New data on the Middle Miocene flora of the Satovcha Graben (SW Bulgaria)

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Abstract. Leaf imprints of four fossil taxa from the Middle Miocene flora of Satovcha (SW Bulgaria) have been studied. The taxa *Dalbergia* aff. *cochinchinensis, Lithocarpus* aff. *lucidus, Podocarpus* aff. *nubigenus*, and *Populus platyphylla* are new for the Bulgarian fossil flora.

Key words: Bulgaria, *Dalbergia* aff. *cochinchinensis*, *Lithocarpus* aff. *lucidus*, Middle Miocene, palaeoflora, *Podocarpus* aff. *nubigenus, Populus platiphylla*, Satovcha

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Introduction

The Middle Miocene Climatic Optimum (MMCO) (17–15 million years ago) was a period of global warmth and relatively high CO_2 levels and was thought to be associated with a significant retreat of the Antarctic Ice Sheet (Foster & al. 2012). MMCO influence was the reason for the exceptional taxonomic diversity in the palaeoflora on the territory of Bulgaria during the Middle Miocene (Palamarev 1964, 1989; Palamarev & Petkova 1987; Bozukov 2001). The rich palaeofloras of that epoch, with more than 100 taxa found in each of them, have been proof of such diversity: Chukurovo (Palamarev 1964, 1989), Ruzhintsi (Palamarev & Petkova 1987) and Satovcha (Bozukov 2001). The Ruzhintsi palaeoflora was part of the so-called Sarmatian flora, which united 32 local paleofloras in NW Bulgaria (Palamarev & Petkova 1987).

Due to the favorable climatic conditions, those paleofloras included both paleotropical and arctotertiary representatives. Local paleoflora from Satovcha was the richest of them all containing over 140 taxa. Researches on the Satovcha macropalaeoflora began in the middle of the last century (Stefanov & Gantschev 1951) and have continued ever since with

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varying intensity (Bozukov & Ivanova 2015; Bozukov & al. 2018, 2022, 2023; Hristova & Bozukov 2018; Bozukov & Todorov 2021).

The Satovcha Graben, located on the southern slopes of the Western Rhodopes (SW Bulgaria), unfolds eastwards of Satovcha village, Blagoevgrad District. Two official lithostratigraphic units are recognized in the Graben: Satovcha Formation and Sivik Formation (Vatsev & Pirumova 1983). The Sivik Formation covers the Oligocene volcanics and the sediments of the Satovcha Formation. Sedimentary rocks of the Sivik Formation lie discordantly on them and consist of sandstones, aleurolites, sandy clays, and diatomites with coal streaks (Vatsev & Pirumova 1983; Vatsev 1999). The Satovcha palaeoflora originates from the same Formation. According to the analyses of the fossil diatom flora, the site corresponds to a large, deep, eutrophic freshwater palaeolake (Vatsev & Pirumova 1983). The age of this palaeoflora has been determined as Middle Miocene, based on studies of fossil diatoms (Vatsev & Pirumova 1983), macroflora (Bozukov 2002) and palynomorphs (Ivanov 2004, 2012, 2013).

An interesting fact is that the fossil-bearing sediments contain also imprints of insects (Nel & al. 2016; Simov & al. 2021a, b;), pelobatid larvae (Vergilov & Tzankov 2021) and bird feathers (Boev & Bozukov 2021).

Material and methods

The studied material is stored in the palaeobotanical collection of the Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences. It consists of leaf imprints on sedimentary rocks from the Sivik Formation of the Satovcha Graben.

Description of the leaf types follows the scheme for leaf morphology of the angiosperm plants of Dilcher (1974) and Ellis & al. (2009). Arrangement of the corresponding taxa in the article follows the scheme of the Angiosperm Phylogeny Group (1998). The photos have been taken with a Panasonic DC-FZ82 digital camera.

Results

Division *Pinophyta*, Class *Pinopsida*

Family *Podocarpaceae*, Genus *Podocarpus* L'Her. ex Pers.

Podocarpus aff. *nubigenus* Lindl.

Material: two leaf imprints with counterimprints No 1-2015a, b (Plate I, Fig. 2), No 4-2022a, b (Plate I, Fig. 1).

