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Climatic and biotic changes around the Carboniferous/Permian boundary recorded in the continental basins of the Czech Republic

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ABSTRACT

The paper provides an overview of a several decades-long study of transitional Carboniferous–Permian (Stephanian C–Autunian) sedimentary successions in continental basins of the Czech part of the Bohemian Massif. These predominantly monotonous fluvial red beds intercalate with laterally widespread grey to variegated sediments of dominantly lacustrine origin. Both, fossil and climatic records show that apart from a generally known long-term climatic shift to drier conditions in Early Permian, the climate oscillated on several time scales throughout the study interval. Climatic indicators in the red beds part of the succession include palaeosols ranging between red vertisols and vertic calcisols suggesting strongly seasonal dry sub-humid climate. This is in agreement with the rarity of plant remains, which were mostly completely oxidised and only rarely preserved as plant impression in red mudstones or as silicified mostly gymnosperm woods in sandy channel fills. Silicification instead of coalification was the dominant fossilisation process during red-beds deposition. Even drier, possibly semi-arid climate may be indicated by spatially and temporarily restricted bimodal sandstones, dominated by well-rounded quartz grains and interpreted as eolian in origin. Periods of moist sub-humid (or even humid) climate were accompanied by formation of perennial lakes containing grey laminated mudstones, dark grey bituminous mudstones or limestones, muddy limestones, chert layers or even spatially restricted coals, some of them, however, of economic importance. Shorter climatic oscillations operating on a scale of tens to possibly hundreds of thousands of years are represented by transgressive–regressive lacustrine cycles followed by significant changes in lake water salinity reflected by boron content.

The fossil record indicates the presence of dryland and wetland biomes in basinal lowlands although their proportions varied significantly as the climate changed. During deposition of red beds, the alluvial plain was vegetated dominantly by dryland biome assemblages. The composition of these assemblages is indicated by fairly common silicified gymnosperm (cordaitalean and coniferous) woods in sandstone–conglomerate fluvial channel bedforms and by poorly preserved impressions of walchian conifer shoots and cordaitalean leaves in associated mudstone intercalations. This is in agreement with sub-vertical root rhizolites and haloes in calcic vertisols. Occurrence of “wet spots” colonised by wetland assemblages is indicated by rather exceptional findings of silicified calamite stems in fluvial red beds associated with gymnospermous woods.

During the humid intervals parts of the basinal lowlands were occupied by lakes surrounded by broad belts of wetland biome floras. During the “Stephanian C” most of these floras were dominated by tree ferns, calamites and sub-dominant pteridosperms. Local peat swamps were colonised by lycopsids including *Sigillaria brardii*, *Asolanus camptotaenia* and even some lepidodendrid lycopsids. In contrast, the fossil record of “Stephanian C” dryland floras is rarely preserved in lacustrine sediments. The fossil record of “Autunian” lakes, however, suggests increasing proportions of dryland elements, including conifers and peltasperms.

The response of lacustrine faunas to climatic oscillations around the Carboniferous–Permian transition is less prominent than that of plants. The origin of the transition between the local *Elonichthys–Sphaerolepis* and *Acanthodes gracilis* bio/ecozones around the Carboniferous/Permian boundary is impossible to deduce from the existing fossil record.

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1. Introduction

The Late Pennsylvanian to Early Permian in tropical Pangea is a period marked by irregularly increasing climatic aridity and temperature. Climatic oscillations during this time varied significantly between wet sub-humid and dry sub-humid to possibly semi-arid. These climatic oscillations, which evidently operated on several time scales, had a profound effect on composition of floras and faunas (e.g., DiMichele et al., 2010). In general, the floristic response to increasing aridity (seasonality) is marked by contraction of wetland habitats in basinal lowlands resulting in inter-biome floristic dominance and diversity change from dominance by spore-producing vegetation and primitive seed plants to dominantly seed-bearing vegetation rich in conifers and peltasperms (Broutin et al., 1990; DiMichele et al., 2005, 2008, 2009; Kerp, 1996). Alternation of both types of assemblages throughout the basin succession can be observed even within the same outcrop (DiMichele et al., 2007; Kerp and Fichter, 1985). This suggests significant floristic dynamics around the Carboniferous–Permian transition related to high frequency climatic oscillations driven possibly by several orders of orbital cyclicity and poorly understood variations in atmospheric pCO_2 (Montañez et al., 2007; Tabor and Poulsen, 2008).

Faunas of this stratigraphic interval are represented mostly by lacustrine assemblages. Comparing to the floras, the effects of climatic oscillations on aquatic animals are more difficult to discern and/or interpret. The most common finds of terrestrial fauna are represented by insect (notably cockroach) wings, whereas finds of spiders and other terrestrial arthropods are very rare. The entomofauna predominantly favoured locally humid microclimates associated with vegetation that produced litter rich in decomposed biomass.

This floristic and faunistic turnover is recorded in a number of spatially disconnected sedimentary basins across the former equatorial Pangea, now situated in North America and Europe. Significant among them are continental basins in the Czech Republic, which together cover an area of 11,000 km^2 (Fig. 1). These Late Palaeozoic continental basins record not only a late to early post-Variscan tectono-sedimentary history of the Bohemian Massif, the major Variscan unit in central Europe (e.g., Franke, 2006), but also climatic and biotic changes from Late Bashkirian to Early Triassic times. These changes are indicated by the record of sedimentary facies and climate sensitive sediments as well as by changes in composition and dominance patterns of plant assemblages and faunas. Intensive borehole exploration in the second half of the 20th century together with mining activity and geological mapping in these basins produced large amounts of data on lithology, sedimentology, geochemistry and petrology, stratigraphy and basin architecture as well as palaeontology. These analyses are only partly published and most of them still need revision and/or re-interpretation. This need has been recently addressed in currently running projects. As part of this larger revision, the present paper is a brief overview of the current knowledge on the sedimentological and biotic changes that took place around the Carboniferous–Permian transition as recorded in the continental basins of the Czech part of the Bohemian Massif.

2. The Bohemian Massif and formation of the Late Palaeozoic continental basins

The Bohemian Massif encompasses a major part of the territory of the Czech Republic, from where it extends into adjacent parts of Germany, Poland and Austria. It represents the easternmost segment of the Variscan orogenic belt resulting from sub-equatorial collision between two major continents, Gondwana and Baltica (eastern part of Laurussia) and intercalated smaller terranes (Dallmeyer et al., 1995).

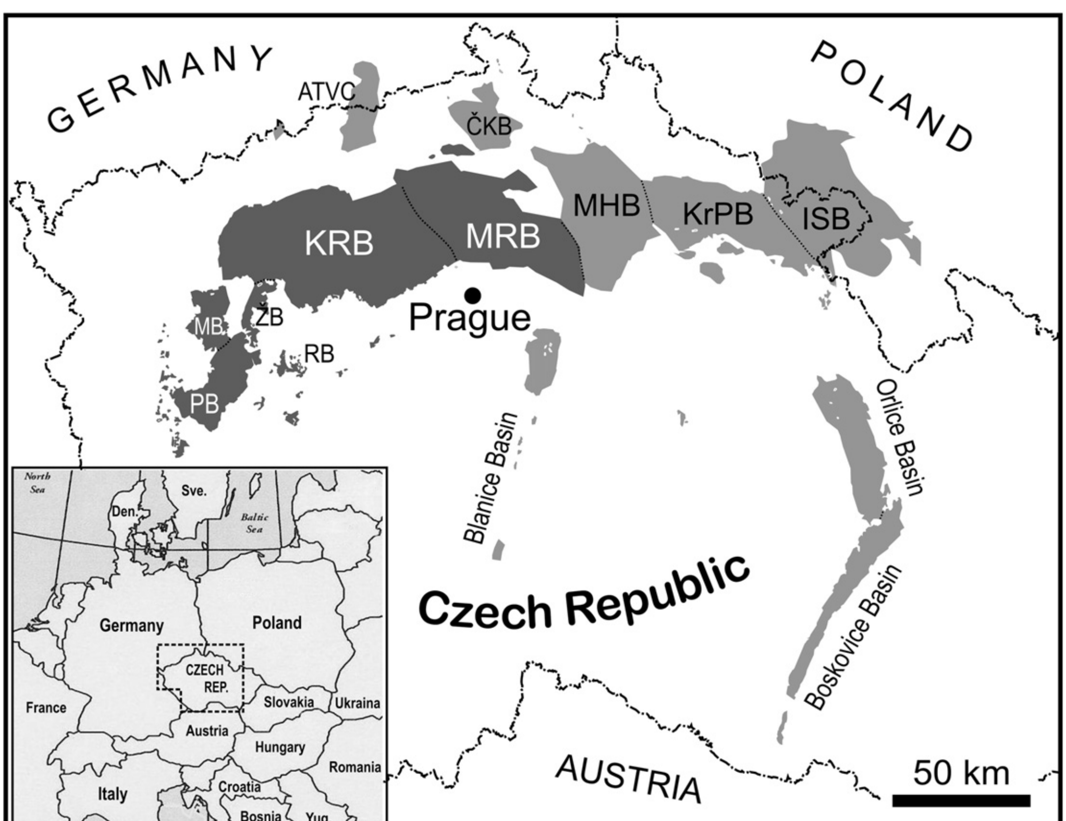

Fig. 1. Late Palaeozoic continental basins of the Czech Republic. Basins shortcuts: PB — Pilsen Basin, MB — Manětín Basin, RB — Radnice Basin, ŽB — Žihle Basin, KRB — Kladno–Rakovník Basin, MRB — Mšeno–Roudnice Basin, MHB — Mnichovo Hradiště Basin, KrPB — Krkonoše Piedmont Basin, ISB — Intra-Sudetic Basin, ČKB — Česká Kamenice Basin, ATVC — Altenberg–Teplice volcanic complex.

Hence, the Bohemian Massif is a complex tectonic collage of four major units characterised by different tectono-metamorphic histories, which are assumed to represent peri-Gondwana-derived terranes (Linnemann et al., 2004; Mazur et al., 2006). These terranes were rifted during Cambro-Ordovician times and mostly between the Late Devonian and late Viséan gradually amalgamated to Eastern Avalonia and Baltica (Franke, 2000, 2006; Schulmann et al., 2009). Assembly of the Bohemian Massif was accompanied by collisional processes, which resulted in crustal thickening, fast uplift and exhumation of Variscan granites and high-grade metamorphic rocks (e.g., Kotková and Parrish, 2000; Kukal, 1984; Schulmann et al., 2009). During that time the Bohemian Massif was a probably about 2 to 3 km high plateau, with no significant deposition until early Westphalian. At that time uplift substantially decreased and waning orogenic processes allowed for development of NW–SE striking normal and/or strike–slip faulting related to Gondwanan rotation. This faulting was responsible for the formation of continental basins (e.g., Matte, 1986, 2001; Pašek and Urban, 1990; Zulauf et al., 2002). These basins were established in two periods. The older period spans the interval from the late Bashkirian to the late Moscovian when most of the basins were established (Fig. 2). By that time altitude of the Bohemian Massif was lowered substantially. Opluštil (2005) reconstructed the early Moscovian drainage system at the beginning of the deposition in the Kladno–Rakovník Basin and inferred that this area was not higher than 1000 m above sea level, perhaps even lower, based on the gradient of river courses. The younger interval of basin formation took place between Gzhelian and Cisuralian times and resulted in formation of the NNE–SSW to NNW–SSE striking narrow Blanice, Boskovice and Orlice half-grabens.

Palaeogeographically the Bohemian Massif and its basins were located near the eastern margin of the equatorial Pangea. Palaeomagnetic measurements indicate that this part of Pangea underwent a northward drift from 0° palaeolatitude during the middle Pennsylvanian to 2°–4°N latitude in the early Permian (Krs and Pruner, 1995). This suggests that the northward shift itself was probably not responsible for an aridisation trend in the Bohemian Massif and in other parts of equatorial Pangea as suggested by some authors (for an overview see Tabor and Poulsen, 2008). A good evidence for more complex controls is that the Late Pennsylvanian–Early Permian transition was not gradual. Instead, it was characterised by climatic fluctuations between moist sub-humid conditions, with the dominance of hygrophyllous flora and hydrologically open lacustrine systems, and more arid dry sub-humid conditions, with the dominance of "dry-type" floral assemblages, hydrologically closed lacustrine systems and abundant carbonate deposition (e.g., Martínek et al, 2006; Opluštil and Cleal, 2007; Schneider et al., 2006). These climatic oscillations had a profound effect on composition of the flora in basinal lowlands, although only plant remains from wetter periods are relatively well represented in otherwise poorly fossiliferous strata.

3. Late Palaeozoic continental basins of the Czech Republic: Current state of investigation

Active coal mining has been going on in the late Palaeozoic continental basins of the Czech part of the Bohemian Massif for about two centuries. This mining initiated geological and palaeontological research. Since that time these basins have undergone detailed surface mapping

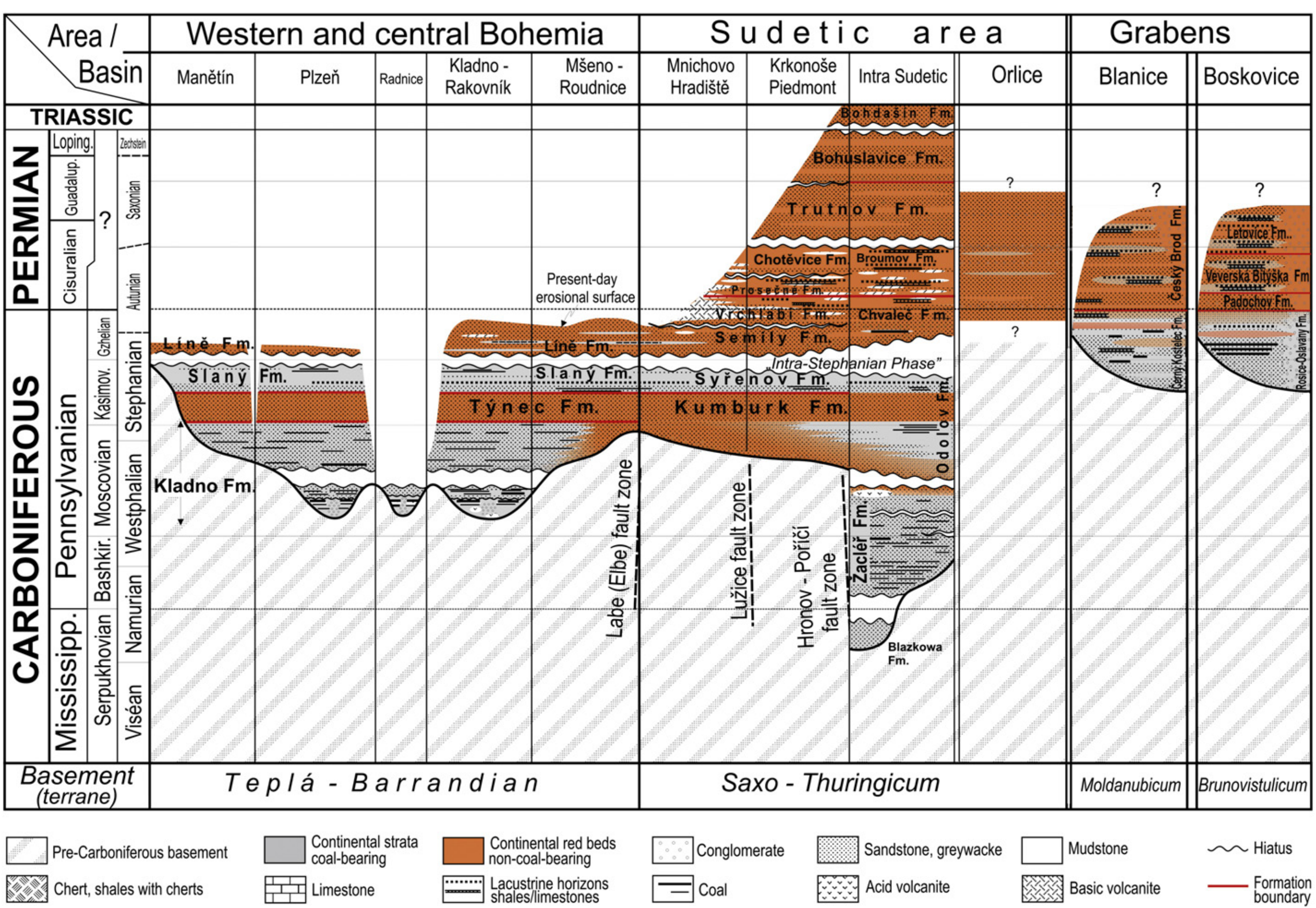

Fig. 2. Stratigraphy of the continental basins of the Czech Republic.

and in the second half of the 20th century also intensive borehole exploration for coal and other raw materials, including kaolin, brick clays, refractory claystone, cooper, uranium, germanium etc. Hence, over a thousand of mostly fully cored deep boreholes were drilled into the basement and an even larger number of shallow boreholes penetrated only part of the basin fill. It is estimated that about 600 of these boreholes penetrated the entire preserved thickness of "Stephanian C"/"Autunian" strata, which are the main object of this study. The boreholes were explored by a broad spectrum of geophysical, petrological, geochemical, mineralogical and palaeontological methods, which produced vast amount of data archived in final reports of exploration companies. Published outputs include macrofloral, palynological and faunal lists and their stratigraphic ranges resolved to the level of formations, lithostratigraphic subdivision and analyses of spatial variability of lithostratigraphic units, interpretation of basic sedimentary environments, palaeogeography and geochemical and technological parameters of coal seams. An overview of current knowledge based on published and unpublished data has been summarised in Šetlík (1977), Tásler et al. (1979), Pešek (1994, 2004) and Pešek et al. (2001). The list of the animal remains is based on Štamberg and Zajíc (2008) with some recent supplements and extensions (Klembara and Steyer, 2012; Štamberg, 2010a, 2010b, 2012; Zajíc, 2007). Archived data and rock and fossil samples taken from boreholes as well as scattered outcrops and quarries still provide a reasonably good opportunity for further re-evaluations of fossil and sedimentary data/records and for ecological and sedimentological studies and palaeoclimatic interpretations. The local bio/eco zonation based on aquatic vertebrates (Zajíc, 2000, 2004, 2007) is used for biostratigraphy. The local bio/eco sub-zone *Sphaerolepis* (younger part of the *Sphaerolepis*–*Elonichthys* bio/ecozone) corresponds to the Stephanian C in the basins of the Bohemian Massif. The oldest Permian units of all basins belong to the *Acanthodes gracilis* local bio/ecozone.

4. Late Palaeozoic continental basins of the Czech Republic and their Gzhelian–Asselian palaeogeography

The Late Palaeozoic continental deposits cover an area of over 11,000 km^2 of the Czech Republic. A major part of this area consists of a continuous belt, several tens of kilometres wide and nearly 300 km long, ranging from the western part of the Czech Republic to its NE border and the adjacent part of Poland (Fig. 1). This belt, which occupies nearly 10,000 km^2, is divided into two parts: the Central and Western Bohemian (=central and western Czech Republic) Basins located on the Teplá–Barrandian basement and Sudetic Basins, which encompass the eastern part of the complex situated on the Saxo-Thuringian block (Pešek, 2004). Both areas, which originally evolved as two independent depocentres, were connected into a single large depocentre beginning at the onset of the Late Pennsylvanian (Fig. 2). Besides this main basin complex there are also half-graben basins located on the Moldanubian and Brunovistulian basement in the southern and SE part of the country (Blanice and Boskovice Grabens) and small relicts of Carboniferous and early Permian sediments and volcanic rocks preserved in the Krušné Hory (Erzgebirge) Mts. around the Czech–German border (Fig. 1). The stratigraphic range of basin fill can differ either as a consequence of uneven onset/termination of basement subsidence and/or post-sedimentary erosion (Fig. 2). Typically, the basin fill consists of a basin-wide alternation of coal-bearing and dominantly grey strata with red coal-barren sediments, believed to indicate climatic oscillations on a scale of >1 My (Cleal et al., 2010; Opluštil, 2013; Opluštil and Cleal, 2007; Skoček, 1974). The proportion of red beds increases during the Late Pennsylvanian and dominates the Permian part of the basin fill. Nevertheless, red beds can appear locally nearly at any level, usually near the basin margin. In such a position, however, they are not related to climatic change but reflect either improved drainage or re-deposition of lateritic weathering crust from exposed parts of the pre-Carboniferous basement (Pešek and Skoček, 1999; Skoček and Holub, 1968).

The palaeogeography of the Bohemian Massif significantly changed throughout Pennsylvanian and into early Permian times. During this interval the depocentre gradually enlarged, reaching its maximum extent around the Carboniferous/Permian boundary (Fig. 3). This event was initiated by the tectonic processes of the Intra-Stephanian phase around the Kasimovian–Gzhelian boundary (Pešek, 1994; Pešek et al., 1998). At this time, deposition in the continental basins of the Bohemian Massif was interrupted and their depocentre and physiography of the source areas significantly re-built. The Intra-Stephanian tectonic phase also resulted in the opening of NNE–SSW striking narrow half-graben basins (Boskovice, Blanice and possibly also in the Orlice) connected with the main basin complex, as suggested by relicts of Permian deposits between them (Fig. 3). The resulting large depocentre was open to Saxony (Germany) and the adjacent part of Poland. Present day thickness of Gzhelian–Asselian strata reaches maximum thickness of 2500 m in the Boskovice Basin (Pešek, 2004).

Interpretations of late Palaeozoic, continental-basin sedimentary environments of the Czech part of the Bohemian Massif are based on conglomerate/sandstone percentage content counted from borehole sections and used for construction of palaeogeographic maps for particular intervals (e.g., Pešek, 1994; Pešek et al., 1998). Although these maps express time-averaged palaeogeography and sedimentary environments for one or even more formations they are broadly in agreement with detailed, but scattered, sedimentological studies focused on narrow, geographically and stratigraphically localised parts of the sedimentary record (e.g., Blecha et al., 1999; Lojka et al., 2009, 2010; Martínek et al., 2006; Opluštil et al., 2005; Skoček, 1990). Thus, the Stephanian C–Autunian palaeogeographic map of the Pešek et al. (1998) suggests the existence of a broad braid plain along the southern and western margins of the main basin complex and also in some erosional outliers of time-equivalent strata scattered in the areas surrounding the basin complex. Alluvial fan deposits are interpreted along the active eastern basin margin of the Blanice and Boskovice half-grabens and locally along the northern tectonic margin of the main basin complex. On the contrary, the prevalence of fine-grained fluvial sediments with intercalated isolated sandstone bodies, exceptionally up to several tens of metres thick, are known from various basin depocentres with high subsidence rates. These sediments are either of lacustrine origin or represent floodplain deposits of meandering rivers as suggested by the common presence of pedogenic horizons often with pedogenic carbonate nodules (Skoček, 1993). Wetland deposits are generally very rare and are usually represented by lake shallows and mudflats or lacustrine delta plains within which local swamps thin high ash peat deposits could develop. However, the two dominant lithological signatures of lake sediments are laminated mudstone intercalated locally with dark bituminous shales, and limestone or pale muddy limestone often containing vertebrate fauna and drifted flora. Cherts, with laminated or brecciated texture, also are common (Skoček, 1969). In Late Pennsylvanian strata of the main basin complex beds of argilised acid volcaniclastics are common, whereas in the Early Permian strata effusive bodies of intermediate and basic volcanites dominate, indicating proximity of volcanic centres (Tásler et al., 1979).

4.1. Central and Western Bohemian Basins (CWBB)

The Central and Western Bohemian Basins (=central and western part of the Czech Republic) encompass about a 6000 km^2 area in the western part of the main basin complex (MBC), subdivided into the Pilsen (PB), Manětín, Žihle, Radnice, Kladno–Rakovník (KRB) and Mšeno–Roudnice (MRB) basins (Fig. 1). This subdivision is, however, rather artificial, since all these basins once were part of a single common depocentre throughout the major part of their sedimentary history and share the same lithostratigraphic subdivision (Fig. 2). For that reason they are discussed together. A larger originally areal extent is

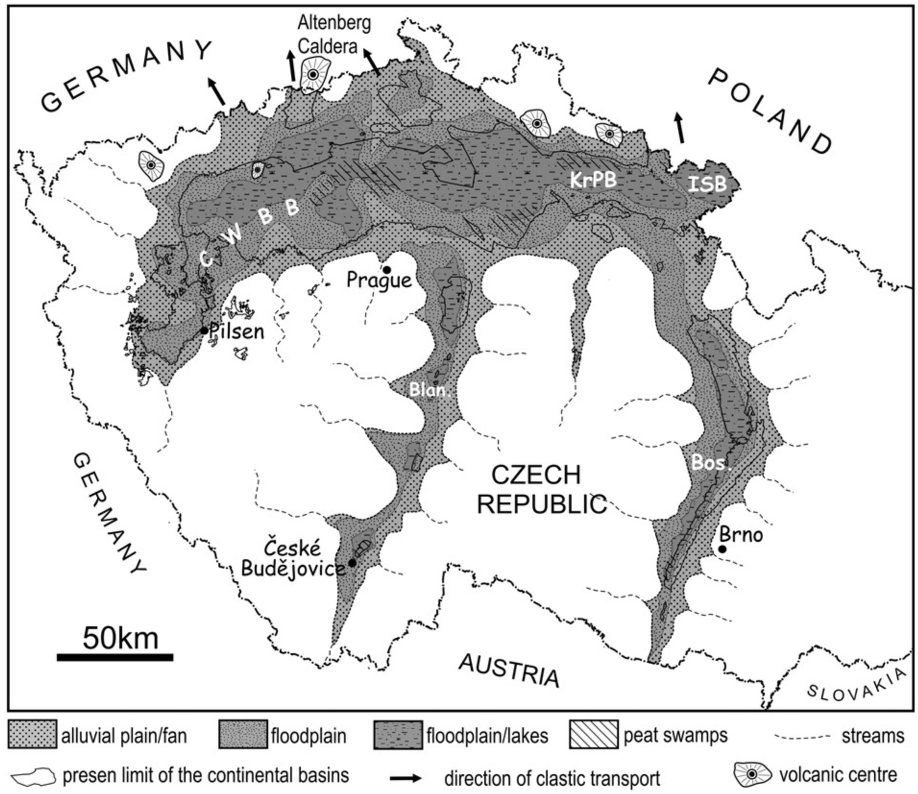

Fig. 3. Palaeogeographic map of the Czech Republic during the latest Stephanian and early Autunian (after Pešek et al., 1998). Different environments were established on percentage sand–gravel content within the corresponding lithostratigraphic units described in the text: alluvial plain/fan (>70% sand-gravel content), floodplain (70–30% sand–gravel content), floodplain/lakes (<30% of sand–gravel content).

indicated by numerous erosional and tectonic relicts of Pennsylvanian sediments scattered south and west of the main basin complex (Fig. 3).

In most of these basins deposition started in the early Moscovian (Bolsovian) and included several basin-wide or local hiatuses that lasted till the end of the Carboniferous. A Permian age for the youngest strata is suggested only by the vertebrate fauna and by borehole correlation to that part of the Sudetic Basins where Permian age was determined floristically; macrofloral and palynological evidence of Permian age is still absent in basins of the Central and Western Bohemia (Pešek, 1994, 2004; Zajíc, 2012). Basin fill, which attains a maximum thickness of up to nearly 1.4 km in the centre of the KRB, is divided into four formations based on a basin-wide alternation of grey-coloured/coal-bearing and red/coal-barren strata and is common for all the CWBB (Fig. 2) (Pešek, 1994; Weithofer, 1896, 1902). The study interval is represented by the youngest strata assigned to the Líně (Upper Red) Formation of late Gzhelian and probably early Asselian age. Its thickness is erosional and varies between 0 and about 1000 m. However, thickness over 300 m is preserved only in the Kladno–Rakovník and Mšeno–Roudnice basins, whereas in the Pilsen and Manětín basins these strata attain merely 47 and 114 m average erosional thickness, respectively (Pešek, 1994).

