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PALAEOGENE AND NEOGENE LOCALITIES IN THE NORTH HUNGARIAN MOUNTAIN RANGE

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Selected Palaeogene and Neogene fossil plant localities in the North Hungarian Mountain Range, introduced to participants of the 8th European Palaeobotany-Palynology Conference in Budapest, 2010, are presented here with site descriptions and data on the fossil plant record.

Key words: EPPC, fossil plant, Hungary, Neogene, Palaeogene, post-congress field trip guide

INTRODUCTION

A post-congress field trip of the 8th European Palaeobotany-Palynology Conference (EPPC 2010, 6–10 July, 2010, Budapest, Hungary) introduced several Palaeogene and Neogene fossil plant localities in the North Hungarian Mountain Range, i.e. the Visonta opencast lignite mine, and sites at Ipolytarnóc, the Eger-Kiseged roadcut, Rudabánya, and Erdőbénye. The field trip guide presented here intends to aggregate both published and unpublished data on the fossil plant record at the localities.

SITE DESCRIPTIONS

Visonta opencast lignite mine (Late Miocene)

Geology

The Pannonian stage (standard chronostratigraphy: Tortonian/Messinian) comprises one of the thickest non-marine late Neogene sedimentary sequences in Europe (RASSER and HARZHAUSER 2008). This sequence was deposited in the Pannonian Basin during the Late Miocene and Pliocene, following the cessation of intermittent marine connections of the basin towards the Mediterranean in the Middle Miocene (POPOV *et al.* 2004). The closed and subsiding Pannonian Basin trapped the sediments derived from the emerging Alps and Carpathians (HORVÁTH *et al.* 2006). Deposition took place in a large brackish lake, Lake Pannon, and in adjacent deltaic and fluvial environments (MAGYAR *et al.* 1999*a*).

In general, the Pannonian sequence in the northern part of the central Pannonian Basin consists of seven lithostratigraphic units, reflecting the gradual filling of the basin. These include (from bottom to top) lacustrine marls (Endrőd Formation), turbidites (Szolnok Formation), slope sediments (Algyő Formation), various deltaic deposits (Újfalu Formation), swamp deposits (Bükkalja Formation) and fluvial sediments (Zagyva and Nagyalföld Formations; CSÁSZÁR 1997, JUHÁSZ 1991). In the lack of marine fossils, the chronostratigraphic subdivision and correlation of the sedimentary succession is based on cross-correlations between regional aquatic biostratigraphy based on endemic Lake Pannon fauna and flora, European mammal stratigraphy, magnetostratigraphy, regional seismic stratigraphy, and radioisotopic age determinations from interbedded volcanic layers (HARZHAUSER *et al.* 2004, MAGYAR *et al.* 1999*b*). These correlations have indicated that the boundaries between the lithological units (formations) are highly diachronous; progradation and resulting shift of the environments from the basin margins towards the centre, dominantly from N–NW to S–SE, lasted for several million years (MAGYAR *et al.* 2007, POGÁCSÁS *et al.* 1994, VAKARCS *et al.* 1994).

The Visonta and Bükkábrány outcrops are located at the northern margin of the Pannonian Basin. Here, in the southern foreland of the Mátra and Bükk Mts, basinward shift of the shoreline remained insignificant, whereas deep basinal areas to the west and to the east had been progressively filled and turned into deltaic plains. The Visonta and Bükkábrány areas thus became a northern embayment of Lake Pannon by about 8 million years ago (MAGYAR *et al.* 1999*a*, VAKARCS *et al.* 1994) (Fig. 1).

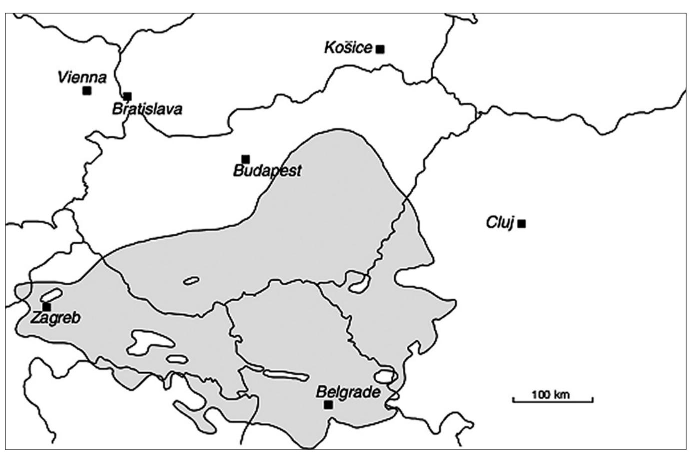


Fig. 1. Interpreted extent of Lake Pannon in the early *Congeria rhomboidea* Biochron, *ca* 8.0 Ma (MAGYAR *et al.* 1999*a*)

Beginning from 7.5 million years ago the water level of Lake Pannon experienced a significant and lasting rise. Aggradation became a dominant pattern, resulting in extreme thickness of the Újfalu and Bükkalja Formations (>1,300 m in the Tiszapalkonya Tk-I well) (ELSTON *et al.* 1994, JUHÁSZ E. *et al.* 1999, JUHÁSZ GY. *et al.* 2007).

The cyclic architecture of the Újfalu and Bükkalja Formations reflects repeated deepening and shoaling of the depositional environment, with formation of huminitic clays or lignite seams at the end of each cycle. Several authors suggested that this cyclicity was governed by astronomically induced climatic cycles (JUHÁSZ E. *et al.* 1997, KORPÁS-HÓDI *et al.* 2000). Paleoecological studies based on macroflora and vertebrate fauna indicate that the overall climate of the Pannonian Basin at this time was favourable for lignite formation (BRUCH *et al.* 2006, ERDEI *et al.* 2007, VAN DAM 2006). In the northern embayment of Lake Pannon, relatively thick (>2 m) lignite seams were deposited during the late phase of the aggradational period. These seams together with the intercalating barren beds comprise the Bükkalja Lignite Formation. The lignite has been industrially exploited in open pits since the 1960s. The lignite-bearing succession and its heteropic changes are shown in a cross section (Szokolai 1981 in CSILLING *et al.* 1985) (Fig. 2).

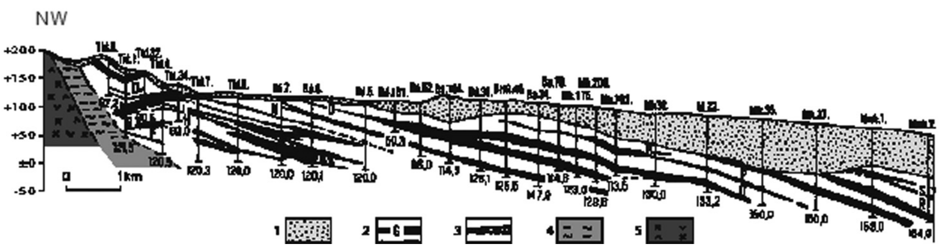


Fig. 2. Geological cross section showing the lateral variation of the Bükkalja Lignite Formation (Szokolai 1981 in CSILLING *et al.* 1985). 1 = Quaternary sediments; 2 = Upper Miocene (Upper Pannonian) succession with lignite seams; 3 = lignitic clay; 4 = Upper Miocene (Lower Pannonian) clay and clay-marl; 5 = Upper Miocene (Sarmatian) rhyolite tuff and brackish water sediments

Deposition of the lignite-bearing succession came to a halt when the area started a gradual tectonic uplifting, and southward tilting at the end of the Miocene. The resulting unconformity is the most significant one within the entire Pannonian stage (JUHÁSZ E. *et al.* 1999). It separates the lignite-bearing sediments (Újfalu and Bükkalja Formations), sometimes with obviously eroded or exposed surface, from onlapping fluvial deposits (Nagyalföld Formation). The age of the unconformity was assessed by biostratigraphic and magnetostratigraphic data (MAGYAR and SZTANÓ 2008, ELSTON *et al.* 1994). The sediments below the unconformity are Messinian in age (*Prosodacnomya vutskitsi* zone, *Galeacysta etrusca* zone, MN13), the youngest polarity zone was interpreted – with much uncertainty – as C3An2n, 6.8 Ma. The sediments above the unconformity belong to the Pliocene, as indicated by molluscs and mammals of MN14–15. The oldest polarity zone in this sequence was interpreted, with great confidence, as C3n2n, 4.6 Ma. Thus, the Bükkalja Lignite can be dated as 7.5–6.8 Ma old (CSÁSZÁR *et al.* 2009) (Fig. 3).

The opencast mine at Visonta, the so-called Southern seams, occupies an area belonging to four settlements, Detk, Ludas, Karácsond and Halmajugra. Exploitation of lignite at the opencast mine at Visonta began in 1964. Geological investigations in Visonta (Thorez mine) demonstrated the presence of three main lignite layers (Fig. 4). Clayey layers below the II lignite seam yielded leaf remains, whereas clayey layers above the same seam yielded leaves, fruits, seeds and a palynoflora, as well.

