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The buried Miocene forest at Bükkábrány, Hungary

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ABSTRACT

A remarkable fossil assemblage—fifteen 'in situ' stumps standing at their original position—was explored at the opencast lignite mine at Bükkábrány, N Hungary. The stumps occupying an area of about 50 × 100 m have been preserved in Upper Miocene grey sands overlying the lignite seam. The height of the trunks ranges from 2 up to 5.2 m, their perimeter at the base reaches up to 8.8 m. The age of the fossil remains is estimated to about 7 Ma according to the regional stratigraphy. The fossil forest is the remains of a swamp forest which is also corroborated by the palaeogeography of the fossil site as the area of the former Lake Pannon. Fossil leaf and fruit assemblages indicating the typical swamp vegetation in the close vicinity of Lake Pannon have already been reported from the site. Wood anatomy of some of the stumps is diagnostic for *Taxodioxylon germanicum* (Greguss) Van der Burgh which is related to modern *Sequoia* Endlicher and was an important element of peat forming vegetation during the Neogene. Some other stumps are comparable to *Glyptostroboxylon* Conwentz emend. Dolezych & Van der Burgh. The organic rich sediments underlying and embedding the stumps provided a high abundance of *Glyptostrobus* Endlicher remains, foliage, cones and seeds.

1. Introduction

During the summer of 2007 a group of fossil stumps was exposed at a depth of 60 m in the opencast lignite mine at Bükkábrány. After removing the sands embedding the fossils 15 stumps positioned at 5–15 m from each other came to light (Plate I, 1–2). The stumps have a diameter of 2–3 m and are of 4–6 m high, respectively. The "mummified" stumps gave the impression of being intact. In addition a huge amount of plant debris accumulated in the lignitic layers underlying the stumps and in the grey sands embedding them.

The village of Bükkábrány is situated in the foothills of the Bükk Mountains (NE Hungary). The opencast mine at Bükkábrány (Fig. 1) occupies an area 2.5 km long and 1 km wide. The lignite seams extend to 10 m and are overlain by sand layers of up to 60 m formed during the Late Miocene. At that time the Inner Carpathian region was mostly inundated by the Lake Pannon. Forests flourishing on the delta plain provided the great amount of organic matter which accumulated and was buried by sediments. The lignite formed in this way is exploited at Visonta and Bükkábrány in the foothills of the Mátra and Bükk Mountains.

In situ stumps similar to the outcrop at Bükkábrány were already exposed in the opencast mine at Visonta (Pálfalvy and Rákosi, 1979), and were defined as *Sequoioxylon gypsaceum* (Goeppert) Greguss. Exploitation of lignite at the opencast mine at Bükkábrány began in 1983. Plant fossils, mainly leaf and fruit remains have been collected since 1986 (Plate I, 3). A nice collection of fossil fruits of *Trapa* (Plate I, 5) permitted the description of a new species, *Trapa praehungarica* Wójcicki & Bajzáth (Wójcicki and Bajzáth, 1997).

2. Geology and stratigraphy

Lake Pannon, a large brackish water body, which filled the Pannonian Basin, was isolated from the sea about 12 Mya and was gradually filled with sediments untill the Early Pliocene (detailed palaeogeographic evolution of Lake Pannon is discussed by Magyar et al., 1999). After subsequent transgressions the lake reached its greatest areal extent about 9.5 Mya and flooded most parts of the Carpathian Basin (*Spiniferites paradoxus* biochron). The basin was filled up by progradation which started in the northeast earlier, at least by the Sarmatian. Due to the following regressive interval of the lake delta plains were formed along the extensive northern shoreline. The delta plains prograded from the northeast and northwest. The forelands of the Mátra and Bükk Mountains became the northern embayment of Lake Pannon nearly 9 Mya and this situation persisted for relatively long time (Magyar et al., 1999). The accumulation and deposition of lignite started at that time along the northern and northeastern shoreline of Lake Pannon. Unfortunately, the lignitic deposits are devoid of stratigraphically diagnostic macro- and microfossils. However knowledge of basin fill process provides information permitting relatively precise dating. Based on indirect stratigraphic and magnetostratigraphic considerations an age of ~6.3–7.7 Ma is estimated by Magyar in Babinszky and Magyar

