GEOLOGICA CARPATHICA, JUNE 2011, 62, 3, 251–266 doi: 10.2478/v10096-011-0020-0

Miocene vegetation pattern and climate change in the northwestern Central Paratethys domain (Czech and Slovak Republic)

MARIANNA KOVÁČOVÁ[1], NELA DOLÁKOVÁ[2] and MICHAL KOVÁČ[1]

[1]Department of Geology and Paleontology, Faculty of Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava, Slovak Republic; kovacova@fns.uniba.sk; kovac@fns.uniba.sk
[2]Institute of Geological Sciences, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic; nela@sci.muni.cz

(Manuscript received October 13, 2010; accepted in revised form December 16, 2010)

Abstract: The case study area covers the slopes of the tectonically quiet European platform and foreland of the tectonically active Carpathian mountain chain (Carpathian Foredeep and Vienna Basin). Therefore the research on pollen spectra mirrors not only the evolution of landscape in two areas with different geodynamics, but also climatic changes in the Central Paratethys domain during the studied time interval. According to the pollen data, the Early to Middle Miocene vegetation reflects subtropical climate with very mild (negligible) cooling events during this period. This is indicated by common occurrence of thermophilous taxa in the whole sedimentary record. The Middle Miocene landscape evolution, conditioned by uplift of the Carpathian mountain chain and subsidence of adjacent lowlands, led to commencement of the altitudinal zonation. The terrestrial and aquatic ecosystems confirm a subtropical climate (Miocene Climatic Optimum, Mi3 event) with some possible long term changes in humidity. The Late Miocene paleogeographical changes, but also general climatic oscillations in the northwestern Central Paratethys realm, resulted in decrease of the number of thermophilous taxa during this time (change in latitudinal position of the vegetation cover). Variously high mountain relief of the uplifted mountain chains (altitudinal zonality) created ideal conditions for mixed mesophytic forests (to open woodland — open grassland type), still with presence of evergreen taxa. A subtropical climate with gradual transition to warm temperate climatic conditions is supposed on the basis of the reconstructed vegetation cover.

Key words: Miocene, Paratethys, Carpathian Foredeep, Vienna Basin, paleoclimate, palynology.

Introduction

The Miocene vegetation pattern and climatic changes were studied by means of palynology in the northwestern part of the Central Paratethys domain (Fig. 1). To determine changes in vegetation pattern (altitudinal zonation) and influence of the global climatic changes (latitudinal zonation) two areas with different geodynamics and therefore also with different landscape evolutions have been choosen. To the West there was the tectonically quiet Variscan Bohemian Massif, and to the East the neo-Alpine tectonically active uplifting Western Carpathian mountain chain. The samples were taken from marine, brackish to freshwater sediments of the Carpathian Foredeep (Czech Republic) and Vienna Basin (Czech and Slovak Republic) in the time interval: Early to Late Miocene–Eggenburgian to Pannonian (Burdigalian to Tortonian, *sensu* Harzhauser & Piller 2007). The analysed sediments were well biostratigraphically dated (Hladilová 1988; Nehyba et al. 1997; Doláková et al. 1999; Rögl et al. 2003; Hudáčková et al. 2003; Kováč et al. 2004, 2006, 2007, 2008).

Paleogeography

The study area — the contact zone between the North European Platform and Western Carpathian orogen had a very complicated Neogene geodynamic history (e.g. Royden 1985, 1988; Ratschbacher et al. 1991a,b; Kováč & Hók 1993; Lankreijer et al. 1995; Meulenkamp et al. 1996; Nehyba et al. 1997; Kováč et al. 1997, 1998a,b, 2001, 2003; Kováč 2000; Kvaček et al. 2006; Harzhauser & Piller 2007). All processes such as subduction, collision, back arc basin development and its tectonic inversion are recorded in great paleogeographical changes (Tomek & Hall 1993; Konečný et al. 2002). These changes strongly influenced not only the relation between areas flooded by the sea and continental areas, but also development of landscape and the evolution of altitudinal zonation in this region (Fig. 2).

The Early Miocene geodynamic development of the Bohemian Massif and Western Carpathians junction area was strongly affected by subduction of the flysch troughs basement below the East Alpine–Western Carpathian orogen and development of the Outer Western Carpathian accretionary wedge from Flysch Belt units (Kováč et al. 1997, 1998a; Kováč 2000; Konečný et al. 2002; Kvaček et al. 2006). Territory in-between the platform and the front of the Carpathian orogen was covered by a wide arm of the Central Paratethys Sea during this time. The Eggenburgian marine transgression flooded the Carpathian Foredeep on the slopes of the Bohemian Massif in the West, continuing eastwards to the Pouzdřany and Ždánice residual flysch troughs. The eastern margin of the Early Miocene sea arm was represented by the western and northern parts of the present Vienna Basin (Fig. 2A). This sea arm represented a system of particular

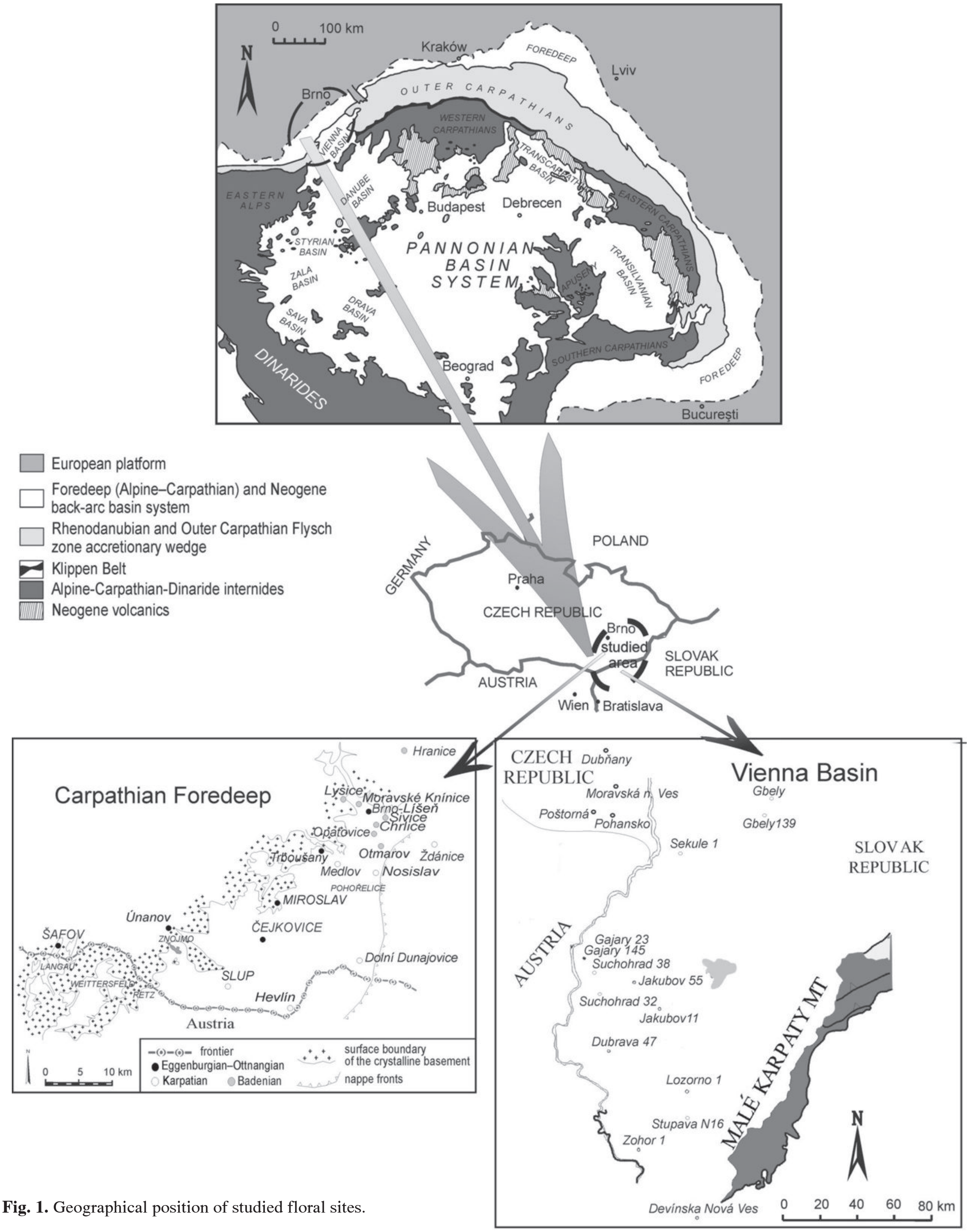

Fig. 1. Geographical position of studied floral sites.

basins with highly complicated shoreline contours and a variable mutual communication with the open sea. As well as a shallow marine environment with common lagoons and deltas at the sea margin (Nehyba et al. 1997; Kováč et al. 1998a,b, 2004), a bathyal to neritic deep water sedimentary environment with proved upwelling in the axial part of the basin was documented (residual flysch troughs), still during the Ottnangian (Roetzel et al. 2006; Grünert et al. 2010). The Early Miocene transgression, following sea connection with the Mediterranean via the Alpine Foredeep, can be correlated

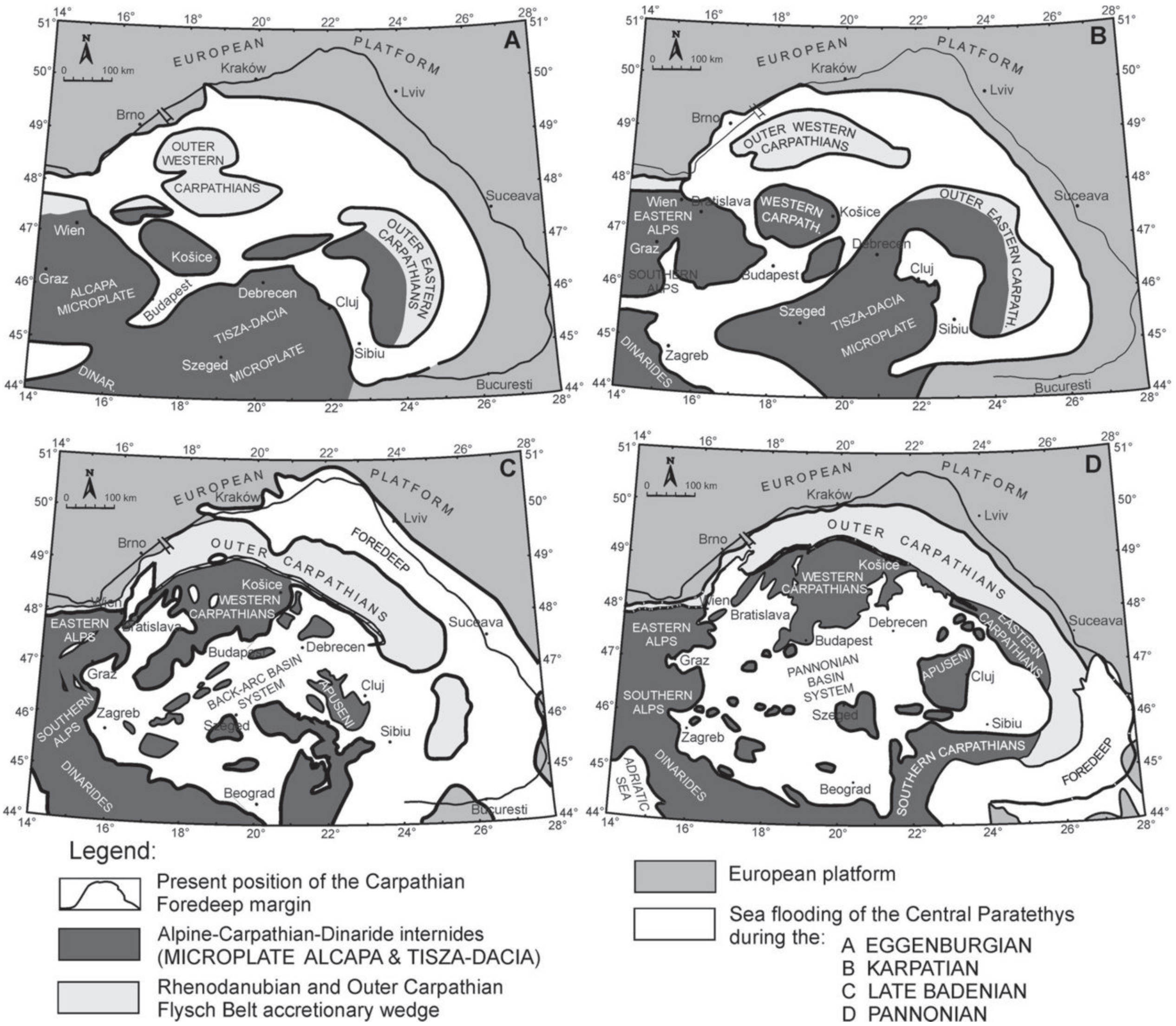

Fig. 2. Paleogeography of the Central Paratethys (according to Kováč 2000).

