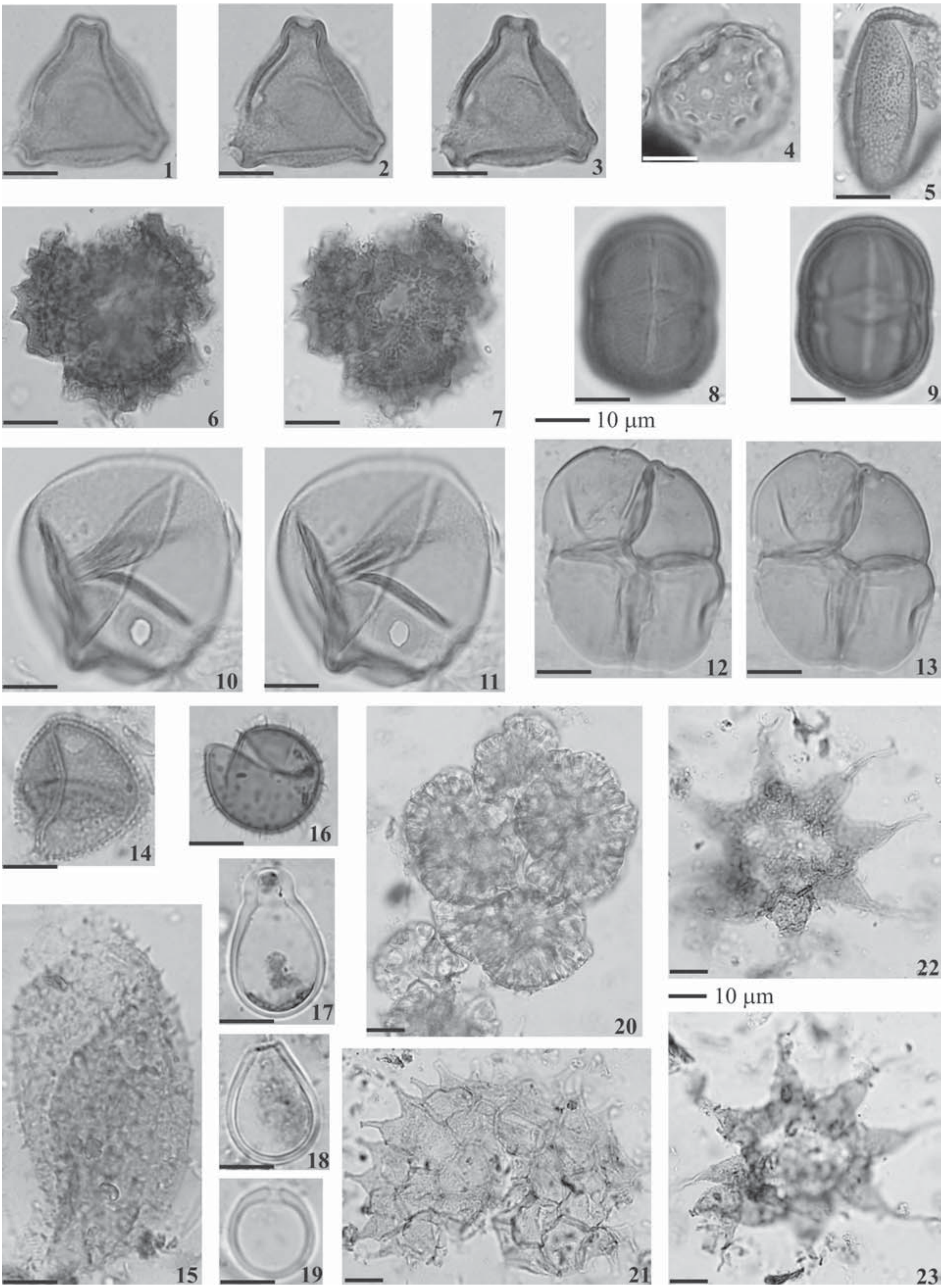

Fig. 7. **1–3** — *Myrica*; 4 — Chenopodiaceae; **5** — *Salix*; **6, 7** — Asteraceae; **8, 9** — *Centaurea*; **10, 11** — Poaceae (Bambusoideae); **12, 13** — *Typha*; **14** — *Sparganium*; **15** — *Stratiotes*; **16–19** — Algal cysts — different types; **20** — *Botryococcus* sp.; **21** — *Pediastrum* sp.1. **22, 23** — *Pediastrum* sp.2.