Sediments of the Líně Formation were deposited after a basin-wide hiatus related to a tectonic event of the Intra-Stephanian Phase. During the hiatus, the basin depocentre was rebuilt and the zone of maximum subsidence shifted along the tectonically active northern margin of the KRB and MRB resulting in half-graben-like geometry of the Gzhelian (Stephanian C–early Autunian) depocentre. This is in agreement with primary reduced thickness of the unit along the present-day southern basin margin. In addition, pebbles of tuffite containing early Moscovian floral remains found in basal conglomerate of the Líně Formation suggest recycling of basal Carboniferous strata (Radnice Member) cropping out south of the Líně Formation depocentre (Havlena and Jindřich, 1975). Due to reduced thickness along the southern basin margin and post-Carboniferous denudation, the sediments of this unit are preserved mostly in the northern half of the main basin complex. In the Pilsen Basin remnants of the formation are preserved in a N–S striking central depression (Pešek, 1994), while being eroded in the marginal parts.

4.1.1. Lithology and sedimentary environments of the Líně Formation

Prevailing lithologies of the Líně Formation are pinkish or rusty sandstones alternating with red mudstones in beds of variable thickness, locally reaching up to several tens of metres (Figs. 4A, 5). The relative proportions of these two basic lithologies vary spatially and temporarily. Contours of sand content indicate a generally higher proportion of sandstones with subordinate conglomerates along the southern and western margins of the main basin complex, where they account for over 50% (locally >70%) (Fig. 3) of the stratigraphic thickness (Pešek et al., 1998). Data from boreholes and rare outcrops show internal erosional surfaces of sandstone bodies and locally intercalated conglomerates, which suggest amalgamation of channel fills. Sandstones are often cemented by carbonate, which is mostly calcite. Locally common in medium to coarse grained sandstones are prostrate mostly decorticated silicified gymnosperm stems, some over 10 m long (Bureš, 2011; Skoček, 1970). Small reworked fragments of these silicified stems occasionally occur in conglomerates in the form of pebbles (Pešek, 1994; Tásler and Skoček, 1964), indicating rapid, early diagenetic silicification processes. Zikmundová and Holub (1965) described conglomerates containing carbonate pebbles with Silurian and Devonian fauna, derived from remote extra-basinal sources. Toward the basin centre, conglomerates become rare and, together with sandstones, their proportion usually decreases below 30%. Mudstones become the prevailing lithologies with fine-grained sandstones confined into thin sheet-like

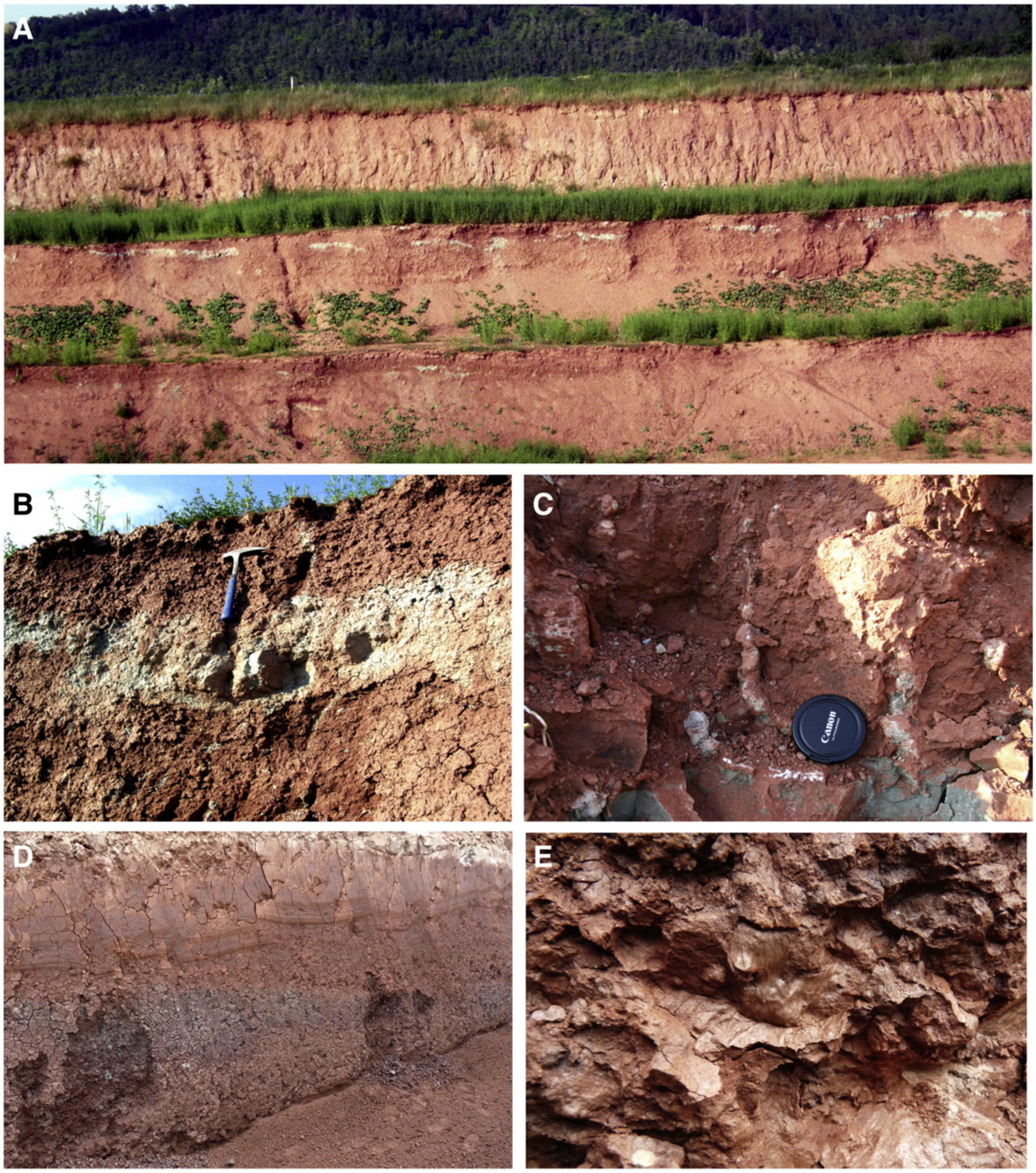

Fig. 4. Líně Formation: A — Red beds exposed in a brick-pit near the village of Kryry in the KRB. Note the discontinuous whitish horizon which indicates position of pedogenic calcretes. B — Detail of calcrete horizon (vertic calcisol) from the Fig. 3A. C — Vertical to sub-vertical rhizoliths in red angular blocky mudstone with disseminated carbonate nodules. Brickpit near Kryry. D — Vertisol in red mudstone with blocky structure and slickensides exposed in the Gazelle gas pipeline near Blatno u Podbořan in the Žihle Basin. E — Calcic vertisol with well-developed slickensides in red mudstones exposed in the Gazelle gas pipeline near Podbořany in the KRB. Photos A–D: S. Opluštil; D–E: R. Lojka.

or, less commonly, isolated sandbodies several metres thick. Mudstones are usually brick-red to purple or carmine, massive or poorly bedded locally bioturbated by sediment feeding macrofauna (Šimůnek et al., 2009; Skoček, 1974). Mudcracks are locally common. Rooted zones also are common and palaeosols are mostly vertisols or calcic vertisols to even vertic calcisols with pedogenic carbonate nodules (Fig. 4B–E). However, carbonate nodules a few millimetres in diameter can be scattered within massive red mudstones and siltstones otherwise lacking any other evidence of pedogenesis (Pešek, 1994; Pešek and Skoček, 1999; Skoček, 1993). Some of them were interpreted as eolian siltstones (= fossil loess deposits) by Tásler and Skoček (1964).

Although sediments of the Líně Formation can be characterised as typical continental red beds, monotonous alternation of red mudstones and sandstones can be interrupted at any level by grey, green-grey or variegated mudstones and intercalated fine-grained sandstones. Most of these grey or non-red mudstones and fine-grained sandstones, however, are concentrated into three distinct lithostratigraphic horizons, which are named the Zdětín, Klobuky and Stránka in stratigraphic order. The Zdětín and Klobuky Horizons are quite widespread covering the eastern half of the KRB and a major part of the MRB from where they continue to the Sudetic part of the main basin complex. Their thickness varies usually between 50 and 100 m (Pešek, 1994). The youngest Stránka Horizon occurs only in the Mšeno–Roudnice Basin and attains an average thickness of 15 m. Mudstones of all these horizons are often laminated and can be accompanied by fresh water limestones (often with clastic admixture), cherts, carbonaceous mudstone or even thin high-ash coals or rarely bituminous claystones and altered

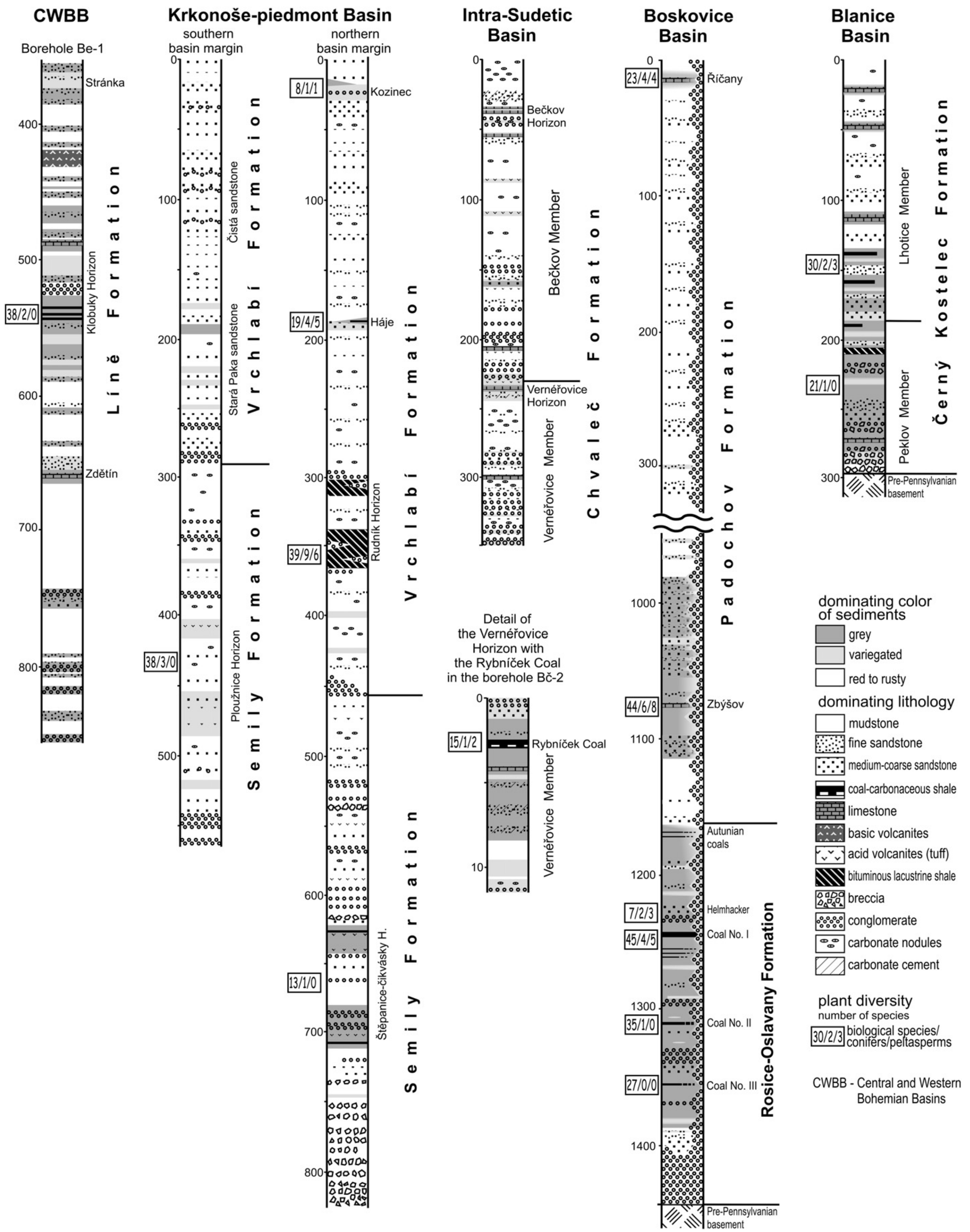

Fig. 5. Examples of basin sections described in detail in the text. Redrawn from Tásler et al. (1979) and Pešek (1994, 2004). Numbers in rectangle indicate plant diversity of particular horizons. The first number refers to the estimated number of biological species, the second number points to conifer species and the third number indicate callipterid species.

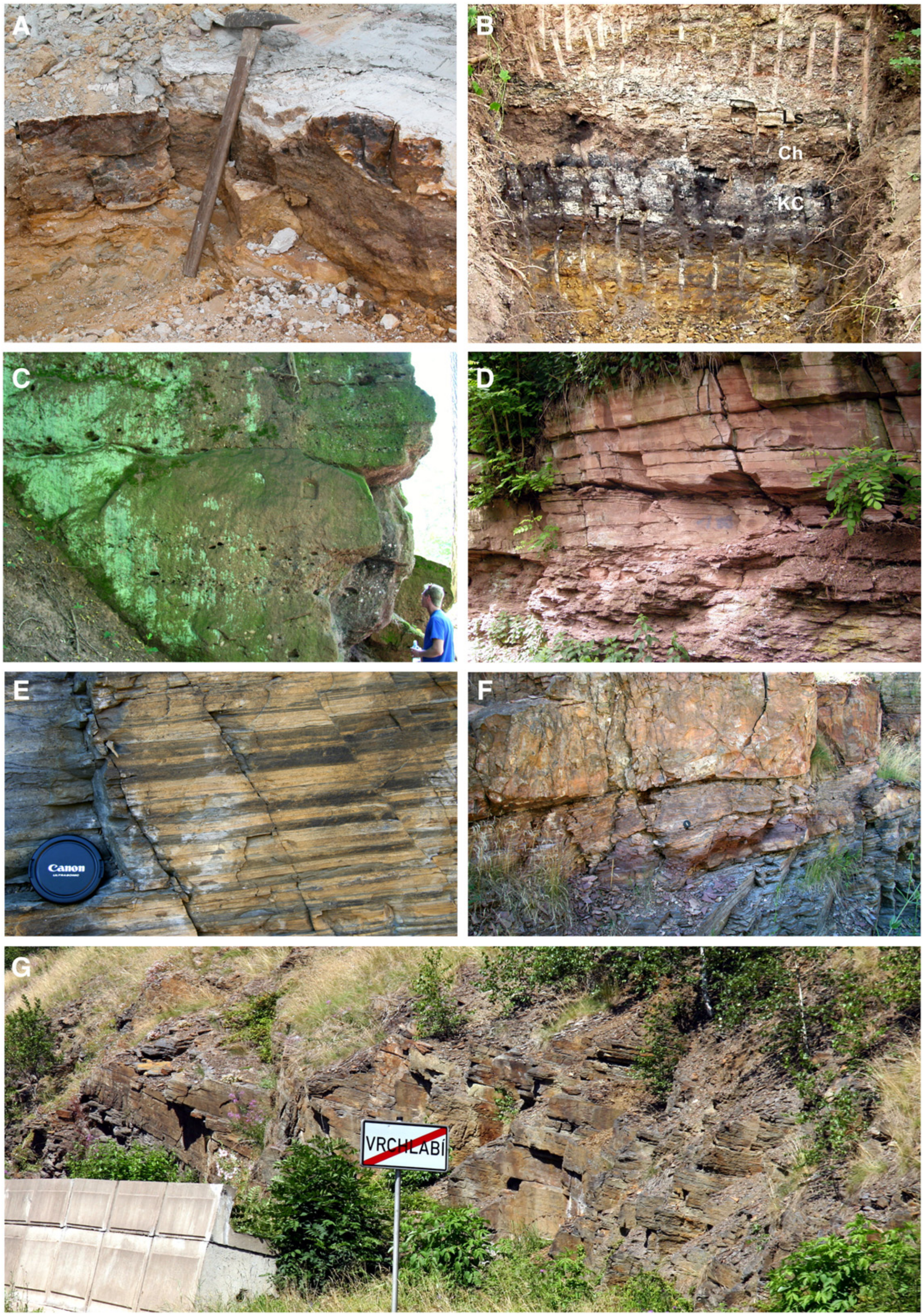

Fig. 6. A — Chert in lacustrine sediments of the Klobuky Horizon (Líně Fm.) exposed in a road cut near Panenský Týnec, KRB. B — Part of the lacustrine succession of the Klobuky Horizon exposed near the village of Klobuky in the KRB. Rusty and poorly laminated nearshore mudstones followed by thin high-ash the Klobuky Coal (KC) containing tonstein (T) in its lower part. The roof of coal consists of chert succeeded by bedded muddy limestone (Ls) both interpreted as offshore facies and further followed by nearshore mudstones. Drifted flora was collected especially from mudstones and bedded muddy limestones (after Opluštil, 2013). C — Coarse-grained feldspathic sandstones with conglomerates intercalations in lower part of the Semily Formation interpreted as braid plain deposits. Exposures north of the town of Semily (KrPB). D — Reddish mudstones with weak pedogenic overprint overlain by sandstones with (?)hummocky cross-stratification. Ploužnice Horizon. Railway road cut near Ploužnice in the KrPB. E — Sharp-to erosional-based normally graded silty laminae of distal turbidity underflows and sharp-to diffuse-based silty laminae of interflows (after Martínek et al., 2006), Rudník Horizon in the Vrchlabí Formation, road cut near Vrchlabí (KrPB). F — Dark-grey bituminous shales overlain by lacustrine limestone, Rudník Horizon in the Vrchlabí Formation exposed in road cut near Vrchlabí in thé KrPB. G — Mostly anoxic offshore facies of the Rudník Horizon exposed in road cut near Vrchlabí. Photos A: Z. Šimůnek; B–C, E–G–D: S. Opluštil; D: K. Martínek.

volcaniclastics (Fig. 6A, B). Except for the volcaniclastics, these lithologies are absent or rare in dominantly red parts of the succession. Up to several high-ash coals of local extent and <0.4 m thick can be present in the Zdětín and Klobuky Horizons (Fig. 6B). Disarticulated vertebrate remains (fish and amphibian teeth, bones, scales or coprolites) as well as invertebrate faunas are common in limestones, some mudstones and some claystones, where they are associated with drifted plant fragments.

Breccia composed of small (<1 cm) angular to sub-angular clasts of crystalline rocks bound in a massive mudstone matrix locally occurs along the northern margin of the KRB and MRB (Pešek, 1994, 2004). This breccia probably represents deposits of cohesive mudflows or debris flows. In a few boreholes in the NW part of the KRB, Valín (in Pešek and Skoček, 1999) described medium- to coarse-grained cross-bedded bimodal sandstones composed of well-rounded grains of quartz, which he interpreted as eolian deposits.

Volcanic rocks, a product of bimodal volcanism, although usually comprising a very small part of the succession, are quite common in this unit. This is especially the case for acid volcaniclastics forming smectitic argilised tuff beds, millimetres to a few metres thick. In some boreholes, Skoček (in Pešek et al., 2001) identified several tens of such individual beds throughout the thickness of the formation (e.g., 58 in the borehole Br 1 Brňany in the MRB). Up to 4 horizons of basalt-to-trachybasalt bodies, several metres to >50 m thick, were penetrated by some boreholes in the NW part of the KRB (Kopecký and Malkovský 1958); some other levels contained volcanic bombs and lapillas.

The depositional environment of the Líně Formation is interpreted as a broad braid plain along the southern and SW part of the basin (Fig. 7B). This is the area today where sandstone and conglomerate are the dominant lithologies. The proportion of these coarse sediments decreases northward into the zone of maximum basinal subsidence. In this are, the braid plain transitioned to a fluvial plain drained by mixed to suspended load-dominated (potentially meandering) fluvial systems and open lakes. During periods of increased climatic humidity large perennial lakes formed (Fig. 7A). Pešek (1994) interprets most of the sediments of the Líně Formation being of lacustrine origin whereas Holub and Tásler (1981) believe they were deposited mainly in low-energy rivers.

4.1.2. Fossil record of the Líně Formation

Although seemingly without fossils, quite a diverse macroflora and microflora, as well as vertebrate and invertebrate fauna, have been gathered from the Líně Formation since the earliest investigations in the second half of the 19th century (Feistmantel, 1883; Krejčí, 1877). The presence of some key taxa, including *Sphenophyllum angustifolium*, in the Zdětín and Klobuky Horizons suggests that the lower half of the formation correlates with the *S. angustifolium* biozone of Wagner (1984), indicating a latest Pennsylvanian age (upper Gzhelian). Plant remains are scarce for up to several hundred metres above the Klobuky Horizon, preventing age constraints based on the floristic record. However, the local vertebrate *A. gracilis* biozone suggests an Early Permian (Asselian) age for the upper part of the formation (Zajíc, 2012). No peltasperm remains have been reported so far from this assumed Permian part of the section (Šetlík, 1977).

4.1.2.1. Flora of the Líně Formation. The floristic record of the Líně Formation is generally poor and distribution of flora is irregular throughout the section. Rather exceptional are determinable plant remains in red fluvial sediments found only in ca. 33 of about 250 boreholes that penetrated this unit (Šetlík, 1977; Šetlík and Rieger, 1970). This scarcity is assumed to be a result of a drier climate, less favourable for plant growth, and oxidative conditions in dry soils promoting fast decomposition of plant remains. However, relatively common rhizoliths or root

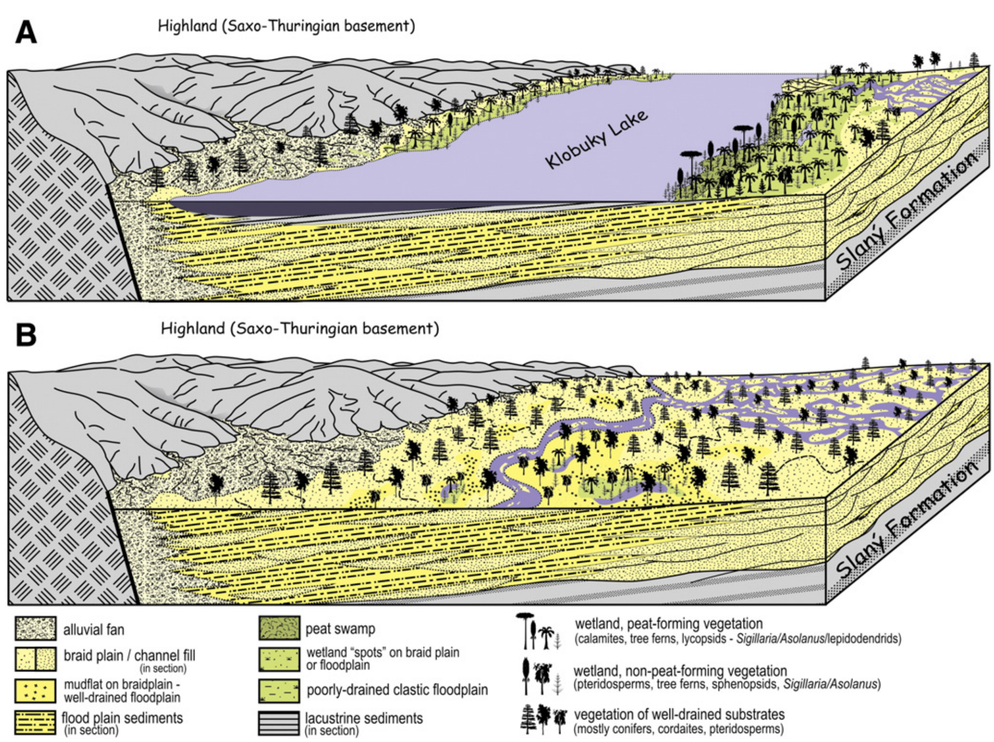

Fig. 7. Landscape reconstruction of the Líně Formation in contrasting stages of climatic oscillations. (A) Humid period characterised by increased precipitation promoted development of lacustrine environment (Klobuky Lake) with coastal wetlands and local peat swamps dominated by tree ferns with sub-dominant pteridosperms and sphenopsids. Present are arborescent lycopsids. Dryland plants occupied distal well-drained parts of basin depocentre. (B) During drier climate with more pronounced seasonality basin lowland was a braid plain to floodplain colonised mostly by dryland flora, dominantly conifers and sub-dominant cordaites. Wetland plans occupied only wet spots located in shallow poorly drained depressions.

haloes in red calcic/vertic palaeosols and silicified stems (Fig. 8) indicate that vegetation cover was at least locally present (Opluštil, 2013). More common are plant compressions in grey mudstones of lacustrine origin (Figs. 9, 10). The preferential occurrence of particular species in certain lithologies of the formation was first mentioned by Šetlík and Rieger (1970), who searched for flora in boreholes. They observed that red mudstones associated with palaeosols provided only a few plant fossils, mostly non-stigmarian roots or unidentifiable plant axes and less common walchian shoots and cordaitalean (*Cordaites* and *Poa–Cordaites*) leaf impressions. Poorly preserved remains of sphenopsids, ferns and pteridosperms are exceptional, and lycopsids are completely absent from this type of sediment. Coarse-grained or conglomeratic sandstones associated with these red mudstones provided silicified stems of gymnosperms, predominantly walchian conifers and subordinate cordaitaleans (Bureš, 2011), and also some exceptional calamites (Fig. 8) (Mencl et al., 2013). In variegated mudstones Šetlík and Rieger (1970) found drifted fragments of cordaitalean leaves and branches and *Calamites* stems, with subordinate ferns and also walchian conifer remains as well as common roots of non-stigmarian affinity (Figs. 4C, 9). However, the most common plant remains they found in grey, mostly lacustrine mudstones were “hygrophilous” elements, dominantly calamites and marattialean ferns and preserved as coalified compressions (Figs. 9, 10). The most plant remains have been found in grey mudstones of the Zdětín and Klobuky Horizons. In the Zdětín Horizon, Šetlík and Rieger (1970) found remains of *Pecopteris cyathea* (Schlotheim), *Dicksoniites pluckenetii* (Schlotheim) Sterzel, *Alethopteris zeilleri* (Ragot) Wagner, *Callipteridium pteridium* Gutbier and *Odontopteris schlotheimii* Brongniart. The first three species are common also in the underlying Slaný Formation whereas the last two species determine the Stephanian C age of the Líně Formation.

Sediments of the Klobuky Horizon, immediately above the Zdětín Horizon, exposed in the vicinity of Klobuky village in the KRB, have provided a fairly rich assemblage of fragmentary plant compressions (Jindřich, 1963; Němejc, 1953; Obrhel, 1959, 1965; Šimůnek et al., 1988; Šimůnek et al., 2009). Among the older elements of the Klobuky Horizon flora are *Asolanus camptotaenia* Wood, *Calamites* cf. *multiramis* Weiss, *C. suckowii*, *Asterophyllites equisetiformis* (Sternberg) Brongniart, *Dicksonites pluckenetii* (Schlotheim) Sterzel, *Pecopteris plumosa* (Artis), *P.* cf. *polypodioides* (Presl in Sternberg) Němejc and *Cordaites* cf. *borassifolius* (Sternberg) Unger, whereas typically Stephanian species are represented by *Sphenopteris* cf. *mathetii* Zeiller and *Odontopteris brardii* (Brongniart) Sternberg. *Sphenophyllum thonii* Mahr, *Pecopteris arborescens* (Schlotheim) Stur, *Pecopteris cyathea* (Schlotheim), *A. zeilleri* (Ragot) Wagner, and *Walchia piniformis* Schlotheim ex Sternberg extend upward stratigraphically from the underlying Slaný Formation, some of them continuing into the Permian. *Calamites gigas* Brongniart, *Sphenopteris cremeriana* Potonié, *Sphenopteris* cf. *dechenii* Weiss, *Sphenopteris* cf. *weissii* Potonié, *Callipteridium pteridium* Gutbier, *Odontopteris schlotheimii* Brongniart, *Neuropteris* cf. *zeilleri* Lima, *Taeniopteris jejunata* Grand 'Eury and *Ernestiodendron filiciforme* (Schlotheim) Florin are known in the Central and Western Bohemian Basins only in the Líně Formation and are indicative of late Stephanian C times. The remaining species are known from both the Stephanian and the Permian.