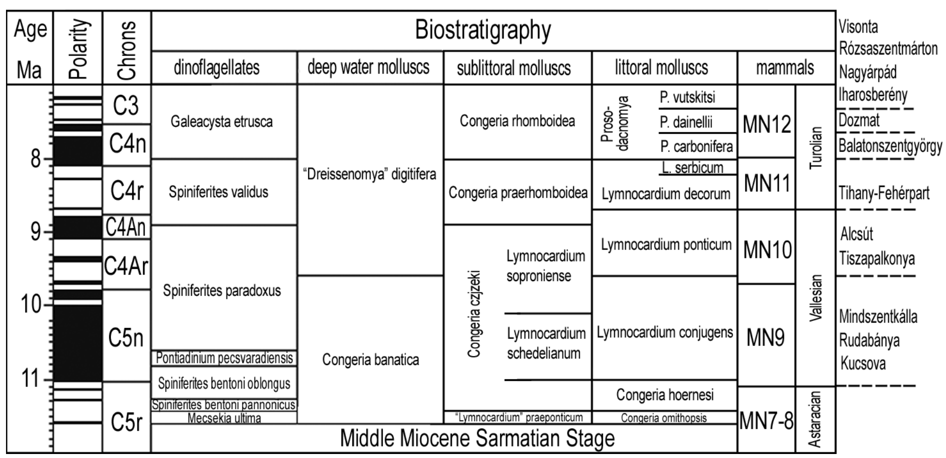


Fig. 3. Stratigraphic correlation of Lake Pannon biozones showing stratigraphic positions of Pannonian fossil plant assemblages of Hungary (Magyar, definition of biozones in MAGYAR *et al.* 1999*b*)

The Pannonian flora of Visonta

Plant fossils have been collected since the 1960s (BŮŽEK and LÁSZLÓ 1992, LÁSZLÓ 1989, PÁLFALVY and RÁKOSI 1979). In situ stumps similar to those discovered at Bükkábrány in 2007 (ERDEI *et al.* 2009) (Fig. 5) were already exposed in the opencast mine at Visonta (PÁLFALVY and RÁKOSI 1979), and were determined as *Sequoioxylon gypsaceum* (Goeppert) Greguss. Among the leaf and carpological remains recorded by PÁLFALVY and RÁKOSI (1979) and LÁSZLÓ (1989) the most abundant ones are gymnosperms (*Glyptostrobus*) and the angiosperm *Byttneriophyllum*, *Alnus*, *Carpinus*, other betulaceous leaf fragments, *Salix*, *Stratiotes*, unidentified monocotyledonous leaves and a fern *Osmunda parschlugiana*.

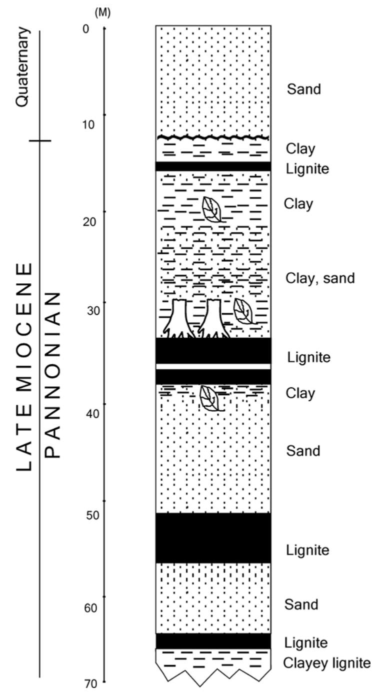


Fig. 4. Generalised geological profile of Pannonian deposits in Visonta (after LÁSZLÓ 1989)

Fig. 5. In situ upright tree trunks in the opencast mine at Bükkábrány (Bükkalja Lignite Formation). The Fossil Forest horizon is underlain by a thick lignite seam (under excavation) and overlain by a soft grey and yellow sand. Six of the stumps were identified: *Glyptostroboxylon* and *Taxodioxylon germanicum* (Dolezych in ERDEI *et al.* 2009; Photo: B. Erdei)

Based on the macro-remains and pollen spectra PÁLFALVY and RÁKOSI (1979) reconstructed the local vegetation. A mosaic of swamp forests was composed of *Glyptostrobus* (and *Taxodium*) or *Alnus* and *Salix*. On the floodplain areas forests flourished consisting of *Salix*, *Ulmus*, *Zelkova*, *Betula*, *Juglans*, *Carya*, *Pterocarya*. Mesophytic habitats were occupied by *Quercus*, *Tilia*, *Carpinus*, *Castanea* and *Fagus*. Aquatic habitats are referred to by *Stratiotes*, *Potamogeton* and *Trapa*.

According to subsequent collections and studies by László, the following taxa were described by BŮŽEK and LÁSZLÓ (1992): *Selaginella* sp., *Equisetum* sp., *Salvinia* cf. *intermedia*, *Taxodium* sp., *Glyptostrobus europaeus*, *Pinus* sp., *Tsuga* sp., *Picea* sp., *Abies* sp., *Liriodendron* sp., *Ranunculus* sp., *Nymphaea szaferi*, *Nuphar palfalvyi*, *Pseudoeuryale* cf. *dravertii*, *Ceratophyllum dubium*, *Lycopus* cf. *europaeus*, *Decodon gibbosus*, *Actinidia faveolata*, *Oenanthe* sp., cf. *Prunus* sp., *Alnus* sp., *Carpinus* sp. ex gr. *betulus*, *Salix* sp., *Fagus decurrens*, *Pterocarya* sp., *Nyssa disseminata*, *Meliosma* cf. *wetteraviensis*, *Cornus* cf. *gorbunovii*, *Sambucus pulchella*, *Hartziella miocenica*, *Ilex* sp., cf. *Stuartia* (*Stewartia*) *beckerana*, *Potamogeton* sp., *Caldesia* cf. *cylindrica*, *Stratiotes tuberculatus*, *Carex* sp. and *Spirematospermum wetzleri*.

According to BŮŽEK and LÁSZLÓ (1992) the plant assemblage represents wetland vegetation with some influence of mesophytic forests. The latter should be considered as allochthonous component in the more or less autochthonous assemblages. Three main types of wetland vegetation are reflected by the fossil remains: marginal riparian, swamp and open water vegetation. Coal-forming swamps are evidenced by *Glyptostrobus europaeus*, which were quite common with a large number of twigs, cone-scales and seeds (Fig. 6).

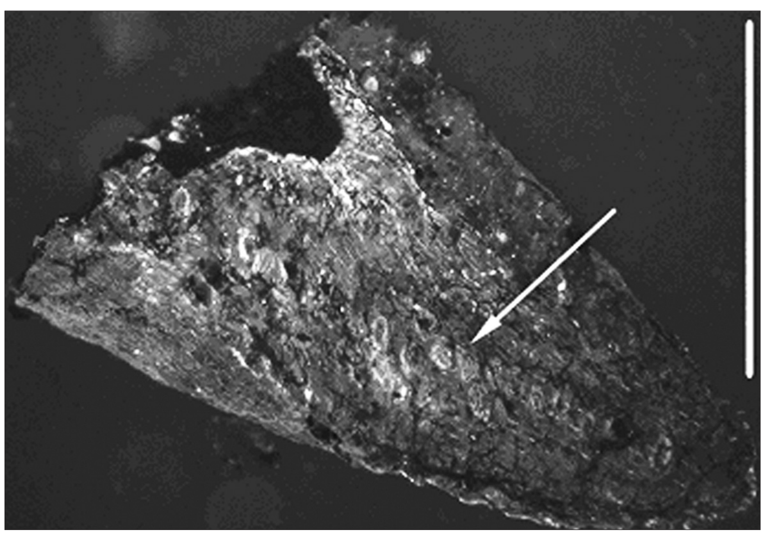


Fig. 6. Cupressoid type leaf of *Glyptostrobus europaeus*. Stomata arranged in two bands (arrow) are well observable on the upper side (fluorescence microscopy) (scale bar = 500 μm; ERDEI *et al.* 2009)

Additional rare elements in swamps were *Taxodium*, *Nyssa* and *Heliosma*. A frequent element, *Spirematospermum* was recorded in high numbers. Hydrophyte herbs are represented by *Caldesia* and *Oenanthe*. Marginal riparian and periodically flooded forest is usually present and seems to be dominant; it was probably widespread in the region of the brown-coal basin of Visonta. In the tree and shrub layers *Alnus* was dominant associated with *Carpinus*, *Salix*, *Cornus*, *Liriodendron*, *Pterocarya*, *Sambucus*, *Actinidia* and *Ilex*. In the herb layers *Carex*, *Ranunculus*, and *Selaginella* can be mentioned. *Decodon* was part of the swamp or aquatic vegetation. The aquatic vegetation is represented by surface floating plants (*Nymphaea*, *Pseudoeuryale*, *Nuphar*, *Salvinia*, *Potamogeton*), emerged water plants (*Stratiotes*), and submerged plants (*Ceratophyllum*). *Hartziella* was probably a subaquatic plant. Allochthonous elements are *Fagus*, cf. *Stuartia* (*Stewartia*), cf. *Prunus* and some members of Pinaceae.