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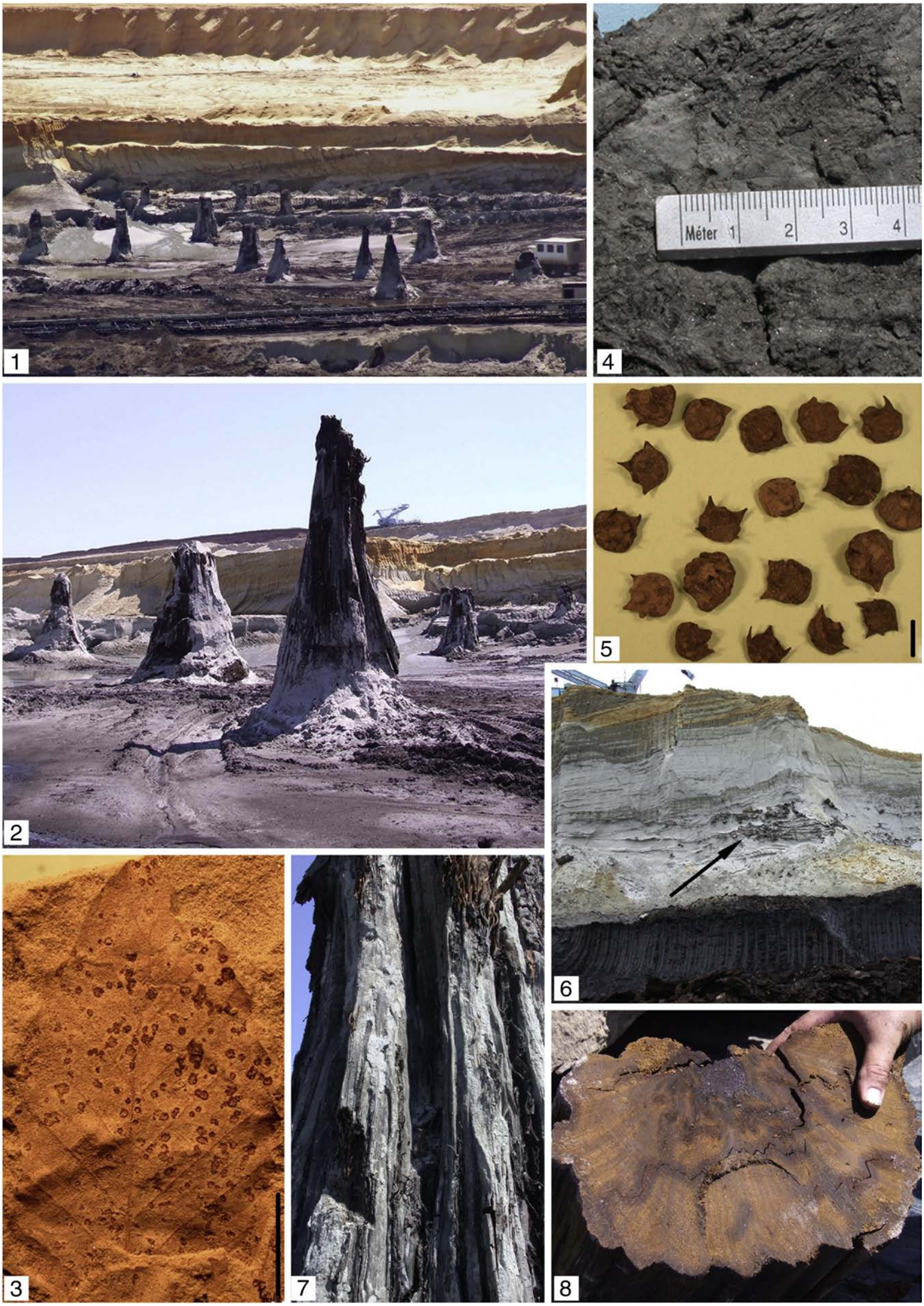
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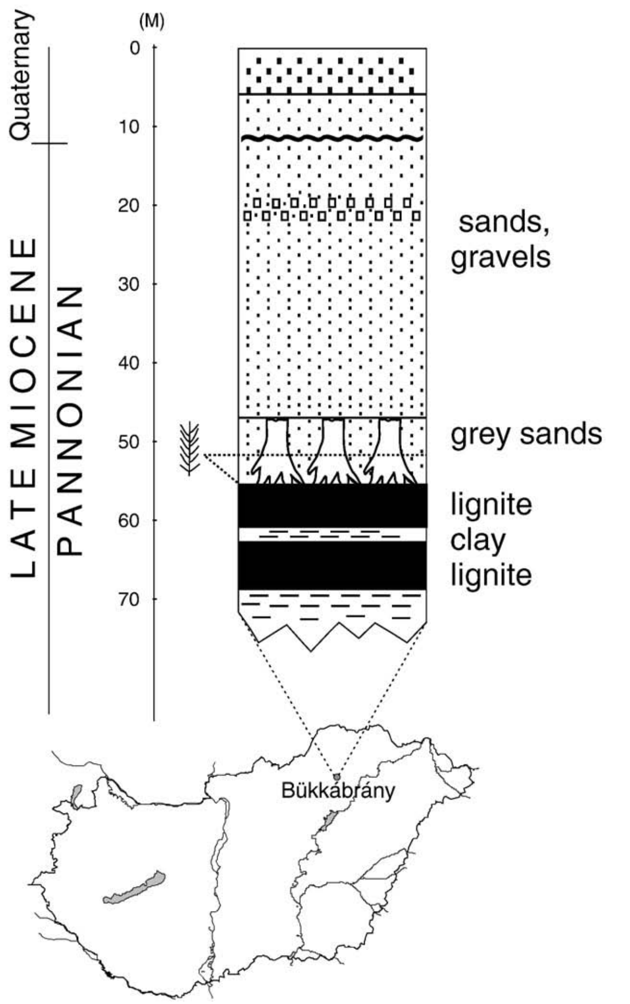


Fig. 1. Simplified stratigraphic section of the fossil site at Bükkábrány (based on field observations and after László, 1989). Dotted lines indicate the organic rich sediments underlying the trunks and in the grey sands embedding the trunks positioned at 1.5–2 m height from the surface of the lignite seam.

(2007). A detailed analysis and discussion on the age of the fossiliferous layers is in progress by Imre Magyar.

The lignite seam is occasionally intercalated by clay layers ranging between 0.2 and 1.5 m. The horizontal, almost flattened, two-dimensional compressed remains of trunks are often observable in the lignite. The lignite is overlain by 5–6 m of grey sands, which is followed by Pannonian and Pleistocene sands, aleurites and gravels (László, 1989, Fig. 1).

The stumps stand directly on the lignite layers. Due to the presumably quick, even "catastrophic" sedimentation of huge amount of sands the stumps became buried and waterlogged which permitted their preservation. The upper part of the stumps (from a height of ~5 m) either did not get buried or later became exposed and was degraded. Plant debris was accumulated in two seams—on the lignitic layers underlying the trunks and at 1.5–2 m height from the top of the lignite seam in layers of 15–20 cm thickness within the grey sands embedding the trunks (Plate I, 4, 6; Fig. 1).

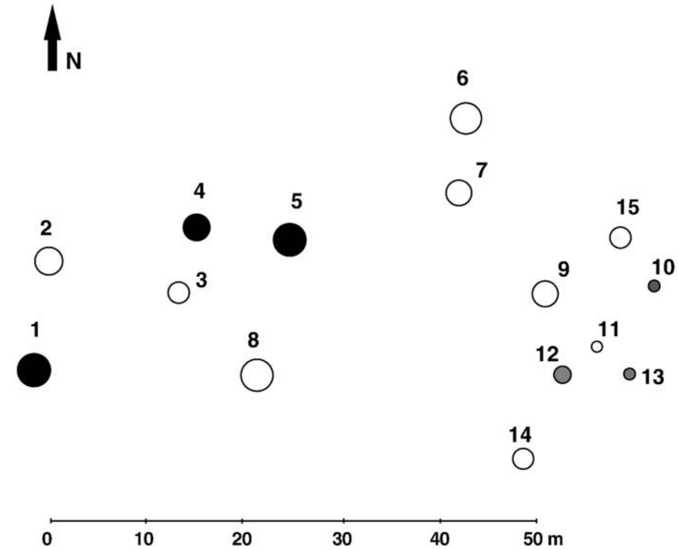


Fig. 2. Distribution of the fossil stumps as discovered during the summer of 2007. The size of circles is proportional to the diameter of each stump. (1, 4, 5—*Glyptostroboxylon* Conwentz emend. Dolezych & Van der Burgh; 10, 12, 13—*Taxodioxylon germanicum* (Greguss) Van Der Burgh).

