

LATE MIOCENE PLANT REMAINS FROM BÜKKÁBRÁNY, HUNGARY

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Plant macrofossils and palynomorphs from the remarkable fossil site of the “buried Miocene forest” at the opencast lignite mine of Bükkábrány (NE Hungary) were studied and preliminary results are presented. Palynological samples suggest a basically forested landscape with predominantly warm temperate arboreal elements that prevailed during the formation of the upper lignite seam underlying the upright trunks, as well as an intervening open water phase represented by clay intercalations. The study of the pollen flora indicates the dominance of swamp forest elements with taxodiaceous conifers and presumes more diverse warm-temperate forests at higher elevations. The macrofossil record (leaves, fruits, seeds) supports the earlier assumptions of xylotomical studies and attests a relatively low-diversity swamp forest with probably long hydroperiod fringing the northern embayment of Lake Pannon.

Key words: Bükkábrány, fossil plants, Late Miocene, Lake Pannon

INTRODUCTION

This paper presents the first results of studies carried out on the macrofossil remains (leaves, fruits and seeds) and palynomorphs from a remarkable fossil site at the opencast lignite mine in Bükkábrány (NE Hungary). During the summer of 2007 a group of large fossil stumps was exposed in the mine, with diameters of 2 to 3 m and heights of 4 to 6 m, and soon subjected to systematical studies as reported in ERDEI *et al.* (2009). The fossil “in situ” forest comprises at least two morphotaxa, 1) *Taxodioxydon germanicum* (Greguss) van der Burgh, which could be related to modern *Sequoia* Endl. or to an extinct morphospecies of *Sequoia* from the Neogene, and 2) *Glyptostroboxylon* Conwentz emend. Dolezych et van der Burgh (Dolezych in ERDEI *et al.* 2009). It is presumed that the taxa uncovered at

Bükkábrány have dominated the arboreal vegetation of the swamps in this area of Lake Pannon. Sediments underlying and embedding the stumps provided the mass (autochthonous-parautochthonous) occurrence of twigs, foliage, cones and seeds of a coniferous plant assigned to *Glyptostrobus europaeus* (Brongn.) Unger. A similar mass occurrence of *Glyptostrobus* twigs, foliage and cones has been observed in the stratigraphically related open-cast mine of Visonta at the foothills of the Mátra Mts (N Hungary).

A recent xylotomical study by GRYC and SAKALA (2010) based on stumps removed from the Bükkábrány site and exhibited at the Ipolytarnóc Fossils Nature Reserve identified four stumps as *Taxodioxylon germanicum* and one additional stump as *Glyptostroboxylon rudolphii* Dolezych et van der Burgh, which is related to the genus *Glyptostrobus*. *Glyptostroboxylon* sp. (in ERDEI *et al.* 2009) was placed in synonymy with *G. rudolphii* by the same authors. The identifications by GRYC and SAKALA (2010) imply the possible reconstruction of the *Glyptostrobus* “whole plant” based on the complex fossil record at Bükkábrány, i.e. leaf, cone, wood, similarly to the Pliocene Stura di Lanzo forest (VASSIO *et al.* 2008).

Glyptostrobus must have had a dominant role in forming the vegetation as attested by numerous oligotypic floras fossilised in Pannonian sediments, e.g. Dozmat (HABLY and KOVAR-EDER 1996), Iharosberény (HABLY 1992), Balatonszentgyörgy (Hably pers. comm.), Rudabánya (observation of the first author), Tiszapalkonya (HABLY 1992), Visonta (LÁSZLÓ 1989, PÁLFALVY and RÁKOSI 1979).

KÁZMÉR (2011) made estimates of stand density, tree height, stem volume and total biomass for the Bükkábrány forest, concluding that the height of the large trees must have been between 44 and 52 m and the trees were spaced at an average distance of 8 m.

Based on organic petrology of the trunks and sedimentology of the overburden sands HÁMOR-VIDÓ *et al.* (2010) recorded a limited alteration of the trunks, which was interrupted by the sudden burial of the trees by sand beds. Periodical fires are indicated by charcoal in the sand deposits embedding the trunks and the common occurrence of fusite in the uppermost layers of the underlying lignite.

Recent investigations of the uppermost lignitic layers directly underlying the stumps resulted in a relatively low diversity of leaf/seed/fruit assemblages and a palynomorph spectrum of higher diversity.

Geology and stratigraphy

The opencast mine at Bükkábrány is situated at the foothills of the Bükk Mts (NE Hungary) and occupies an area of nearly 3 km². The fossil forest was excavated from non-marine Late Neogene sedimentary sequences deposited in the Pannonian Basin during the Late Miocene and Pliocene. The Bükkábrány area became a northern embayment of Lake Pannon by about 8 million years ago. This was due to the insignificant basinward shift of the shoreline in the southern foreland of the Mátra and Bükk Mts contrasting the deep basinal areas westward and eastward turning progressively into deltaic plains (MAGYAR *et al.* 1999a, VAKARCS *et al.* 1994). The relatively thick lignite seams deposited in the northern embayment of Lake Pannon, together with the intercalated barren beds, comprise the Bükkalja Lignite Formation (for a more detailed discussion on the geology and sedimentology of the site see CSÁSZÁR *et al.* 2009 and HÁMOR-VIDÓ *et al.* 2010).

