



# Palaeobotanical research of the Early Miocene deposits overlying the main coal seam (Libkovice and Lom Members) in the Most Basin (Czech Republic)

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The present article re-evaluates the record of Early Miocene plant megafossils in the upper part of the Most Formation (Libkovice and Lom Members) according to current taxonomy, and applies the results to phytostратigraphical correlation. The characteristics of the floras have been studied, and palaeovegetation has been reconstructed based on leaf, fruit, and seed assemblages for the sites studied within the basin. New methods based on foliar physiognomy (CLAMP) have been used for obtaining palaeoclimatic estimates, and are correlated with additional studies of CO<sub>2</sub> concentration. Climatic fluctuations are indicated by changing plant spectra during the deposition of the Libkovice Member. The position of the Miocene climatic optimum has been located in the upper part of the Libkovice Member, and is shown to be of late Early Miocene age. On that basis, this level has been correlated with adjacent regions (e.g., the Cypris Formation of the Cheb Basin, the Upper Coal Seam of the Hrádek part of the Žitava/Zittau Basin). • Key words: palaeoecology, palaeoclimatology, phytostратigraphy, Lower Miocene, leaves, fruits and seeds, Most Basin.

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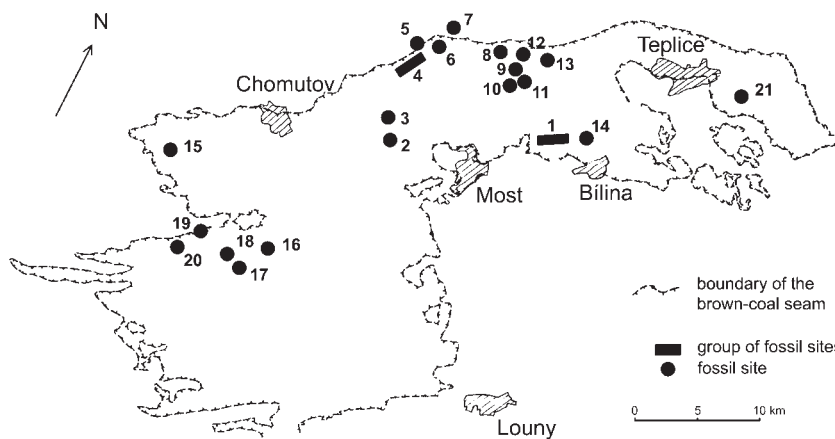
An increase of palaeobotanical research in the Most Basin began during the first half of the nineteenth century. However, most published work has been focused on plant fossils from sediments of the main coal seam *sensu* Elznic *et al.* (1986) and its clastic equivalents, such as the Holešice Member *sensu* Domáci (1977) in the areas of the Žatec and the Bílina deltas and other parts of the Most Basin (e.g., Bůžek 1971, Kvaček 1998, Teodoridis 2004). On the other hand, palaeobotanical research of the Libkovice and Lom Members of the Most Formation *sensu* Domáci (1977), including the floras from the micaceous psammite facies occurring along the Krušné hory Mts. Fault between Vysoká Pec and Albrechtice, has never been completed. Only preliminary information has been available from brief reports (Elznic 1973, Bůžek *in* Malkovský *et al.* 1985, pp. 240–241) and systematic studies of individual plant groups (Bůžek & Holý 1964, Kvaček & Bůžek 1982, Bůžek *et al.* 1993, Wójcicki & Kvaček 2002a, b, Kvaček *et al.* 2004, Kvaček 2005). Similarly, Hurník (1961, 1973), Kvaček & Bůžek (1982), and Boulter *et al.* (1993) identified palaeofloristic areas and distinguished vegetation associations from the Libkovice and Lom Members of the Most Formation.

The present paper gives tentatively complete lists of taxa from the Libkovice and Lom Members based on available fossil carpological and leaf material, in advance of more detailed systematic studies planned for the future. Phytostратigraphical correlations within the Czech Republic and the Boreal European Province, and palaeoenvironmental (including palaeoclimatical) interpretations of the vegetation cover using CLAMP software (see Wolfe 1993), have also been attempted. The results of this work have been correlated with preliminary data from studies of CO<sub>2</sub> concentration based on variations in stomatal index and stomatal density (Kuerschner & Kvaček submitted).

## Material and methods

The fossil carpological material studied here comes from the collections of the late Č. Bůžek and F. Holý from open-cast mines, J. Šverma and ČSA, and from the following drill-cores: Břežánky (M 541), Mariánské Radčice (MR 58, MR 59), Libkovice (P 542, Lb 188), Lom (LOM 15), Kundratice (KU 108, KU 114, KU 115, KU 116, KU 127),





**Figure 1.** Location of the outcrops and cores studied in the Most Basin. • 1 – Břešňany, Břežánky (Břešňany Clay), 2 – opencast mine J. Šverma, 3 – opencast mine ČSA, 4 – Kunderatice (KU 108, KU 114, KU 115, KU 116, KU 127), Jezeří (PVJK 234, JZ 42, JZ 44, JZ 47), 5 – Černice, Albrechtice (CN 54, CN 85, AI 55), 6 – Dolní Jiřetín, Horní Jiřetín (HJi 142), 7 – Janov (Ja 28), 8 – Horní Litvínov (LiH 13), 9 – Mariánské Radčice (MR 59), 10 – Mariánské Radčice (MR 58), 11 – Libkovice (Lb 188, P 542), 12 – Lom (LOM 15, LOM 16), 13 – Osek (Os 9), 14 – Břežánky (M 541), 15 – opencast mine Merkur-North, 16 – Přivlaky, 17 – Soběsuky, 18 – Nechranice, 19 – Čermníky, 20 – Dolany, 21 – Nechvalice.

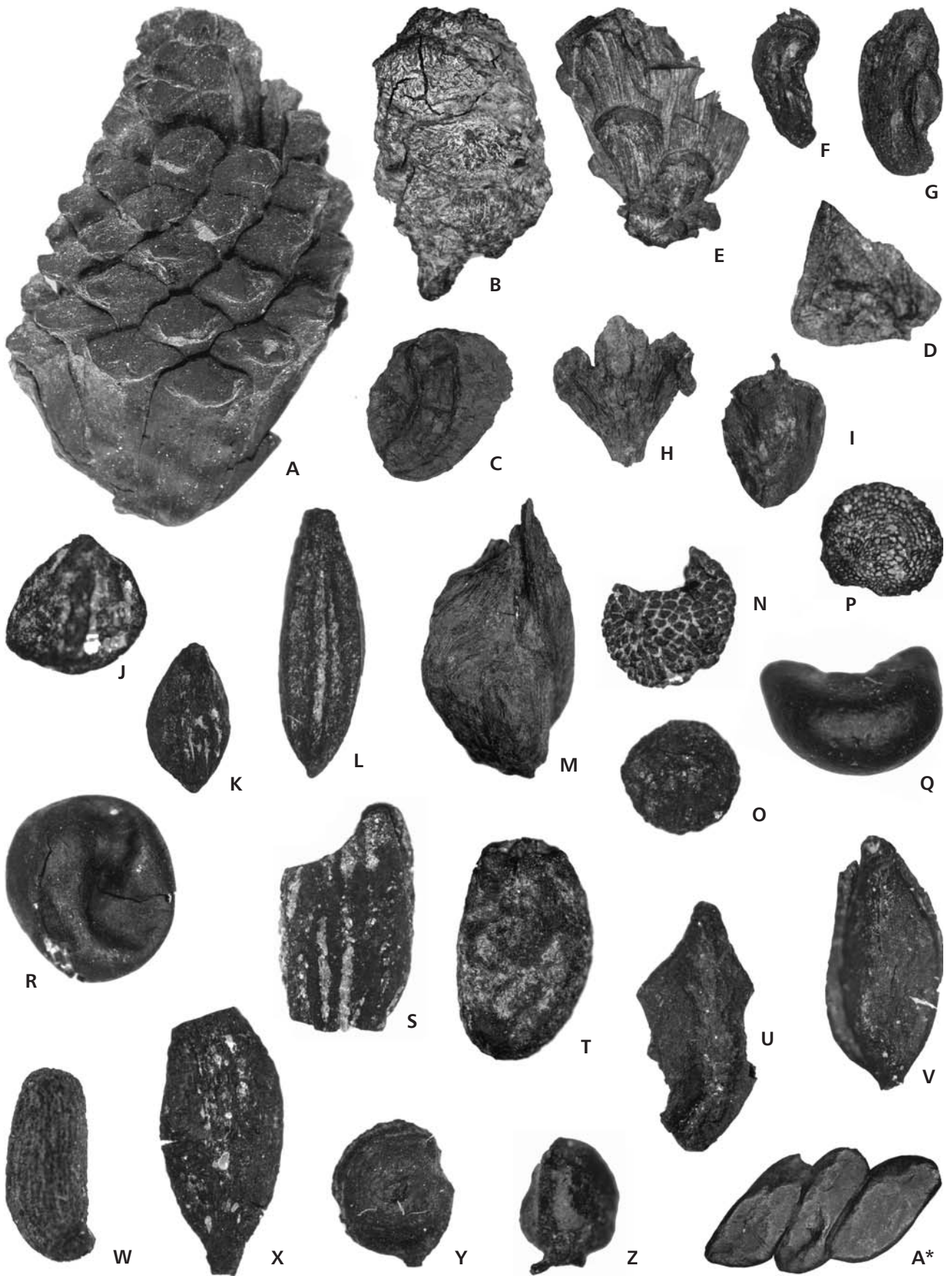
and Jezeří (PVJK 234) (for further details see Kvaček & Bůžek 1982). The fossil leaf material studied here was collected from areas at which the Bílina-Břešňany Clay is exposed at the localities Břešňany, Břežánky, and Jenišův Újezd, including the classic material described by Unger (1847, 1852, 1861, 1864, 1866) and Ettingshausen (1866, 1868, 1869) and at the Žatec Delta (Přivlaky, Čermníky, Dolany, Soběsuky, Nechranice). Other localities include the opencast mines ČSA and J. Šverma, Nechvalice and Dolní Jiřetín, and new collections from the Merkur-North opencast mine at Tušimice. Similarly, the leaf fragments have been collected from cores sampled from various parts of the basin, such as KU 108, KU 115, KU 127, PVJK 234 (Kunderatice), JZ 42, JZ 44, JZ 47 (Jezeří), CN 54, CN 85 (Černice), AI 55 (Albrechtice), HJi 142 (Horní Jiřetín), Ja 28 (Janov), LiH 13 (Horní Litvínov), MR 58, MR 59 (Mariánské Radčice), and LOM 16 (Lom) (for further details see Kvaček & Bůžek 1982). All of the above mentioned localities belong stratigraphically to the Libkovice Member. The material available from the Lom Member was much poorer. The carpological material is known from

the cores MR 59 (Mariánské Radčice), LOM 15 (Lom), and the Dolní Jiřetín locality, while leaf remains were taken from the cores MR 59 (Mariánské Radčice), Os 9 (Osek), and LOM 16 (Lom).