Several other species found at the Klobuky locality were encountered in boreholes by Šetlík and Rieger (1970). These species, known also in the Slaný Formation, include *Nemejcopteris feminaeformis* (Schlotheim) Barthel, *Pecopteris* cf. *polymorpha* (Brongniart), *Pecopteris unita* Brongniart, *Sphenophyllum* cf. *emarginatum* (Brongniart) Brongniart, *Sphenophyllum oblongifolium* (Germar) and *Neuropteris nervosa* Šetlík. *Sphenophyllum angustifolium* (Germar) Goeppert and *Pecopteris densifolia*

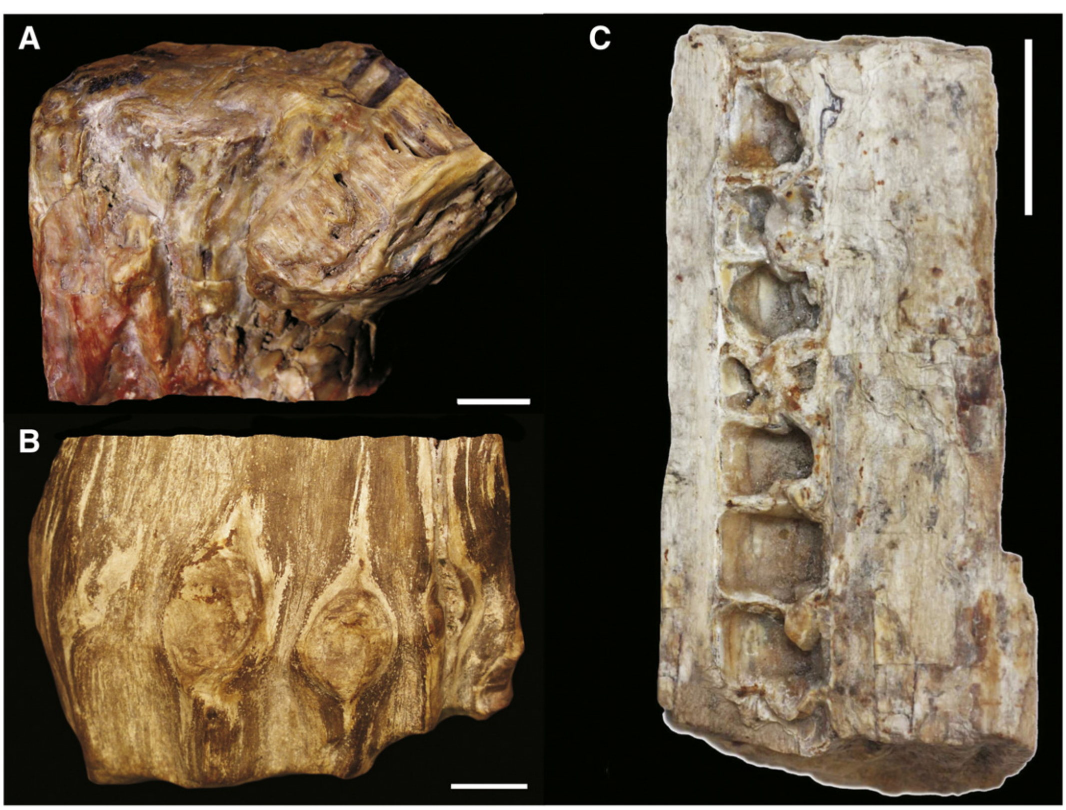

Fig. 8. Silicified stems from fluvial red beds of the Líně Formation. A — Cordaitalean stem with exposed pith of the *Artisia* type (sample FP00066, West Bohemian Museum in Pilsen), Líně near Pilsen, Pilsen Basin. B — Silicified wood of walchian conifer showing position of branches (sample FP00067, West Bohemian Museum in Pilsen). Zbůch near Pilsen, Pilsen Basin. After Bureš (2011). C — Calamite stem with wood of *Arthropitis* cf. *bistriata*, Podbořany area, Kladno–Rakovník Basin. After Mencl et al. (2013). Photos A, B: J. Bureš, C: J. Holeček.

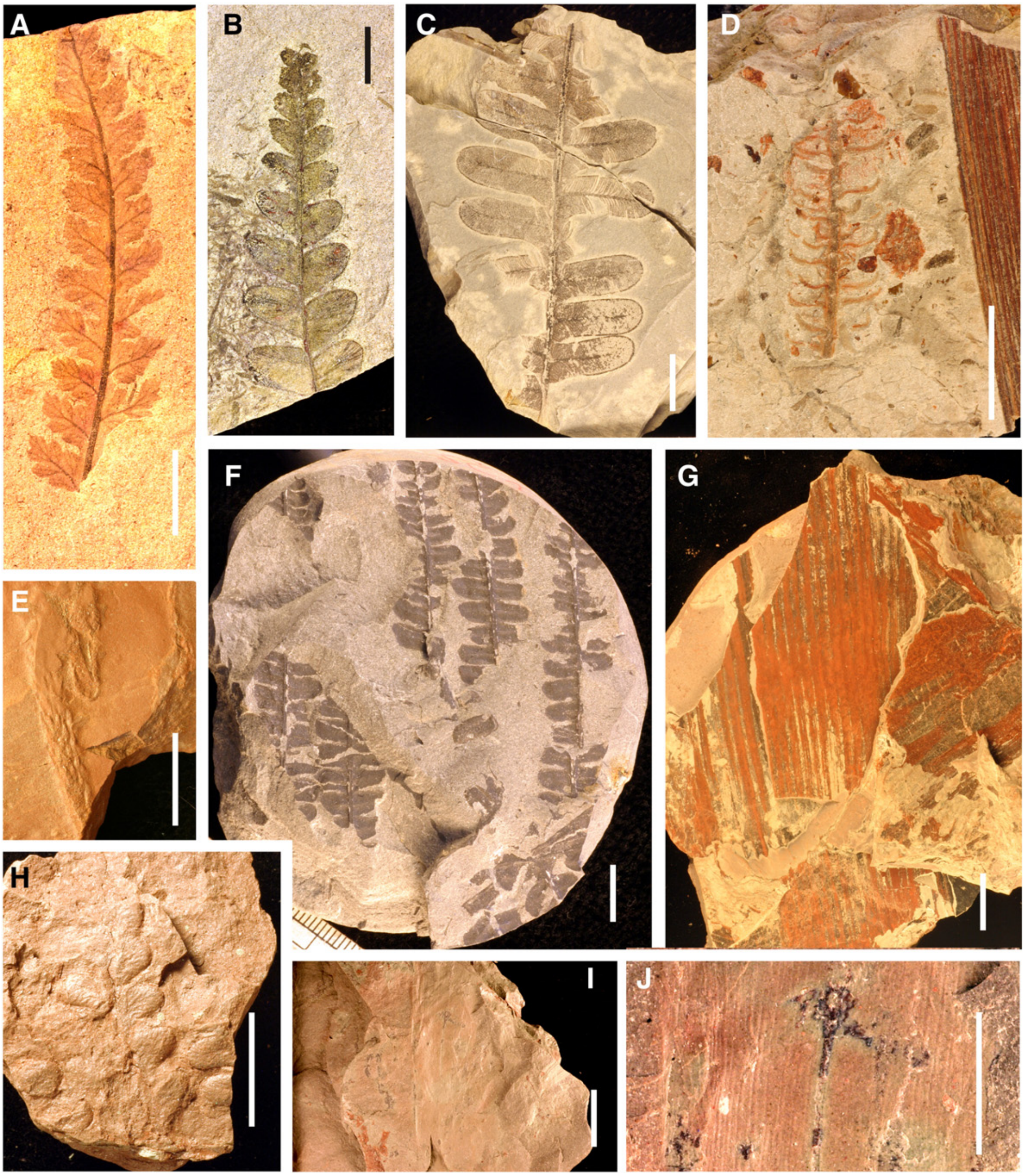

Fig. 9. Flora of the Líně Formation. A — *Dicksoniites plukenetii*, loc. Klobuky, grey mudstone beneath the coal. B — *Odontopteris schlotheimii*, loc. Klobuky, grey mudstone beneath the coal. C — *Alethopteris zeilleri*, loc. Klobuky, grey mudstone beneath the coal. D — *Ernestiodendron filiciforme*, loc. Klobuky, limestone above the coal. E — *Walchia* sp., red mudstone, loc. Semčice in the MRB, borehole Sč 1, depth 894.4 m. F — *Callipteridium pteridium*, grey mudstone, loc. Semčice (MRB), borehole Sč 1, depth 1249.4 m. G — *Calamites* sp., variegated mudstone, loc. Sazená in the KRB, borehole Sč 1, depth 67.3 m. H — *Neuropteris nervosa*, red mudstone, loc. Skůry in the KRB, borehole Sy 1, depth 183–183.7 m. I — *Cordaites* sp. (cf. *borassifolius*), loc. Nýřany in the PB, borehole Ny 13, depth 49.4–50 m. J — Detail of venation from previous figure, showing alternation of thin and thick veins, scale bar = 5 mm. Scale bars 1 cm except the Fig. J. All photos: Z. Šimůnek.

Goeppert have not been found in older deposits and indicate the level of *S. angustifolium* biozone.

In all, nearly 50 taxa have been reported from the formation (Table 1) (Pešek, 2004; Šimůnek et al., 2009). These are estimated to represent about 40 biological species. Apart from walchian conifer-dominated assemblages in red mudstones and cordaitalean-rich associations of variegated mudstones, plant assemblages of the Klobuky Horizon are dominantly composed of tree ferns with *Pecopteris* foliage. Sub-dominant are calamites and pteridosperms and also cordaitaleans, whereas walchian conifer remains are rare.

4.1.2.2. Palynology of the Líně Formation. The red beds nature of the Líně Formation does not favour preservation of palynomorphs. Consequently, miospore assemblages have been obtained only from grey mudstones or thin coals, whereas in red mudstones and claystones spores are not preserved. In all, only about 60 miospore species representing major plant groups (Table 2) have been reported so far from this lithostratigraphic unit (Pešek, 2004). The richest spore assemblages have been obtained from grey mudstones or thin coals.

One of the richest assemblages was obtained from the grey near-shore mudstones of the Klobuky Horizon. Here the assemblage is

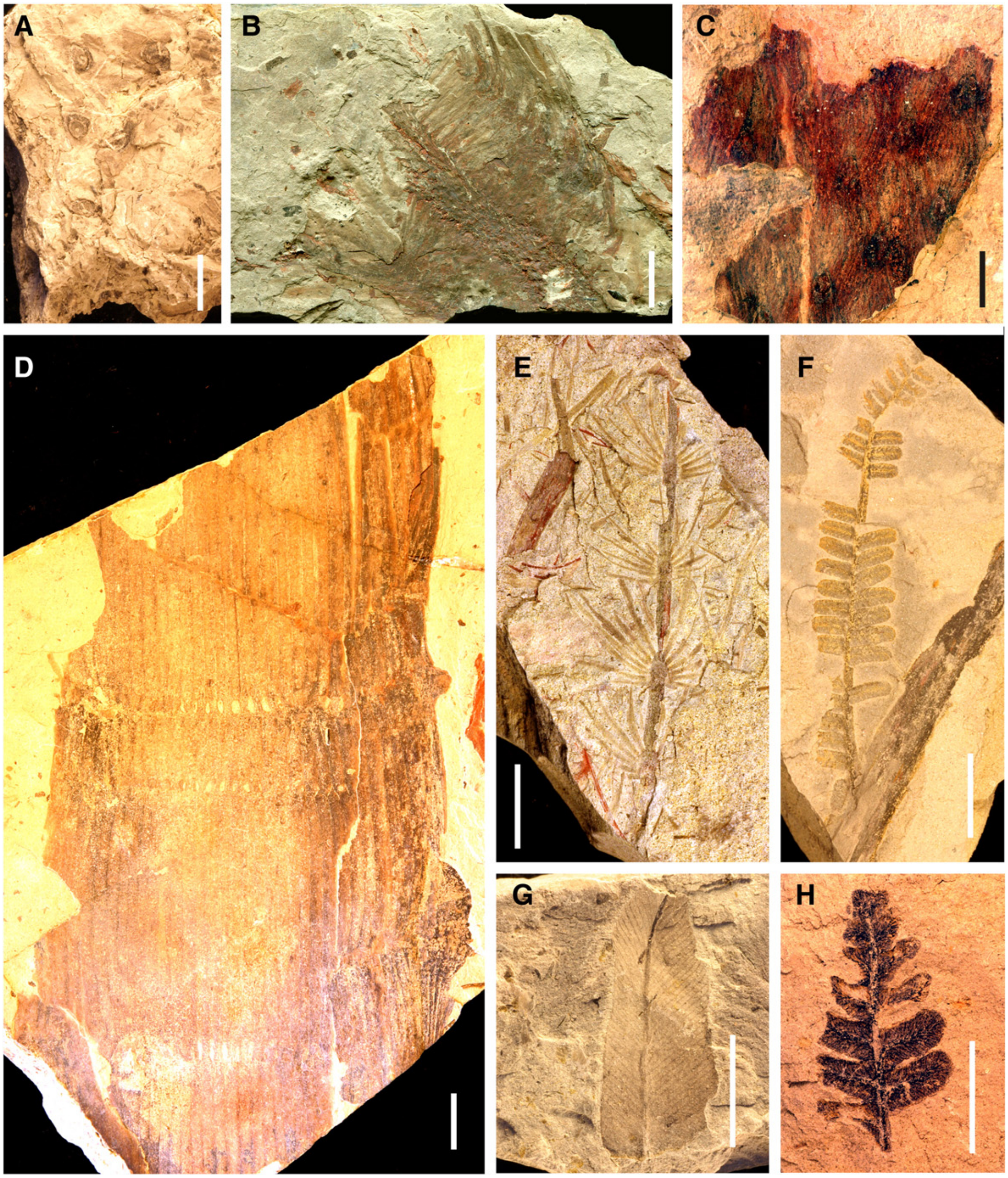

Fig. 10. Flora of the Klobuky Horizon (Líně Formation) from the type area near Klobuky village in the KRB. A — *Stigmaria ficoides* in mudstone just beneath the Klobuky Coal. B — *Lepidostrobus* sp., muddy limestone above the Klobuky Coal, coll. Obrhel. C — *Asollanus camptotaenia*, muddy limestone above the Klobuky Coal. D — *Calamites suckowii*, muddy limestone above the Klobuky Coal. E — *Asterophyllites equisetiformis* in nearshore lacustrine mudstone beneath the coal. F — *Pecopteris cyathea*, lacustrine mudstone beneath the coal. G — *Taeniopteris jejunata*, lacustrine mudstone beneath the coal. H — *Callipteridium pteridium* in mudstone, coll. Jindřich. Scale bars 1 cm. Photo B: S. Opluštil, Photos A, C–H: Z. Šimůnek.

dominated by the genus *Cyclogranisporites* followed by the genera *Laevigatosporites*, *Latosporites* and *Punctatisporites*, whereas representatives of the genera *Convolutispora*, *Microreticulatisporites*, *Leiotriletes*, and *Verrucosisporites* are rare (Šimůnek et al., 2009). The genera *Calamospora*, *Cadiospora* (*Sigillaria brardii*), *Cirratriradites* (herbaceous lycopsids), *Florinites* (*Cordaites*), *Potonieisporites* (conifers) and *Schopfipollenites*, *Vesicaspora*, *Wilsonites* and *Vittatina*, which represent pteridosperms, all are found very rarely.

Assemblages isolated from thin coals are dominated by representatives of the genus *Lycospora* (Kalibová, 1970). These contrast with those from the grey shales, such as that from the Klobuky Horizon.

4.1.2.3. Fauna of the Líně Formation. Animal remains in the Central and Western Bohemian Basins are known not only from the all three grey horizons of the Líně Formation but also from both intercalated sequences of generally red colour (Figs. 11, 12; Table 3). The majority of the Líně Formation, including the Zdětín and the Klobuky Horizons, is doubtless of Stephanian C age. The Stránka Horizon is, however, more probably of Lower Rotliegend age (Zajíc, 2012). Three boreholes yielded fossil remains of the Stránka Horizon, yet its stratigraphic position is still based on the circumstantial evidence.

The Zdětín Horizon (Late Gzhelian–Stephanian C) is known only from twenty boreholes but their common faunal content is quite well known. Invertebrates are represented by the pelecypod *Anthraconaia* sp.,

Table 1
List of the most important plant species and their stratigraphic ranges in the Stephanian C–Autunian successions of the continental basins of the Czech Republic. Some organ genera (e.g., seeds and roots) are omitted.

Basin >	CWBB	Krkonoše-piedmont Basin					ISB	Boskovice Basin						Blanice Basin	
Formation >	Líně Fm.	Semily Fm.		Vrchlabí Formation			Chvaleč Fm.	Rosice-Oslavany Formation				Padochov Fm.		černý Kostelec Fm.	
Taxon Horizon/Member >	Klobuky	Ploužnice H.	Štepanice-Čikvásky H.	Rudník H.	Háje H.	Kozinec H.	Verněřovice M.	Coal No. III	Coal No. II	Coal No. I	Helmhacker H.	Zbýšov H.	Říčany H.	Peklov M.	Lhotice M.
Asolanus camptotaenia	X	X													X
Sigillaria brardii		X	?					X	X	X				X	
Lepidostrobus variabilis		x													
Lepidostrobus sp.	x	x													
Lepidodendron sp.		?				?				X					
Calamites cistii	X	X		X				X		X		X			
Calamites cruciatus		X						X						X	
Calamites suckowii	X	X	X					X				X		X	X
Calamites undulatus		X	X												
Calamites multiramis	X							X							X
Calamites gigas	X	X	?	X	?					X		X	X	X	X
Calamites infractus												X			
Annularia sphenophylloides	X							X		X		X		X	
Annularia carinata				X											
Annularia stellata		X	X	X				X	X	X		X	X	X	X
Annularia spicata												X			
Annularia cf. mucronata									X						
Annularia cf. pseudostellata									X						X
Asterophyllithes equisetiformis	X		X	X				X	X	X		X	X		X
Asterophyllithes longifolius												X			
Calamostachys germanica	X						X								
Calamostachys dumasii				X	X			X				X			
Calamostachys tuberculata		X		X			X					X	X		
Sphenophyllum angustifolium	X							X	X						X
Sphenophyllum emarginatum	?														
Sphenophyllum oblongifolium	X	X						X	X	X		X		X	X
Sphenophyllum incissum										X					
Sphenophyllum longifolium														X	
Sphenophyllum thonii	x													X	X
Nemejcopteris feminaeformis	X			X					X	X					X
Sphenopteris cremeriana	X														
Sphenopteris germanica				X		X				X	X	X	X		
Sphenopteris cf. dechenii	X							X	X	X					X
Sphenopteris cf. mathetii	X							X	X	X					
Sphenopteris cf. weisii	X														
Pecopteris arborescens	X	X	X	X	?		?	X	X	X		X	X	X	
Pecopteris cyathea	X	X	X	X	X			X	X	X		X	X	X	X
Pecopteris candolleana	X	X	X						X	X		X	X	X	
Pecopteris densifolia	X				?			X	X			X		X	
Pecopteris pseudobucklandii	X							X	X						
Pecopteris imbricata														X	
Pecopteris hemitellioides	X	X						X	X	X					
Pecopteris polymorpha				X											
Pecopteris polypodioides	X	X	X	X					X	X			X		X
Pecopteris lepidorhachis		?					X	X	X	X				X	
Pecopteris unita	X	X						X	X			X			X
Senftenbergia plumosa	X	X							X					X	X
Senftenbergia saxonica									X	X					
Remia pinnatifida				X								X	X		
Dicksonites plueckenetii	X	X		X			X	X	X	X				X	X
Pseudomariopteris busquetii									X	X					
Pseudomariopteris cordato-ovata															X
Alethopteris zeilleri	X	X	X	X			X	X	X	X		?		X	
Alethopteris moravica										X					
Alethopteris schneideri												X			
Neuropteris nervosa	X														
Neuropteris cordata		X		X					X			X	X		X
Neuropteris zeilleri	X	X												X	

Table 1 (*continued*)

Basin >	CWBB	Krkonoše-piedmont Basin					ISB	Boskovice Basin						Blanice Basin	
Formation >	Líně Fm.	Semily Fm.		Vrchlabí Formation			Chvaleč Fm.	Rosice-Oslavany Formation				Padochov Fm.		černý Kostelec Fm.	
Taxon Horizon/Member >	Klobuky	Ploužnice H.	Štepanice-čikvásky H.	Rudník H.	Háje H.	Kozinec H.	Verněřovice M.	Coal No. III	Coal No. II	Coal No. I	Helmhacker H.	Zbýšov H.	Říčany H.	Peklov M.	Lhotice M.
Neuropteris cf. pseudo-blissii										X					
Barthelopteris germarii		X		X					X	X		X			
Odontopteris subcrenulata		X		X	X	X		X	X	X		X	X		
Odontopteris brardii	X	X					X	X		X					
Odontopteris lingulata				X	X							X			
Odontopteris minor							X	X	X	X		?			
Odontopteris schlotheimii	X	X	X				X	X	X	X	X				X
Neurodontopteris auriculata		X		X	X	X	X		X	X		X			X
Neurocallipteris neuropteroides		X		X	X			?	X	X			X	X	X
Callipteridium pteridium	X	X													
Callipteridium gigas							X							X	X
Arnhardtia scheibei				X	X							X			
Autunia conferta				X	?	X				X	X	X	X		X
Autunia naumannii				X	?		X			X	X	X	X		X
Dichophyllum flabellifera				X			X			X	X	X			
Lodevia nicklesii					X					X		X			
Rhachiphyllum lyratifolia				X	X							X	X		
Rhachiphyllum curretiensis												X			
"Callipteris" zbejsovensis										X		X			
Rhachyphyllum schenkii				X											
Gracilopteris bergeronii				X											
Taeniopteris jejunata	X	X						?	X	X					
Taeniopteris abnormis				X								X	X		X
Taeniopteris multinervis							?								
Taenioptris carnotii															X
Taeniopteris coriacea															X
Cordaites cf. *borassifolius*	X	X						X	X	X		X	X		
Cordaites cf. *palmaeformis*	X		X	X				X	X	X		X	X		X
Cordaites cf. *principalis*			X	X	X			X		X		X	X		X
Cordaites sp.	x	X	X			X				X					
Poacordaites sp.	X	X				X				X			X	X	
Dicranophyllum longifolium				X											
Dicranophyllum gallicum												X			
Ernestiodendron filiciforme	X	X		X						X	X	X	X		X
Walchia piniformis	X	X		X	X	X	X			X		X	X	X	X
Walchia goeppertiana				X						X		X			
Walchia sp.				X					X	X	X	X	X		X
Carpentieria marocana												X			
Culmitzschia frondosa		X		X											
Culmitzschia laxifolia		X		X											
Culmitzschia angustifolia				X	X								X		
Culmitzschia speciosa				X	X							X	X		
Culmitzschia parvifolia				X											
Otovicia hypnoides					X							X			
Hermitia rigidula				X											
Gomhostrobus bifidus	X	X			X							X	X		X
Pterophyllum sp.												X			
Zamites sp.												X			
Number of species	42	41	15	43	20	8	15	31	35	47	7	50	27	23	34
Estimated biological species	38	38	13	39	19	8	15	27	35	45	7	44	23	21	30

? — uncertain; x — very rare; X — rare; **X** — common.

abundant ostracods assignable to *Carbonita* sp., conchostracans assignable to Lioestheriidae indet. and one insect wing fragment. Vertebrate remains are mostly represented by isolated teeth, scales and other skeletal remains. Acanthodian scales, scapulocoracoids and fin spines of *Acanthodes* sp. are usual. Hybodontid sharks are represented by rare scales of *Sphenacanthus carbonarius*, one tooth of *Lissodus lacustris* and some other hybodontid dermal denticles. Xenacanthid shark teeth, including *Orthacanthus* sp., are common. The most diversified actinopterygian fishes are represented by teeth, scales, bones and segments of lepidotrichia of *Elonichthys krejcii*, *Progyrolepis speciosus*,

Table 2
Miospores and their stratigraphic ranges in the Stephanian C–Autunian strata of the continental basins of the Czech Republic. After Pešek et al. (2001), partly modified.

Table 2 (*continued*)

	Krkonoše-piedmont Basin					
	CWBB		Vrchlabí Formation			ISB
Taxon	Líně Fm.	Semily Formation	Rudník H.	Háje H.	Kozinec H.	Verněřovice M.
Acanthotriletes sp.			x			
Ahrensisporites minutus	X					
Alisporites sp.	x		x	x	x	
Angulisporites splendidus						x
Apiculatisporites aculeatus		x				
Apiculatisporites baccatus						X
Apiculatisporites sp.			x			
Apiculatisporites spinulistratus	X					
Bascanisporites sp.			x	x		
Cadiospora magna	X		x			X
Calamospora breviradiata	X		x	X		
Calamospora liquida	X					
Calamospora microrugosa	X	x	x			x
Calamospora mutabilis	X					
Calamospora pedata						X
Calamospora saariana	X					
Camptotriletes cf. triangularis			x	x		
Columnisporites sp.				x		
Converrucosisporites triquetrus	X					
Convolutispora sp.			x			
Costaepollenites elipsoides				x		
Cristatisporites indignabundus		x				
Cyclogranisporites aureus	X		x	x		X
Cyclogranisporites densus						X
Cyclogranisporites jelenicensis	X	x	x			
Cyclogranisporites orbicularis		x	x	x		
Densosporites sp.	X	x	x			
Densosporites sphaerotriangularis				x	x	
Endosporites formosus	X	x	x			X
Endosporites globiformis	x		x	x		X
Florinites antiquus	x	x				
Florinites mediapudens	x					
Florinites millotii			x	x		
Florinites minutus	x	X	x			
Florinites ovalis			x	x		
Florinites pierarti						X
Florinites pumicosus	x					X
Florinites similis			x			x
Florinites sp.		x	X	X		X
Gardenaisporites heiselii			x	x		
Gardenaisporites leonardi			x	x		
Gillespieisporites discoideus	X		x			x
Granulatisporites piroformis	X	x				
Granulatisporites sp.			x			
Gravisporites sphaerus	X					
Guthoerlisporites magnificus			x	x		
Hamiapollenites sp.			x			
Illinites unicus	x	x	X			
Jugasporites sp.			x	x		
Knoxisporites glomus			x	x		
Kosankeisporites elegans	x	X	x	x		
Laevigatosporites densus						X
Laevigatosporites desmoinesensis	X	x	x		x	X
Laevigatosporites maximus	X		x			
Laevigatosporites medius	X	x	x	x		X
Laevigatosporites minimus	X		x	x	x	X
Laevigatosporites perminutus	x		x			
Laevigatosporites striatus						X
Laevigatosporites vulgaris	X		x			
Latensina sp.			x			
Latosporites globosus	X		x	x		
Latosporites latus	X					X
Latosporites robustus	x					
Latosporites saarensis	X					
Leiotriletes adnatoides	X					
Leiotriletes adnatus		x		x		
Leiotriletes convexus	X			X		
Leiotriletes grandis	X					
Leiotriletes gulaferus			x			
Leiotriletes minutus	X		x			
Leiotriletes sphaerotriangulus		x	x	x	x	
Limitisporites latus			x			
Lophotriletes commissuralis			x			
Lophotriletes gibbosus	X					
Lophotriletes gulaferus	X					
Lophotriletes insignitus						X
Lophotriletes microsaetosus	X					X
Lophotriletes mosaicus						X
Lueckisporites sp.			x			
Lundbladispora gigantea			x			
Lycospora sp.	X	X	X		x	X
Microreticulatisporites fistulosus						X
Microreticulatisporites nobilis	X					
Nuskoisporites sp.		x	x	x		
Pityosporites sp.	x	x				
Planisporites kosankei	X					
Planisporites sp.			x			
Platysaccus sp.			x			
Polymorphysporites sp.						x
Potonieisporites bhardwaji			x	X		
Potonieisporites elegans			x			
Potonieisporites novicus	x	X	X			X
Potonieisporites sp.	x	x	X			X
Protohaploxipinus cf. Globosus			x	x		
Protohaploxipinus samoilovichii			x	x		
Protohaploxipinus sevardi				x	x	
Ptonieisporites simplex				x		
Punctatisporites minutus			x			x
Punctatisporites obliquus	X	x	x			x
Punctatisporites provectus						x
Punctatosporites granifer	x	x				
Punctatosporites microgranifer				x		
Punctatosporites minutus	X					X
Punctatosporites oculus			x			
Punctatosporites punctatus	x	x	x			X
Punctatosporites pygmaeus	x					
Punctatosporites sp.			x		x	
Raistrikia aculeolata						X
Raistrikia crinita			x			
Raistrikia saetosa			x			
Reticulatisporites reticulatus						X
Reticulatisporites sp.			x			

Table 2 (*continued*)

	Krkonoše-piedmont Basin					
	CWBB	Vrchlabí Formation				ISB
Taxon	Líně Fm.	Semily Formation	Rudník H.	Háje H.	Kozinec H.	Vernéřovice M.
Sclerotites angulatus						x
Scheuringipollenites sp.			x			
Speciososporites sp.	x					X
Spinosporites sp.		x	x			
Spinosporites spinosus						X
Sporonites unionus	X					
Striatopodocarpites sp.			x			
Thymospora obscura		x		x		
Thymospora sp.	x	x	x			
Thymospora thiessenii	x	X				
Thymospora verrucosa						X
Torispora sp.	x			x		
Triquitrites bransonii			x			
Triquitrites exiquus	X					
Triquitrites spinosus			x			
Tuberculatosporites sp.						x
Tuberculatosporites stephaniensis	x					
Variouxisporites plicatus						x
Verrucosisporites grandiverrucosus	X	X	x			
Verrucosisporites sinensis	X	x	x	x		X
Vesicaspora ovata				x		
Vesicaspora sp.			X			
Vesicaspora wilsonii			X	X		
Vestigisporites sp.			x			
Vittatina costabilis		x	x	x		
Vittatina ovalis				x		
Vittatina sp.	x	x	x	x	x	X
Vittatina thuringica				x		
Westphalensisporites irregularis			x			
Wilsonites kosankei	x	x	x			
Wilsonites vesicatus			x			

x — very rare; X — rare; **X** — common.