Due to the lack of marine fossils, the chronostratigraphic subdivision and correlation of the sedimentary succession is based on cross-correlations applying the results provided by regional biostratigraphy, European mammal stratigraphy, magnetostratigraphy, regional seismic stratigraphy, and radioisotopic age determinations (HARZHAUSER *et al.* 2004, MAGYAR *et al.* 1999b). On the basis of cross-correlations the Bükkábrány lignite-bearing succession can be dated to 7.5–6.8 Ma years (Magyar in CSÁSZÁR *et al.* 2009).

Forests flourishing on the delta plain provided large amounts of organic matter that kept accumulating, and time to time burying by sediments. The lignite formed this way has been exploited by the Visonta and Bükkábrány mines at the foothills of the Mátra and Bükk Mts. The upper lignite seam of Bükkábrány is overlain by approximately 60 m thick, mainly Late Miocene–Quaternary sand deposits. The upper lignites were directly underlying the fossil trunks and the trunks themselves, due to the presumably rapid sedimentation of huge amounts of sand, became buried and water-logged, permitting their excellent preservation.

Plant debris accumulated periodically in several seams. Organic accumulations in the uppermost lignitic layers underlying the trunks and at a height of 1.5–2 m from the top of the lignite seam in layers of 15–20 cm were dominated by leaves and twigs of *Glyptostrobus europaeus* (ERDEI *et al.* 2009). This paper focuses on the fossil plant record of the lignite seam.

MATERIALS AND METHODS

Plant fragments and pollen samples described in this work originate from the uppermost, transitional (clayey) lignitic layers of the upper lignite seam in the close vicinity of the fossil forest location (Fig. 1). Two additional pollen samples were taken from the clay layers intercalating the lignite seam.

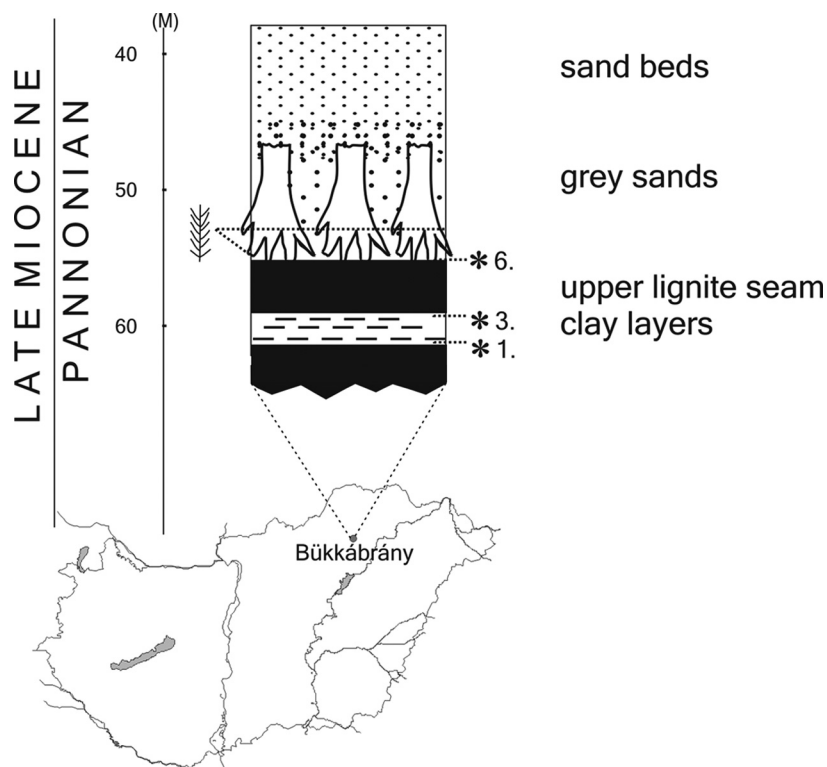


Fig. 1. Simplified generalised geological profile of the locality in the Bükkábrány lignite mine. Asterisks indicate palynological samples

In order to disaggregate the matrix for plant macrofossil analysis dilute hydrogen peroxide (H_2O_2) was used. Disaggregated samples were washed through a fine sieve. Car-pological remains were treated by hydrofluoric acid (HF).

Leaf fragments were isolated from the matrix by using dilute hydrogen peroxide (H_2O_2). After washing in distilled water, the cuticles were recovered by standard methods (JONES and ROWE 1999). For studying the preparations, a Nikon Eclipse (E600) microscope was used.

Pollen samples were prepared using standard methods (JONES and ROWE 1999). The samples of 10 g were treated by 10% HCl and 38% HF to remove carbonates and silica. This

was followed by treatment by diluted Schultze's solution in case of the lignite samples, and 10% NaOH in case of the clay samples. Further concentration of the pollen was achieved by heavy liquid separation using ZnCl_2 (density = 2). This was followed by microsieving through a 10- μm nylon sieve. Pollen residues were stored in glycerol and mounted on microscope slides. A transmitted light microscope with magnifications $\times 400$, $\times 600$ and $\times 1000$ was used for pollen classification. Pollen identification was based on the atlases of NAGY (1985), STUCHLIK (2001, 2002) and in case of the Taxodiaceae, YAMAZAKI and TAKEOKA (1956). Photo plates of Rákosi (in PÁLFALVY and RÁKOSI 1979) were also consulted. Due to difficulties in separating genera within the family, the Taxodiaceae-type pollen material is presented in this paper as a group. However, *Glyptostrobus* pollen similar to the drawings of YAMAZAKI and TAKEOKA (1956) was counted separately and in fact dominated the Taxodiaceae-type pollen group.