The fossil track site at Ipolytarnóc (Early Miocene)

The age of the fossiliferous layers

Abundant Early Miocene mammal and bird tracks and a rich plant assemblage are preserved by the emplacement of an ignimbrite sheet of the Gyulakeszi Rhyolite Tuff Formation (GRTF) near Ipolytarnóc in northern Hungary. The tuff that overlies the track-bearing sandstone yielded an U–Pb total isochron age of 17.42±0.04 Ma and a 40Ar/39Ar age of 17.02±0.14 Ma. An additional 40Ar/39Ar age of 16.99±0.16 Ma was obtained from the equivalent rhyolite tuff near Nemti, where the underlying terrestrial clay yielded early proboscidean remains assigned to the MN4 mammal zone. The new, high-precision dates allow revision of the numeric age and correlation of the Ipolytarnóc fossil site and the GRTF, previously based on an average K–Ar age of 19.6±1.4 Ma. Published biostratigraphic data from under- and overlying marine strata establish correlation with the NN3 nannoplankton zone and, together with the new radioisotopic ages, suggest assignment of the fossils and the tuff to the Ottnangian regional stage of the Central Paratethys. A global correlation lends support to the recently suggested astronomical calibration of the Early Miocene time scale that revised the previous scales towards younger ages. The 40Ar/39Ar age from Nemti provides a reliable correlation of the MN4 mammal zone in Central Europe with the numeric time scale and places a minimum constraint on the age of the regional Proboscidean Datum, the migration event of proboscideans from Africa to Europe through the emerging "Gomphotherium landbridge". Contrary to suggestions for a significantly earlier European Proboscidean Datum, it appears that the originally suggested age of *ca* 17.5 Ma is realistic but it is significantly younger than the South Asian Proboscidean Datum (Pálfy *et al.* 2007).

Geological setting

Ipolytarnóc and the Nógrád Basin lie on the inner side of the Western Carpathian Arc, near the northern margin of the Pannonian Basin. The Alpine–Carpathian–Pannonian region is characterised by a complex Tertiary tectonic evolution. Orogenic uplift of the Alpine range led to the formation of Paratethys, semi-isolated marine epicontinental basins with variable degree of connection to the Mediterranean, Atlantic, and Indo-Pacific during the Palaeogene and Early Neogene. The sedimentary basin evolution of the north Pannonian Basin is linked with the history of Central Paratethys and controlled by the interplay of eustasy and regional tectonics. As part of the Central Paratethys, the Hungarian Palaeogene Basin is interpreted as a retroarc flexural foredeep where molasse-type sedimentation prevailed until the Early Miocene. Miocene succession basins, including the Nógrád–Filakovo Basin, record a change from compressional to extensional tectonic setting. The Lower Miocene stratigraphy is well established locally for the vicinity of Ipolytarnóc (Fig. 7), more broadly for the Nógrád Basin, and regionally for Hungary. The chronostratigraphic framework uses the Central Paratethys regional stages of Eggenburgian, Ottnangian and Karpatian, correlated with the standard Burdigalian Stage. Much of the upper Eggenburgian is comprised of a transgressive–regressive sedimentary cycle.

At Ipolytarnóc, a borehole penetrated nearly 200 m of basinal, deep-water siltstone (Szécsény Schlier Formation). Its uppermost part is exposed on the surface and overlain by up to 50 m of locally glauconitic sandstone of nearshore facies (Pétervására Sandstone Formation). This unit is transitional to the Budafok Sand Formation, exposed farther to the west. At certain levels the sandstone contains abundant marine Eggenburgian mollusc fauna and shark teeth, and is in turn overlain by terrestrial strata of the Zagyvapálfalva Formation. An unconformity between the two formations is indicated by an irregular erosion surface. Whereas elsewhere the Zagyvapálfalva Formation is dominated by variegated clays of continental to lagoonal facies, at Ipolytarnóc it contains 1–6 m of fluvial conglomerate overlain by 2 m of the track-bearing sandstone (informally called the Ipolytarnóc beds). The sequence is capped by a 10–30 m thick ignimbrite sheet, the subject of radio-isotopic dating mentioned above. The dated tuff is traditionally assigned to the Gyulakeszi Rhyolite Tuff Formation (GRTF), previously called the "Lower Rhyolite Tuff". This unit is the oldest product of the explosive silicic volcanism that is widespread in the Miocene of the Pannonian Basin. It is widely held that the silicic pyroclastics occur in three distinct horizons, although recently reported geochemical and petrological evidence suggests the possibility of a more continuous temporal distribution of multiple eruptions. The age of GRTF is known from numerous K–Ar dates and stratigraphically it is conventionally regarded to mark the base of the Ottnangian, even though the biostratigraphic constraints are loose. The ignimbrite grades upwards into reworked pyroclastics, overlain by terrestrial variegated clay, siltstone, and sand of the Salgótarján Formation. Elsewhere in the Nógrád Basin, this formation contains economically important coal measures of paralic facies. The other sampled site between Nemti and Bátonyterenye is located in the southern part of the abandoned Salgótarján mining district. The site is within the type area of the GRTF, where the ignimbrite is underlain by variegated clay of the Zagyvapálfalva Formation.

As the Nógrád–Filakovo Basin straddles the Hungarian–Slovak state border, a partly different lithostratigraphic nomenclature is used in the Slovak literature. Of interest are the Lipovany Sandstone Formation, equivalent of the Pétervására/Budafok formations, and the Bukovinka Formation, equivalent of the Zagyvapálfalva Formation, and the "Rzehakia beds", referred to as the Medokys Member of Modry Kamen Formation in Slovakia and the Kazár Member of Egyházasgerge Formation in Hungary (PÁLFY *et al.* 2007).

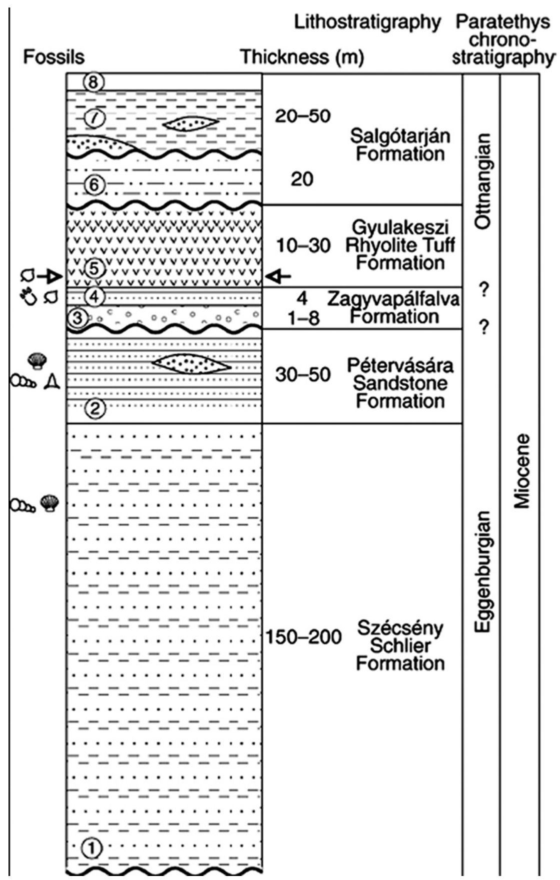


Fig. 7. Generalised Miocene stratigraphy of the Ipolytarnóc area (after BARTKÓ 1985). The position of samples for radio-isotopic dating is marked by arrowheads. Lithology: 1 = silty and clayey sandstone; 2 = glauconitic sandstone with conglomerate lenses; 3 = pebble conglomerate; 4 = trackbearing sandstone; 5 = rhyolitic ignimbrite; 6 = redeposited tuff and sandstone; 7 = variegated clay; 8 = sand

The Early Miocene flora of Ipolytarnóc

The enormous silicified trunk exhibited in the main exhibition hall was the first object that has drawn widespread attention to the unique fossils of Ipolytarnóc. Latest Pál Greguss studied the trunk and described it as a new species, *Pinuxylon tarnocziense* (GREGUSS 1967). High number of leaf remains, in the order of 10 thousands, was excavated from the Botos-árok (pit), Borókás-árok (pit), Csapás-völgy (valley), Fehér-hegy (hill). Most of the fossil leaves were yielded by the 20–40 cm thick lower layers of the Gyulakeszi Rhyolitic Tuff Formation. JABLONSZKY (1914) was the first who studied the fossils, later RÁSKY (1959, 1964, 1965), PÁLFALVY (1976) and HABLY (1985, 1986) published the flora of the tuff. The sandstone layers underlying the tuff contain less and rather poorly preserved plant remains. Among others, the flora of the tuff comprises lichens and pteridophytes – *Lobaria jablonszkyi* Rásky, *Pronephrium stiriacum* (Unger) Knobloch et Kvacek, *Woodwardia muensteriana* (Presl in Sternberg) Kräusel, *Dryopteris kümmerlei* Jablonszky, *Asplenium* sp., gymnosperms – *Tetraclinis salicornioides* (Unger) Kvaček, *Pinus saturni* Unger, *Pinuxylon tarnocziense* (Tuzson) Greguss and *Pinus* sp. However, the dominance of angiosperms is proved first of all by the high frequency and diversity of Lauraceae. Due to the high ratio of laurophyllous elements MAI (1995) characterised it as an "extremely laurophyllous" flora and established a separate "Florenkomplex" based on the Ipolytarnóc assemblage. The family Juglandaceae is well represented by *Engelhardia orsbergensis* (Wess. et Web.) Jähnichen, Mai et Walther and *Cyclocarya cyclocarpa* (Schlecht.) Knobloch. Another noteworthy dominant element is *Platanus neptuni* (Ett.) Buzek, Holy et Kvaček belonging to the Platanaceae family. Besides the *ca* 50 dicotyledonous taxa, monocotyledonous plants have also formed a significant part of the flora and vegetation. *Smilax* div. sp. frequently occurred in the flora and palms were represented by *Sabal major* (Unger) Heer and *Calamus noszkyi* Jablonszky.

