New results for the fossil macroflora of the Beli Breg Lignite Basin, West Bulgaria

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Abstract. Recent studies carried out into the flora-bearing sediments of Beli Breg Lignite Basin have provided a total of 19 identified taxa at the species level, 13 of them new for that site. The new results confirm dominance of the *Fagaceae* family and high diversity of genus *Quercus* in the palaeoflora. *Quercus gigas, Q.* aff. *acrodonta* and genus *Euonymus* are described for a first time for Bulgaria. The species *Laurus pliocenica* has been determined both by leaf imprint and cuticle. *Potamogeton pectinatus* foss. for the first time has been determined by imprint of stem and leaves. The Coexistence Approach was used to calculate the quantitative palaeoclimatic records for five parameters. The obtained results indicate a warm, temperate and humid climate, with mean annual temperatures around 16 °C, and annual precipitation rates around the 1000 mm. The presently obtained data were compared to the published microflora-based records. The comparison has shown that in most cases narrower coexistence intervals result from the macroflora, thus providing a better climatic resolution.

Key words: Bulgaria, Coexistence Approach, cuticles, Dacian, fossil macroflora, palaeoclimate, Pontian

Introduction

The fossil macroflora of the Beli Breg Lignite Basin was studied in detail by Palamarev & Kitanov (1988). The authors described a total of 34 different taxa and outlined the ecological and coenotical characteristics of the macroflora. On the basis of geological and palaeobotanical data, they suggested a Dacian age for the fossil flora.

Ivanov & al. (2007) analysed the fossil microflora, aiming to obtain the main features of palaeovegetation and climate conditions during the sedimentation process. The authors paid also attention to the problems of stratigraphic subdivision of the studied basin.

Analyzing all earlier reports, Vatsev & Zdravkov (2004) sugested Pontian to Early Dacian age of the Kaisiynitsa Formation, which includes the studied flora-bearing sediments. That statement has been accepted in the present article.

During palaeobotanical researches carried out in 2005, new macrofossil material was collected, as well as material for pollen analysis. The new macrofossil material has been analyzed, together with the so far unprocessed leaf imprints from the fossil collection of the Palaeobotany and Palynology Division of the Institute of Biodiversity and Ecosystem Research, BAS. Nineteen taxa have been identified at the species level, and 13 of them are new for that site. The leaf imprints

determined as *Euonymus* aff. *japonicus* Thunb. are of special interest, because so far the genus *Euonymus* has not been registered in the fossil flora of Bulgaria. Another interesting find is *Quercus gigas* Goepp. described for the first time for the Bulgarian palaeoflora. Mention deserves the fact that for the first time in the European palaeoflora the East Asian oak *Q. acrodonta* Seem. has been identified as a Nearest Living Relative (NLR) of a fossil taxon.

Material and methods

The studied material comprises 52 fragments of sediment samples with phytomacroremains on them. They were collected from grey-green clayey marl at 53 m, and marls at 60 m in the Tsatsarovtsi section of the lignite basin (Figs 1-2). According to information provided by Palamarev & Kitanov (1988), most of the fossils identified by them were collected from sandy clay and reddish-brown shales of the Nedelishte section of the Basin, located at a depth of 2.0 to 45.0 m. Judging by the sediment type, the three specimens collected by these authors and studied by us probably originate from this area. The rest of the fossils studied by Palamarev & Kitanov (1988) come from the sage-green sandy clays of the Tsatsarovtsi section (Fig. 3).

The order of families in the text is following the system of Meyen (1984) for Gymnosperms and of Takhtajan (1987) for Angiosperms. The genera and species in the families are arranged in an alphabetical order. For determination of macroremains, the ich-
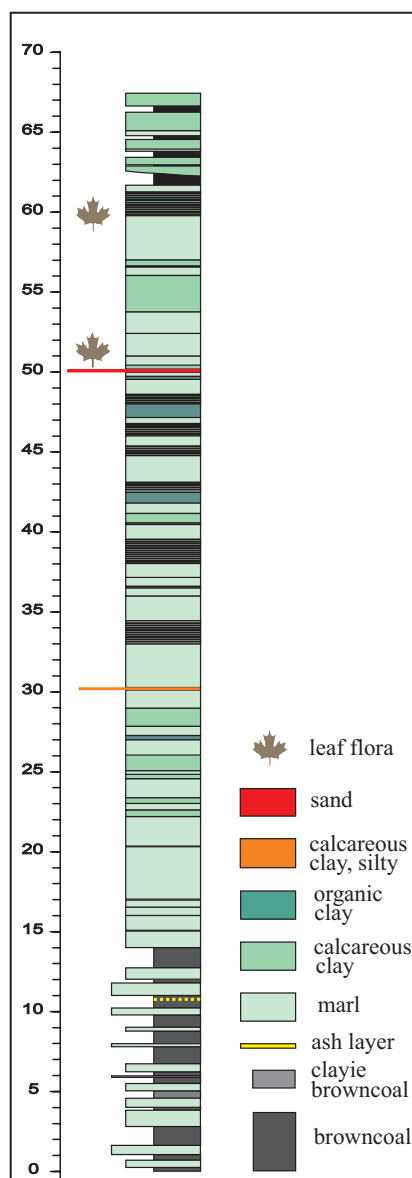

Fig. 2. Lithological column of the Tsatsarovtsi section of the Beli Breg Lignite Basin.

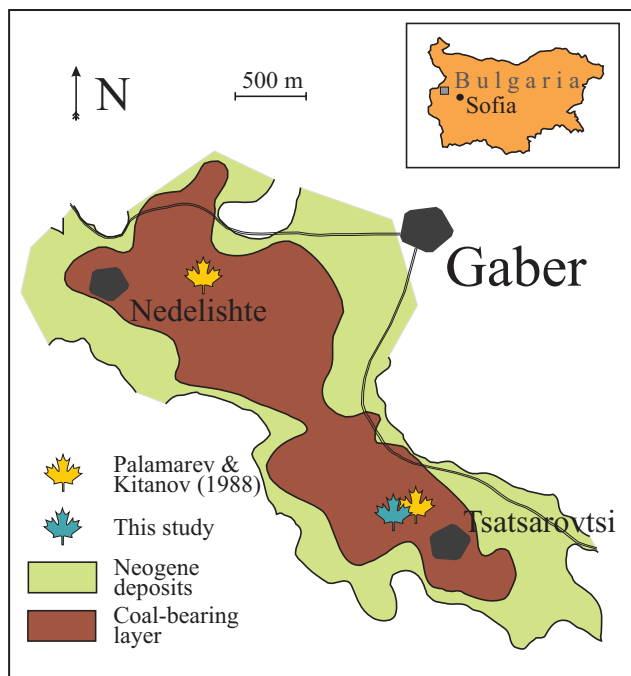**Fig. 1.** Tsatsarovtsi section of the Beli Breg Lignite Basin: general view.

Fig. 3. Geological map of the Beli Breg Lignite Basin (redrawn after Yovchev 1960, with corrections).

nophytological method (Zhilin 1969) has been used. The system of Dilcher (1974) has been applied for the description of morphological characteristics of the leaf imprints of Angiosperms, as well as for the preparated cuticles. Specimens from the Collection of Recent Leaves of the Palaeobotany and Palynology Division (CRLPPD) of the Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, were used for comparing the fossil and recent specimens.

Owing to the fact that the fossil cuticle is very fragile, we have managed to prepare only few small fragments with the help of the following method: leaf fragments are macerated and bleached by 5 % sodium hypochlorite solution for 30 min, stained with 1 % safranin for 1 min and mounted in glycerine jelly.

To reconstruct palaeoclimate from the macrofossils record of the Beli Breg Lignite Basin, the Co-existence Approach (CA) was applied (Mosbrugger & Utescher 1997). The method uses the climatic tolerances of all Nearest Living Relatives (NLRs) known for a fossil flora, in order to determine a range for each considered climate variable, in which the maximum number of NLRs known for the fossil flora may co-exist. The resulting ranges obtained for the different climate variables are denoted as CA

intervals defining the climatic space in which the fossil flora had existed. The climatic resolution of the method and the significance of the obtained results mainly depend on the diversity of the analyzed fossil flora, and on the taxonomic level of identification of NLR for a given fossil taxon (Mosbrugger & Utescher 1997). In the present study, three temperature variables have been calculated: mean annual temperature (MAT), mean temperature of the coldest and warmest month (CMM; WMM) and two precipitation variables – mean annual precipitation (MAP) and precipitation of the driest month (MPdry).