Description: Shape symmetrical; base symmetrical; form very narrow elliptic. Apex of the lamina acute. Leaves sessile. Leaf margin entire. Midvein straight. It can be observed as a darker line along the leaf length. Dimensions: leaf lamina - length 2.8 cm, width 0.4-0.5 cm.

Comparison: The genus *Podocarpus* is recorded in the Bulgarian fossil flora only with the species *P. eocenica* (Palamarev 1963; Palamarev & Petkova 1991). The authors' material here differs from the species cited above by its very narrow elliptical shape, whereas in *P. eocenica* it is lorate. Moreover, the studied leaves are sessile, unlike *P. eocenica*. Unger (1850) had compared the described species with *P. chilensis* Rich., which is common today in Chile and Peru. The authors consider the nearest living relative (NLR) of the material described by them to be the *P. nubigenus* Lindl. species (Plate I, Fig. 3), because the leaves of *P. nibigenus* are sessile and have very narrow elliptic form. This species grows at elevations of 0-1000 m, often on saturated inundated soils or near streams in the Valdivian Temperate Rain Forest (Chile and Argentina) (https://www.conifers.org/po/Podocarpus_nubigenus.php).

Geographic and stratigraphic distribution: So far, this taxon has been found only in the Middle Miocene Satovcha palaeoflora.

Division *Magnoliophyta*, Class *Magnoliopsida*

Family *Fagaceae*, Genus *Lithocarpus* Blume

Lithocarpus aff. *lucidus* (Roxb.) Rehder

Material: 1 leaf imprint No 1-2023 (Plate I, Fig. 4).

Description: Leaf lamina shape symmetrical; base symmetrical; form elliptic. Apex of the lamina emarginate. Base of the acute cuneate type. Leaf margin

