Univerzita Karlova v Praze

Přírodovědecká fakulta

Studijní program: Geologie

Studijní obor: Paleobotanika

Mgr. Václav Mencl

Zkřemenělé stonky svrchnopaleozoických rostlin z vnitrosudetské a podkrkonošské pánve

Silicified stems of upper Paleozoic plants from the Intra Sudetic and Krkonoše Piedmont basins

Disertační práce

Školitel: RNDr. Jakub Sakala, Ph.D.

Praha, 2014

Prohlášení

Prohlašuji, že jsem tuto disertační práci vypracoval samostatně a že jsem uvedl všechny použité informační zdroje a literaturu. Tato práce, ani její podstatná část, nebyla předložena k získání jiného nebo stejného akademického titulu.

V Praze, 7.7.2014

Václav Mencl

Poděkování

Stejně jako každé dílo podobného druhu, také tato práce vznikla díky laskavému (a někdy i nevědomému) přispění mnoha osob. Rád bych zde poděkoval alespoň těm, jejichž pomoc byla pro výslednou podobu práce nejzásadnější.

Děkuji tedy zejména:

- rodičům a babičce L. Nývltové za materiální i morální podporu během celého mého studia

- školiteli J. Sakalovi za téměř otcovský přístup, velkou trpělivost a mnoho cenných rad

- spoluautorům publikovaných prací, především P. Matysové, J. Holečkovi a J. Burešovi za spolupráci a poskytnutá data

- R. Rößlerovi (*Museum für Naturkunde Chemnitz*); V. Prouzovi, V. Rapprichovi, M. Stárkové a Z. Šimůnkovi (*ČGS Praha*); S. Opluštilovi a K. Martínkovi (*PřF UK Praha*) a J. Pšeničkovi (*Západočeské muzeum v Plzni*) za velmi přínosné konzultace o geologické, stratigrafické a paleobotanické problematice

- J. Juráčkovi a S. Štambergovi (*Muzeum východních Čech Hradec Králové*); T. Řídkošilovi (*Muzeum Českého ráje v Turnově*); J. Luštincovi a J. Šimurdovi (*Krkonošské muzeum v Jilemnici a Vrchlabí*) za ochotné zpřístupnění sbírek a zapůjčení exponátů ke studiu

- L. Běhounkovi, J. Boudnému, J. Červenkovi, J. Konůpkovi, O. Myslivcovi, O. Rešovi, J. Svejkovskému, J. Zajíčkovi, B. Zasadilovi a dalším sběratelům zkřemenělých dřev za možnost zhlédnutí a zapůjčení vzorků ze svých sbírek

Abstrakt

Svrchnopaleozoické pánve České republiky jsou proslulé hojnými výskyty zkřemenělých zbytků rostlin. Přestože jsou tyto zkameněliny často popisovány a mezi odborníky i sběrateli dobře známy, jejich modernímu výzkumu se věnuje jen málo pozornosti. Tato práce shrnuje výsledky studia zkřemenělých stonků ze dvou pánví Českého masívu, kde je jejich bohatý výskyt historicky zdokumentován. Na základě revize materiálu z veřejně dostupných i soukromých sbírek a novým nálezům z terénních sběrů se podařilo prokázat přítomnost zkřemenělých stonků v jedné stratigrafické úrovni ve vnitrosudetské pánvi a několika úrovních v pánvi podkrkonošské. Tato data lze korelovat s nálezy z dalších pánví stejného stáří. Z hlediska systematické příslušnosti byla věnována pozornost zejména stonkům přesličkovitých a některých nahosemenných rostlin. Na základě anatomického studia druhotného dřeva a dalších znaků byly mezi zkřemenělými přesličkami, vyskytujícími se v ploužnickém obzoru podkrkonošské pánve, prokázány dva druhy: *Arthropitys* cf. *bistriata* a *Calamitea striata*. Dřeva nahosemenných rostlin typu *Agathoxylon* byla rozdělena do dvou skupin, náležejících kordaitům, resp. koniferám. Terénním měřením a statistickým zpracováním poměrů kordaitů vůči koniferám v jednotlivých fosiliferních jednotkách byla provedena částečná rekonstrukce prostředí a podmínek během sedimentace v pánvích.