Results

Taxonomic studies

The studied material has presented an opportunity for determining the taxa shown in Table 1. The newly described taxa for the Beli Breg palaeoflora are as follows: two representatives of the Gymnosperms and 11 of the Angiosperms, which belong accordingly to two and eight families.

Below, the quotation blocks of the new taxa for the Beli Breg flora are presented, as well as a full description only of those that are new for the Bulgarian fossil flora. These are three taxa determined at species level.

Pinophyta

Pinaceae
Pinus laricioides Menzel (Pl. I, Fig. 1)
1900. Menzel, p. 66, Pl. 3, Fig. 16.
1987. Palamarev & Petkova, p. 24, Pl. 4, Fig. 7.

Material: an impression of needle-shaped leaves (B-734).

Geographical distribution and stratigraphic range: the species had sporadic occurrence in separate parts of Central, South and Southeast Europe. So far as its stratigraphic distribution has been given as Sarmatian – Pannonian.

Comment: Detailed description of the species in the Bulgarian palaeoflora was provided by Palamarev & Petkova (1987). The sample studied here had no morphological deviations from the type. The new find has enlarged the stratigraphic coverage of the taxa to Sarmatian – Upper Pontian – Lower Dacian.

Table 1. List of the taxa determined in the present article, number of studied specimens and floristic importance of some of them.

Taxa	Number of specimens		RGE, */**	Ecological type
	NS	SC		
Pinaceae				
1. *Pinus laricioides*	1	–	Eu, *	mesoxerophyte
Taxodiaceae				
2. *Glyptostrobus europaeus*	15	–	EA	hygrophyte
Cupressaceae				
3. *Juniperus* aff. *communis*	–	2	EuB, *	xerophytes
Magnoliaceae				
4. *Magnolia mirabilis*	5	–	EA, *	mesophyte
Lauraceae				
5. *Laurus pliocenica* f. *lanceolata*	1	–	Ma, *	hygromesophyte
Ulmaceae				
6. *Zelkova zelkovifolia*	2	–	EH	mesophyte
Fagaceae				
7. *Quercus* aff. *acrodonta*	4	–	EA, **	mesophyte
8. *Q. ceris* foss.	3	–	EuB	mesophyte
9. *Q. drymeja*	6	–	EA, *	mesophyte
10. *Q. gigas*	3	–	EuB, **	mesophyte
11. *Q. mediterranea*	1	–	Me	xerophyte
12. *Q. sosnowskyi*	1	–	Me, *	mesoxerophyte
Betulaceae				
13. *Carpinus betulus* foss.	2	–	EuB	mesophyte
Myricaceae				
14. *Myrica lignitum*	1	–	NA, *	mesophyte
Aceraceae				
15. *Acer subcampestre*	1	–	EuIT, *	mesophyte
Celastraceae				
16. *Euonymus* aff. *aponicus*	2	–	EA, **	mesoxerophyte
Apocynaceae				
17. *Nerium oleander* foss.	1	–	Me, *	xerophytes
Potamogetonaceae				
18. *Potamogeton pectinatus* foss.	–	1	Cs, *	hydrophyte
Poaceae				
19. *Phragmites oeningensis*	3	–	Cs	hygrophyte

Legend: NS – new specimen; **SC** – specimen in collection; **RGE** – Refugial-geographic element: **Eu** – European, **EuB** – Euroboreal, **EuIT** – Euro-Irano-Turanian, **EA** – East Asian, **EH** – Euxinian-Hyrcanian, **Ma** – Macaronesian, **Me** – Mediterranean, **NA** – North American, **Cs** – Cosmopolitan; * – new taxa for the site; ** – new taxa for the Bulgarian palaeoflora.

Cupressaceae

Juniperus aff. *communis* L. (Pl. I, Fig. 2)
1956. Kitanov & Nikolova, p. 87.

Material: two imprints of twigs with needles (B-79, 300).

Geographical distribution and stratigraphic range: The taxon is known only from sediments of the Romanian age found in the city of Sofia (Bulgaria) (Kitanov & Nikolova 1956).

Comment: The new find has enlarged the stratigraphic coverage of the taxon to Upper Pontian – Lower Dacian – Romanian.

Magnoliophyta

Magnoliaceae

Magnolia mirabilis Kolak. (Pl. I, Figs 3-4)
1959. Kolakovsky, p. 243, Pl. 14, Figs 1-3.
1987. Palamarev & Petkova, p. 30, Pl. 7, Fig. 6.
1998. Bozukov, p. 4, Pl. 5, Fig. 3.

Material: six leaf imprints (B-725, 724a-b, 736, 739, 744).

Geographical distribution and stratigraphic range: The species was distributed geographically in Georgia and Bulgaria, its stratigraphic distribution has so far been Sarmatian – Pontian. Owing to our find, it now includes also Lower Dacian.

Comment: Detailed description of the species in the Bulgarian palaeoflora was given by Palamarev & Petkova (1987). The specimens studied here are smaller in size.

Lauraceae

Laurus pliocenica (Saporta & Marion) Kolak. f. *lanceolata* Kolak. (Pl. I, Figs 5-10)
1960. Kolakovsky, p. 43, Pl. 10, Fig. 2.
1987. Palamarev & Petkova, p. 41, Pl. 10, Fig. 2.
1876. *L. canariensis* Webb & Berthel. *pliocenica* Saporta & Marion, p. 116, Pl. 27, Fig. 6-7; Pl. 28, Fig. 1-8.

Material: a leaf and cuticle imprint (B-740).

Description: Leaf hypostomatic. Adaxial epidermis medium cutinized, ordinary cells irregular, polygonal, slightly elongated, $33.5 \pm 2.8 \times 20.1 \pm 2.7$ μm, with undulate U-shaped walls (wave length – 5.2 ± 0.7 μm ; wave amplitude – 4.8 ± 0.9 μm), more elongated above the veins, trichome bases absent. Abaxial epidermis medium cutinized, ordinary cells irregular, polygonal, more or less elongated, $50.1 \pm 13.6 \times 18.6 \pm 3.9$ μm, with undulate Ω-shaped walls

Plate I.
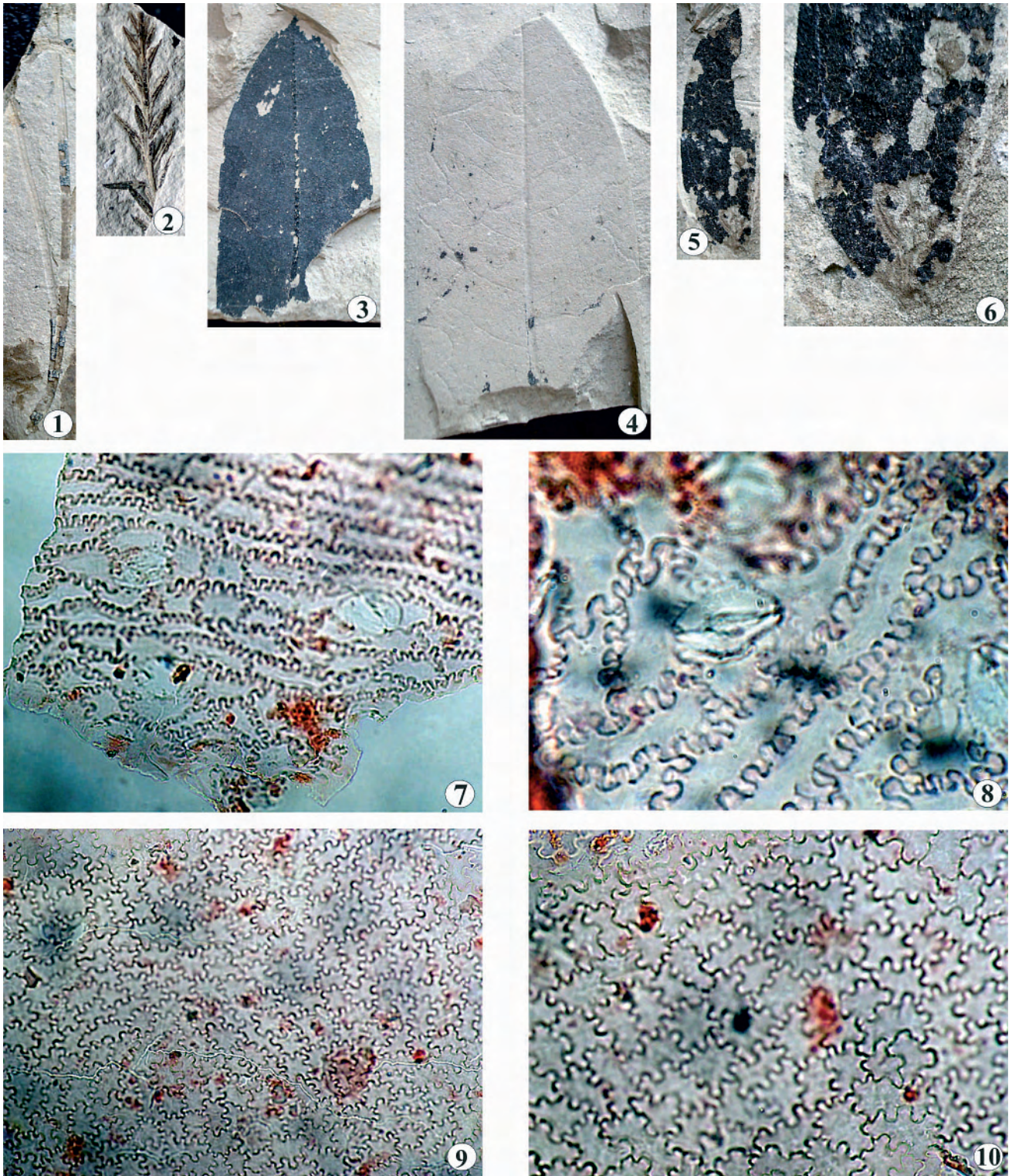
Figs 1-10. Photographs of fossil specimens:
1, *Pinus laricioides* B-734 (×1), **2,** *Juniperus* aff. *communis* B-79 (×2), **3-4.** *Magnolia mirabilis*: **3,** B-724a (×1), **4,** B-724b (×1.3),
5-10. *Laurus pliocenica* f. *lanceolata*: **5,** B-740 (×1), 6, B-740, leaf basal part (×2), **7,** lower epidermis (×300), **8,** lower epidermis (×650),
9, upper epidermis (×200), **10,** upper epidermis (×400).