3. Field observations

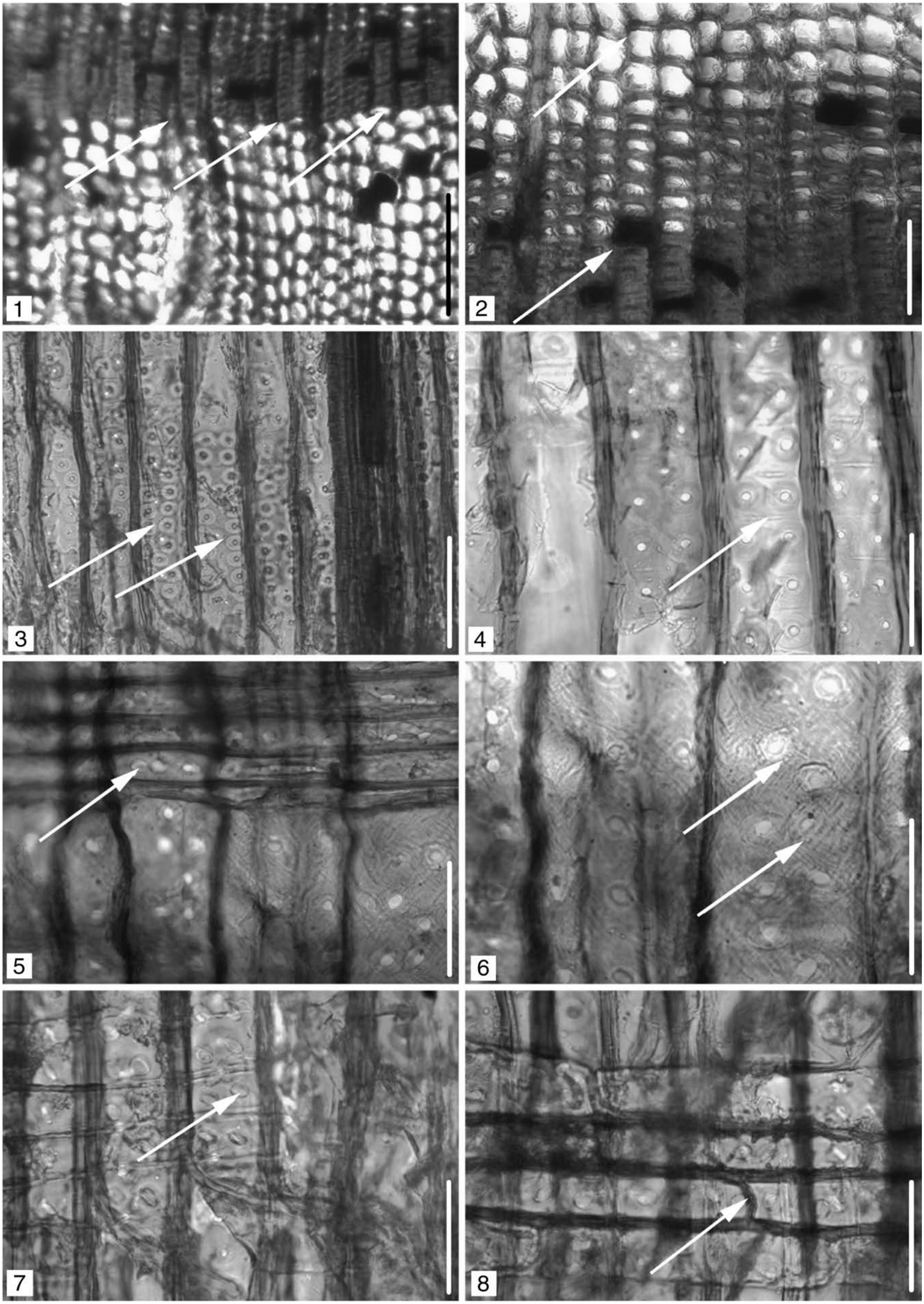
The stumps have a diameter of 2–3 m and are of 4–6 m high, respectively. They are 5–15 m apart and gave the impression of being intact but a closer observation showed that the stumps are decorticated and definitely degraded by various biotic and abiotic factors, e.g. fungi, animals, climatic factors (Plate I, 7; the study of degradation, burial and diagenesis of the stumps and trunks is in progress by M. Kázmér, Palaeontological Department, Eötvös Lóránd University, Budapest; Kázmér et al., 2008). The trunks all indicated a basally buttressed form and showed lobed xylem in cross section (Plate I, 8). In most cases the central (30–50 cm) part of the xylem was not retained due to heartrot. The cavity inside the stumps was often filled with the grey sand that embedded the stumps. The basal part of the stumps were embedded in the underlying lignitic layers. Roots attached to the stumps could not be recognized, possibly these are not retained. The palaeoenvironment of the forest may be reconstructed as a swamp on the delta plain. An inundation must have occurred which permitted the abrupt sedimentation of huge amounts of sands and consequently the preservation of the stumps.

4. Materials and methods

The stumps are preserved at their original position and retained their original structure. The lignitic layers underlying

Plate I.

1–2. In situ upright stumps in the opencast mine at Bükkábrány.
3. Angiosperm leaf remain fossilized in the Pannonian sediments of Bükkábrány.
4. A slab composed mainly of gymnospermous twigs (*Glyptostrobus europaeus*) from the lignitic layers underlying the stumps.
5. Fossil fruits of *Trapa* collected from the intercalated clayey layers of the lignite seam at Bükkábrány.
6. The position of the organic rich layers (arrow) above the lignite seam at Bükkábrány that provided a great amount of plant debris including twigs and cones of *Glyptostrobus europaeus* (Brongn.) Unger.
7. A closer observation showed that the stumps are decorticated and definitely degraded by various biotic and abiotic factors (fungi, animals, climatic factors).
8. The trunks showed lobed xylem in cross section.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the stumps and the grey sands embedding them comprise great amount of plant debris, leaves, twigs and cones (Plate I, 4).

The position of the stumps was mapped (Fig. 2). Length and diameter of each trunk were measured by means of metric tape and rule-scale. Position of stumps and distance between stumps were mapped by means of compass and metric tape. Samples of wood were collected from each upright trunk. Slabs with abundant leaf remains (leafy twigs) and cones were collected from the underlying organic sediments and from an organic rich layer in the grey sands embedding the stumps located at 1.5–2 m height from the top of the lignite seam.

Wood samples were studied by M. Dolezych. Thin sections of 20 µm thickness were cut with razor blades and mounted in glycerine jelly. The observations were made with a Leica (DM LS) light microscope. Wood remains were identified with the aid of literature on recent and fossil wood (e.g. Gothan, 1905; Kräusel, 1949; Greguss, 1955, 1967, 1972; Van der Burgh, 1973) as well as by comparison with reference collections of recent and fossil wood from the Laboratory of Palaeoecology, Utrecht University as well as from the own collection of the second author. The xylotomical terms correspond to wood-anatomical terminology (e.g. Van der Burgh, 1973; Grosser, 1977; International Association of Wood Anatomists, 2004).

From both organic rich layers compressed gymnosperm twigs up to 5–10 cm in length could be separated by sieving or leaching with water. Most of the litter-like accumulation seemed to be of gymnospermous origin (Plate I, 4). Cuticles were recovered by standard methods. Pieces of the organic material were treated with hydrochloric and hydrofluoric acid and washed in water to remove the adhering sediment. For cuticular preparation the organic material was macerated with SCHULTZE'S solution and subsequently treated with a diluted solution of potassium hydroxide. The remaining cuticles were washed in demineralized water, and mounted in glycerine. Some intact whole leaves were prepared for fluorescence microscopy and were treated only with hydrofluoric acid. For studying the preparations, a NIKON Eclipse (E600)-microscope was used.