Sphaerolepis kounoviensis, *Spinarichthys dispersus* and Actinopterygii indet. Small but characteristic scale fragments of the dipnoan *Sagenodus* sp. occur infrequently. The special intercalated bed of blackish-grey "tetrapod" claystone is rich in isolated bones mostly attributable to amphibians. This layer (or two stratigraphically close layers) was detected in four boreholes. One partially articulated amphibian specimen was described (Zajíc et al., 1990) as *Branchierpeton* cf. *saalensis*. This taxon is also important from the stratigraphic point of view because it was originally described from the Wettin Member (Stephanian C) in the Saale Basin (Germany).

The Klobuky Horizon (Late Gzhelian–Stephanian C) fauna is known chiefly from several outcrops (especially from the Klobuky localities) and from three boreholes. The main fauna-bearing bed comprises yellowish pink limestone, which is full of microremains. Hundreds of ichthyoliths were separated chemically from this sediment. Common pelecypods are traditionally described as *Anthracosia stegocephalum* or, less commonly, *Anthraconaia* sp. Lioestheriid conchostracans are often determined as *Pseudestheria* sp., ostracods as *Carbonita salteriana* or, more likely, *Carbonita* sp. Rare exoskeletal fragments of syncarids were discovered. All vertebrates are disarticulated and their remains (including bones) are isolated. Acanthodians are represented both the closely indeterminable remains *Acanthodes* sp. and *Acanthodes fritschi*. Among remains of xenacanthid sharks are teeth of *Orthacanthus* sp., *Plicatodus plicatus* and *Plicatodus* sp. Other small teeth and tiny fragments of calcified cartilage are still labelled as Xenacanthiformes indet. Hybodontid sharks are represented by common ichthyoliths of *Sphenacanthus carbonarius* (scales and one tooth), rare small teeth of *Lissodus lacustris*, and dermal denticles of Hybodontiformes indet. *Progyrolepis speciosus*, *Sphaerolepis kounoviensis*, *Spinarichthys dispersus*, *Zaborichthys fragmentalis*, and *Elonichthys krejcii* represent determinable taxa of actinopterygian fishes. Other specimens are labelled as Actinopterygii indet. Rather rare remains (scale fragments) of sarcopterygian fishes belong to dipnoan *Sagenodus* sp. and Osteolepiformes indet. Rare amphibian remains consist of both chemically separated tiny jaw fragments and isolated bones on the bedding planes of a drill core (Dissorophoidea indet.).

The Stránka Horizon (?Lower Rotliegend) is the youngest of the main three non-red horizons. Its age has been debated since it was established by Holub (1972). The horizon is known only from three boreholes but circumstantial evidence speaks in favour of lowermost Permian age. Unmistakable thin cycloid scales of *Sphaerolepis kounoviensis* are the hallmark of the local bio/eco sub-zone *Sphaerolepis*. These abundant scales can be found almost in all samples of that subzone containing fauna (even together with pelecypods). No scales of *S. kounoviensis* have been found in the Stránka Horizon. Positive evidence (for the presence of *Sphaerolepis–Elonichthys* or *A. gracilis* zones) could provide a future evaluation of discovered xenacanthid teeth. In the horizon, thin-walled pelecypods Myalinidae indet., ostracods *Carbonita* sp., conchostracans Lioestheriidae indet., xenacanthid sharks Xenacanthida indet., and indeterminable smooth actinopterygian scales Actinopterygii indet. were found.

Red sequences among all three horizons (Stephanian C) are, despite the traditional assertion, not completely sterile. Four boreholes yielded quite diversified faunas, all of which are of the same nature. Invertebrates are represented by pelecypods *Anthraconaia* sp., ostracods *Carbonita* sp., and conchostracans of the family Lioestheriidae. Scales and fin spines of acanthodians (*Acanthodes* sp.) and poorly preserved teeth of xenacanthid sharks Xenacanthiformes indet. were discovered. A majority of the actinopterygian fishes found are preserved as isolated scales and skeletal remains except one completely articulated specimen discovered in a drill core. *S. kounoviensis*, *Spinarichthys dispersus*, *Progyrolepis speciosus*, and *Elonichthys krejcii* were recognised. Scale fragments of the dipnoan fish *Sagenodus* sp. complete the set of piscine remains. Some isolated amphibian bones belong to Dissorophoidea indet.

4.1.3. Climatic indicators recorded in the Líně Formation

The predominantly red colour of mudstones and fine-grained sandstones together with absence of coal led Pešek (1994) and other authors to the conclusion that the climate during the deposition of the Líně Formation was dry but still not arid. Although the red colour of sediments is indicative of well-drained oxidative conditions, which can occur in a wide spectrum of climates (Pešek and Skoček, 1999; Sheldon, 2005), the basin-wide extent of red beds, in combination with the presence/absence of other climate sensitive lithologies, can provide unequivocal information on palaeoclimate. The absence of coal in red fluvial sediments and its scarcity in some grey lacustrine horizons indicates climatically unfavourable conditions for peat accumulation except during periods of increased humidity, represented by lake horizons. However, even in these humid periods precipitation did not reach the level required for the kind of long-term peat accumulation necessary for the formation of economically important regional coals, such as those present in underlying Slaný Formation of middle Late Pennsylvanian age. Relatively dry and seasonal climate even during humid period of significant lacustrine deposition may indicate the presence of limestones (Pešek and Skoček, 1999) as suggested by lateral transitions from non-marine limestones into calcic vertisols observed in some North American basins (DiMichele et al., 2010). Millimetre-scale to 40 cm thick chert layers to lenses are locally common in some lacustrine deposits (Fig. 6A, B), very often associated with volcaniclastics. Cherts

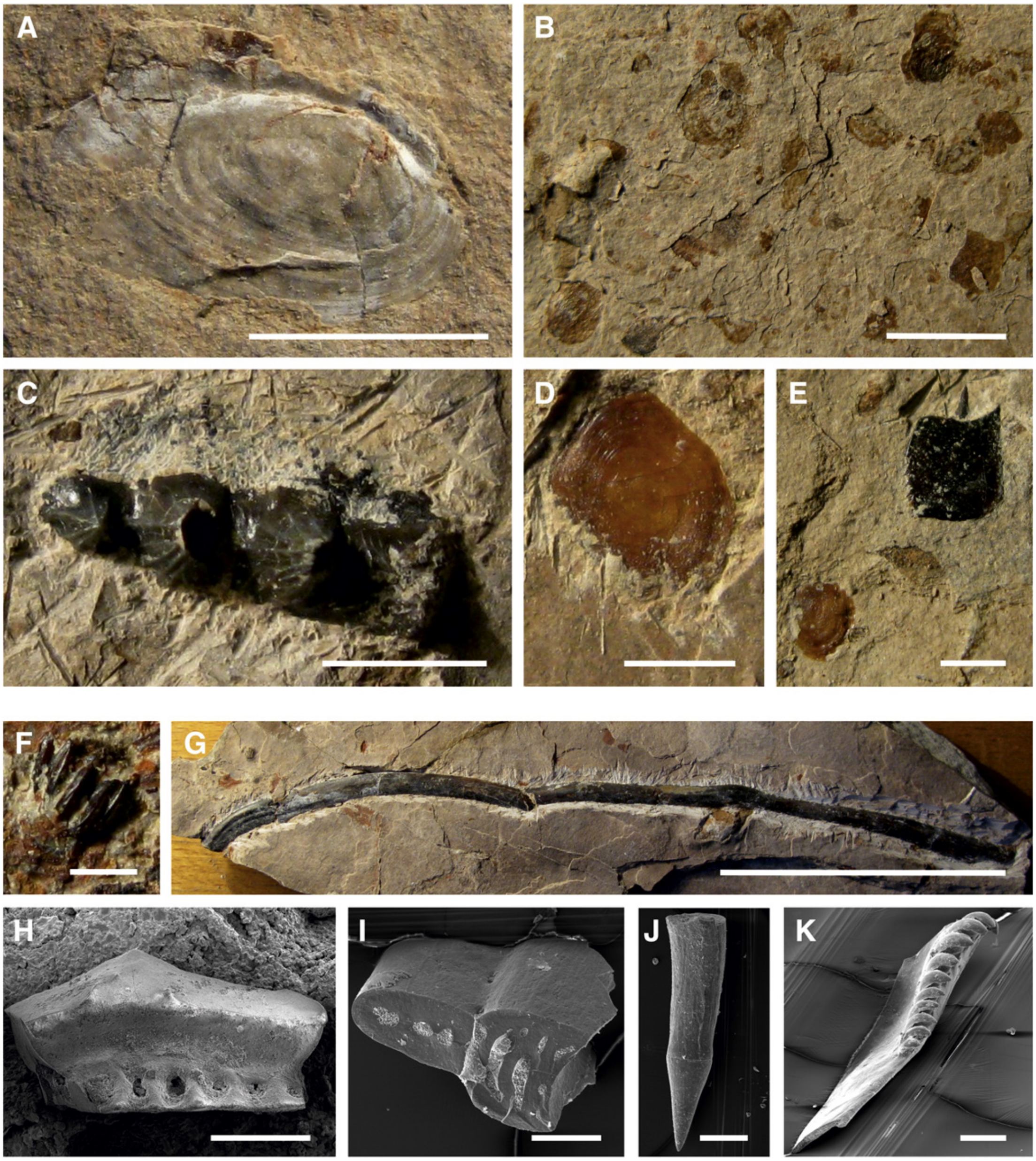

Fig. 11. Fauna of the Kladno–Rakovník Basin (CWBB), Klobuky Horizon, Klobuky locality. Photos by Zajíc. A — *Anthraconaia* sp., scale bar equals 5 mm. B — Lioestheriidae indet., scale bar equals 5 mm. C — *Sphenacanthus carbonarius*, tooth in coronal view, scale bar equals 3 mm. D — *Sphaerolepis kounoviensis*, scale, scale bar equals 2 mm. E — scales *Sphaerolepis kounoviensis* (left down) and *Spinarichthys dispersus* (right up), scale bar equals 2 mm. F — *Sphenacanthus carbonarius*, scale in anterior view, scale bar equals 1 mm. G — *Sagenodus* sp., broken rib, scale bar equals 5 mm. H — *Lissodus lacustris*, incomplete tooth in lingual view, scale bar equals 0.2 mm. I — *Acanthodes* sp., fragment of small fin spine with inner canals system in cross section, scale bar equals 0.2 mm. J — Actinopterygii indet., sculptured tooth, scale bar equals 0.2 mm. K — Amphibia indet., jaw fragment in posterocoronal view, scale bar equals 0.2 mm.

are finely laminated or brecciated and locally mud cracked (Skoček, 1969). This author explains the origin of cherts by decomposition of volcaniclastics, which provided silica that precipitated at the contact with underlying coal due to low pH as the strong evaporation increased its concentration in lake water.

In predominating red beds between grey lacustrine horizons, associated palaeosols, which are vertisols often with nodules of precipitated pedogenic carbonates locally coalescing into continuous calcrete horizons (Pešek and Skoček, 1999; Skoček, 1993), indicate climates with strongly seasonal moisture deficits (Cecil, 2003; Driese and Ober, 2005; Nordt et al., 2006). Such conditions result in full oxidation of plant remains, which are preserved as impressions, which is a typical preservation pattern in fluvial red beds (Fig. 9E, G, H, I, J). Roots, if present in these palaeosols, are mostly sub-vertically oriented (Fig. 4C) and of non-stigmarian affinity. *Stigmaria*-like root systems were rarely reported (Opluštil, 2013; Šetlík and Rieger, 1970) only from grey mudstones (Fig. 10A). Another fossilisation pattern of plant remains typical for fluvial red beds deposited under seasonally dry climate is silicification of wood and other tissues in porous coarse-grained feldspathic sandstones and conglomerates (Fig. 8). Skoček (1970) and Matysová et al. (2008, 2010) consider fluctuating water table to be a pre-requisite for wood silicification in alluvial sediments. Prostrate silicified stems up to >10 m long lack bark, branches and roots, which together with the absence of parent palaeosols, are good indicators of transport prior final burial. Probably even drier climate and the absence of a dense vegetation cover are indicated by bimodal

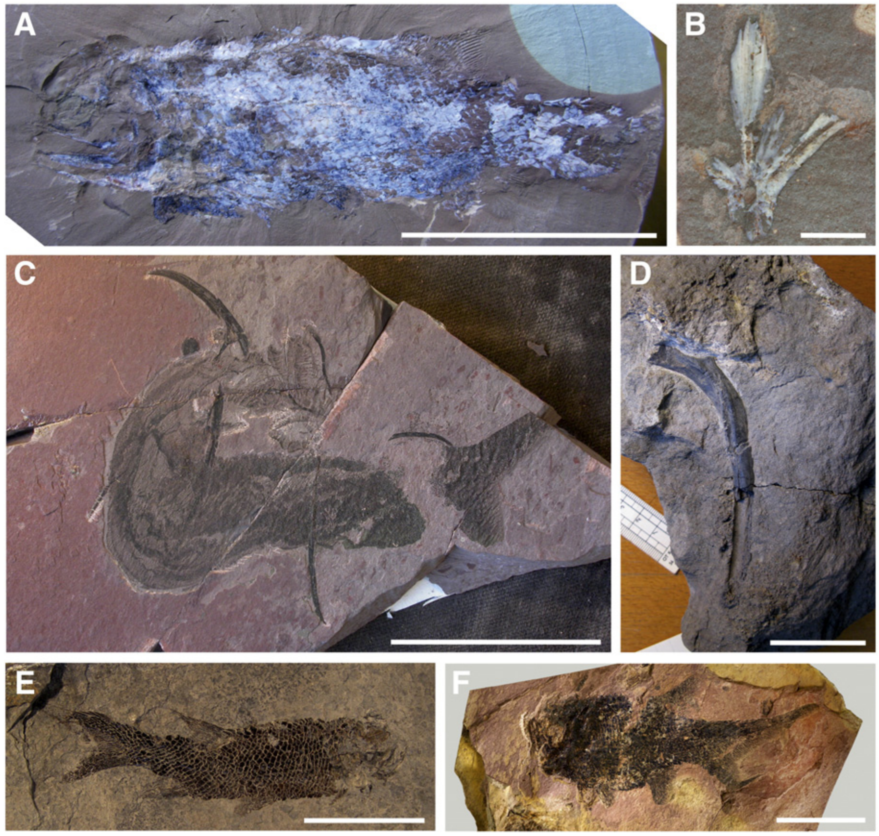

Fig. 12. A — Actinopterygii indet., articulated specimen, Mšeno–Roudnice Basin (CWBB), red sequence of the Líně Formation between the Klobuky and Stránka Horizons, Lib-1 Liběchov borehole, scale bar equals 30 mm. B — *Sphaerolepis kounoviensis*, incomplete parasphenoid, KrPB, Ploužnice Horizon, Ploužnice locality, scale bar equals 3 mm. C — *Acanthodes* sp., distorted specimen, KrPB, Rudník Horizon, Vrchlabí locality, scale bar equals 50 mm. D — Tetrapoda indet., incomplete rib, KrPB, Kozinec Horizon, Kozinec locality, scale bar equals 50 mm. E — *Neslovicia elongata*, articulated specimen, KrPB, Rudník Horizon, Košt'álov locality, scale bar equals 20 mm. F — *Paramblypterus* sp., articulated specimen, KrPB, Rudník Horizon, Vrchlabí locality, scale bar equals 50 mm. Photos by Zajíc (A, C, D) and Štamberg (B, E, F).

eolian sandstones described from NW part of the KRB and possibly some loess deposits from the Manětín Basin (Tásler and Skoček, 1964). Seasonal climate is also inferred by Skoček (1974) and Pešek and Skoček (1999) from clay mineralogy of argilised tuffs and palaeosols, which are rich in smectites, and from a generally high variation of heavy mineral spectra suggesting reduced intensity of chemical weathering in the Líně Formation compared to the underlying coal-bearing Slaný Formation.

All the aforementioned lithologies in the Líně Formation suggest the climate during deposition of this unit was seasonal, the intensity of which varied temporally. Evidently less pronounced seasonality existed during the deposition of grey-coloured horizons, which are assumed to represent the wettest parts of climatic oscillations because of peat accumulation, even though of limited extent, whereas calcic vertisols to calcisols, associated with fluvial red beds between grey horizons, indicate strongly seasonal conditions. Existing data allow us to speculate that the climate under which deposition took place thus probably varied from moist sub-humid to dry sub-humid (Cecil, 2003) but occasionally could perhaps approached even drier (?semi-arid) climate as indicated by local presence of eolian sediments. However, findings of fish and shark remains in red beds suggest existence of “surface” water (lakes and/or rivers) throughout the year even during deposition of this part of the Líně Formation. The duration of these oscillations, however, is difficult to estimate from existing data. Assuming that these low-latitude climatic cycles represent far-field responses to changes of continental ice, then they could correspond to medium-term intervals of glacial advance and retreat of ice in the former Gondwana portions of Pangaea, which lasted from about a hundred thousand to about a million years (Birgenheier et al., 2009; Cecil, 2003; DiMichele et al., 2010; Driese and Ober, 2005; Fielding et al., 2008). Moreover, superimposed on these climatic oscillations during deposition of the Líně Formation there seems to be a hierarchically overriding trend of increasing aridity recorded by the decreasing occurrence of grey-coloured sediments above the Stránka Horizon.

4.2. Sudetic Basins

The eastern part of the main basin complex (MBC) is subdivided into the Mnichovo Hradiště (MHB), Krkonoše Piedmont (KrPB) and Intra-Sudetic (ISB) basins, which together with the adjacent, but nowadays isolated, Česká Kamenice (ČKB) and Orlice basins (OB), comprise the Sudetic Basins, encompassing an area of about 4000 km^2 (Figs. 1, 2) located onthe Saxo-Thuringian basement. Individual basins of the eastern part of the MBC are separated by prominent NW–SE striking faults, the reverse nature of which is a result of later reactivation during the Alpine Orogeny (Pešek, 2004; Tásler et al., 1979). As indicated by small denudation relicts of Early Permian strata in the surrounding of the MBC, all the Sudetic Basins once formed a large single depocentre around the time of the Pennsylvanian/Permian boundary. These Sudetic Basins generally differ from those of central and western Bohemia in having a well-developed and biostratigraphically dated Permian part of the succession. The stratigraphic range of deposition between particular basins can differ significantly as can their thickness and lithostratigraphic units. Therefore only those basins where the Carboniferous–Permian transition is present and proved by the fossil record are discussed in detail. These basins include the KrPB and ISB. In the

Table 3
Fauna of the Líně Formation from the central and western Bohemian basins.

Lithostratigraphy		*Anthracosia stegocephalum*	*Anthraconaia* sp.	Myalinidae indet.	*Carbonita salteriana*	*Carbonita* sp.	*Pseudestheria* sp.	Lioestheriidae indet.	*Acanthodes fritschi*	*Acanthodes* sp.	*Sphenacanthus carbonarius*	*Lissodus lacustris*	Hybodontiformes indet.	*Plicatodus plicatus*	*Plicatodus* sp.	*Orthacanthus* sp.	Xenacanthiformes indet.	*Elonichthys krejcii*	*Sphaerolepis kounoviensis*	*Progyrolepis speciosus*	*Spinarichthys dispersus*	*Zaborichthys fragmentalis*	Actinopterygii indet.	Osteolepiformes indet.	*Sagenodus* sp.	*Branchierpeton* cf. *saalensis*	Dissorophoidea indet.	Amphibia indet.
Líně Formation		no fauna																										
	Stránka H.			x		x		x									x						x					
						x		x		x							x	x	x	x	x		x		x		x	
	Klobuky H.	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
			x			x													x		x		x		x			
	Zdětín H.		x			x		x		x	x	x				x	x	x	x	x	x		x		x	x		x
		no fauna																										

remaining basins the deposition either started later (OB) or the fossil record is generally poor.

4.2.1. Krkonoše Piedmont Basin (KrPB)

In the KrPB deposition spans the interval from the latest Moscovian to the Triassic and the whole basin thickness reaches up to 1800 m (Pešek, 2004). The basin fill is subdivided into nine lithostratigraphic formations (Fig. 2). The latest Pennsylvanian and earliest Permian strata are represented by the Semily and Vrchlabí Formations separated by a hiatus, the stratigraphic extent of which varies across the basin.

4.2.1.1. Lithology and sedimentary environments of the Semily and Vrchlabí Formations. The Semily Formation (Stephanian C) consists usually of a 300–500 m thick complex of fluvial to lacustrine sediments, except in the southern part of the basin where the formation thickness is reduced to <200 m. It is separated from the underlying Syřenov Formation by a basin-wide and biostratigraphically proven hiatus identified also in the basins of central and western Bohemia (Fig. 2). The basic lithological pattern of the formation consists of a cyclic alternation of petromict conglomerates and sandstones (Fig. 6C) with red mudstones often cemented by calcite. Less common but stratigraphically important are red to variegated mudstones accompanied by bituminous shales, limestones and cherts. These non-red mudstones are grouped into the Štěpanice–Čikvásky and Ploužnice Horizons (Fig. 6D) formerly described as two independent stratigraphic intervals but later proven to be stratigraphically equivalent (Pešek, 2004). Deposition was accompanied by volcanic activity, which produced layers of acid tuffs, and exceptionally, also small effusions of basaltic bodies (Pešek, 2004).

Lithological development of the Semily Formation between northern and southern parts of the KrPB differs (Fig. 5). In the northern part along the W–E trending tectonic basin margin the lower, about 100 m thick succession is dominated by purple to carmine-brown poorly sorted conglomerates to breccias composed of clasts derived from surrounding crystalline complexes (Fig. 6C). Clast size is commonly a few to about 30 cm; however, the basal conglomerate locally contains gneiss cobbles up to 50 cm in diameter (Pešek et al., 2001). Subordinate purple-brown massive mudstones locally display an angular blocky structure with rare carbonate nodules probably representing fossil calcretes. Overlying this lower part of the formation is the about 95 to 130 m thick Štěpanice–Čikvásky Horizon composed of two and locally even three 5 to 50 m thick sequences of grey to green-grey mudstones, claystones and sandstones with one or two coals, locally developed. Coals are usually between 20 and 50 cm thick although locally can reach up to 1 m and some of them are accompanied by limestone and/or bituminous shale. Locally present are volcaniclastics up to a few metres in thickness. The remaining upper, about 200 m thick, part of the formation consists of red to purple mudstones with intercalated fine-grained sandstones and subordinate sandstone and rare conglomerates. In the southern part of the KrPB, the Semily Formation is dominantly composed of red to purple mudstones alternating with subordinate sandstones and rare conglomerates except in the basal part of the formation. Sandstones to fine-grained conglomerates are cross-bedded and quite well sorted, with sub-angular to sub-rounded clasts. The stratigraphic equivalent of the Štěpanice–Čikvásky Horizon in the southern half of the basin is the Ploužnice Horizon (Fig. 6D). It is built up of pale grey to variegated mudstones and claystones with local deposits, up to a few tens of centimetres thick, of layers or lenses of chert, subordinate limestones and associated volcaniclastics. Locally present is a <20 cm thick silicified peat layer (Fig. 13). The horizon is divided into two parts by 10 to 30 m thick red mudstones with subordinate sandstones. The sandstones contain prostrate, silicified, but anatomically often well-preserved stems of seed and spore producing plants.

Deposition of the Semily Formation took place after a basin wide hiatus related to the Intra-Stephanian phase. Conglomerates, breccias and sandstones dominating the lower part of the succession in the northern half of the basin (Fig. 5) are interpreted as alluvial fan deposits. The central and especially the southern parts of the basin were occupied at that time by an alluvial plain drained by rivers transporting a mixed load. Later, as tectonic subsidence increased and/or climate became more humid alluvial fans retreated further north and the basin depocentre changed into a perennial lake. The northern part of the depocentre is interpreted as a lake with oxic to locally anoxic conditions at the bottom (Štěpanice–Čikvásky Horizon). Thin coals, developed in a W–E striking narrow belt of coastal peat swamps along the northern basin margin, indicate climatic conditions temporary suitable for peat accretion. In the southern part of the depocentre the lake had a mostly oxic bottom (Ploužnice Horizon). Several mudcrack horizons and/or the presence of roots suggest lake-level oscillations (Martínek et al., 2006). Together with intercalated red mudstones and subordinate sandstones, these features may indicate that even during this wettest phase of formation, the climate was not stable but oscillated in a similar manner to that inferred during the deposition of the grey horizons of the CWBB. The upper half of the Semily Formation was deposited on an extensive alluvial plain drained by rather low energy rivers with floodplains and small local lakes.