(wave length – 6.5 ± 0.9 μm ; wave amplitude – 5.5 ± 1.1 μm). Cells above the veins tetragonal, more or less elongated, 31.4 ± 5.9 × 13.4 ± 2 μm, with straight walls and oblique end walls. Stomatal complex anomocytic, stomata randomly orientated and distributed, guard cells half-moon or triangular shaped, 25.9 ± 1.5 × 9.3 ± 1.6 μm. SD – 204 stomata per mm^2; SI – 11.36 %.

Geographical distribution and stratigraphic range: The area of the species covers Southwest, East and Southeast Europe, and its stratigraphic distribution is Middle Miocene – Upper Pliocene.

Comment: Detailed description of the morphology of the leaf lamina of that species in the Bulgarian local palaeoflora was given by Palamarev & Petkova (1987). The comparison between the epidermis of *L. pliocenica* f. *latifolia* studied by Kolakovsky (1964) and the one described by us of *L. pliocenica* f. *lanceolata* has shown identity, thus proving that they belong to one species. The species is specific with its highly variable leaf morphology and our find has contributed to its more thorough identification.

Fagaceae
Quercus aff. *acrodonta* Seem. (Pl. II, Figs 1-2)

Material: four leaf imprints (B-737, 738, 745, 746).

Description: Shape of the lamina narrow elliptic or oblanceolate; the base of lamina obtuse, normal; the apex acuminate. Entire leaf margin in the lower half of the lamina; in the upper half two pairs of teeth are found or the margin is entire. Depending on the size of the leaf lamina, it is the bigger, the more expressed are the teeth. There are rounded sinuses between the teeth. Their basal side is much longer than the apical one. The bigger teeth are inflected to the lamina apex. Venation is craspedodromous, simple; midvein is more or less arched. Secondary veins 6–7 pairs, straight at their basis, but arched close to the lamina margin; arranged at an angle of 50–60° towards the midvein; opposite or nearly opposite. Intersecondary veins can be observed in the lower half of the lamina; tertiary veins are not preserved.

Dimensions: length 5–7 cm, width 2–2.8 cm.

Comparison. The closest morphology to one of our finds has the material determined by Palamarev & Tsenov (2004) as *Q. abhasica* Kolak. However, the difference in the number of teeth is obvious –

six pairs in the above-mentioned and two pairs in the here described material. Difference can be also found in the shape of the secondary veins. In *Q. abhasica* (Palamarev & Tsenov 2004) they are more or less arched. Of recent oaks, almost identical morphology with the species described here has *Q. acrodonta* Seem., distributed in Central China (Pl. II, Fig. 3). The only more essential difference between *Q. acrodonta* and our fossil taxa is that the leaves of contemporary species have three pairs of teeth mainly, while laminas with two pairs of teeth are seldom found.

Geographical distribution and stratigraphic range: Beli Breg Lignite Basin, Pontian to Lower Dacian.

Quercus drymeja Unger (Pl. II, Fig. 4)
1847. Unger, p. 113, Pl. 32, Figs 1-4.
1932. Konjarov, p. 125, Pl. 32, Figs 3-5.
1934. Stefanov & Jordanov, p. 18, Pl. 6, Figs 8-10.
1935. Stefanov & Jordanov, p. 40, pars, Pl. 12, Fig. 4 (non Pl. 11, Fig. 6 = sp. indet., Figs 7-12 = *Q. bulgarica* Kitan. fill.; Pl. 12, Figs 1-3, 5; Pl. 13, Fig. 1 = sp. indet.).
2004. Palamarev & Tsenov, p. 150, Pl. 2, Fig. 3; Pl. 4, Figs 3-4.

Material: seven leaf imprints (B-712, 732a-b, 733, 735, 743, 747).

Geographical distribution and stratigraphic range: This species is distributed nearly across entire Europe (without its northern parts), and its stratigraphic distribution is Lower – Upper Miocene.

Comment: A detailed description of the species in the Bulgarian palaeoflora was provided by Stefanov & Jordanov (1935). The samples studied here differ with smaller sizes of the teeth and smaller number.

According to Palamarev & Mai (1998), *Q. drymeja* is a Neogene derivative of *Q. lonchitis* Unger and the announced finds of *Q. drymeja* in Paleogene floras of Brezhani (Palamarev 1967) and Bobovdol (Palamarev & al. 1998) should be revised as *Q. lonchitis*.

Quercus gigas Goeppert (Pl. II, Figs 7-8)
1855. Goeppert, p. 16, Pl. 8, Fig. 2.
1991. Walther & Zastavniak, p. 160, Pl.4, Figs 1-3; Pls 5-6; Pl. 7, Figs 1-3; Pls 8-10; Figs-text 3-7.
2002. Kvaček, Velitzelos & Velitzelos, p. 62, Pl. 11, Figs 8-10; Pl. 12; Pl. 13, Figs 1-2; Pl. 14, Fig. 3.

Material: three leaf imprints (B-726, 727, 728).

Description: Shape of the lamina narrow elliptic or narrow ovate; base of the lamina acute, normal; apex acuminate; leaf margin serrate, the teeth more expressed in the upper part of the lamina; with rounded sinuses between them, their basal side much longer than their apical. Venation craspedodromous, simple; midvein more or less arched, secondary veins 13–15 pairs, straight or slightly arched, at an angle of 45–70° towards the midvein, the angle decreases from the base towards the lamina apex, most of the pairs opposite or nearly opposite; intersecondary veins are not observed; tertiary veins are not preserved.

Dimensions: length 9.5–16.0 cm, width 4.0–7.0 cm.

Comment: The closest morphology to the one of our find has the material determined by Kvaček & al. (2002) from the Miocene flora of Vegora (Greece). According to these authors, *Q. gigas* has its nearest relative among the representatives of Sect. *Cerris*.

Geographical distribution and stratigraphic range: According to Walther & Zastavniak (1991), the species was widely distributed in the Paratethys area, but obviously absent from more thermophilic assemblages, e.g. in South France. Its stratigraphic distribution is also wide, from the Upper Oligocene to Pliocene.

Quercus sosnowskyi Kolak. (Pl. II, Figs 5-6)
1955. Kolakovsky, p. 447, Pl. 8, Fig. 4.
1984. Kitanov, p. 60, Fig.-text 12.4.
2004. Palamarev & Tsenov, p. 149, Pl. 1, Fig. 3; Pl. 2, Fig. 5; Pl. 3, Figs 1-2.
Material: a leaf imprint (B-729).