To aid palaeovegetation reconstruction and ecological classification of the pollen types, in this study we identified the pollen grains following the suggestion of JIMÉNEZ-MORENO *et al.* (2005).

A minimum of 300 pollen grains were counted in each sample. Here we present a simplified pollen diagram where pollen percentages are calculated relative to the terrestrial pollen sum. In addition, synthetic pie-charts are shown, in which terrestrial pollen taxa have been grouped into 10 different ecological groups. The names of the groups and the corresponding pollen types are shown in Table 1.

Table 1. Ecological groups of the most abundant pollen types from Bükkábrány

Ecological group	Taxon name
Middle altitude trees	<i>Pinus</i> (subgenus Haploxylon), <i>Picea</i> , <i>Tsuga</i> , <i>Cedrus</i>
Swampy/riparian trees and shrubs	Taxodiaceae, <i>Nyssa</i> , <i>Alnus</i> , <i>Myrica</i>
Megathermic (tropical) trees	<i>Reevesia</i>
Mega-mesothermic (subtropical) trees and shrubs	<i>Engelhardia</i> , Sequoia-type, <i>Cycas</i> , Palmae
Warm-temperate/mega-mesothermic trees	<i>Elaeagnus</i>
Mediterranean xerophytic trees	<i>Quercus ilex-coccifera</i>
Warm-temperate trees and shrubs (liana)	<i>Celtis</i> , <i>Carya</i> , <i>Pterocarya</i> , <i>Zelkova</i> , <i>Ulmus</i> , <i>Quercus</i> (deciduous), <i>Juglans</i> , <i>Vinca</i> , <i>Vitis</i>
Temperate trees	<i>Fagus</i> , <i>Betula</i>
Terrestrial herbs	Poaceae, Compositae (subfamily Tubuliflorae)
Wetland herbs and pteridophytes	<i>Elatine</i> , <i>Polygonum persicaria</i> - type, <i>Lythrum</i> , Filicales, <i>Laevisporites</i> , <i>Osmunda</i>

RESULTS

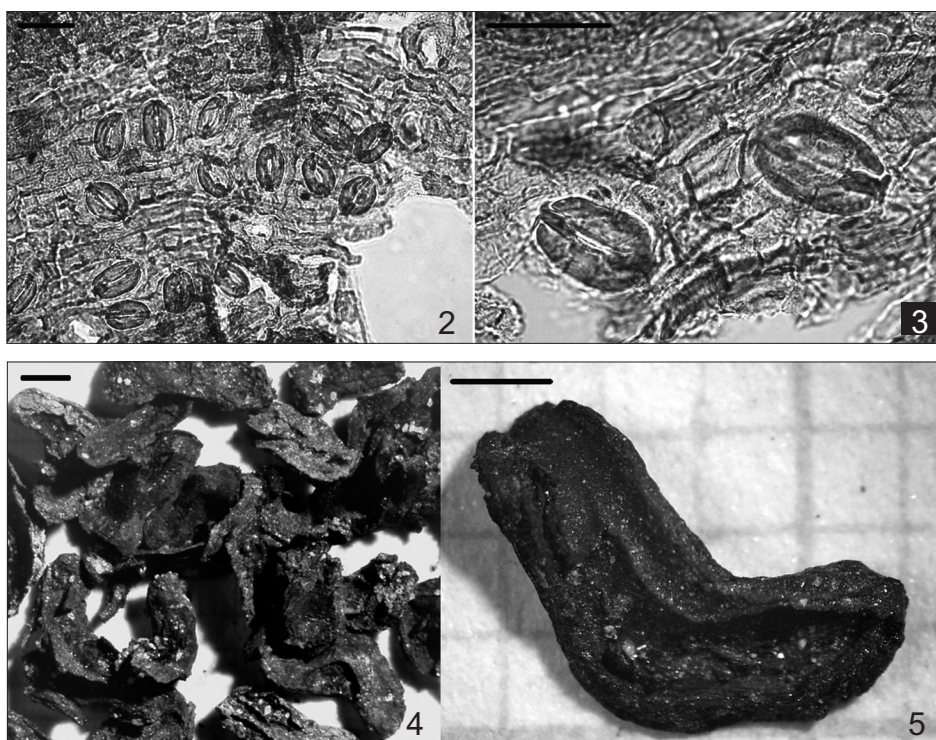
Macrofossils – leaves, carpological remains

Cupressaceae

Glyptostrobus europaeus (Brongn.) Unger
(Figs 2–5)

Description: Leaves scale-like, cupressoid type, helically arranged. Leaf length 1.2–2.5 mm, width 0.5–1 mm. Leaves amphistomatic, stomata irregularly dispersed abaxially, arranged in two bands adaxially. Cuticle delicate, non-modified epidermal cells elongated, length 25–100 μm , width 20–40 μm (Figs 2–3). Stomata 35–50 μm in length, amphicystic, mostly obliquely arranged to the longitudinal axes of the leaf. Stomatal pore 15–25 μm .

