

MIOCENE PERMINERALIZED WOODS FROM BOZOVICI BASIN, ROMANIA

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Abstract. In recent years, extensive palaeobotanical studies have been conducted on the Miocene deposits of the Bozovici Basin, South Carpathians. Despite the long-standing exploitation of its Miocene coals since the early XX-th Century, palaeontological investigations remain scarce. Based on anatomical analyses of transverse, tangential, and radial sections of nine fossil wood specimens, the occurrence of *Glyptostroboxylon rudolphii* is reported, as well as the first occurrence of *Taxodioxylon germanicum* in the Lăpușnicul Mare Formation, a second record of this species from Romania. The stratigraphy of the basin and the age of the Lăpușnicul Mare Formation are discussed using previously published palynological and palaeontological data. Both conifer species lived in swamp forests developed under a low-gradient fluvial regime, and they indicate warm and humid environmental conditions, while representing the main and primary coal generators in the Bozovici Basin.

Key words: Miocene, fossil woods, *Taxodioxylon*, *Glyptostroboxylon*, Bozovici Basin

1. INTRODUCTION

The Bozovici Basin (Fig. 1) is a typical Alpine intramontaneous basin in the South Carpathians, having a NE–SW orientation and extending for approximately 40 km between the villages of Lăpușnicel and Șopotul Nou (Iliescu *et al.*, 1967). The basin reaches a maximum width of about 13 km between Bozovici and Eftimie Murgu, narrowing to less than 1 km towards its extremities (Iliescu *et al.*, 1967). Since 1868, the basin has been investigated mainly for its coals, which range from lignite to sub-bituminous coals (Bițoianu, 1976; Preda *et al.*, 1994). Lateral facies variations and the lack of marker fossils induced divergent stratigraphic correlations and age interpretations. Palaeontological studies relevant for the age of the basin include Grigorescu (1985), who identified a molar of *Brachyodus onoideus* Gervais from the basal part of the sedimentary succession of the basin. Petrescu and Nicorici (1989), investigated the spores and pollen of the basal coal-bearing formation and identified 11 coal seams in drill cores from the Lighidia Valley, near Bozovici, considering the Late Eggenburgian to Ottnangian

age. Plant macrofossils have largely been ignored over time or merely cited and without systematic descriptions. Preda *et al.* (1994) cited *Glyptostrobus europaeus* (Brongniart) Unger, *Sequoia abietina* (Brongniart) Knobloch, *Carya bilinica* (Unger) Ettingshausen, *Castanea atavia* Unger, *Ficus cf. lanceolata* Heer, *Salix macrophylla* Heer, *Myrica lignitum* (Unger) Saporta, *Quercus apocynophyllum* Ettingshausen, *Acer tricuspidatum* Bronn, *Phragmites oeningensis* Al. Braun, *Rhamnus* sp., as well as fossil woods from coal-bearing sequences. Preda *et al.* (1994) reported that some fossil woods were both silicified and calcified. The first detailed palaeobotanical studies of the basin began only recently, with the description and illustration of *Pronephrium stiriicum* (Unger) Knobloch et Kvaček from the Lăpușnicul Mare Formation (Pirnea and Popa, 2018), as well as the identification of *Cercidiphyllum crenatum* (Unger) Brown from the same stratigraphic level (Călin *et al.*, 2019). Subsequently, Iamandei *et al.* (2020) studied five fossil wood samples from the basin, identifying *Glyptostroboxylon rudolphii* Dolezych et Van der Burgh and *Spiroplatanoxylon densiradiatum* (Petrescu) Süss.