5. Taxonomy

Cupressaceae Li *sensu lato* 1953
Taxodioxylon Hartig emend. Gothan 1905
Taxodioxylon germanicum (Greguss 1959) Van der Burgh 1973
Synonymy, see Van der Burgh (1973)
Plates II and III

Material: Wood of the upright stumps, Palaeobotanical Coll. Musei Hist. Nat. Hung. Department of Botany, Budapest, No. 090907/10, 090907/12, 080907/13.

Description (Plates II and III):

Growth rings: The early wood is clearly separated from the late wood. Growth rings are variable of width and the boundaries are distinct (Plate II, 1–2).

	Radial	Tangential	Wall thickness
Early wood	40–55 µm	20–35 µm	5–8 µm
Late wood	2–10 µm	13–20 µm	8–17 µm.

Tracheids: The lumina are polygonal in cross section (Plate II, 1–2). The dimensions are:

Bordered pits: Bordered pits in the radial walls of the tracheids occur in one to three adjacent vertical rows, mostly in two rows (Plate II, 3–6). The diameter of the bordered pits sometimes reach a size of up to 19 µm. Crassulae are often present (Plate II, 4). The pits in the tangential walls are significantly smaller and round in shape; their diameter is about 10 µm.

Parenchyma: The parenchyma is scattered loosely but concentrated in tangential zones in both early and late wood. The longitudinal walls bear many cupressoid pits with a diameter of up to 8 µm (Plate III, 5). The transverse walls of the parenchyma are up to 5 µm thick and pitted (Plate III, 3–4, 6).

Rays: These are uniseriate, occasionally biseriate and homocellular (Plate III, 1–2). They can be up to 20 cells high (Plate III, 2). The horizontal walls, with a thickness up to 4–5 µm, are simply pitted (Plate II, 5, 8). The tangential walls are smooth, up to 4 µm in thickness and appear to be smooth (Plate II, 8). Indentures are not observed. In the cross-fields there are 1–3 taxodioid pits, mostly arranged in pairs; glyptostroboid- and cupressoid pits also occur infrequently (Plate II, 5, 7). Their diameter can reach a size up to 13 µm with the majority ranging between 8 and 10 µm. In the outer cells up to six pits can be found. The average height of the central cells is about 20 µm. The outer cells are somewhat higher.

Identification and discussion:

The predominately taxodioid cross-field pits and the occurrence of parenchyma point to the morphogenus *Taxodioxylon*; based on the identification key by Kräusel (1949, p. 168). However, the wood differs in its characters from the *Taxodioxylon*-species listed by Kräusel. It differs from *Taxodioxylon gypsaceum* (Goeppert) Kräusel in having thick pitted ray walls and smaller cross-field pits and bordered pits. Van der Burgh (1973, p. 155) mentioned the thin walls in the rays as being an important feature for differentiating the species *T. gypsaceum* from other *Taxodioxylon* species. In contrast to *Taxodioxylon taxodii* Gothan our material has not so thick pitted parenchyma walls.

The above described wood is conspecific with specimens of *Taxodioxylon germanicum* (Greguss) Van der Burgh (Van der Burgh, 1973, 1978) found in the Lower Rhine Embayment.

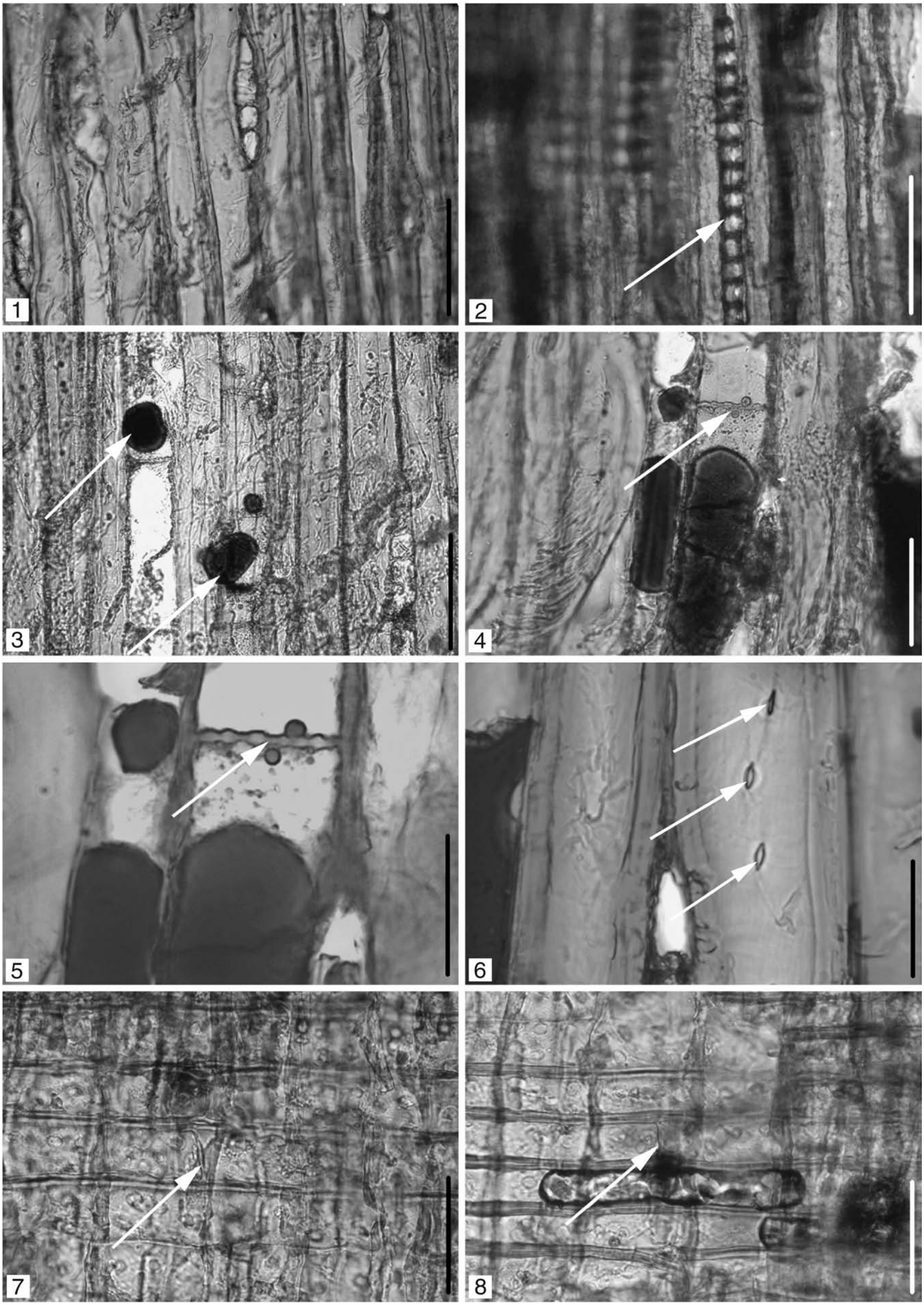
Greguss (1959) described *Sequoioxylon germanicum* Greguss (basionym of *Taxodioxylon germanicum*) from Rixhöft/formerly Germany (today Rozewie/Poland) on the Baltic Sea and from the Early Palaeocene and Late Oligocene of Hungary (Greguss, 1967).