Seeds elliptical, slightly flattened, wing not preserved, dimensions 3–4 mm $\times$ 1.5–2.2 mm (Figs 4–5).



Figs 2–3. Cuticle of the scale leaves of *Glyptostrobus europaeus* showing characteristic stomata (scale bar = 50 μm). Figs 4–5. Seeds of *Glyptostrobus europaeus* (scale bar = 1 mm)

Twigs isolated from the matrix all bear leaves of the cupressoid type. Modern *Glyptostrobus* develops two (ECKENWALDER 2009) or three leaf types (“taxodioid”, “cryptomeroid” and “cupressoid”; DEBRECZY and RÁCZ 2011, FARJON 2005, FLORIN 1931, HENRY and MCINTYRE 1926). Cupressoid leaves are characteristic of older trees and persistent long shoots. Leaves of both *Glyptostrobus* and *Sequoia* may bear cupressoid type leaves and even cuticular analysis gives minor support for differentiation. The co-occurrence of the seeds unequivocally representing *Glyptostrobus*, supports the identification of the scale leaves as *Glyptostrobus*. Well-preserved three-dimensional seed cones were recovered from the sandy deposits overlying the lignite and embedding the trunks (ERDEI *et al.* 2009).

Fossils of the genus *Glyptostrobus* are widespread and common elements in the Pannonian floras of Hungary (including sites at Balatonszentgyörgy, Dozmat, Iharosberény, Rózsaszentmárton, Rudabánya, Tiszapalkonya, Visonta). It must have been dominant in peat-forming vegetation, suggesting swampy habitat with abundant water supply.

Today *Glyptostrobus* is treated monotypic with the type species *Glyptostrobus pensilis* (Staunton ex D. Don) K. Koch distributed in SE China (Fujian, Guangdong) and a few localities in Vietnam and Lao PDR (DEBRECZY and RÁCZ 2011, ECKENWALDER 2009, FARJON 2005). Generally, it occurs in river deltas, swampy areas, and occasionally develops buttressed base and pneumatophores (“knees”) (ECKENWALDER 2009, HENRY and MCINTYRE, 1926, ZHANG and XU 1997).

Material: BP.2008.99.6; BP.2008.100.20; BP.2011.230.10.

Betulaceae

Betulaceae gen. et sp. (Figs 6–7)

Description: Small fragments of leaf lamina with mostly unrecognisable macromorphology. In rare cases remnants of leaf margin show teeth with a vein entering each (craspedodromous venation). Cuticle thin, strongly damaged due to compression. Leaf hypostomatic, randomly arranged stomata seem anomocytic. Length and width of stomata 22–28 µm and 15–22 µm, respectively. Anticlinal cell walls not recognisable.

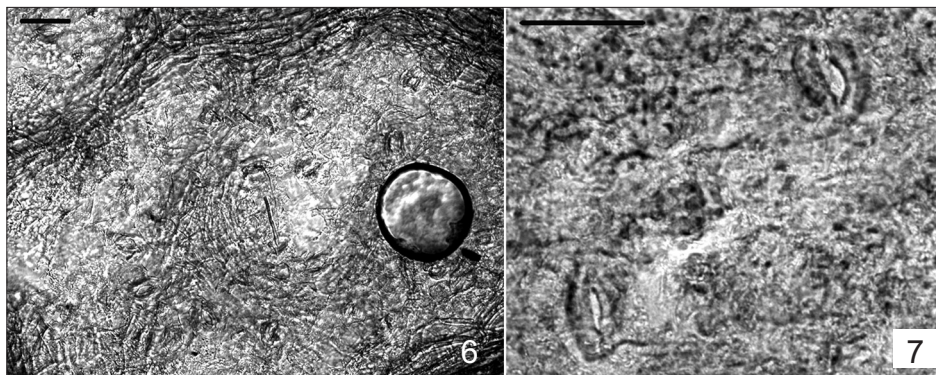
Leaf fragments may represent *Alnus*, since the occurrence of the genus is proven by its fruit scales. However, the limited size of fragments hinders the possibility of any detailed description.

Material: BP.2011.231.1.

Alnus sp. (Fig. 8)

Description: Isolated, fragmentary fruit scale, 3.3 mm long, 3 mm wide by distal end. Surface striated with coarse ribs.

Material: BP.2011.232.1.



Figs 6–7. Cuticle of *Betulaceae* gen. et sp. indet. showing randomly arranged stomata. Anticlinal cell walls hardly recognisable (scale bar = 50 μ m)

Potamogetonaceae

Potamogeton sp. (Fig. 9)

Description: Endocarp 2.1×1.1 mm, slightly obovate. Ventral margin rounded. Lid slightly keeled. Style short, centrally positioned. Stalk inconspicuous. Shallow central depression observable. Due to compression surface strongly eroded, surface features not observable.