The following unit in the KrPB is the Vrchlabí Formation (lower Autunian), which is a complex of fluvial to lacustrine strata. The unit is up to 530 m thick along the tectonically active northern basin margin but only 300 m or less in its southern half (Pešek, 2004). Differences in subsidence are responsible not only for the half-graben-like geometry of the depocentre but also for differences in sedimentary environment. In the more subsiding northern part of the basin depocentre the prevailing lithological pattern of the formation is characterised as “rhythmic” alternation of red-brown massive mudstones with subordinate mostly

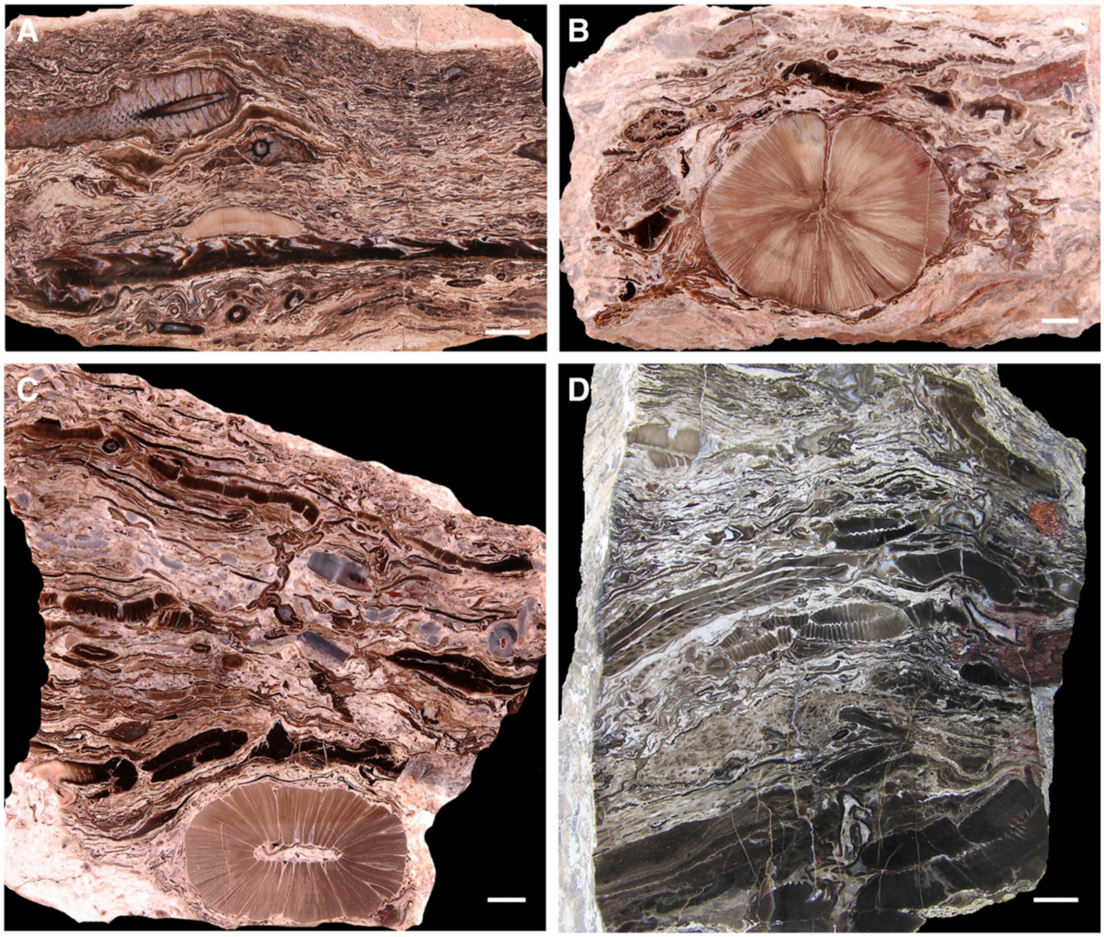

Fig. 13. Silicified peat from the Ploužnice Horizon (Semily Formation) in the KrPB. A — Part of a lycopsid cone. B — Woody cylinder of lycopsid axes (?*Stigmaria* sp.). C — Cross section of the secondary xylem cylinder of *Stigmaria* sp. D — Calamite stems showing wedges of secondary xylem. Scale bars 1 cm. All photos: V. Mencl. Collection of the Municipal Museum Nová Paka.

thin sheet-like bodies of fine- to medium-grained sandstones (Pešek et al., 2001). Grey to variegated mudstones are concentrated into three distinct horizons in stratigraphic order called the Rudník, Háje and Kozinec (Fig. 5), of which only the Rudník Horizon is of basin-wide extent, traceable over a distance >30 km. Grey to black and variegated lacustrine mudstones, laminites and carbonates of this horizon cover an area of about 400 km^2 (Martínek et al., 2006). This 30–150 m (60 m in average) thick horizon comprises the lower part of the formation and is dominantly composed of green-grey to grey mudstones and claystones with thin sheet-like bodies of fine-grained sandstones, several bituminous shales, varying from a few decimetres to locally over a metre thick (Fig. 6E, F, G) with vertebrate fauna and drifted flora, and grey to dark-grey locally developed bituminous limestones also with fauna. In proximity to the northern tectonic basin margin the Rudník Horizon locally contains intercalations of conglomerates interpreted as a coarse fan delta (Martínek et al., 2006). The remaining grey horizons, the Háje and Kozinec, are of local extent situated in the NW part of the basin. The Háje Horizon, located about 100–180 m above the Rudník Horizon. It is a usually 10 to 30 m thick complex of grey to green-grey mudstones and subordinate fine-grained sandstones locally with the <30 cm thick Háje Coal, with grey to dark bituminous limestone intercalations in mudstones above the coal. It is laterally traceable over a distance of about 8 km. Even smaller lateral extent of about 2 km is typical for the youngest Kozinec Horizon, which is a 15 to 20 m thick complex of grey conglomerates and sandstones with green-grey to dark grey mudstones locally containing carbonaceous mudstones a few centimetres thick or even high ash coal. In the southern half of the basin the lower part of the formation is dominantly composed of cross-bedded feldspathic sandstones with thinner conglomerate intercalations together forming thick amalgamated and erosively based bodies (Stará Paka Sandstone Member) with subordinate red-brown mudstones (Pešek et al., 2001). Arkoses contain silicified woods of gymnosperms and less common *Psaronius* (tree fern) stem remains. The proportion of mudstones increases in the middle part of the succession where pale red-grey mudstones, thin and less common limestones and beds of altered tuffs occur as an equivalent of the Rudník Horizon. In the remaining upper part of the formation in the south of the basin, the proportion of coarse lithologies increases, again being dominantly composed of cross-bedded to massive fine to coarse grained sandstones with scattered pebbles and intercalated decimetres-thick conglomerate beds (Čistá Sandstone Member). Compared to the Stará Paka Sandstone in the lower part of the succession, the petrographic composition of the Čistá Sandstone is more variable; sediments are less sorted and are cemented by calcite and locally also by dolomite. Silicified stems are rare or absent (Pešek, 2004; Tásler and Skoček, 1980; Tásler et al., 1981).

Sediments of the Vrchlabí Formation were deposited in a half-graben-like depocentre. Maximum subsidence was along its northern margin, which is bordered by coarse grained fan deltas (Martínek et al., 2006) that pass southward into an alluvial plain. Along the southern basin margin a broad braid plain existed. This basic palaeogeographic pattern changed during the humid periods when perennial lakes developed.

The largest extent and longest duration was the Rudník Lake in the lower part of the formation, which was a basin-wide stratified lake deepest in northern half of the basin near the active fault and gradually passing southward into broad coastal mudflat and subsequently into a braid plain represented by the Stará Paka Sandstones Member (Martínek et al., 2006). The sedimentary record of the lake indicates the presence of lacustrine cycles related to lake level oscillations reflected in the alternation of transgressive and regressive facies and by vertical changes in values of $\delta^{18}O$ and $\delta^{13}C$ in lacustrine carbonates, and in boron content and some other geochemical proxies (Martínek et al., 2006). These changes provide good evidence of repeating lake shallowing and drying. During periods of low lake level increased salinity indicated by boron content suggests that the lake was probably hydrologically closed, whereas during the high lake level the low salinity suggests that it was a hydrologically open sedimentary system (Martínek et al., 2006). Highstand periods are characterised by increased organic content, abundant pyrite and lack of bioturbation, which indicate high bioproductivity and anoxic bottom conditions. Microspar laminae alternating with dark organic-rich clay laminae are interpreted as to represent seasonal (late summer) bio-induced calcite precipitation during algal blooms (Martínek et al., 2006).

The remaining the Háje and Kozinec Horizons record the existence of local lakes, which developed during a period of increased humidity only in the NW part of the basin. Although much less

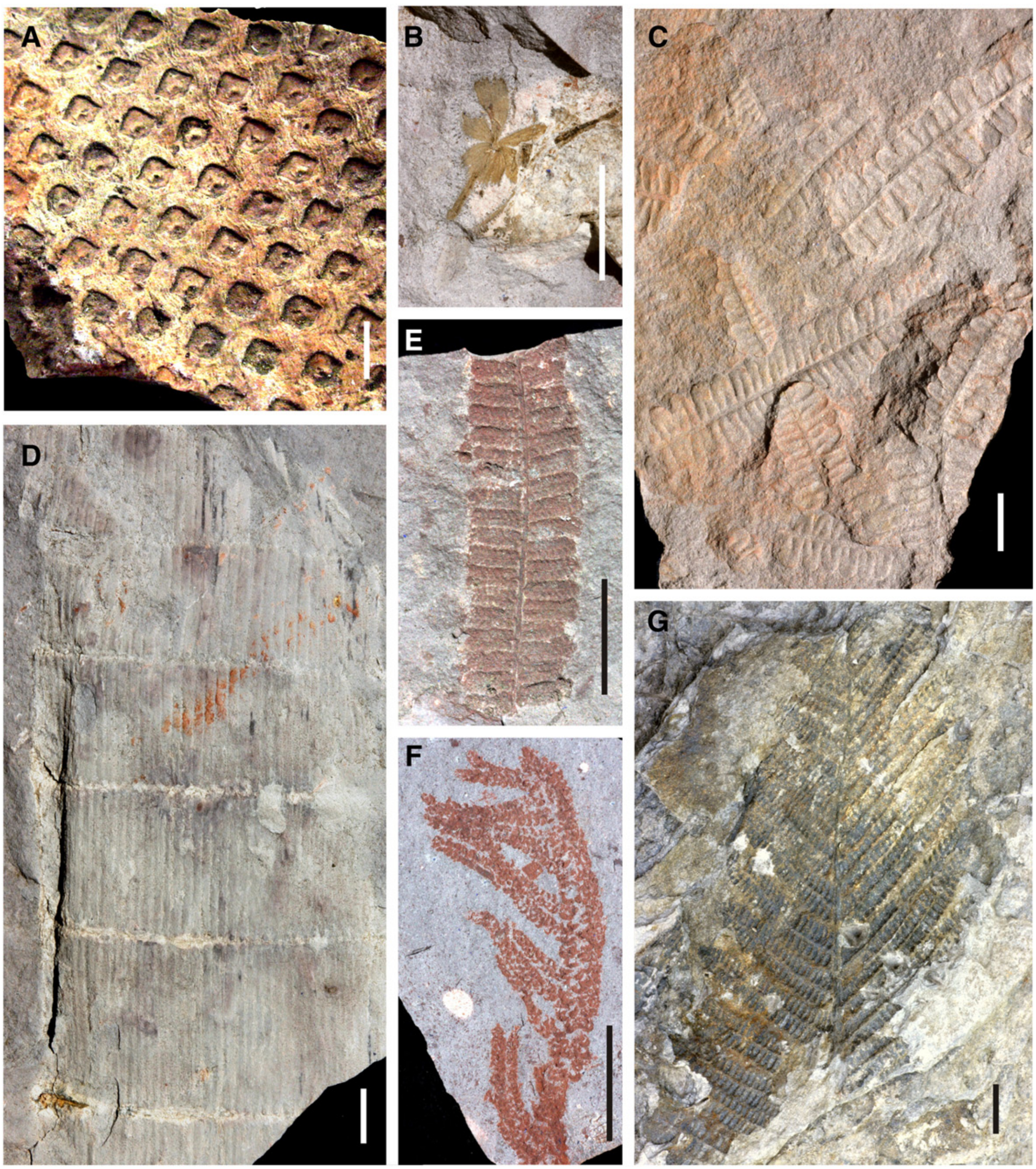

Fig. 14. Flora from the Ploužnice and Štěpanice–Čikvásky Horizons (Semily Fm.) in the KrPB. A — *Sigillaria brardii*, carbonaceous mudstone, Ploužnice Horizon, loc. Ploužnice, coll. Benda, Lomnice Museum. B — *Sphenophyllum oblongifolium*, carbonaceous mudstone, Ploužnice Horizon, loc. Ploužnice, coll. Havlata. C — *Callipteridium pteridium*, carbonaceous mudstone, Ploužnice Horizon, loc. Lísek near Stará Paka. D — *Calamites suckowii*, carbonatic mudstone, Ploužnice Horizon, loc. Ploužnice, coll. Havlata. E — *Pecopteris cyathea* — fertile, carbonatic mudstones, Ploužnice Horizon, loc. Ploužnice, coll. Havlata. F — *Ernestiodendron filiciforme*, carbonatic mudstone, Ploužnice Horizon, loc. Ploužnice. G — *Pecopteris arborescens*, grey mudstone, Štěpanice–Čikvásky Horizon, loc. Čikvásky, Bosna Mine, coll Rieger. Scale bars 1 cm. All photos: Z. Šimůnek.

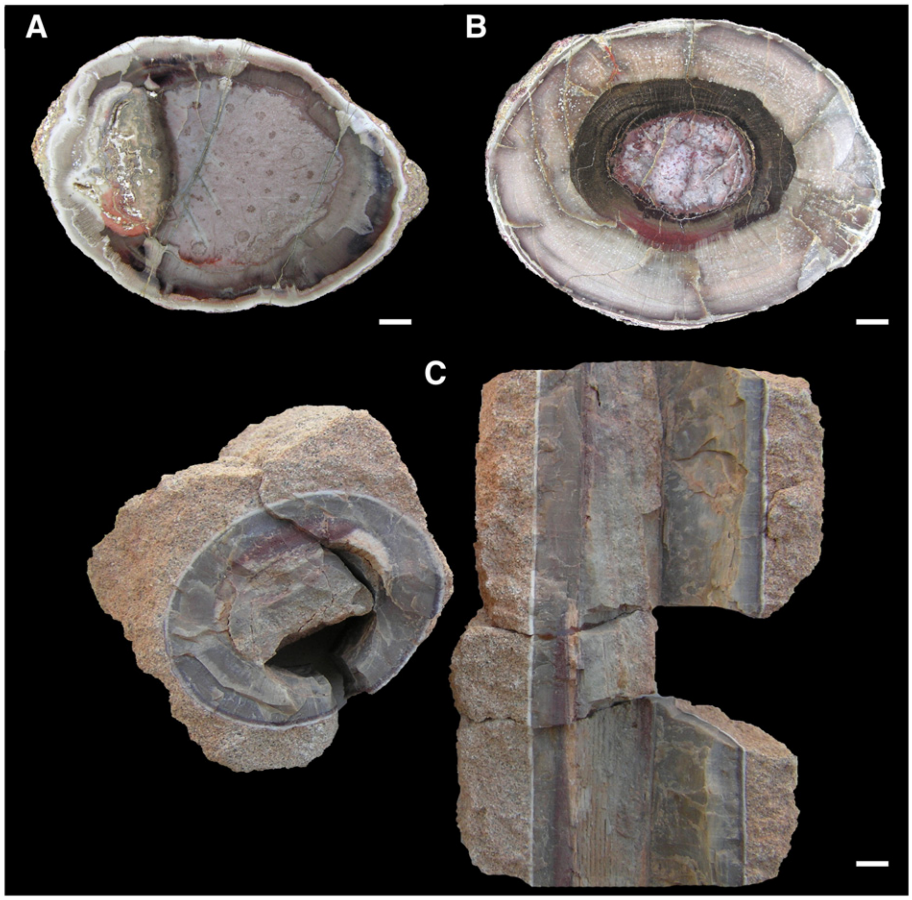

Fig. 15. Silicified stems from sandstone above the Ploužnice Horizon (Semily Fm.) in the KrPB. A — Medullosan stem. B — Calamite stem with thick woody tissues. C — Calamite stems preserved in sandstone. Scale bars 1 cm. All photos: V. Mencl.
Collection of the Municipal Museum Nová Paka.

pronounced than that during the deposition of the Rudník Horizon, the humid period still was sufficient for spatially and temporarily restricted peat accumulation resulting in thin, high-ash coals.

4.2.1.2. Fossil records of the Semily and Vrchlabí Formations. Although red bed parts of the succession of both formations are very poor in fossil remains, grey to variegated horizons provide fairly rich fossil flora and fauna.

4.2.1.2.1. Flora of the Semily and Vrchlabí Formations. The bulk of macroflora of the Semily Formation has been found in the Ploužnice and Štěpanice–Čikvásky Horizons, which are stratigraphically identical but represent different facies. In the Ploužnice Horizon the flora is preserved as compressions without coaly matter. In some places (e.g., near Nová Paka) silicified woods also commonly occur. Although plant remains are generally not common, being restricted to few fossiliferous beds, quite a rich collection has been gathered during a century of investigation. This collection includes remains of about 37 species (Table 1; Fig. 14) of all the major plant groups (Němejc, 1932; Purkyně, 1929; Rieger, 1958, 1968). Lycopsids are represented by *A. camptotaenia* Wood, *Lepidostrobus variabilis* Lindley and Hutton, *Lepidophyllum* cf. *lanceolatum* Lindley and Hutton, *S. brardii* Sternberg and *Stigmaria ficoides* Sternberg. Sphenopsids include *Calamites cistii* Brongniart, *C. cruciatus* Sternberg, *C. gigas* Brongniart, *C. suckowii* Brongniart, *C. undulatus* Sternberg, *Annularia stellata* (Schlotheim) Wood, *Sphenophyllum oblongifolium* (Germar and Kaulfus) Unger. Diversed ferns are represented by *P. arborescens* (Schlotheim), *P. candolleana* Brongniart, *P. cyathea* (Schlotheim), *P. hemitelioides* Brongniart, *P.* cf. *lepidorachis* Brongniart, *P. polymorpha* Brongniart, *P. polypodioides* (Presl in Sternberg) Němejc, and *P. unita* Brongniart. Pteridosperms are represented by *Dicksoniites plukenetii* (Schlotheim) Sterzel, *A.* cf. *zeilleri* (Ragot) Wagner, *Callipteridium pteridium* (Schlotheim) Zeiller, *Odontopteris schlotheimii* Brongniart, *O. subcrenulata* Rost, *O. brardii* Brongniart, *Neurodontopteris auriculata* (Brongniart) Potonié, *Neurocallipteris neuropteroides* (Goeppert) Cleal, Shute and Zodrow, *Neuropteris cordata* Brongniart, *Neuropteris zeilleri* Lima, and *Barthelopteris germarii* (Giebel) Cleal and Zodrow. Coniferophytes include the cordaitalean *C. borassifolius* (Sternberg) Unger and the conifers by *Culmitzschia frondosa* (Renault) var. *zeilleri* (Florin) Clement-Westerhof, *C. laxifolia* (Florin) Clement-Westerhof, *Ernestiodendron filiciforme* (Schlotheim) Florin and *Walchia piniformis* Sternberg.

In the upper part of the Ploužnice Horizon, or just above it, a permineralised flora occurs (Figs. 15, 16). It consists mainly of silicified stem remains of sphenopsids (*Calamites* sp.), ferns (*Psaronius alsophiloides* Corda, *P. asterolithus* Cotta, *P. bohemicus* Corda, *P. haidingeri* Stenz, *P. hemitholithus* Corda, *P. infarctus* Unger, *P. radiatus* Unger, *P. scolecolithus* Unger, *P. zeidleri* Corda), pteridosperms (*Medullosa* aff. *stellata* Cotta) and cordaitalean or conifers (*Dadoxylon* sp. Corda, 1867; Purkyně, 1927). Silicified stems in growth position have never been observed. They are very rarely found in outcrop, but they were always transported and secondarily embedded in lacustrine and fluvial deposits. Most fossil trunks are split into pieces and found in alluvial sediments. According to Matysová et al. (2010), this unit can be interpreted as a lacustrine environment with influence of volcanism.

The Štěpanice–Čikvásky Horizon in the northern half of the basin has provided about 20 species. Plant remains were collected mainly in mudstone from coal roof and, surprisingly, are less diversified than in

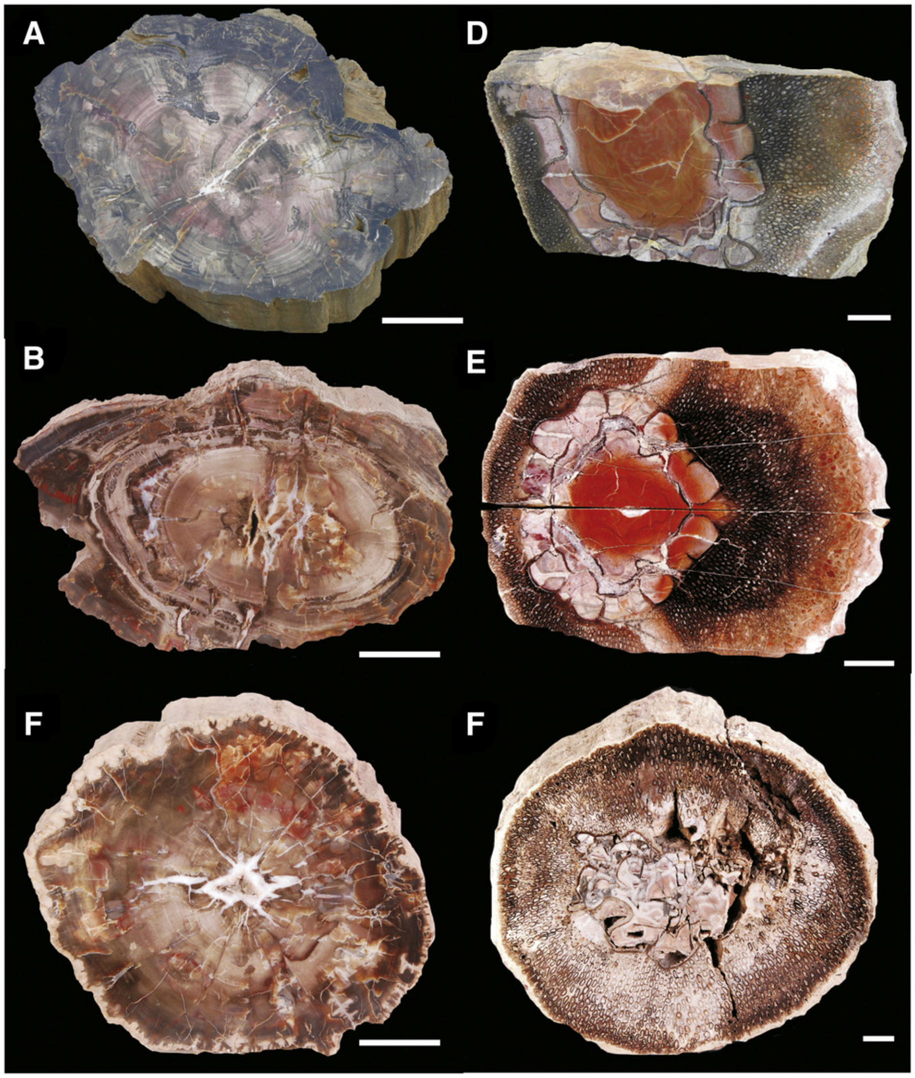

Fig. 16. Silicified stems from sandstone above the Ploužnice Horizon (Semily Fm.) in the KrPB. A–C — gymnospermous woods (Scale bars 5 cm). D–F — *Psaronius* stems (Scale bars 2 cm). All photos: V. Mencl.
Collection of the Municipal Museum Nová Paka.

the case of the Ploužnice Horizon. Flora of this horizon includes lycopsid roots *Stigmaria ficoides* Sternberg and decorticated bark *Syringodendron* sp. (probably from *S. brardii* Sternberg), the sphenopsids *Calamites* cf. *gigas* Brongniart, *C. suckowii* Brongniart, *C. undulatus* Brongniart, *A. stellata* (Schlotheim), and *A. equisetiformis* (Schlotheim), the ferns *P. arborescens* (Schlotheim), *P. candolleana* Brongniart, *P. cyathea* (Schlotheim), *P. plumosa* Artis, *P. polymorpha* Brongniart, and *P. polypodioides* (Presl in Sternberg) Němejc, the pteridosperms *Sphenopteris* cf. *tridactylites* Brongniart, *A. zeilleri* (Ragot) Wagner, *Odontopteris schlotheimii* Brongniart, *Neuropteris* sp., the cordaitaleans *Cordaites* cf. *palmaeformis* (Goeppert) Weiss and *Cordaites* cf. *principalis* (Germar) Geinitz and the conifer *Walchia* sp. (Katzer, 1904; Němejc, 1932; Rieger, 1958, 1968, 1971). Preserved flora indicates that the Semily Formation is of the Stephanian C (late Gzhelian) age and belongs to the *Sphenophyllum angustifolium* zone (Wagner, 1984). Particularly diagnostic of the age of this formation are the medullosans *A. zeilleri* (Ragot) Wagner, *Callipteridium pteridium* (Schlotheim) Zeiller and *Odontopteris schlotheimii* Brongniart. As a whole the type area of the Ploužnice Horizon is dominated by pteridospems. Some localities are characterised by high dominance of particular species (e.g., *Odontopteris schlotheimii* or *C. pteridium*). Lycophytes and conifers are very rare. The time equivalent Štěpanice–Čikvásky Horizon represents a wet lowland association characterised by dominance of tree ferns (*P. arborescens*, *P. cyathea*).

The Vrchlabí Formation is of the Early Permian (Asselian) age. Fossil flora has been found only in three grey to variegated lacustrine horizons. In the lowermost of these, the Rudník Horizon, plant remains occur in light grey or brownish mudstones called the "*Walchia* shales" and also in lacustrine bituminous shales. In all about 48 plant species have been found in the Rudník Horizon (Table 1; Fig. 17). They include the sphenopsids *A. equisetiformis* (Schlotheim) Brongngniart, *Annularia carinata* Gutbier, *A. stellata* (Schlotheim) Wood, *Calamites cisti* Brongniart, *C. gigas* (Brongniart) Remy, *Metacalamostachys dumasii* (Zeiller) Barthel and *Calamostachys tuberculata* (Sternberg), the ferns *Nemejcopteris feminaeformis* (Schlotheim) Barthel, *P. arborescens* (Schlotheim), *P. cyathea* (Schlotheim) Stur, *P. polymorpha* Brongniart and *P. polypodioides* (Presl in Sternberg) Němejc, the pteridosperms *Sphenopteris germanica* Weiss, *Dicksoniites pluckenetii* (Schlotheim) Sterzel, *Remia pinnatifida* (Gutbier) Knight, *Odontopteris lingulata* (Goeppert) Schimper, *O. subcrenulata* Rost, *N. auriculata* (Brongniart) Potonié, *Neurocallipteris neuropteroides* (Goeppert) Cleal, Shute and Zodrow, *Neuropteris cordata* Brongniart, *Neuropteris zeilleri* Lima, *B. germarii* (Giebel) Cleal and Zodrow, *Arnhardtia scheibei* (Gothan) Haubold and Kerp, *Autunia conferta* (Sternberg) Kerp, *A. naumannii*

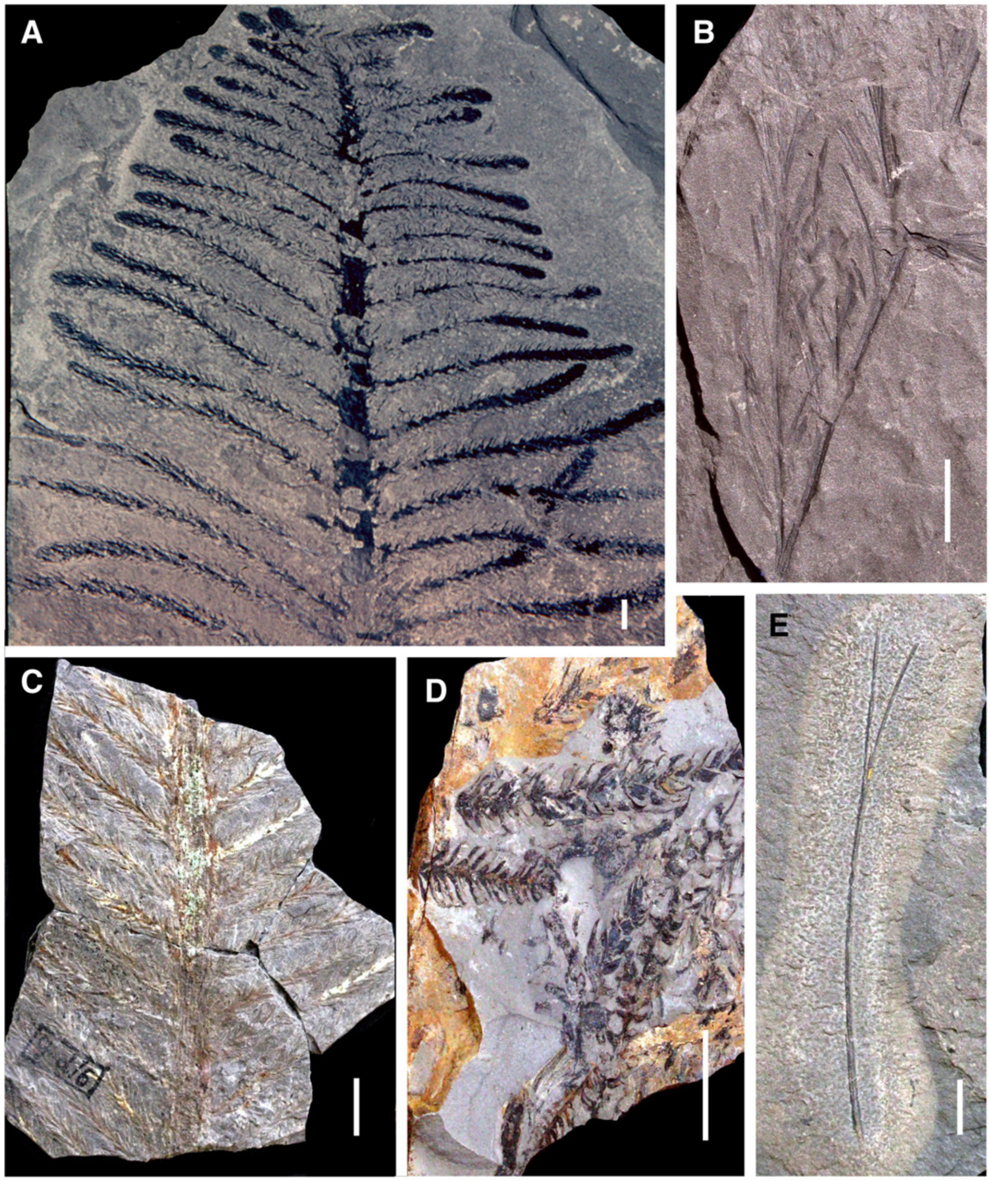

Fig. 17. Flora of the Rudník and Kozinec Horizons (Vrchlabí Formation) in the KrPB. A — *Walchia goeppertiana*, bituminous shale, loc. Vrchlabí — road cut section, Rudník Horizon — upper part. B — cf. *Dichophyllum flabelliferum*, bituminous shale, loc. Valtěřice, Rudník Horizon. C — *Walchia piniformis*, bituminous shale, Kozinec Horizon, loc. Kozinec near Jilemnice, coll. East Bohemian Museum Hradec Králové. D — *Walchia goeppertiana*, *W. piniformis* and *Ernestiodendron filiciforme*, grey mudstone, loc. Vrchlabí N. edge of the town, behind the sawmill, Rudník Horizon — lower part. E — *Dicranophyllum longifolium*, bituminous shale, loc. Košťálov, behind the pub, Rudník Horizon, East Bohemian Museum Hradec Králové. Scale bars 1 cm. All photos: Z. Šimůnek.