Composition of the sandstone flora does not differ essentially from the flora of the tuff, however, it shows lower diversity and poor preservation. The floral spectrum is quite similar, comprising the same dominant taxa. *Ulmus pyramidalis* Goeppert is the only species missing in the tuff flora. The riparian habit of this species may serve as a possible explanation for its absence in the tuff.

Nearly all taxa occurring in the Ipolytarnóc assemblage represent the so-called "Palaeotropical" elements. Temperate or "Arcto-Tertiary" elements play a definitely subordinate role. In this context coeval European floras differ considerably since displaying a dominance of temperate elements. The flora of Ipolytarnóc is characterised by the mass occurrence of laurophyllous and other "Palaeotropical", exotic and thermophilous elements, suggesting a subtropical-tropical climate. In the respect of both climate requirements and floristical character the assemblage is even definitely distinct of regional floras, which lends support to the assumption that Ipolytarnóc must have developed isolated from other European floras at more southerly latitudes than its present-day position (HABLY and KÁZMÉR 1996).

The Kiseged road cut (Early Oligocene, Bükk Mountains)

Geology

Geotectonic interpretation of the pre-Neogene basement of the Pannonian Basin has been completely changed in the last twenty years. Increasing surface and especially borehole data have revealed the total untenableness of the classical concept. Instead, it has been recognised, that this basement and the close Alpine–Carpathian–Dinaric surroundings of the basin are built up by a collage of allochthonous terranes deriving from different parts of the Tethys, which have finally accreted in the Late Oligocen–Early Miocene times. This discovery was important to understand the relations between the pre-Neogene floras as well.

This terrane collage is bounded on the north and northeast by the Pieniny Klippen Belt, on the east and southeast by the Mures Ophiolite Belt and the Median Dacides of the East and South Carpathians, whereas on the south and southwest by the Inner Dinaric–Vardar ophiolitic complex. On the other hand, there is no distinct boundary on the west towards the Eastern Alps, from where the eastward directed escape of the "North Pannonian–Inner West Carpathian" units, nearly along strike, took place.

Within the Pannonian domain five evolutionary stages can be distinguished, which characterise all the basement units. In our point of view the Mesoalpine structural stage is important, which during the Palaeogene, is characterised by major strike-slip faulting and terrane movements. It is unique in the Pannonian domain in the European Alpides, that here formations and structures related both to the Axios/Vardar Ocean and of the Pennic Ocean overlap each other, mainly due to Mesoalpine terrane movements. All these terranes had a far more southerly position than today, and even the stable Europe was found more to the south than today.

During the Eocene–Early Oligocene a large Palaeogene basin existed in Slovenia, which gave rise to the deposition of the Tard Clay. Sediments of the Tard Clay Formation are well dated by nannoplanktons as representing the NP21-23 nannoplankton zones. Sediments belonging to the NP23 zone contain a rich fossil plant assemblage.

Sediments well corresponding to the Tard Clay were described in other parts of the Alpine–Carpathian–Dinaric region, containing a quite similar flora, i.e. Häring in Austria, Sotzka beds in Slovenia, Mera and Bizusa-Ileanda beds in Transylvania (Romania), in the Outer Carpathian Flysch the Menilite Formation, in Bulgaria and partly in Serbia, there are several other plant bearing sediments found in close proximity to each other matching well to the others. In the South Alpine foreland, at Vicenza, Italy, similar sediments of Early Oligocene age have been documented as well.

Starting from Eger through the Vécsey valley in the direction of Noszvaj the road clambers up from the valley of the Ostoros streamlet to a small depression between the Eged and Sík hills. Road bends are often cut into the Kiseged hill. These pits provide interesting profiles spanning the Priabonian–Kiscellian stages. A disadvantage of the open casts is that the profile is non-contiguous, which is further increased by falling rocks. A normal fault stretching towards the valley of the Ostoros streamlet had displaced the sediments of the upper Kiscellian Kiscell Clay adjacent to sediments of the lower Kiscellian Tard Clay. Though the NE–SW trending fault is nearly parallel to the serpentine road this fact is not apparent at first sight.

The Kiseged profile, though from another pit, was well known for geologists as early as between the two World Wars, however it was not published. WEILER (1933, 1938) described the "middle" Oligocene ichtyofauna of Kiseged. A detailed description of the Kiseged profile was published by BÁLDI *et al.* (1983), and later by NAGYMAROSY (NAGYMAROSY 1986, NAGYMAROSY *et al.* 1989). Regional biostratigraphy was studied by BÁLDI *et al.* (1984) and MONOSTORI (1986, 1987).

Fossil plants have been collected since the 1950s mainly by Ferenc Legányi. Most of the considerably rich collection is housed in the Hungarian Natural History Museum and partly in the Mátra Museum. ANDREÁNSZKY (1954) and his students (ANDREÁNSZKY and CZIFFERY 1964, NOVÁK 1950) started to investigate this collection and recent systematic works have followed them, i.e. HABLY and FERNANDEZ-MARRON 1998, HABLY and MANCHESTER (2000), HABLY and THIÉBAUT (2002), KVAČEK and HABLY (1998), KVAČEK *et al.* (2001), MANCHESTER and HABLY (1997).

The geological profile can be seen on Figure 8.

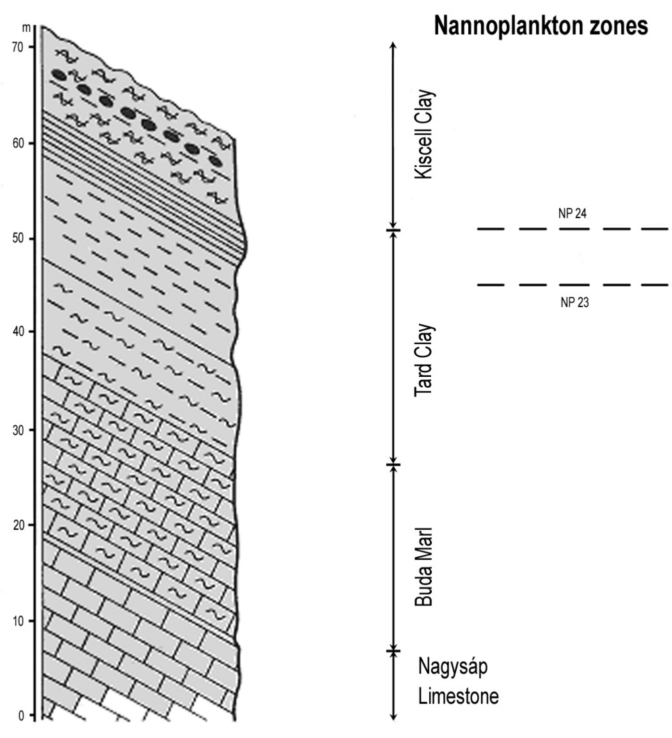


Fig. 8. Geological profile of the Kiseged road cut (NAGYMAROSY 1986)

Priabonian slightly clayey limestone: Its fossil content is rarely molluscs, large foraminifers and small coral reefs. A detailed palaeontological study has not been accomplished yet. The sediments represent a shallow marine facies, not deeper than 20 m and belong to the Szépvölgy Limestone Formation. The latter shows an increasing clay content and graduates into the Buda Marl Formation the lower two thirds of which represents the Upper Eocene. In the road cut we can find a yellowish variety of the Buda Marl.

Tard Clay: There are excellent outcrops of this formation along the road. The nearly ten metres thick lower layers of the Tard Clay do not exhibit the laminated character of the facies. The single Hungarian occurrence of the endemic mollusc assemblage with *Cardium lipoldi*, *Ergenica cimlanica* and *Janschinella melitopolitana* was recorded from the upper level of this section (BÁLDI 1979, 1980, 1983, 1986). The level ("solenoj horizon") can be detected from the upper Austrian molasse basin towards the Aral-Caspian Basins and documents the first isolation, the birth of the Paratethys (Eoparatethys). In addition to the taxa mentioned above, *Hydrobia*, *Spiratella* (*Limacina*) species and quite a large ostracod are noteworthy. Due to its widespread occurrence the level was described as "osztrakodovije szloji" in the Caspian, Caucasian region.

According to MONOSTORI (1986), euryhalin species dominate the ostracod fauna whereas stenohalin elements are subordinate and limnic forms appear in the uppermost layers: *Bosquetina reticulata*, *B. zalanyii*, *Cancona? recta*, *Cuneocythere marginata anterodepressa*, *Curvopsis curvata*, *Cytheromorpha subalpina dorsodepressa*, *Cytheropteron emmeneggeri*, *Eucytheridea reticulata*, *Loxoconcha carinata tardense*, *Megahemicythere oertlii*, *Pterygocythereis* sp., *Schuleridea rauracica*.