Geographical distribution and stratigraphic range: The species was distributed in Bulgaria, Greece and Georgia, and its stratigraphic distribution was Badenian – Pontian. Owing to the new find, the stratigraphic range can be extended to Pontian – Lower Dacian.

Comment: Detailed description of the different morphotypes of the species in the Bulgarian palaeoflora was given by Kitanov (1984) and Bozukov (1999). The presently studied specimen is incomplete and probably represents *Q. sosnowskyi* f. *angustifolia* Kolak.

Betulaceae
Carpinus betulus L. foss. (Pl. II, Fig. 9)
1984. Kitanov, p. 53, Fig. 9 (2-3).
1934. *C. betulus* L., Stefanov & Jordanov, p. 15, Pl. 3, Fig. 10, Pl. 5, Figs 7-8.
Material: a leaf imprint (B-632); an involucre imprint (B-711).

Geographical distribution and stratigraphic range: The fossil form of this species was distributed nearly across entire Europe (without its northernmost parts), and its stratigraphic distribution was Pliocene.

Comment: The studied specimen did not deviate from the type. So far the fossil form in this locality has been known only from involucres of *C. betulus* L. foss. (Palamarev & Kitanov 1988). Now it has been determined also by a leaf imprint.

Myricaceae
Myrica lignitum (Unger) Saporta (Pl. III, Fig. 6)
1865. Saporta, p. 102.
1987. Palamarev & Petkova, p. 80, Pl. 22, Figs 1a-b.
1847. *Quercus lignitum* Unger, p. 113, Pl. 31, Figs 5-7.
Material: a leaf imprint (B-632).

Geographical distribution and stratigraphic range: This fossil species was distributed in Southwest, Central, East and Southeast Europe, and its stratigraphic distribution is Lower Oligocene – Lower Pliocene.

Comment: A detailed description of the species in the Bulgarian palaeoflora was given by Palamarev & Petkova (1987). The specimen studied here is identical.

Aceraceae
Acer subcampestre Göpp. (Pl. III, Fig. 1)
1855. Göppert, p. 32, Pl. 22, Figs 16-17.
2005. Palamarev & al., p. 241.
2005. Walther & Zastawniak, p. 93, Pl. 5, Figs 1-4; Pl. 6, Figs 1-9.
Material: a leaf imprint (B-723).

Geographical distribution and stratigraphic range: This fossil species was distributed in two separate areas: West and East Europe, but it was not found in Central Europe. Its stratigraphic distribution is Middle Miocene – Pliocene.

Comment: A detailed description of the species in the Bulgarian palaeoflora was given by Bozukov (1999). The specimen studied here is identical.

Celastraceae
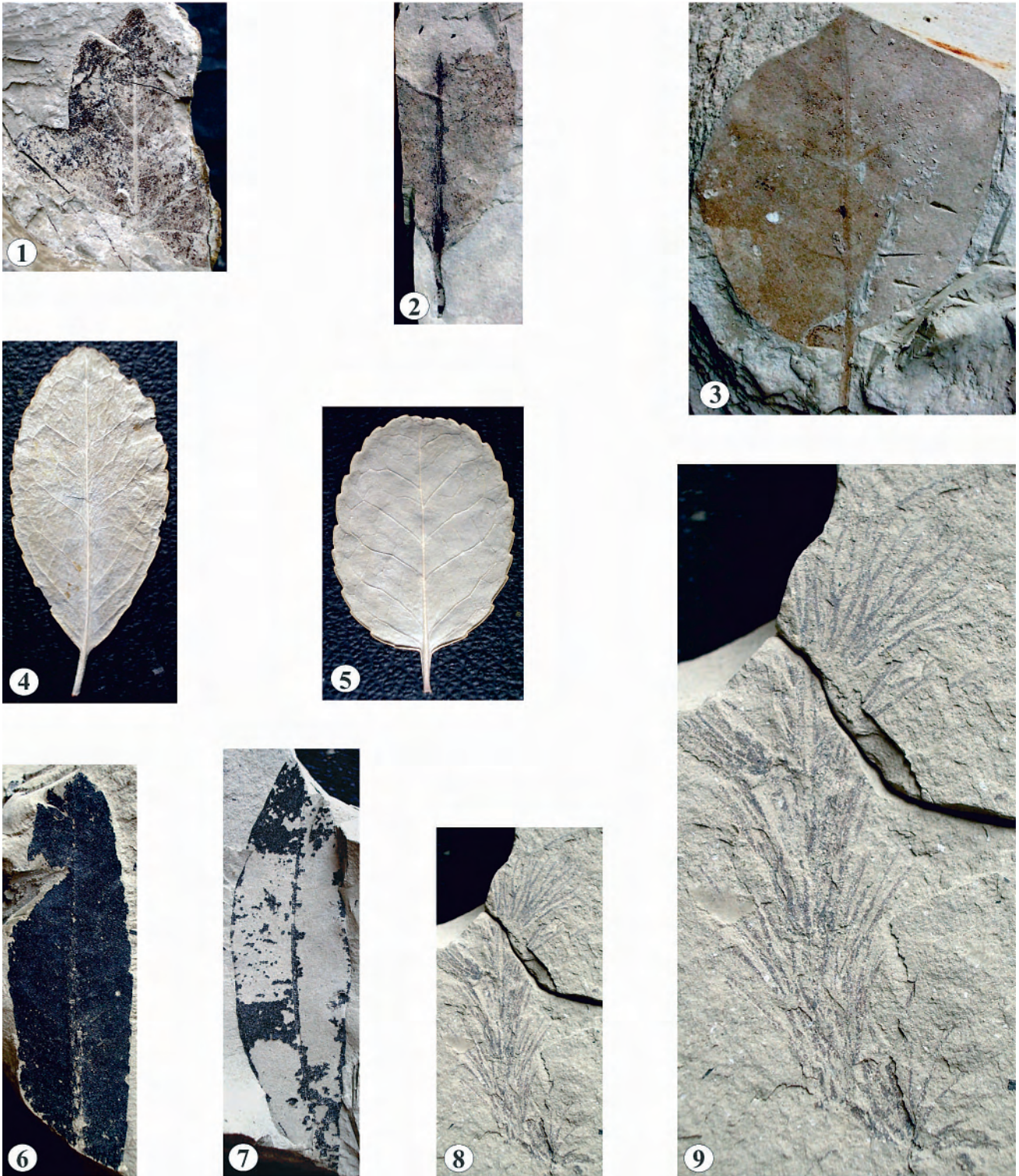*Euonymus* aff. *japonicus* Thunb. (Pl. III, Figs 2-3)