Fossil fruits and seeds have been obtained by sieving. The specimens are isolated carbonaceous compressions, often cracked, but still preserved in three dimensions. The fruits of *Hemitrapa* (Regional Museum, Most) are preserved as impressions. All carpological specimens described here are housed in the National Museum in Prague (NM). Preliminary observations and studies of morphological features were made using a binocular microscope. Scanning electron microscopy (SEM) was used for detailed observations of seed coat structure and for documenting the specimens. The specimens were mounted on brass stubs using nail polish, and remounted with acetone, coated with gold in a sputter coater, and examined using a CAMECA SX 100 scanning electron microscope (Institute of Geology, ASCR, Prague) at 20 kV.

The studied leaf fossils are preserved both as impressions and as compressions with cuticles also preserved.

**Figure 2.** A – *Pinus urani* (Ung.) Schimper, cone, NM G 8513, core KU 114 (depth 72–73 m), x 1.6. • B – *Quasisequoia couttsiae* (Heer) Kunzmann, cone, NM G 4093, core P 542 (depth 94–95 m), x 4. • C – *Quasisequoia couttsiae* (Heer) Kunzmann, seed, NM G 8510, core P 542 (depth 94–95 m), x 6. • D – *Taxodium dubium* (Sternberg) Heer, cone scale, NM G 8495, opencast mine J. Šverma, x 6. • E – *Glyptostrobus europaeus* (Brongn.) Ung., cone, NM G 4072, core P 542 (depth 94–95 m), x 4. • F – *Glyptostrobus europaeus* (Brongn.) Ung., seed, NM G 8511, core P 542 (depth 94–95 m), x 6.5. • G – *Glyptostrobus europaeus* (Brongn.) Ung., seed, NM G 8512, core P 542 (depth 94–95 m), x 6.5. • H – *Alnus lusatica* Mai, bract, NM G 8496, opencast mine J. Šverma, x 5.5. • I – *Alnus lusatica* Mai, fruit, NM G 8498, opencast mine J. Šverma, x 9. • J – *Pterocarya* cf. *limburgensis* C. & E.M. Reid, fruit, NM G 8504, core KU 127 (depth 68–69 m), x 9.5. • K – *Comptonia goniocarpa* Mai, endocarp, NM G 8485, core KU 115 (depth 98.5–98.6 m), x 8.5. • L – *Comptonia longistyla* (Nikitin) Dorofeev, endocarp, NM G 8484, core KU 127 (depth 64–65 m), x 7. • M – *Trigonobalanopsis exacantha* (Mai) Z. Kvaček & Walther, fruit, NM G 8499, opencast mine J. Šverma, x 4.5. • N – *Myrica ceriferiformis* Kownas, fruit with exocarp, NM G 8502, core KU 115 (depth 99.2–99.3 m), x 10. • O – *Myrica suppanii* Kirchheimer vel *M. ceriferiformis* Kownas, endocarp, NM G 8505, core PVJK 234 (depth 62–63 m), x 12. • P – *Eurya stigmosa* (Ludwig) Mai, seed, NM G 8507, core KU 127 (depth 75–76 m), x 20. • Q – *Toddalia maii* Gregor, seed, NM G 8491, core KU 127 (depth 68–69 m), x 11. • R – *Meliosma wetteraviensis* (Ludwig) Mai, endocarp, NM G 8500, core PVJK 234 (depth 62–63 m), x 7. • S – cf. *Mastixia lusatica* Mai, endocarp, NM G 8501, core PVJK 234 (depth 70–71 m), x 5.5. • T – *Symplocos* sp., endocarp, NM G 8494, core KU 115 (depth 90–95 m), x 8.5. • U – Vitaceae gen. et sp. indet., seed, NM G 8483, core KU 114 (depth 72–73 m), x 10. • V – cf. *Carex* sp., fruit, NM G 8489, core KU 115 (depth 99.2–99.3 m), x 19.5. • W – *Stratiotes kaltennordheimensis* (Zenker) Keilhack, seed, NM G 8509, core P 542 (depth 91 m), x 5. • X – *Sparganium* cf. *camenzianum* Kirchheimer, endocarp, NM G 8506, core KU 127 (depth 75–76 m), x 19. • Y – *Potamogeton* cf. *wiesiensis* Kirchheimer, endocarp, NM G 8343, core MR 59 (depth 48.8–50 m), x 9. • Z – *Cladium trilobatum* Mai, endocarp, NM G 8487, core KU 114 (depth 72–73 m), x 16. • A\* – *Spirematospermum wetzleri* (Heer) Chandler emend. Koch & Friedrich, seed, NM G 8493, opencast mine J. Šverma, x 3.5.





The studied leaf material is housed in the National Museum in Prague (NM), and at the headquarters of the Bílina (DB) and Nástup mines in Tušimice (DN). Cuticle preparations are presently kept at the Institute of Geology and Palaeontology at Charles University in Prague (PRC). The specimens that were described in the nineteenth century have been studied in the collections of the Hungarian Natural History Museum (BP) and the Austrian Geological Survey (Geologische Bundesanstalt) in Vienna (GBA). Similarly, a binocular microscope was used for studying the morphological characters of these specimens. The epidermal anatomy of the leaves have been observed and documented by using an Olympus BX 51 biological microscope in normal transmitted or in polarised light. Currently accepted terminology and applied methods of cuticular analysis follow Hickey (1973) and Kvaček (1985). Hydrofluoric acid was applied to clean inorganic particles in all samples for the cuticular analysis. The chosen fragments were macerated in a drop of Schulze solution or in SAVO® bleach solution directly on the slide. After reaching the required oxidation, the oxidative reagent was removed by filter paper or fine tissue. The epidermal samples were rinsed with several water drops and then immersed in a 5% solution of KOH. The carbonized leaf tissue dissolved in the latter solution, and the adaxial and abaxial cuticles were separated mechanically with preparation needles. The resulting cuticles were placed on the slide in a drop of glycerine, covered with a cover glass, and sealed with nail polish. Figures in the text were created as digital pictures using Photoshop 6.0 CZ.

Palaeoenvironmental reconstruction has been attempted using CLAMP (Climate Leaf Analysis Multivariate Program) software, a multivariate statistical technique that decodes the climatic signal inherent in the physiognomy of leaves of woody dicotyledonous plants. The principles and methods of this technique are explained in Wolfe (1990, 1993), Wolfe & Spicer (1999), and Teodoridis (2003a, p. 67). Symbols for distinguishing vegetative storeys in the environmental reconstruction are used according to Moravec *et al.* (2000), i.e., E1 (herbs and vines), E2 (shrubs and lianas), E3 (trees under 25 m high), and E4 (trees over 25 m high). The following is a list of abbreviations used in the text and tables: MAT – Mean Annual Temperature, WMMT – Warmest Month Mean Temperature, CMMT –

Coldest Month Mean Temperature, MART – Mean Annual Range of Temperature, 3WET – Precipitation during 3 Consecutive Wettest Months, 3DRY – Precipitation during 3 Consecutive Driest Months, MAP – Mean Annual Precipitation.

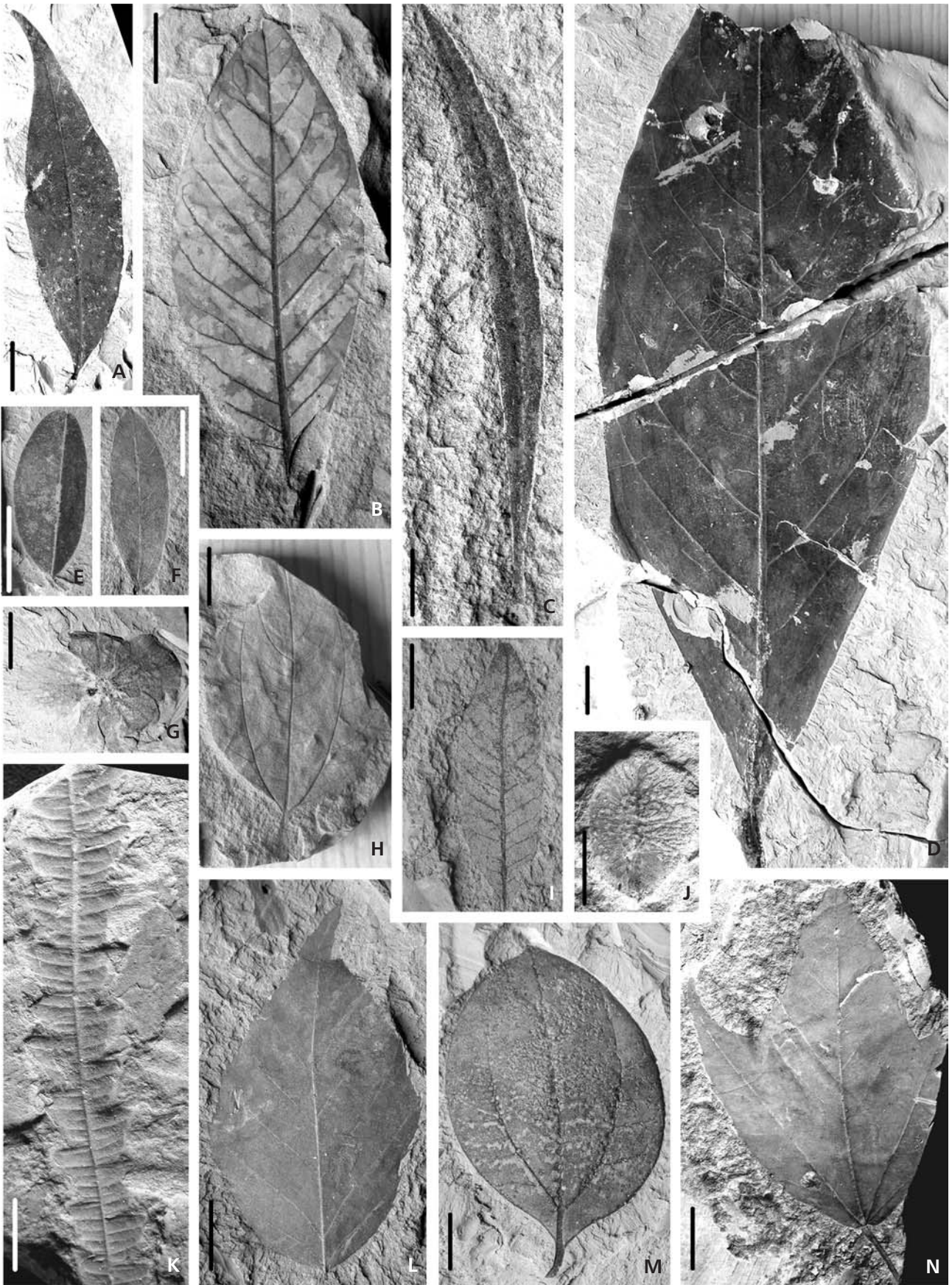
Comparative extant material was obtained from the following herbaria: Charles University in Prague (PRC), the National Museum in Průhonice (PR), the Faculty of Biology at the State University of Moscow (MW), the Main Botanical Garden of the Russian Academy of Science in Moscow (MHA), and the Botanical Institute of W. Szafer, PAN Krakow (KRAM).

