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The Miocene Bükkábrány Fossil Forest in Hungary – field observations and project outline

Miklós KÁZMÉR[1]

(with 22 figures)

The oldest, standing forest preserved as wood has been found at Bükkábrány, Hungary. An open-pit mine working Upper Miocene (Pannonian) lignite revealed sixteen stumps, 1.8 to 3.6 m diameter at base, preserved up to 6 m height, standing on top of the coal bed. Suddenly rising water level of Lake Pannon drowned the forest 7 Ma ago. Sand of a prograding delta covered the landscape, preserving the trunks in waterlogged condition. A brief review of the environment allowing preservation is provided here, and investigations in progress are outlined.

Introduction

Fossil forests are those where trees stand in upright position, and where original forest structure is preserved. For various causes acting before and after – discussed below in some detail –, these instances are very rare.

A fossil forest was found in Bükkábrány open-pit coal mine, Hungary in July, 2007. Miners working on removal of overburden sand at 60 m depth excavated tree trunks on top of the coal seam. Directed to preserve these unusual fossils they removed sand layers with care and exposed 16 huge trees. Upon request of mine director Tibor MATA the local museum at Miskolc swiftly called a team of geologists and palaeontologists to study the sensational fossils.

We were guided to the site by mining engineer László SZOMOR. Driving down to the top of the coal seam at 60 m depth, we have seen dark tree trunks, 4–6 m high, several metres in diameter, standing 10–30 m apart. We felt like walking around in a Miocene forest (Fig. 1). Trees were intact, seemingly with bark, only the portion above 6 m was missing.

Fig. 1. Five excavated trunks standing on top of the lignite. See figure on the left for scale.

Scientific investigations started on the spot; here we report the first results. A team of geologists, palaeontologists and soil scientists from Eötvös University and the Hungarian Natural History Museum (both Budapest) and Szent István University (Gödöllő) was formed. Field observations and measurements were carried out on the stems and on the rapidly changing sand walls of the coal pit.

[1] Department of Palaeontology, Eötvös University, Pázmány Péter sétány 1/c, H-1117 Budapest, Hungary.
E-mail: mkazmer@gmail.com

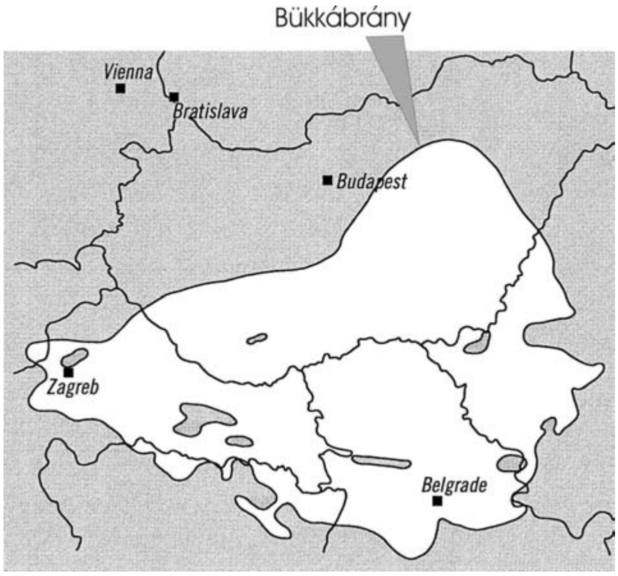

Fig. 2. Location of Bükkábrány at the northern margin of Lake Pannon – white, surrounded by land, shaded – in the Late Miocene (8 Ma palaeogeography map: MAGYAR et al. 1999).

This paper offers a first overview of field experiences during excavation and removal of fossil trunks. Initial observations on trees, forest structure, embedding sediment, preservation and mineralization are provided and illustrated.

Stratigraphy

The arcuate Carpathian Range surrounded Lake Pannon at the end of the Miocene. Rapidly emerging and eroding mountains supplied abundant sand – carried by large rivers from NW and NE – to fill the lake, deposited by enormous deltas. In Late Miocene (Pannonian) time the lake coast was just south of Bükk Mts (MAGYAR et al. 1999) (Fig. 2). A lush forest produced enough organic matter to accumulate in marshes, which formed coal seams when buried by sediments. Open-pit mines at Visonta and Bükkábrány work this coal.