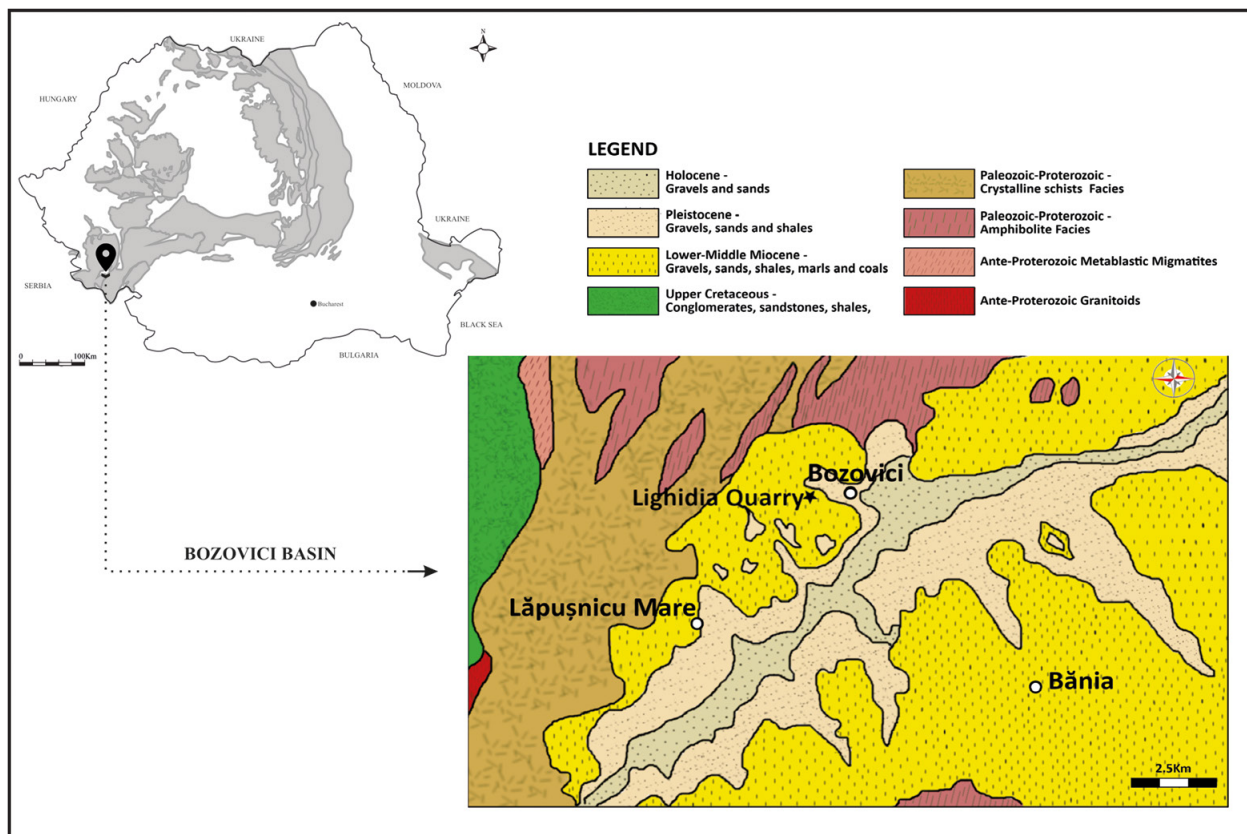


Fig. 1. Occurrence of the Bozovici Basin (after Codarcea and Răileanu, 1968; scale 1:200,000) on a simplified, geological map of Romania.

To complement previous palaeobotanical studies of the Bozovici Basin, a new systematic and taxonomic study of fossil woods is now introduced. This analysis is paired with ongoing research into foliage remains, mineralogy, and taphonomy to provide a deeper understanding of the fossil assemblage.

2. GEOLOGICAL SETTINGS

The Bozovici Basin is associated with late Alpine tectonic events in the South Carpathians (Fig. 2), with a metamorphic basement incorporating both Getic and Danubian units (Iliescu *et al.*, 1967; Balintoni, 1997; Iancu *et al.*, 2005), and a succession of Neogene sediments (Gheorghiu, 1954; Iliescu *et al.*, 1967).

Early stratigraphic interpretations of the Bozovici Basin were proposed by Schretter (1939), Pop (1959) and later by Iliescu *et al.* (1967), based mainly on lithological criteria (Fig. 2). These authors assigned a Middle Miocene age to the succession, based on lithological similarities with neighbouring basins, particularly with respect to coal-bearing deposits and volcanic tuffs, where fossil assemblages were better preserved.

Iliescu *et al.* (1967) provided a detailed subdivision, separating four formations (Fig. 2): (a) the basal formation, about 400 m thick, divided into two members, the sand-

clay member with interlayers of gravels and polygenic conglomerates to the bottom, and an upper marl-clay member with interlayers of coal, volcanic tuffs, limestone, sands and gravels; (b) gravels, conglomerates and sands formation with interlayers of clays and marls, about 100 m thick; (c) variegated clays and marls formation with interbedded sands, sandstones, gravels and volcanic tuffs, between 40 and 150 m thick; and (d) an upper formation with gravels and sands, only locally found and representing the final sedimentary phase of the Bozovici Basin, about 30 m thick.

Marinescu *et al.* (1998) subsequently formalized the units previously referred to as "horizons", assigning them formal formation names, designating the basal formation as the Lăpuşnicul Mare Formation, the gravels and conglomerates formation as the Dalboşeţ Formation, the variegated clays and marls formation as the Şopot Formation, and the upper gravels and sands formation as the Vindinului Formation.

Codrea (2001) further refined the basal succession by subdividing the Lăpuşnicul Mare Formation into two members, the Pârâul Lighidia Member and the overlying Valea Slătînicului Member, and suggested a Badenian age for the latter, based on micromammal remains.