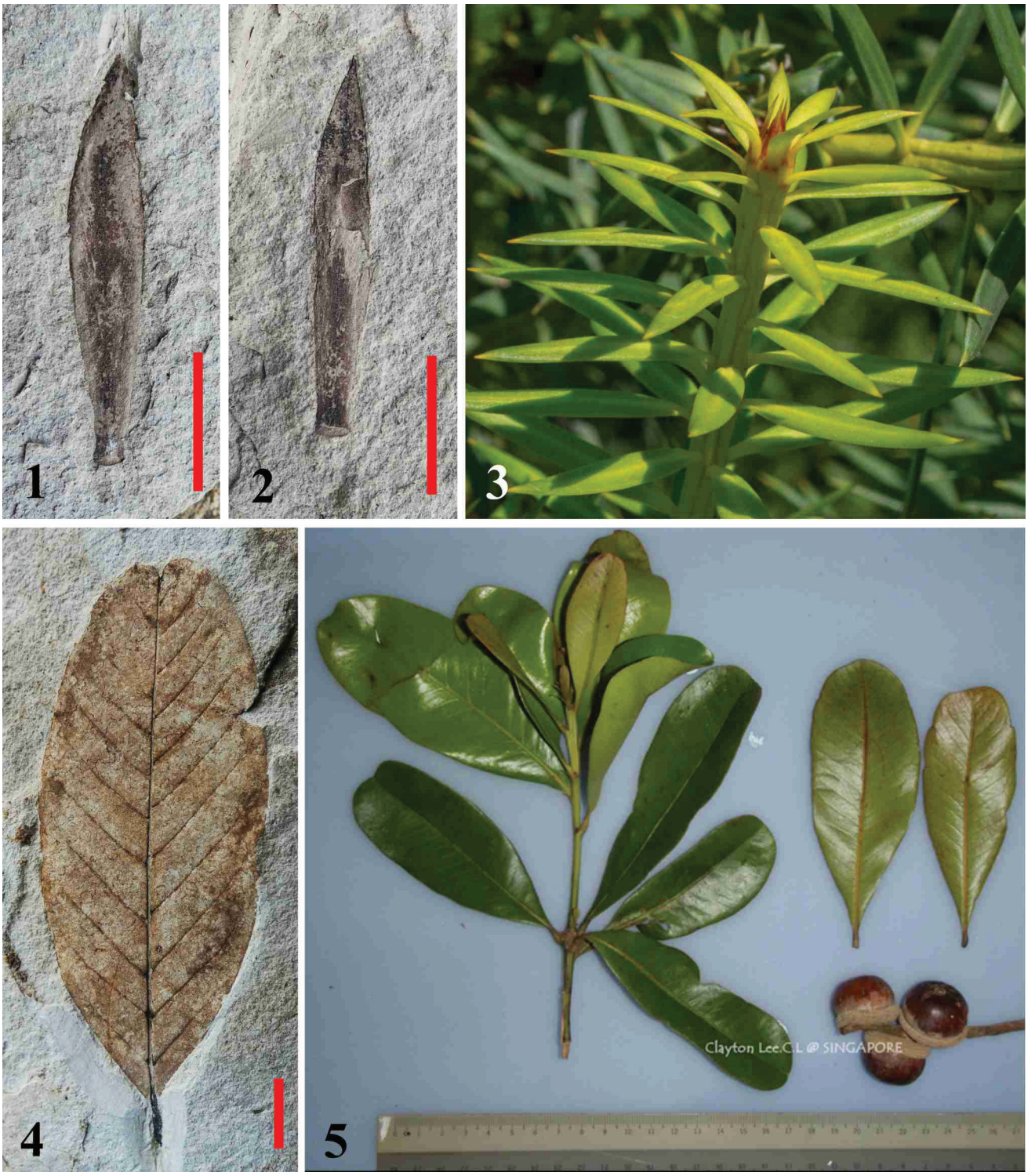

Plate I

Figs 1-5. Pictures of fossil taxa and their NLR (Measuring bar – 1 cm).

1. *Podocarpus* aff. *nubigenus* (No 1-2015b); 2. *P.* aff. *nubigenus* (No 4-2022a); 3. *P. nubigenus* (after https://www.conifers.org/po/po/nubigenus04.jpg); 4. *Lithocarpus* aff. *lucidus* (No 1-2023); 5. *L. lucidus* (after https://asianplant.net/Fagaceae/Lithocarpus_lucidus.htm).

entire. Petiole normal type. Venation of the pinnate type, camptodromous, brochidodromous. Midvein straight. Secondary veins 11 pairs; straight; interconnected by a loop close to the leaf margin; at an angle of 45 degrees to the midvein. No intersecondary veins. No tertiary veins have been preserved. Dimensions: leaf lamina - length 8.0 cm, width 3.5 cm; petiole - length 0.7 cm, width 0.1 cm.

Comparison: The morphological characters of the studied fossil material correspond to a large extent to those of the leaf blades of the modern species *Lithocarpus lucidus* (Roxb.) Rehder (Plate I, Fig. 5), distributed in Thailand, Peninsular Malaysia, Singapore, Sumatra, and Borneo in primary hill mixed dipterocarp forest to lower montane forest, at altitude up to 1400 m, on clay, sandy-clay and sandstone-derived soils (https://asianplant.net/Fagaceae/Lithocarpus_lucidus.htm). The absence of traces of tertiary veins on the fossil material suggested that the leaf lamina had a thick cuticle and the leaf had a leathery structure, as in *L. lucidus*. These facts prompted the authors to assume that species is NLR of the fossil material and use the taxonomic combination *Lithocarpus* aff. *lucidus* in determining the researched imprint.

Geographic and stratigraphic distribution: So far, that taxon has been found only in the Middle Miocene Satovcha palaeoflora.

Family *Salicaceae*, Genus *Populus* L.

Populus platiphylla (Goepp.) W. Schimp.

1852. *Populites platiphylla* Goeppert, p. 276, Pl. 35, Fig. 5.

1872. *Populus platiphylla* (Goepp.) W. Schimper, p. 692.

2005. Iljinskaja, p. 121, Pl. 61, Fig. 1-5; text-fig. 64.

Material: 1 leaf imprint No 2-2023 (Plate II, Fig. 1).