Plate II.
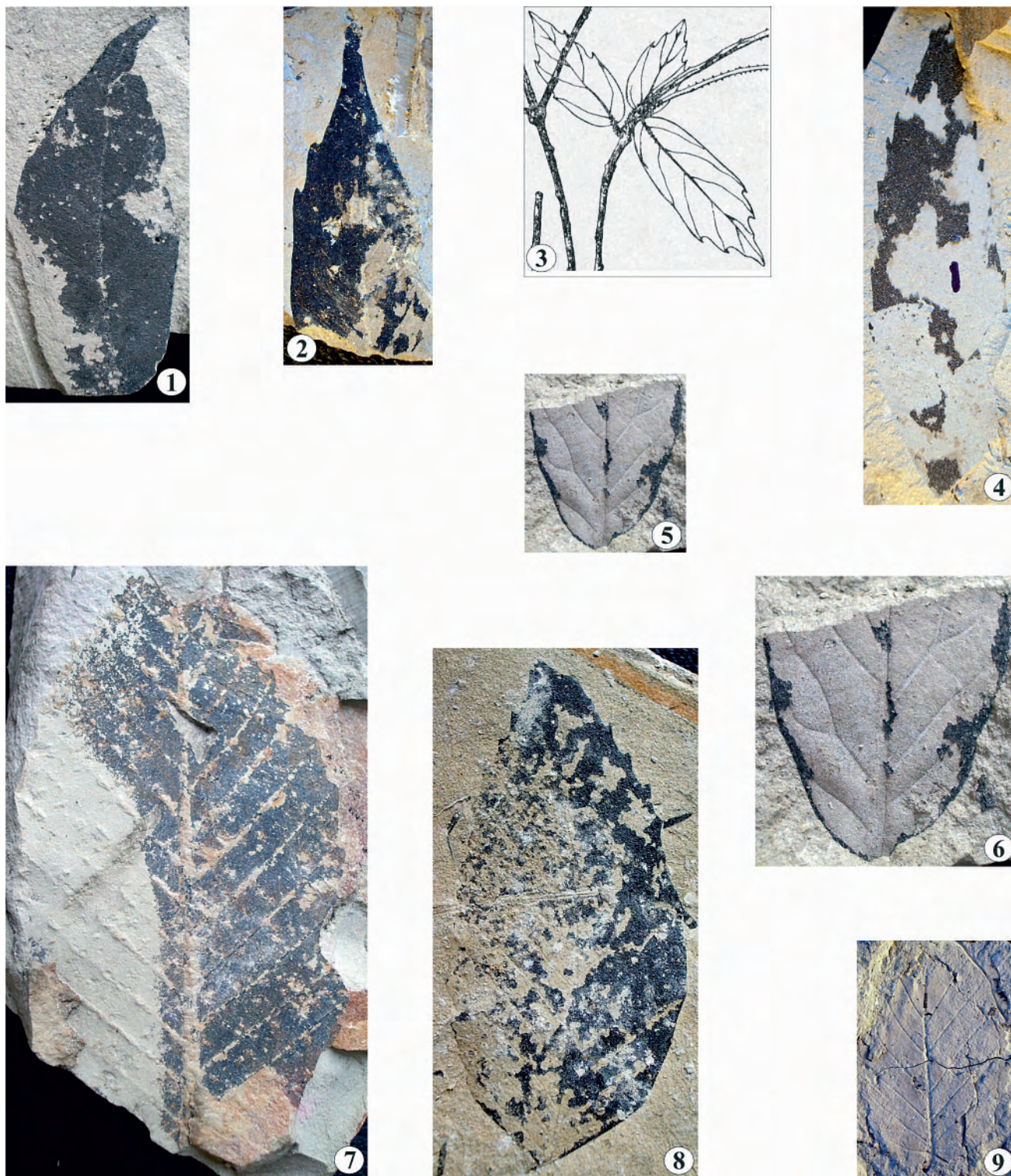
Figs 1-9. Photographs of fossil and recent specimens:
1-2. *Quercus* aff. *acrodonta*: **1,** B-738 (×1), 2, B-737 (×1), **3,** *Q. acrodonta* (after Menitski 1984), **4,** *Q. drymeja* B-732a (×1),
5-6. *Q. sosnowskyi*: 5. B-729 (×1), the same (×2), **7-8,** *Q. gigas:* 7. B-726 (×1), 8. B-727 (×1), **9,** *Carpinus grandis* foss. B-632 (×1).

Plate III.

Figs 1-9. Photographs of fossil and recent specimens:
1, *Acer subcampestre* B-723 (×1), **2-3.** *Euonymus* aff. *japonicus*: **2,** B-716 (×1), 3, B-709 (×1), **4-5.** *E. japonicus*: **4,** CDPP1 (×1), **5,** CDPP2 (×1), **6,** *Myrica lignitum* B-742 (×1), **7,** *Nerium oleander* foss. B-741 (×1), **8-9.** *Potamogeton pectinatus* foss.: **8,** B-498a (×1), **9,** the same (×2).

1959. Andreánszky, p.174, Fig.-text 216.

Material: two leaf imprints (B-709, 716a).

Description: Shape of the lamina elliptic to wide elliptic; base normal – acute to obtuse; the upper part of imprints was not preserved, probably obtuse; margin of the leaf blade entire at the base and otherwise slightly serrate; the teeth   are very small, with obtuse apical angle and of convex serration type. Venation: brachydodromous; midvein straight and thick; secondary veins arciform, probably 6–7 alternating pairs, at an angle from 45 to 75° to the midvein. depending on the width of the leaf lamina; intercalary veins and tertiary veins are not detected. The petiole is of normal type, about 1 cm long.

Dimensions: length probably 5.0–6.0 cm, width 2.0–4.0 cm.

Comparison: The registered variability of the leaf in the fossil samples studied by us is within the range of one of the contemporary species (Pl. III, Figs 4-5). The difference between the fossil specimens and the herbarium material, and the results published by Andreánszky (1959) refer only to their bigger size. The bad conservation of the fossil material did not permit its more specific determination and that is why we have used the combination *Euonymus* aff. *japonicus.*

Geographical distribution and stratigraphic range: This fossil taxon was distributed in sites in Hungary and Bulgaria. Its stratigraphic distribution could be extended by our find to cover the interval from Sarmatian to Upper Pontian – Lower Dacian.

Apocynaceae

Nerium oleander L. fossilis (Pl. III, Fig. 7)

1963. Jordanov & Kitanov, p. 34, Pl. 4, Figs 1-3; Figstext 7. 1-4.

1987. Palamarev & Petkova, p. 141, Pl. 36, Fig. 6.

Material: a leaf imprint (B-741).

Geographical distribution and stratigraphic range: The fossil form of the species had a distribution area in regions of Southwest, Central and Southeast Europe. It stratigraphic range is Middle Miocene – Upper Pliocene.

Comment: Detailed description of the fossil form in the Bulgarian palaeoflora was given by Palamarev & Petkova (1987). The sample studied here has no deviations.

Potamogetonaceae

Potamogeton pectinatus L. fossilis (Pl. III, Figs 8-9)

1965. Palamarev, p. 137, Pl. 1, Fig. 2; Pl. 3, Fig. 6.

Material: imprints of a stem with leaves (B-498).

Description: A fragment of a stem with threadlike leaves on it. Leaves up to 2.0 cm long, about 0.5 mm wide, some with dichotomous division.

Dimensions of the fragment: length 5.0 cm, width 2.0 cm.

Geographical distribution and stratigraphic range: The fossil form of this species had a palaeodistributioin in regions of Central (Mai & Walther 1988) and Southeast Europe (Palamarev 1965; Kolakovsky 1973). Its stratigraphic range is Middle Miocene (Sarmatian) – Lower Pleistocene.

Comment: So far, the fossil form has been known only as seed. Our finds have demonstrated the existence of the species by imprints of parts of the plant.

Palaeoclimate analysis

Forty one taxa have been considered for palaeoclimate analysis and are listed in Table 2, together with their corresponding Nearest Living Relatives (cf. previous chapter and Palamarev & Kitanov 1988). Monotypic taxa (*Gingko, Glyptostrobus*) and phytogeographical relics (*Quercus pontica* K. Koch) have been excluded from the analysis. For the taxa *Daphne* sp., *Phragmites* sp. and *Typha latifolia* L. (Palamarev & Kitanov 1988), climate data have not been available. To obtain a maximum climatic resolution, the allocation of the fossil taxa to NLRs was aimed at the species level. In nine cases the genus or section level was used, because a more specific attribution does not seem justifiable. The obtained results are shown in Figs 4-9 and in Table 3. The comparatively high taxonomic diversity and resolution of the Beli Breg flora yields a rather precise reconstruction, with narrow CA intervals. According to Mosbrugger & Utescher (1997), significance of the obtained results depends on the percentage of taxa that may co-exist. In the present analysis, these percentages range between 97.6 and 100 % in each case, indicating a very high significance level (Table 3). The temperatures are 15.7 °C to 15.8 °C for MAT, with CMM around 5.6 °C and WMM from 23.8 °C to 25.2 °C. As regards MAT, the lower CA interval limit has been set by the genera *Parrotia persica* C.A. Mey, while for the upper limit *Cyclobalanopsis glaucoides* was the delimiting factor (MAT < 15.8 °C)

Table 2. Fossil and recent taxa used in the application of CA.