(Gutbier) Kerp, *Dichophyllum flabelliferum* (Weiss) Kerp and Haubold, *Rhachiphyllum schenkii* (Heyer) Kerp and *Gracilopteris* cf. *bergeronii* (Zeiller) Kerp, Naugolnykh and Haubold, the possible pteridosperm or cycadophyte *Taeniopteris abnormis* Gutbier, the cordaitaleans *Cordaites rudnicensis* Šimůnek, *C. sudeticus* Šimůnek, *Artisia* sp., and *Cordaitanthus* sp., the dicranophyll *Dicranophyllum longifolium* Renault and Zeiller, and the conifers *Ernestiodendron filiciforme* (Schlotheim) Florin, *Hermitia rigidula* (Florin) Kerp and Clement-Westerhof, *Walchia goeppertiana* (Florin) Clement-Westerhof, *W. piniformis* Schlotheim ex Sternberg, *Culmitzschia angustifolia* (Florin) Clement-Westerhof, *C. frondosa* (Renault) Clement-Westerhof, *C. laxifolia* (Florin) Clement-Westerhof, *C. parvifolia* (Florin) Clement-Westerhof, *C. speciosa* (Florin) Clement-Westerhof, *Walchiostrobus* cf. *elongatus* Florin and *Gomphostrobus bifidus* (Geinitz) Zeiller (Havlena, 1957; Havlena and Špinar, 1955; Rieger, 1968). The common presence of peltasperm pteridosperms in the Rudník Horizon indicates that it belongs to the *A. conferta* zone (Wagner, 1984). Worth noting is the dominance (~90% of identifiable specimens) of walchian conifers in grey "*Walchia* shales" (Rieger, 1971) at the base of the Rudník Horizon near the northern basin margin. The most diversified flora containing about 40 species has been found in a roadcut section near Vrchlabí along the northern tectonic basin margin. In 9 fossiliferous layers mostly dryland elements like cordaitaleans and conifers prevail with locally common peltasperms (*A. conferta*), whereas sphenopsids and tree ferns are very rare and medullosans are not very common. Other localities along the northern basin (lake) margin located further west and east of Vrchlabí provided only a low diversity flora of 15 to 20 species, in which it seems that conifers also prevail and peltasperms are very rare. However, assemblages near the southern basin margin near Koštálov are completely different; Rieger (1968) collected assemblages dominated by tree ferns (*Pecopteris cyathea*).

The Háje Horizon flora comes from pale to dark grey mudstones in roof of the Háje Coal or in intercalated partings (Šimůnek and

Drábková, 1997). In outcrops with coarser deposits, where coal is not developed, the flora is very poor in species with dominance of cordaitaleans. Based on Šimůnek and Drábková (1997) and Pešek (2004), about 21 plant species have been found in the Háje Horizon (Table 1) including the sphenopsids *Annularia* sp. *Calamites* cf. *gigas* Brongniart, *Metacalamostachys dumasii* (Zeiller) Barthel, ferns *Pecopteris* cf. *arborescens* (Schlotheim), *P.* cf. *cyathea* (Schlotheim) Stur and *P.* cf. *densifolia* Goeppert, the pteridosperms *Odontopteris lingulata* (Goeppert) Schimper, *O. subcrenulata* Rost, *N. auriculata* (Brongniart) Potonié, *Neurocallipteris neuropteroides* (Goeppert) Cleal, Shute and Zodrow, *A. scheibei* Gothan Haubold and Kerp, *A.* cf. *conferta* (Sternberg) Kerp, *A.* cf. *naumannii* (Gutbier) Kerp, *Lodevia* cf. *nicklesii* (Zeiller) Haubold and Kerp and *Rhachiphyllum* cf. *lyratifolia* (Goeppert) Kerp, the cordaitalean *Cordaites* sp. [cf. *principalis* (Germer) Geinitz] and the conifers *Walchia piniformis* Sternberg, *C. angustifolia* (Florin) Clement-Westerhof, *C. speciosa* (Florin) Clement-Westerhof, *Otovicia hypnoides* (Brongniart) Kerp and *G. bifidus* (Geinitz) Zeiller. Species composition suggests that the Háje Horizon lies within the same biozone as the Rudník Horizon. Flora in mudstones surrounding the Háje Coal is composed dominantly of tree ferns (*P. cyathea*) with subdominant *N. auriculata*. Conifers occur in the roof of the coal and are common also in some mudstones not associated with the coal. Cordaitaleans dominated in one fossiliferous sandy mudstone layer whereas peltasperms are rare.

In the youngest Kozinec Horizon, a species-poor flora was collected only at a single locality (Kozinec Hill) in copper-bearing shales associated with carbonaceous mudstones and thin high-ash coal streaks (Table 1; Figs. 17, 18). The index Early Permian taxa (peltasperms) are nearly missing. Instead it contains a rather "Stephanian-like" plant assemblage including lycopsid leaves *Cyperites* sp., the pteridosperms *Sphenopteris germanica* Weiss, *Odontopteris subcrenulata* (Rost), *N. auriculata* (Brongn.) Potonié and *A. conferta* (Sternberg.) Kerp, the cordaitaleans *Cordaites* sp. and *Poa–Cordaites* sp., and the conifers *W. piniformis* Schloth. So far, the only reported occurrence of *A. conferta* is that of Petrascheck (1904) and its verification is impossible. Since that time this species has not been found at the locality and therefore it is not surprising that a Stephanian age was assigned to this horizon by Němejc (1932), Němejc, 1953. Subsequent borehole exploration and mapping of the area, however, proved its superposition above the Háje Horizon and therefore its Early Permian age (Pešek et al., 2001).

Fig. 18. *Neurodontopteris auriculata*, Krkonoše Piedmont Basin, bituminous shale, Kozinec Horizon, loc. Kozinec near Jílemnice, coll. East Bohemian Museum Hradec Králové, scale bar = 1 cm. Photo: Z. Šimůnek.

4.2.1.2.2. Palynology of the Semily and Vrchlabí Formations. Miospores of the Semily Formation are known only from the Štěpanice–Čikvásky and Ploužnice Horizons from which about 20 and 34 species respectively have been described (Table 2). Miospores from the Ploužnice Horizon (borehole Pé 1 Prosečné) and Štěpanice–Čikvásky Horizon (borehole HK 1 Horní Kalná) have similar character and predominantly represent assemblages produced by vegetation of "drier" habitats. The genera *Florinites* and *Potonieisporites* dominate in assemblages of both boreholes. "Permian" elements are represented mainly by the genera *Pityosporites* and *Vittatina*. The ecologically opposite "hygrophilous" assemblage, dominated by *Punctatosporites*, was described by Kaiserová (unpublished data) from the borehole Kv 1 (Košťálov). Interesting is the presence of the Stephanian–Autunian species *Spinosporites spinosus* (Pešek et al., 2001).

In the Vrchlabí Formation, miospores have been obtained from all the three grey lacustrine horizons. The richest assemblage was described from the Rudník Horizon where 56 genera and nearly 80 miospore species (Table 2) have been determined (Pešek et al., 2001). Assemblages differ in composition both spatially and temporarily. Most of the assemblages are dominated by monosaccate pollen of conifers and cordaitaleans, which in sediments close to lake margin are often associated with subdominant miospores produced by ferns (genera *Cyclogranisporites*, *Verrucosisporites* and *Punctatisporites*). This suggests that tree ferns locally covered areas along the lake coast. *Vesicaspora*, *Illinites* and *Kosankeisporites* represent bisaccate pollen. Spores of calamites and lycopsids were also found. Assemblages from around the town of Vrchlabí, near the northern tectonic margin, are strongly dominated by pollen grains of the genus *Potonieisporites*, especially by *Potonieisporites novicus* and *Potonieisporites bharadwai* potentially derived from elevated areas of basin slopes. The Permian genus *Vittatina* is also present but spores of ferns are nearly absent (Pešek et al., 2001). In the eastern part of the basin, Valterová (in Pešek et al., 2001) found assemblage dominated (up to 70%) by *Lycospora* spores. The taxa *Laevigatosporites medius*, *L. minimus*, *Cadiospora magna*, *Endospoeites formosus* and *Gillespieisporites discoideus* are also relatively common. This assemblage represents a "Stephanian-like" hygrophilous peat-forming vegetation that persisted in swamps located in lake shallows and/or margins from Stephanian to Permian (Pešek et al., 2001).

In the Háje Horizon, Drábková (in Pešek et al., 2001) and Šimůnek and Drábková (1997) determined 36 miospore genera and 49 species (Table 2). Monolete spores *Punctatosporites* are well represented in the Háje Coal. Assemblages from mudstones above the coal are dominated by monosaccate pollen grains and trilete spores or, in other places, by *Vittatina* which dominates over trilete and monolete spores. Besides the locally high proportion of the genus *Vittatina*, some miospore assemblages of the Háje Horizon also differ from the underlying Rudník Horizon by the presence of *Costaepollenites* and striated bisaccates of the genera *Hamiapollenites* and *Striatopodocarpites*.

The most depauperate assemblage comes from the Kozinec Horizon, which comprises only representatives of few genera, e.g., *Calamospora*, *Leiotriletes* and *Lycospora* (Pešek et al., 2001).

4.2.1.2.3. Fauna of the Semily and Vrchlabí Formations. The Carboniferous fauna of the KrPB was recently reviewed by Zajíc (2007). The Stephanian C interval (local bio/eco sub-zone *Sphaerolepis*) is represented by the Semily Formation, where only lacustrine sediments of the Štěpanice–Čikvásky and Ploužnice Horizons are fossiliferous (Table 4). In the subsequent Vrchlabí Formation (Asselian), fossil faunas are known from the Rudník and Kozinec Horizons (Table 4; Fig. 12), whereas no faunistic remains have been found in the Háje Horizon.

Table 4
Fauna of the Semily and Vrchlabí Formations of the KrPB.

Lithostratigraphy	Kozinec H.	Rudník H.	Štěpanice-Čikvásky H.	Ploužnice H.
Carbonicola bohemica				×
Anthraconaia sp.		×		
Palaeanodonta castor	×			
Myalinidae indet.		×		×
Carbonita sp.		×	×	
Limnestheria palaeoniscorum		×		
Lioestheria paupera				×
Pseudestheria tenella		×		×
*Pseudestheria*aff. *breitenbachensis*		×		
Lioestheriidae indet.			×	×
Monicarisrudnicensis		×		
Arthrolycosa sp.				×
Neorthroblattina germari				×
Neorthroblattina cf. *multineura*				×
Spiloblattina lawrenceana				×
Sysciophlebia rubida				×
Anthracoblattina sp. 1				×
Insecta indet.		×		×
Acanthodes gracilis		×		
Acanthodes sp.		×	×	×
Sphenacanthus sp.				×
Turnovichthys magnus				×
Bohemiacanthus carinatus		×		
Xenacanthif ormes indet.		×	×	×
Elonichthys krejcii			×	×
Sphaerolepis kounoviensis			×	×
Progyrolepis speciosus				×
Spinarichthys dispersus			×	
Zaborichthys fragmentalis				×
Paramblypterus rohani		×		
Paramblypterus caudatus		×		
Paramblypterus reussii		×		
Paramblypterus gelberti		×		
Paramblypterus sp.		×		
"*Amblypterus*" *lepidurus*		×		
Neslovicellaelongata		×		
"*Elonichthys*" sp.		×		
Letovichthys sp.		×		
Igornichthys sp.		×		
Actinopterygii indet.		×	×	×
Ctenodus tardus		×		
Archegosaurus dyscriton		×		
"*Ptyonius*" *bendai*		×		
?*Cheliderpeton* sp.		×		
Melanerpeton sp.		×		
*Apateon*cf. *umbrosa*		×		
Branchiosaurus sp.		×		
Branchiosauridae indet.				×
Tetrapoda indet.	×			

In the Štěpanice–Čikvásky Horizon a lacustrine fauna was collected at six dumps of abandoned small coal mines and from three boreholes. Fossil remains are represented by the ostracod *Carbonita* sp., the conchostracan Lioestheriidae indet., the acanthodians *Acanthodes* sp., teeth of xenacanthid sharks, and the actinopterygian fishes *Elonichthys krejcii*, *Sphaerolepis kounoviensis*, and *Spinarichthys dispersus*. The fauna of this facies comes from dark grey siltstones, dark grey laminated mudstones and blackish grey finely laminated mudstones with coal laminae and indicates relatively deep lake conditions. In the laterally equivalent Ploužnice Horizon the fauna of the southern part of the lake was discovered in twelve outcrops. Some of pelecypods were formerly labelled as *Carbonicola bohemica*, others are evaluated as Myalinidae indet. Similarly, some conchostracans were named *Pseudestheria tenella* and *Lioestheria paupera* in the past and others belong to Lioestheriidae indet. One spider remain was described as *Arthrolycosa* sp. by Frič (1912). Several outcrops yielded diversified entomofauna as follows: *Neorthroblattina germari*, *Neorthroblattina* cf. *Neorthroblattina multineura*, *Spiloblattina lawrenceana*, *Sysciophlebia rubida*, *Anthracoblattina* sp. 1, and other unidentifiable wing fragments. Vertebrate remains are strictly disarticulated but rather well diversified. Acanthodian (*Acanthodes* sp.) and xenacanthid (Xenacanthiformes indet.) remains are not common. Rare shark remains belong to hybodonts (scales of *Sphenacanthus* sp.) and ctenacanths (fin spine of *Turnovichthys magnus*). Among actinopterygian fishes, several taxa were identified including *Progyrolepis speciosus*, *Sphaerolepis kounoviensis*, *Zaborichthys fragmentalis*, and *Elonichthys krejcii*. Some poorly preserved amphibian remains (Branchiosauridae indet.) were also found. Fauna and fossiliferous sediments of this facies indicate shallow lake conditions with relatively well-aerated water near the bottom (an epilimnion of a stratified lake).

The Permian fauna of the Rudník Horizon in the Vrchlabí Formation represents the local bio/ecozone *A. gracilis*, which is particularly characterised by the nominal taxon and by the xenacanthid shark *Bohemiacanthus carinatus*. Pelecypods are nowadays identified as *Anthraconaia* sp. or Myalinidae indet. Ostracod carapaces of *Carbonita* sp. are common. Conchostracans often occur on a massive scale and encompass the taxa *Limnestheria palaeoniscorum*, *Pseudestheria tenella*, and *Pseudestheria* aff. *Pseudestheria breitenbachensis*. The syncarid *Monicaris rudnicensis* was described only from the Rudník Horizon. Insect wing fragments are rare. Acanthodians (*A. gracilis* and *Acanthodes* sp.) are common or abundant in some layers. Sharks are restricted to the xenacanth *B. carinatus* and unidentifiable remains of Xenacanthiformes indet. The number of actinopterygian taxa has increased recently. The present list includes *Paramblypterus rohani*, *Paramblypterus caudatus*, *Paramblypterus reussii*, *Paramblypterus gelberti*, *Paramblypterus* sp., "*Amblypterus*" *lepidurus*, *Neslovicella elongata* (described by Štamberg, 2010a), *Elonichthys* sp., *Letovichthys* sp., and *Igornichthys* sp. One dipnoan specimen is classified as *Ctenodus tardus*. Amphibian remains have been described as *Archegosaurus dyscriton*, an indeterminate juvenile eryopoid "*Ptyonius*" *bendai*, ?*Cheliderpeton* sp. (poorly preserved specimen, probably not this genus) and *Melanerpeton* sp. K. Other mentioned specimens labelled as *Melanerpeton* sp., *Apateon* cf. *Apateon umbrosa*, *Branchiosaurus* sp. remain unrevised.

In the upper part of the Vrchlabí Formation, rare fauna have been found in siltstones and sandstones from the old copper mines in the Kozinec Horizon. Siltstones provided pelecypods described as *Palaeanodonta castor* and from sandstones a single tetrapod rib fragment has been found (Fig. 9D) but not described yet. No stratigraphically important taxa were discovered that can shed light on the age of the Upper Vrchlabí Formation.

4.2.1.3. Climatic record in the Semily and Vrchlabí Formations. Climatic indicators recorded in the Late Pennsylvanian and Early Permian strata of the KrPB are in good agreement with those of the Líně Formation in the CWBB. The basic lithological pattern of the Semily and Vrchlabí Formations is comparable and is characterised by cyclic alternation of red mudstones with red to pinkish sandstones and subordinate conglomerates. Most of these red beds are of fluvial origin (including temporary floodplain lakes) and indicate a basinward transition from high and bedload dominated (?braided) rivers to lower energy mixed load (?meandering) fluvial styles. Floodplain strata are characterised by an absence of coal. Instead, red vertisols often with pedogenic carbonates can be present (Pešek and Skoček, 1999; Skoček, 1993) and fluvial sandstones are often carbonate (calcite < dolomite) cemented. This suggests existence of strongly seasonal climate, which is in agreement with the character and distribution of the plant fossils (Driese and Ober, 2005). Overall rareness of identifiable plant remains in red mudstones or their preservation as impressions suggest oxidative conditions due to low or fluctuating ground water table resulting in fast decomposition of plant remains and overall poor potential for their fossilisation (Gastaldo and Demko, 2010). Common presence of silicified trunks in sandstones further supports the interpretation of a seasonally dry climate during the deposition of the Semily and Vrchlabí Formations (Matysová et al., 2008, 2010; Mencl et al., 2009; Skoček, 1970). However, as in the case of the Líně Formation in the CWBB, the deposition of equivalent strata in the KrPB took place under seasonally rather than uniformly "dry" climate. Alternation of fluvial red beds with widespread and thick horizons of variegated to grey lacustrine sediments (e.g., laminated mudstones, bituminous shales, limestones, cherts and coal) is mostly explained as a consequence of temporarily increased climatic humidity (Martínek et al., 2006), although a parallel explanation of increased tectonic subsidence producing more accommodation and hence resulting in lake formation also exists. However, imprints of evaporite crystals, pseudomorphs of dolomite after anhydrite and dolomite cement in offshore mudstones of most of the lacustrine succession of the Ploužnice Lake indicate increased evaporation resulting in high salinity and hence the existence of hydrologically closed lakes during these semi-arid periods (Martínek et al., 2006). This suggests a climatic origin for lake level fluctuations. Frequent vertical alternation of nearshore and offshore facies in southern parts of the depocentre probably indicates a low bottom gradient where even small relative lake level changes resulted in a significant shift of the shoreline. Frequent shifts of the shoreline along the southern margin of the Ploužnice Lake probably prevented this area from supporting long-lasting peat accretion, resulting in the absence of coals.

In the even larger Rudník Lake, climatically driven lake-level oscillations are indicated not only by the presence of transgressive–regressive cycles but also by changes in concentration of boron and values of the hydrogen index in lacustrine mudstones and by the isotopic composition of $\delta^{18}O$ and $\delta^{13}C$ in lacustrine carbonates and organic matter (Martínek et al., 2006). These values suggest that lake level fluctuations were driven by changes in precipitation/evaporation ratio related to climatic oscillations between semi-arid and sub-humid climate, the former corresponding to the period of lake level rise and lake highstand and the latter to lake level drop and lowstand. High concentrations of boron in lowstand sediments suggest increased salinity of the lake during this period and the potential existence of a hydrologically closed lake system. Agreement between rise of TOC and HI recorded in anoxic facies suggests increased lake bioproductivity during high lake level. Low values of $\delta^{18}O$ in carbonates marking the onset of anoxic deposition suggest that lake level rise was accompanied by increase in humidity (Martínek et al., 2006). Subsequent oscillations of the isotopic values are indicative of climatically driven lake level changes. In all, several orders of climatic cyclicity are recorded in the Rudník lake sediments. The presence of transgressive–regressive cycles several metres to tens of metres thick probably represent periods of tens to possibly 100 kyr (Martínek et al., 2006). Changes in salinity between highstands and lowstands indicated by boron content are best explained by alternation between humid and more arid climatic conditions respectively. Variations in bioproductivity on the order of hundreds of years to 1000 years are recorded by stable isotopes and organic matter geochemistry and are possibly also climatically driven. The seasonal lamination represents the highest frequency climatic record of the Rudník Lake (Martínek et al., 2006).

4.2.2. Intra-Sudetic Basin (ISB)

The ISB, located along the Czech–Polish border, has the longest sedimentary history of all the continental basins of the Bohemian Massif. Basin fill up to 5 km thick spans the interval from the middle of Viséan to the Triassic and includes several hiatuses (Fig. 2). The Czech part of the basin fill, which lacks the oldest strata, is divided into eight formations of which the Chvaleč Formation spans the Carboniferous–Permian boundary and is described in detail.

4.2.2.1. Lithology and sedimentary environments of the Chvaleč Formation. The Chvaleč Formation (late Gzhelian–early Asselian) is a between 100 and 500 m thick complex of dominantly fluvial red beds that is divided into the Vernéřovice and overlying the Bečkov members (Fig. 5). The Vernéřovice Member is usually 50 to about 140 m thick, composed of 50 to 70% of mudstones. The succession, however, starts with an about 30 m thick sequence of basal conglomerates containing large pebbles up to >10 cm in diameter, subordinate sandstone and only thin siltstones intercalations. Conglomerates and sandstones are cemented by carbonate, which is mostly calcite. Overlying the basal conglomerate is a 20 to 40 m thick sequence of red-brown mudstones locally with carbonate (calcite > dolomite) nodules, occasionally coalescing into a continuous limestone bed (Tásler et al., 1979). Following this interval is about 10 m of thick conglomerates with sandstone intercalations strongly cemented by calcite and locally containing anhydrite. Just above and below the conglomerate there are about 0.5 to 1 m thick green-grey massive mudstones with (?)pedogenic carbonate concretions and disseminated copper-bearing minerals bornite and chalcosine. The upper half of the Vernéřovice Member is dominated by red-brown mudstones except the uppermost 10 to 15 m, which is composed of variegated to even grey mudstones with thin sandstones intercalations. This part of the succession comprises the Vernéřovice Horizon. The most apparent lithology is a 0.5 to 1 m thick, laterally widespread bed of grey limestone with chert nodules. It is sandwiched in bituminous mudstones containing fish scales. Present also is a bed of argilised and partly re-deposited volcaniclastics. Locally the limestone passes into the about 0.5–0.8 m thick Rybníček Coal (formerly Walchia Coal, Herbing 1904) whereas accompanying bituminous mudstones grade into grey ones. The coal contains uranium mineralisation (Tásler et al., 1979).

Deposition of the Vernéřovice Member started after the basin-wide Intra-Stephanian hiatus on a braid plain dominated by bed load transport and deposition that alternated with a well-drained alluvial plain occupied by a low energy fluvial system depositing mixed and/or suspended load and with local temporary lakes on the floodplain. Sediments of the Vernéřovice Horizon were deposited in a shallow lake with local lake margin peat swamps.

The upper part of the Chvaleč Formation consists of the Bečkov Member, which is an about 50 to 220 m thick succession of fluvial to lacustrine strata dominantly composed of red to purple mudstones with subordinate sandstones and conglomerates (Fig. 5). An approximately 80 m thick complex at the base of the member is, however, fairly rich in conglomerates and sandstones cemented by calcite. They alternate with mudstones up to few metres thick that locally contain carbonate nodules. The remaining up to 140 m thick part of the member is dominated by red mudstones locally containing anhydrite. Mudstones are either laminated or massive with pedogenic carbonate nodules (Tásler et al., 1979). Laminated mudstones might be bioturbated and preserve rare impressions of walchian shoots. Grey to variegated mudstones with limestones are concentrated into the about 50 m thick the Bečkov Horizon in the upper part of the member. This horizon consists of three cycles starting with sandstones (and locally even conglomerates) passing up into grey to dark bituminous mudstones containing limestone beds a few decimetres thick, occasionally with reddish chert intercalations (Tásler et al., 1979).

Sediments of the Bečkov Member were deposited on a broad alluvial plain alternatively occupied by bed load and mixed/suspended load dominated fluvial systems, depending on intensity of tectonic activity (Tásler et al., 1979) and possibly on climatic oscillations. The Bečkov Horizon in the upper part of the member represents a set of three transgressive–regressive lacustrine cycles. Cyclic pattern suggests significant lake level oscillations resulting in temporary lake drying.

4.2.2.2. Fossil records of the Chvaleč Formation. The fossil record of the Chvaleč Formation is relatively poor compared to the stratigraphically equivalent strata in the KrPB and CWBB. It is concentrated in the grey lacustrine horizons.

4.2.2.2.1. Flora of the Chvaleč Formation. Except for very rare, scattered impressions of walchian conifers in red mudstones (Tásler et al., 1979) all the plant remains of the Chvaleč Formation have been found only in grey mudstones accompanying the Rybníček Coal, especially its roof, in the upper part of the Vernéřovice Member (Table 1). The following species have been found. Sphenopsids: *A. stellata* (Schlotheim) Wood, *Calamostachys tuberculata* (Sternberg) Unger, *Macrostachya carinata* (Germar), *Sphenophyllum* cf. *oblongifolium* Germar and Kaulfus (Unger); Ferns: *Pecopteris* cf. *arborescens* (Schlotheim); Pteridosperms: *Dicksonites pluckenetii* (Schlotheim) Sterzel, *A. zeilleri* (Ragot) Wagner, *O. brardii* Brongniart, *N. auriculata* (Brongniart) Potonié, *Autunia naumannii* (Gutbier) Kerp and *Dichophyllum flabelliferum* (Weiss) Kerp and Haubold; and conifers *Walchia* sp. Tásler et al. (1979) mentioned finding in a borehole a single specimen of *Odontopteris schlotheimii*, which is considered to be indicative of the late Stephanian. The occurrence of two peltasperms (*A. naumannii* and *Dichophyllum flabelliferum*) within an assemblage of otherwise late "Stephanian" species is not considered unusual and is not a reason to put the Vernéřovice Horizon into the Autunian. The assemblage of the Rybníček Coal is considered to be late "Stephanian C" age. This interpretation is in agreement with presence of peltasperms in the stratotype of the Stephanian in Massif Central (e.g., Bourouz and Doubinger, 1977; Kerp, 1988).

4.2.2.2.2. Palynology of the Chvaleč Formation. About 45 miospore species of 28 genera (Table 2) were obtained from grey mudstones of the Vernéřovice Horizon (Pešek et al., 2001). The most common were species already known from underlying early Gzhelian (Stephanian B) sediments, e.g., *Verrucosisporites sinensis*, *Cyclogranisporites jelenicensis*, *C. densus*, *Endosporites globiformis* and *Cadiospora magna* and various species of genera *Punctatosporites*, *Thymospora and Potonieisporites*, *Florinites* or *Lycospora* etc. Typical for "Autunian" is the presence of the genus *Aumancisporites*.