with the first Burdigalian global sea-level rise (*sensu* Vail et al. 1977; Haq et al. 1988; Haq 1991; Kováč 2000).

At the end of the Ottnangian, the transpressive tectonics resulted in a partial uplift of the Alpine-Carpathian chain, followed by closing of the sea connections with the Mediterranean in front of the Alps. Short term isolation of the Western Carpathian sedimentary basins took place. This process was accompanied by closing of the residual flysch troughs and folding and thrusting of their sedimentary fill towards the platform. Gradual uplift of the Outer Western Carpathian accretion wedge started (Kováč et al. 1998a). On the other side, initial rifting of the Pannonian back arc basin began in the Western Carpathians hinterland (Horváth et al. 1988).

The Karpatian transpressive tectonics led to extrusion of the Western Carpathian orogene (ALCAPA Microplate) from the Alpine domain (Ratschbacher et al. 1991a,b; Kováč et al. 1998a). Oblique collision between the orogen and the Bohemian Massif resulted in left lateral displacement along this zone followed by opening of the Vienna Basin "pull apart" depocentres (Royden 1985; Tomek & Hall 1993; Lankreijer et al. 1995; Fodor 1995; Kováč et al. 2004). Initial rifting in the Pannonian back arc basin opened new marine connections in this time. The sea transgression from the Mediterranean advanced via the Trans-Tethydian Trench Corridor (Rögl 1998; Pavelič 2001). The broad Karpatian sea flooding extended beside the back arc basin also into the Vienna Basin and the Western Carpathian Foredeep domain (Fig. 2B). The continental areas were represented beside the European platform by uplifted parts of internal zones of the Eastern Alps and Western Carpathians; the accretion wedge of the Outer Carpathian Flysch Belt showed a minimal uplift in its western part only.

The Middle Miocene geodynamic development influenced factors such as the end of subduction in front of the Western Carpathian orogen, its soft docking on the slopes of the European platform (Konečný et al. 2002) and back arc synrift subsidence in the Pannonian Basin domain (Horváth et al. 1988). Voluminous acid and calc-alkaline volcanism is observed during this time. The Central Paratethys Sea can be characterized in this time as an epicontinental sea with a number of archipelagoes and a lot of separate basins. The sea flooding extended in front of the orogen (foredeep basin), as in the Pannonian back arc basin area. In the study area (southern part of the Carpathian Foredeep and Vienna Basin), the late Early Badenian transgression was completely controlled by tectonics (Lankreijer et al. 1995; Kováč et al. 2001, 2004) and associated with basin subsidence and continuous mountain chain uplift. During the Middle Badenian a part of the Western Carpathian basins were isolated with the resulting salinity crisis (Kováč et al. 1998b); in the southern part of the Carpathian Foredeep the sedimentation ended. The Vienna Basin still subsided and was connected towards the Pannonian domain by straits in the uplifting Malé Karpaty and Leitha Mountains. The changes in relief led to development of a drainage system, the paleo-Danube river delta entered the Vienna Basin and voluminous deltaic sequences started to be deposited (Kováč et al. 2004; Lambert et al. 2008). The Late Badenian flooding covered the whole northen part of the Pannonian back arc basin system (Fig. 2C). In the Vienna Basin the transgression was accelerated by basin subsidence and sea-level rise (Kováč et al. 2001, 2006). The basins were filled by clastic material transported by rivers, entering the basin from elevated mountain ranges in the basin surroundings. In front of the orogene, the Carpathian Foredeep started to disintegrate and depocentres moved from West towards East (Meulenkamp et al. 1996). During the Sarmatian, closing of the Central Paratethys Sea connections with the Mediterranean Sea led to isolation and salinity decrease in all the Western Carpathian basins. The sea started to be shallower, but its extent did not change significantly.

The Late Miocene geodynamic development represents the final stage of the Pannonian back arc basin evolution, with related thermal subsidence (Horváth 1988; Kováč et al. 1993; Lankreijer et al. 1995; Konečný et al. 2002). The Vienna Basin represented a partly isolated bay at its northwestern boundary during this time (Kováč et al. 1998a; Kvaček et al. 2006). Uplift of the Western Carpathian mountain chain was accompanied by the next development of the river net, resembling the Pliocene paleogeography (Fig. 2D). The Central Paratethys brackish sedimentary environment — represented by Lake Pannon in the study area (Magyar et al. 1999) gradually changed into a freshwater lake environment, particularly in the back arc basin domain. During the Pannonian, the Vienna Basin was filled by a huge amount of deltaic sediments (Kováč et al. 1998, 2004, 2006; Harzhauser et al. 2004). The shallow-water fluvial to lacustrine environment changed to swamps and alluvial plains with ephemeral lakes representing the greater part of its territory until the end of the Late Miocene. The Pannonian and Pontian mountain ranges gained features similar to their present form.

Material and methods

In this study, 44 outcrops and boreholes (Carpathian Foredeep — Eggenburgian–Early Badenian (23 localities), Czech and Slovak parts of Vienna Basin — Karpatian–Pannonian (21 localities)) were analysed. Due to the absence of index fossils, the studied Lower Miocene sediments are undistinguishably (Upper Eggenburgian–Ottnangian). The analysed samples come from the localities in the southern part of the Carpathian Foredeep — boreholes Šafov 12, Šafov 13, Čejkovice, Únanov, Miroslav, Trboušany, Nosislav 3, Židenice. Carpathian Foredeep marine and brackish sediments, Karpatian in age, were evaluated from several stratotype localities Slup, Hevlín, Dolní Dunajovice, Medlov, boreholes Nosislav 3, Ždánice 67, 68 and from the Vienna Basin boreholes Zohor 1 and Gbely 139 were analysed (Doláková & Slamková 2003). Palynological data, Early Badenian in age, come from the Carpathian Foredeep marine sediments from the localities Židlochovice, Lysice, boreholes Moravské Knínice, Sivice, Chrlice, Opatovice and Otmarov. Pollen data, Late Badenian in age, come from outcrop Devínska Nová Ves and borehole Lozorno 1 in the Vienna Basin. Studied sediments, Late Miocene in age, with well-determined plant macrofossils (Knobloch 1968, 1985) come from the Poštorná, Dubňany, Moravská Nová Ves outcrops; clay pit Gbely, boreholes Suchohrad 32, Suchohrad 38, Jakubov 54 and six shallow Pohansko boreholes near Břeclav city.

In the chemical treatment 20–30 g of dry sediment was used. The samples were treated with cold HCl (35%) and HF (70%), removing carbonates and silica. Separation of the palynomorphs from the rest of the residue was carried out using $ZnCl_2$ (density = 2 g/cm^3). Sieving was done using 10 μm nylon sieve. The palynological residue, mixed with glycerine, was prepared on slides. A transmitted light microscope with 250, 400, 630, 1000 (oil immersion) magnifications and SEM microscope was used for pollen counting and identification. Original micrographs are housed at the Institute of Geological Sciences MU in Brno. The pollen diagrams have been created using POLPAL 4 software (Walanus & Nalepka 1999).

To have a better idea about the vegetation composition the differentiated vegetation groups (zonal, azonal, extrazonal) were used *sensu* Kovar Eder et al. (2008a,b) and Kvaček et al. (2006). A semiquantitave evaluation of climate evolution has been done based on the proportion of paleotropical (thermophilous) and arctotertiary elements (*sensu* Mai 1981, 1991) in terms of mesophytic plants. We devided the floristic elements of zonal vegetation into two groups.

In the thermophilous-mesophytic group we included *Engelhardia*, Sapotaceae, Palmae, evergreen Fagaceae (including morphospecies *Quercoidites microhenrici* and *Quercoidites henrici*), *Trigonobalanopsis*, *Symplocos*, *Cornaceaepollis satzveyensis*, *Tricolpopollenites liblarensis*, Araliaceae, Rutaceae. Mostly broad-leaved deciduous elements of warm-temperate mixed mesophytic forests such as *Quercus*, *Celtis*, *Carya*, *Tilia*, *Zelkova*, *Ostrya*, *Carpinus*, *Betula*, *Juglans* are included into the group of arctotertiary–mesophytic elements. Extrazonal mountain vegetation is represented by: *Cedrus*, *Tsuga*, *Picea*, *Cathaya*. Azonal vegetation is influenced by edaphic factors and in our study it is represented by riparian forests with *Alnus*, *Salix*, *Ulmus*, swamps with Taxodiaceae, Myricaceae, Nyssaceae and aquatic plant communities.

All the studied material is housed at the Institute of Geological Sciences MU in Brno and the Faculty of Sciences of Comenius University in Bratislava.

Results and discussion

Early Miocene

Eggenburgian–Ottnangian–Karpatian (Late Aquitanian–Late Burdigalian)

During the Early Miocene thermophilous taxa *Engelhardia*, *Platycarya*, Sapotaceae, Palmae and ferns *Lygodium*, Pteridaceae, ?Davalliaceae, Schizaeaceae–Cyatheaceae were frequent. Evergreen Fagaceae were represented by the *Trigonobalanopsis* type, morphotaxa *Tricolporopollenites microhenrici* and *Tricolpopollenites liblarensis*, *Tricolporopollenites henrici*. Also *Symplocos*, *Reevesia*, *Parthenocissus*, Araliaceae, Rutaceae and morphotaxa *Cornaceaepollis satzveyensis*, *Tricolporopollenites pseudocingulum* were common in pollen spectra. Arctotertiary elements *Carya*, *Juglans*, *Quercus*, *Betula*, *Liquidambar* were less frequent (Fig. 3).

The vegetation of the salt marshes and also insolated places (Chenopodiaceae up to 37 %, *Ilex*, *Tamarix*, Ericaceae, Poaceae less *Ephedra*, Asteraceae and Buxaceae) was typical. Due to the salinity oscillations as well as occasional higher evaporation *sensu* Hladilová (1988), the coasts of individual sea gulfs and lagoons could be repeatedly salinized and overgrown by the halophilous flora (Doláková et al. 1999). Pollen grains of the formal genus *Monocirculipollis* assigned to the family Caryophyllaceae (*sensu* Doláková 2004), were typical for this time span being absent in younger ones (Fig. 6). Salt marsh vegetation was sometimes replaced by swamp plants.