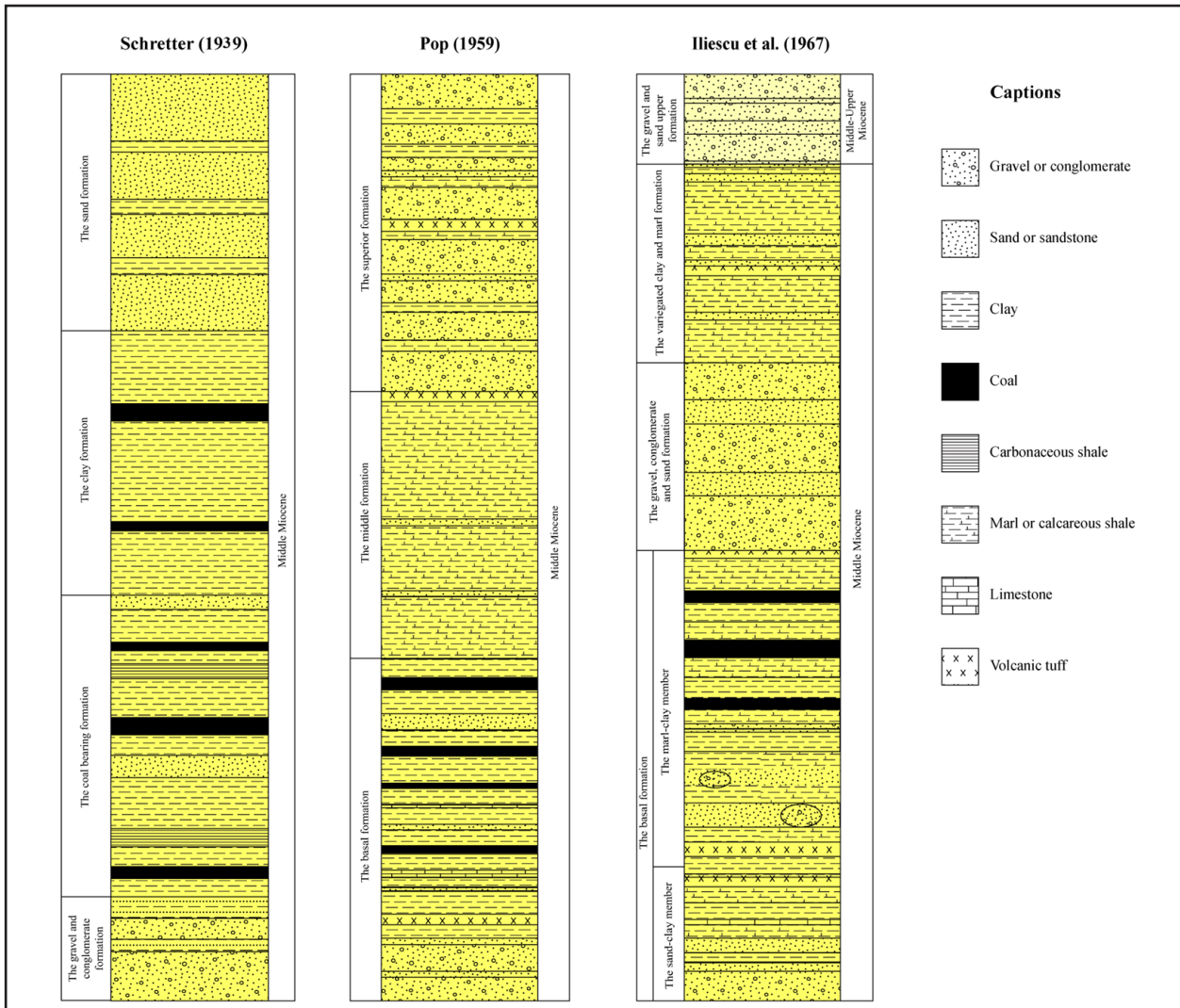


Fig. 2. Synthetic lithological columns of the Miocene formations of the Bozovici Basin modified after Schretter (1939), Pop (1959), and Iliescu *et al.* (1967).

Within this stratigraphic succession, the Lighidia quarry (Fig. 3), an open-cast mine near the town of Bozovici, provides a well-exposed section of the Lăpuşnicul Mare Formation (Fig. 2)

and represents the main fossil-bearing outcrop investigated in this study. These deposits show a siliciclastic succession of fine-grained sequences with coals and coarse sediments interlayers.



Fig. 3. Fossil woods from the Lighidia quarry, Lăpuşnicul Mare Formation, Bozovici Basin. (a) A permineralized trunk, approximately 1.5 m in length, in horizontal position, roof shale of a local lignite seam; (b) A large, white silicified trunk (under study) within a coaly shale layer.

The fine-grained sediments include marls, clays, silts and fine sands, with various sedimentary structures: massive to planar, parallel lamination or cross bedding, sometimes with ripple marks and fining upwards features. Lignite seams have a variable thickness between 50 and 200 cm, and they occur in the fine-grained deposits. Medium- to coarse-grained levels occur, displaying horizontal stratification, normal grading or slight imbrication. The coarse layers often show erosional boundaries, poor sorting, and the presence of plant fragments and freshwater fauna. The colour varies from one layer to another: gray, black, yellowish, brown or even reddish colours were recorded. The fine sediments contain numerous fragments of fossil flora and fauna. The invertebrate group includes freshwater gastropods and bivalves, in various stages of fragmentation. They occur either scattered within the sediment or concentrated in the upper parts of the layers.

Fossil plant remains are well preserved and include tree trunks preserved in situ, stumps (Fig. 3), leaf impressions and compressions.