4.2.2.2.3. Fauna of the Chvaleč Formation. Rare faunas of the Chvaleč Formation are known both from the Vernéřovice and Bečkov Members (Table 5). Two known localities in the Vernéřovice Member yielded the ostracod *Carbonita* sp., conchostracans of the family Lioestheriidae (described as *Limnestheria palaeoniscorum*), acanthodian remains *Acanthodes* sp. and stratigraphically important scales of the actinopterygian fish *Sphaerolepis kounoviensis*. Further actinopterygian scales were mentioned in drill core documentations of two boreholes but these remains are not accessible and cannot be revised. Based on presence of scales of *Sphaerolepis kounoviensis* this unit is assigned to the local bio/ecozone *Sphaerolepis–Elonichthys* of the Stephanian B–C age. Fauna of the following Bečkov Member is poor and supposed age (Lower Rotliegend) is not validated by animal remains. Only pelecypods Myalinidae indet were discovered in one borehole.

4.2.2.3. Climatic record in the Chvaleč Formation. Sediments of the Chvaleč Formation display similar sedimentary patterns and stratigraphically equivalent units to rocks of the KrPB and CWBB. Strongly seasonally dry climate prevailed during deposition of these rocks, indicated by fluvial red beds with sandstones and conglomerates cemented by calcite and subordinate dolomite, local presence of anhydrite and vertic palaeosols with carbonate nodules. This is in agreement with the very rare occurrence of poorly preserved impressions of conifer shoots. Climatic oscillations are, however, indicated by the presence of variegated to grey lacustrine horizons, some composed of several transgressive–regressive cycles. Late Stephanian lacustrine horizons typically include thin coals, indicative of coastal peat swamps, whereas "Autunian" (Lower Rotliegend) lakes lacked peat swamps and the coals that formed from them.

Table 5
Fauna of the Vernéřovice and Bečkov members of the Chvaleč Formation in the Intra-Sudetic Basin.

Lithostratigraphy	Myalinidae indet.	*Carbonita* sp.	*Limnestheria palaeoniscorum*	*Acanthodes* sp.	*Sphaerolepis kounoviensis*	Actinopterygii indet.
Bečkov M.	x					
Vernéřovice M.		x	x	x	x	x

4.3. Grabens

South of the main basin complex are two NNE–SSW striking narrow basins of half-graben geometry with a prominent fault along the eastern margin (Fig. 1). These are called the Boskovice and the Blanice Basins (or grabens). The former represents nearly a continuous basin structure whereas the Blanice Basin consists of several relicts following the main fault.

4.3.1. Boskovice Basin (BB)

The Boskovice Basin is nearly a hundred kilometre long and 3–10 km wide half-graben that covers an area about 500 km^2. It consists of two depocentres with partly different ranges of deposition. In the south is the Rosice–Oslavany depocentre, which is filled by "Stephanian C"–"Autunian" sediments. In the Letovice depocentre further north, deposition started in the "Autunian" and lasted probably till the early "Saxonian". Up to 3000 m of basin fill is estimated from seismic sections and is divided into four formations (Pešek, 2004). The two oldest formations, the Rosice–Oslavany and Padochov span the interval around the Carboniferous–Permian boundary and are discussed here in detail (Fig. 2).

4.3.1.1. Lithology and sedimentary environments of the Rosice–Oslavany and Padochov Formations. The Rosice–Oslavany Formation, about 300 m thick, is of "Stephanian C" age based on floristic content (Pešek et al., 2001). In the lower part, above the basal Balín Conglomerate, red-brown sandstones alternate with mudstones (Fig. 5). In the upper part of the formation, mudstones are predominantly grey to variegate. In this part of the formation, three economically important coals are present, which together constitute the Rosice–Oslavany group of coals. Coals are numbered from top to bottom as Nos. I, II and III and attain thicknesses of 1.5–6.5 m, 0.8–2.4 m and 0.8–1.4 m respectively. Near the top of the formation is the Helmhacker Horizon. Lateral equivalent to the whole formation, along the tectonically active eastern basin margin, is the coarse-grained Rokytná Conglomerate (Fig. 5).

Deposition of the Rosice–Oslavany Formation took place along the tectonically active eastern basin margin in the southern part of the basin. It started on a braid plain with deposition of the Balín

Conglomerate. After the filling of depressions in pre-sedimentary palaeotopography the braid plain gradually changed into an alluvial plain dominated by a low energy fluvial system and small floodplain lakes. Periods of increased humidity/subsidence resulted in formation of long-lasting peat swamps. The Rokytná Conglomerate represents alluvial fan deposits accumulated along the fault following the eastern margin of the depocentre.

The Padochov Formation, which is about 1200 m thick, lies immediately above Rosice–Oslavany Formation (Fig. 5). The lower part, about 50 m thick, is a red beds succession composed of alternating sandstones, mudstones and claystones. Above this, about 60 m thick, is a succession of mudstones that become grey and contain a 3 to 4 m thick horizon of bituminous carbonates known as the Zbýšov Horizon. The remaining 1000 m thick part of the formation is characterised by monotonous alternation of red and locally feldspathic sandstones and mudstones. Another but much less prominent grey horizon with grey carbonates is the Říčany Horizon situated about 900 m above the Zbýšov Horizon.

Deposition of the Padochov Formation continued without an interruption from the Rosice–Oslavany Formation, under intensive subsidence along the eastern basin margin bordered by large alluvial fans. The higher subsidence rate favoured formation of a low energy alluvial plain that passed eastward into lakes, the extent of which varied depending on climate and/or subsidence from small temporary floodplain lakes to larger perennial lakes, the deposits of which represent grey horizons.

4.3.1.2. Fossil record of the Rosice–Oslavany and Padochov Formations. Similar to other basins of the Bohemian Massif, fossils are dominantly concentrated in variegated to grey, mostly lacustrine horizons whereas in the accompanying red beds strata are rare, scattered and poorly preserved (Table 1).

4.3.1.2.1. Flora of the Rosice–Oslavany and Padochov Formations. The oldest plant fossils of the Rosice–Oslavany Formation occur in grey to variegated mudstones accompanying the Rosice–Oslavany group of coals situated just below the Carboniferous–Permian boundary (Table 1; Fig. 19). Plant remains of older coals (No. II and III), which occur mostly in roof shales, are dominated by tree ferns (pecopterids) with co-dominant calamites, whereas pteridosperms (except for a few species) are relatively rare. The plant association represents a sub-autochthonous, relatively hygrophilous assemblage characterised by *S. brardii* Sternberg, *Calamites cistii* Brongniart, *Calamites multiramis* Weiss = *Calamites rittleri* Stur, *Annularia sphenophylloides* Zenker, *A. stellata* (Schlotheim) Wood, *A. equisetiformis* (Schlotheim), *Asterophyllites longifolius* Sternberg, *Sphenophyllum angustifolium* (Germar), *Sphenophyllum oblongifolium* (Germar and Kaulfus) Unger, *Sphenopteris dechenii* Weiss, *Sphenopteris mathetii* Zeiller, *Dicksoniites plukenetii* (Schlotheim) Sterzel, *Pseudomariopteris busquetii* (Zeiller) Danzé-Corsin, *Nemejcopteris feminaeformis* (Schlotheim) Barthel, *P. arborescens* (Schlotheim), *Pecopteris candolleana* Brongniart, *Pecopteris cyathea* (Schlotheim), *Pecopteris densifolia* (Goeppert), *Pecopteris hemitelioides* Brongniart, *Pecopteris plumosa* (Artis) Brongniart, *Pecopteris polymorpha* Brongniart, *Pecopteris unita* Brongniart, *A. zeilleri* (Ragot) Wagner, *Alethopteris moravica* Augusta, *Odontopteris schlotheimii* Brongniart, *Odontopteris subcrenulata* (Rost), *O. brardii* Brongn., *Odontopteris minor* Brongn., *N. auriculata* (Brongniart) Potonié, *Neurocallipteris neuropteroides* (Goeppert) Cleal, Shute and Zodrow, *Neuropteris cordata* Brongniart, *B. germarii* (Giebel) Cleal and Zodrow, *Taeniopteris jejunata* Gr.'Eury, *Cordaites* cf. *palmaeformis* (Goeppert) Weiss, *Cordaites* cf. *principalis* (Germar) Geinitz. The flora of these two coals indicates that they correspond to the *Sphenophyllum angustifolium* biozone (Wagner, 1984).

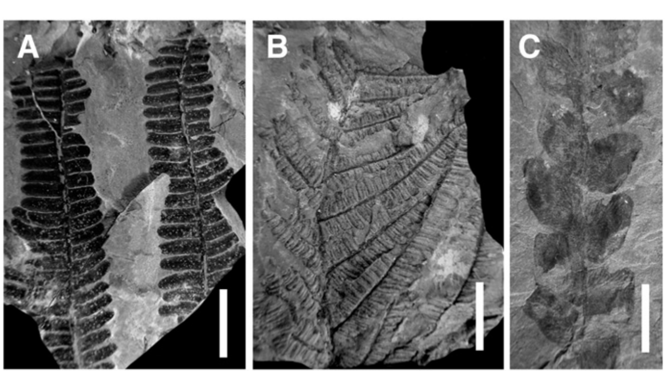

Fig. 19. Flora of the Oslavany group of coals (Oslavany Formation) from the Oslavany section, Boskovice Basin. A — *Pecopteris cyathea*, mudstone parting in the No. 1 Coal. B — *Pecopteris cyathea*, mudstone parting in the No. 1 Coal. C — *Odontopteris schlotheimii*, roof of the No. 1 Coal. Scale bars 1 cm. All photos: Z. Šimůnek.

Floristic change was identified in the roof-shale of coal No. I, which has produced a diverse pteridosperm assemblage including five "callipterid" species (Augusta, 1937; Katzer, 1895; Němejc, 1951; Rieger, 1965; Šetlík, 1951). Tree ferns are subordinate. This assemblage is also rich in walchian conifers and cordaitaleans are fairly common. Remy and Havlena (1960, 1962) considered "*Callipteris*" as an index Permian genus; nevertheless some other pteridosperms (e.g., *Odontopteris schlotheimii* Brongniart) indicate a Stephanian age (Rieger, 1965) for this coal. The presence of callipterids does not contradict a Stephanian age because also Bourouz and Doubinger (1977) found "callipterids" in the Stephanian stratotype.

Additional plant species appear higher up in sandy mudstone or muddy sandstone above coal No. I (Table 1). These are mainly "callipterids" like *A. conferta* (Sternberg) Kerp, *A. naumannii* (Gutbier) Kerp, *Dichophyllum flabelliferum* (Weiss) Kerp and Haubold, *Lodevia nicklesii* (Zeiller) Haubold and Kerp and "*Callipteris*" *zbejsovensis* Augusta and some other pteridosperms, e.g., *Sphenopteris germanica* Weiss. Also common are the conifers *Culmitzschia speciosa* (Florin) Clement-Westerhof, *Ernestiodendron filiciforme* (Schlotheim) Florin, *Walchia goeppertiana* (Florin) Clement-Westerhof and *Walchia piniformis* Schlotheim ex Sternberg. All these floral elements are allochthonous, derived either from clastic wetlands or uplands.

In the Helmhacker's Horizon, situated about 20 m above coal No. I, the flora is rather poor and consists predominantly of allochthonous elements: *Sphenopteris germanica* Weiss, *Odontopteris schlotheimii* Brongniart, *A. conferta* (Sternb.) Kerp, *A. naumannii* (Gutbier) Kerp, *Dichophyllum flabelliferum* (Weiss) Kerp and Haubold, *Ernestiodendron filiciforme* (Schloth.) Florin and *Walchia* sp. The last appearance datum of *Odontopteris schlotheimii* Brongniart in this horizon led Rieger (1965) to put the Carboniferous–Permian boundary at the top of the Helmhacker's Horizon. Together with coal No. I the flora of the Helmhacker's Horizon is assigned to the *A. conferta* biozone (Wagner, 1984).

In the Padochov Formation, plant remains are concentrated into the Zbýšov and Říčany Horizons (Table 1; Figs. 20, 21, 22). Their flora is pteridosperm-conifer dominated (Šimůnek and Martínek, 2009). The Zbýšov (1st Bituminous) Horizon is situated about 300 m above coal No. I (Havlena, 1964) and already contains a typically "Autunian" (Asselian) flora with seven "*Callipteris*" species. The assemblage is characterised by the following species: *Calamites gigas* Brongniart, *A. sphenophylloides* Zenker, *Annularia spicata* (Gutbier), *A. stellata* (Schlotheim) Wood, *Asterophyllites dumasii* Zeiller, *Sphenopteris germanica* Weiss, *P. arborescens* (Schloth.), *Pecopteris cyathea* (Schloth.), *Remia pinnatifida* (Gutb.) Knight, *Alethopteris schneideri* (Sterzel) Sterzel, *Odontopteris subcrenulata* (Rost), *Odontopteris* cf. *lingulata* (Goeppert) Schimp., *N. auriculata* (Brongniart) Potonié, *B. germarii* (Giebel) Cleal and Zodrow, *A. scheibei* (Gothan) Haubold and Kerp, *A. conferta* (Sternberg) Kerp, *A. naumannii* (Gutbier) Kerp, *Dichophyllum flabellifera* (Weiss) Kerp and Haubold, *Lodevia nicklesii* (Zeiller) Haubold and Kerp, *Rhachiphyllum curretiensis* (Zeiller) Kerp, *Rhachiphyllum lyratifolia* (Goeppert) Kerp, "*Callipteris*"

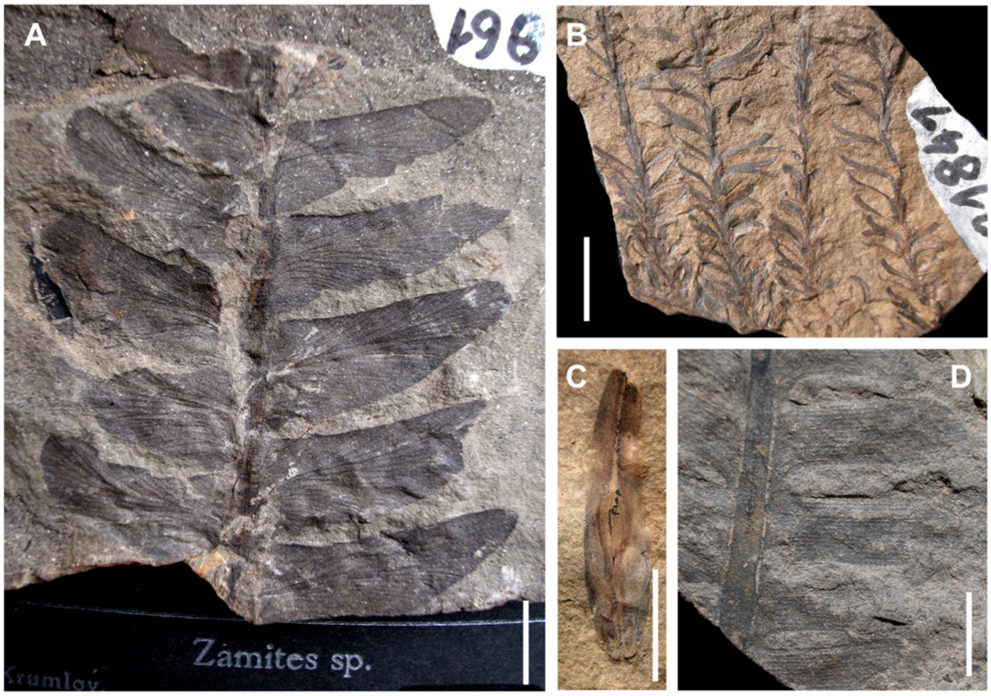

Fig. 20. Flora from the Zbýšov Horizon of the Padochov Formation, Boskovice Basin. A — *Zamites* sp., loc. Moravský Krumlov (No. 21961). B — *Carpentieria marocana*, loc. Moravský Krumlov, Augusta and Němejc orig. (No. 21841). C — *Samaropsis helmhackeri*, loc. Moravský Krumlov (No. 21904). D — *Pterophyllum* sp. loc. Moravský Krumlov (No. 21942). Collection of the Moravian Museum Brno, specimen numbers indicated. Scale bars 1 cm. All photos: Z. Šimůnek.

zbejsovensis Augusta, *T. abnormis* Gutbier, *Cordaites* cf. *principalis* (Germar) Geinitz, *Dicranophyllum gallicum* Grand'Eury, *Culmitzschia speciosa* (Florin) Clement-Westerhof, *Ernestiodendron filiciforme* (Schlotheim) Florin, *Otovicia hypnoides* (Brongniart) Kerp, *Walchia goeppertiana* (Florin) Clement-Westerhof, *Walchia piniformis* schlotheim ex Sternberg, *Carpentieria marocana* Němejc and Augusta and some “exotic” elements — cycads: *Pterophyllum* sp. and *Zamites* sp. (Fig. 21).

The overlying Říčany Horizon appears to be an impoverished version of the Zbýšov Horizon. Although all the major lineages are present, some species of calamites, annularias, pteridosperms, “callipterids” and conifers are missing. The Říčany Horizon flora is known by the dominance of conifers (Table 1). The following plant groups and species have been reported: *Calamites gigas* Brongniart, *A. stellata* (Schlotheim) Wood, *Sphenopteris germanica* Weiss, *P. arborescens* (Schlotheim), *Pecopteris cyathea* (Schlotheim), *Remia pinnatifida* (Gutbier) Knight, *Odontopteris subcrenulata* Rost, *Neurocallipteris neuropteroides* (Goeppert) Cleal, Shute and Zodrow, *A. conferta* (Sternberg) Kerp, *A. naumannii* (Gutbier) Kerp, *Rhachiphyllum lyratifolia* (Goeppert) Kerp, *T. abnormis* Gutbier, *Cordaites* cf. *principalis* (Germar) Geinitz, *Culmitzschia speciosa* (Florin) Clement-Westerhof, *Ernestiodendron filiciforme* (Schlotheim) Florin, *Walchia goeppertiana* (Florin) Clement-Westerhof and *Walchia piniformis* Schlotheim ex Sternberg. This assemblage is of Asselian age.

4.3.1.2.2. Palynology of the Padochov Formation. High coal rank of the Rosice–Oslavany coal group excludes preservation of spores. Within the study units, spores have been gathered only from the Říčany Horizon in the upper part of the Padochov Formation. In the lower part of the Říčany Horizon spores from the triletes group prevail (Zajíc et al., 1996). The most common are *Crassispora plicata* and *C.* sp. *Lycospora pusilla* is frequent. *Leiotriletes minimus*, *L. sphaerotriangulus*, *Reistrickia saetosa* and *Calamospora breviradiata* are present. The monoletes group is represented by *Spinosporites spinosus* and *Latosporites latus*. This assemblage is strongly impoverished and “Stephanian-like”. Monosaccate genera (82%) dominate in the upper part of the Říčany Horizon: *Potoniesporites* (*P. novicus* and *P. bhardwaji*) and *Florinites* (*F. minutes*). The following species are present: *Illinites unicus*, *Gardanaisporites heiselii*, *G.* sp., *Alisporites* sp., striate *Protohaploxipinus samoilovichii* and other non-determined bisaccate forms (8%). The trilete spores are represented by *Crassispora* sp., *Leiotriletes minutus* and *Calamospora* sp.; the group of monoletes is represented by *Laevigatosporites minutus* and *L. medius*. These strongly impoverished “Autunian” miospore assemblages represent floras of the different habitats ranging from wetland to seasonally dry with soil moisture deficits. It provides evidence of temporal and spatial coexistence of “Stephanian” and “Permian” floras as in the case of other continental basins of the Bohemian Massif.

4.3.1.2.3. Fauna of the Rosice–Oslavany and Padochov Formations. Faunistic remains in these units are restricted to “grey” horizons (Table 6). Only sporadic fauna have been found in the Rosice–Oslavany Formation in mudstones accompanying coals. The fauna includes identifiable insect wings (*Anthracoblattina* sp. 3) and unidentifiable wing fragments. Vertebrates are represented by actinopterygian scales, *Elonichthys krejcii*, and Actinopterygii indet. and by small remain of the pelycosaur reptile ?*Edaphosaurus* sp. Scales of *Elonichthys krejcii* indicate the local bio/ecozone *Sphaerolepis–Elonichthys* and consequently Stephanian B–C age.

Fauna of the Zbýšov and Říčany Horizons in the Padochov Formation fall into the local bio/ecozone *A. gracilis* (Lower Rotliegend) and is equivalent to that of the Rudník Horizon in the Krkonoše Piedmont Basin. The fauna of the Zbýšov Horizon includes pelecypods, described as *Carbonicola thuringensis*, *Carbonicola remesi*, *Palaeanodonta sophiae*, *Palaeanodonta compressa*, *Palaeanodonta* cf. *Palaeanodonta compressa*, *Palaeanodonta verneuili* and *Palaeanodonta castor*. Conchostracans probably belong to the family Lioestheriidae. The entomofauna is rather diversified and includes *Moraviptera reticulata*, *Opsiomylacris* cf. *Opsiomylacris procera* (Fig. 23), *Phyloblatta flabellata*, *Phyloblatta moravica*, *Phyloblatta* sp. 1, *Kashmiroblatta* sp. 1, *Blattinopsis* (*Blattinopsis*) *antoniana*, and *Permoedischia moravica*. Acanthodians are represented by *A. gracilis* and *Acanthodes* sp. *B. carinatus*, *Xenacanthus* sp., and Xenacanthiformes indet. were recognised among xenacanthid sharks. Actinopterygian fishes can be identified only as Actinopterygii

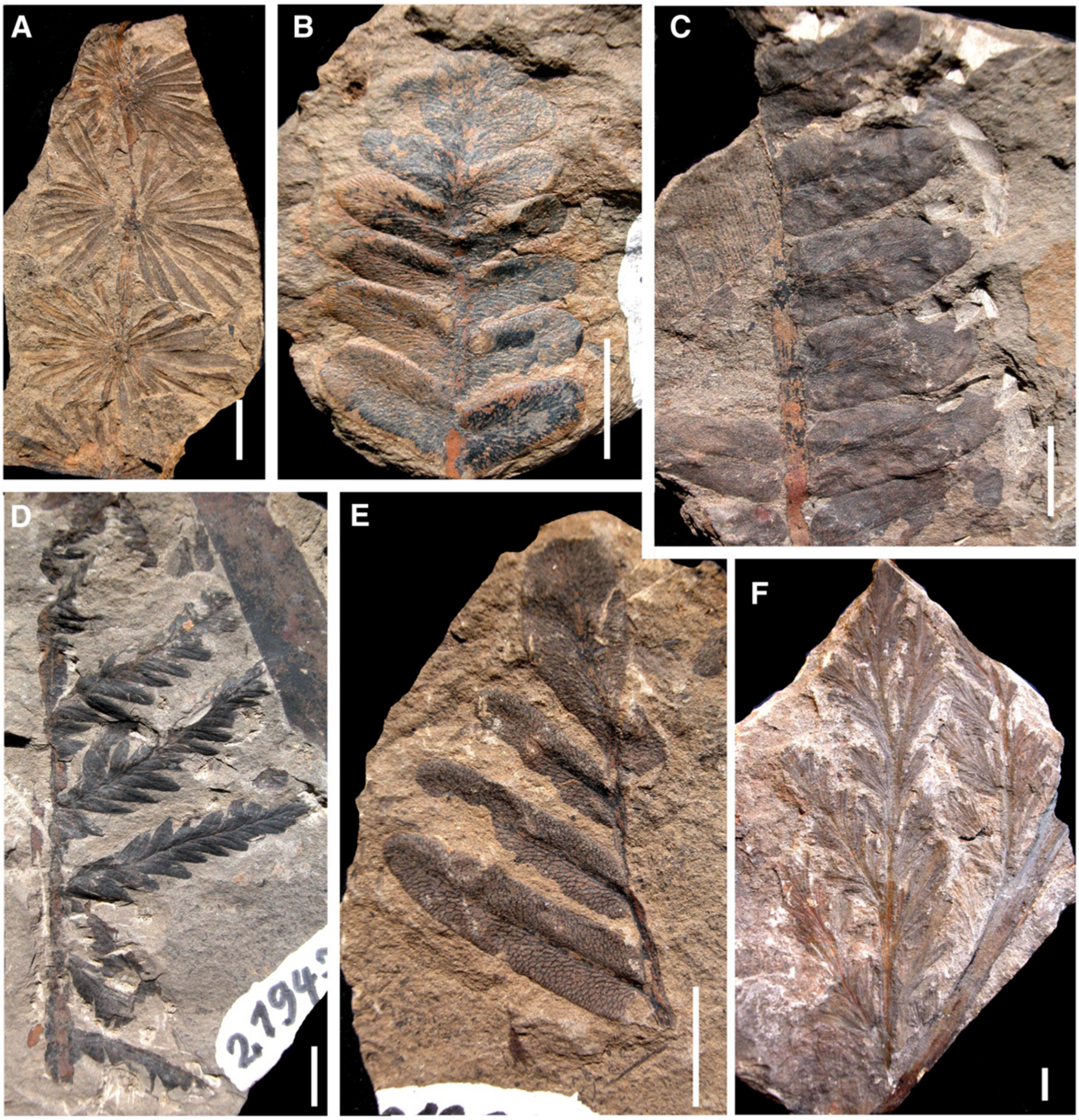

Fig. 21. Flora from the Zbýšov Horizon of the Padochov Formation, Boskovice Basin. A — *Annularia stellata*, loc. Moravský Krumlov (No. 21901). B — *Neurocallipteris neuropteroides*, loc. Moravský Krumlov (No. 21940). C — *Neurocallipteris planchardii*, loc. Moravský Krumlov (No. 21932). D — *Autunia conferta*, loc. Moravský Krumlov (No. 21947). E — *Barthelopteris germarii*, loc. Moravský Krumlov (No. 21935). F — *Lodevia nicklesii*, loc. Zbýšov (No. 2042). Collection of the Moravian Museum Brno, specimen numbers indicated. Scale bars 1 cm. All photos: Z. Šimůnek.

indet. Amphibians have been described as *Moraverpeton remesi*, ?*Branchiosaurus* sp., and ?*Pelosaurus* sp.

The fauna of the Říčany Horizon was discovered in four outcrops and is generally similar to that of the Zbýšov Horizon. No pelecypods have been found yet but conchostracans, assignable to Lioestheriidae indet., were detected. The remarkably diversified entomofauna is represented by *Moravamylacris ricanyensis*, *Phyloblatta flabelata*, *Phyloblatta* cf. *Phyloblatta curvata*, *Phyloblatta dyadica*, *Phyloblatta* cf. *curvata*, *Spiloblattina weissigensis*, *Poroblattina rotundata*, *Blattinopsis* (*Blattinopsis*) *angustai*, *Blattinopsis* (*Blattinopsis*) *latissima*, *Blattinopsis* (*Blattinopsis*) *campestris*, *Blattinopsis* (*Blattinopsis*) *martynovae*, *B.* (*Blattinopsis*) cf. *martynovae*, *Blattinopsis* sp., and *Pseudomerope gallei*. Vertebrates are divided into acanthodians *Acanthodes* sp. and actinopterygians *Neslovicella rzehaki* and Actinopterygii indet.

4.3.1.3. Climatic indicators of the Rosice–Oslavany and Padochov Formations. Climatic interpretations of the succession around the Carboniferous–Permian transition in the Boskovice Basin, is basically similar to those in other basins discussed earlier in this paper. Coals of the Rosice–Oslavany group are considered to represent wet sub-humid climate, which is consistent with presence of coals in other basins at similar stratigraphic level. Increasing humidity is also assumed for deposition of grey to variegated lacustrine horizons. Red beds succession between coals and lacustrine horizons are believed to represent periods of drier climate. The first excursion to such conditions starts just after deposition of the youngest coal (No. I).