### General characteristics and lithostratigraphy of the Most Basin

The Most Basin is the largest freshwater Cenozoic sedimentary body of the Bohemian Massif. The total thickness of the basin fill (i.e., Most Formation *sensu* Domáci 1977) in the centre is about 500 m (Mach *in* Kvaček *et al.* 2004). The lignite and brown coal seams that have been worked in the basin constitute the main fuel reserves of the Czech Republic. The base of the Most Formation has been estimated at the Oligocene-Miocene boundary (Bucha *et al.* 1987, Lotsch *et al.* 1994, Teodoridis 2002, Suhr 2003). The volcanic rocks underlying the basin fill belong to the Střezov Formation of the local lithostratigraphical scale (Domáci 1977), and consist mostly of deeply weathered lava flows and associated volcanogenic deposits. The basin began to be filled in before the Krušné hory Mts. formed a prominent elevation, and thus the earlier sediment originated from the weathered residua of older rocks from the wider surroundings. Rivers and streams transported pebbles, sand, silt, and clay into the basin. Stream deposits formed a wide belt of fluvial sandy facies (“Hlavačov Gravel and Sand” *sensu* Váně 1985) in a north-south direction, heading from central Bohemia and entering the basin near Žatec, then leaving the basin probably near Chomutov (Mach *in* Kvaček *et al.* 2004, Teodoridis 2004, Rajchl & Uličný 2005) or across the České středohoří Mts. (Suhr 2003). Similar allochthonous fluvial sediments of limited extent in the NW periphery of the basin, which passed into layers of sub-autochthonous weathering products, were transported

**Figure 3.** Typical plants of the Břešťany (Preschen) Clay (scale bars = 10 mm). • A – *Laurophyllum pseudoprinceps* Weyland & Kilpper, leaf, NM G 3894. • B – *Nyssa bilinica* (Ung.) Z. Kvaček, leaf, NM G 3893. • C – *Myrica lignitum* (Ung.) Saporta, leaf, NM G 533. • D – *Laurophyllum saxonicum* Litke, leaf, NM G 4415. • E – *Leguminosites* sp., leaflet, NM 3766.3. • F – *Podocarpium podocarpum* (A. Br.) Herendeen, leaflet, NM G 4392. • G – *Chaneya oeningensis* (Unger) Teodoridis & Z. Kvaček, perianth, NM G 4399. • H – *Paliurus tiliaefolius* (Ung.) Bůžek, leaf, NM G 4443. • I – *Carya cf. serrifolia* (Goep.) Kräusel, leaflet, NM G 4497. • J – *Craigia brononii* (Ung.) Z. Kvaček, Bůžek & Manchester, fruit valve, lectotype, Unger (1845, pl. 26, fig. 2). • K – *Comptonia difformis* (Sternb.) Berry, leaf, BDA 1868.02.75, orig. Ettingshausen (1868, pl. 35, fig. 26). • L – *Alnus julianiformis* (Sternb.) Z. Kvaček & Holý, leaf, NM G 1671. • M – *Daphnogene polymorpha* (A. Br.) Ett., leaf, NM s.n. (1). • N – *Acer tricuspidatum* Bronn, leaf, BDA 1869.02.94, orig. Ettingshausen (1869, pl. 44, fig. 3).







from crystalline rocks, while at the SE periphery sediment was transported from flat volcanic slopes or erosion valleys. These sediments formed the Duchcov Member of the Most Formation (Domáci 1977), previously called the Underlying Formation (see e.g., Elznic 1973). They include well known localities of vertebrate fossils such as Skyřice, the main seam of the Merkur-North mine at the former village of Ahníkov, and the limestone at Tuchořice, all dated to zone MN 3 (Fejfar 1989).

During the Early Miocene, the increasing subsidence of the basin caused the spreading of flatlands with the formation of swamps and shallow lakes. In most parts of the basin, deposits of this period belong to a new unit called the Holešice Member (Domáci 1977). At first, only occasional flooding inundated these wetlands, but they gradually transformed into periodically or steadily inundated local swamps in which plant biomasses accumulated as peat. Individual swamps gradually fused into continuous wide belts along the main stream and its tributaries. This type of landscape had become stable in the basin during the formation of the sediments that became the main coal seam. A stream from the south continued to inundate the basin at Žatec town, and passed northwards across the system of swamps. During flooding events the fluvial facies spread over larger areas of the basin, forming clayey-sandy layers in the peat. The swamp system corresponded mostly to the low moor type. Increased precipitation rarely supplied the swamps more intensely, which is typical of the raised bog regime (Mach in Kvaček *et al.* 2004).

In the wider environs of Žatec, where most of the streams discharged, sandy deposits prevailed due to the lowering of the river gradient, so that the conditions for peat formation in this area were limited (Václ & Malkovský 1962). A partial stream later reached the environs of Bílina, where a delta body, called the “Bílina Delta” (see also Hurník 1959, Mach 1997, Dvořák & Mach 1999, Uličný *et al.* 2000, Rajchl & Uličný 2005), originated. This delta was formed by a river that belonged to a large drainage system encompassing NE, E, and SW Bohemia (Malkovský 1995). As stated above, these deposits containing lignite seams and equivalent sandy-clayey delta bodies have been included into the Holešice Member (e.g., Mach 2002), previously called the Coal Seam Formation (see Elznic 1973).

The sudden sinking of the basin base caused progressive flooding, during which the clay and claystone facies (“Overlying Clay” or Overlying Formation *sensu* Elznic

1973) spread over the swamps and buried the peat layer. These thick strata have been included into the Libkovice Member (Domáci 1977). In the Bílina area, the base of this member is composed of the Břešťany Clay, as suggested by Elznic (1964) and corroborated by exposures in the Bílina opencast mine. Though the Bílina Delta ceased to exist, several small streams entered the basin from the north (e.g., at Jezeří) while others existed at Ústí nad Labem and Žatec. The northern streams transported less sands, but still influenced the character of the clay layers deposited in the lake by bringing traces of mica. Eventually, the lake probably extended well beyond the current limits of the basin. In the area of the Žatec Delta, the Libkovice Member is developed partly in the sandy-clayey facies (Žatec facies *sensu* Procházka 1954) such as the Přívklady locality. The quartzose sandstone of Hradiště Hill at the Černovice locality (Tschernowitz), now high above the basin on the Krušné hory Mts., may belong to the Libkovice Member (Hurník 1960), although its position below the seam cannot be excluded (e.g., Bůžek 1963, 1984, Hurník 2001).

About 17–18 Ma (Bucha *et al.* 1987, Malkovský 1995), the lake had become nearly filled with sediment, and shallow swamp conditions were renewed in the environs of Lom in the central part of the basin. This uppermost part of the Most Formation is defined as the Lom Member *sensu* Domáci (1977), and was originally called the “Lom Formation” (Elznic 1973). The Lom Seam is an incomplete denudation relict of limited extent. It arose in a temporary swamp that was connected with the highest level of the basin fill (Elznic *et al.* 1998, fig. 15, Hurník 2001, fig. 42).

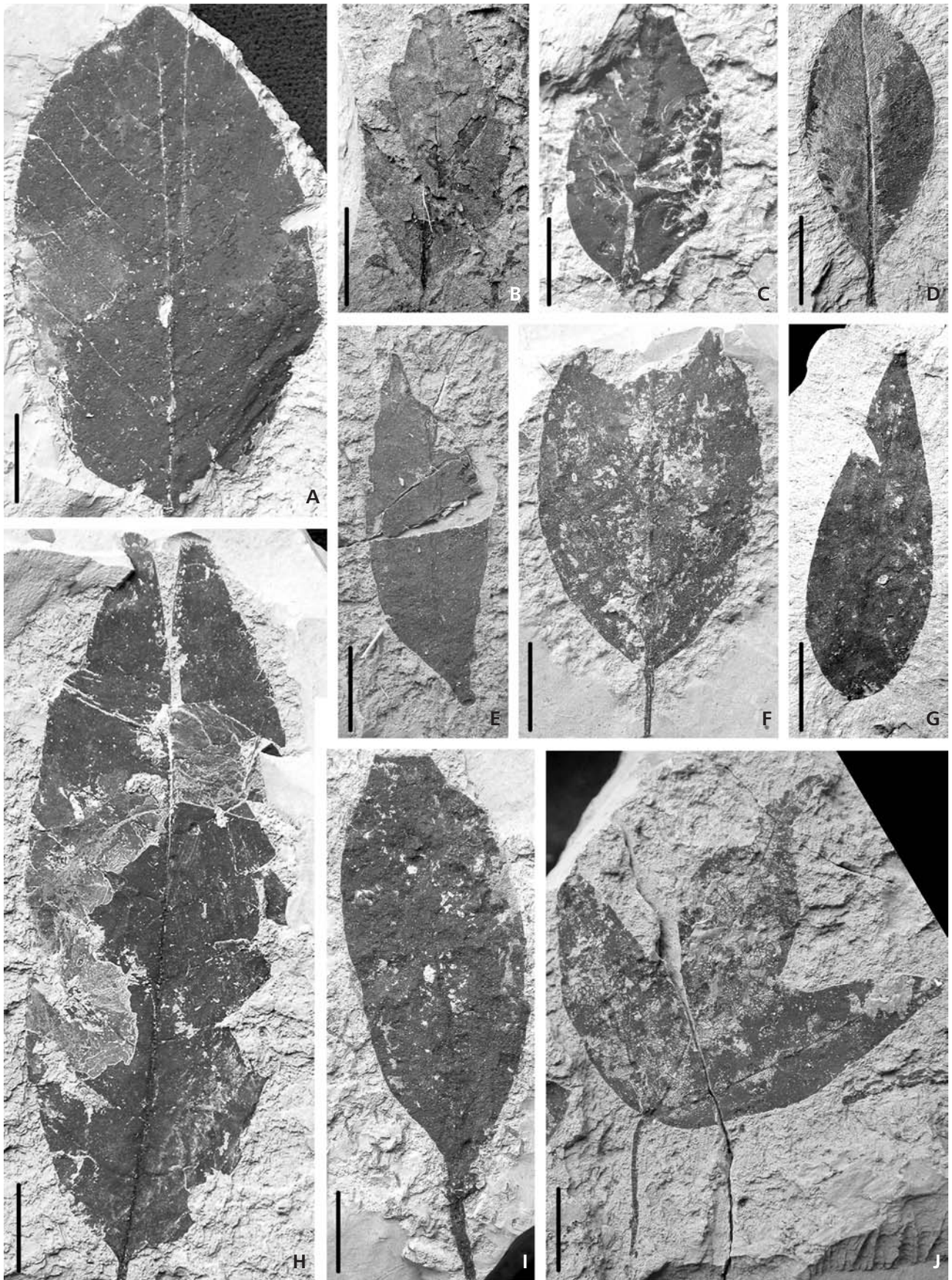
The lithostratigraphical subdivision employed in this paper adopts the formal units of the International Stratigraphical Nomenclature (see Domáci 1977) and deviates somewhat from the informal system introduced for the needs of practical geology in the basin (Elznic *et al.* 1986, Malkovský 1987). The previous stratigraphical scales of the Most Basin and their correlation are summarised in Kvaček & Hurník (2000, p. 23).