3. MATERIAL AND METHODS

The studied samples were collected from the Lighidia quarry, an open cast mine (44.918950° N, 21.978207° E) located near Bozovici town, from the Lower Miocene Lăpuşnicul Mare Formation. The fossil plants are preserved as permineralized woods. The fossil woods are curated as Pb27664, Pb27665, Pb27666, Pb27667, Pb27668, Pb27669, Pb27670, Pb27671, Pb27672 at the National Geological Museum of the Geological Institute of Romania, in Bucharest, Romania. The fossil woods were studied in thin sections cut along three different planes: transversal, tangential, and radial sections. The wood-anatomy terminology corresponds to IAWA (2004), but also to other specific publications such as Van der Burgh (1973), Dolezych and Van der Burgh (2004), and Philippe and Bamford (2008). A Carl Zeiss Axio Imager M1 microscope was used, while the macro- and microphotographs were taken using a Canon EOS 60D digital camera with a Canon EF-S 18-55 mm macro lens.

4. SYSTEMATIC PALAEOBOTANY

Cupressaceae Gray, 1822

Genus *Taxodioxyton* Hartig, 1848 emend. Gothan, 1905

Taxodioxyton germanicum (Greguss) Van der Burgh, 1973

Plate 1, Figs. a-f

Synonymy

1973 *Taxodioxyton germanicum* (Greguss) Van der Burgh, p. 226, pl. 20, figs. 1-7;

2009 *Taxodioxyton germanicum* (Greguss) Van der Burgh: Dolezych in Erdei et al., p. 73, pl. 2, fig. 18, pl. 3, figs. 1-6.

2026 *Taxodioxyton germanicum* (Greguss) Van der Burgh: Călin, Popa et Pirnea, p. 4, fig. 3a-f.

Material: Pb27664, Pb27665, Pb27666, Pb27667, Pb27668.

Description: The wood is coniferous, with distinct annual rings. The transition from the earlywood to the latewood is predominantly abrupt. No resin canals were observed. The width of the growth rings is variable, as is the diameter of the tracheids or the number of tracheids in the early and latewood. The tracheids have a radial diameter between 40–70 µm and the tangential diameter between 20–40 µm, in the earlywood, and 5–15 µm with 10–20 µm in the latewood. Between two rays occur 4–12 tracheids. The lumen of the tracheids has various shapes, from polygonal to rounded, flattened radially in the latewood. The double wall thickness of the tracheids in earlywood is between 4–6 µm, and 8–12 µm in latewood. The bordered pits on the radial walls of the tracheids are uni- to triseriate, often biseriate (Plate 1e) and separated by the Bars of Sanio. The diameter of the bordered pits is between 14–18 µm, 15 µm in average. The bordered pits are aligned oppositely, they have a circular shape and sometimes they are flattened when touched. The bordered pits aperture is often circular (Plate 1e), with 6 µm in average diameter. Helical thickenings are absent. The axial parenchyma is diffuse but may locally be concentrated in tangential zones. It contains abundant fossil resin remains, and the cells are often rectangular in shape. Transverse walls are relatively thick, ranging between 3 and 5 µm, and are sometimes pitted (Plate 1c,d). Rays are homocellular, uniseriate (Plate 1c), sometimes with biseriate parts and even biseriate. The height of the rays in cells varies from 3 to 24 cells, with 12 cells on average. The height in microns varies from 70–430 µm, 200 µm in average. The width of the median ray cells varies from 17–20 µm, the marginal ones being larger, between 20–25 µm. The end walls are smooth and thin while the horizontal walls are thicker. Ray tracheids were not observed. In the cross-fields there are usually three taxodioid pits in a single horizontal row (Plate 1e,f), rarely glyptostroboid, but in the marginal cells there can be up to 6 or 7 pits in two horizontal rows. The cross-fields pits have a diameter between 8–12 µm.

Remarks: Based on Kräusel's identification (Kräusel, 1949), the dominance of taxodioid pits in the cross-fields and the presence of axial parenchyma are typical of the genus *Taxodioxyton*. *Taxodioxyton taxodii* Gothan differs from *Taxodioxyton germanicum* (Greguss) Van der Burgh by the presence of nodular or beaded horizontal walls of the axial parenchyma (Dolezych, 2011). *Taxodioxyton cryptomerioides* Schoenfeld differs from *T. germanicum* in having shorter rays and ray cells, as well as fewer and smaller cross-field pits (Dolezych and Schneider, 2006). *T. germanicum* differs from *Taxodioxyton gypsaceum* (Goeppert) Krausel by its thicker ray cell walls and smaller cross-field and bordered pits. Although these differences are minor, Van der Burgh (1973) noted that the thin walls of *T. gypsaceum* ray cells represent an important distinguishing character among *Taxodioxyton* species. *Taxodioxyton lesbium* (Unger) Mantzouka and Sakala differs

in having predominantly uni- to biseriate bordered pits and longer rays (Mantzouka *et al.*, 2017). In Europe, *Taxodioxyylon germanicum* has been reported from the Tertiary of Hungary, Slovakia, and Germany (Erdei *et al.*, 2009; Brezinová and Kourimský, 1974; Greguss, 1967; Dolezych, 2005).