Foraminifers occur only sporadically in this level of the Tard Clay. According to Horváth (in BÁLDI *et al.* 1983) the taxonlist includes: *Globigerina gortanii*, *G. officinalis*, *G. ouachitaensis ouchataensis*, *G. praebulloides occlusa*, *G. praebulloides praebulloides*, *Globigerinita martini scandretti*, *Globorotalia* (*Turborotalia*) *obesa*, *G.* (*T.*) *optima nana*, *Lagena isabella*, *Lenticulina* sp., *Pseudonodosaria discreta*, *Sphaeroidina bulloides*, *Subbotina* (*Globigerina*) *angiporoides*, *S.* (*G.*) *ouachitaensis gnaucki*, *Uvigerina eocaena*.

The nannoflora of the "*Cardium lipoldi*" horizon is characterised by the association of the endemic *Reticulofenestra ornata*, *Transversopontis latus*, and *T. fibula* (NAGYMAROSY 1991). The occurrence of *Sphenolithus distentus* supports the classification of the endemic forms to the NP 23 nannoplankton zone.

The upper level of the Tard Clay is laminite and strongly resembles the coeval but deeper marine menilit or dyzodyl shales known from the flysch zone of the Carpathians. The characteristic trait of this facies is the high silica content, which had hardened the sediments. Presumably hydrothermals leaking along the fissures had silicified the sediments as it was observed in the Buda Mountains. Great numbers of plant and fish fossils were yielded by these layers.

The silicified "fish" layers and layers above them contain neither microfauna nor nannoplanktons. The youngest layers of the profile belong to the Kiscell Clay, representing better oxygenated marine conditions of normal salinity. According to Horváth (in BÁLDI *et al.* 1983) the rich epibathyal benthonic fauna comprises the following taxa: *Globigerina anguliofficinalis*, *G. angustiumbilicata*, *G. eocaena*, *G. euapertura*, *G. officinalis*, *Globorotalia* (*Turborotalia*) *munda*, *G.* (*T.*) *trefa*, *Subbotina angiporoides*.

The plantonic foraminifers of the sediment mark the P20 zone of Blow (Horváth in BÁLDI *et al.* 1983).

Based on benthonic foraminifers the *Cassidulina vitalisi* zone is characterised by the following taxa (Horváth in BÁLDI *et al.* 1984): *Ammobaculoides humboldti*, *Anomalina affinis*, *A. cryptomphala*, *Bolivina antiqua*, *B. elongata*, *B. fastigia*, *B. reticulata*, *B. semistriata*, *Bulimina alazanensis*, *Cassidulina margareta*, *C. vitalisi*, *Cibicides pseudungerianus*, *Cyclammina acutidorsata*, *Globocassidulina subglobosa*, *Gyroidina soldanii*, *Heterolepa costata*, "*Neobulimina*" *budensis*, *Osangularia umbonata*, *Planularia nummulitica*, *Planulina costata*, *Pullenia bulloides*, *Rectobolivina zsigmondi*, *Trifarina globosa*, *Triplasia hungarica*, *Tritaxia szabói*, *Tritaxilina reussi*, *Uvigerina farinosa*, *U. hantkeni*, *Vulvulina haeringensis*.

Monostori (in NAGYMAROSY *et al.* 1989) described a deep sublittoral–epibathyal ostracod assemblage from these layers of the Kiscell Clay with *Cytherella pestiensis*, *Cytherella* sp., *Eucytherura dentate*, *Krithe pernoides* and *Paracypris rupelica*.

The Kiseged profile contains the nannoflora characteristic of the Kiscell Clay, which corresponds to the NP24 nannoplankton zone: *Cyclicargolithus abisectus*, *Sphenolithus ciperoensis*, *S. distentus*, *S. predistentus*.

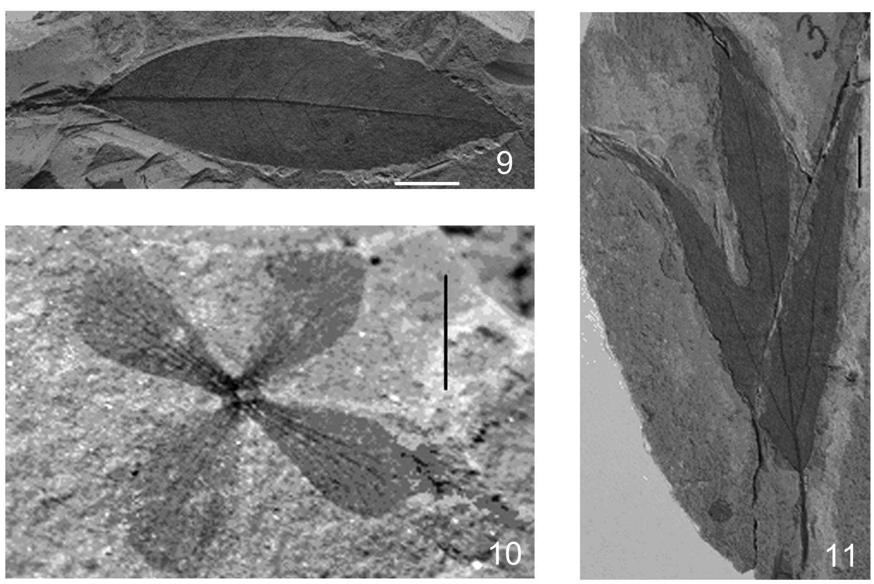
The Kiseged macroflora

A rich macroflora was yielded by sediments of the Tard Clay Formation in Kiseged (Figs 9–11). Since the 1950s several thousands of remains have been collected from this area, mainly leaf fossils originating from the upper fish layers belonging to the NP23 zone. According to the latest revision, the flora list contains: *Osmunda lignitum*, *Pronephrium stiriacum*, *Acrostichum aureum* = *A. lanzaeanum*, *Anthrophytes egedensis*, *Pteris budensis*, *Blechnum dentatum*, *Doliostrobus taxiformis*, *Chamaecyparites hardtii*, *Tetraclinis brachiodon*, *T. salicornioides*, *Calocedrus suleticensis*, *Pinus palaeostrobus*, *Pinus* sp. div., *Laurophyllum. acutimontanum*, *L. hradekense*, *L. kvacekii*, *L. markvarticense*, *L. medimontanum*, *Daphnogene cinnamomifolia*, *Sassafras tenuilobatum*, *Nymphaea* sp., *Platanus neptuni*, *P. schimperi*, *Matudaea menzeli*, *Eotrigonobalanus andreanszkyi*, *E. furcinervis*, *Quercus lonchitis*, *Comptonia schrankii*, *Comptonia* sp. (div. ?), *Myrica* (*Comptonia*) *acutiloba*, *Engelhardia macroptera*, *E. orsbergensis*, *Hooleya hermis*, *Alnus* sp., *Cedrelospermum aquaticum*, *C. fichei*, *Craigia bronnii*, *Dombeyopsis* sp. = *Byttneria apiculata*, *Ailanthus* sp., *Sloanea elliptica*, *S. eocenica*, *Dalbergia bella*, *Mimosites haeringianus* = *M. budensis*, *Leguminocarpum* sp. div., *Dolichites triangularis* = ?*Phaseolites glycinoites*, *Cercis hungarica*, cf. *Gordonia* = *Saportaspermum*, *Acer* sp., *Zizyphus zizyphoides*, *Tetrapterys harpyiarum*, *Hydrangaea microcalyx*, *Raskya vetusta*, *Tarrietia hungarica* = *Machaerites hungaricus*, *Sabal major* = *S. hoeringiana*, *Smilax weberi*, *Dioscoreites giganteus* and *Dioscoreaecarpum marginatum*.

The flora of Kiseged comprises thermophilous "Palaeotropical" elements frequently indicating xerophytic traits. Its floristical composition nearly equals that of the Óbuda localities, although with a more pronounced xerophytic character. Some dominant taxa of the Tard Clay, i.e. *Eotrigonobalanus furcinervis*, *Palaeocarya* (*Engelhardia*) *orsbergensis*, *Zizyphus zizyphoides* have 1–5 cm smaller and slender leaves in Kiseged than in Óbuda and this is true for other, accessory elements such as *Sloanea olmediaefolia.* Small-scale difference of floristical composition is observed between the Kiseged and Óbuda localities, *e.g. Ailanthus tardiensis* is missing from Kiseged, but other taxa previously thought as evidence of floral distinction are present in both Tard Clay outcrops (Buda and Bükk Mts).

High number of winged fruits/seeds have also been collected here, *e.g. Cedrelospermum* sp., *Engelhardia brongniarti*, *Eotrigonobalanus andreánszkyi*, *Raskya vetusta*, and *Tetrapterys harpyiarum*, etc. In numerous cases organic material (cuticle) of leaves is preserved, providing tool for systematic identifications (*e.g. Laurophyllum*, *Sloanea* species). The Tard Clay flora is quite similar to the floras of the Sotzka, Búzási, Nagyilondai and Mérai layers and at the same time definitely distinct from Central European coeval floras at northerly latitudes, which include high numbers of "Arcto-Tertiary" elements. In addition to the characteristic and dominant elements, shared endemics with the Slovenian floras are noteworthy here, which support reconstructed palaeogeographical constraints. Accordingly, the Palaeogene basins of the Buda, Bükk and the Slovenian regions are outlined as located much closer to each other and forming one single basin (Báldi 1989, Csontos *et al.* 1992, Royden and Báldi 1988).