Brezinová and Kourimský (1974) reported the presence of this morphospecies *T. germanicum* from the Miocene of Pôtor near Modrý Kameň in the South Slovakian Basin.

A comparison of the studied material with wood from Miocene of Crèche, France, indicates a strong resemblance with *Taxodioxylon grangeonii* Privé (Privé, 1970). However, this species differs from the

Plate II. Woods of *Taxodioxylon germanicum* (Greguss) Van der Burgh from the opencast mine at Bükkábrány.

1. Cross section showing polygonal tracheids, parenchyma and the abrupt transition from the early wood to the late wood (see arrows). Scale bar 200 µm. prep. 080907/13.
2. Cross section showing polygonal lumen of tracheids, parenchyma and the late wood tracheids (dark) and the early wood tracheids (light). Scale bar 100 µm. prep. 080907/13.
3. Radial section with bi- and triseriate bordered pits. Scale bar 100 µm. prep. 080907/13.
4. Radial section with crassulae. Scale bar 50 µm. prep. 080907/13.
5. Radial section with taxodioid cross-field pits in the cross-field and smooth as well as simply pitted horizontal ray cell walls. Scale bar 50 µm. prep. 080907/12.
6. Radial section with bordered pits. Scale bar 50 µm. prep. 080907/12.
7. Radial section with taxodioid cross-field pits and smooth as well as simply pitted horizontal ray cell walls in the cross-field. Scale bar 50 µm. prep. 080907/12.
8. Radial section with horizontal and tangential ray cell walls (for tangential wall see arrow). Scale bar 50 µm. prep. 080907/12.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above described wood by its up to 80 µm wide tracheids, and up to 8 µm thick horizontal ray walls.

Comparison with recent conifer wood indicates that *T. germanicum* is similar but not identical to those of *Sequoia gigantea* (Lindley) Buchholz. Living *S. gigantea* has significantly larger cross-field pits, up to 20 µm and cross tracheids, which are not observed in the Pannonian wood. Some smaller differences exist between our fossil wood and those of extant *Sequoia sempervirens* (D. Don) Endlicher. During the Palaeogene and Neogene, over the entire Northern Hemisphere we have the evidence of fossil plants, which are very similar to the modern *S. sempervirens*, even if they are usually assigned to different morphospecies (e.g. *S. abietina* in Europe). But our material could also represent an extinct morphospecies of *Sequoia*.

Wood inventories from brown coal mines in Lusatia (Dolezych and Van der Burgh, 2004; Dolezych, 2005; Dolezych and Schneider, 2006, 2007; Dolezych and Van der Burgh, in press) indicate that *Taxodioxylon germanicum* represented an important element of the peat-forming vegetation in the Tertiary. The occurrence of this wood-species together with other fossils of *Sequoia* supports the recognition of a *Sequoia*-facies in Lusatia (S-facies according Schneider, 2004; Dolezych, 2005, Table 18).

Glyptostroboxylon Conwentz, 1884 emend. Dolezych and Van der Burgh (2004)

Plates III and IV

Material: Wood of the upright trunks, Palaeobotanical Coll. Musei Hist. Nat. Hung. Department of Botany, Budapest, No. 090907/1, 090907/4, 080907/5

Description (Plates III and IV)

Growth rings: early wood separated from the late wood. Tracheids in the early wood wider than in the late wood.

Tracheids: lumina polygonal in cross section. Early wood tracheids larger and cell wall thinner if compared to late wood.

Bordered pits: Bordered pits in the radial walls of the tracheids in 1–3 vertical rows (Plate IV, 1). Crassulae seldom present. Pits in the tangential walls significantly smaller and round in shape.

Parenchyma: The parenchyma loosely scattered with thin and smooth to moderately thick and pitted cross walls.

Rays: homocellular and mostly uniseriate (rarely biseriate) and characterized by a variable number of cells in height (Plate III, 7–8; Plate IV, 2). Glyptostroboid cross-field pits predominate in the early wood , but taxodioid and cupressoid pits also present (Plate IV, 2).

Identification and discussion:

The investigations of these woods proved that they can only be identified on the level of morphogenus.

Glyptostrobus Endl. 1847

Glyptostrobus europaeus (Brongn. 1833) Unger, 1850

1833 *Taxodium europaeum* Brongniart, Ann. Sci. nat. 30: 168.

1850 *Glyptostrobus europaeus* (Brongniart, 1833) Unger, Sitz.-Ber. Akad. Wiss. Math.-naturwiss. CI. 5: 434–435.

Plates IV and V

Material: foliage, cones, seeds, Palaeobotanical Coll. Musei Hist. Nat. Hung. Department of Botany, Budapest, PB.2008.99.6.; PB.2008.100.20.

Description:

Leaves: Twigs with helically arranged leaves of the cupressoid type. Leaves scale-like, length 1.2–2.5 mm, width 0.5–1 mm. Leaves amphistomatic, abaxially stomata irregularly dispersed (Plate IV, 3) and arranged in two bands adaxially (Plate IV, 4) Cuticle delicate, non-modified epidermal cells elongated (Plate IV, 5), length 50–100 µm, width 25–40 µm (length/width ratio 1.25–4). Stomata 35–50 µm in length, amphicyclocytic, mostly obliquely arranged to the longitudinal axes of the leaf (Plate IV, 6–7). Stomatal pore 15–30 µm.

Seed cone: Cone (Plate V, 1–5), terminal, obovate 14×9 mm in length and width. Cone scales min. 12 (cones incomplete), woody, 8–10×3–4 mm in length and width, helically arranged, imbricate, oblong, distally rounded, proximally cuneate (Plate V, 6–7). On the abaxial surface subcentral lobe (~2×1 mm), on the adaxial surface seed cavities observable. Great number of seeds (Plate V, 8–9) were taken out from the sediments; their systematic treatment, description and interpretation are in progress in cooperation with Barbara Meller.

Identification and discussion:

The mass occurrence of *Glyptostrobus* twigs was recorded in the layers directly underlying the trunks. Modern *Glyptostrobus* develops various leaf types—“taxodioid”, “cryptomeroid” and “cupressoid” after Henry (Henry and McIntyre, 1926) or “Jugend-, Übergangs-, und Folgeblätter” by Florin (1931). Cupressoid leaves are characteristic of older trees. In our case twigs all bear monomorphic leaves of the cupressoid type.