Genus *Glyptostroboxylon* Conwentz, 1884 emend.

Dolezych et Van der Burgh, 2004

***Glyptostroboxylon rudolphii* Dolezych et Van der Burgh, 2004**

Plate 2, Figs. a-f

Synonymy

2004 *Glyptostroboxylon rudolphii* Dolezych et Van der Burgh, p. 410-411, figs. 6, 7; pl. 2, figs. 1-9; pl. 3, figs. 1-5;

2020 *Glyptostroboxylon rudolphii* Dolezych et Van der Burgh: lamandei *et al.*, p. 5-9, figs. 4, 5;

2026 *Glyptostroboxylon rudolphii* Dolezych et Van der Burgh: Călin, Popa et Pirnea, p. 8, fig. 6a-f.

Material: Pb27669, Pb27670, Pb27671, Pb27672.

Description: The wood is coniferous, with distinct annual rings. The transition from the earlywood to the latewood is predominantly abrupt. The width of the growth rings is variable, as is the diameter of the tracheids or the number of tracheids in the early and latewood. False annual rings occur, and no resin canals were observed. The shape of the tracheids is generally polygonal, in the latewood many tracheids are flattened radially. The tracheids have a radial diameter between 30–50 µm and the tangential diameter between 20–40 µm, in the earlywood, and 5–20 µm with 12–20 µm in the latewood. Between the two rays there are 3–9 tracheids. The double wall thickness of the tracheids in earlywood is between 3–6 µm and 6–12 µm in latewood. The bordered pits on the radial walls of the tracheids are arranged from uni- to triseriate, but the biseriate tracheids predominate (Plate 2e). The Bars of Sanio occur often. The diameter of the bordered pits is between 12–17 µm, 14 µm in average. The bordered pits are opposite, circular and sometimes flattened, with an aperture ranging from circular to elliptical. The bordered pits occur in the tangential walls of tracheids, they are small with a diameter between 6–8 µm usually scattered but in the latewood, they often form continuous rows on the tracheids walls. Helical thickenings are absent. The axial parenchyma is abundant, with a diffuse arrangement through the growth rings. The axial parenchyma contains resinous remains and is made up of rectangular cells with generally unevenly thickened transverse walls 2-5 µm, but beaded or thin walls are found as well (Plate 2c,d). Rays are homocellular, uniseriate (Plate 2c,d), exceedingly rare with biseriate parts. The ray's height in cells varies between 2–14, with an average of 8 cells. The height in microns varies between 45–350 µm, with an average of 120 µm. The ray cells have a width of about 20 µm. The rays have both horizontal and end walls smooth and thin. Intercellular spaces occur within the ray cells. Ray tracheids are absent. In the cross-fields occur between 2 - 4 glyptostroboid (taxodioid with very narrow borders) and

subordinate taxodioid pits (Plate 2e,f). The diameter of the pits is generally 8-10 µm.

Remarks: According to Dolezych and Van der Burgh (2004), *Glyptostroboxylon rudolphii* is characterized by distinct growth rings; 2 to 3 (occasionally 4) vertical rows of bordered pits on the radial walls of the tracheids; the presence of Bars of Sanio; smooth horizontal walls of the axial parenchyma that are sometimes pitted; homogeneous and relatively short rays with intercellular spaces between cells; and cross-fields dominated by glyptostroboid pits, with taxodioid pits being subordinate. This combination of characters matches the Bozovici material. *G. rudolphii* is similar to species of the genus *Taxodioxyylon*; however, the dominance of glyptostroboid pits and the presence of intercellular spaces among the ray cells differentiate *G. rudolphii* from *Taxodioxyylon* species. *Glyptostroboxylon* includes two species, *G. rudolphii* and *Glyptostroboxylon tenerum* (Kraus) Conwentz (Dolezych and Van der Burgh, 2004). The main difference between the two species lies in the number of vertical rows of bordered pits on the radial walls of the tracheids: *G. tenerum* typically shows mostly uniseriate pits and lacks Bars of Sanio, whereas *G. rudolphii* exhibits biseriate pits with bordered pits separated by Bars of Sanio (Dolezych and Van der Burgh, 2004).

Glyptostroboxylon rudolphii is a common species in Tertiary formations across Europe and has been described by numerous authors, including Teodoridis and Sakala (2008), Vassio *et al.* (2008), Erdei *et al.* (2009), Gryc and Sakala (2010), Dolezych (2011), Havelcová *et al.* (2013), Koutecký and Sakala (2015), Akkemik *et al.* (2017), Akkemik and Acarca Bayam (2019) and lamandei *et al.* (2020).