## Palaeogeography, facies, and dating

In general, the following facies were widespread during the deposition of the Most Formation. Early stages of the basin are typically flat land with stagnant lakes. In the north-western parts these landforms became filled with volcanic sediments. Lakes in the central part became filled with clay

**Figure 4.** New plant fossils from the opencast mine Merkur-North, Tušimice (scale bars = 10 mm). • A – *Alnus gaudinii* (Heer) Knobloch & Z. Kvaček, leaf, DN 47. • B – *Zelkova zelkovifolia* (Ung.) Bůžek & Kotlaba, leaf, DN 25. • C – *Trigonobalanopsis rhamnoides* (Rossm.) Z. Kvaček & Walther, DN 18. • D – *Trachelospermophyllum* sp., leaf, DN 8a. • E – “*Celastrus*” *pyrrhae* Ett., leaf, DN 28. • F – cf. *Alnus* sp., leaf, DN 12. • G – *Leguminosites* sp., leaflet, DN 19. • H – *Fraxinus bilinica* (Ung.) Z. Kvaček & Hurník, leaflet, DN 48. • I – *Laurophyllum pseudoprinceps* Weyland & Kilpper, leaf, DN 13. • J – *Acer pseudomonspessulanum* Ung., leaf, DN 33a.







deposits (Elznic 1964), and by fluvial and delta facies near the mouth of the stream coming from central Bohemia (“Hlavačov Gravel and Sand” – Váně 1985, Teodoridis 2002, 2004). The next stage was that of the vast swamps of the Holešice Member, intercalated with clay and sand layers coming from deltas in the Žatec and Bílina areas. We are reluctant to accept the subdivision of this sizeable complex of deposits on the basis of mineralogical and geochemical properties (Elznic *et al.* 1998), which were diachronically distributed due to local influences. As stated above, a sudden subsidence of the basin transformed the landscape into a large lake in which the clay of the Libkovic Member was deposited. The Libkovic Member is also developed in the delta facies of the Žatec part and in the mica sand and gravel facies on the periphery of the Krušné hory Mts. (e.g., at Jezeří). The most fossil-rich deposits, the facies of the Břešťany Clay, arose during this event. The renewed shallowing of the lake resulted in the accumulation of the Lom Seam in the uppermost part of the basin fill, which was also connected with a small delta in the central part of the basin near the town of Osek (Elznic 1964).

The present paper is focused on the evaluation of the fossil plant record of the Libkovic and Lom Members. The accumulation of these units was only tentatively dated to late Early Miocene according to palaeomagnetic dating (Bucha *et al.* 1987, Malkovský 1995) and by palaeoflora correlation (Kvaček *et al.* 2004). The floor of the Main Seam was assigned to mammal zone MN 3 of Early Burdigalian (~ Early Eggenburgian) age (see Fejfar 1989, Fejfar & Kvaček 1993).

### Phytogeography and palaeofloristic characteristics

The composition of plant assemblages is not uniform throughout the basin due to local environmental conditions and evolution through time. Previous studies on the phytogeography of this basin (Hurník 1961) revealed characteristic combinations of taxa that occur in particular parts or horizons. Plant fossils from the Most Formation have so far been assigned to hundreds of taxa, of which about 200 species have been accepted after critical revisions. Woody angiosperms predominate the floral spectrum, while ferns, fern allies, and conifers are far less diversified, though they

may compose dominant components of swamp vegetation. In the case of herbs, particularly of monocots, the most reliable studies are based on carpological material because the taxonomic resolution of leaf remains is low.

The flora of the Duchcov Member is not uniform with respect to stratigraphical and palaeogeographical position. The basal seam has been characterised by deciduous broad-leaved elements such as *Fagus*, Betulaceae, Salicaceae, Hamamelidaceae, and Aceraceae, all of which are known mainly from palynological data (Konzalová 1976). The flora of the “Hlavačov Gravel and Sand” deposits may correspond to this level (see Teodoridis 2002, 2004). An additional plant assemblage comes from the micaceous sandy clay (core JZ 44), and contains evergreen elements (*Laurophyllum pseudovillense*, *Laurophyllum pseudo-princeps*) in addition to *Pinus* and *Alnus julianiformis*. The quartzose sandstone of Hradiště (Purberg; Engelhardt 1877) at Černovice probably belongs to the same level, although the locality is high up on the Krušné hory Mts., beyond the area of the lignite seam (see Hurník 2001). This assemblage is rich in seed cones of pines, and in principle does not differ from the micaceous clay flora immediately overlying the seam on the Krušné hory Mts. periphery. At the southern periphery of the basin at Tuchořice, the limestone of hot spring origin yielded a unique flora with date palm and other thermophilous plants (*Toddalia cf. turovensis*, cf. *Tectocarya* sp.), as well as deciduous broad-leaved trees (*Acer tricuspidatum*, *Celtis lacunose*, *Ulmus*, *Zelkova* etc. – Kvaček & Bůžek 1982). Another kind of thermophilous assemblage with *Platanus neptuni* and *Trigonobalanopsis rhamnoides* has been recovered from the underlying claystone in the Bílina region (core Je 96).

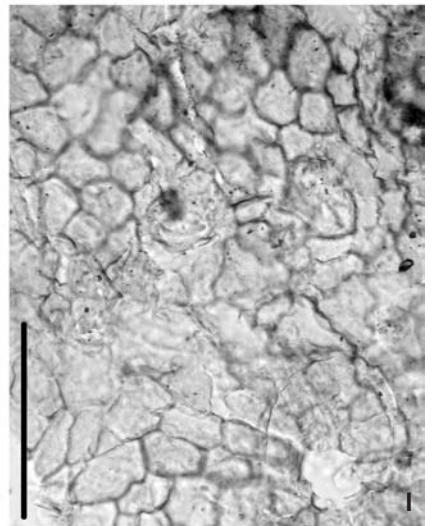
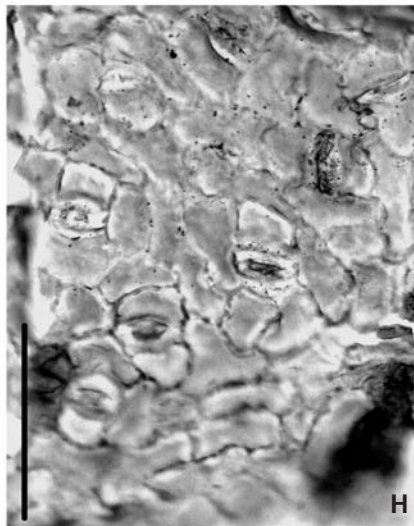
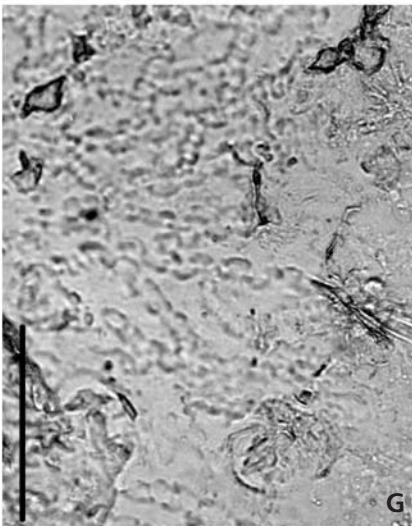
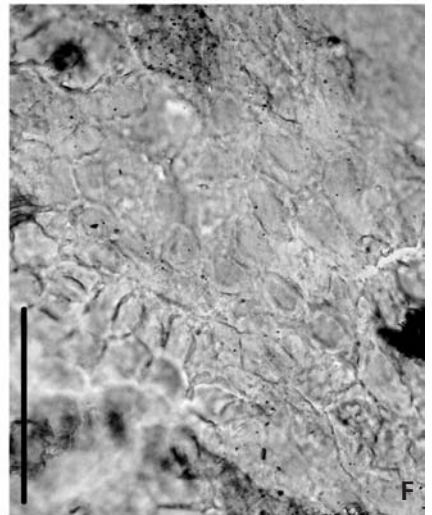
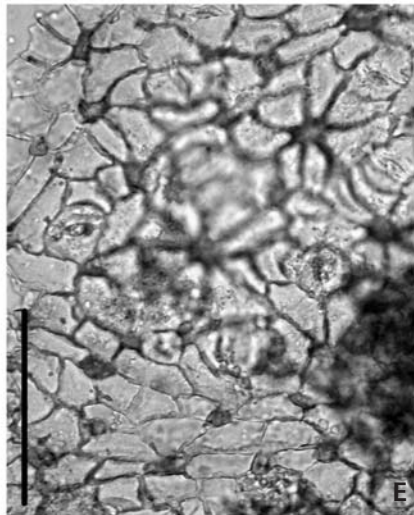
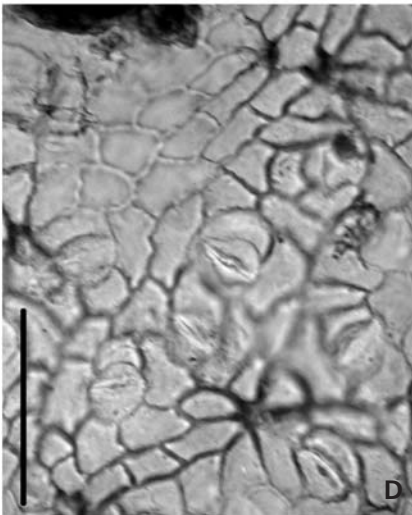
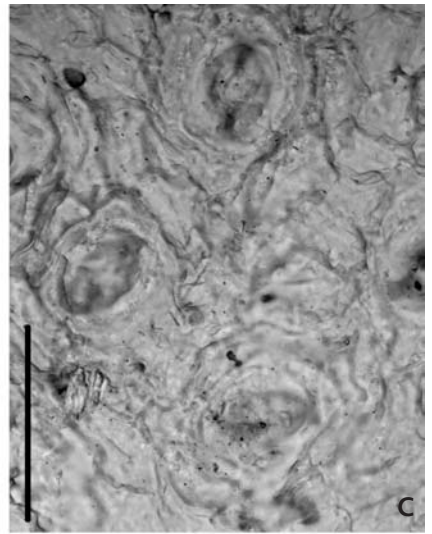
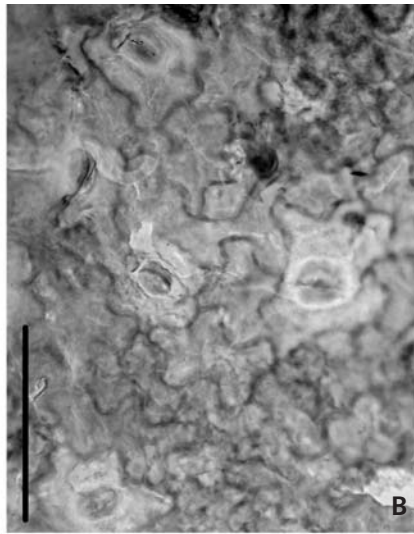
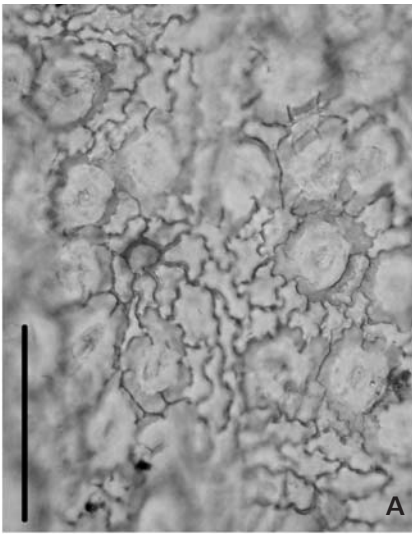
The flora of the Holešice Member is more diversified in the depocentres of deltas. Both coal and sandy-clayey facies are unusually rich in aquatic plants (*Salvinia*, *Stratiotes* etc.). Many woody elements are also shared between both deltas (see Kvaček in Kvaček *et al.* 2004). Pine fossils are extremely rare. Palms of the *Sabal* and *Calamus* type occur mainly in the Most-Bílina area *sensu* Hurník (1961).