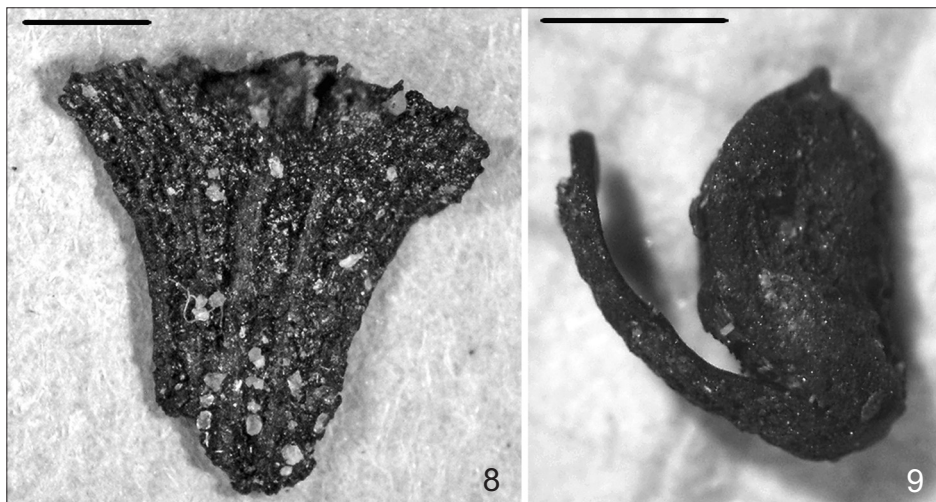


Fig. 8. Poorly preserved fruit scale of *Alnus* sp. (scale bar = 1 mm). Fig. 9. Endocarp of *Potamogeton* sp. (scale bar = 1 mm)

Modern species are mostly freshwater, but also brackish perennials or annuals occurring in diverse aquatic ecosystems in stagnant waters, lakes, but also in flowing waters.

Material: BP.2011.233.1.

Hydrocharitaceae

Stratiotes sp.

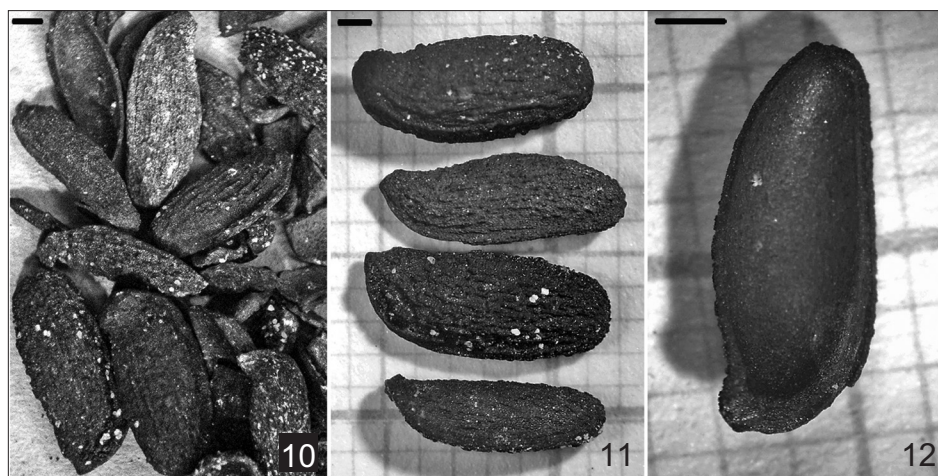
(Figs 10–12)

Description: Seeds and seed halves semicylindrical, 6–7.5 mm long, 2.5–3 mm wide. The slightly brownish colour of seeds in rare instances observable. The dorsal side raised, the ventral side rather flat, sculpture elements arranged in longitudinal striae, keel well developed. The overall description is well comparable to that of seeds from Visonta, another outcropping of the Bükkalja Lignite Formation (see in BŮŽEK and LÁSZLÓ 1992).

The seed sculpture is often corroded, not visible in detail. It is relatively variable in even the modern species and its usefulness as a reliable diagnostic feature is questioned by some authors (BŮŽEK and LÁSZLÓ 1992, COOK and URMI-KÖNIG 1983), whereas others attribute taxonomic importance to it (VELICHKEVICH and ZASTAWNIAK 2006).

The genus comprises perennial submerged aquatic plants, but they have floating shoots near water surface in flowering time. The modern representatives of *Stratiotes* thrive in swamps, oxbow-lakes (BOJŇANSKÝ and FARGAŠOVÁ 2007).

Material: BP.2011.234.10.



Figs 10–12. Seeds and seed halves of *Stratiotes* sp. (scale bar = 1 mm)

Cyperaceae

Carex sp.