Fossil taxa	NLRs according to Palamarev & Kitanov (1988)	NLRs according to this paper	NLRs according to the Paleoflora Database (Utescher & Mosbrugger 1990–2011)
1. *Pinus laricioides*		*P. nigra* Ait.	*P. nigra*
2. *Juniperus* aff. *communis*		*J. communis*	*J. communis*
3. *Magnolia mirabilis*		*M. liliiflora* Desr., *M. kobus* DC	*Magnolia* sp.
4. *Laurus pliocenica*		*L. azorica* (Seub.) Franco	*L. azorica*
5. *Parrotia pristna* (Ettingsh.) Stur	*P. persica*	*P. persica*	*P. persica*
6. *Buxus pliocenica* Saporta & Marion	*B. sempervirens* L., *B. colchica* Pojark., *B. balearica* Lam.	*Buxus* sp.	*Buxus* sp.
7. *Ulmus* aff. *minor* Mill.	*U. minor*		*U. minor*
8. *Zelkova zelkovifolia* (Unger) Buzek & Kotl.	*Z. carpinifolia* Dippel		*Z. carpinifolia, Z. serrata* Makino
9. *Z. praelonga*	*Z. serrata*	*Zelkova* sp.	*Zelkova* sp.
10. *Fagus attenuata*	*F. longipetiolata* Seemen	*Fagus hayatae*	*F. hayatae*
11. *F. pliocenica* Saporta	*F. orientalis* Lipsky, *F. sylvatica* L.		*F. orientalis, F. sylvatica*
12. *Castanea sativa* Mill. foss.	*C. sativa*		*C. sativa*
13. *Cyclobalanopsis stojanovii* Palam. & Kitan. fil.	*C. glaucoides*		*C. glaucoides*
14. *Quercus glaucifolia* Andr.	*Q. glauca* Thunb.		*Q. glauca*
15. *Q. mediterranea* Unger	*Q. coccifera* L., *Q. ilex* L.		*Q. coccifera, Q. ilex*
16. *Q. kubinyi* (Kovats ex Ett.) Czeczott	*Q. libani* Oliv., *Q. acutissima* Carruth.		*Quercus* Sect. *Cerris*
17. *Q. cerris* DC foss.	*Q. cerris*		*Q. cerris*
18. *Q. trojana* Webb foss.	*Q. trojana*		*Q. trojana*
19. *Q. cardanii* A. Massal.	*Q. hartwissiana* Steven, *Q. macranthera* Fisch. & C.A. Mey, *Q. canariensis* Willd.		*Q. hartwissiana, Q. macranthera, Q. canariensis*
20. *Q.* aff. *acrodonta* Seemen		*Q. acrodonta*	*Q. acrodonta*
21. *Q. drymeja*		*Q. lancifolia* Liebm., *Q. xalapensis*	*Q. xalapensis*
22. *Q. sosnowskyi* Kolak.		*Q. semecarpifolia* Sm., *Q. alnifolia* Poech, *Q. suber* L.	*Quercus* Sect. *Cerris*
23. *Q. gigas*		*Quercus* Sect. *Cerris*	*Quercus* Sect. *Cerris*
24. *Alnus kefersteinii*	*A. cordata* Desf.	*Alnus* Sect. *Clethropsis*	*Alnus* Sect. *Clethropsis*
25. *A. subcordata* C.A. Mey foss.	*A. subcordata*		*A. subcordata*
26. *Carpinus betulus* L. foss.	*C. betulus*	*C. betulus*	*C. betulus*
28. *C. orientalis* Mill. foss.	*C. orientalis*		*C. orientalis*
29. *Myrica palaeogale*	*M. gale* L.		*M. gale*
30. *M. lignitum*		*M. californica* Cham., *Myrica* sp.	*Myrica* sp.
31. *Pterocarya paradisiaca*	*P. fraxinifolia* (Poir.) K. Koch	*P. fraxinifolia*	*P. fraxinifolia*
32. *Bumelia* aff. *lanuginosa* Pers.	*B. lanuginose*		*B. lanuginosa*
33. *Pteleaecarpum europaeum*	*Ptelea baldwinii* Torr. & A. Gray	*P. trifoliate* Bol.	*P. trifoliata*
34. *Acer tricuspidatum*	*A. rubrum* L.	*Acer* Sect. *Rubra*	*Acer* Sect. *Rubra*
35. *A. pseudomonspessulanum*	*A. monspessulanum* L., *A. ibericum* M. Bieb.		*A. monspessulanum*
36. *A. subcampestre*		*A. campestre* L.	*A. campestre, A. miyabei* Maxim.
37. *Ilex aquifolium* L. foss.	*I. aquifolium*		*I. aquifolium*
38. *Euonymus* aff. *japonicus*		*E. japonicus*	*E. japonicus*
39. *Nerium oleander* L. foss.		*N. oleander*	*N. oleander*
40. *Potamogeton praenatans*	*P. natans* Sturm		*P. natans*
41. *Typha* aff. *angustifolia* L.	*T. angustifolia*		*T. angustifolia*

Table 3. Palaeoclimate data obtained from CA.

Climate variable	CA interval	% of coexisting taxa	warm/wet outliers	cold/dry outliers
MAT	15.7–15.8 °C	95.2	*Quercus xalapensis*	*Myrica gale*
CMM	5.6–5.6 °C	95.2	*Quercus xalapensis*	*Parrotia persica*
WMM	23.8–25.2 °C	95.2	*Parrotia persica*	*Myrica gale*
MAP	867–1018 mm	95.2	*Cyclobalanopsis* glaucoides	*Parrotia persica*
MPdry	32–41 mm	97.6		*Parrotia persica*

Legend: **CA** – Coexistence Approach; **MAT** – mean annual temperature; **CMM** – cold month mean temperature; **WMM** – warm month mean temperature; **MAP** – mean annual precipitation; **MPdry** – mean precipitation of the driest month.

(Fig. 4). As shown in the bar charts for CMM and WMM, CA interval limits are constrained by various taxa (Figs 5-6). *Parrotia persica* forms an outlier in the calculations of CMM and MPDry. This species is native to North Iran, where it is endemic. In the calculations of MAT and WMM, *Myrica palaeogale* forms an outlier with *M. gale* L. being the NLR taxon. In Europe, the genus *Myrica* is now restricted to the summer-cooler, Atlantic climate types, while it was widely distributed in the Cenozoic (cf. Mai 1995). If climate data are used for the genus (Utescher & Mosbrugger 1990–2011), no inconsistencies would occur. In the calculations of MAT and CMM, *Quercus drymeja* forms an outlier with *Q. xalapensis* Humb. & Bonpl., being the NLR taxon. This species is a Mexican endemic.
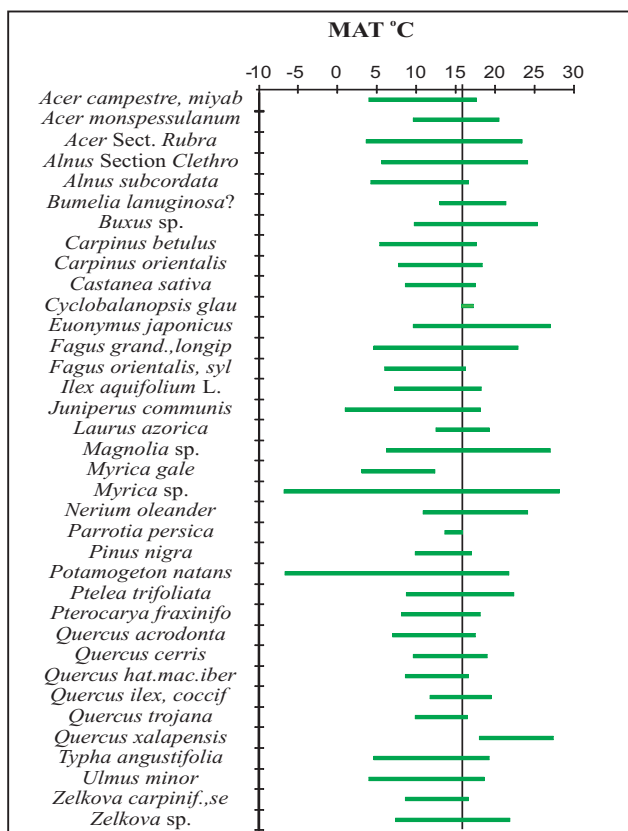

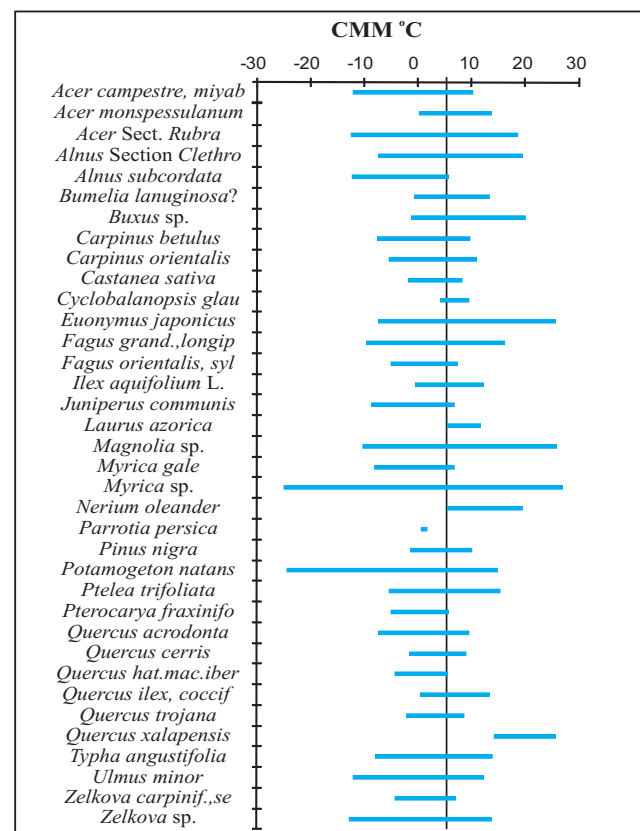**Fig. 4.** CA charts for Mean Annual Temperature.