The flora of the lacustrine clay of the Libkovic Member is distinct, probably due to its environmental setting. The mixture of deciduous (Ulmaceae, Betulaceae, *Comptonia*, *Parrotia*, *Podocarpium*) and evergreen

**Figure 5.** Cuticles of woody plants from the Libkovic Member (scale bars = 100 µm). • A – *Trigonobalanopsis rhamnoides* (Rossm.) Z. Kvaček & Walther, abaxial cuticle, PRC MR 59-1, core MR 59 (depth 129–130 m). • B – *Magnolia* sp., abaxial cuticle, PRC MR 59-19, core MR 59 (depth 158–159 m). • C – *Gordonia hradekensis* (Z. Kvaček & Bůžek) Palamarev & Bozokov, abaxial cuticle, PRC MR 59-90, core MR 59 (depth 141.2 m). • D – *Laurophyllum nechranicense* Bůžek & Z. Kvaček, abaxial cuticle, PRC MR 58-27, core MR 58 (depth 125–126 m). • E – *Laurophyllum saxonicum* Litke, abaxial cuticle, PRC ČSA 2, opencast mine ČSA. • F – *Laurophyllum pseudovillense* Z. Kvaček, abaxial cuticle, PRC MR 58-13, core MR 58 (depth 108–109 m). • G – *Laurus abchasica* (Kolakovskii & Shakryl) Ferguson, abaxial cuticle, PRC MR 59-5, core MR 59 (depth 129–130 m). • H – *Laurophyllum pseudoprinceps* Weyland & Kilpper, abaxial cuticle, opencast mine Merkur-North, PRC Nástup 50/1. • I – cf. *Alnus* sp., abaxial cuticle, PRC MR 59-39, core MR 59 (depth 143.2 m).









elements (*Myrica lignitum*, Lauraceae, *Trigonobalanopsis*), together with common pine fossils, is typical of the Břešťany Clay from the lowest levels of the Libkovice Member. An index fossil *Schenkiella credneri* has been collected from the upper part of the Bílina section both in the delta facies and the Břešťany Clay (Wójcicki & Kvaček 2002a). This fossil establishes a link to the Early Miocene Brandis flora of Saxony. Other levels of the Libkovice Member, accessed mostly by cores, have yielded thermophilous assemblages characterised by Lauraceae (*Laurophyllum* sp. div., *Laurus abchasica*), Theaceae (*Gordonia hradekensis*), and Ericaceae (*Vaccinioides*, *Andromediphyllum*). Accessory elements such as *Cedrelospermum* (extinct Ulmaceae), *Platanus neptuni*, and *Quercus kubinyii* confirm links to the flora of the Cypris Formation.

The following phytogeographical areas are recognised in our study:

**Břešťany area** (*sensu* Hurník 1961). – This area encompasses classic sites of the Břešťany Clay situated northwards from Bílina: Břešťany (Preschen in German), Břežánky (Priesen), Jenišův Újezd (Langugest). In clay pits where clay (Libkovice Member) has been excavated for making ceramics, the underlying sandy facies (Holešice Member) have been exposed. This close proximity caused plant fossils from both levels to be intermixed in older collections under the names of sites such as Bilin or Priesen, Preschen, etc. Previous collectors sometimes mentioned the type of fossiliferous sediment, e.g., sphaerosiderite and plastic clay (see Ettingshausen 1866, 1868, 1869). Only plant fossils embedded in the grey clay facies are considered in our study, while those from the underlying sediments, which belong in our opinion to the Holešice Member and should be ranged into the Most-Bílina area *sensu* Hurník (1961), have been omitted.

**Krušné hory Mts. – Ervěnice area** (*sensu* Hurník 1961). – Drill cores from the Krušné hory Mts. and the centre of the basin have provided most of the newly acquired data. Typical fossiliferous deposits are the micaceous sandy clays to coarse sands (at the NW periphery of the basin) that pass into the firm grey claystone towards the deeper central part. More frequent plant fossils (leaves, fruits, and seeds) are concentrated in the lower levels that usually form the direct roof of the main coal seam (e.g., at Jezeří and Kundratice). Plant fossils are very rare higher in the claystone facies.

**Chomutov area.** – These deposits are similar to the claystone facies of the Libkovice Member (Chomutov facies *sensu* Procházka 1954). The Hradiště site (Purberg) at Černovice (Engelhardt 1877) has also tentatively been included by Bůžek & Kvaček (1982), but may instead belong to the Duchcov Member (see below).

**Žatec area.** – This area typically includes the sandy-clayey facies (Žatec facies *sensu* Procházka 1954) that extend from the Holešice Member into the Libkovice Member. Only a few sites can be safely ranged into the Libkovice Member, such as Přívlaky (Teodoridis 2004, 2006). The clay (Chomutov) and sandy (Žatec) facies are interfingering, so that the boundaries of these areas overlap (Václ & Malkovský 1962, Váně 1985).

**Ústí nad Labem area.** – This area is a NE extension of the Libkovice Member in the claystone (incl. porcelainite) facies (e.g., Modlany, Nechvalice, Český Újezd). The flora is similar to that of the central (Ervěnice) part (see Kvaček & Hurník 2000, p. 29).

The Lom Member is of limited extent around the town of Lom. Plant fossils have been obtained only from the coal seam and its equivalents, and from cores and an outcrop at Dolní Litvínov. Additional elements of the flora of the Lom Member have been recovered, such as *Nyssa* cf. *haidingeri sensu* Knobloch & Kvaček 1976 (i.e., *Nyssa gmelinii*), and *Hemitrapa heissigii*, which typically occur in the Upper Freshwater Molasse in Bavaria, starting with the Late Otnagian-Karpatian (Meller, personal communication 2005).

The position of the Osek quartzose sandstone and its correlation with the Lom Member, or the other members of the Most Formation, remains problematic (see Hurník 2001, p. 96 vs. Váně 1961, 1999). Plant fossils in this deposit are very rare (e.g., *Carya* endocarps) and are not considered in our study.

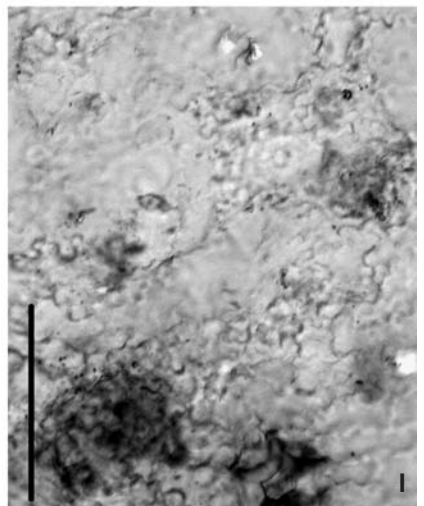
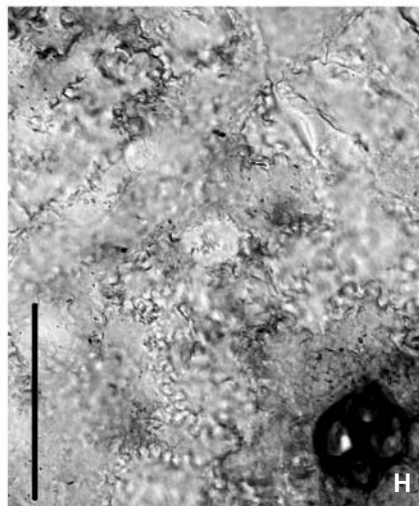
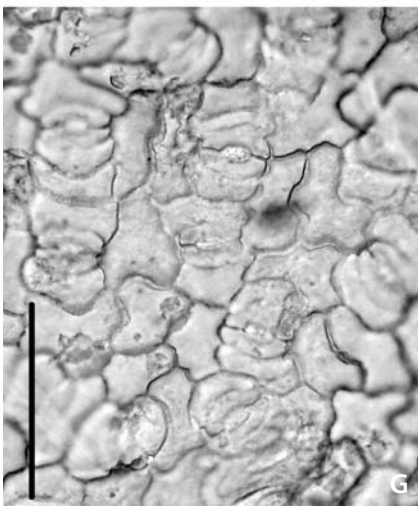
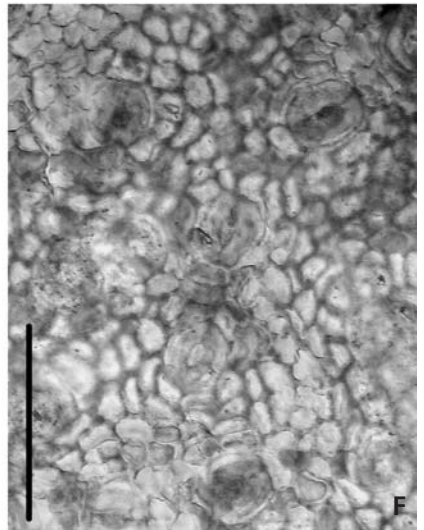
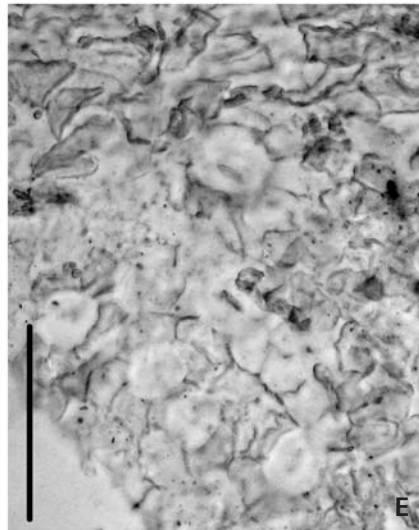
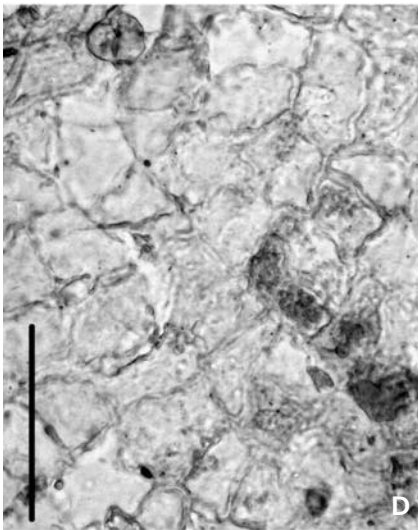
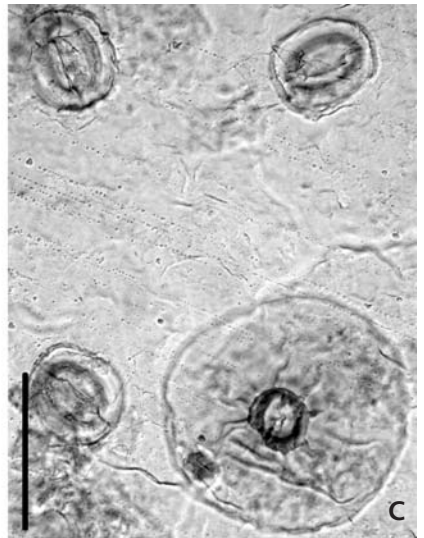
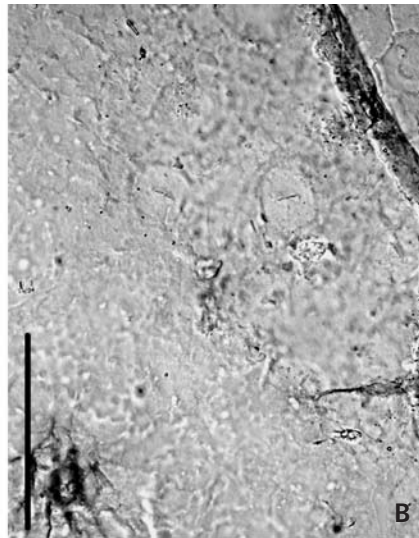
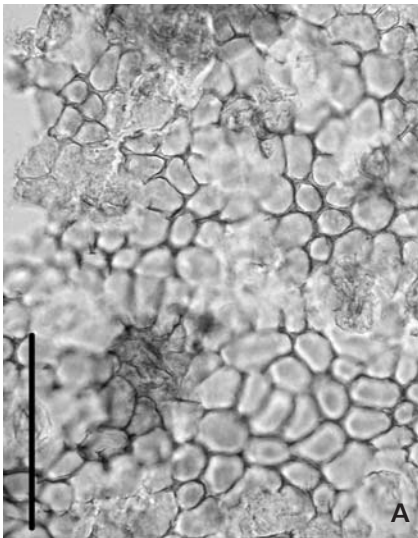
## Review of the floras studied