Taxodiaceae, Myricaceae, Cyrillaceae, Gleicheniaceae, *Decodon*, *Lygodium*, *Selaginella*. Even the aquatic flora appeared — *Sparganium*, *Potamogeton*, Onagraceae, *Nelumbo*, Cyperaceae (Figs. 3, 5, 7). The genus *Platanus* was the common member of the pollen spectra since this time span. A permanently low amount of intrazonal elements (Taxodiaceae, Myricaceae and ferns) without strong oscilation occurred in the palynospectra. Regularly higher ratios of Fagaceae, *Carya* and also heliophilous taxa were observed. Pinaceae (up to 40 %) and extrazonal vegetation, including abundant *Cathaya* and less frequent *Cedrus*, *Picea*, *Abies,* occurred frequently (Fig. 3). A high proportion of Ulmaceae, *Myrica*, *Alnus* was observed in sediments of the Eggenburgian–Ottnangian. Pollen spectra contain a larger amount of spores of thermophilous ferns as *Lygodium* (up to 5 %), Pteridaceae, Gleicheniaceae together with *Selaginella* and bryophyte *Riccia* (Fig. 3). These findings are in a good conformity with macrofloristic results of Knobloch (1982) who described a unique oryctocoenosis from the rhyolite tuffites at Znojmo and Přímětice. He considered them as the shrubby — arboreal heliophilous vegetation with mostly evergreen fine dentate or spiny leave (sclerophyllous) similar to Mediterranean “macchias”. Swamp vegetation with *Glyptostrobus*, *Myrica*, aquatic flora with *Salvinia*, *Potamogeton*, *Nymphaea* and coastal reed with *Typha*, *Decodon*, *Sparganium* were identified based on macrofloristic remains too (Knobloch 1982). The accumulations of *Limnocarpus* fruits growing in the brackish water were described by Knobloch (1984). The pollen often found in clumps (Myricaceae, Chenopodiaceae, Caryophyllaceae, Oleaceae, Onagraceae, *Platanus*) support the low water dynamics and a short transport (Figs. 5, 6, 7).

During the Karpatian the thermophilous elements like Rutaceae, *Symplocos* and *Platanus* occurred less regularly. Temperate taxa are represented generally in low frequencies, but the amount and diversity of the temperate mesophytic elements slightly increased (Fig. 4). Mountain vegetation with *Tsuga* and *Abies* was common (Fig. 4). Subtropical humid climate was also supported by the macrofloristic remains described from the stratotype localities Slup and Dolní Dunajovice. Leaves of the family Lauraceae predominated with small proportion of deciduous trees in this association (Knobloch 1967, 1982; Kvaček 2003). The azonal vegetation is represented by swamp and riparian forests dominated by *Glyptostrobus* and *Myrica*.

Marshy-palm forest with *Calamus*, Poaceae, *Lygodium, Sparganium*, *Potamogeton* and riparian forest with *Alnus*, *Ulmus*, Myricaceae, Lythraceae or *Selaginella* are frequent (Figs. 4, 8). The associations with Taxodiaceae, *Craigia* and Pteridaceae (up to 10 %) and Polypodiaceae document a well developed swamp environment (Figs. 4, 8). During the present time the genus *Craigia* occurs in broad-leaved evergreen and deciduous mixed forests and seasonally wet forests. However, according to Kvaček et al. (2002), ecological tolerances of its fossil representatives may have been greater during the Tertiary. This tree surely tolerated swampy conditions and entered even coal-forming forests in wetland habitats namely swamp forests dominated by the Taxodiaceae and many other swampy and riparian woody plants as well aquatic herbs. Konzalová (1976) described a very similar horizon with *Intratriporopollenites insculptus* Mai (*Craigia*) from the coal seam formation and Cypris claystones of the North Bohemian basins.

During this time interval the plant assemblages with higher portion of arctotertiary elements were described by several authors from the Silesian part of the Carpathian Foredeep in the Polish Lowland (Oszast & Stuchlik 1977; Stuchlik 1980; Sadowska 1989; Ważyńska et al. 1998). The decrease of thermophilous elements during the Ottnangian–Early Karpatian has been recognized and defined as the microfloristic Zone MF-3 by Planderová (1990) and Planderová et al. (1993a,b). Such an event has never been found in the Carpathian Foredeep. This fact is probably related to different paleogeography. The most similar pollenspectra of Karpatian age was published by Nagy (1999) from the Mecsek Mts. Environmental interpretation of data from the Carpathian Foredeep is similar to the conditions in the Korneuburg Basin (Hofmann et al. 2002), except for absence of *Avicenia* and the lower portion of the Palmae in the studied area. Early Miocene was the warmest period of the Miocene in the Pannonian Basin and the sporomorphs indicate a warm subtropical climate (Nagy 2005).

Middle Miocene

Badenian–Sarmatian (Langhian–Serravallian)

Swamp elements (Taxodiaceae) have more regular occurrence without oscillations in comparison with the Karpatian. *Olea* type pollen was less frequent in comparison with Lower Miocene pollen spectra. In the Badenian pollen spectra the

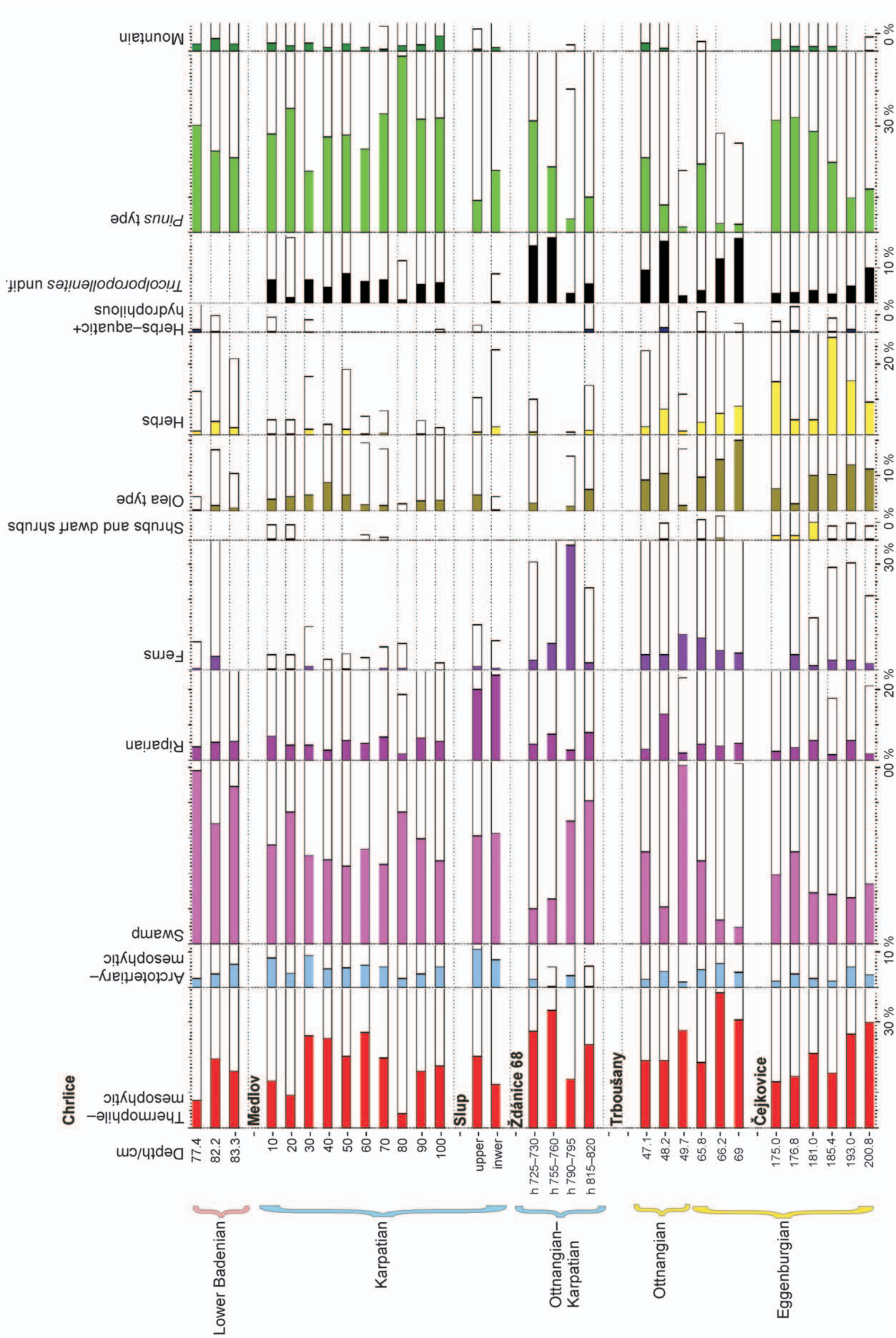

Fig. 3. Vegetation assemblage distribution during the Eggenburgian–Early Badenian time intervals.

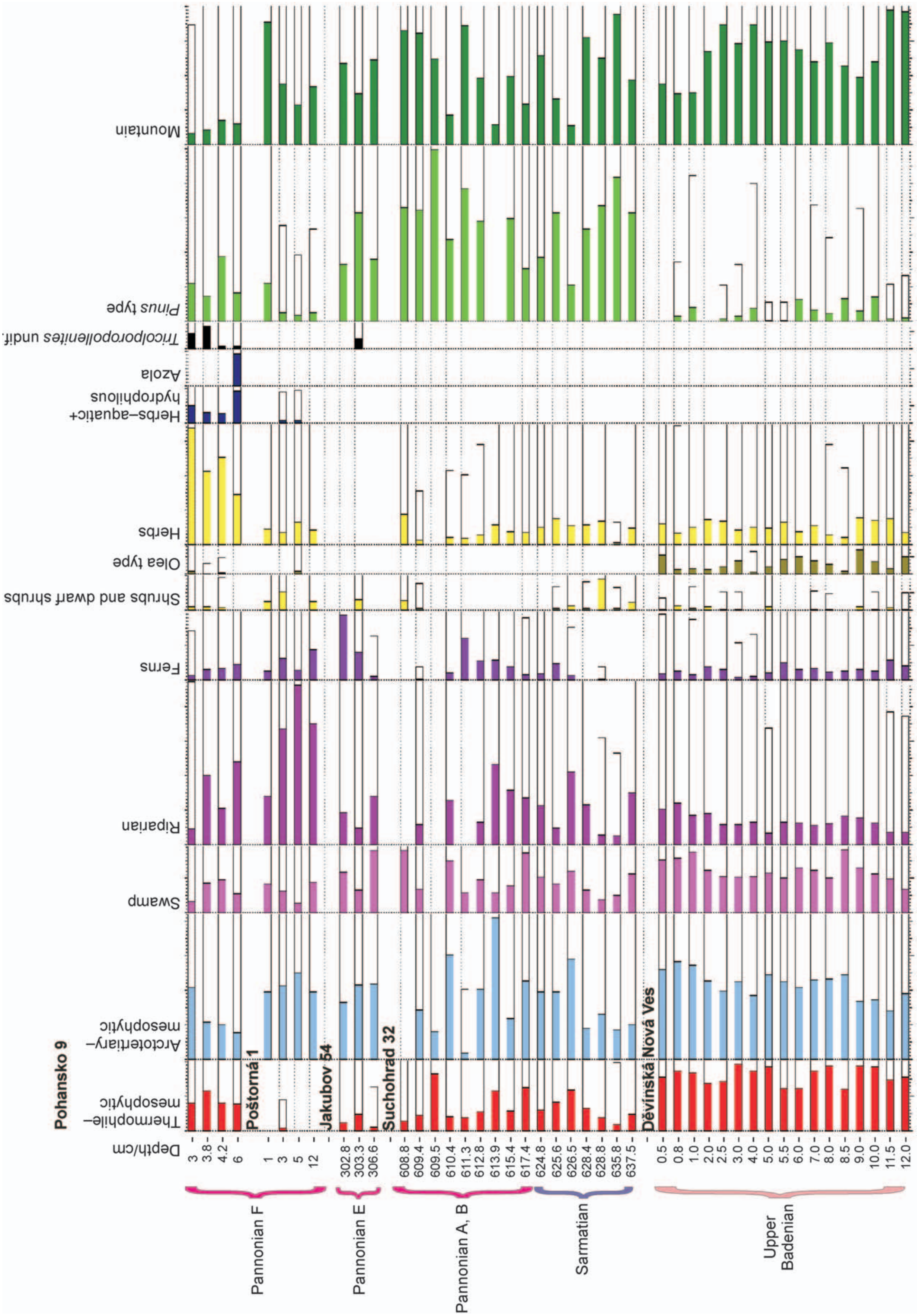

Fig. 4. Vegetation assemblage distribution during the Late Badenian–Pannonian time intervals.