5. DISCUSSION

The age of the Bozovici Basin, especially the Lăpuşnicul Mare Formation yielding the coal-bearing deposits, has long been debated. Due to this aspect, earlier researchers assigned a Middle Miocene age based on lithological similarities with the neighbouring Caransebeş–Mehadia Basin. This interpretation was later supported by Codrea (2001), who suggested a Badenian age for the Valea Slătineului Member based on micromammal remains. However, the age of the palynological assemblages identified by Petrescu and Nicorici (1989) in the Lăpuşnicul Mare Formation range as Late Eggenburgian – Ottnangian. Grigorescu (1985) also suggested the Eggenburgian age for the lower part of the formation. Some earlier researchers (Schretter, 1939; Pop, 1959; Iliescu *et al.*, 1967; Preda *et al.*, 1994) reported freshwater gastropods fossils from the coal-bearing strata of the Lăpuşnicul Mare Formation, originally described as *Helix robusta* and *Archeozonites semiplanus*. According to subsequent taxonomic revisions, these forms are generally referred to as *Papillotopsis robusta* Reuss and *Miozonites algiroides* Reuss, respectively. After Binder (2008) and Harzhauser *et al.* (2014), *P. robusta* mainly occurs in the Early Miocene, while *M. algiroides* is considered a typical species

for this interval (Reuss in Reuss and Meyer, 1849; Sandberger, 1875; Nordsieck, 2014; Harzhauser *et al.*, 2014).

The fine-grained siliciclastic deposits with interbedded coal seams, together with the limited development of coarse-grained sediments, indicate a low-gradient fluvial depositional system typical of floodplain overbank environments, where silts and muds dominate (Einsele, 1982; Miall, 2006). The frequent fine lamination reflects low-energy sedimentation, locally disturbed by biogenic activity such as invertebrate bioturbation and root penetration, as well as by pedogenetic processes (Retallack, 2001). Coarser-grained beds are interpreted as the result of avulsion and crevasse-related processes, with the coarsest sediments representing crevasse channels and the medium- to fine-grained sands corresponding to crevasse splay deposits (Miall, 2006). For a detailed sedimentological study of the Lăpuşnicul Mare Formation exposed in the Lighidia quarry, see Barbu and Brănoiu (2018).

The woods identified so far in the Bozovici Basin indicate an azonal swamp and riparian vegetation. This assemblage is dominated by *Taxodioxyton germanicum* and *Glyptostroboxylon rudolphii* which are among primary coal generators in the Bozovici Basin. The occurrence of *Spiroplatanoxylon densiradiatum* Süss, previously reported from the Bozovici Basin by Iamandei *et al.* (2020), complements this currently limited assemblage. Iamandei *et al.* (2020) also identified four fossil wood samples from the Bozovici Basin as *Glyptostroboxylon rudolphii*. Compared with our material, their specimens display some minor anatomical differences that reflect the intraspecific variability of this species. In Romania, *Taxodioxyton germanicum* has only recently been reported from the Petroşani Basin (Călin *et al.*, 2026). One of the reasons for the rare occurrence of *Taxodioxyton germanicum* in Romania is linked to its high similarity to *T. gypsaceum*, a species reported more frequently, although it was mainly described as *Sequoioxylon gypsaceum* (Iamandei *et al.*, 2008; Iamandei and Iamandei, 2017). According to Erdei *et al.* (2009), *Taxodioxyton germanicum* is similar to the genus *Sequoia* Endlicher, although the latter exhibits much higher cross-field pits. However, it cannot be excluded that *Taxodioxyton germanicum* may represent an extinct species of *Sequoia* (Dolezych, 2011). *Glyptostroboxylon rudolphii* is commonly reported from Tertiary deposits of Romania (Iamandei *et al.*, 2023). Iamandei *et al.* (2003) described an Early Sarmatian specimen of *Glyptostroboxylon tenerum* from northeastern Romania, which they later reassigned to *G. rudolphii* (Iamandei *et al.*, 2020). Nagy *et al.* (2002) also identified a Late Badenian *Glyptostroboxylon tenerum* from Prăvăleni, south of the Apuseni Mountains; this material was subsequently reassigned to *G. rudolphii* by Iamandei *et al.* (2020). The presence of false growth rings in *Glyptostroboxylon rudolphii* may be related to periodic flooding within the fluvial environment. The extant counterpart of *Glyptostroboxylon rudolphii* is *Glyptostrobos pensilis* (Staunton ex D. Don) K. Koch, which grows in warm and humid forests in China

and Vietnam (Farjon, 2010). The occurrence of *Pronephrium stiriacum* (Unger) Knobloch et Kvaček in the Bozovici Basin (Pirnea and Popa, 2018) also supports the warm and humid environmental conditions previously reported.

Palynological data from Petrescu and Nicorici (1989) revealed two distinct microfloristic assemblages within the Lăpuşnicul Mare Formation, based on samples from depths between 90 and 44 m. The lower assemblage (90–50 m) is characterized by a dominance of pteridophytes (25%) and gymnosperms (41%), with angiosperms representing 34%. For the lower assemblage, a warm temperate climate has been suggested, with mean annual temperatures of 16–17 °C and annual precipitation ranging from 1200 to 1800 mm. In the upper assemblage (50–44 m), angiosperms increase to 43%, while pteridophytes and gymnosperms decrease to 19% and 38%, respectively. Petrescu and Nicorici (1989) suggested that the increase of temperate climate elements in this interval may also reflect palaeorelief differentiation around the basin. In both assemblages, Petrescu and Nicorici (1989) identified pollen of taxodiaceous and sequoiaceous affinity, such as *Inaperturopollenites hiatus* (in both assemblages), *Inaperturopollenites verrupapillatus* (upper assemblage), and *Sequoiapollenites polyformosus* (lower assemblage).