### Libkovice Member

The flora of the Libkovice Member (Table 1) does not differ profoundly from the previous Holešice Member. Many components are shared by these two members, particularly in the lowermost part (the Břešťany Clay and the sandy

**Figure 6.** Cuticles of woody plants from the Libkovice Member (scale bars = 100 µm). • A – *Myrica lignitum* (Ung.) Saporta, abaxial cuticle, PRC MR 58-12, core MR 58 (depth 110–111 m). • B – *Oleinites* sp., abaxial cuticle, PRC MR 58-16, core MR 58 (depth 110–111 m). • C – *Platanus neptuni* (Ett.) Bůžek, Holý & Z. Kvaček, abaxial cuticle, PRC CSA 46, opencast mine ČSA. • D – *Quercus kubinyii* (Ett.) Czecczot, adaxial cuticle, PRC MR 59-84, core MR 59 (depth 99–135 m). • E – *Quercus kubinyii* (Ett.) Czecczot, abaxial cuticle, PRC MR 59-84, core MR 59 (depth 99–135 m). • F – *Symplocos volkeri* Z. Kvaček, abaxial cuticle, PRC LiH13-8, core LiH 13 (depth 42–57 m). • G – *Vaccinioides lusatica* Z. Kvaček & Walther, abaxial cuticle, PRC CN 85-2, core CN 85 (depth 54.5 m). • H – *Andromediphyllum* sp., abaxial cuticle, PRC CSA 12, opencast mine ČSA. • I – Hamamelidaceae gen. et sp. indet., abaxial cuticle, PRC Al 55-3, core Al 55 (depth 97.7 m).









facies of the Žatec Delta). This similarity may partly be due to the presence of facies that are common to both members. In the coal facies, the most common plants are *Salvinia reussii* among pteridophytes, *Glyptostrobus*, *Taxodium* and *Quasisequoia* among conifers, and *Alnus julianiformis*, *Nyssa bilinica*, *Laurophyllum saxonicum*, *Quercus rhenana*, *Acer tricuspidatum*, *Craigia brononii*, and *Cercidiphyllum* among angiosperms (Břešťany Clay, J. Šverma mine). In the delta facies, some more mesophytic elements are abundant, i.e., *Daphnogene polymorpha*, *Podocarpium*, *Liquidambar*, *Parrotia*, *Salix haidingeri*, *Carya cf. serrifolia*, *Populus populina*, *Ulmus pyramidalis*, *Zelkova*, *Rosa*, “*Sapindus*”, *Acer angustilobum*, *Acer pedomonspessulanum* (= *Acer integrilobum sensu* Walther 1972), and *Fraxinus bilinica*. The index fossil *Schenkiella* is also common to the uppermost part of the Bílina Delta (Holešice Member) and the base of the Libkovice Member in the Bílina area. The distinguishing elements are primarily the various species of *Pinus*, namely those based on cones: *Pinus engelhardtii* (former *P. oviformis sensu* Menzel 1901 from the Trmice, Věštany, Břešťany, Most and Chomutov periphery, Stranná), *P. urani* (*P. laricio sensu* Menzel 1901 from the Jezeří, Břešťany), and *P. ornata* (Břešťany). A typical combination of angiosperms known in most localities consists of *Comptonia*, *Myrica lignitum*, and *Trigonobalanopsis* (e.g., Nechvalice, Český Újezd, Břešťany, Merkur-North mine). *Fagus saxonica* re-appears in addition only in the Žatec Delta (Přívlačky, Stranná). Locally, some mostly thermophilous elements appear for the first time, i.e., leaves of *Vaccinioides lusatica*, *Gordonia hradekensis*, *Symplocos volkeri*, and fruits/seeds of *Mastixia lusatica*, *Symplocos* sp., and *Schisandra moravica* (micaceous facies at Jezeří and Kundratice).

The area of the micaceous facies yielded the richest carpological record of the Most Basin (KU 114, KU 115, KU 108, KU 116, KU 127, PVJK 234, Lb 188, P 542), including *Acer* sp., *Azola* aff. *nana*, *Azola* aff. *rossica*, *Azola* aff. *ventricosa*, cf. *Carex* sp., cf. *Mastixia lusatica*, *Cladiocarya* sp., *Cladium trilobatum*, *Comptonia goniocarpa*, *Comptonia longistyla*, *Dulichium* sp., *Engelhardia macroptera*, *Eurya stigmosa*, *Glyptostrobus europaeus*, *Meliosma wetteraviensis*, *Myrica ceriferiformis*, *Myrica* sp., *Myrica suppanii* vel *Myrica ceriferiformis*, *Pinus engelhardtii*, *Pinus urani*, *Potamogeton* cf. *wiesaensis*, *Pterocarya* cf. *limburgensis*, *Selaginella* sp., *Schisandra moravica*, *Sparganium* cf. *camenzianum*, *Spirematospermum wetzleri*, *Stratiotes kaltennordheimensis*, *Symplocos* sp., and *Vitaceae* gen. et sp. indet.

Higher levels of the Libkovice Member, just below the Lom Seam, are characterised by a diversified flora consisting mostly of palaeosubtropical elements, such as *Laurus abchasica*, *Laurophyllum pseudovillense*, *Laurophyllum pseudoprinceps*, *Gordonia hradekensis*, along with *Quercus kubinyii*, *Lygodium*, and *Platanus*

**Table 2.** Summary of the floral composition of the localities studied from the Lom Member (see also Appendix). • Abbreviations: C (cone), Ec (endocarp), F (fruit), L (leaf), S (seed), Sp (spore), 1 – MR 59, 2 – Dolní Jiřetín, 3 – OS 9, 4 – LOM 15, 5 – LOM 16.

Taxa	Organs	Cores/Localities				
		1	2	3	4	5
cf. <i>Alnus</i> sp.	L	–	–	–	–	+
<i>Azolla</i> aff. <i>nana</i>	Sp	+	–	–	–	–
<i>Azolla</i> aff. <i>rossica</i>	Sp	+	–	–	–	–
<i>Azolla</i> aff. <i>ventricosa</i>	Sp	+	–	–	–	–
<i>Decodon</i> sp.	L	–	–	+	–	–
<i>Glyptostrobus europaeus</i>	C, S, L	–	–	–	–	+
<i>Hemitrapa heissigii</i>	F	–	+	–	–	–
<i>Myrica undulatissima</i>	L	–	–	–	–	+
<i>Nyssa gmelinii</i>	L	–	–	–	–	+
Poaceae vel Cyperaceae indet.	L	–	+	+	–	–
<i>Potamogeton</i> cf. <i>wiesaensis</i>	Ec	+	–	–	–	–
<i>Pronephrium stiriicum</i>	L	–	–	+	–	–
<i>Quasisequoia couttsiae</i>	C, S, L	–	–	–	–	+
<i>Salix</i> cf. <i>varians</i>	L	–	–	+	–	–
<i>Salvinia reusii</i>	Sp, L	+	–	–	+	–

*neptuni* (cores MR 58, MR 59, LiH 13). This type of the flora is limited to the central part of the Most Basin (see Table 1).