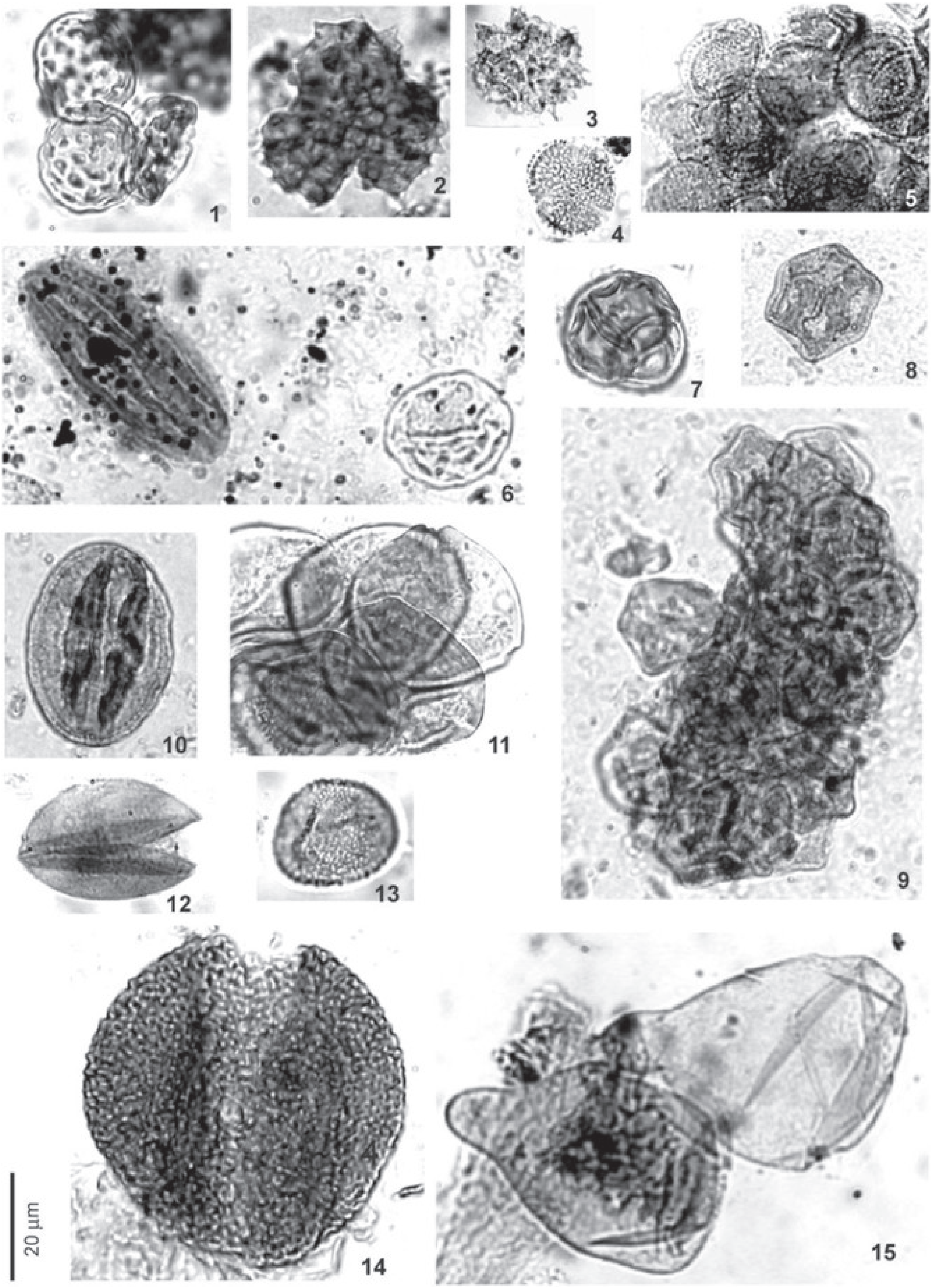

Fig. 5. Early Miocene sporomorphs from the studied area. **1** — Chenopodiaceae accumulation, **2** — Asteraceae–Asteroideae — *Tricolporopollenites grandis* Nagy, **3** — Asteraceae–Cichorioideae — *Cichoreacidites gracilis* Nagy, **4** — Oleaceae — (*Oleoidearumpollenites* sp.), **5** — Oleaceae accumulation, **6** — *Ephedra* sp. + Chenopodiaceae, **7** — Ericaceae (*Ericipites callidus* (Potonié) Krutzsch), **8** — Caryophyllaceae (*Monocirculipollis* sp. Krutzsch), **9** — Caryophyllaceae accumulation, **10** — Mastixia — (*Tricolporopollenites satzvayensis* Pflug), **11** — *Myrica* accumulation, **12** — Taxodiaceae — ?*Glyptostrobus* sp., **13** — *Potamogeton* — (*Potamogetonicidites paluster* (Mamten) Mohr), **14** — *Nelumbo* sp. (*Nelumbopollenites europaeus* (Tarasewich) Skawińska), **15** — Cyperaceae — (*Cyperaceaepollis piriformis* Thile-Pfeifer).

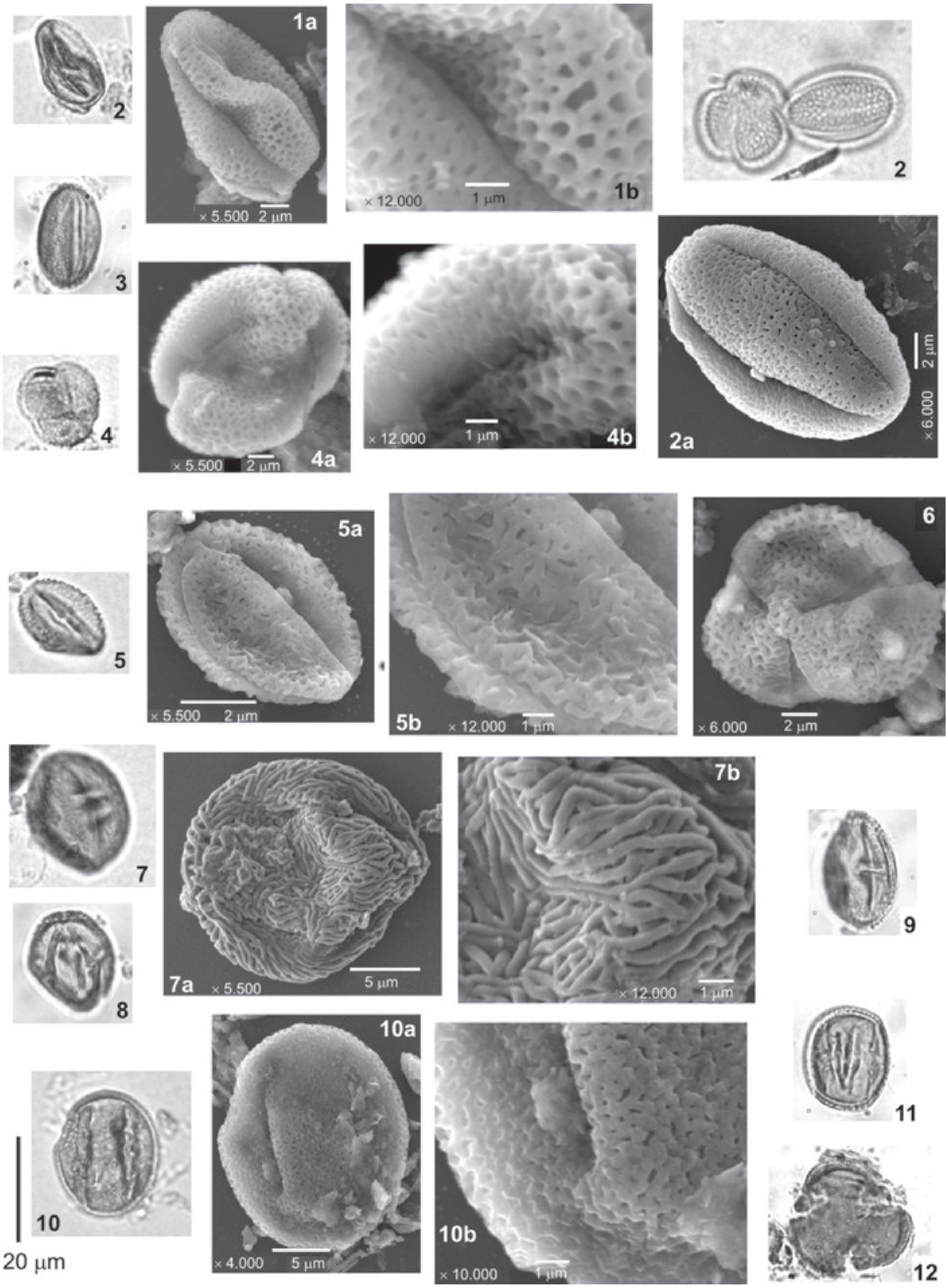

Fig. 6. Eggenburgian palynomorphs. **1a,b, 3, 4a,b** — *Tamarix* sp.; 1, 3, 4 — LM 1000×; 1a — SEM 5500×; 1b — SEM 12,000×; 4a — SEM 5500×; 4b — SEM 12,000×. **2** — *Tamarix gallica* — recent — LM 1000×; 2a — SEM 6000×. **5a,b, 6** — *Salix* sp.; 5 — LM 1000×; 5a — SEM 5000×; 5b — SEM 12,000×. **6** — SEM 6000×. **7a,b, 8, 9** — Rutaceae; 7, 8, 9 — LM 1000×; 7a — SEM 5000×; 7b — SEM 12,000×. **10, 11, 12** — *Platanus* sp.; 10a,b, 11, 12 — LM 1000×; 10a — SEM 4000×; 10b — SEM 10,000×.