Neither lignite nor overlying sand contain any fossils suitable for precise age determination. Correlation with well-dated borehole successions via seismic profiles is in progress, indicating an age of approx. 7 million years.

Trees and the forest

Fossil trees have been known from this and nearby localities, considered as *Taxodium* (e.g. KORDOS & BEGUN 2002) or *Sequioxylon* (PÁLFALVI & RÁKOSI 1979). Initial anatomical studies of the freshly recovered woody material allowed taxonomic affiliation of six trunks. *Taxodioxylon germanicum* (GREGUSS) VAN DER BURGH – related to modern *Sequoia* – and *Glyptostroboxylon* sp. Topmost layer of the coal yielded abundant foliage and cones of *Glyptostrobus* (ERDEI et al. 2008). Additionally, previous studies reported *Alnus, Ulmus,* and an extinct broadleaf shrub, *Byttneriophyllum* from nearby locations (e.g. HABLY 1992). Pollen assemblage of the lignite attest to a species-rich swamp and riparian forests dominated by Taxodiaceae (ERDEI et al. 2008).

Sharp ribbing seen on several trees is similar to those of giant redwood (*Sequoia*) (Fig. 3) . This genus is restricted to small areas in the mountains of California today; it never lives in marshes. However, before the ice age probably several, now extinct species of *Sequoia* lived in wetlands in America and Eurasia, proven by large amounts of its pollen in pre-Quaternary sediments (David DILCHER, pers. comm. 2007). Exact identification of these trees, and others found as driftwood, is in progress.

Trees of the forest stood in their life position, about 10-30 m apart, covering an area 100 m long, 50 m wide (Fig. 4). Taxonomic affiliation and a search for similar Recent environments brought up significant similarity with *Taxodium* forests of Florida (Fig. 5).

There are classical studies available on the leaf and pollen flora of Bükkábrány (PÁLFALVI 1952, RÁKOSI 1963). The poorly coalified coal bed contains significant amount of compressed wood debris. Occasionally an erect trunk was found both in Visonta and at Bükkábrány (PÁLFALVY & RÁKOSI, 1979). However, this is the first contiguous forest ever found.

Fig. 3. Heavily ribbed trunks resemble *Sequoia.*

Significance of the tree fossils

Fossil forests have been found on all continents and in most geological ages. Their wood is mostly mineralized: turned to silica or carbonate, rarely to pyrite. Forests preserved as wood are extremely rare. Ellesmere Island in Arctic Canada yielded several Eocene forests. Mummified trees there are either uprooted or preserved up to a few decimetres height only. The fossil forest of Dunarobba in the Italian Apennines is slightly mineralized, despite being only 2 million years old (ANONYMOUS 2000).

There are mummified, fallen logs and upright stumps up to 0.5 m height in Eocene strata of Arctic Canada (e.g. JAGELS et al. 2005). Erect, silicified or calcified trunks are known on all continents and from most geological ages (VADÁSZ 1963). However, it is a worldwide rarity to find such huge trees, in life position, preserwed as wood.

The Bükábrány Fossil Forest is the only location worldwide where large trees are preserved standing, in the original forest structure, as wood.

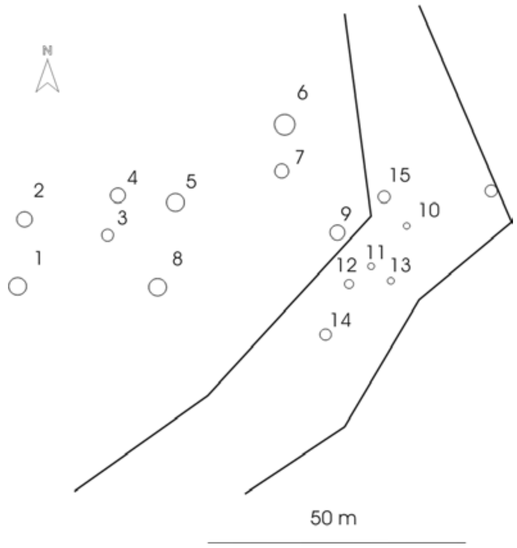

Fig. 4. Structure of the mature cypress forest. Circles are proportional to trunk diameter at ground level. Heavy lines indicate work walls in July 2007. Fifteen trunks were excavated and measured. The sixteenth one in the far right was made unavailable by quicksand. Map courtesy of Bükkábrány Mine, Ltd.