Abstract

The late Paleozoic deposits of the Czech Republic are famous for their rich occurence of silicified stems. Despite the fact they have been often described and are well-known among scientists and collectors, their modern evaluation is lacking. This work summarizes results of recent anatomical and paleoenvironmental studies of silicified stems of the Intra Sudetic and Krkonoše Piedmont basins, where are these fossils found very frequently. Based on field research and review of public and private collections, the presence of silicified remnants was proved in several stratigraphic units. Firstly, this work deals with silicified stems of calamitaleans, which are known from the Ploužnice Horizon of the Krkonoše Piedmont Basin, and some gymnosperms. Based on anatomical studies of the secondary xylem and other related features there were found two species of calamitaleans: *Arthropitys* cf. *bistriata* and *Calamitea striata*. Secondly, the more abundant *Agathoxylon* – type of wood was divided into two groups, which are assigned to cordaitaleans, and conifers. The palaeoenvironmental conditions were partly reconstructed according to sedimentary structures and also according to cordaitaleans – conifers ratio in each wood-bearing layer.

Obsah

1. Cíle disertační práce

Tato disertační práce je předkládána jako konvolut článků zabývajících se výskytem a systematickým zařazením zkřemenělých stonků rostlin ze dvou pánví svrchního paleozoika České republiky: vnitrosudetské a podkrkonošské.

Cílem práce je podrobné zmapování výskytu a stratigrafické příslušnosti zkřemenělých zbytků rostlin v obou pánvích, stejně jako jejich taxonomické zařazení s ohledem na nejnovější poznatky a klasifikaci rostlin. Práce se zabývá zejména systematikou druhotně tloustnoucích stonků stromovitých přesliček a nahosemenných rostlin. V rámci studovaných oblastí je porovnáván stratigrafický výskyt a složení rostlinných společenstev, což je v přiložených článcích rozšířeno o další svrchnopaleozoické pánve Českého masívu. Dílčí částí práce je pak snaha částečně popsat paleoekologické a paleoenvironmentální podmínky během ukládání fosiliferních sedimentů v pánvích.

2. Úvod

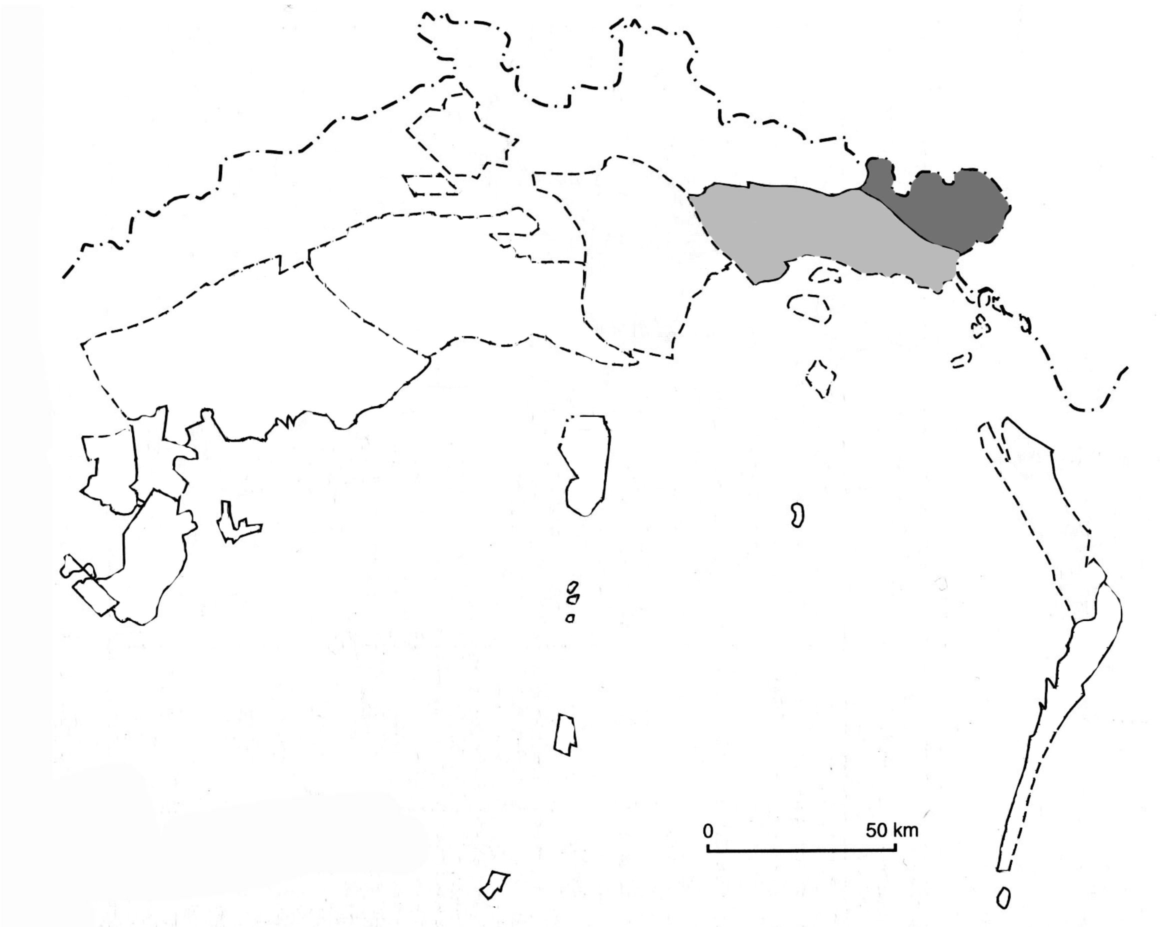
Zkřemenělé části rostlin, hojně se vyskytující v českých svrchnopaleozoických pánvích, jsou významnou součástí fosilního záznamu z tohoto období. Zatímco historicky byly nálezy z vnitrosudetské a podkrkonošské pánve řazeny do svrchního karbonu (Göppert 1858), resp. permu (Göppert 1858, Feistmantel 1873a, b, c), dnes je jejich stáří odhadováno na svrchní moscov až assel (např. Matysová 2006, Mencl 2007, Sakala *et al.* 2009, Mencl *et al.* 2009, 2013a, b, Opluštil *et al.* 2013 – viz přílohy I–V).