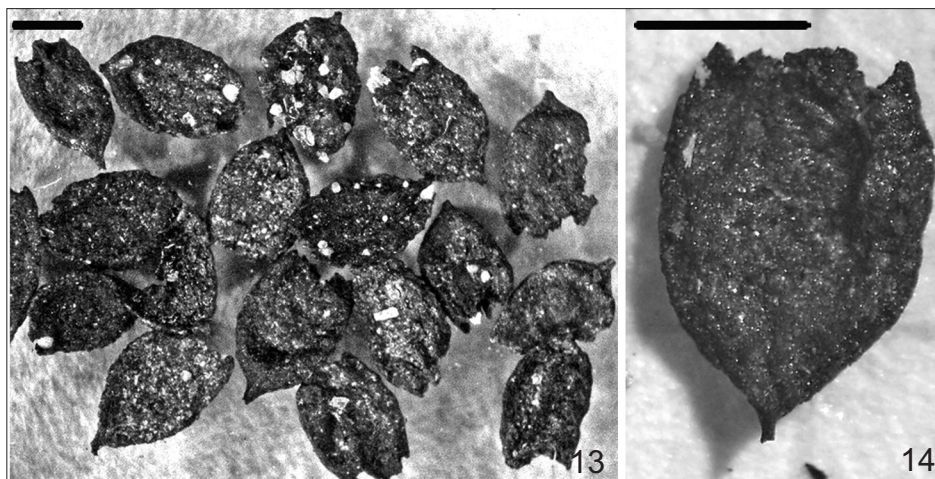
(Figs 13–14)

Description: Fruits (achenes) $1.8\text{--}2.3 \times 1.2\text{--}1.6$ mm, shape ovate, rather compressed, nearly two-dimensional, surface features hardly observable. Apex narrowed into the base of the style. At base narrowed into a thick stalk.

Preservation of fruits is rather poor, surface structures and cell walls are not visible due to strong compression.

Species of the genus occur on swampy meadows, reeds, brook and pond banks, peat and loamy grounds.

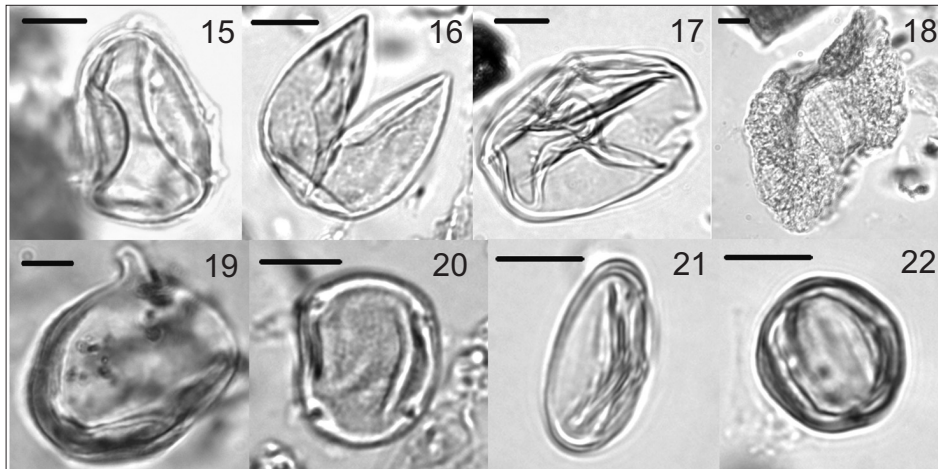
Material: BP.2011.235.6.



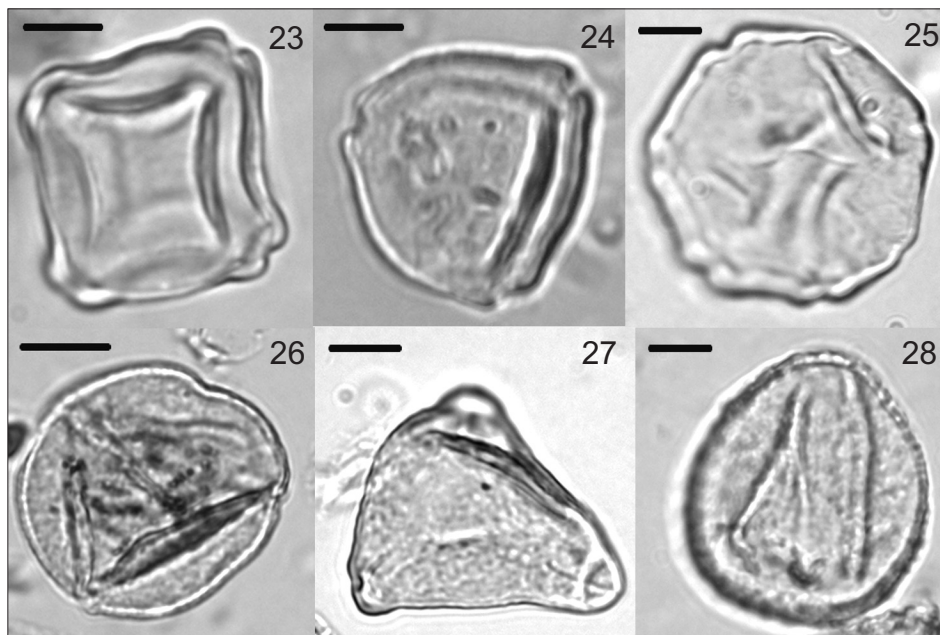
Figs 13–14. Utricles/fruits of *Carex* sp. (scale bar = 1 mm)

Palynomorphs – results of pollen analysis

Figures 15–28 display some distinctive elements of the rich pollen flora. The pollen percentage diagram is shown in Figure 29. Important arboreal elements and their affiliation to ecological groups are included in Table 1, while relative abundances of these ecological groups in the pollen samples are displayed in Figure 30.