Most of the plant remains represent the zonal vegetation and suggest a warm, relatively dry (with an apparent dry season) subtropical climate.



Figs 9–11. 9 = *Platanus neptuni*, Eger-Kiseged (scale bar = 1 cm, HNHM); 10 = *Raskya vetusta*, Eger-Kiseged (scale bar = 1 cm, HNHM); 11 = *Sassafras tenuilobatum*, Eger-Kiseged (scale bar = 1 cm, HNHM)

Rudabánya, former open cast iron ore mine (Late Miocene, Rudabánya Mts)

Introduction and geology

The most important Eurasian locality of the early phase of hominisation (i.e. the time when only apes of ancient type lived) can be found at Rudabánya, in the abandoned open-pit of the iron ore mine. The iron ore, which developed within the Lower and Middle Triassic successions, is accompanied by an extremely rich mineral assemblage. The most frequent minerals are coppers (*e.g.* native copper, azurite, malachite and chalcopyrite); nevertheless, noble metals, such as gold and silver also occur.

The Triassic successions are overlain by Pannonian formations (stand. chron.: Tortonian/Messinian, Late Miocene) the original geomorphology of which has been essentially altered due to intense mining activities having a starting point as early as the Middle Ages. The overall landscape of the former mine area is now basically defined by mine dumps and the original sediment successions and dimensions are hardly or cannot be reconstructed at all (Kretzoi *et al.* 1976). The original superposition of layers remained intact locally in the mine, among which the most important are the famous "Ape Site" and an additional section yielding plant fossils. Deposition of the fossiliferous Pannonian formations, mainly swamp deposits, took place about 10 million years ago based on biostratigraphy (Fig. 3), in a large brackish lake, Lake Pannon.

The swamp at Rudabánya accumulated a large number of fossils under a variety of depositional conditions. The sediment today consists of alternating sequences of clays, muds, and lignites, but almost all the fossils are found in the upper black mud and the underlying gray and black clays. The clays are fine-grained gray sediments with pockets that are rich in organic material, or black clay, which accumulated under low-energy depositional conditions, such as those that prevail in a calm, shallow lake. The fossils found in these sediments tend to be fairly complete. These animals were deposited shortly after death under low-energy conditions, probably close to the water's edge. At other times large tree trunks and other tree parts, together with disarticulated bones and isolated teeth, were washed into the site with considerable energy, which is typical of seasonal flooding. This is characteristic of the black mud layer.

The age of the locality is based primarily on the fauna (biostratigraphy), which is consistent with faunas from Europe attributed to MN9. This is particularly true of the rodent fauna, but also of the *Hippotherium* and mustelid remains, and of course, the primates, which sharply declined in Europe after MN9. Drill cores reveal that the fossil sediments at Rudabánya lie above a rhyolitic (volcanic) tuff dated to 11.4 Ma, while the fauna, consistent with MN9, indicates an age older than the MN9/MN10 transition in central Europe (9.7 Ma). Based on the rodents and horses, which are more advanced than the earliest of these taxa from the base of the Vallesian (the MN8/9 transition; 11.2 Ma), Rudabánya is probably closer to the top than to the base of MN9, or around 10 Ma (Kordos and Begun 2002).

Ten million years ago (in the Late Miocene) the Rudabánya range formed a peninsula, which extended into a bay belonging to Lake Pannon; this peninsula was located in the current Borsod area. Valleys ran from this mountain range towards the surrounding swamps. The valley fill sediments, lacustrine clays and lignite beds (formed in the swamp) have been preserved locally in the open pit mine. Carcasses of animals killed by storms accumulated in the narrow valleys the latter sometimes referred as "carrion pits". Among the remains of plant impressions and seeds almost 100 vertebrate species were found here, there are those of three-toed horses, mastodons, extinct rhinos and two types of Primates, the *Rudapithecus* and *Anapithecus*. The *Rudapithecus* is considered to have been very important in the process of hominisation, since it could have been the common ancestor of the evolutionary lines towards the development of the African chimpanzee and the gorilla and to the humans. This ancient ape of a weight of 25–30 kg walked on four legs, and occasionally moved hanging in the trees, and ate predominantly the soft parts of plants. Its brain size (280–320 cm^3) was similar to that of a smaller female chimpanzee living today.

As a result of the excavations, which started in 1971, more than 200 ape remains have been found at Rudabánya. The most famous one is "Gabi", the young female of *Rudapithecus*, whose cranium, lower jaw, pelvic bones and femora have been found (Kordos 1987, 1991).

The Pannonian flora of Rudabánya

In the locally preserved clays and lignite beds of the Rudabánya mine area plant fossils, mainly impressions, have been collected since the late 1950s. Collections were made first of all by geologists of the Geological Institute of Hungary and recently by colleagues of the Hungarian Natural History Museum.

According to Nagy Lászlóné and Pálfalvy (Nagy and Pálfalvy 1961, Pálfalvy in Kretzoi *et al.* 1976) first collecting activities proved the dominant occurrence of *Glyptostrobus europaeus*, *Cercidiphyllum crenatum*, *Byttneriphyllum tiliifolium*, *Alnus* cf. *incana*, *A. crebrinervis* and *Betula macrophylla*. Besides macrofossils (leaves, twigs) the pollen spectrum indicated the high frequency of *Pinus*, *Picea*, *Cedrus*, Taxodiaceae, *Ulmus*, *Alnus*, *Fagus*, *Quercus*, Gramineae and Cyperaceae.

List of taxa based on macrofossils (Pálfalvy in Kretzoi *et al.* 1976): *Osmunda parschlugiana*, *Ginkgo adiantoides*, *Pinus* sp., *Taxodium dubium*, *Glyptostrobus europaeus*, *Glyptostroboxylon tenerum*, *Sequoioxylon gypsaceum*, *Cercidiphyllum crenatum*, cf. *Sassafras ferretianum*, *Liquidambar europaea*, *Myriophyllum* sp., *Trapa* cf. *transcarpatica*, *Banisteriaecarpum giganteum*, *Acer* sp. div., *Nyssa disseminata*, *Byttneriophyllum tiliifolium*, *Diospyros brachysepala*, *Ulmus pyramidalis*, *Zelkova zelkovifolia*, *Celtis* sp., *Carpinus grandis*, *Betula macrophylla*, *B.* cf. *lenta*, *Alnus crebrinervis*, *Alnus* sp. div., *Fagus haidingeri*, *Quercus* cf. *drymeja*, *Juglans acuminata*, *Pterocarya castaneaefolia*, *Carya denticulata*, *Engelhardia macroptera*, *Myrica* sp., *Salix varians*, *Salix* sp., *Populus* cf. *balsamoides*, *Stratiotes intermedius*, *S.* cf. *tuberculatus*, *Potamogeton* cf. *martinianus*, *Cyperites* sp., *Phragmites oeningensis*, *Palmoxylon* sp., *Typha latissima*.

List of taxa based on palynological study by Nagy Lászlóné and Lőrincz (Nagy and Pálfalvy 1961, Lőrincz in Kretzoi *et al.* 1976): *Osmunda* sp., Polypodiaceae, *Azolla* sp., *Ginkgo* sp., *Pinus* sp., *Tsuga* sp., *Picea* sp., *Abies* sp., *Keteleeria* sp., *Larix* sp., *Cedrus* sp., Taxodiaceae, *Sciadopitys* sp., *Podocarpus* sp., *Ephedra* sp., *Liriodendron* sp., *Laurus* sp., Nymphaeaceae, *Liquidambar* sp., Rosaceae, *Myriophyllum* sp., *Rhus* sp., *Acer* sp., *Ilex* sp., Aquifoliaceae, *Nyssa* sp., *Hedera* sp., Umbelliferae, *Scabiosa* sp., *Tilia* sp., Sterculiaceae, *Fraxinus* sp., *Menyanthes* sp., *Drosera* sp., *Artemisia* sp., Compositae, Ericaceae, Caryophyllaceae, *Armeria* sp., *Diospyros* sp., Polygonaceae, *Urtica* sp., *Ulmus* sp., *Zelkova* sp., *Celtis* sp., *Carpinus* sp., *Ostrya* sp., *Corylus* sp., *Betula* sp., *Alnus* sp., *Fagus* sp., *Quercus* sp., *Castanea* sp., *Juglans* sp., *Pterocarya* sp., *Carya* sp., *Engelhardia* sp., *Myrica* sp., *Salix* sp., *Potamogeton* sp., Cyperaceae, Gramineae, Palmae, *Sparganium* sp.