Vzdor tomu, že jsou tyto fosílie široce známé, pro svou estetickou hodnotu velmi ceněné a často popisované v různých publikacích, se u nás jejich modernímu výzkumu věnuje pozornost až v posledních letech (např. Matysová 2006, Mencl 2007, Matysová *et al.* 2008, Mencl *et al.* 2009, Sakala *et al.* 2009, Matysová *et al.* 2010, Holeček 2011, Bureš 2011, 2013, Mencl *et al.* 2013a, b – viz přílohy I–V). Vnitrosudetská a podkrkonošská pánev jsou oblasti, kde je velké množství nálezů zkřemenělých stonků rostlin historicky doloženo a lze je v terénu běžně sbírat i v současné době.

Tato práce je zaměřena na zkřemenělé stonky z výše uvedených oblastí, zejména na jejich druhotné dřevo, které bývá zachováno nejčastěji. V přiložených článcích jsou však v rámci komplexního přístupu popisovány i stonky z jiných pánví Českého masívu. Je zde uveden přehled historických výzkumů a výskytu těchto fosílií v porovnání s dnešním stavem jejich nalezišť, která byla prověřena během terénního výzkumu. Další část práce se věnuje systematice některých zkřemenělých stonků, konkrétně dřev přesličkovitých rostlin a araukaroidních dřev náležejících nahosemenným rostlinám. Při jejich taxonomickém zařazování jsou využívány nejnovější přístupy a poznatky, aplikované v současné době mj. při výzkumech v tzv. *Zkřemenělém lese* (*Versteinerten Wald*) v německém Chemnitz (např. Noll *et al*. 2005, Röβler & Noll 2006, 2007, 2010, Röβler *et al*. 2012a, b). Na základě taxonomické příslušnosti zkřemenělých stonků bylo možné částečně rekonstruovat rostlinná společenstva v jednotlivých obdobích svrchního paleozoika. Měření sedimentárních struktur ve výchozech fluviálních uloženin s výskytem zkřemenělých kmenů ve vnitrosudetské pánvi poskytlo data pro stanovení směru proudění a podmínek během sedimentace těchto fosiliferních vrstev.

3. Přehled geologie a lokalit studovaného území

Svrchnopaleozoické limnické pánve na území Českého masívu vznikaly v závěrečných fázích variského vrásnění následkem lokálních extenzí při postorogenním kolapsu pohoří. Vyplňovány byly nejčastěji klastickými sedimenty snášenými z denudovaného masívu variského orogenu. Geograficky se rozdělují na pánve středočeské a západočeské, krušnohorské, lugické a tzv. brázdy (Pešek *et al*. 2001). V této práci je věnována pozornost pouze stratigrafickým jednotkám s výskytem zkřemenělých zbytků rostlin ve 2 pánvích lugických: vnitrosudetské a podkrkonošské (obr. 1).