Fig. 5. Present-day *Taxodium* marsh in Florida – a similar forest is envisaged for the Miocene of Bükkábrány.

Burial

Lignite is covered by grey sand. It is well-sorted, fine to medium-grained sand, lacking certain grain-size fractions, behaving as quicksand if saturated with water. Sand was removed every morning from the lignite bed, being replaced again nightly by slowly flowing, water-saturated quicksand. Dangerous cavities were formed in the mine wall where water flowing from strata washed out sand.

Kilometre-long walls in the mine display stratified sand. Adjacent to the lignite bed, up to 1–2 m elevation it displays horizontal bedding. Stratification is accentuated by layers of organic debris (Fig. 6) and driftwood (Fig. 7). Thin pebbles strings embedded in sand (Fig. 8) were observed attached to the trunks. These features represent a lake bottom and toe-of-slope environment.

Upwards an approximately 20 m thick set of parallel beds follows, tilted northwards by 15˚ (Fig. 9). These are foresets of a prograding delta, covered by small-scale cross-bedding of a delta plain (Fig. 10).

The sand embedding trees is grey, up to a maximum of 6 metres above lignite. Upwards sand is variously coloured: yellow and brown. Boundary of grey and yellow sand conspicuously coincides with the top of tree trunks (Fig. 11).

We suggest that a sudden rise of 20 metres in level of adjacent Lake Pannon drowned the forest 7 million years ago. At this time some of the trees were already dead. Sand, transported by rivers in the lake enclosed the stems, and filled hollows and cavities within the trees. For 7 million years oxygen-free, bacteria-free, upwards percolating groundwater preserved the trees and particulate organic matter.

Fig. 6. Abundant organic debris outlines parallel bedding of lake bottom sediment.

Fig. 7. Driftwood embedded at toe of delta slope.

Fig. 8. Parallel pebble strings in coarse sand attached to ribbed cypress trunk at toe of delta slope.

Fig. 9. Oblique beds of delta front dip to north. Amplitude exceeds 20 m.

Fig. 10. Small-scale cross-bedding of delta plain.

Hydrogeology

Bükkábrány mine is a 2.5 km long, 1 km wide open pit. Sixty metres thick overburden is being removed to reach 12 m of low-calory coal, lignite. Tens of pumps depress ground water level by 80 metres so that all miners and machinery work in a dry pit.

The coal layer is exposed in a 2 km long, less than 100 m wide strip. The fossil forest has been found only in an 50 x 100 m area. This exceptional preservation even within the mine is due to a rare condition: grey sand, usually overlying the coal bed in about 0.5 m thickness, is about 6 m thick here. Reducing conditions here allowed preservation of trunks up to 6 m height. Further trunks are found elsewhere in the mine from time to time, as we were told by the miners.

Groundwater chemistry and ionic concentration determines degradation processes of buried wood (JORDAN 2001). Composition of groundwater within the sand surrounding the trees, within the yellow sand forming much of the overburden (pH, Eh, dissolved oxygen, NH_4 and NO_3 concentration) will be correlated with results of a scanning electron microscope study of wood-degrading organisms (BLANCHETTE 2000). We expect results on age of wood decay: preceding or contemporaneous with or postdating sedimentation.

Fig. 11. Trunks are preserved in grey sand. Darker, xidized, yellow to brown sand above displayed no trace of any embedded tree. The boundary along light grey colour of sand below cross-sects the leftward tdipping delta front beds dipping to north. North to left.

Preservation

At a first glance trees look like normal, wet wood, relatively soft when pressed by the finger. Only bark was missing except within pockets surrounded by xylem.