### Lom Member

The flora of the Lom Member (Table 2) is so far only fragmentally known. Most of the plant remains come only from the coal facies, and are facies-influenced. Representatives of the aquatic flora are more diversified, as indicated mostly by carpological material (Dolní Jiřetín, cores LOM 15, MR 59) – i.e., *Salvinia reusii*, *Azola* aff. *nana*, *Azola* aff. *rossica*, *Azola* aff. *ventricosa*, *Hemitrapa heissigii*, and *Potamogeton* cf. *wiesaensis*. A few species have been identified based on leaf compressions (LOM 16, MR 59, Os 9, Dolní Jiřetín), such as *Pronephrium stiriicum*, *Glyptostrobus europaeus*, *Quasisequoia couttsiae*, *Myrica undulatissima*, *Nyssa gmelinii*, *Decodon* sp., cf. *Alnus* sp., *Salix* cf. *varians*, and Poaceae vel Cyperaceae gen. et sp. indet. Uniform accumulations in specific layers (e.g., *Salix* and *Decodon* in Os 9) are typical of this coal seam. The mesophytic part of the spectrum is not available from the macrofossil record, so a detailed comparison with adjacent floras cannot be made. It is true that the coal facies includes elements unknown in the Holešice Member (e.g., *Myrica undulatissima*). Furthermore, the finding of a single fruit of *Hemitrapa* from the Ležáky mine (Wojcicki & Kvaček 2002) is equivocal and does not allow identification with the mass occurrence of *Hemitrapa heissigii* in

the Lom Member. The Salesius quartzstone has so far yielded only a few species, including *Carya pusilla* (Hurník 2001), and cannot contribute much to the floral characteristics of this locality.

### Phytostratigraphical correlations

Plant megafossil assemblages are not the best way of dating. The following consideration may help to correlate the plant assemblages of the Most Basin with others in the Bohemian Massif and its periphery. The system of floral assemblages (“Florenkomplexe”) in the sense of Mai (1995) has also been considered. All of these have been based on the macrofossil record.

The flora of the locality Přivlaky shows fossil elements in common with the floras of the Pětipsy area and the “Hlavačov Gravel and Sand” (Teodoridis 2004, 2006). However, based on a study of the drilling documentation and profiles from this area (Anonym 1980), it is possible to confirm the correlation of this locality with the basal part of the Libkovice Member of the Most Formation (Rajchl in Teodoridis 2004, fig. 5). Similarly, the stratigraphical position of the fossil material from the cores from the localities Břešřany, Břežánky (Břešřany Clay), Čermníky, Dolany, Soběsuky, Nechranice, Nechvalice, and from the opencast mines J. Šverma, ČSA and Merkur-North, is also clear (e.g., Jirotko 1976). Stratigraphically, they all belong to the Libkovice Member. According to the composition of the above-mentioned floras, mainly *Schenkiella credneri*, *Vaccinioides lusatica*, *Engelhardia macroptera*, *E. orsbergensis*, *Pinus engelhardtii*, *P. rigios*, and *Trigonobalanopsis rhamnoides*/*Trigonobalanopsis exacantha*, these levels have been correlated to the Bílina-Brandis floral assemblage *sensu* Mai & Walther (1991), i.e., floral zone IV *sensu* Mai (1967). Additional floral elements occur in cores MR 59, MR 58, LOM 16, and Os 9 that stratigraphically correspond to the deposits closely underlying the Lom Seam within the Libkovice Member (Bůžek *et al.* 1993). These floras have a subtropical character and are usually correlated with the assemblage of Eichelskopf-Wiesa *sensu* Mai (1995), or floral zone VI *sensu* Mai (1967; Ottnangian-Karpatian). Newly discovered elements of this flora include *Laurus abchasica*, *Cedrelospermum* sp., *Quercus kubinyii*, and *Laurophyllum pseudovillense*. The persisting thermophilous elements, e.g. *Lygodium*, *Platanus neptuni*, emphasize warming trends. The floras of the Libkovice Member can be correlated with those of the Upper Coal Seam of the Hrádek Basin (Holý 1974, 1975a, b, 1976, Teodoridis 2003b) based on the occurrence of a unique endocarp fragment of cf. *Masixia lusatica* Mai from core PVJK 234 (depth 70–71 m). We must revise the original assumption of Teodoridis

(2003b, p. 30), who correlated all floras of the Lower, Middle, and Upper Coal Seam in the Hrádek part of the Zittau Basin with the floral assemblage of Eichelskopf-Wiesa *sensu* Mai (1995) on the basis of similarities. The new record of *Mastixia* corroborates the phytostratigraphical correlation of the floras from the Libkovice Member with the Upper Coal Seam of the Hrádek part of the Zittau Basin.

The flora of the Lom coal seam (Lom Member) is too poor to be reliably utilised for phytostratigraphy. Based on its superposition, this level can be correlated with the same floral assemblages mentioned above. Still, the appearance of younger elements like *Hemitrapa heissigii* and *Nyssa* cf. *haidingeri* (= *Nyssa gmelinii*) suggests links with the oldest floras of the Younger Bavarian Freshwater Molasse (MN 4b zone) and Wackersdorf in Germany (Knobloch & Kvaček 1976, Wojcicki & Kvaček 2002b, Böhme, personal communication).

### Vegetation of the Libkovice Member, and palaeoenvironmental signals

It is possible to distinguish several partial associations that are defined by specific ecological factors and mutually integrated on their ecotons. In the Břešřany and Krušné hory Mts. and Ervěnice areas, an atypical coniferous peat-forming swamp forest is identical to the association of *Glyptostrobus sensu* Kvaček & Bůžek (1982) characteristically developed for the main coal seam of the Holešice Member. The dominant elements are representatives of the family Taxodiaceae, i.e., *Glyptostrobus europaeus* (E4) and *Quasisequoia couttsiae* (E4), which are well represented also in the following association. There is also a mixed swamp forest overlapping with the coniferous swamp forest towards the shore. This is comparable to the *Nyssa – Taxodium* association *sensu* Kvaček & Bůžek (1982), and is typically developed in the Most-Bílina paleofloristic area *sensu* Hurník (1961), and also in the Libkovice Member, mainly in the Břešřany area, and rarely elsewhere (Šverma mine, Čermníky). Besides the above mentioned elements of Taxodiaceae, this association also includes *Taxodium dubium* (E4), *Quercus rhenana* (E3), *Alnus julianiformis* (E3), *Ulmus pyramidalis* (E3), *Acer tricuspdatum* (E3), *Craigia brononii* (E3), *Dombeyopsis lobata* (E3), *Cercidiphyllum crenatum* (E3), *Fraxinus bilinica* (E3), *Nyssa bilinica* (E3-2), *Salix varians* (E2), *Myrica* (E2), and *Woodwardia muensteriana* (E1). The riparian forest is mainly confined to sandy clay or sand of the Žatec Delta (Přivlaky). The composition of this riparian forest corresponds to the *Parrotia – Ulmus pyramidalis* association *sensu* Kvaček & Bůžek (1982), or the association of the levée riparian mixed deciduous broad-leaved forest *sensu* Boulter *et al.* (1993). It includes *Fagus saxonica* (E3), *Carya* cf.

*serrifolia* (E4), *Zelkova zelkovifolia* (E4), *Ulmus pyramidalis* (E3), *Liquidambar europaea* (E3), *Alnus* sp. *sensu* Bůžek (E3), “*Parrotia*” *pristina* (E2), *Salix haidingeri* (E2), *Rosa europaea* (E2), *Comptonia difformis* (E2), *Acer angustilobum* (E3-2), *Daphnogene polymorpha* (E3), and *Podocarpium podocarpum* (E2). Free-floating aquatic vegetation corresponds to the association of *Salvinia reussii sensu* Kvaček & Bůžek (1982, p. 20). It includes *Salvinia reussii* (E1), *Azolla* sp. (E1), *Stratiotes* (E1), and *Potamogeton* sp. (E1). The aquatic vegetation often overlaps distally with the coniferous swamp forest, mixed swamp forest, and the association of canebrakes. This association is comparable to the *Decodon* – Poaceae *vel* Cyperaceae association *sensu* Kvaček & Bůžek (1982), or to horizons of aquatic vegetation *sensu* Hurnik (1961, 1973), and is typical of aquatic rooted elements that bordered riparian or mixed swamp forests. The association of canebrakes includes *Decodon*, Poaceae *vel* Cyperaceae (E1), and *Sparganium* sp. (E1).

The most typical forest vegetation associated with the sandy and micaceous facies is the evergreen broad-leaved forest mixed with pine stands. This association occupied crystalline rock elevations of the Krušné hory Mts. where mesophytic and acid biotopes covered by homogenous *Pinus* stands (E3) combined with Lauraceae (*Laurophyllum*, *Daphnogene* – E3-2), Theaceae (*Eurya* – E3-2), *Comptonia* (E2), *Myrica* (E2), *Symplocos* (E3-2), *Toddalia* (E2), *Mastixia* (E3-2), and as accessory elements *Leguminosites* (E3-2), *Laurus abchasica* (E3), *Gordonia hradekensis* (E3-2), *Quercus kubinyii* (E3), *Lygodium* (E1), *Cedrelospermum* (E2), and *Platanus neptuni* (E4). This assemblage of typical elements occurs in the lacustrine sediments beneath the Lom Seam, and overlaps towards to the centre of the basin with the swamp and riparian forests of *Glyptostrobus* (E4), *Quasisequoia* (E4), *Alnus julianiformis* (E3), *Acer tricuspdatum* (E3), and *Myrica* (E2).

In terms of the system proposed by Kvaček & Bůžek (1982), it corresponds to the associations of *Comptonia*–*Pinus oviformis*, *Pinus*–*Laurophyllum pseudoprinceps*, and *Quercus kubinyii*–*Myrica lignitum*, or to the coline forest *sensu* Boulter *et al.* (1993).

## Vegetation of the Lom Member

The macrofossils obtained so far from the Lom Seam reflect a coal-forming swamp forest of *Glyptostrobus* (E3), *Myrica* (E2-3), *Salix* (E2-3), *Nyssa* (E2-3), and *Pronephrium* (E1) with a high groundwater table. Open water between the trees allowed the spreading of both free-floating (*Azolla*, *Hemitrapa*) and rooted (*Decodon*, Cyperaceae *vel* Poaceae) aquatic vegetation.

## Paleoclimatic signals based on the CLAMP analysis

The CLAMP (Climate-Leaf Analysis Multivariate Program) software has been developed for palaeoclimatic estimates based on arboreal dicotyledonous leaf assemblages (Wolfe 1993). The advantage of this method is its physiognomic approach, which does not require determinations of leaf fossils into the natural system. Therefore, it was mostly employed for Late Cretaceous and Early Tertiary localities. Only recently attempts have been made to evaluate younger Tertiary floras with known systematic compositions. Our present attempt is a study of this kind conducted at the localities Přívklady and Břešťany of the Libkovice Member. The localities have been climatically defined as follows: Břešťany – MAT = 16.5 °C, CMMT = 5.7 °C, WMMT = 27.2 °C, 3WET = 81.9 mm, 3DRY = 49.4 mm; Přívklady: MAT = 8.9 °C, WMMT = 20.2 °C, CMMT = –1.6 °C, 3WET = 50.6 mm and 3DRY = 30.4 mm (based on 174 comparable sites of recent vegetation) – see Table 3.

**Table 3.** Results of the CLAMP analysis from the flora of Přívklady and floras of the Břešťany Clay. • Symbols: MAT (Mean Annual Temperature), WMMT (Warmest Month Mean Temperature), CMMT (Coldest Month Mean Temperature), 3WET (Precipitation during 3 Consecutive Wettest Months), 3DRY (Precipitation during 3 Consecutive Driest Months) and SD (Standard Deviation).