Further ongoing studies on fossil plants from the Bozovici Basin will contribute with important data and help confirming the role of these warm temperate climate species within the vegetation of the basin and their significance in the context of the Central Paratethys.

6. CONCLUSIONS

The Lăpuşnicul Mare Formation of the Bozovici Basin is rich in permineralized woods that have been poorly studied over time. This study documents the occurrence of *Glyptostroboxylon* in the basin and introduces *Taxodioxyton germanicum* into the assemblage, representing the second record of this species in the Tertiary of Romania. These conifers thrived in warm and humid swamp forests developed under a fluvial regime, while their distribution was influenced by both climatic conditions and water bodies, contributing to coal deposition and accumulation. *Taxodioxyton* and *Glyptostroboxylon* were among the primary coal generators of the Bozovici Basin.

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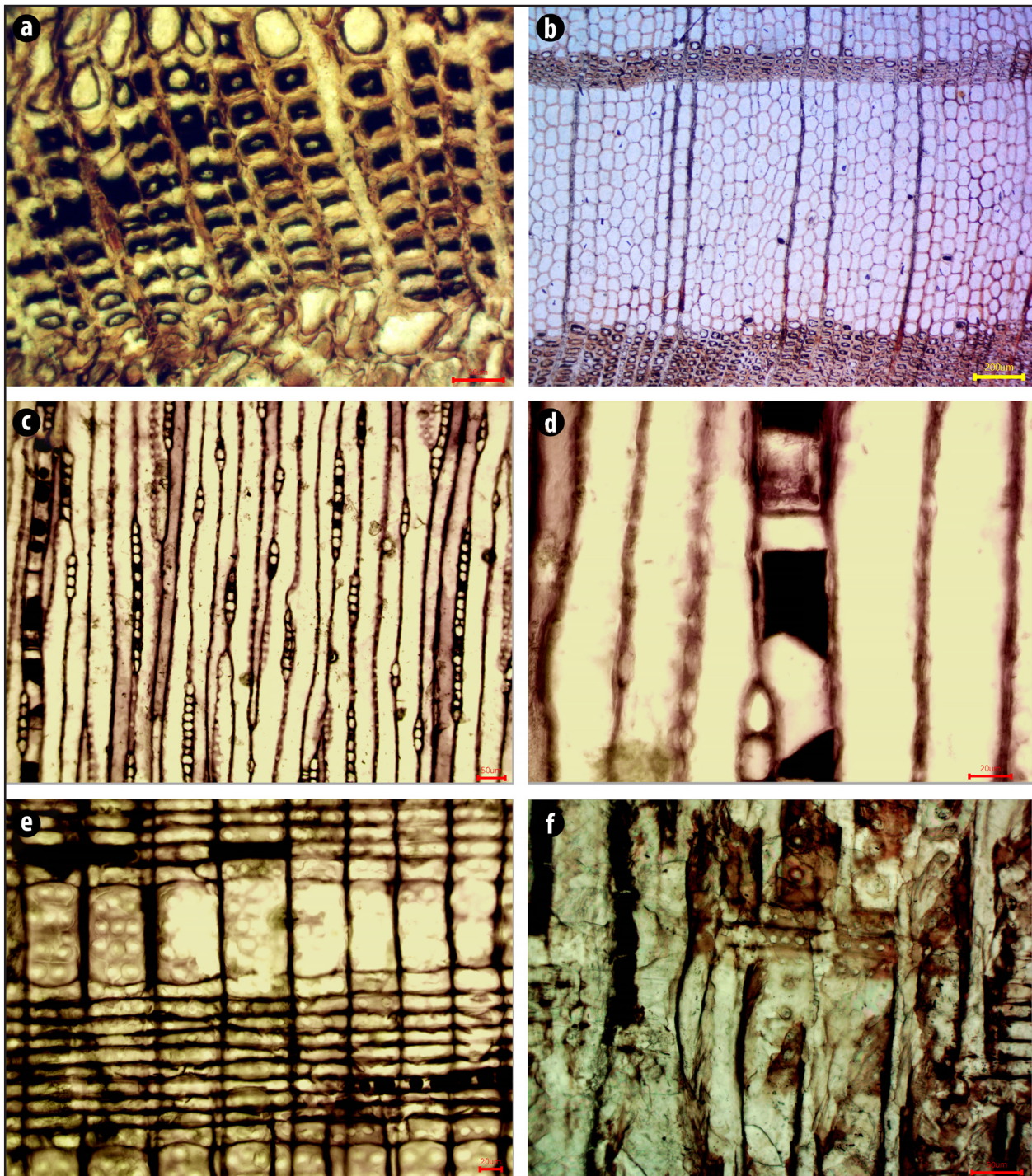


Plate 1. *Taxodioxydon germanicum* from the Lighidia quarry, Lăpuşnicul Mare Formation: transverse section with (a) distinct growth rings, and (b) an abrupt transition from earlywood to latewood; tangential section with (c) rays and axial parenchyma, and (d) axial parenchyma with a beaded and thin horizontal wall; radial section with (e, f) bordered pits and cross-fields with mainly taxodioid pits. Scale bar: a, c, f – 50 μ m; b – 200 μ m; d, e – 20 μ m.