Description: Leaf lamina shape symmetrical; base symmetrical; form elliptic. Apex of lamina not preserved. Base obtuse. Leaf margin toothed, of the serrate type with an obtuse apical angle. Sinuses between serrations rounded. Teeth simple on complete margin. Petiole normal in type. Venation of the pinnate type, camptodromous, brochidodromous. Midvein slightly S-shaped, 2 mm thick at the base and tapering strongly towards the tip. Secondary veins 8 pairs; interconnected by multiple loops close to the leaf margin; arcuate; at an angle of 60-70 degrees to the midvein. Intersecondary vein of the simple type, only one at leaf base. Tertiary veins form a random reticulate type pattern. Dimensions: leaf lamina - length 10.0 cm, width 5.6 cm; petiole - length 2.0 cm, width 0.3 cm.

Comparison: Iljinskaja (2005) has found the greatest similarity between the fossil species and the recent *P. angulata* Ait., distributed in N America. In the authors' opinion, the morphological structure of the present material and the leaf impression indicated by Iljinskja (2005, p. 122, Text-fig. 64) (Plate II, Fig. 2) is more similar to the Central Asian species *P. laurifolia* Ledeb. (Plate II, Fig. 3), which is growing along the riverbanks in NW Mongolia, the Altai Moutains and NW China; at 500-1900 m a.s.l. (http://www.efloras.org/florataxon.aspx?flora_id=2&taxon_id=200005683).

The genus *Populus* is widely represented in the palaeoflora from Satovcha (Bozukov & Palamarev 1992; Bozukov 2001), but all its species identified so far have developed basal veins. In the newly discoveded imprint, basal veins are absent. Mention also deserves the fact that some species of the genus *Salix* have morphological features close to the fossil material, e.g. *S. carpea* L., *S. cordata* Michx., *S. syrticola* Fern. However, in them, the serration of the leaf margin has more numerous and smaller teeth, the shape of the leaf lamina is mostly obovate, seldom elliptical, and the petiole is shorter than in the present material.

Geographic and stratigraphic distribution: The geographic range covers Central Europe to W Siberia. The stratigraphic range is Lower Miocene to Pliocene (Iljinskaja 2005). That species is new for the Bulgarian palaeoflora.

Family *Fabaceae*, Genus *Dalbergia* L. f.

Dalbergia aff. *cochinchinensis* Pierre

1859. *Dodonaea pteleaefolia* Heer, p. 64, Pl. 121, Fig. 10 (without Figs 9, 11, 12).

1954. *Leguminose*, Hantke, p. 74, Pl. 12, Figs 16-19.

Material: 1 leaf imprint No 6-2023 (Plate II, Fig. 4).