Obr. 1: Svrchnopaleozoické pánve ČR. **podkrkonošská pánev** **vnitrosudetská pánev.** Upraveno dle Peška *et al.* (2001).

3.1. Vnitrosudetská pánev

3.1.1. Geologie

Vnitrosudetská pánev zaujímá mezi lugickými pánvemi čelní pozici z hlediska své rozlohy i stratigrafického rozsahu sedimentace (viz tab. 1). Z její celkové plochy přibližně 1800 km^2 však leží na našem území jen asi třetina, zbytek se nachází na území Polska. Sedimentace v pánvi probíhala (vyjma několika hiátů) kontinuálně od visé do středního triasu a uloženiny dosahují mocnosti přes 3500 m (Tásler *et al*. 1979, Pešek *et al*. 2001). Stratigraficky je v pánvi možno dle Táslera, Spudila a Šimůnka (in Pešek *et al*. 2001) vydělit osm souvrství (viz tab. 1).

Přítomnost petrifikovaných zbytků rostlin byla nynějším výzkumem potvrzena v jediné stratigrafické úrovni, v jednotce stáří spodní kasimov (barruel), označované jako žaltmanské arkózy, která je součástí jíveckých vrstev odolovského souvrství. Tato jednotka, stratigraficky odpovídající štikovským arkózám v podkrkonošské pánvi, je tvořena převážně narůžovělými, fluviálními arkózovitými slepenci a hrubozrnnými pískovci s polohami červených aleuropelitů (Tásler *et al*. 1979, Pešek *et al*. 2001). Dle Matysové *et al*. (2010) lze prostředí, v kterém ukládání probíhalo, charakterizovat jako fluviální až lakustrinní bez vlivu vulkanismu. Zkřemenělé stonky v subhorizontálních (alochtonních) pozicích byly objeveny v několika výchozech, většina nálezů však pochází z eluvia (Mencl 2007, Mencl *et al*. 2009 – viz příloha I).

3.1.2. Významné lokality

Žaltmanské arkózy vycházejí na povrch zejména v oblasti Jestřebích hor, na území o ploše cca 200 km^2 mezi Trutnovem a Hronovem, a tvoří jejich hlavní hřeben. Při terénním výzkumu bylo objeveno množství výchozů těchto hornin, v šesti případech se zachovanými zkřemenělými kmeny v alochtonních subhorizontálních pozicích. Ty jsou v maximální délce cca 2,5 m odhaleny např. na historicky známé lokalitě Kryštofovy kameny (obr. 2). Další části dřev se podařilo objevit v Hronově, Bezděkově či Slavětíně. Množství jejich různě velkých úlomků je pak běžně nalézáno v eluviu či půdním profilu na celém území Jestřebích hor i v jejich okolí. Zajímavé exempláře lze rovněž spatřit v soukromých zahradách nebo jako součásti různých pomníků a památníků (obr. 2).

STÁŘÍ				VSP SOUVRSTVÍ	VSP VRSTVY	PKP SOUVRSTVÍ	PKP VRSTVY	KLIMATICKÉ FÁZE
TRIAS			bundsandstein	bohdašínské	-	bohdašínské	svrchní	
							spodní	
PERM	LOPING	changsingh	-	bohuslavické	-	bohuslavické	-	
		wuchiaping	zechstein					
	GUADALUP	capitan	-	trutnovské	-	trutnovské	suchovršické	
		word	saxon				havlovické	
							vlčické	
		road					hornoměstské	
	CISURAL	kungur						
		artinsk	autun			chotěvické	-	
		sakmar		broumovské	martínkovické	prosečenské	svrchní	
		assel			svrchní olivětínské			
					spodní olivětínské		spodní	
KARBON	PENNSYLVAN	gzhel			noworudské	vrchlabské	svrchní	
							spodní	
			stephan C	chvalečské	bečkovské			
					vernéřovické	semilské	svrchní	
							střední	
							spodní	
		kasimov	stephan B	odolovské	jívecké	syřenovské	svrchní	
							spodní	
			stephan A			kumburské	štikovské arkózy	
		moscov	cantabr		svrchní svatoňovické		brusnické	
			astur		spodní svatoňovické			
			bolsov	žacléřské	petrovické			
		bashkir	duckmant		dolsko-žďárecké			
			langsett					
			namur		lampertické			
	MISSISSIPP	serpukhov						
		visé	visé	blažkówské	-			