Living Cupressaceae (esp. *Taxodium*) are known to resist wood-degrading fungi and wood-borer insects. Despite this, several trunks display severe heartrot features, filled by grey sand and/or pyrite (Fig. 12). Tangential cracks and fissures indicate a variety of degradation processes (Fig. 13). Elastic cellulose of cell walls has been decayed to various degrees, while plastic lignin remained. When wet trunks are exposed to sunlight and air, they got fractured and contracted, producing thin peels (Fig. 14). The strong curvature is produced by high surface tension of evaporating pore water.[2]

[2] We thank András MORGÓS, chief conservator of the Hungarian National Museum, Budapest (now in Tsukuba, Japan) for his valuable observations and comments.

To understand type and pattern of subaerial fungal degradation and underwater bacterial decay, we are mapping of patterns by X-ray computer tomography (FÖLDES 2004) and identify decaying agents by scanning electron microscope study (Blanchette 2000) are in progress.

While erect tree trunks seemingly preserved their original three-dimensional shape, wood within the lignite bed is heavily flattened (Fig. 15). A fallen log (12 m long, 0.8 m thick) was a mere 0.2 m thick when dug up. In general, upright trunks and fallen logs differ in shape, compaction, and appearance. Changes can be described by colour and specific weight (Guyette & Stambaugh 2003), by porosity (MACCHIONI 2003), and by SEM study of cell structure (KISS 2008). The root collar seemingly have been sheared off stumps during differential compaction of wod and lignite (Fig. 16).

Trees suffered minor, but pervasive compaction as well. Faults and folds within trunks contributed to vertical shortening of trees (Fig. 17). Stems has been permanently below groundwater level for 7 million years. In the summer of 2007, while excavation work progressed, trees stood in summer heat, under direct sunlight, starting to dry. Centimetre-thick peels fell off their surface, and slowly curled while on the ground. András MORGÓS, a specialist in wood conservation, told us that elastic cellulose in wood cell walls has decayed some time ago, while plastic lignin remained. Surface tension of evaporating water within cells exerted so high stress on the cellulose-poor wood that it could not resist, bending in circular form.

Other trees suffered heartrot back in the Miocene. Their central cavity has been filled by sand, or by the mineral pyrite.

Fig. 12. Heartrot cavity filled by sand.

Mineralization

Seemingly the Bükkábrány fossil trees are preserved as wood. Appearance is like real wood, touching by fingers offers feel of wood. Soft when wet, hard when dry.

However, appearance can be deceptive: trees of the Pliocene forest of Dunarobba, Italy, are seemingly woody, while at least part of the wood is carbonatic now (SCOTT & COLLINSON, 2003).

While no pervasive mineralization is observed at Bükkábrány, there are a few pyrite-filled open fissures covered by mm-sized pyrite crystals[3] , at least one heartrot cavity fully filled by pyrite, and pyrite-cemented sandstone cakes attached to the surface here and there (Fig. 18).

Distribution of pyrite mineralization is traced by X-ray computer tomography. Intra-cellular distribution of mineralization will be tracked by scanning electron microscopy, X-ray fluorescence, microprobe, and laser ablation ICP-MS (KAGEMORI et al. 1999; SCOTT & COLLINSON 2003).

[3] István DÓDONY (Department of Mineralogy, Eötvös University, Budapest) kindly provided X-ray diffraction analysis of pyrite.

Fig. 13. Heartrot cavity filled by sand. Tangential fissures indicate a variety of degradation processes.

Fig. 14. Peeled-of fragments of trunks are curled while on sunshine due to low resistance of cellulose-poor degraded wood to tensile stress of evaporating water.

Sampling

Twelve trees out of sixteen excavated have been sampled (four were either unaccessible due to flowing quicksand or too dangerously fractured to access. Trees were mapped by the geodetic service of the mine. Diameter at base, at breast height and at the top were measured. Half disks ~20 cm thick were cut by a chain saw with vidia-tipped cutting chain enabled to cut through quartz sand or pyrite infill. Driftwood of overburden sand was sampled, too. Samples are kept under water in the tree-ring laboratory of the Deparment of Palaeontology, Eötvös University in Budapest, to avoid drying, deformation and fracturing.