Localities Climate parameters	Přívklady	Břešťany	SD
MAT (°C)	8.9	16.5	1.7
WMMT (°C)	20.2	27.2	1.8
CMMT (°C)	–1.6	5.7	2.5
3WET (mm)	50.6	81.9	13.8
3DRY (mm)	30.4	49.4	9.0

The large difference in climatic estimates between both localities is probably due to different environmental conditions. The Přívklady assemblage represents a riparian, mostly deciduous forest, while the Břešťany assemblage is a mixture of upland and swamp forests. The results of this analytical research (except the mentioned anomaly) are generally similar to climate estimates for the floras of the Břešťany Clay as published by Mai & Walther (1983, 1991), Kvaček (1998), and Teodoridis (2004, 2006), particularly in respect of the floral composition. The climate regime of these localities was optimally humid and warm-temperate (i.e., MAT = 10–15 °C, CMMT = 0 °C, WMMT = 24–26 °C and MAP = 1800 mm). The reconstructed vegetation corresponds to the warmer parts of the Mixed Mesophytic Forest of Southeast Asia, which was climatically defined by Wolfe (1979) as follows: MAT = 10–13 °C, CMMT = 1–(–2) °C and MART = 20–29 °C. Higher levels of the Libkovice Member have been correlated with the global curve of MAT on the basis of the variations



in the stomatal index of *Laurophyllum pseudoprinceps* and *Laurus abchasicus* (Kuerschner & Kvaček submitted). An increase in MAT of about 3 °C was given for the level below the Lom coal seam. Thus, the MAT for this level is estimated as 19 ± 1 °C. This value agrees well with the changing vegetation from the Mixed Mesophytic Forest at the base of the Libkovice Member to the Subtropical Nothophyllous Evergreen Forest in its higher levels. The climatic data derived from the living East Asian vegetation for the Nothophyllous Evergreen Forest, according to Wolfe (1979), are: MAT = 13–20 °C, CMMT = > 1 °C, MART = 25–26.5 °C.

The CLAMP method has been most frequently applied to plant assemblages of Late Cretaceous to early Tertiary floras, where controls based on the nearest-living relative method have failed. The application of CLAMP to the later Tertiary (e.g., Kvaček & Walther 2004, Teodoridis 2004) has shown that relevant climatic estimates can also be obtained for more recent plant assemblages. According to our experience, and to previous analyses of ancient vegetation (Kovar-Eder *et al.* submitted), the zonal assemblages, i.e., those outside swampy and flooded riparian settings, are more reliable climatic signals. The “wet soil effect” biases climatic estimates derived from leaf physiognomy. This fact has been reported several times by previous authors (Burnham *et al.* 2001, Kowalski & Dilcher 2003). We must emphasize that this phenomenon has not been taken into account in current CLAMP studies. We therefore warn other researchers not to rely on purely azonal (intraazonal) plant assemblages as the sole source for studies using CLAMP. Another difficulty with which we were confronted in working with CLAMP was the inaccuracy of evaluating the fossil floral spectrum based on leaf impressions (mostly determined as morphotypes). However, extant models of vegetation are based on the natural species (i.e., variation in foliar morphology is included), and can be evaluated without any error in the CLAMP databases. In the case of the Břešťany assemblage in particular, the foliage types (morphotypes) have been partly delimited intuitively when experience from previous cuticular studies have not been available. The question is how far a natural variation of a single morphotype can go. In legumes and lauroids the differentiation of morphotypes with natural extent is usually problematic without epidermal characteristics. Considering the above weak points of the CLAMP analysis, the results cannot be accepted absolutely, but can show only the approximate climatic characteristics of an environment. In our opinion, the CLAMP method can complement others that suffer from different weaknesses (e.g., Mossbrugger & Utescher 1997), particularly in neglecting evolutionary change in the autecology of extant descendants (Kvaček submitted). The CLAMP method, as in other methods based on leaf physiognomy (for details see Royer *et al.* 2005), crucial weakness that are possible

sources of error, are derived from the uncertain delimitation of morphotypes, particularly in impression floras.

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## Appendix

List of taxa mentioned in the tables.

- Acer angustilobum* Heer  
*Acer pseudomonspeulanum* Ung.  
*Acer* sp.  
*Acer tricuspdatum* Bronn *sensu* Procházka & Bůžek  
*Alnus gaudinii* (Heer) Knobloch & Z. Kvaček  
*Alnus julianiformis* (Sternb.) Z. Kvaček & Holý  
*Alnus lusatica* Mai  
*Alnus menzelii* Ran.-Bohr.  
 cf. *Alnus* sp.  
*Alnus* sp. *sensu* Bůžek  
*Andromediphyllum* sp. n. (“?Rosaceae gen. et sp.”)  
*Azolla* aff. *nana* Dorofeev  
*Azolla* aff. *rossica* Dorofeev  
*Azolla* aff. *ventricosa* P. Nikitin *sensu* Dorofeev  
*Berchemia multinervis* (A. Br.) Heer  
*Betula* sp.  
 cf. *Carex* sp.  
*Carya* cf. *serrifolia* (Goepf.) Kräusel  
*Cedrelospermum* sp.  
 “*Celastrus*” *pyrrhae* Ett.  
*Cercidiphyllum crenatum* (Ung.) R. Brown  
*Cladiocarya* sp.  
*Cladium trilobatum* Mai  
*Comptonia difformis* (Sternb.) Berry  
*Comptonia goniocarpa* Mai  
*Comptonia longistyla* (Nikitin) Dorofeev  
*Craigia bronniei* Z. Kvaček, Bůžek & Manchester  
*Daphnogene polymorpha* (A. Br.) Ett.  
*Decodon* sp.  
*Dicotylophyllum* sp. n.  
 cf. *Diospyros brachysepala* A. Br. *sensu* Hantke  
*Diversiphyllum aesculapi* (Heer) Bůžek  
*Dombeyopsis lobata* Ung.  
*Dulichium* sp.  
*Engelhardia macroptera* (Brongn.) Ung.  
*Engelhardia orsbergensis* (Weber) Jähnichen, Mai & Walther  
*Eurya stigmosa* (Ludwig) Mai  
*Fagus saxonica* Z. Kvaček & Walther  
 “*Ficus*” *truncata* Heer *sensu* Bůžek  
*Fraxinus bilinica* (Ung.) Z. Kvaček & Hurník  
*Fraxinus macroptera* Ett.  
*Glyptostrobus europaeus* (Brongn.) Ung.  
*Gordonia hradekensis* (Z. Kvaček & Bůžek) Palamarev & Bozukov  
 Hamamelidaceae gen. et sp. indet.  
*Hemitrapa heissigii* Gregor  
*Chaneya oehningensis* (Heer) Teodoridis & Z. Kvaček  
*Juglans* sp.  
*Laurophyllum nehranicense* Bůžek & Z. Kvaček  
*Laurophyllum pseudoprinceps* Weyland & Kilpper  
*Laurophyllum pseudovillense* Knobloch & Z. Kvaček  
*Laurophyllum saxonicum* Litke  
*Laurophyllum* sp. 1  
*Laurophyllum* sp. 2  
*Laurus abchasica* (Kolakovskii & Shakryl) Ferguson  
*Leguminosites* sp. 1  
*Leguminosites* sp. 2  
*Liquidambar europaea* A. Br.  
*Lygodium gaudinii* Heer  
 cf. *Magnolia* sp.  
*Mahonia bilinica* (Ung.) Z. Kvaček & Bůžek  
 cf. *Mastixia lusatica* Mai  
*Meliosma wetteraviensis* (Ludwig) Mai  
*Myrica ceriferiformis* Kownas  
*Myrica lignitum* (Ung.) Sap.  
*Myrica undulatissima* Knobloch & Z. Kvaček  
*Myrica* sp. 1  
*Myrica* sp. 2  
*Myrica suppanii* Kirchheimer *vel* *M. ceriferiformis* Kownas  
*Nyssa bilinica* (Ung.) Z. Kvaček  
*Nyssa gmelinii* (Heer) Mai  
*Nyssa* sp.  
*Oleinites* sp. n.  
*Paliurus favonii* Ung.  
*Paliurus tiliaefolius* (Ung.) Bůžek  
 “*Parrotia*” *pristina* (Ett.) Stur *sensu* Bůžek  
*Phyllites* sp.



- Pinus engelhardtii* Menzel  
*Pinus ornata* (Sternb.) Brongn.  
*Pinus rigios* Ung.  
*Pinus* sp.  
*Pinus urani* (Ung.) Schimper  
*Platanus neptuni* (Ett.) Bůžek, Holý & Z. Kvaček  
 Poaceae vel Cyperaceae gen. et sp. indet.  
*Podocarpium podocarpum* (A. Br.) Herendeen  
 cf. *Populus populina* (Brongn.) Knobloch  
*Populus* sp.  
*Potamogeton* cf. *wiesaensis* Kirchheimer  
*Pronephrium stiriacum* (Ung.) Knobloch & Z. Kvaček  
*Pterocarya* cf. *limburgensis* C. & E.M. Reid  
*Pungiphyllum cruciatum* (A. Br.) Frankenhäuser & Wilde  
*Quasisequoia couttsiae* (Heer) Kunzmann  
*Quercus kubinyii* (Kováts ex Ett.) Czechtz  
*Quercus rhenana* (Kräusel & Weyland) Knobloch & Z. Kvaček  
 cf. *Rhus pyrrhae* Ung.  
*Rosa europaea* (Ett.) Z. Kvaček & Hurník  
*Sabal major* (Ung.) Heer  
*Salix haidingeri* Ett. emend. Bůžek  
*Salix* cf. *varians* Goepf.  
*Salvinia reussii* Ett.
- “*Sapindus*” *falcifolius* (A. Br.) A. Br.  
*Selaginella* sp.  
*Schisandra moravica* (Mai) Gregor  
*Smilax weberi* Wessel  
*Sparganium* cf. *camenzianum* Kirchheimer  
*Spirematospermum wetzleri* (Heer) Chandler  
*Stratiotes kaltennordheimensis* (Zenker) Keilhack  
*Symplocos* sp.  
*Symplocos volkeri* Z. Kvaček  
*Taxodium dubium* (Sternberg) Heer  
*Tetraclinis salicornioides* (Ung.) Z. Kvaček  
*Thypha latissima* A. Br.  
*Tilia brabenecii* Bůžek & Z. Kvaček  
*Toddalia maii* Gregor  
 cf. *Toxicodendron* sp.  
*Trachelospermophyllum* sp.  
*Trigonobalanopsis exacantha* (Mai) Z. Kvaček & Walther  
*Trigonobalanopsis rhamnoides* (Rossm.) Z. Kvaček & Walther  
*Ulmus pyramidalis* Goepf.  
*Vaccinioides lusatica* Z. Kvaček & Walther  
 Vitaceae gen. et sp. indet.  
*Vitis stricta* (Goepf.) Knobloch  
*Zelkova zelkovifolia* (Ung.) Bůžek & Kotlaba