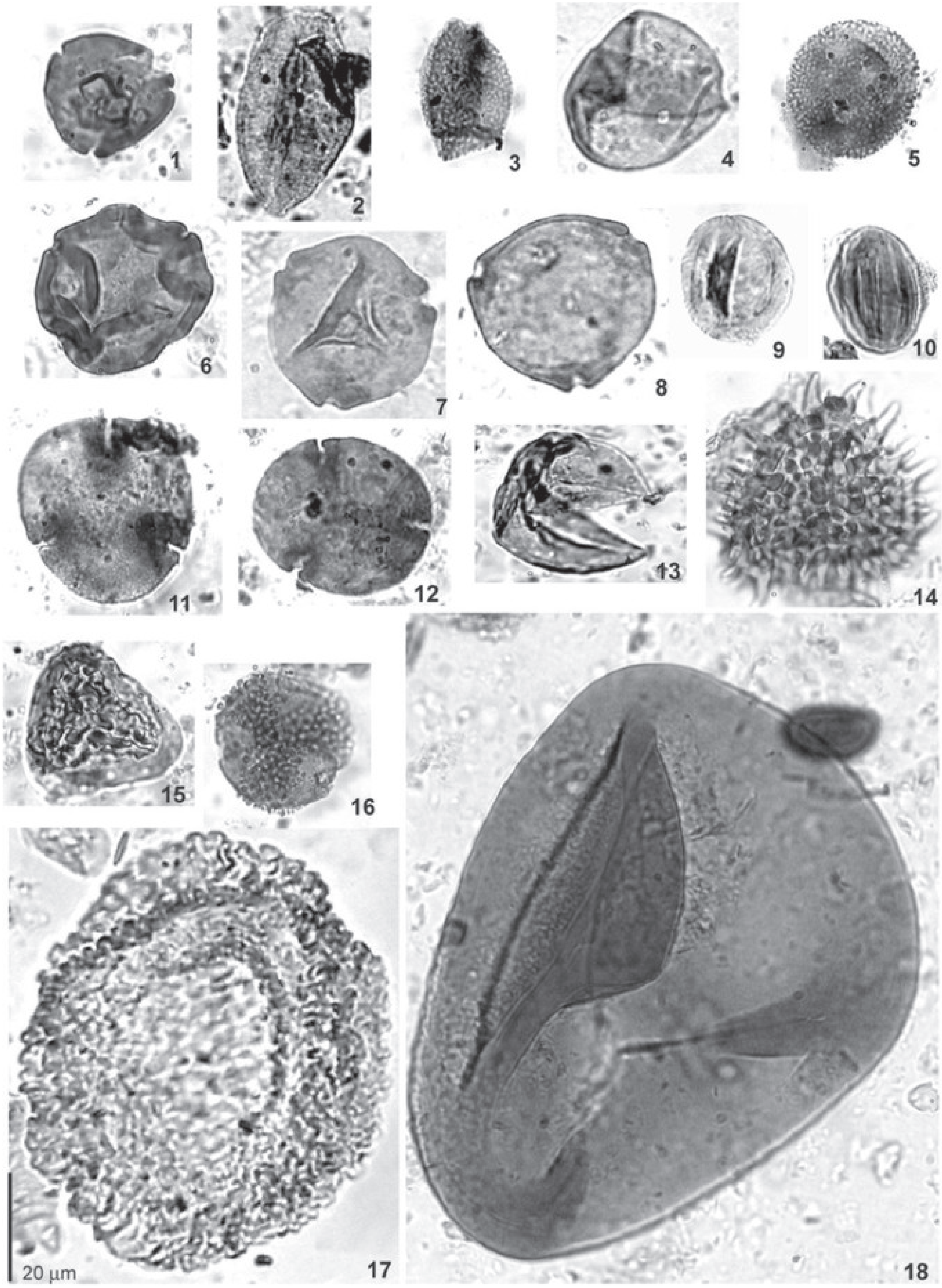

Fig. 7. Karpatian sporomorphs from the studied area. **1** — *Engelhardia* sp. with cavities after pyrite crystals; **2** — Palmae — *Monocolpopollenites tranquillus* (Potonié) Thomson & Pflug; **3** — Palmae — *Arecipites* sp.; **4** — Poaceae — *Graminidites* sp.; **5** — *Sparganium* sp. — (*Sparganiaceaepollenites neogenicus* Krutzsch); **6** — *Alnus* sp. — (*Alnipollenites verus* (Potonié) Potonié); **7** — *Myrica* sp. (*Myricipites coryphaeus* (Potonié) Potonié); **8** — *Myrica* sp. (*Myricipites peregriniformis* (Gladkova) Grabowska &Wazynska); **9, 10** — Lythraceae; **11, 12** — *Craigia* sp. (*Intratriporopollenites insculptus* Mai); **13** — Taxodiaceae — ?*Glyptostrobus* sp.; **14** — *Selaginella* sp. (*Echinatisporis miocenicus* Krutzsch & Sontag in Krutzsch); **15** — *Pteris* sp. — (*Polypodiaceoisporites muricinguliformis* Nagy); **16** — *Ilex* sp. — (*Ilexpollenites margaritatus* (Potonié) Raatz); **17** — Tsuga sp. — (*Tsugaepollenites maximus* (Raatz) Nagy; **18** — *Lygodium* sp. (*Leiotriletes maxoides maxoides* W.Kr.).

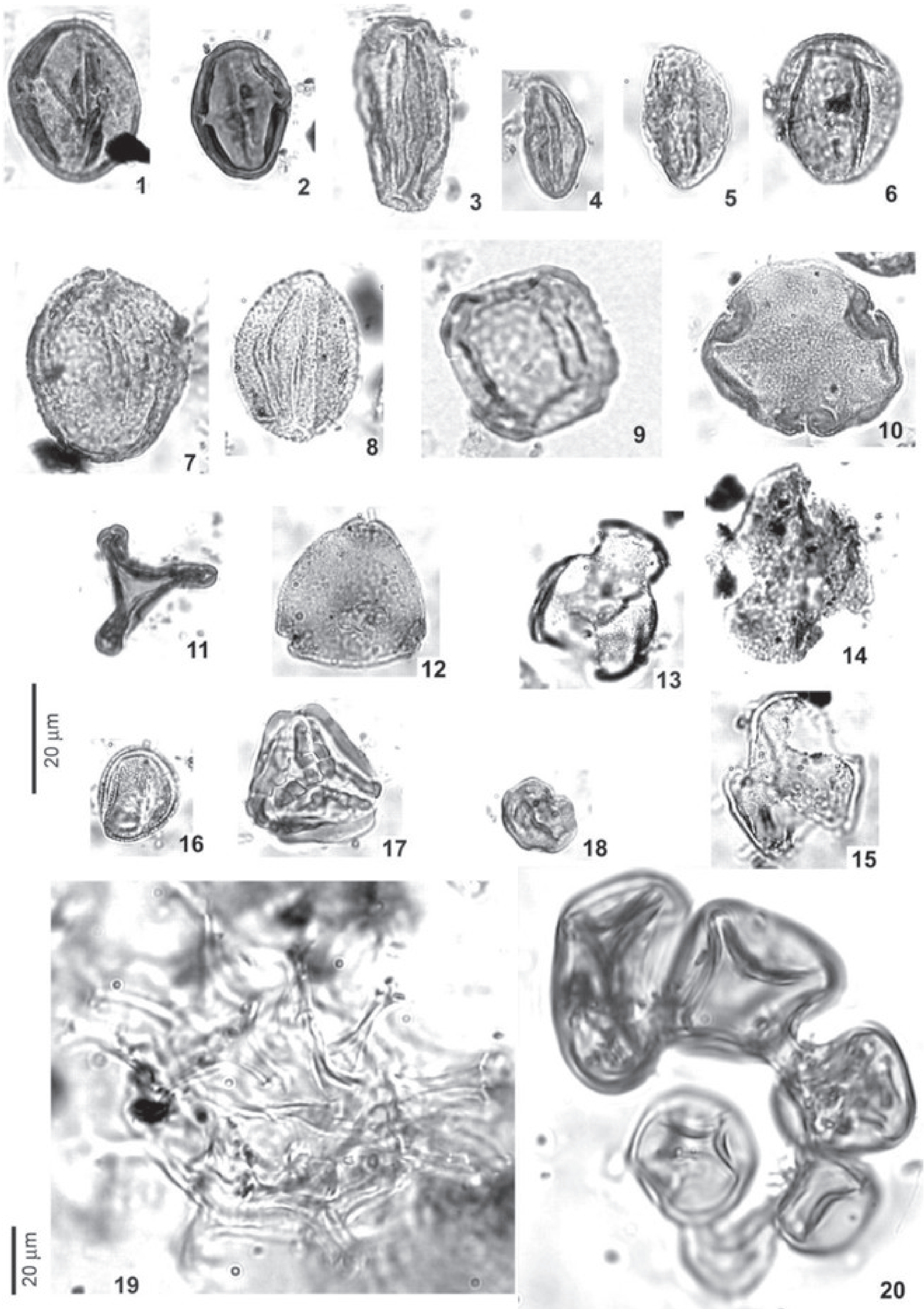

Fig. 8. Badenian sporomorphs from the studied area. **1** — *Mastixia* sp. — (*Tricolporopollenites satzvayensis* Pflug); **2** — Sapotaceae — (*Sapotaceoipollenites sapotoides* (Pflug & Thomson) Potonié); **3** — *Quercoidites henrici* (Potonié) Potonié, Thomson & Thiergart; **4, 5** — *Quercoidites microhenrici* (Potonié) Potonié, Thomson & Thiergart; **6, 7** — *Q. robur* (*Quercoidites granulatus* (Nagy) Slodkowska); **8** — *Quercoidites* sp.; **9** — *Zelkova* sp. — (*Zelkovaepollenites potoniei* Nagy), **10** — *Tilia* sp. – (*Intratriporopollenites instructus* (Potonié) Thomson), **11** — Loranthaceae — *Gothanipollenites gothani* Krutzsch; **12** — *Symplocos* sp. — *Symplocoipollenites vestibulum* (Potonié) Potonié, **13** — *Cercidiphyllum* sp. — (*Cercidiphyllites minimireticulatus* (Trevisan) Ziembińska-Tworzydło); **14, 15** — *Distylium* — *Parrotia* type — (*Tricolporopollenites indeterminatus* (Romanovicz) Ziembińska-Tworzydło); **16** — *Platanus* sp.; **17** — Pteridaceae — (*Segmentizonosporites paucirugosus* (Nagy) Stuchlik); **18** — Caryophyllaceae (*Caryophyllidites microreticulatus* Nagy); **19** — Marine dinoflagellates; **20** — foraminiferal lining.

higher differentiation of the Fagaceae in thermophilous evergreen (morphotypes *Tricolporopollenites henrici* and *Tricolporopollenites microhenrici*) and deciduous oaks, some thermophilous taxa *Gothanipollenites gothani* (Loranthaceae) or *Tricolporopollenites indeterminatus* (Hammamelidaceae) occurred (Fig. 9). Herbs such as Caryophyllaceae (*Minutipollis granulatus* Krutzsch) were common. Early Badenian Lauraceae and Betulaceae leaves from the Carpathian Foredeep have been found at the Smolín locality (Sitár et al. 1978). During the Late Badenian the following were frequently present: Pinaceae (*Pinus*, *Picea*, *Abies*, *Tsuga*) and deciduous elements with *Quercus*, *Alnus*, *Ulmus*, *Carya*. Subtropical taxa are commonly represented by *Magnolia*, *Platycarya*, *Engelhardia*, *Myrica*, *Trigonobalanopsis* and *Distylium*. Paleoecological conditions favoured development of swamp forests with Taxodiaceae, *Nyssa* and *Myrica* and riparian forest elements with *Alnus*, *Ulmus* and *Pterocarya.* Drier areas were overgrown with mixed mesophytic forest represented by *Pinus*, *Juglans*, *Carya*, *Sciadopitys* and the extrazonal vegetation type is documented by the presence of *Picea*, *Tsuga* and deciduous oaks. Herbs are represented mostly by Poaceae. During the Early Sarmatian time interval the azonal vegetation was well developed in swamps with Taxodiaceae, *Myrica*, *Nyssa* and salty marshes with Poaceae and halophytes (Chenopodiaceae). Riparian forests with *Alnus*, *Salix* and *Ulmus* were also common. The extrazonal vegetation portion increased mainly in the mountain vegetation elements. The decrease to disappearance of the Taxodiaceae, Nyssaceae, Myricaceae and halophytes suggests a large reduction of the swamp biotops. Riparian forests with *Ulmus*, *Salix*, *Alnus* and Poaceae were still present. Gradual decrease of thermophilous taxa indicates moderate cooling. Syabryaj & Vodoryan (1975) described similar, well diversified pollen spectra from the NE Carpathian territory in Čop–Munkacevo. Ivanov (1995) and Ivanov et al. (2002) described presence of *Symplocos* in Badenian pollen spectra from NW Bulgaria. In our studied material we noticed *Symplocos* presence only from Early Miocene localities, probably due to temperature gradient.