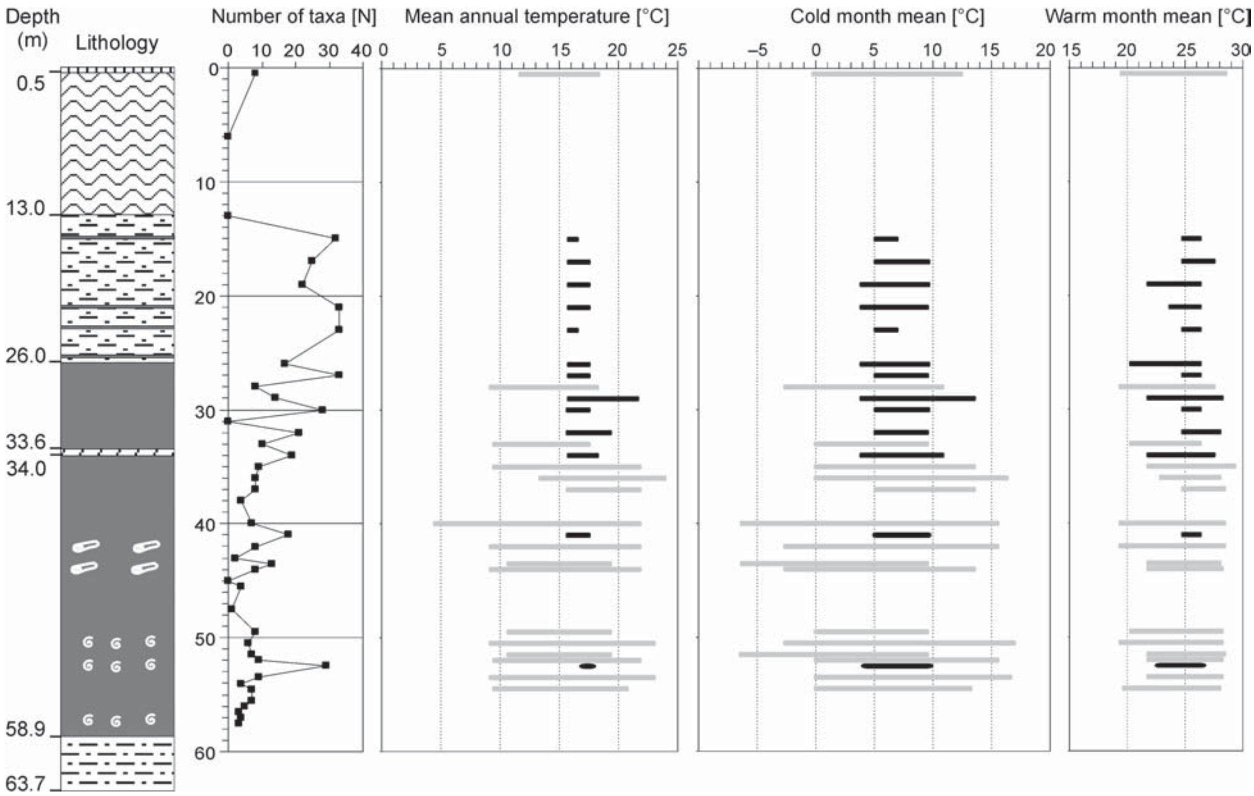

Fig. 8a. Lithological section (cf. Fig. 2), numbers of taxa contributing climate data in the analysis, coexistence intervals (bars) for mean annual temperature (MAT), and temperature of the coldest (CMT) and warmest month (WMT). For microfloras with less than 15 taxa contributing with climate data coexistence intervals are plotted in light grey.