Figs 15–22. Photo illustrations of selected pollen types from Bükkábrány. 15 = *Chamaecyparis*; 16 = Taxodiaceae (cf. *Glyptostrobus*); 17 = *Cycadopites*; 18 = *Cedrus*; 19 = *Sequoia*; 20 = *Reevesia*; 21 = *Elatine*; 22 = *Lythrum*



Figs 23–28. Photo illustrations of selected pollen types from Bükkábrány. 23 = *Alnus*; 24 = *Engelhardia*; 25 = *Pterocarya*; 26 = *Fagus*; 27 = *Elaeagnus*; 28 = *Quercus* (deciduous)

Preliminary analysis of three samples revealed 67 taxa, of which 30 were trees. Excluding aquatics and wetland herbs from the main pollen sum, the relative frequencies of trees were above 90% in all three samples suggesting a forested landscape during both the (delta) swamp phase (lower and upper seams) and the intervening open water phase represented by the clay (Fig. 30).

DISCUSSION

Palynological analysis indicated (Figs 29–30) that Taxodiaceae pollen was the dominant swamp forest element, and *Pterocarya* was also abundant in all 3 samples, with higher relative frequencies in the clay samples. Although *Pterocarya* has been grouped as a warm-temperate element, its abundance can most likely be explained by its association with the higher flood-plain forests thriving in the vicinity of the site.

It should be noted that the first clay sample (No. 1) taken from directly above the lower lignite (at the bottom of the clay intercalation) is still dominated by swampy/riparian elements indicating the persistence of the swamp forest in close vicinity of the expanding lake. An important change in the upper clay sample (No. 3) is shown by the increase in the relative frequencies of Mediterranean xerophytes and warm-temperate elements (e.g. *Carya*, *Celtis*, *Pterocarya*, *Quercus ilex-coccifera*, *Quercus* (deciduous), *Zelkova*). To explain this, one possible reason is that these assemblages are better represented due to the receding swamp forest; or, one can speculate that the zonal vegetation changed due to increasing summer water deficit.

Based on pollen analysis of the 6th sample (No. 6) extracted from levels directly underlying the upright trunks, the pie-chart (Fig. 30) shows that swampy/riparian forest elements (mainly of *Taxodium*-type) are dominant (54%) and subtropical elements are also frequent (8%) suggesting a warm and wet climate in the river delta during the formation of the upper lignite. Characteristic elements of these forests were species of Taxodiaceae (?*Glyptostrobus*), *Nyssa*, *Alnus*, *Myrica*, *Elatine*, *Polygonum persicaria*-type, *Lythrum*, *Laevigatosporites*, and *Osmunda*. The pollen flora also indicates warm temperate forests in the neighbouring hills (with *Engelhardia*, *Sequoia*-type, ?*Cycadales*, and *Celtis*).

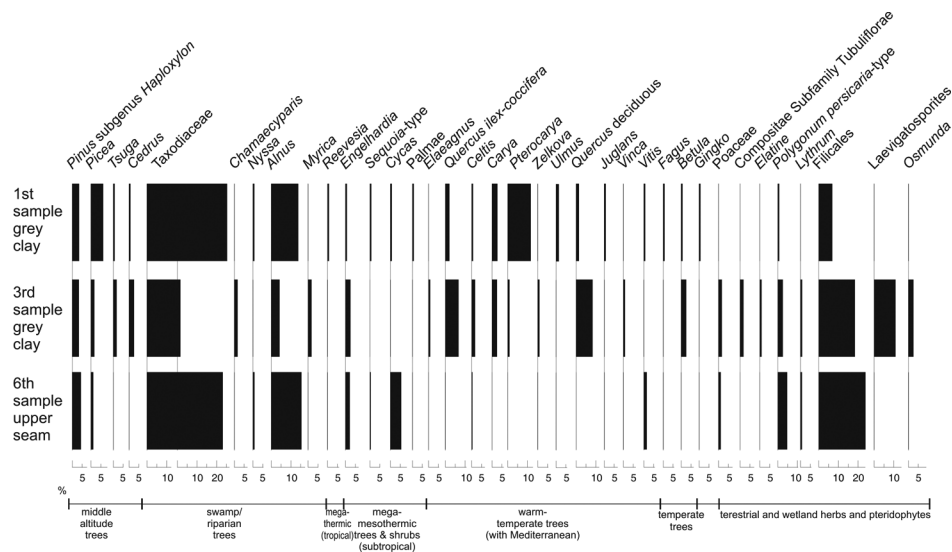


Fig. 29. Pollen percentage diagram showing the result of palynological analyses of pollen samples 1, 3 and 6