Vegetation description based on KRETZOI *et al.* (1976): the assemblage comprises members of the open water vegetation (*e.g. Stratiotes*, *Trapa*, Nymphaeaceae, *Potamogeton*, *Myriophyllum*) swamps (*e.g. Phragmites*, *Typha*, etc.), swamp forests, flood plain forests composed of *Alnus*, Taxodiaceae, *Byttneriophyllum*, *Betula*, *Liquidambar*, *Nyssa*, *Carya*, *Salix*, *Populus*, etc. On rarely flooded higher elevations forests were composed of *Ulmus*, *Zelkova*, *Fraxinus*, *Quercus* and *Alnus*. Mesophytic forests are indicated by remains of *Tilia*, *Acer*, *Cercidiphyllum*, *Quercus*, *Fagus*, *Carpinus*, *Engelhardia*, *Pinus*, *Cedrus*, *Keteleeria*, *Picea*, *Abies*, etc.

Based on the fossil plant assemblage the authors assumed a subtropical-warm temperate climate.

A revision of the old material and subsequent collecting are in progress. List of taxa based on the so far revised material (Figs 12–13): *Osmunda parschlugiana*, *Ginkgo adiantoides*, *Alnus* sp., *Glyptostrobus europaeus*, *Myrica lignitum*, *Salix varians*, *Juglans acuminata*, *Byttneriophyllum tiliifolium*, *Liquidambar europaea*, *Ulmus carpinoides*, Monocotyledonae gen. et sp., *Acer* sp., *Stratiotes* sp., *Potamogeton* sp., *Trapa* sp., *Pinus* sp., *Cercidiphyllum crenatum*, *Zelkova zelkovifolia*, *Fagus haidingeri*, *Banisteriaecarpum giganteum.*

Fig. 12. A clayey slab from Rudabánya with *Byttneriophyllum tiliifolium* and *Alnus* (scale bar = 1 cm, HNHM)

Fig. 13. *Glyptostrobus europaeus* seed cone, Rudabánya (scale bar = 1 cm, HNHM)

Erdőbénye-Ligetmajor, diatomaceous earth mine (Middle Miocene, Tokaj Mts)

Some of the Sarmatian (Late Middle Miocene) sites of Hungary became well known as early as the 19th century first of all by works of ETTINGSHAUSEN (1853), KOVÁTS (1856*a*, *b*), STUR (1867) and UNGER (1870) introducing the floras of Erdőbénye-Barnamáj, Tállya and Szántó. Later ANDREÁNSZKY (1959) summarised most of the Sarmatian fossil plant assemblages of Hungary in a monograph. Recently two new sites, Erdőbénye-Ligetmajor (ERDEI 1995) and Sopron-Piusz puszta (ERDEI and LESIAK 2000) have been recovered. Additional works concerning the Hungarian Sarmatian floras are ERDEI and HÍR 2003, ERDEI *et al.* 2007, and KVAČEK and ERDEI 2001.

Fossilised remains representing the Sarmatian flora are known from several sites of smaller or greater importance. Most of them have been excavated in the northeastern region of Hungary, in the Bükk (*e.g.* Felsőtárkány, Sály, Mikófalva, Balaton, etc.) and the Tokaj Mountains (*e.g.* Erdőbénye, Tállya, Füzérradvány, etc.) and some in western Hungary (*e.g.* Várpalota, Sopron-Piuszpuszta). Unfortunately, our efforts to revisit the old "classical" sites of Kővágó-oldal and Barnamáj in Erdőbénye and Tállya, were not successful. Most of the Sarmatian localities yielded leaf impressions (or fruits) without any organic matter preserved except for some specimens of gymnospermous affinity from Felsőtárkány. In contrast, the site at Sopron-Piuszpuszta provided some dispersed coalified fragments of plants (leaves, fruits and cones; ERDEI and LESIAK 2000).

Geology

During the Sarmatian (s. str., sensu Suess, and PAPP *et al.* 1974) in the Late Middle Miocene, (late Seravallian, standard chronostratigraphy) the most part of the Pannonian Basin surrounded by the Carpathians was inundated by the hyposaline, brackish water of the (Central) Paratethys (Fig. 14). Its connection with the Mediterranean had ceased, however a connection towards the Aral-Caspian Basins still existed during the Sarmatian. Later, due to a regression of the sea, nearshore deposition and littoral facies rocks became predominant with layers of gypsum and halite content (HÁMOR 2001, HÁMOR and BÉRCZI 1986).

Related to the Neogene tectonic evolution intense volcanic activity characterised the region (CSONTOS 1995) with four eruptional phases during the Miocene as corroborated by K–Ar radiometric data (RAVASZ 1987). The third and fourth volcanic phases having a developmental centre in northeastern Hungary had a definite influence on the formation of the fossil sites in the Tokaj Mountains, as well as the varied geomorphology and indented basin margin played an important role in the deposition and fossilisation of plant remains. Formation of the Erdőbénye fossiliferous deposits is related to the intense volcanic phase, which started in the region during the Badenian with rhyolitic tuff, it is the so called "Middle Rhyolitic Tuff". After a parallel rhyolitic, andesitic and dacitic volcanism throughout the Sarmatian, it came to an end with basaltic volcanism in the Early Pannonian (BALOGH *et al.* 1983, SZÉKY-FUX *et al.* 1980).

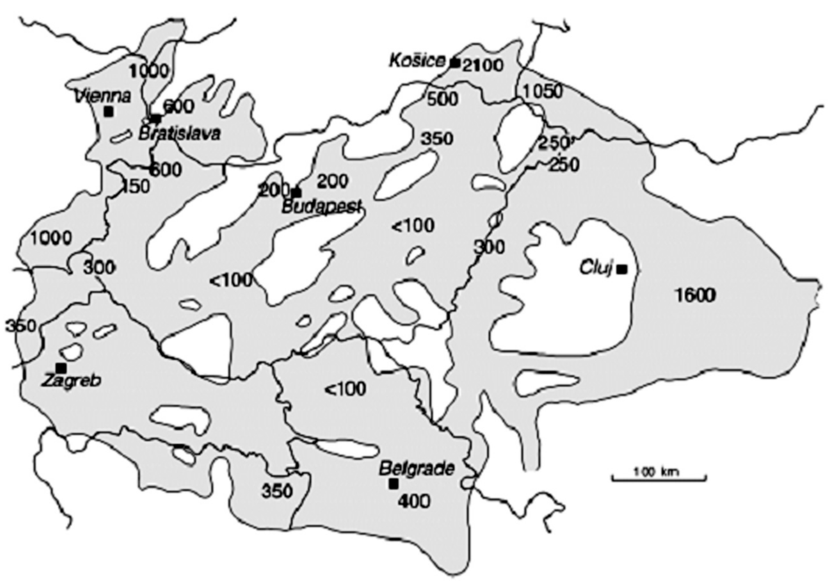


Fig. 14. Interpreted extent of the early Sarmatian sea within the Pannonian Basin. Numbers indicate the thickness of Sarmatian deposits in metres (MAGYAR *et al.* 1999*a*)

Due to the absence of appropriate samples for radiometric dating the regional lithostratigraphy and the correlation of fossil faunas, like molluscs, were applied to specify the stratigraphic position of fossiliferous layers.

Based on the mollusc fauna preserved in the fossiliferous sediments of Erdőbénye (Kővágó-oldal, Barnamáj) and Tállya, Bohn-Havas identified typical taxa characteristic of the Sarmatian (Budajenő type fauna, pers. comm.). Based on the faunal composition and the FAD and LAD data of *Cardium gleichenbergense* Papp being predominant at all the sites, Bohn-Havas presumed that the layers represent the upper part of the lower Sarmatian or lower part of the upper Sarmatian. Based on additional taxa (*Cardium suessi* Barb., *C. pestis* Zhizch., *Mactra* sp.) in Kővágó-oldal (Erdőbénye) it may represent somewhat younger layers. According to the regional lithostratigraphy (Zelenka, pers. comm.) and diatoms (HAJÓS 1987) the lacustric layers of Ligetmajor (Erdőbénye) represent presumably one of the youngest formations of the Sarmatian.

Geological settings of the Erdőbénye fossil sites: Kővágó-oldal, Barnamáj and Ligetmajor (Tokaj Mts)

The geological history can be read in the explanatory book to the geological map of the area by PENTELÉNYI (1968). The Tokaj Mountains are bordered by two remarkable structural elements, which are the more or less N–S striking Hernád fault (on the West) and the Gálszécs (Sečovce) fault on the East. The basement of the area was uplifted at the end of the Triassic, and after a long period of denudation subsidence started in the Miocene. Rock series building up the basement can be found at a depth of at least 2,000 m. Based on the data of boreholes in the surroundings, sedimentary formations of the Badenian transgression are to be found at some hundreds of metres below the surface. Along the faults – which came into being coevally with the subsidence – a dynamic volcanic activity commenced. Volcanism started with the accumulation of a thick succession of rhyolite tuff and tuffites. The andesitic volcanism was preceded by the accumulation of mixed tuff. Coevally with the eruptions resulting in pyroxenic andesite lava, tuff explosions and redeposition continued. Locally, dacitic formations have been developed as well. As volcanism went on a more basic pyroxenic andesite erupted onto the surface and this was followed by the accumulation of rhyolite in relatively large areas. Namely, the geological formations in the surroundings of the fossiliferous deposits at Erdőbénye are predominantly made up of Sarmatian rocks of varied appearance and genetic types. In the depressions of the volcanic terrane limnic sedimentation occurred. The fossil plant remains of Kővágó-oldal and Barnamáj were deposited in clayey tuffite with lignitic lenses of less than 1–2 m thickness. The fossiliferous layers of Barnamáj were uplifted by an andesite laccolith. In Kővágó-oldal and Barnamáj the fossiliferous sediments were deposited in a brackish shallow marine environment (PENTELÉNYI 1968).