Tab. 1: Stratigrafická tabulka vnitrosudetské (VSP) a podkrkonošské pánve (PKP) se znázorněním klimatických výkyvů. - polohy zkřemenělých dřev typu *Agathoxylon*, - poloha rostlinného společenstva ploužnického obzoru. Sestaveno dle Peška *et al.* (2001), Opluštila & Cleala (2007), Mencla (2007), Mencla *et al.* (2009, 2013b – viz přílohy I, V).

Obr. 2: Zkřemenělý kmen na lokalitě Kryštofovy kameny (vlevo) **a kaplička v Malých Svatoňovicích vyzdobená zkřemenělými dřevy** (vpravo); **vnitrosudetská pánev**.

3.2. Podkrkonošská pánev

3.2.1. Geologie

Podkrkonošská pánev vyplňuje prostor o rozloze cca 1100 km^2, ležící mezi krkonošsko-jizerským a orlicko-sněžnickým krystalinikem. Od pánve vnitrosudetské je oddělena hronovsko-poříčským hlubinným zlomem. Sedimentace zde začala ve svrchním moscovu (asturu) a krom několika hiátů pokračovala až do středního triasu, zejména ve východní části pánve (viz tab. 1). Výplň je tvořena převážně fluviálními a lakustrinními sedimenty s vložkami vulkanických, zejména v permu se objevujících hornin. Vulkanosedimentární výplň pánve dosahuje mocnosti až 1800 m a je zpravidla rozdělována do devíti souvrství (Pešek *et al*. 2001). Historicky je výskyt petrifikovaných částí rostlin znám ve štikovských arkózách (kumburské souvrství) a ploužnickém obzoru (semilské souvrství). Nově byly tyto fosílie popsány také z brusnických vrstev kumburského souvrství a ze svrchní části souvrství prosečenského (Mencl *et al*. 2013b – viz příloha V).

Kumburské souvrství

Kumburské souvrství je se stářím sv. moscov – sp. kasimov nejstarší jednotkou v podkrkonošské pánvi. Litologicky je značně různorodé, tvoří jej zejména červenohnědé aleuropelity s vložkami arkózovitých pískovců, slepenců a brekcií. Souvrství lze rozdělit na spodní -

brusnické vrstvy a svrchní část - štikovské arkózy (Pešek *et al.* 2001). Zkřemenělá dřeva byla nalezena v obou těchto jednotkách (Mencl *et al.* 2013b – viz příloha V).

Brusnické vrstvy

Jednotka, známá pouze z jižní části pánve, je tvořena zejména aleuropelity červených barev s hojnými, až několik metrů mocnými polohami šedavých, středně- až hrubozrnných pískovců a slepenců, které se ukládaly v lakustrinním a fluviálním prostředí bez vlivu vulkanismu (Pešek *et al.* 2001, Matysová *et al.* 2010). Silicifikované stonky se vyskytují velmi zřídka a z této jednotky byly popsány vůbec poprvé (Mencl *et al.* 2013b – viz příloha V).

Štikovské arkózy

Jednotka je tvořena šedavými až narůžovělými, středně- až hrubozrnnými pískovci, přecházejícími do slepenců s valouny o průměru až okolo 10 cm (Pešek *et al.* 2001). Tyto horniny se ukládaly ve fluviálním prostředí bez vlivu vulkanismu (Matysová *et al.* 2010). Zkřemenělé stonky rostlin jsou zde velmi hojné a v několika případech byly objeveny zachované v horninových výchozech v subhorizontálních pozicích.

Semilské souvrství

Tato jednotka stáří sp. gzhel (stephan C) je tvořena zejména červenohnědými aleuropelity a slepenci. Díky výskytu dvou poloh (obzorů) pestrých a šedých prachovců je možné rozdělit souvrství na spodní, střední a svrchní (Pešek *et al.* 2001). Silicifikované zbytky rostlin jsou známy ze střední části souvrství, z tzv. ploužnického obzoru.