The distinction between vegetative remains of *Glyptostrobus* and *Sequoia* is problematic. Both may bear cupressoid type leaves and even cuticular analysis has revealed only minor differences, i.e. in the ratio of length/width of non-modified epidermal cells, i.e. 3–4 for *Glyptostrobus* and 7–12 for *Sequoia* (Sveshnikova, 1963). Considering the length/width ratio transitional forms were found which hinders clear distinction of the two taxa (Kovar-Eder, 1996; Meller et al., 1999). In fact the ratio calculated for our leaves is comparable (even less) to that indicated by Sveshnikova (1963) as characteristic for *Glyptostrobus*. The occurrence of the seed cones and seeds unequivocally representing *Glyptostrobus*, together with the foliage remains, however, gives further support to the identification of the scale leaves as *Glyptostrobus*. A similar phenomenon was recognized in the much younger (~3 Ma years old) Pliocene locality by the Stura di Lanzo river (N Italy, Martinetto, 1994; Vassio et al., 2008).

Fossils of the genus are widespread and common element in the Pannonian floras of Hungary. It was dominant in peat forming vegetation suggesting swamp habitat with abundant water-supply.

Today *Glyptostrobus* is monotypic with one species *Glyptostrobus pensilis* (Staunton ex D. Don) K. Koch distributed in SE China (Fujian, Guangdong; Farjon, 2005). Generally it occurs in river deltas up to 730 m above sea level. It grows always near water, occasionally develops buttressed base and pneumatophores (Henry and McIntyre, 1926; Zhang and Xu, 1997). It is a heliophilous species, usually found in pure stands (Farjon, 2005).

6. Comparisons

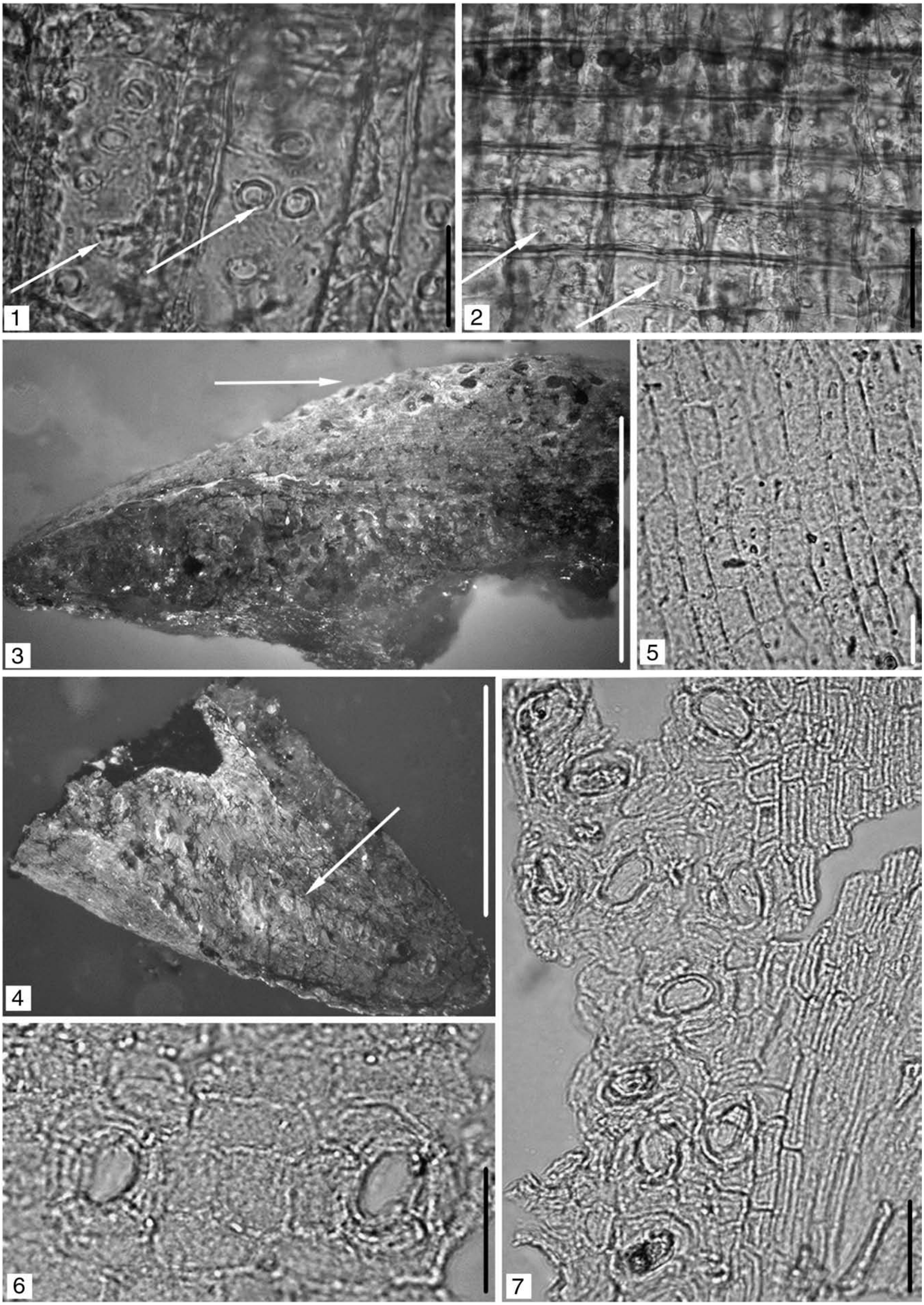
Large arboreal stumps are common within muddy sediments of several Pliocene localities of central and northern Italy (e.g. Dunarobba in Umbria, Biondi and Brugiapaglia, 1991; Martinetto, 1994 and

Plate III. Woods of *Taxodioxylon germanicum* (Greguss) Van der Burgh from the opencast mine at Bükkábrány.

1. Tangential section with tracheids and uniseriate low rays. Scale bar 100 µm. prep. 080907/12.
2. Tangential section with a uniseriate high ray. Scale bar 100 µm. prep. 080907/10.
3. Tangential section with tracheids, rays, tracheid walls and resin (see arrow). Scale bar 100 µm. prep. 080907/13.
4. Tangential section with tracheids and slightly pitted transverse parenchyma wall (see arrow). Scale bar 50 µm. prep. 080907/12.
5. Tangential section with tracheids, a ray, parenchyma and cupressoid pits in longitudinal wall (see arrows). Scale bar 30 µm. prep. 080907/13.
6. Tangential section with tracheids and slightly pitted transverse parenchyma wall (see arrow). Scale bar 30 µm. prep. 080907/12.