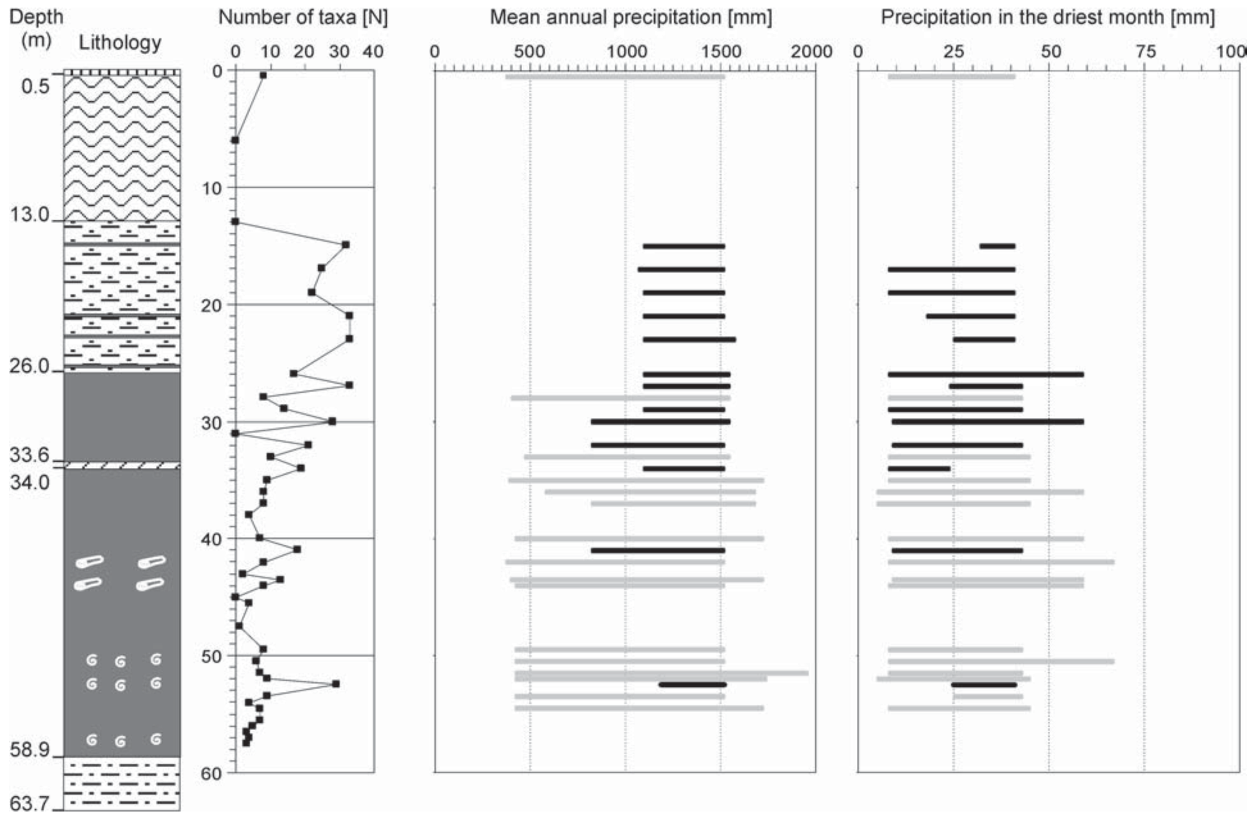

Fig. 8b. Coexistence intervals for mean annual precipitation (MAP) and mean precipitation in the driest month (MMPdry).

Ostrya type — Fig. 5.11–12; Fig. 6.10–19) were also quite limited in distribution, depending on local, edaphic and/or microclimatic conditions. Macrofloristic data (Palamarev & Kitanov 1988) also support this assumption.

Climate reconstruction

The climate data calculated for 30 palynomorph samples from core 670 (cf. Table 1) are shown in Fig. 8 where they are plotted together with the lithological profile. As it is shown by the analysis, microfloras with less then 15 taxa yield very broad, unspecific coexistence intervals of almost ten degrees for the temperature variables, and about 1000 mm for mean annual precipitation. More precise data are obtained when only the more diverse samples are selected (Fig. 8).

A MAT of 17.2 °C to 17.6 °C obtained for the lower part of the brown coal section (50.2 m) is among the highest in this reconstruction. In the upper part of the brown coal and in the overlying clays, the lower limits of MAT ranges are at 15.6 °C not exceeding 16.6 °C at 15 and 23 m in the profile. CMT ranges between 4 °C and 9 °C for most of the selection of diverse microfloras, in the upper part of the section, the upper CMT limit may decline to 7 °C (at 15 m and 23 m in the profile). WMT stays at the same level ranging between ca. 25 °C and 26.5 °C although slightly cooler values can be admitted for the basal part of the section (22.8 °C–26.4 °C at 52.2 m). Annual precipitation totals were well above 1000 mm in the lower part of the profile (at 50.5 m), and in the upper part, between 29 m and 15 m. Between 30 m and 41 m, slightly lower totals of 800 mm are possible. This trend to drier conditions in the middle part of the section is supported by the results obtained for MMPdry where, at 34 m, a range of 8 mm to 24 mm is obtained while MMPdry rates of at least 25 mm result for the lowermost part of the section (52.5 m), and also for parts of the clays on top.