Description: Leaf lamina shape symmetrical; base

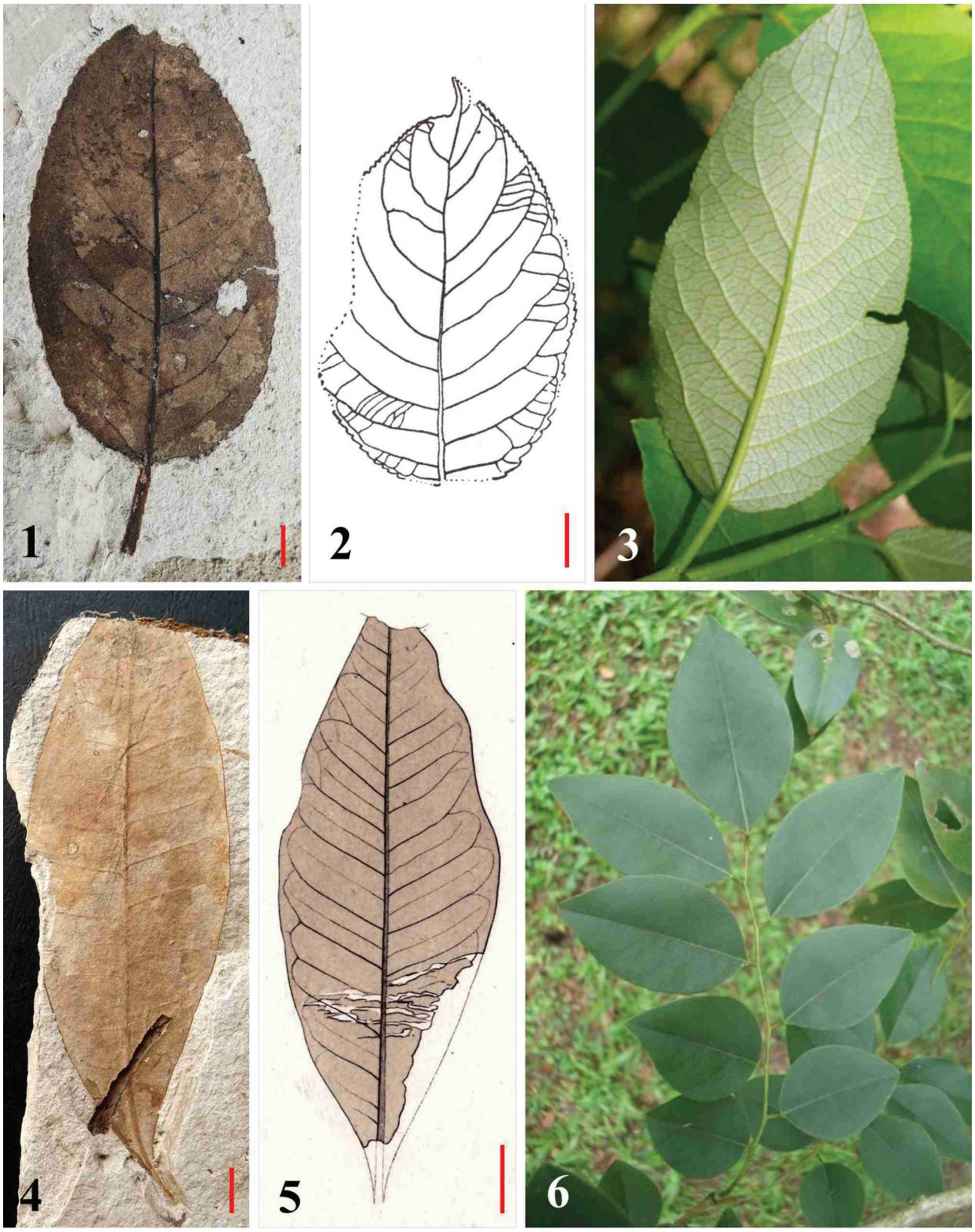

Plate II

Figs 1-6. Pictures of fossil taxa and their NLR (Measuring bar: 1 cm).

1. *Populus platiphylla* (No 2-2023); 2. *P. platiphylla* (after Iljinskaja 2005); 3. *P. laurifolia* (after https://www.cherrug.se/); 4. *Dalbergia* aff. *cochinchinensis* (No 6-2023); 5. *D.* aff. *cochinchinensis* (after Heer 1859); 6. *D. cochinchinensis* (after https://www.natureloveyou.sg/Dalbergia%20cochinchinensis/Main.html).

slightly asymmetrical; form elliptic. Apex of the lamina not preserved. Base of acute cuneate type. Leaf margin entire. Petiole of the normal type. Venation of the pinnate type, camptodromous, brochidodromous. Midvein straight, bent at the base only. Secondary veins preserved, 14 pairs, probably 15 in the entire lamina; straight; interconnected by a loop close to the leaf margin; at an angle of 70 degrees to the midvein at one side of the leaf lamina and 80 degrees at the other side. Intersecondary veins developed between most secondary veins. Tertiary veins form a random reticulate type pattern. Dimensions: preserved part of the leaf lamina - length 12.5 cm (probably 13.5 cm of the entire lamina), width 4.7 cm; petiole - length 0.9 cm, width 0.2 cm.

Comparison: Hantke (1954) revised the species *Dodonea pteleaefolia* Heer (1859) as the fossil referred on Pl. 121, Fig. 10 (Plate II, Fig. 5) and referred it to the family *Fabaceae* (*Leguminosae*). Mention deserves the fact that the leaf impression studied by the authors, as far as it is preserved, has had the morphological features of the material described by Heer (1859). The authors share the opinion of Hantke (1954) that that material should be revised as a taxon of the family *Fabaceae*. Based on the similarity of the morphological characters of the considered fossil imprint to those of the recent species *Dalbergia cochinchinensis* Pierre (Plate II, Fig. 6), the authors have used the taxonomic combination *Dalbergia* aff. *cochinchinensis* to define more accurately the studied fossil material. An insufficient number of imprints at the authors' disposal does not allow assigning the fossils to species, and therefore, the authors have used the taxonomic combinations that indicate similarity to certain recent species. In this case, this is the species *D. cochinchinensis,* distributed in SE Asia (Thailand, Laos, Cambodia and Vietnam) in mixed deciduous and dry evergreen forests; near the sea level and up to 200 m a.s.l.