Woods of *Glyptostroboxylon* sp. from the opencast mine at Bükkábrány

7. Radial section with a ray, thin and smooth horizontal ray walls as well as smooth tangential ray wall (see arrow). Scale bar 50 µm. prep. 0710007/1.
8. Radial section with a ray, thin and smooth horizontal ray walls as well as smooth tangential ray wall (see arrow). Scale bar 50 µm. prep. 0710007/4.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Stura di Lanzo near Turin, Vassio et al., 2008). Upright stumps of the Stura di Lanzo forest were assigned to *Glyptostroboxylon rudolphii* Dolezych & Van der Burgh and, based on the set of fossil organs (foliage, cone, seed and wood), considered as a part of the *Glyptostrobus europaeus* "whole-plant" (Vassio et al., 2008). The Stura di Lanzo forest comprises trunks belonging to one species. The stumps of both Stura di Lanzo and Dunarobba (Biondi and Brugiapaglia, 1991) have a diameter of 1–3 m, are basally buttressed and have a general habit and position of trunks which are quite similar to that observed in Bükkábrány. Stumps of both Dunarobba and Stura di Lanzo are mummified (waters rich in suspension load buried the swamps and permitted their preservation) (Biondi and Brugiapaglia, 1991; Palanti et al., 2004). The stumps are often connected with roots embedded in sandy gravely muds. In situ stumps of Dunarobba are buried by sediments (clayey silts with irregular silty laminae) suggesting a shallow still-water environment by occurrent floods or probably storms (Basilici, 1997). Contrasting with the Italian fossil forests the stumps of Bükkábrány are embedded in sands suggesting high rate of deposition and "rooted" in clayey lignite or lignitic layers. In fact roots were not retained thus lignite layers are directly underlying the former aboveground parts of the trees. This situation may be explained by an abrupt burial of the trees with sands in which the upright stumps could retain their original dimension whereas horizontal plant parts became compressed, e.g. horizontal trunks are flattened in cross section.

An abundance of foliage and cones of *Glyptostrobus europaeus* (Brongniart) Unger has already been reported from both localities, in the Stura di Lanzo Pliocene deposits since the end of the 19th century (Peola, 1896; Martinetto, 1994). Based on his palaeocarpological analyses Martinetto (1994) provided good evidence that *G. europaeus* is an autochtonous element in the Stura di Lanzo fossil forests. The litter-like accumulation of *Glyptostrobus* twigs in the layers underlying the stumps at Bükkábrány led us to a similar conclusion.

An additional noteworthy example of fossil forests is the Eocene in situ *Glyptostroboxylon* forest of Hoegaarden (Belgium, Fairon-Demaret et al., 2003). Here the silicified stumps are smaller (diameter max. 80 cm) and much more dense, i.e. 1–3 m apart. However, similarly to the stumps at Bükkábrány the bases of the stumps are embedded in a lignite layer with no or few retained roots and the trees were lignite builders colonising lowland habitats.

7. Conclusions

According to our studies the abundant fossil plant material—vegetative (woods, foliage) and reproductive (cones, seeds) structures—from Bükkábrány can mostly be assigned to the Coniferae (Table 1.). Though poor preservation did not allow systematic assignment of some stumps the fossil "in situ" forest turns out to be more diverse than a pure stand and it comprises at least two morpho-taxa. Tree stumps (10, 12, 13) positioned close to each other (Fig. 2) were assigned to the *Taxodioxylon germanicum* morphospecies which could be related to modern *Sequoia* or to an extinct morphospecies of *Sequoia* from the Neogene. Additional tree stumps (1, 4, 5; Fig. 2) were described as *Glyptostroboxylon*. Probably the trees discovered at Bükkábrány predominated in the vegetation of the swamps in this area of the Lake Pannon.

Layers underlying and embedding the stumps provided the mass (probably autochtonous) occurrence of twigs, foliage, cones and seeds of a conifer type assigned to *Glyptostrobus europaeus*. The autochtonous origin of the plant debris is supported by the nicely preserved twigs and three-dimensional cones. The mass occurrence of *Glyptostrobus* twigs, foliage and cones has been commonly recorded from the lignitic layers of the opencast mine of Bükkábrány during the last decades, whereas vegetative or reproductive remains of other conifers have so far not been proved. The same case is observed in the stratigraphically related opencast mine of Visonta in the foothills of the Mátra Mountains (N Hungary). However, organic connection between stumps and twigs/foliage/cones has never been observed.

Recent investigations of the sandy layers embedding the stumps resulted in a diverse seed/fruit assemblage in which gymnosperms are represented solely by seeds of *Glyptostrobus*. In addition, *Glyptostrobus* must have had a dominant role in forming the vegetation. As attested by numerous oligotypic floras fossilized in Pannonian sediments, e.g. Dozmat (Hably and Kovar-Eder, 1996), Iharosberény (Hably, 1992), Balatonszentgyörgy (Hably, in prog.), Rudabánya (Erdei, in prog), Tiszapalkonya (Hably, 1992), Visonta (Pálfalvy and Rákosi, 1979; László, 1989), *Glyptostrobus* must have been the predominant conifer element of swamps which extensively evolved related to the succession of Lake Pannon.

The Pliocene fossil forests of Stura di Lanzo and Dunarobba in northern and central Italy (Biondi and Brugiapaglia, 1991; Vassio et al., 2008) have autochtonous mummified trunks displaying a habit (trunk diameter, basally buttressed trunk form) comparable to that of Bükkábrány. Contrasting with the Hungarian fossil forest all trunks of Stura di Lanzo seem to represent a pure stand and are assigned to *Glyptostroboxylon rudolphii* Dolezych & Van der Burgh. However at both localities (Stura di Lanzo and Bükkábrány) the mass occurrence of *Glyptostrobus* shoots bearing monomorphic foliage was encountered.

Future, systematic (collecting trips, carpological, palynological analyses) studies may recover additional (vegetative or reproductive) remains giving further proof of systematic diversity of the Bükkábrány fossil forest.

All the trees discovered at Bükkábrány had basally enlarged and buttressed trunks which are clearly indicated by the habit of their fossilized remains (Plate I, 1–2). The stumps of the Italian fossil forest show similar morphology. Based on the complex fossil record (leaf, cone, wood) related to *Glyptostrobus* Vassio et al. (2008) suggested the set of fossils of Stura di Lanzo serve as an example of the *Glyptostrobus europaeus* "whole-plant". A "whole-plant" reconstruction provided by Kovar-Eder et al. (2001) indicates a similar, basally buttressed habit of the trunks for *G. europaeus*. Probably this trunk morphology was common among conifers in peat-forming vegetation of the Neogene as well as among modern analogues, i.e. *Taxodium distichum* (L.) Richard in North America, and occasionally in *Glyptostrobus* depending on habitat.