Fig. 5. CA charts for Cold Month Mean Temperature.

For MAP, 867 mm to 1018 mm have been obtained, with *Bumelia* and *Laurus pliocenica* (*Laurus azorica* (Seub.) Franco as LNR) being the delimiting taxa (Fig. 7). Regarding the relict status of Recent European *Laurus,* reliability of the upper CA limit is somewhat questionable, and MAP rates could have been up to 1180 mm, a limit set by the occurrence of Mediterranean oaks in the flora. For MPdry, a precipitation range from 32 mm to 41 mm results, with the limits set by *Bumelia* (>32 mm) and *Fagus orientalis,* and *Laurus azorica* (<41 mm), respectively (Fig. 8). Recent climatic analogue regions for the reconstructed palaeoclimate conditions can be identified by using the reconstructed climate values together with modern climatology. By following the technique described in Utescher & al. (2009), we have identified a climate space using reconstructed temperature ranges together with MAP to query for the corresponding grid point in the New & al. (2002) global climate data set. We have obtained a single grid point in N Pakistan (72.12° N, 34.94° E, ca. 1800 m asl) representing the fossil conditions. According to the climate classification system of Köppen-Geiger (Kottek & al. 2006), a Cfa/Csa transitional type was obtained.
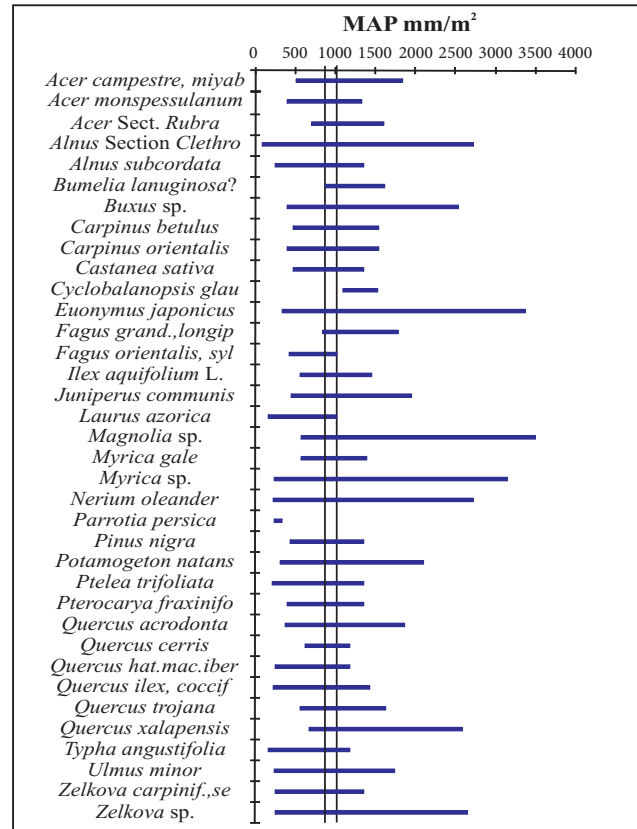

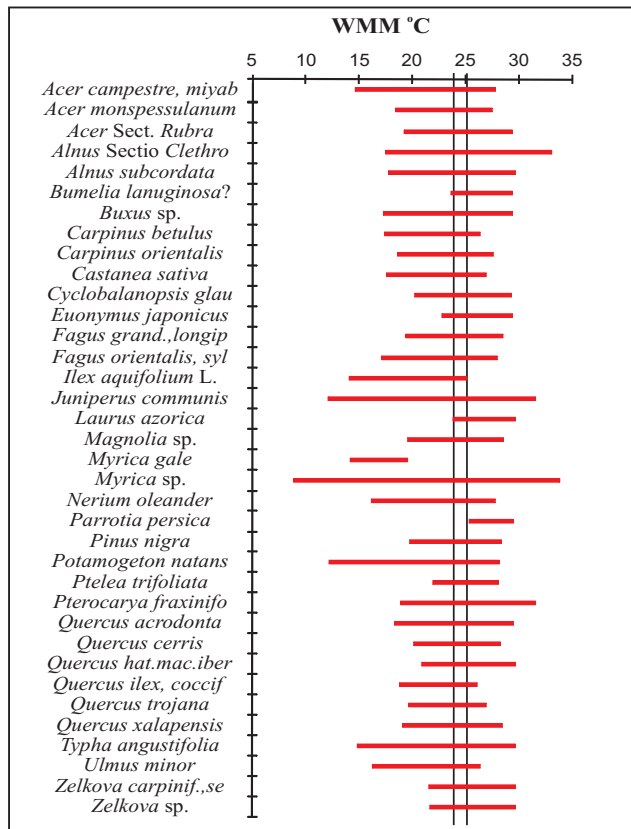**Fig. 7.** CA charts for Mean Annual Precipitation.

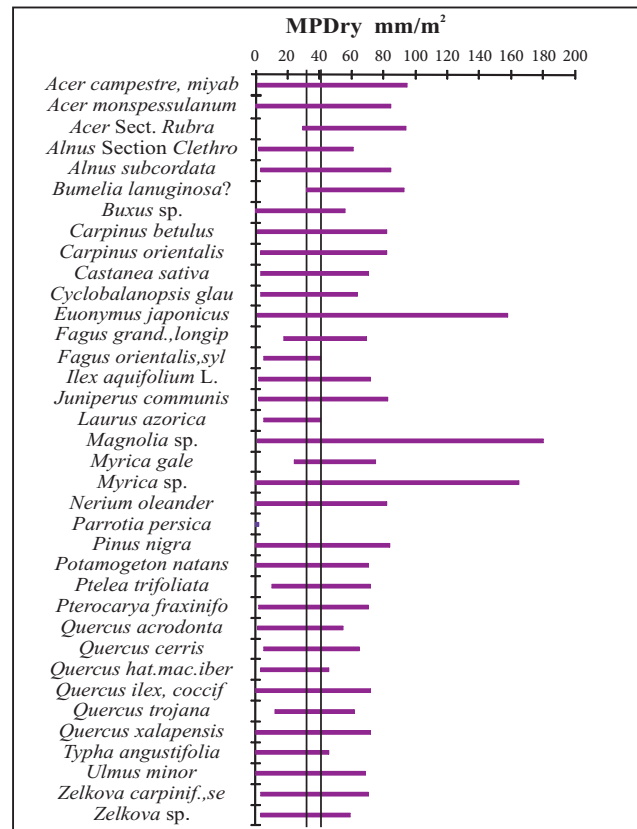**Fig. 6.** CA charts for Warm Month Mean Temperature.

Fig. 8. CA charts for Mean Precipitation of the Driest Month.

Discussion and conclusion

The new results confirm the dominance of the *Fagaceae* family in the palaeoflora, as already mentioned by Palamarev & Kitanov (1988), and especially the importance of *Quercus*. In addition to the already known seven species belonging to the genus, four new are reported. Among those, *Q. sosnowsky* deserves special attention, because its stratigraphic ranges can be extended by the new records, while *Q. aff. acrodonta* is described for the first time. Also, the stratigraphic distribution is extended for *Pinus laricioides* and *Magnolia mirabilis*. The first occurrence of *Juniperus* aff. *communis,* previously known from the Romanian age, can be placed now into the Upper Pontian – Lower Dacian.

The presence of *Quercus gigas* Goepp. in the Bulgarian Neogene flora is also of special interest. It belongs to the so-called alienoid (roburoid) oaks (sect. *Quercus*). Along with some other oaks (e.g., *Q. pseudocastanea* Goepp. belonging to cerroid oaks (sect. *Cerris*)), it marks a new evolutionary trend in the family. The emergence of a younger lineage is closely related to the evolutionary more advanced oak species, such as *Q. griffithii* Hook. & Thoms., *Q. aliena* Bl.*,* and *Q. aegilops* L. (Palamarev & Petkova 1987, Palamarev & Ivanov 2003).