There was a warm subtropical climate. Early Badenian transgression and uplift of the Alpine and Carpathian Mountains produced favourable local climate for vegetation change (Nagy 2005).

Late Miocene

Pannonian–Pontian (Tortonian–Messinian)

In the pollen spectra from the Early Pannonian *sensu* Harzhauser et al. (2004) or Early Tortonian *sensu* Harzhauser & Piller (2007), mostly broad-leaved deciduous elements dominate, with some thermophilous elements admixture of *Engelhardia*, *Ilex*, *Castanopsis* and *Castanea*, suggesting a warm temperate mixed mesophytic forest with low representation of evergreen elements. The proportion of NAP — non arboreal pollen — Ericaceae and Chenopodiaceae is higher (10 and 14 % respectively) suggesting local marshes and open herbaceous plant communities within the forests. Mountain conifers, such as *Picea*, *Tsuga*, *Abies*, *Cedrus* are common accessories. Lowland vegetation was comprised of the azonal *Alnus*, *Pinus*, *Ulmus* mixed and broad-leaved riparian forest with common deciduous oaks, and swamp taxa Taxodiaceae, *Nyssa*, *Myrica*. Sporadic occurrences of dinoflagellates and green algae Tasmanaceae indicate a slightly higher salinity, *Botryococcus* can thrive in both brackish or freshwater environments, whereas green algae *Pediastrum*, *Mougeotia*, aquatic ferns *Azolla*, and aquatic and coastal plants (*Nelumbo*, *Nymphaea*, *Myriophyllum*, *Sparganium*, *Potamogeton* etc.) represent a freshwater environment (Doláková & Kováčová 2008). In the pollen spectra, from the middle Pannonian (*sensu* Harzhauser et al. 2004), coniferous woody plants of mountain vegetation (*Picea*, *Abies*, *Tsuga*, *Cedrus*, *Pinus*) and deciduous oaks were abundant. Angiosperm trees and shrubs with *Alnus*, *Betula*, *Liquidambar*, *Myrica*, *Nyssa* and *Salix* indicate a well developed riparian forest. The subdominance of herb species is good evidence of the local open woodland environment.

The facies mutually changing in time and space in individual pollen spectra are created by azonal types of vegetation (marshes, riparian, coastal and aquatic) or by high amounts of herbaceous plants *Artemisia*, *Plantago*, *Polygonum*, Asteraceae, Lamiaceae, Daucaceae, Caryophyllaceae, which indicate existence of local open areas.

In the Slovak part of the Danube Basin Planderová (1972, 1990) described reduced marshes, isolated lakes surrounded by steppe meadows (dominance of *Artemisia*) with rare woody plants. In comparison with Hungary she considered the climate cooler and drier (Nagy 1985; Nagy & Planderová 1985; Planderová 1990). Hoffmann & Zetter (2005) determined a pollen assemblage rich in herbs from the Late Pannonian in the Styrian Basin.

The extensive Pannonian and Pontian sea and the protective mountain range provided a very equable, warm temperate climate, where even the summer season was not too dry (Nagy 2005).

Conclusions

Development of Miocene vegetation patterns in the area of the northwestern Central Paratethys was derived (above all) from palynological analysis. The case study area covers the slopes of the tectonically quiet European platform and the foreland of the tectonically active Carpathian mountain chain (Carpathian Foredeep and Vienna Basin). Interpretation of pollen spectra reflects both, the landscape evolution in two areas with different geodynamics, and the climatic changes in the Central Paratethys domain during the studied time intervals. Based on pollen data, the Early to Middle Miocene vegetation document a subtropical climate with very mild (negligible) cooling during this period. This is indicated by common occurrence of thermophilous taxa: Sapotaceae, Palmae, *Engelhardia*, *Platycarya* and *Tricolporopollenites henrici*, *Lygodium* and Pteridaceae. *Reevesia*, *Cornus-Mastixia*, *Symplocos*, *Parthenocissus*, *Tricolporopollenites pseudocingulum*, Rutaceae and Araliaceae. The proportion of the temperate elements such us *Carya*, *Pterocarya*, *Juglans*, *Celtis*, *Fagus* is noticeably lower. The lower portion of extrazonal (mountain) vegetation and well developed riparian forests with *Alnus*, *Craigia*, Pteridaceae, Polypodiaceae, Lythraceae,

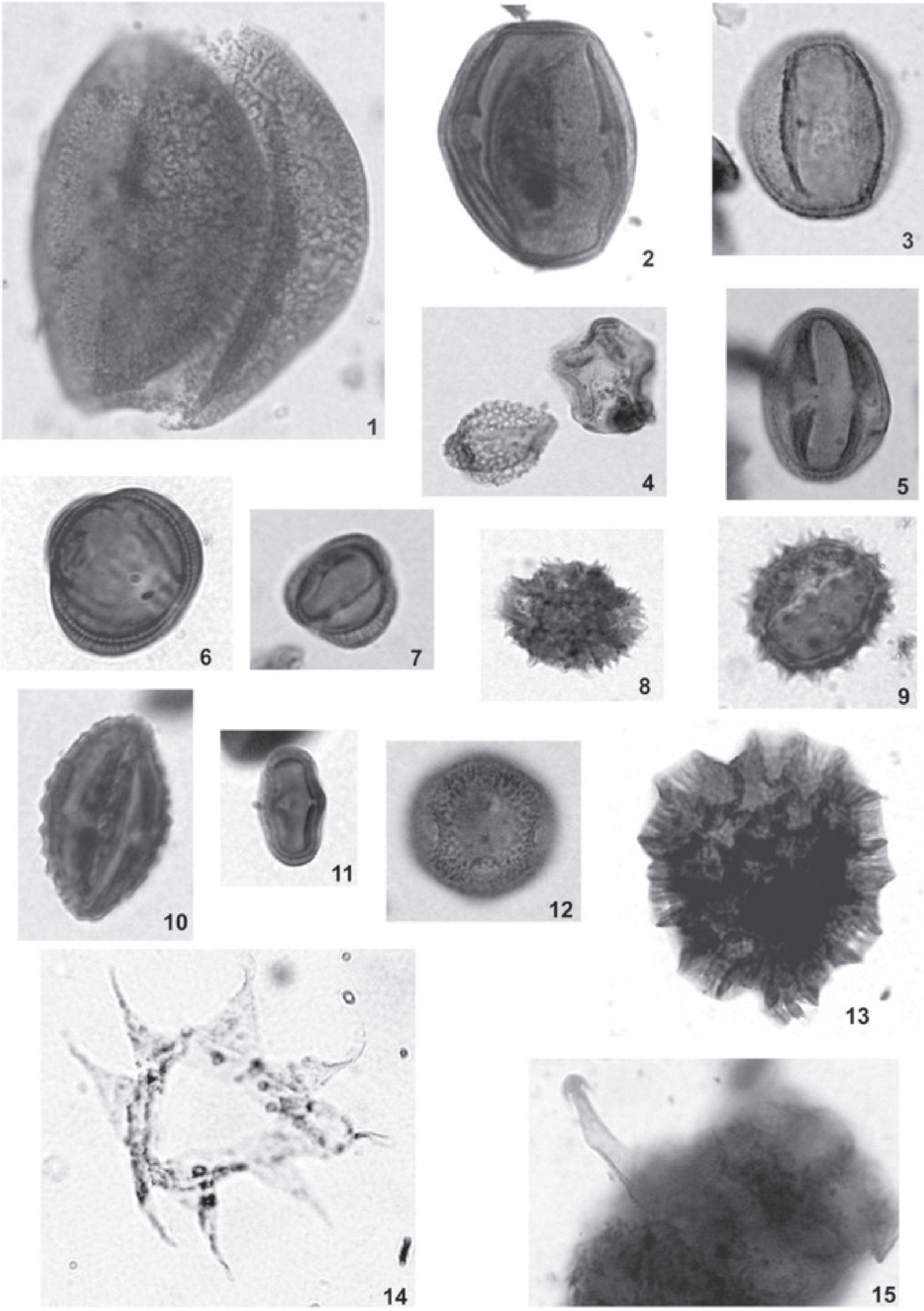

Fig. 9. Pannonian palynomorphs from the studied area. **1** — *Picea* sp. — (*Piceapollis* sp.); **2** — *Nyssa* sp. — (*Nyssapollenites rodderensis* (Thiergart) Kedves); **3** — *Quercus robur* type; **4** — *Salixipollenites* sp. + *Alnipollenites* sp.; **5** — Rosaceae gen. indet.; **6, 7** — *Artemisia* div. sp.; **8** — Cichorioideae — (*Cichoreacidites gracilis* Nagy); **9** — Asteroideae - (*Tubulifloridites macroechinatus* (Trevisan) Nagy); **10** — *Centaurea jacea* type; **11** — Daucaceae gen. indet.; **12** — Caryophyllaceae gen. indet.; **13** — *Polygonum persicaria* — (*Persicarioipollis pliocenicus* Krutzsch); **14** — *Pediastrum simplex* Meyen; **15** — Microsporangium with glochidium of *Azolla bohemica* Pacltová.

Cyperaceae, *Sparganium*, *Potamogeton*, *Nelumbo* and swamps with Taxodiaceae, Myricaceae alternated with salt marshes represented by Chenopodiaceae up to 37 %, Poaceae, Caryophyllaceae, Asteraceae, Ericaeae, Lythraceae, which document a moderate relief of landscape during the whole Early Miocene. The frequent pollen clumps support a theory of the low water dynamics and a short transport distance. The alteration in palynomorphs caused by the crystallization of pyrite in anoxic conditions was observed.