4.3.2. Blanice Basin

The Blanice Basin is a complex of about six isolated relicts of Late Pennsylvanian and Permian strata striking in a NNE–SSW direction over a hundred-kilometre long tectonically bounded zone. Thickness of sedimentary successions of particular relicts varies between tens of metres to >800 m. Whether these relicts represent former isolated depocentres or are only erosional remnants of a once larger continuous narrow depocentre comparable to the Boskovice Basin has not been proven and both opinions exist (e.g., Pešek et al., 2001). Similarly to the Boskovice basin, the sedimentary fill of the Blanice Basin also spans the interval from the “Stephanian C” (late Gzhelian) to the “Autunian” and hence records a continuous transition from the Pennsylvanian to Permian (Fig. 2). The basin fill consists of two formations

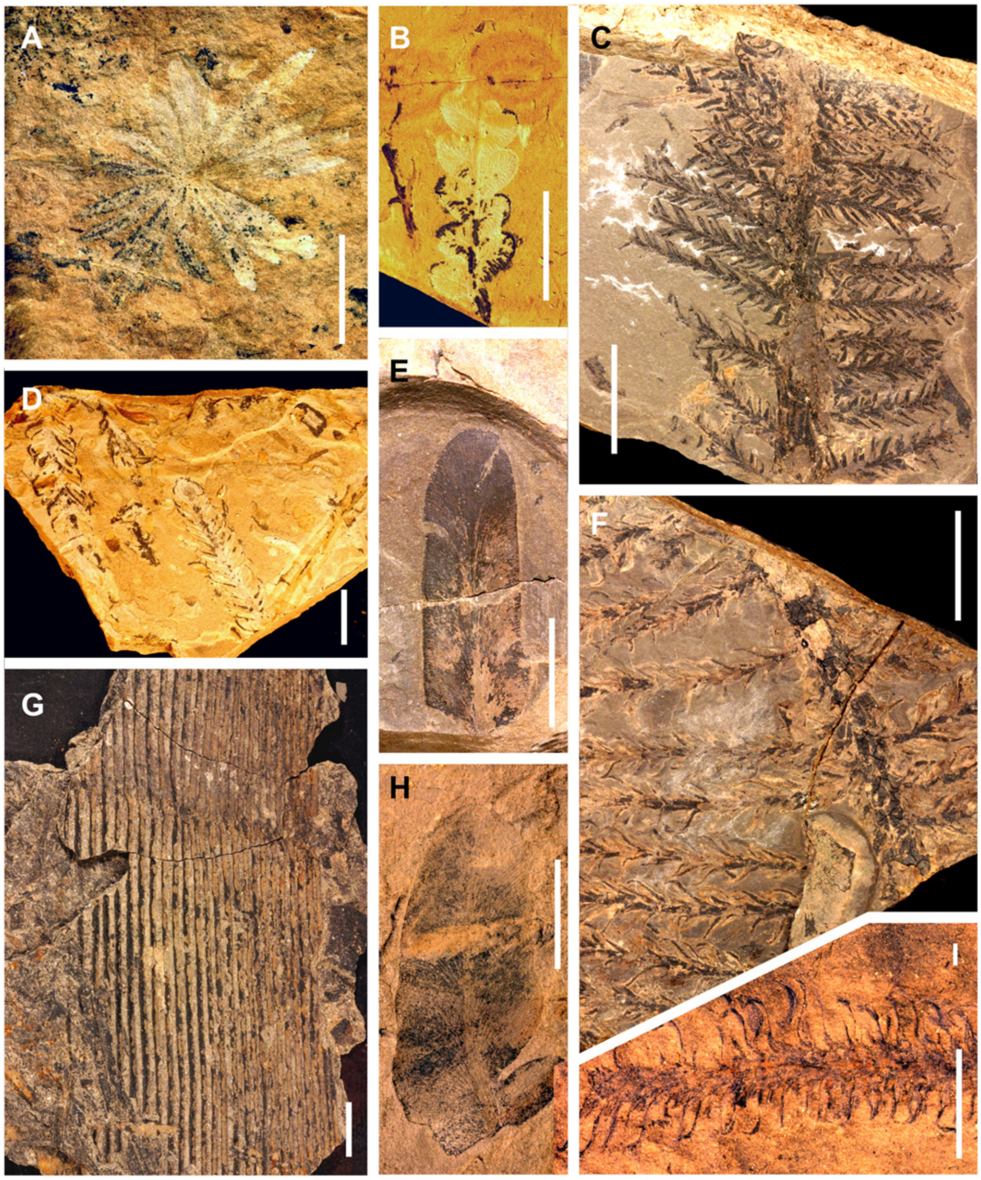

Fig. 22. Flora from the Říčany Horizon of the Padochov Formation, Boskovice Basin. A — *Annularia stellata*, pile from house foundation on NE edge of Veverské Knínice village. B — *Remia pinnatifida*, outcrop behind the house, Veverské Knínice loc. C — *Culmitzschia frondosa* v. *zeilleri*, outcrop behind the house, Veverské Knínice loc. D — *Culmitzschia parvifolia*, grey mudstone, loc. Neslovice, Fish rock. E — *Neurocallipteris planchardii*, grey mudstone, loc. Neslovice, Fish rock. F — *Culmitzschia laxifolia*, grey mudstone, loc. Neslovice, Fish rock. G — *Calamites gigas*, sandy mudstone, loc. Oslavany section, 80–100 m above the Zbýšov Horizon. H — *Neurodontopteris auriculata*, pile from house foundation on NE edge of Veverské Knínice village. I — *Culmitzschia speciosa*, pile from house foundation on NE edge of Veverské Knínice village. Scale bars 1 cm. All photos: Z. Šimůnek.

further split into members. The study interval is recorded in the lower of these formations, the Černý Kostelec Formation (Fig. 5).

4.3.2.1. Lithology and sedimentary environments of the Černý Kostelec Formation. The Černý Kostelec Formation is divided into an older Peklov Member (Stephanian C) and an overlying Lhotice Member (lower "Autunian"). The Peklov Member is between 40 and 275 m thick and is a succession composed of grey, grey-brown to red-brown sandstones often feldspathic, which predominate over grey to green-grey mudstones and siltstones (Holub, 1972, 1982; Pešek, 2004). At the base, red conglomerates to breccias are common whereas in the upper part of the member, locally present, are one or two 0.2–0.65 m thick coals. Sediments of this unit fill valleys of the pre-sedimentary palaeotopography striking mostly NNE–SSW and were deposited in colluvial, fluvial, deltaic and lacustrine settings. Lakes and/or peat swamps were established during periods of increased humidity (wet sub-humid).

The Lhotice Member is a 50–175 m thick fluvio–lacustrine succession the lower part of which consists of grey to red-grey sandstones alternating with mudstones. Up to 2 coals are present, 0.4–1.2 m thick. The upper part of the member is characterised by alternation of red (feldspathic) sandstones and mudstones with intercalated bituminous mudstones and limestones. The depocentre of the Lhotice Member is larger than that of the Peklov Member, but the depositional environments of both units are very similar.

4.3.2.2. Fossil record of the Černý Kostelec Formation. The fossil record of the Černý Kostelec Formation is restricted mainly to the coal-bearing or lacustrine horizons. In red beds between these horizons, only very sparse and poorly preserved remains have been found.

4.3.2.2.1. Flora of the Černý Kostelec Formation. The Peklov Member belongs to the *Sphenophyllum angustifolium* Zone (Wagner, 1984) of Stephanian C age. The flora of this unit contains typical European Stephanian and "Autunian" elements (Table 1): e.g., *A. sphenophylloides*,

Table 6
Fauna of the Rosice–Oslavany and Padochov Formations in the Boskovice Basin.

Lithostratigraphy	*Carbonicola thuringensis*	*Carbonicola remesi*	*Palaeanodonta castor*	*Palaeanodonta sophiae*	*Palaeanodonta compressa*	*Palaeanodonta verneuili*	Lioestheriidae indet.	*Moravíptera reticulata*	*Moravamylacris ricanyensis*	*Opsimylacris* cf. *Opsimylacris procera*	*Phyloblatta flabellata*	*Phyloblatta moravica*	*Phyloblatta dyadica*	*Phyloblatta* cf. *Phyloblattacurvata*	*Phyloblatta* sp. 1	*Spiloblattina weissigensis*	*Poroblattina rotundata*	*Kashmiroblatta* sp. 1	*Blattinopsis (Blattinopsis) antoniana*	*Blattinopsis (Blattinopsis) angustai*	*Blattinopsis (Blattinopsis) latissima*	*Blattinopsis (Blattinopsis) campestris*	*Blattinopsis (Blattinopsis) martynovae*	*Blattinopsis (Blattinopsis)* cf. *martynovae*	*Blattinopsis* sp.	*Anthracoblattina* sp. 3	*Permoedischia moravica*	*Pseudomerope gallei*	Insecta indet.	*Acanthodes gracilis*	*Acanthodes* sp.	*Xenacanthus* sp. U-m	*Bohemiacanthus carinatus*	Xenacanthiformes indet.	*Elonichthys krejcii*	*Neslovicella rzehaki*	Actinopterygii indet.	*Moraverpeton remesi*	*?Pelosaurus* sp.	*?Branchiosaurus* sp.	*?Edaphosaurus*sp.
Řičany H.					x	x	x		x		x	x	x	x		x	x			x	x	x	x	x	x			x			x					x	x				
Zbýšov H.	x	x	x	x			x	x		x	x				x			x	x								x			x	x	x	x	x			x	x	x	x	
Rosice-Oslavany F.																										x			x						x		x				x

A. stellata, *Dicksoniites plukenetii*, *Pecopteris cyathea* and *A. zeilleri*. The absence of "callipterids" is an indirect indicator, consistent with a Stephanian age. The presence of specimens resembling *Alethopteris bohemica* and also *Odontopteris schlotheimii* further supports the Stephanian age of the member.

The Lhotice Member flora is typified by the presence of "callipterids" — *A. conferta* and *A. naumannii*. Both species are known from the Stephanian (Bourouz and Doubinger, 1977), but become dominant beginning in the Permian. The flora is a mixture of plant species that colonised different habitats: *Calamites suckowii*, *A. equisetiformis*, *Sphenophyllum oblongifolium*, *Pseudomariopteris cordato-ovata*, *Dicksoniites pluckenetii*, *Pecopteris cyathea*, *Callipteridium gigas*, *Neurocallipteris neuropteroides*, *Ernestiodendron filiciforme* and *Walchia piniformis*. Interesting is the presence of *Odontopteris schlotheimii*, which is considered by Rieger (1968) to be a Stephanian element. Recently, however, Barthel (2011) found *Odontopteris schlotheimii* also in the lower Rotliegend in Manebach in Thüringen. An assemblage with *Odontopteris schlotheimii*, *Callipteridium gigas*, *A. conferta* and *A. naumannii* is typical for the transitional zone between the Carboniferous and Permian and corresponds to the *A. conferta* biozone (Wagner, 1984). The Lhotice Member flora is characterised by dominance of dryland conifers.

4.3.2.2.2. Palynology of the Černý Kostelec Formation. Palynological assemblages have been obtained from grey mudstones of the Peklov Member (Pešek et al., 2001) and contain miospores that belong to 34 genera and 56 species at least. The most common are representatives of the genera *Punctatosporites*, *Calamospora*, *Apiculatisporites*, *Lophotriletes*, *Laevigatosporites* and the saccate forms *Florinites* and *Illinites*. Rarely present is the genus *Lycospora*.

4.3.2.2.3. Fauna of the Černý Kostelec Formation. Fossil faunas of the Černý Kostelec Formation are known from both the Peklov and Lhotice Members (Table 7). The fauna of the Peklov Member includes conchostracans *Pseudestheria tenella* and ?*Pseudestheria* sp. and rare findings of non-marine gastropods ?*Maturipupa* sp. and ?*Dawsonella* sp., which, however, cannot confirm the "Stephanian C" age of the member suggested by the flora.

The fauna of the Lhotice Member is known from old coal mine dumps and one outcrop. Invertebrates are represented by pelecypods (Myalinidae indet.), ostracods (*Carbonita* sp.), conchostracans ("*Bythocypris*" *mytyloides*, Lioestheriidae indet.), and insect wing fragments. Vertebrates were identified as xenacanthid sharks (*B. carinatus* and Xenacanthiformes indet.) and actinopterygian fishes (scales of Actinopterygii indet.), the former supporting the lowermost Permian age suggested by the floristic assemblage.

4.3.2.3. Climatic indicators of the Černý Kostelec Formation. Although sediments of the Blanice Basin are only poorly exposed and modern sedimentological studies are nearly absent, existing data suggest that climatic interpretation of lithological and fossil records is in agreement with similar interpretations from the Boskovice and Sudetic basins.

Fig. 23. *Opsimylacris* cf. *Opsimylacris procera*, fore wing, BB, Zbýšov Horizon, Zbýšov locality, scale bar equals 10 mm. Photo by Štamberg.

Table 7
Fauna of the Peklov and Lhotice members of the Černý Kostelec Formation in the Blanice Basin.

Lithostratigraphy	Myalinidae indet.	*?Maturipupa* sp.	*?Dawsonella* sp.	*Carbonita* sp.	„*Bythocypris*" *mytyloides*	*Pseudestheria tenella*	*?Pseudestheria* sp.	Lioestheriidae indet.	Insecta indet.	*Bohemiacanthus carinatus*	Xenacanthiformes indet.	Actinopterygii indet.
Lhotice M.	x			x	x			x	x	x	x	x
Peklov M.		x	x			x	x					

5. Summary and conclusions

Sedimentary successions recording the transitional interval between Carboniferous and Permian are present in most of the continental basins of the Czech part of the Bohemian Massif. The thickness of these strata ranges significantly between less than 100 m and about 1500 m as a result of uneven tectonic subsidence. These sediments consist predominantly of fluvial red bed successions characterised by alternation of sandstones, subordinate conglomerates and mudstones. Spatial and temporal variations in proportions of particular lithologies are related to changes in sedimentary environments ranging from alluvial fan and braid plains to broad floodplain occupied by low energy (?meandering) rivers transporting mixed load. In all basins these monotonous red beds contain intercalations of grey to variegated mostly fine grained sediments that tend to be concentrated into a few tens of metres to more than 100 m thick horizons of predominantly lacustrine origin, traceable over large part of the basins. These "grey horizons" were deposited during humid periods in otherwise much drier climate and contain bituminous mudstones, limestones or cherts, i.e. lithologies absent in red beds part of the succession (Havlena, 1964; Martínek et al., 2006; Opluštil and Cleal, 2007; Pešek et al., 2001).

The climatic signature recorded in sediments deposited around the Carboniferous–Permian boundary in these continental basins has been only partly studied using sedimentological and lithological indicators and geochemical proxies (e.g., Martínek et al., 2006; Mikuláš and Martínek, 2006; Pešek and Skoček, 1999). Available data however, suggest climatic oscillations operating on several time scales (Fig. 25). The longest climatic cycles are probably represented by alternation of dominantly fluvial red beds with grey to variegated sediments mainly of lacustrine origin. The duration of individual cycles is estimated to reach 100,000 years or even more. The shorter cycles are represented by major lake level fluctuations recorded by shallowing-up facies units observed in most of the lacustrine sections throughout the basin (Martínek et al., 2006). These transgressive–regressive cycles are followed by significant changes in lake water salinity reflected in boron content in the clay fraction of mudstones. Lake level highstands correspond to periods of low salinity whereas high boron content in lowstand sediments suggests increased salinity due to high evaporation/precipitation ratio under hydrologically less open conditions (Martínek et al., 2006). These climatically induced lake level oscillations operated on a scale of tens to possibly hundreds of thousands of years. In red beds between particular grey lacustrine horizons these climatic oscillations have not been documented. We can only speculate that they may be recorded as temporal changes in proportion of bed load to suspended load sediments reflecting changes in fluvial styles, or by the local presence of thin, only a few metres thick, grey to variegated mudstones at various levels of an otherwise dominantly red succession. Even shorter oscillations are recorded as lake-level and bioproductivity fluctuations on the order of millennia to centuries and recorded by stable isotopes and organic matter geochemistry. The highest frequency climatic record is represented by lacustrine laminites, the formation of which is related to seasonal algal blooms (Martínek et al., 2006). In fluvial red beds these seasonal climatic conditions are indicated by the presence of vertisols often with carbonate nodules, the formation of which requires strongly seasonal climate (e.g., Cecil et al., 2003; Sheldon and Tabor 2009).

Fig. 24. "Stephanian C" landscape during the deposition of the red beds of the Líně Formation or other stratigraphically equivalent units in the Sudetic basins. Dominantly dryland area is colonised by walchian conifers (right) and cordaitaleans (left). Their stems were often transported during floods and left of channel bedforms after drop of water table. Small scattered "wet spots" are colonised by wetland plants, mostly calamites and ferns. Painted by J. Svoboda under supervision of J. Bureš (West Bohemian Museum in Pilsen).

The character of climate is assumed to vary between moist sub-humid and dry sub-humid and possibly even to semi-arid during the driest periods (Cecil, 2003). The moist sub-humid climate corresponds to the wettest parts of the lacustrine cycles and was moist enough to allow for occasional long-term peat accretion resulting in the formation of economic coals (Fig. 25). Presence of eolian sands, although spatially and temporarily very restricted (to W part of the KRB), may point to the existence of semi-arid climate as the counterpart to moist sub-humid conditions. It is worth noting that coals are widely absent in biostratigraphically determined "Autunian" strata, suggesting a shift to generally drier climate.

The plant fossil record of Late Stephanian to "Autunian" (Gzhelian–Asselian) strata indicates the existence of two different and ecologically separated wetland and dryland biomes, the former represented by lycopsids, calamites, ferns and some pteridosperms, the latter composed dominantly of conifers and cordaitaleans and in the Autunian also by peltasperm pteridosperms. Differences in the landscape morphology of basinal lowlands and associated variations in ground water table were responsible for further partitioning of biomes into different plant assemblages, which differed in dominance of particular plant groups. Rare plant fossils in fluvial red beds indicate that vegetation cover existed even during red-bed deposition under seasonally dry sub-humid climate. Prostrate and probably mainly allochthonous silicified stems of cordaites and walchian conifers (Bureš, 2011; Mencl et al., 2009) are fairly common in sand bar deposits whereas impressions of walchian conifer shoots or cordaitalean leaves and branches are scarce in mudstone intercalations in fluvial deposits (Šetlík and Rieger, 1970). Existence of this dryland plant assemblage is further supported by occurrence of sub-vertical root systems preserved either as haloes or rhizoliths in red and often carbonaceous vertisols (Fig. 4). They indicate the presence of plants adapted to soil moisture deficits possibly under strongly seasonal climate, probably gymnosperms. The presence of torrential rains during the wet season is suggested by the fact that large stems several decimetres in diameter were transported by floodwaters and deposited mostly within channels as the water table dropped. On the other hand, foliage was usually transported/preserved in mudstones deposited either in floodplain areas or in small pools left on the braidplain after flood events. A conifer–cordaitalean plant assemblage growing in dryland areas, however, was not the only assemblage colonising the landscape during red beds deposition (Fig. 24). This is evident from exceptional finds of silicified calamite stems (Mencl et al., 2013) in fluvial sandstones or very rare calamite stem or fern foliage impressions in variegated mudstone intercalations in an otherwise red succession, i.e. in similar strata as silicified gymnosperm woods. As noticed by these authors and by Bureš (2011), the rarity of calamite stem remains can be, however, partly a taphonomical bias since calamite stems contain high parenchymatous wood and thus are prone to be more easily destroyed during transport. This may be indicated by a silicified stem assemblage occurring in sandstones above the Ploužnice Horizon (Mencl et al., 2009) in the southern part of the KrPB. Here silicified stems of cordaites and conifers occur together with common

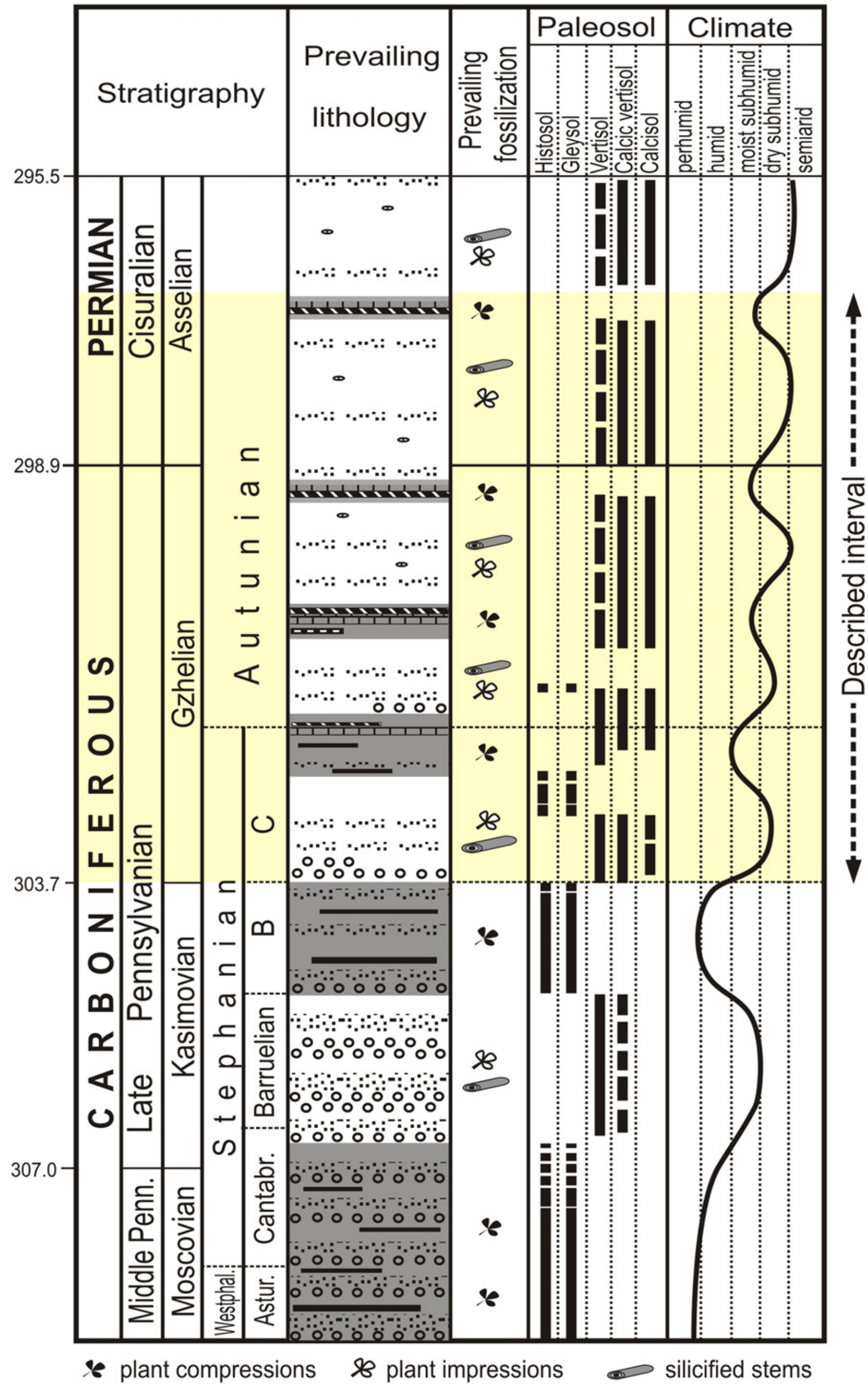

Fig. 25. Generalised section of the Stephanian C/early Autunian strata in the basins of the Czech Republic with climatic indicators and interpreted climatic changes during the Late Pennsylvanian–early Permian. For explanation of lithological symbols see Fig. 5.

calamites, tree ferns and medullosaleans in a relatively narrow stratigraphic interval. However, where found in outcrops, these stems have never been observed in growth position. Instead they are transported and secondarily embedded in fluvial and lacustrine deposits. Most of fossil stems are, however, split into pieces and found in fields (Matysová et al., 2008; Mencl et al., 2009; Skoček, 1970). In any case, silicified stem assemblages suggest temporary co-existence of dryland and wetland assemblages in lowlands of continental basins during fluvial red beds deposition during early Gzhelian (Stephanian C) times. During that time, wetland plant elements probably survived in localised wetlands in/along small temporary ponds scattered across the basinal lowland (Opluštil, 2013). The proportion of the total landscape represented by these wetland and dryland areas varied throughout the time as the climate oscillated between dry sub-humid and moist sub-humid.

The fossil record indicates that during humid periods accompanied by lake formation basinal lowlands were dominated by wetland assemblages composed mainly of ferns and sphenopsids. In locally present peat swamps sub-arborescent (*Endosporites*-producing) and arborescent lycopsids were also common. The arborescent assemblage is extremely rare, being represented by very sporadic compressions of *S. brardii*, *A. camptotaenia* and even of *Lycospora*-producing lepidodendrid lycopsids. Permineralised (silicified) peats of the Ploužnice Horizon (Stephanian C) contain stigmarian roots and lepidodendrid cones

(Fig. 10B). Tree fern spores are often common in sediments along the southern margin of some "Stephanian C" lakes (Klobuky, Ploužnice) where broad mudflats existed. The mudflats of the Ploužnice Horizon are associated with silicified stems of ferns and calamites and pteridosperms. Therefore, it is assumed that tree fern – calamite and subdominant pteridosperm – growth covered lake shallows and vast mudflats especially along these low-gradient lake margins in the half-graben depocentres of the KRB and KrPB.

However, the presence of dryland spots during these wet intervals, when part of the basin floor was occupied by a lake, is also highly possible. This is indicated by mixture of allochthonous plant fragments of dryland and wetland assemblages on the same bedding plane or within the same section of "Stephanian C" lakes. The proportion of conifers further increases during the "Autunian". Some plant assemblages in offshore mudstones of the Rudník Lake (Autunian) along the tectonically active northern margin of the KrPB are dominated by walchian conifers, including fragments several tens of centimetres long (e.g., Rieger, 1971). This indicates the presence of conifer forests in close proximity to the lake, growing possibly on well-drained slopes along tectonically active lake margin from where their remains were easily washed down into the lake by rains. The coexistence of dryland and wetland biomes in basinal lowland during the humid periods is further suggested by some palynological spectra. Those palynofloras of "Stephanian C" age are usually dominated by tree-fern spores whereas most of "Autunian" miospore assemblages are rich in pollen of cordaites and conifers. However, even in the "Autunian" tree ferns are locally dominant as are, in exceptional cases, representatives of the genus *Lycospora*.

A general climatic shift from wetter to drier conditions around the Pennsylvanian–Permian transition (Stephanian C–Autunian) is accompanied by an increasing proportion of dryland biome assemblages in the fossil record during the "Autunian". This pattern is explained as an expansion of the dryland biome across the basinal lowland. However, several orders of high frequency climatic oscillations superimposed on a general climatic shift to increasing aridity make this transition far from being gradual. Instead wetland assemblages represented by macrofloral remains as well as by miospores are repeatedly found in some "Autunian" sediments, suggesting survival of wetland plant assemblages in contracting "wet spots" (DiMichele et al., 2009, 2010). The best example of this oscillatory, directional trend is some palynological samples from the "Autunian" Rudník Horizon in the KrPB, dominated by 70% lycospores (Pešek et al., 2001; Valterová, 1987). Repetition of basically the same wetland plant assemblages in successive lake horizons makes it difficult to distinguish them floristically. The "Stephanian C" grey horizons, characterised by the absence or rare occurrence of peltasperms, are especially difficult to distinguish stratigraphically. Differences in composition of plant assemblages between particular "Stephanian C" horizons are rather of an ecological nature. Similarly, it is difficult to distinguish between particular "Autunian" lacustrine horizons. The richer occurrence of peltasperms distinguishes them from the "Stephanian C" grey horizons but is not always sufficient for separation of particular "Autunian" horizons. The main floristic difference between the "Stephanian C" and "Autunian" part of basin succession is an increase in the proportion of conifers, and locally peltasperms, and decrease of ferns (especially tree ferns with pecopterid foliage).

Unlike their effect on the flora, climatic oscillations around the Carboniferous–Permian transition had only a minor effect on lake faunas. Typical for the study interval are seasonal changes related to a torrential rainy season resulting in lake water eutrophication and algal blooms accompanied by mass occurrence of conchostracans on bedding planes. The mechanism driving the transition between the local bio/ecozones *Elonichthys*–*Sphaerolepis* and *A. gracilis*, which roughly corresponds to the Carboniferous/Permian boundary, is impossible to deduce from the fossil record. In "Autunian" lakes where salinity increased substantially during the climatic oscillations observed, there was a preferential drop in diversity of some faunas depending on their tolerance to changes in lake water chemistry.

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