Among the 13 taxa registered for the first time for the site, only three (Table 1) belong to the "Euroboreal Refugial Geographic Element" (in the sense of Kolakovsky 1964). This corroborates the assumption of Palamarev & Kitanov (1988) that the Beli Breg floristic complex reflects a development phase of the Bulgarian Neogene flora, clearly pre-dating the late Pliocene, when the floras had a more modern aspect (Kitanov 1956). Correlation exists too in the ra-

tio between the widely distributed ecological type among the so far known and newly described taxa. Palamarev & Kitanov (1988) recognized the mesophyte ecological type as the most important and widest distributed (67.6 % of the floristic composition). Approximately the same proportion of mesophytes in the structure of the palaeoflora was established in the present study, which confirms the importance of this ecological type for the structure of fossil vegetation. Hydrophytes and xerophytes are poorly presented in the fossil flora, both in this and in earlier studies. Thus our data confirm with high level of reliability the earlier published data and conclusions**.** Some hygromesophytes and mesoxerophytes have been also identified in the recent study, but in low percentage (Table 1).

The palaeoclimate evolution of the Pontain/Dacian sequence of the Beli Breg Basin was outlined by Ivanov & al. (2007). The climate record is based on 28 microfloras collected from a core, well analyzed with the same method of palaeoclimate reconstruction as the presently used. When comparing the presently obtained data with the already published microflora-based record, it appears that in most cases narrower coexistence intervals result from the macroflora, thus providing a better climatic resolution. A direct correlation of data is difficult, because the macro-remains originate from several layers and integrate over the timespan of Pontian-Early Dacian (Fig. 2). Temperatures obtained in both cases are largely consistent. As regards MAT, the data obtained for the macroflora show a slightly lower temperature, but intervals overlap at 15.7 °C to 16.6 °C, with the exception of the lowermost part of the brown coal seam, where definitely higher MAT of around 17.6 °C is

Table 4. Palaeoclimate data obtained from CA in the neighbouring area (for abbreviations cf. Table 3).

Cite	Age	MAT, °C	CMM, °C	WMM, °C	MAP, mm	Mpdry, mm	Reference
Vegora (Greece)	Late Miocene to Early Pliocene	13.3–14.6	0.4–4.5	23.8–24.6	897–1018	–	Kvaček & al. (2002) (macroflora)
Beli Breg (W Bulgaria)	Pontian to Early Dacian	15.7–15.8	5.6–5.6	23.8–25.2	867–1018	32–41	This study
Beli Breg (W Bulgaria)	Pontian to Early Dacian	15.7–16.6	5.0–7.0	24.7–26.4	1096–1520	25–41	Ivanov & al. (2007) (microflora)
Drenovets (NW Bulgaria)	Early Pontian	15.6–17.2	5.0–7.0	24.7–27.3	1187–1308	43–47	Ivanov & al. (2002) (microflora)
Crveni Breg, Grocka (Serbia)	Late Pannonian to Pontian	13.8–15.4	-0.1–4.1	25.7–26.4	879–1297	32–47	Utescher & al. (2007) (macroflora)
Osojna (Kladovo) (Serbia)	Late Pannonian to Pontian	13.8–16.6	1.8–5.8	26.5–26.7	897–1297	42–59	Utescher & al. (2007) (macroflora)

evident from the microfloras (Ivanov & al. 2007). The CMM range is completely within the intervals resulting from the microfloras (CMM: 5.0–7.0 °C). For WMM, the microflora record reveals some variability of the climate signal and possibly higher values at certain levels, when compared to the present data (24.7–26.4 °C). As obvious from the MAP record of the Beli Breg well showing rates of 1096–1520 mm throughout the entire succession, some doubt is justified concerning reliability of *Laurus azorica* in this context (cf. Table 3; Fig. 7, see also chapter "Palaeoclimate analysis"), but data do not diverge considerably. On the other hand, the results obtained from the macroflora stand against the conditions with very high MAP rates around 1500 mm. As regards MPdry, a high variability is revealed indicating short-term climate changes (25–41 mm; 8–24 mm). Our data are closer to the wetter phases described there, but a delimited time resolution of the macroflora does not allow for a more detailed view.

Climate data calculated for the Beli Breg macroflora are well within the range of values reconstructed for the Pontian succession in neighbouring areas, e.g., the Forecarpathian Basin (Ivanov & al. 2002) and the Danube Valley/Belgrade (Utescher & al. 2007; Ivanov & al. 2010). The climate record of the Forecarpathian Basin shows comparative values at a stage, while subsequently the record displays a trend to higher temperature and annual precipitation, when compared to our data. A comparison of climate data calculated by us to those from the Danube Valley in Serbia shows that, besides a comparable MAT, a significant difference exists in the values of WMM and CMM. Lower temperatures for the coldest month and higher during the warmest, characteristic for the Serbian flora, are probably the result of a more continental type of climate resulting from the climate change caused by changes within the boundaries of water basins located in close vicinity.

Closest to our climatic parameters are these obtained by Kvaček & al. (2002) for fossil floras from Northern Greece (Table 4, Fig. 9), but Vegora flora shows a somewhat cooler climate (cf. MAT, CMM). The strong similarity of climatic requirements of the analyzed fossil floras could also be due to their close geographical position and, possibly, synchronous stratigraphic age.
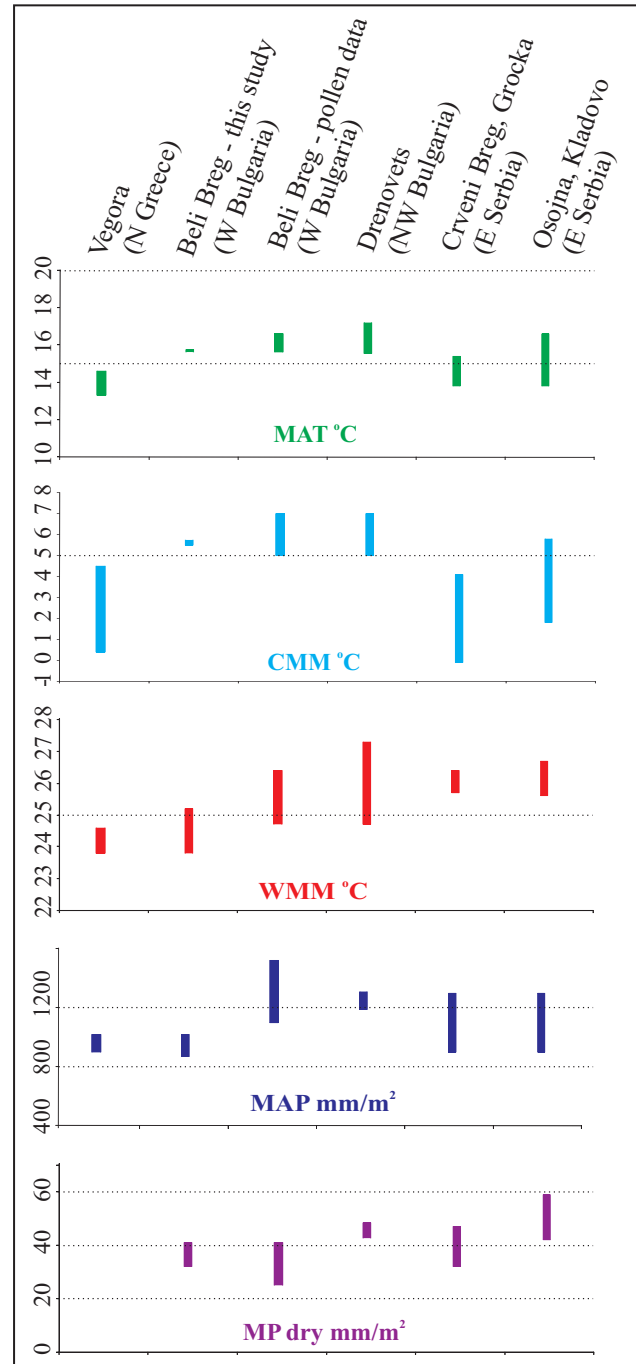

Fig. 9. Paleoclimate data obtained from CA in the neighbouring area (for abbreviations cf. Table 3).

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