The Middle Miocene landscape evolution, conditioned by the uplift of the Carpathian mountain chain and subsidence of adjacent lowlands, led to commencement of the altitudinal zonation. This process is documented by changes in paleovegetation cover. In spite of this presence of zonal vegetation with evergreen broadleaved forests supplemented by azonal vegetation (riparian forests, swamps) is typical of the Early Badenian. Only several thermophilous plants, such as *Engelhardia* and *Platycarya*, which were frequent in all of the Early Miocene associations, decreased in the Early Badenian pollenspectra. From the Late Badenian a higher proportion of extrazonal (mountain) vegetation were present in pollen spectra (*Picea*, *Abies*, *Tsuga*, *Cedrus*). The terrestrial and aquatic ecosystems confirm a subtropical climate with visible changes at the boundary between the Early and Late Badenian. An increased proportion of the arctotertiary taxa during the Late Badenian is documented in pollenspectra by *Quercus*, *Ulmus* and *Carya*, whereas *Platycarya*, *Engelhardia*, *Myrica*, *Distylium* and thermophilous Fagaceae are less frequent. Herbs are represented mainly by the halophytes (Chenopodiaceae).

Vegetation during the Early Sarmatian time interval was formed by swamp elements with Taxodiaceae, Myricaceae, Nyssaceae. High elevation species of woody plants *Tsuga*, *Picea*, *Cedrus*, *Abies* are indicative of mountainous relief resulting from volcanic activity. During the Late Sarmatian the proportion of swamp elements decreased and was replaced mostly by riparian forests.

The Late Miocene paleogeographical changes and general climatic oscillations in the northwestern Central Paratethys realm reflected the decrease especially of the thermophilous taxa *Engelhardia*, *Castanea*, evergreen Fagaceae *Quercoidites microhenrici*, and to a lesser extent of *Quercoidites henrici*, *Trigonobalanopsis*, *Symplocos*, *Cornaceaepollis satzveyensis*, *Tricolpopollenites liblarensis.* An apart from the mountain vegetation the amount of herbaceous plants in the pollen spectra increased during this time span. The varying height's of the moutain relief of the uplifted mountain chains (altitudinal zonality) created ideal conditions for extrazonal vegetation (*Cedrus*, *Tsuga*, *Picea*) and dominance of mixed mesophytic forests with *Quercus*, *Celtis*, *Carya*, *Tilia*, *Zelkova*, *Ostrya*, *Liquidambar*, *Carpinus*, *Betula*, *Juglans* and with regular presence of evergreen taxa.

The swamp, riparian, often hydrophilous (*Azolla*, *Nymphaea*, *Potamogeton*) and halophytic (Chenopodiaceae) plants represent coastal swamps, local lagoons, and marshlands. The higher percentage of the herbs (*Artemisia*, Asteraceae, Lamiaceae, *Polygonum*, Daucaceae, Caryophyllaceae, *Plantago*) and shrubs in the comparison with older time intervals, shows that local open woodland — open grassland started to develop during the Pannonian.

The gradual retreat of areas flooded by the sea, as well as following retreat of the lake and swamp environment was confirmed by the decrease of azonal vegetation towards the end of this period. The reconstructed vegetation cover suggest a subtropical climate with gradual transition to warm temperate climatic conditions.

Acknowledgments: The authors wish to express their gratitude to reviewers L. Hably, Z. Kvaček and D. Ivanov for useful and constructive comments. This work was supported by the Slovak Research and Development Agency under the contracts APVV-LPP 0120-06, APVV-0280-07, ESF-EC-0006-07, ESF-EC-0009-07 and the Slovak Grant Agency VEGA (Projects No. 2/0060/09, 1/0483/10) and Czech Grant Agency under the contract No. 205/09/0103.

References

Doláková N. 2004: Discussion on some Thermophile palynomorphs from the Miocene sediments in the Carpathian Foredeep (Czech Republic) and Modrý Kameň Basin (Slovakia). *Acta Paleobot.* 44, 1, 79–85.

Doláková N. & Kováčová M. 2008: Pannonian vegetation from the northern part of Vienna Basin. *Acta Mus. Nat. Pragae*, Ser. B, 64 (2–4), 163–171.

Doláková N. & Slamková M. 2003: Palynological characteristics of Karpatian sediments. In: Brzobohatý R., Cicha I., Kováč M. & Rögl F. (Eds.): The Karpatian a lower Miocene stage of the Central Paratethys. *Masaryk University Brno*, 325–346.

Doláková N., Hladilová Š. & Nehyba S. 1999: Development of sedimentation, molluscs and palynospectra in the Lower Miocene of the south-western Part of the Carpathian Foredeep in Moravia (Czech Republic). *Acta Palaeobot.*, Suppl. No. 2, 269–278.

Fodor L. 1995: From transpression to transtension: Oligocene–Miocene structural evolution of the Vienna basin and the East Alpine-Western Carpathian junction. *Tectonophysics* 242, 151–182.

Grünert P., Soliman A., Harzhauser M., Müllegger S., Piller W.E. & Rögl F. 2010: Upwelling conditions in the Early Miocene Central Paratethys Sea. *Geol. Carpathica* 61, 2, 129–145.

Haq B.U. 1991: Sequence stratigraphy, sea-level change and significance for the deep sea. *Spec. Publ. Int. Ass. Sed.* 12, 3–39.

Haq B.U., Hardenbol J. & Vail P.R. 1988: Mesozoic and Cenozoic chronostratigraphy and cycles of sea level changes. In: Wilgus C.K., Hastings B.J., Posamentier H., van Wagoner J.C., Ross C.A. & Kendall C.G. St. C. (Eds.): Sea level changes: an integrated approach. *SEPM Spec. Pub.* 42, 71–108.

Harzhauser M. & Piller E.W. 2007: Benchmark data of changing sea — Palaeogeography, palaeobiogeography and events in the Cenral Paratethys during the Miocene. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 253, 8–31.

Harzhauser M., Daxner-Höck G. & Piller E.W. 2004: An integrated stratigraphy of the Pannonian (Late Miocene) in the Vienna Basin. *Austrian J. Earth Sci*. 95/96, 6–19.

Hladilová Š. 1988: Palaeoecology of Eggenburgian Molluscs (Bivalvia, Gastropoda) from the HV-301 Čejkovice borehole (Moravia). *Čas. Miner. Geol*. 3, 1–33 (in Czech).

Hofmann Ch.Ch. & Zetter R. 2005: Reconstruction of different wetland plant habitats of the Pannonian Basin System (Neogene, Eastern Austria). *Palaios* 20, 266–279.

Hofmann Ch.Ch., Zetter R. & Draxler I. 2002: Pollen- und Sporenvergesellschaftungen aus dem Karpatium des Korneuburger Beckens (Niederösterreich). *Beitr. Paläont*. 27, 17–43.

Hochuli P.A. 1978: Palynologische Untersuchungen im Oligozän und Untermiozän der Zentralen und Westlichen Paratethys. *Beitr. Paläont Österr.* 4, 1–132.

Horváth F., Dovenyi P., Szalay S. & Royden L.H. 1988: Subsidence, thermal and maturation history of the Great Hungarian Plain. In: Royden L.H. & Horváth F. (Eds.): The Pannonian Basin. *AAPG Memoir* 45, 355–372.

Hudáčková N., Halásová E., Fordinál K., Sabol M., Joniak P. & Kráľ J. 2003: Biostratigraphy and radiometric dating in the Vienna Basin Neogene (Slovak part). *Slovak Geol. Mag.* 9, 4, 233–235.

Ivanov D.A. 1995: Palynological data about the presence of the family Symplococaceae in the Miocene of Northwestern Bulgaria. *Geol. Carpathica* 46, 1, 37–40.

Ivanov D., Ashraf A.R., Mosbrugger V. & Palamarev E. 2002: Palynological evidence for Miocene climate change in the Forecarpathian Basin (Central Paratethys, NW Bulgaria). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 178, 19–37.

Knobloch E. 1967: Pflanzenfunde aus der karpatischen Serie in der Vortiefe in Mähren. In: Cicha I., Seneš J. & Tejkal J. (Eds.): Chronostratigraphie und Neostratotypen, Miozän M3 — Karpatien. *SAV*, Bratislava, 244–256.

Knobloch E. 1968: The plant association in Czechoslovakian Tertiary. *Čas. Miner. Geol.* 13, 1, 109–118 (in Czech, German summary).

Knobloch E. 1982: The Early Miocene flora from South Moravia. *Zemní Plyn Nafta* XXVII, 415–428 (in Czech).

Knobloch E. 1984: Die Halophile Gattung *Limnocarpus* C. Reid im Neogen von Mähren. *Věst. Ústř. Úst. Geol.* 59, 2, 155–165.

Knobloch E. 1985: Die floren des Pannonien im Wiener Becken und in der Donauebene. In: Papp et al. (Eds.): Chronostratigraphie und Neostratotypen. Miozän M6 Pannonien. *Jugosl. Serb. Akad. Wiss. Künste*, Zagreb/Beograd, 616–631.

Konzalová M. 1976: Microbotanical (palynological) research of the Lower Miocene of Northern Bohemia. *Rozpr. Čes. Akad. Věd* 86, 12, 1–75.

Konečný V., Kováč M., Lexa J. & Šefara J. 2002: Neogene evolution of the Carpatho-Pannonian region: An inter-play of subduction and back-arc diapiric uprise in the mantle. *EGS Stephan Mueller Spec. Publ. Ser.* 1, 105–123.

Kováč M. 2000: Geodynamic, paleogeographic and structural evolution of the Carpathian-Pannonian region in the Miocene: New view on the Neogene basins of Slovakia. *VEDA*, Bratislava, 1–202 (in Slovak).

Kováč M., Nagymarosy A., Soták J. & Šutovská K. 1993: Late Tertiary paleogeographic evolution of the West Carpathians. *Tectonophysics* 226, 1–4, 401–416.

Kováč M., Bielik M., Lexa J., Pereszlényi M., Šefara J., Túniy I. & Vass D. 1997: The Western Carpathian intramountain basins. In: Grecula et al. (Eds.): Geological evolution of the Western Carpathians. *Miner. Slovaca*, 43–65.

Kováč M., Nagymarosy A., Oszczypko N., Ślączka A., Csontos L., Marunteanu M., Matenco L. & Márton E. 1998a: Palinspastic reconstruction of the Carpathian-Pannonian region during the Miocene. In: Rakús M. (Ed.): Geodynamic development of the Western Carpathians. *Geol. Surv. Slovak Republic*, Bratislava, 189–217.

Kováč M., Baráth I., Kováčová-Slamková M., Pipík R., Hlavatý I. & Hudáčková N. 1998b: Late Miocene paleoenvironments and sequence stratigraphy: Northern Vienna Basin. *Geol. Carpathica* 49, 6, 445–458.

Kováč M., Nagymarosy A., Holcová K., Hudáčková N. & Zlinská A. 2001: Paleogeography, paleoecology and eustacy: Miocene 3rd order cycles of relative sea-level changes in the Western Carpathian — North Pannonian basins. *Acta Geol. Hung.* 44/1, 1–45.

Kováč M., Andreyeva-Grigorovich A.S., Brzobohatý R., Fodor L. Harzhauser M., Oszczypko N., Pavelič D., Rögl F., Saftič B., Sliva L. & Stráník L. 2003: Karpatian paleogeography, tectonics and eustatic changes. In: Brzobohatý R., Cicha I., Kováč M. & Rögl F. (Eds.): Karpatian — a Lower Miocene Stage of the Central Paratethys. *Masaryk University Brno*, 49–72.

Kováč M., Baráth I., Harzhauser M., Hlavatý I. & Hudáčková N. 2004: Miocene depositional systems and sequence stratigraphy of the Vienna Basin. *Cour. Forsch.-Inst. Senckenberg* 246, 187–212.