Summarizing the results obtained it can be stated that a warm temperature climate persisted during the studied time period. Temperatures stayed at about the same level. Towards the upper part of the profile a slight decreasing trend can be detected, affecting MAT and CMT. In most of the cases, MAP totals above 1000 mm with MMPdry above 25 mm point to a permanently humid climate (Cfa-type). However, data obtained for one sample from the middle part of the section (at 24 m) indicate seasonally drier conditions.

The paleoclimate data reconstructed using the NLR technique are over all supported by the broader vegetation data. For instance in most cases warm temperate and permanently humid conditions coincide with the presence of forest cover (mixed mesophytic forest with warmth-loving evergreens in the undergrowth; see above). The calculated MAP total, commonly above 1000 mm, explains the rareness of xerophytic elements in the pollen spectra. However, the more pronounced seasonality of precipitation calculated for the middle part of the section is not clearly reflected by the frequency of xerophytic pollen types (see above).

So far uncertainties of stratigraphical dating of the studied section do not allow correlation with climate curves available for other continental parts of Europe or global records, but work is in progress. However, if a latest Miocene age (Pontian) can be assumed for at least the basal part of the section, the data can be discussed in a European context. When compiling paleoclimate data for the latest Miocene from various sources for different parts of Europe (Table 2) it is clear that the Beli Breg region was characterized by favourable climate conditions with comparatively high MAT and mild winter temperature. When comparing temperatures (MAT, CMT) calculated for the Pontian of the nearby Forecarpathian Basin of NW Bulgaria values obtained for the Beli Breg Basin tend to be higher by a few degrees (Table 2). This can be explained by a more southerly latitudinal position and/or a favourable microclimate caused by a small-scale relief. In the study area, MAP was apparently high when compared to other European regions (Table 2). However, precipitation rates of the driest month were among the lowest. As in the Forecarpathian Basin where the climate record displays cycles of more humid and drier conditions (Ivanov et al. 2002) there is also evidence for fluctuations in precipitation rates in the present data.

Table 2: Paleoclimate data for the W Bulgarian latest Miocene compared to other European regions.

Region	MAT	CMT	WMT	MAP	MMPdry	Reference
Beli Breg Basin/ W Bulgaria	15.7–16.6 (top) 17.2–17.6 (base)	5.0–7.0 (top) 4.3–9.6 (base)	24.7–26.4	1096–1520	25–41 8–24 (middle)	This study
Forecarpathian Basin/Bulgaria	13.7–17.2	2.7–7.0	23.0–27.3	650–1310	–	Ivanov et al. (2002) (microfloras, summary)
Peripannonian realm (Danube Valley)/Serbia	14.8–15.3	1.7–4.0	25.4–26.7	890–1300	43–47	Utescher et al. (2007) (macrofloras, summary)
Ukraine Plane/Ukraine	11.6–15.7	–0.1–1.1	21.7–24.8	843–1018	32–41	Syabryaj et al. (2007) (microfloras, summary)
Lower Rhine Basin/Germany	13.6–13.8	2.9–4.1	24.0–25.9	897–1258	40	Utescher et al. (2000, 2007) (macrofloras, summary)

Conclusions

As a summary of the results from the research we can stated that mixed mesophytic forest dominated the vegetation. It can be characterized as mainly deciduous forest with evergreen components while swamp forests were comparatively scarce. In addition, local vegetation types such as aquatic communities have been recorded. Floristic data evidence that a dense forest cover existed in the study area while the distribution of grasslands and open landscapes was limited. The minor importance of xerophytic plants observed in the pollen spectra argues against a Mediterranean type climate.

Climate data support the results obtained from vegetation analyses. A warm temperature climate with high rainfall and mild winter temperatures persisted in the time period considered. Temperatures stayed about at the same level, although towards the upper part of the profile, a slight decreasing trend can be detected which involved mean annual temperature (MAT) and mean temperature of the coldest month (CMT). Ongoing studies in the Beli Breg Basin will provide more precise stratigraphic dating. Additional pollen records will provide a significantly higher resolution, and the analysis of the sedimentary cycles displayed in the sections will considerably increase our knowledge about vegetation and climate evolution in the Late Miocene of West Bulgaria.

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