Geographic and stratigraphic distribution: So far, the geographic range of this taxon has covered S Germany. The stratigraphic range is Middle Miocene (Heer 1859) to Upper Miocene (Hantke 1954). That taxon is new for the Bulgarian palaeoflora.

Discussion

The ongoing research of the Satovcha Middle Miocene flora is constantly increasing the number of fossil taxa found in Bulgaria. The new taxonomic data presented here are another proof of the floristic richness of the Satovcha palaeoflora. Although the identified species from that site exceed 140 in number, new taxa are still being discovered. They enrich both the Bulgarian and the European palaeoflora. In the present investigation, *Populus platiphylla* and *Dalbergia* aff. *cochinchinensis* are new for the territory of Bulgaria, and *Podocarpus* aff. *nubigenus* and *Lithocarpus* aff. *lucidus* have been found only in the so far studied palaeoflora.

The new data also support the idea that the palaeoflora from Satovcha has a polytopic character (Bozukov 2001). In the area of the palaeolake, where the plant material was concentrated and fossilized, species with different ecological requirements have been found. Species that formed the shrub layer of the vegetation around the palaeolake (e.g. *Gordonia stefanovii* Palam. & Bozukov) and those that formed the tree layer (e.g. *Quercus lyellii* Heer) have been very abundant (Bozukov 2001). NLRs of both mentioned fosil species, namely *Gordonia lasianthus* (L.) Ellis and *Quercus laurifolia* Michx., are distributed presently in the interval from 0 to 200 m a.s.l. The first of the two recent species inhabits wet soils, including swamp forests, especially pocosins, wet savannas, floodplain forests, depressions and ridges along rivers (http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=220005783). The second one grows in sandy flood plains and bottoms river banks and terraces, occasionally in poorly drained uplands (http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=233501055).

Obviously, both fossil species with these NLRs inhabited the shores of the paleolake under the same ecological conditions. Seldom, single fossils have been found of some taxa, whose NLR presently inhabit areas with an altitude from 500 to 2000 m (e.g. *Populus laurifolia*). Thus, it could be assumed that in the vicinity of the paleolake there were elevations from which plant material was transported by the rivers

and streams feeding the paleolake to the fossiliferous sediments. Certainly, the longer the transport, the less identifiable the plant material would end up in the palaeolake.

The new data supported once again the coexistence of palaeotropical and arctotertiary elements in the palaeoflora from Satovcha reported by Bozukov (2001). The favorable climatic conditions during the Middle Miocene made possible the successful development of both types of elements in the same area at the same time. For example, such were the newly identified species *Populus platiphylla* in the Satovcha palaeoflora, which was a representative of the arctotertiary element, and the *Podocarpus* aff. *nubigenus*, *Dalbergia* aff. *cochinchinensis* and *Lithocarpus* aff. *lucidus*, which were representatives of the palaeotropical element.

Mention deserves the fact that NLRs of the studied fossil material here come from distant biogeographical regions. For example, *Podocarpus nubigenus* is from the Andean region, *Populus laurifolia* from the Irano-Turranian region, and *Dalbergia cochinchinensis* and *Lithocarpus lucidus* from the Indochinese-Malaysian region. All these regions have their representatives in the paleoflora of Satovcha (Bozukov 2001) and the new data simply confirm what has been established so far.

Apart from its floristic wealth, palaeoflora of the Satovcha Graben is also distinguished by its uniqueness. The endemic elements in that palaeoflora account for 4.6% of its composition (Bozukov 2001). Taxa that have been established only in the Satovcha palaeoflora are present again in the new fossil material studied here. *Podocarpus* aff. *nubigenus* and *Lithocarpus* aff. *lucidus* have no similar fossil taxa described so far. Thus, the authors' new data on the great floristic diversity and high endemism of the Satovcha Middle Miocene flora confirm the opinion of Palamarev (2003) about the important role of the Rhodopes in the palaeofloristic processes that took place on the territory of Europe during the Cenozoic.

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