Four trees have been packed and removed to Herman Ottó Museum in Miskolc (Figs 18–21), where they are being conserved with various methods: covered by wet sand, kept in clear water, and in sugar solution of various concentrations. Six trunks have been treated with construction glue and various resins by staff of the Bükk National Park. These are now on display at Ipolytarnóc Fossil Park.

Fig. 15. Roots (?) and coarse woody debris of cypress trees preserve shape and texture. Other woody material, degraded easier, makes the 'coal'.

Fig. 16a and b. Shiny fault planes with slickensides (encircled above) surround some trunks: the root zone was sheared off during compaction.

Tree-ring studies

At the time of cutting samples for tree-ring studies narrow rings less than 1 mm width were observed. Up to 400 rings were counted in a tree of 80 cm diameter. Unfortunately, freshly cut surfaces were oxidized within a few hours and ring boundaries cannot be observed at the moment. We expect trees of significantly higher age: living cypresses up to 1700 years are known in North Carolina (STAHLE et al. 1988).

It is expected that the oldest, 7 million years old, so-called long dendrochronological scale will be developed from the Bükkábrány material when chemical procedures make ring boundaries visible again. The next oldest scale is 50,000 years old, consisting of 1229 rings taken from a fossil forest buried by volcanic eruption (ROIG et al. 2001). This chronology will tell whether trees lived simultaneously, which were dominant, which were suppressed in growth, about recruitment periods, and other aspects of forest dynamics (SCHWEINGRUBER 1996).

Fig. 17. Trunk folded and faulted. Wavy fibers denote zones of heavy vertical compaction in trunk; shiny, black surface is a normal fault, obliquely cross-cutting fibers at ~5 m height.

Cell structure of tree rings allows studying of seasonality (rate of early and latewood), variability of precipitation (STAHLE & CLEAVELAND 1994), eventual aridity (incomplete and missing rings), intrannual ring width variability (sensitivity) (KELLER & HENDRIX 1997, FAIRON-DEMARET et al. 2003), and exposition to environmental stress (mean sensitivity of tree-ring series: ARTABE et al 2007).

We can tell if cypresses were evergreen or deciduous (based on cell structure and wall thickness of latewood: FALCON-LANG 2000a,b). Recent baldcypress forests are deciduous in North Carolina, while being evergreen in Florida.

Ring width of recent *Taxodium* species positively correlates with spring precipitation (despite their roots being underwater most of the year) and negatively correlates with temperature of growth period (STAHLE et al. 1998). Climate cycles, at least a decadal cyclicity is obvious in the ring series. Cycles being thicker than in living trees in Hungary we shall address the problem: which climate regime controlled Late Miocene climate in the Pannonian Basin? (See STAHLE et al. (1988) on shifting of the Bermuda high-pressure centre towards and away from US east coast every 30 years). We will check for NAO-like oscillations every 40 years, if solar cycles are recorded (a 7 year cycle has been proposed for the Miocene by BAKTAI et al. 1964).

Fig. 18. Pyrite-cemented sandstone encrusting a trunk.

Forest structure

Map of the fossil forest and measured data of individual trees allow to produce parameters used for characterizing forest structure: tree diameter, basal area, height, volume, dominant, subdominant and suppressed individuals, age/diameter relationship, trunk density, annual wood production, aboveground biomass (MOSBRUGGER et al. 1994; POLE 1999), and centennial trend of CO_2-sequestration under a greenhouse climate (OSBORNE & BEERLING 2002).

Age groups: germination of baldcypress seeds and initial growth of seedlings is possible under a multi-year arid period only; seeds do not germinate underwater. Therefore living baldypress forest consists of well distinguished age groups (STAHLE & CLEAVELAND 1992, STAHLE et al. 2006). Whether recent and Miocene forest structure are the same, whether there is any difference caused by evolution (PREGITZER et al. 2000), can be jointly answered with leaf flora analysis of L. HABLY and E. ERDEI and by pollen analysis of E. Magyari.

Alternation of regular flooding and multi-year aridity certainly leaves traces in the humic acid composition of soil.

Fig. 19. Trunks are packed in preparation for removal. A tree, surrounded by planks and fastened by steel bands, is being prepared for lift-off and transport.