The diatomaceous earth of Ligetmajor and the lacustric layers with plant remains are located in a tectonic subsidence. The underlying layers are the products of neutral, effusive and acidic volcanism. In the course of post-volcanic activity thermal waters with high silica content formed in numerous limnic basins provided favourable conditions for diatoms, among which *Melosira* and *Navicula* species are predominant (HAJÓS 1959). During four depositional sequences deposits containing clayey, tuffitic and diatomaceous layers, as well as limnoquartzite were formed in the Erdőbénye-Sima (Ligetmajor) lacustric basin. The fossiliferous rocks of all the three sites are often silicified.

The Quaternary sequence – overlying the Sarmatian succession – has a large areal extent, nevertheless its thickness does not exceed 10 metres. It is made up of Pleistocene-Holocene terrestrial-fluviatile deposits (MÁTYÁS and VETŐ 1965).

The diatomaceous earth of Ligetmajor occurring in lenses (Fig. 15) has been exploited for some decades. Since it has high porosity and low specific gravity it is used for building material, insulators, infiltration and clarifying. Diatomaceous earth derived from this pit undergoes calcination and is used as the carrier material of artificial manures.

The Tokaj Mountains are famous for their kaoline deposits, formed by the hydrothermal alteration of the Middle Miocene (Sarmatian) rhyolite tuff. The main centres of kaoline mining were in the villages Szegilong and Mád-Bomboly. The kaoline derived from Szegilong was used mainly in papermaking as a filter.

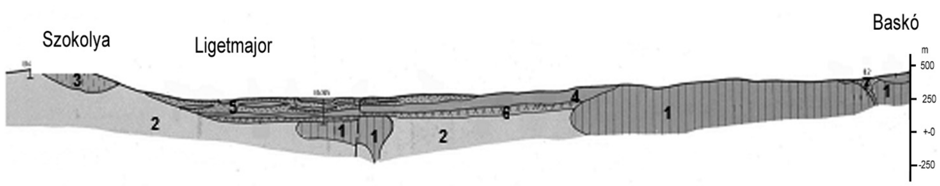


Fig. 15. Geological cross section of the Ligetmajor area, Erdőbénye (after PENTELÉNYI 1967). 1 = acidic pyroxene andesite; 2 = rhyolite tuff; 3 = pyroxene andesite; 4 = acidic (upper) pyroxene andesite; 5 = redeposited rhyolite tuff; 6 = mixed tuff; 7 = amphibole dacite

The Sarmatian flora of Erdőbénye (Kővágó-oldal, Barnamáj and Ligetmajor)

As a result of extensive volcanic deposits and intense postvolcanic (hydrothermal) activity, especially in the Tokaj region, the preservation of organic matter in the mostly highly silicified fossiliferous matrix was not favoured and plant remains are mainly fossilised as impressions. The floras are predominated by angiosperms (84–99%) first of all by Fagaceae (18–26%), Leguminosae (9–29%), Ulmaceae (11–35%) and Betulaceae (7%), monocotyledonous plants are rarely preserved (Table 1). Algae, i.e. *Cystoseirites partschii* are strikingly highly represented at Kővágó-oldal (more than 8% of the total number of specimens) and Barnamáj, which recalls some similar aged fossil floras preserved in diatomaceous sediments of lagoonal facies (HÁMOR 2001) from the Transylvanian Basin (*e.g.* Minisu de Sus/Felménes, Feleac/Fellak, Tampa-Deva, Daia, GIVULESCU 1997). However,

Table 1. Flora lists of the Erdőbénye localities (ERDEI and HÍR 2003)

Taxon	Kővágó-oldal	Barnamáj	Ligetmajor
Acer integerrimum	+	+	+
Acer tricuspidatum	+		
Acer sp. (fruit)	+	+	+
Ailanthus confucii	+		
Alnus sp.	+	+	
Berberis andreanszkyi	+		
Berberis sp.		+	
Betulaceae	+		
Buxus sp.	+		
Carpinus betulus L. fossilis	+	+	+
Carpinus grandis	+	+	+
Carpinus neilreichii	+	+	+
Carya serriifolia	+	+	+
Celtis trachytica	+	+	+
Cupressaceae	+	+	+
Cystoseirites partschii	+	+	
cf. *Daphnogene* sp.			+
"*Diospyros*" *brachysepala*	+		
Engelhardia orsbergensis	+		+
Fagus haidingeri	+	+	+
Ginkgo adiantoides	+		
Glyptostrobus europaeus	+	+	
Ilex parschlugiana			
Lauraceae	+	+	+
Leguminosae		+	+
Liquidambar europaea	+		
Magnolia sp.		+	
Monocotyledoneae	+	+	+
Parrotia pristina	+		+
Pinus sp.	+	+	+
Pistacia lentiscoides	+		
Platanus sp.	+		
Podocarpium podocarpum	+	+	+
Podocarpium podocarpum (fruit)	+		+
Populus populina		+	
Populus sp.	+		
Pterocarya paradisiaca	+		+
Quercus drymeja	+	+	+
Quercus kubinyii	+	+	+
Quercus mediterranea	+	+	+
Quercus pseudorobur		+	+
Quercus sp.	+	+	+
Rhamnaceae	+	+	
Rosa lignitum			+
"*Sapindus*" *falcifolius*	+	+	+
Tetraclinis salicornioides	+		
Ulmus braunii	+	+	+
Ulmus sp. (fruit)		+	
Zelkova zelkovifolia	+	+	+
Zizyphus vel *Paliurus*	+		

only few additional evidence of aquatic vegetation, i.e. some unidentifiable monocotyledonous remains shared by all the sites, are at disposal. The special sedimentary environment, namely the abundance of thermal waters as resulted by the intense postvolcanic activity, especially in the Ligetmajor region may have changed the microclimatic conditions (temperature, pH values) not favoured by higher plants. Predominating taxa shared by all the sites are species of *Quercus*, i.e. *Q. kubinyii*, *Q. drymeja* and *Q. mediterranea*, *Zelkova zelkovifolia*, *Podocarpium podocarpum*, *Carpinus grandis*, and *Acer integerrimum*. As frequent elements *Ulmus braunii* and some juglandaceous taxa like *Pterocarya paradisiaca* and *Carya serriifolia* should be mentioned. Gymnosperms comprise a subordinate part of the taphofloras with some needles of various *Pinus* species at all sites. The occurrence of some foliage remains of *Tetraclinis* (*T. salicornioides*) at Kővágó-oldal is noteworthy. Some cupressaceous remains were recorded at all sites. Rare elements are *Fagus haidingeri* occurring at all the sites, *Pistacia lentiscoides*, *Berberis andreanszkyi* and *Buxus* sp. excavated exclusively in Kővágó-oldal. Palms surprisingly have been recorded only from Ligetmajor considered as the youngest one among the Sarmatian sites of the Tokaj Mountains. When evaluating the characteristics of the fossil floras it must be kept in mind that the high rate of volcanism in the Tokaj area and consequently the accumulation of first of all rhyolites, rhyolitic tuff and tuffites in layers of enormous thickness must have exerted a considerable influence on the floristical composition of the sites by means of forming lithomorph soil types and changing the microclimatic conditions.

As compared to the earlier Cenozoic floras of Hungary thermophilous elements play clearly a subordinate role in forming the flora and vegetation of the Sarmatian sites (ERDEI *et al.* 2007). A low number of specimens belonging to the family of Lauraceae were recorded from the sites. *Engelhardia* leaflets regarded as both thermophilous and relict element were recorded in Kővágó-oldal and Ligetmajor. Remains of palms were yielded exclusively by the latter site. It may be noteworthy that among the sites Ligetmajor provided a higher number of thermophilous elements than the other presumably somewhat older sites.

As endemic element *Berberis andreanszkyi* should be mentioned. After the Early Miocene the ratio of endemics in the Hungarian fossil floras showed a decreasing tendency, a phenomenon, which is likely to be related to the terrane development of the Inner-Carpathian area (CSONTOS 1995).

The Pliocene flora of Gérce (W Hungary, HABLY and KVAČEK 1997) may denote the survival of "volcanic" Sarmatian floras with numerous elements shared by both of them, i.e. *Quercus kubinyii*, *Zelkova zelkovifolia*, *Engelhardia*, *Buxus pliocenica*, *Ulmus braunii*, *Celtis trachytica*, *Acer integerrimum*, *Parrotia pristine*, etc., however, based on several younger elements occurring only in Gérce its considerable distinction should be made.

Based on the Sarmatian flora a warm-temperate climate was estimated, with a mean annual temperature of 13–16 °C and a mean annual precipitation of 800–1,200 mm (ERDEI *et al.* 2007).

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