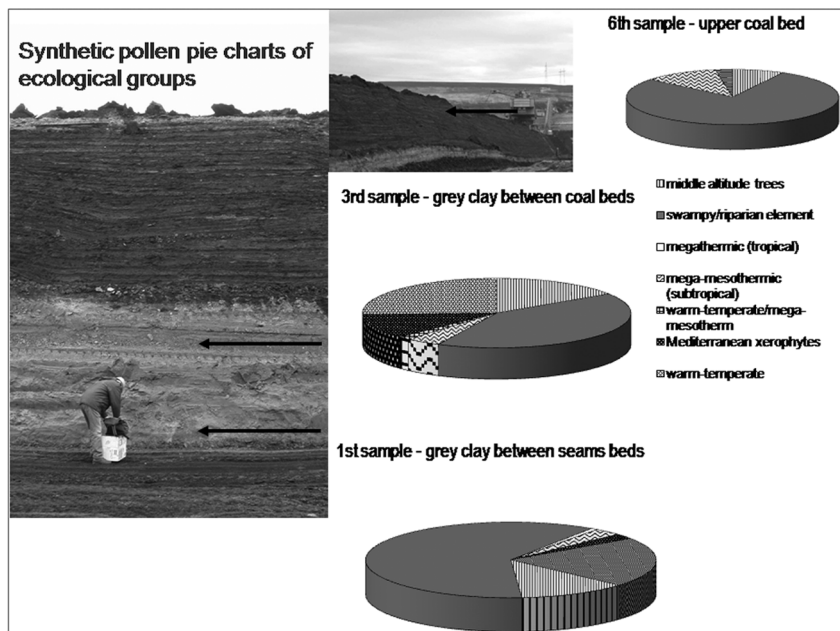


Fig. 30. Relative abundances of ecological groups in pollen samples 1, 3 and 6

Contrasting the diverse local, extralocal and regional flora and vegetation revealed by the analysis of pollen assemblages, the auto- and pseudo-utochthonous macrofossils provided information on the local plant cover of relatively low diversity.

Gymnosperms are represented solely by the remains (twigs, leaves and seeds) of *Glyptostrobus*. Based on previous xylotomical studies (Dolezych in ERDEI *et al.* 2009, GRYC and SAKALA 2010) the upright trunks do not represent a pure stand in Bükkábrány, rather, the forest vegetation was composed of at least two taxa (morphotaxa) related to the family Cupressaceae *s. l.* (former Taxodiaceae). According to the spatial arrangement of trunks assigned to certain morphotaxa, they represent clearly distinct groups differing in size (Fig. 2 in ERDEI *et al.* 2009). Buttressed base and other characteristics of the trunks at Bükkábrány do not represent specific characters, since these traits are often observed in various extant taxodiaceous taxa and seem to be strongly dependent on the environment (*e.g.* *Glyptostrobus*; FARJON 2005). Moreover, buttressed trunk base may even be developed in other wetland (including angiosperm) taxa as seen in *Quercus* sp. occurring in mixed *Taxodium* forest, Western Florida (personal observation).

The heights of buttressed sections of the Bükkábrány stumps reached up to 3 m (KÁZMÉR 2011). In modern *Taxodium* trees this character appears to be related to the depth of flooding, although this relationship needs to be verified (EWEL 1991).

Looking for existing forests that can be comparable to the assumed vegetation structure of the Bükkábrány forest, examples can include pure stands as in the case of some remaining fragments of *Glyptostrobus* (FARJON 2005), as well as mixed types, such as the *Taxodium-Nyssa* swamp forests (EWEL 1991).

Taxodium is considered a modern taxon occurring under ecological conditions most probably comparable to the environment in which the Bükkábrány trees thrived. However, it should be emphasised that none of the wood taxa identified in Bükkábrány were related to *Taxodium*. Modern *Sequoia* (*S. sempervirens* (D. Don) Endl.), often treated as a possible ally to *Taxodioxylon germanicum*, typically occurs in lowland coastal vegetation occasionally in pure stands especially at low altitudes on river flats near the coast, but usually as part of mixed stands with both conifers and angiosperms (DEBRECZY and RÁCZ 2011, FARJON 2005). However, *Sequoia* avoids swamps and peat-forming vegetation types. Modern *Glyptostrobus* (*G. pensilis*),

treated as the botanical affinity to *Glyptostroboxylon rudolphii* (DOLEZYCH and VAN DER BURGH 2004, GRYC and SAKALA 2010) occurs on river floodplains or deltas restricted to subtropical to tropical coastal lowlands usually growing in pure stands. However, it has been widely planted for a long time and it is nearly impossible to distinguish between its indigenous and introduced populations (FARJON 2005).

Taxodium (*T. distichum* (L.) Rich.) occurs in diverse ecosystems, in lowland river floodplains and swamps often growing in pure stands. A distinct vegetation type is formed by the association of *Nyssa aquatica* L. and *N. sylvatica* Marshall; other commonly associated trees include *Acer rubrum* L., *Magnolia grandiflora* L., and species of *Pinus*, *Fraxinus*, *Quercus* and *Liquidambar* (FARJON 2005).

The relatively low diversity of the leaf fossils (Taxodiaceae and Betulaceae) recorded at Bükkábrány suggests that the environment was characterised by still water or nearly stagnant, slow flowing water, with presumably long hydroperiod. The high volumes of organic matter accumulation may indicate that it was a swamp fringing upon the lake. Open water habitat is suggested by plentiful remains of *Stratiotes* and the occurrence of *Potamogeton*; whereas Cyperaceae (*Carex*) remains may document diverse wetland environments.

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