Kováč M., Baráth I., Fordinál K., Grigorovich A.S., Halásová E., Hudáčková N., Joniak P., Sabol M., Slamková M., Sliva L., Töröková I. & Vojtko R. 2006: Late Miocene to Early Pliocene sedimentary environments and climatic changes in the Alpine-Carpathian-Pannonian junction area: a case study from the Danube Basin northern margin (Slovakia). *Paleogeogr. Paleoclimatol. Paleoecol.* 238, 32–52.

Kováč M., Andreyeva-Grigorovich A., Bajraktarević Z., Brzobohatý R., Filipescu S., Fodor L., Harzhauser M., Nagymarosy A., Oszczypko N., Pavelić D., Rögl F., Saftić B., Sliva Ľ. & Studencka B. 2007: Badenian evolution of the Central Paratethys Sea: paleogeography, climate and eustatic sea-level changes. *Geol. Carpathica* 58, 6, 579–606.

Kováč M., Hudáčková N., Hlavatá J., Sopková B., Andrejeva-Grigorovič A., Halásová E., Kováčová M., Kováčová P., Sliva Ľ. & Baráth I. 2008: Miocene deposits in the boreholes from the Záhorska lowland area: sedimentology, biostratigraphy and environmental condition. *Geol. Práce*, *Spr.* 114, 7–49 (in Slovak, English abstract).

Kováč P. & Hók J. 1993: The Central Slovak Fault System — field evidence of a strike-slip. *Geol. Carpathica* 44, 3, 155–160.

Kovar-Eder J., Jechorek H., Kvaček Z. & Parashiv V. 2008a: The integrated plant record: An essential tool for reconstructing Neogene zonal vegetation in Europe. *Palaios* 23, 97–11.

Kovar-Eder J., Suc J.-P. & Kvaček Z. 2008b: Definition of relevant botanical terms and vegetation units. www.neclime.de Krutzsch W. 1989: Palaeogeography and historical phytogeography (paleochorology) in the Neophyticum. *Pl. Syst. Evol.* 162, 5–61.

Kvaček Z. 2003: The flora and vegetation of the Karpatian. In: Brzobohatý R., Cicha I., Kováč M. & Rögl F. (Eds.): The Karpatian a lower Miocene stage of the Central Paratethys. *Masaryk University Brno*, 347–356.

Kvaček Z., Manchester S.R., Zetter R. & Pingen M. 2002: Fruites and seeds of *Craigia bronni* (Malvaceae–Tilioideae) and associated flower buds from the Late Miocene Inden Formation, Lower Rhine Basin, Germany. *Rev. Paleobot. Palynol.* 119, 311–324.

Kvaček Z., Kováč M., Kovar-Eder J., Doláková N., Jechorek H., Parashiv V., Kováčová M. & Sliva Ľ. 2006: Miocene evolution of landscape and vegetation in the Central Paratethys. *Geol. Carpathica* 57, 4, 295–310.

Lambert O., Schlögl J. & Kováč M. 2008: Middle Miocene toothed whale with Platanista-like teeth from the Vienna Basin (Western Carpathians, Slovakia). *Neu. Jb. Geol. Paläont. Abh.* 250, 2, 157–166.

Lankreijer A., Kováč M., Cloetingh S., Pitoňák P., Hlôška M. & Biermann C. 1995: Quantitative subsidence analysis and forward modelling of the Vienna and Danube Basins: thin skinned versus thick skinned extension. *Tectonophysics* 252, 433–451.

Magyar I., Geary D.H., Sütő-Szentai M., Lantos M. & Müller P. 1999: Integrated biostratigraphical, magnetostratigraphic and chronostratigraphic correlations of the Late Miocene Lake Pannon deposits. *Acta Geol. Hung.* 42, 1, 5–31.

Mai H.D. 1981: Entwicklung und klimatische Differenzierung der Laubwaldflora Mitteleuropas in Tertiär. *Flora* 171, 525–582.

Mai H.D. 1991: Palaeofloristic changes in Europe and the confirmation of the Arctotertiary — Palaeotropical concept. *Rev. Palaeobot. Palynol.* 68, 1, 29–36.

Meulenkamp J.E., Kováč M. & Cicha I. 1996: On Late Oligocene to

Pliocene depocentre migration and the evolution of the Carpathian-Pannonian system. *Tectonophysics* 266, 301–317.
Nagy E. 1985: Sporomorphs of the Neogene in Hungary. *Geol. Hung., Ser. Palaeont.* 47, 1–470.
Nagy E. 1999: Palynological correlation of the Neogene of the Central Paratethys. *Geol. Inst. Hung.*, Budapest, 1–126.
Nagy E. 2005: Palynological evidence for Neogene climatic change in Hungary. *Occass. Pap. Geol. Inst. Hung.,* Budapest, Vol. 205, 120.
Nagy E. & Planderová E. 1985: Palynologische Auswertung der Floren des Pannonien. In: Papp A., Jámbor Á. & Steininger F.F. (Eds.): Chronostratigraphie und Neostratotypen: Miozän der Zentralen Paratethys, Band VII. M6, Pannonien. *Akadémiai Kiadó*, Budapest, 586–615.
Nehyba S., Hladilová Š. & Doláková N. 1997: Sedimentation and fossil assemblages development during the Early Miocene in Southwest part of Carpathian Foredeep in Moravia. In: Hladilová Š. (Ed.): Dynamics of marine and continental environment relationships. *Grant Project report GAČR 205/95/1211*, Brno, 47–58 (in Czech).
Oszast J. & Stuchlik L. 1977: Vegetation in Podhala during the Neogene. *Acta Paleobot.* XVIII, 1, 45–86 (in Polish).
Pacltová B. 1982: Organically preserved microfossils as indicators of the paleoenvironment. In: Novák V.J.A. & Mlíkovský J. (Eds.): Evolution and environment. *ČSAV*, Praha, 757–773.
Pavelić D. 2001: Tectonostratigraphic model for the North Croatian and North Bosnian sector of the Miocene Pannonian Basin System. *Basin Research* 13, 359–376.
Planderová E. 1972: Pliocene sporomorphs from the Western Carpathians Mountains and their stratigraphic interpretation. *Geol. Práce, Spr.* 59, 209–283.
Planderová E. 1990: Miocene microflora of Slovak Central Paratethys and its biostratigraphical significance. *Geol. Inst. D. Štúra*, Bratislava, 1–144.
Planderová E., Ziembińska-Tworzydło M., Grabowska I., Kohlman-Adamska A., Konzalová M., Nagy E., Pantić N., Ryłova T., Sadowska A., Słodkowska B., Stuchlik L., Syabraj S. & Zdražílková N. 1993a: On palaeofloristic and palaeoclimatic changes during the Neogene of Eastern and Central Europe on the basis of palynological research. Proceedings of the International Symposium: Palaeofloristic and palaeoclimatic changes during Cretaceous and Tertiary. *Dionýz Štúr Inst. Geol.*, 119–129.
Planderová E., Ziembińska-Tworzydło M., Grabowska I., Kohlman-Adamska A., Sadowska A., Słodkowska B., Stuchlik L. & Ważyńska H. 1993b: Climate in Central Europe during the Neogene based on presence palaeotropical and arctotertiary sporomorphs. *Przegl. Geol.,* 41, 12, *Państw. Inst. Geol.*, Bratislava, 829–834 (in Polish).
Ratschbacher L., Merle O., Davy P. & Cobbols P. 1991a: Lateral extrusion in the Eastenn Alps. Part 1. Boundary conditions and experiments scaled for gravity. *Tectonics* 10, 245–256.
Ratschbacher L., Frisch W., Linze H.G. & Merle O. 1991b: Lateral extrusion in the Eastern Alps. Part 2. Structural analysis. *Tectonics* 10, 257–271.
Roetzel R., Ćorić S., Galović I. & Rögl F. 2006: Early Miocene (Ottnangian) coastal upwelling conditions along the southeastern scarp of the Bohemian Massif (Parisdorf, Lower Austria, Central Paratethys). *Beitr. Paläont.* 30, 387–413.
Royden L.H. 1985: The Vienna basin: a thin skinned pull apart basin. In: Biddle K.T. & Christie-Blick N. (Eds.): Strike-slip deformation, basin formation and sedimentation. *Soc. Econ. Paleont. Mineralogists, Spec. Publ.*, Tulsa 37, 319–339.
Royden L.H. 1988: Late Cenozoic tectonics of the Pannonian basin system. In: Royden L. & Horváth F. (Eds.): The Pannonian Basin: A study in basin evolution. *AAPG Memoir* 45, 27–48.
Rögl F. 1998: Paleogeographic considerations for Mediterranean and Paratethys Seaways (Oligocene to Miocene). *Ann. Naturhist. Mus. Wien* 99A, 279–310.
Rögl F., Brzobohatý R., Cicha I., Ćorić S., Daxner-Höck G., Doláková N., Harzhauser M., Hladilová Š., Kroh A., Kvaček Z., Mandic O., Olshtynska A., Pisera A., Reichenbacher B., Schultz O., Švábenická L., Tempfer P., Vávra N. & Zorn I. 2003: Paleobiological characterization of the Karpatian Stage. In: Brzobohatý R., Cicha I., Kováč M. & Rögl F. (Eds.): The Karpatian a lower Miocene stage of the Central Paratethys. *Masaryk University Brno*, 357–360.
Sadowska A. 1989: Miocene palynostratigraphy of the Silesian part of the Paratethys Basin. *Cour.-Forsch. Inst. Senckenberg* 109, 229–235.
Sadowska A. 1993: The stratigraphical table of the Neogene floras from Poland. Proceedings of the International Symposium: Palaeofloristic and palaeoclimatic changes during Cretaceous and Tertiary. *Dionýz Štúr Inst. Geol.*, Bratislava, 133–139.
Sitár V., Knobloch E., Roman S. & Ticleanu N. 1978: Die Makroflora des Badenian (Rumänien und Tschechoslowakei). In: Papp A., Cicha I., Seneš J. & Steininger F.F. (Eds.): Chronostratigraphie und Neostratotypen. Miozän der Zentralen Paratethys. M_4 Badenien. (Moravien, Wielicien, Kosovien). *Veda*, Bratislava, 555–563.
Stuchlik L. 1980: Chronostratigraphy of Neogene in the South of Poland (North part of Paratethys) based on palaeobotanical research. *Przegl. Geol.* 8, 443–448 (in Polish).
Syabryaj S.V. & Vodoryan N.S. 1975: Vegetation and paleogeographical conditon of Middle Sarmatian in the Carpathian area from the data of diatom, spore and pollen analysis. *Ukraine Bot. Zsurnal* 33, 1, 71–77.
Tomek Č. & Hall J. 1993: Subducted continental margin imaged in the Carpathians of Czechoslovakia. *Geology* 21, 535–538.
Walanus A. & Nalepka D. 1999: POLPAL. Program for counting pollen grains, diagrams plotting and numerical analysis. *Acta Paleobot.*, Suppl. 2, 659–661.
Ważyńska H. (Ed.) 1998: Palynology and paleogeography of the Neogene in the Polish Lowlands. *Pr. Panstw. Inst. Geol.*, 1–160.
Vail P.R., Mitchum R.M.J., Todd R.G., Widmier J.M., Thompson S., Sangree J.B., Bubb J.N. & Hatlelid W.G. 1977: Seismic stratigraphy and global changes of sea level. In: Clayton C.E. (Ed.): Seismic stratigraphy — application to hydrocarbon exploration. *Amer. Assoc. Petrol. Geol. Mem.* 26, 49–212.