Fig. 20. Tightly packed trunks were separated from stumps by chain saw while held by a crane. This tree starts its long journey to Herman Ottó Museum in Miskolc.

DNA

We got various suggestions to analyze fossil DNA presumably preserved in the wood. A 1320-base pair long chloroplast DNA fragment has been identified in Early Miocene *Taxodium* (SOLTIS et al. 1992). Since most of our trees had suffered some kind of decay in the Miocene (esp. fungal degradation), then were attacked by bacteria when underwater, even sterile sampling methods do not ensure identification of baldcypress gene. After consulting several DNA specialists it was concluded that hydrolysis of DNA underwater during 7 Ma probably severely destroyed the amino acid structure; we shall proceed with DNA analysis only if a resin pocket will be found.

Fig. 21. Packed trunk being fixed on trailer.

Fig. 22. Trunk in the foreground is too degraded and fragile for salvaging. It has been decayed back in the Miocene. In the background a tractor pulls a trailer with a trunk to be transported to the museum.

Summary of results and further studies in progress

An approx. 7 Ma fossil forest has been excavated at Bükkábrány, preserved as wood. Preservation was made possible due to a sudden rise of level of Lake Pannon, drowning the forest and burying it by the sand body of a delta. Water saturation lasting for 7 million years allowed preservation of woody material, with minimum of mineral precipitation. Being the oldest known forest on Earth preserved as wood, the Bükkábrány fossil forest deserves special study, outlined as follows.

- Age of the coal bed and forest (Imre MAGYAR)
- Taxonomy of plant fossils: wood (Martina DOLEZYCH), leaf flora (Lilla HABLY, Boglárka ERDEI), pollen flora (Enikő MAGYARI)
- Dendrochronology – age of the trees, their relative age, palaeoenvironmental changes (climate, seasonality, aridity, flooding), forest structure: dimensions of trees, social structure, comparison with recent forests (Miklós KÁZMÉR).
- Carbon isotope record of environmental change (Boglárka ERDEI)
- Formation of accommodation space and burial – lake level rise *vs* climate change and tectonics (Imre MAGYAR, Orsolya SZTANÓ, Miklós KÁZMÉR, Balázs FISCHER).
- Preservation of wood – cellulose loss, succession and timing of fungal and bacterial decay, mineralization (Miklós KÁZMÉR, Ákos KISS).
- Neotectonics of the overburden succession (Márton PALOTAI).

Acknowledgements

Travellers at Mátra and Bükk mountains do not think that there is a millions of years old, fossil forest underground. Spirit and dedication of directors and workers of the Bükkábrány mine made possible this exceptional fossil to be found, excavated, and preserved for science and for all of us. The greatest thanks goes to them!

Discovery, excavation, protection, and removal of trees from the mine was supported by Bükkábrány Coal Mine of Mátra Power Plant Co. Director Tibor MATA and engineer László SZOMOR initiated the study and – together with numerous co-workers – provided enthusiastic help and full logistics throughout field work in July-August 2007. Geodesy team of the mine surveyed the site. Personnel of Herman Ottó Museum, Miskolc, chiefly János VERES, archaeologist, were instrumental in digging, packing, transport and conservation of four trees. Directorate of Bükk National Park provided logistics for transport and cared for initial conservation and exhibition space for six trees. Enthusiastic field work assistance was provided by Lilla HABLY, Boglárka ERDEI, Sándor JÓZSA, Katalin SZABÓ, Balázs SZINGER, László MAKÁDI, András GRYNAEUS, Imre MAGYAR (all Budapest). András MORGÓS (Budapest–Tsukuba), and David DILCHER (Florida) generously shared their observations and expertise. Eleven TV, Bükkábrány: editor-cameraman Ákos VUKOVICH and City Television, Gyöngyös: editors and cameramen Zoltán FARAGÓ and Tibor GUBICS were the first representatives of the media ready to experience heat and mud and tell the general public about the new fossils. András GALÁCZ and Zoltán KERN read previous versions of the manuscript. Geological and palaeontological study is being supported by Hungarian National Science Foundation grant (K73.195).

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