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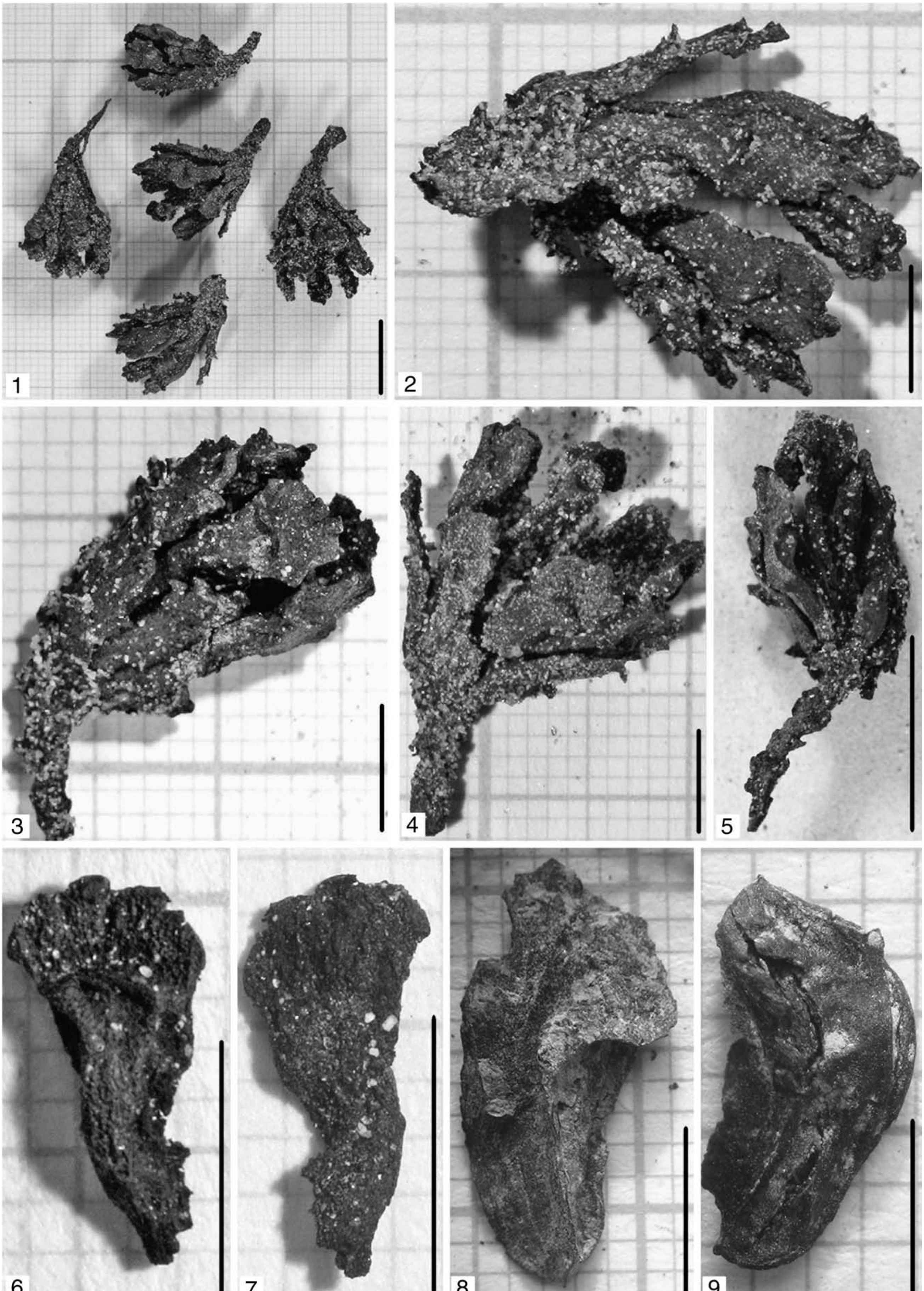
Plate IV. Woods of *Glyptostroboxylon* sp. from the opencast mine at Bükkábrány.

1. Radial section of *Glyptostroboxylon* sp. with radial tracheids and uniseriate and biseriate bordered pits (see arrows). Scale bar 30 µm. prep. 0710007/4.
2. Radial section of *Glyptostroboxylon* sp. of with a ray, thin and smooth horizontal and tangential ray walls as well as glyptostroboid cross-field pits (see arrows). Scale bar 50 µm. prep. 0710007/1.

Vegetative and reproductive remains of *Glyptostrobus europaeus* (Brongn.) Unger from the opencast mine at Bükkábrány.

3. Cupressoid type leaf. Scattered stomata are observable on the abaxial side (fluorescence m.). Scale bar 500 µm (PB.2008.100.20./1).
4. Adaxial side of a cupressoid type leaf. Stomata are arranged in two bands obliquely to the longitudinal axis of the leaf (fluorescence m.). Scale bar 500 µm. (PB.2008.100.20./1).
5. Non-modified epidermal cells on the cuticle of a cupressoid type leaf (transmitted light m.). Scale bar 50 µm (PB.2008.100.20./2).
6. Amphicyclic stomata on the cuticle of a cupressoid type leaf (transmitted light m.). Scale bar 50 µm (PB.2008.100.20./3).
7. Scattered stomata on the abaxial cuticle of a cupressoid type leaf (transmitted light m.) Scale bar 50 µm (PB.2008.100.20./3).


1
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9

Table 1
Taxonomical list of wood, foliage and cones from Bükkábrány.

Taxonomical list of plant fossils	
Sample	Taxon
Numbers (see on Fig. 2)	Wood samples
1 (071007/1)	*Glyptostroboxylon* sp.
2 (080907/2)	Dried out
3 (300907/3)	Coniferae/only stump wood
4 (071007/4)	*Glyptostroboxylon* sp.
5 (071007/5)	*Glyptostroboxylon* sp., stump wood
6 (100907/6)	Taxodiaceae *cf.*/only stump wood
7 (080907/7)	Dried out
8 (300907/8)	Dried out
9 (090907/9)	Coniferae/only stump wood
10 (090907/10)	*Taxodioxylon germanicum* (Greguss) Van der Burgh
11 (071007/11)	Dried out
12 (090907/12)	*Taxodioxylon germanicum* (Greguss) Van der Burgh
13 (080907/13)	*Taxodioxylon germanicum* (Greguss) Van der Burgh
14 (300907/14)	Dried out
15 (15)	Dried out
	Foliage
PB.2008.100.20.	*Glyptostrobus europaeus* (Brongn.) Unger
	Seed cone
PB.2008.99.6.	*Glyptostrobus europaeus* (Brongn.) Unger

Bükkábrány opencast mine) for providing access to diverse, "key-areas" of the mine. We owe our thanks to Edoardo Martinetto and an anonymous reviewer for their useful suggestions and Mike Pole for linguistic corrections.

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Plate V. Seed cones, cone scales and seeds of *Glyptostrobus europaeus* (Brongn.) Unger from the opencast mine at Bükkábrány.

1–5. Three-dimensionally preserved seed cones. Cone obovate, scales imbricate (up to 12) and helically arranged. Scale bar 1, 5: 1 cm, 2–4: 0,5 cm (PB.2008.99.6.).
6–7. Cone scale from a seed cone, both sides indicated. Cone scale oblong, distally rounded, proximally cuneate. Scale bar 0,5 cm (PB.2008.99.6.).
8–9. Seeds with remains of the wing. Scale bar 8: 0,5 cm, 9: 0,3 cm (Photo by Barbara Meller, Geological Survey).