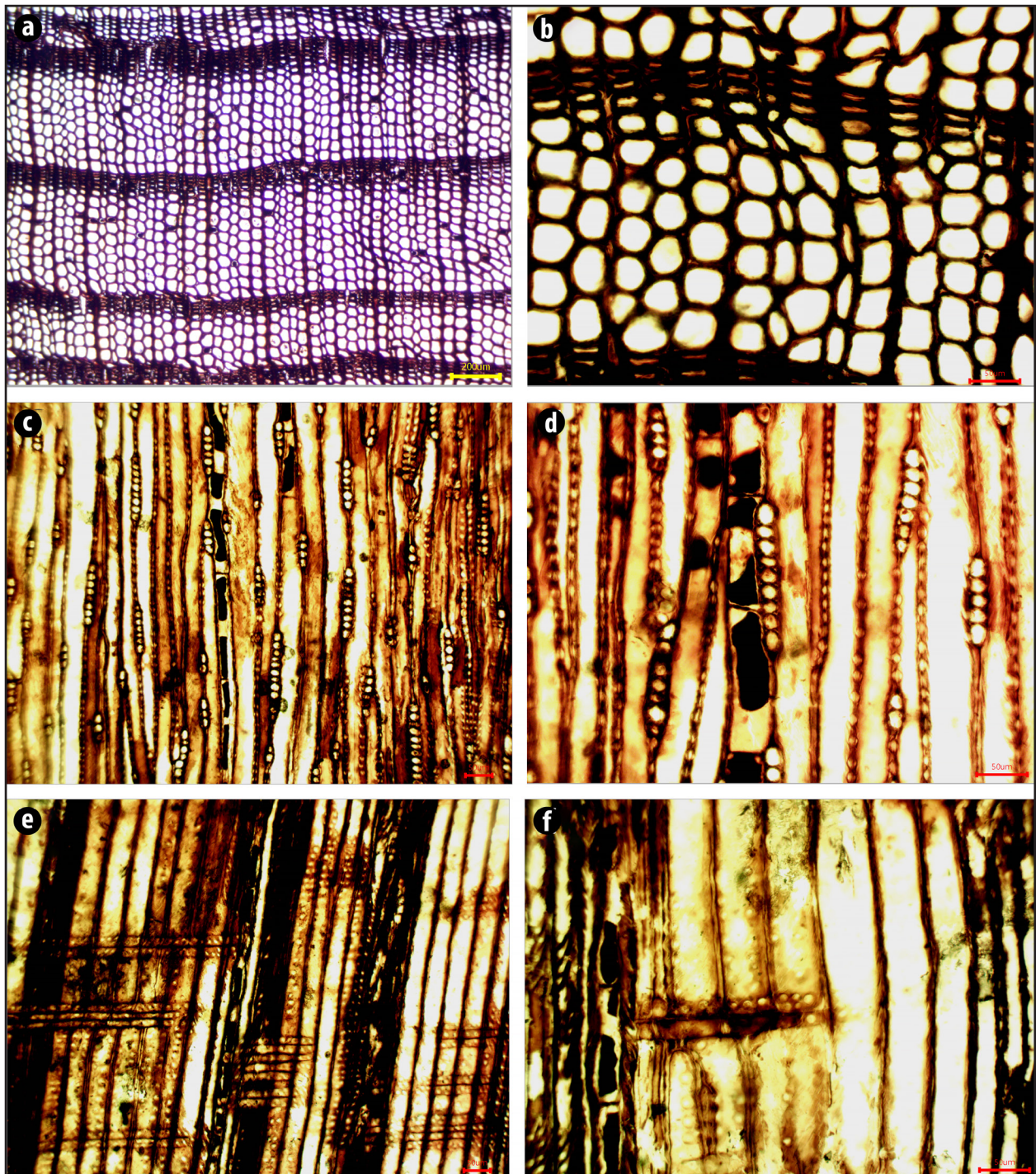


Plate 2. *Glyptostroboxylon rudolphii* from the Lighidia quarry, Lăpuşnicul Mare Formation: transverse section with (a) distinct growth rings, and (b) an abrupt transition from earlywood to latewood; tangential section with (c) rays and axial parenchyma, and (d) axial parenchyma with beaded horizontal walls; radial section with (e, f) bordered pits, and cross-fields with mainly glyptostroboid pits. Scale bar: a – 200 µm; b–f – 50 µm.

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