Ploužnický obzor

Je charakteristický jemnozrnnými červenohnědými jílovci až prachovci, místy s tenkými polohami vápenců a křemitými (karneolovými) konkrecemi. Významnou část horninového sledu tvoří vulkanoklastika, zejména tufy, tufity a vulkanodetritické pískovce, transportované a uložené ve vodním prostředí (Martínek 1997, Pešek *et al.* 2001, Stárková *et al.* 2009). Ze spodní část ploužnického obzoru jsou známy četné výskyty zkřemenělých částí různých rostlin. Kromě araukaroidních dřev jsou to také stonky výtrusných a kapraďosemenných rostlin (Mencl *et al.* 2013a, b, Opluštil *et al.* 2013 – viz přílohy III–V). Zlomky různých částí rostlinných pletiv se nacházejí také v tzv. zkřemenělých rašelinách, tvořících čočkovitá tělesa v horninovém sledu. Charakter sedimentů odpovídá lakustrinnímu prostředí s významným vlivem vulkanismu (Matysová *et al*. 2010). Vzhledem k absenci větších výchozů ploužnického obzoru jsou fosílie nalézány pouze v eluviu nebo volně na povrchu terénu. Jejich stratigrafické zařazení bylo provedeno, stejně jako v případě následujícího prosečenského souvrství, pouze na základě staršího geologického mapování.

Prosečenské souvrství

Jednotku stáří assel – sakmar (autun) tvoří převážně jemnozrnné aleuropelity červenavých barev, často se světlými, kruhovitými redukčními skvrnami. V těchto horninách se často objevují polohy pestrých a šedých slínovců, prachovců a vápenců, nebo jemnozrnných pískovců, tufů a tufitů. Obvykle je prosečenské souvrství děleno na dva oddíly: spodní a svrchní. Nejvyšší část svrchního prosečenského souvrství je tvořena šedorůžovými arkózami a arkózovými pískovci (Pešek *et al*. 2001). Zkřemenělá dřeva jsou nacházena pouze v eluviu. Podle Matysové *et al*. (2010) je jednotku možné charakterizovat jako sedimenty lakustrinního prostředí s vlivem vulkanismu.

3.2.2. Významné lokality

Zkřemenělá dřeva zachovaná v horninových výchozech se podařilo v podkrkonošské pánvi nalézt pouze v horninách kumburského souvrství, a to v obou jeho částech. Na lokalitě Šárovcova Lhota byly v několik metrů vysokém defilé hrubozrnných arkózovitých slepenců brusnických vrstev objeveny dvě části různých kmenů se dřevem typu *Agathoxylon* v subhorizontální pozici, větší z nich o délce asi 50 cm a průměru 30 cm, menší exemplář zhruba poloviční velikosti. Jsou to zatím jediné známé nálezy zkřemenělých dřev v této stratigrafické jednotce (Mencl *et al*. 2013b – viz příloha V).

Štikovské arkózy vystupují v podkrkonošské pánvi na povrch poměrně často a zkřemenělé kmeny zachované v těchto výchozech v alochtonních pozicích byly objeveny na několika místech. V současné době je možné pozorovat tyto zkameněliny na lokalitě Zlámaniny, kde jsou ve stěně bývalého lomu, tvořené převážně hrubými arkózovými pískovci, odhaleny tři kmeny s průměrem okolo 50 cm, nebo ve výchozu arkózovitých slepenců ve sklepení hradu

Pecky (obr. 3). Drobnější úlomek dřeva s cca 20 cm průměrem se nachází ve zvětralých arkózovitých pískovcích při bázi stěny bývalé pískovny ve Stavu. Několik až 7 m dlouhých kmenů uložených v hrubých arkózovitých slepencích bylo odhaleno v roce 2007 na dočasném odkryvu při stavbě obchodu Lidl v Nové Pace, na historických nákresech je pak znázorněno několik poměrně velkých kmenů v lomech u nedalekého novopackého nádraží a pod hradem Peckou (Purkyně 1927). Nálezy několikametrových kmenů v okolí Pecky uvádí také Jokély (1861, 1862) a Frič (1912). Nejdelší a nejmohutnější dosud nalezený kmen, jenž dosahuje délky přes 8 metrů, byl objeven v roce 1953 při stavbě sportovního areálu v Nové Pace. V současné době je uložen ve sbírce Městského muzea Nová Paka a vystaven před budovou Klenotnice drahých kamenů.

Obr. 3: Zkřemenělý kmen ve výchozu štikovských arkóz na hradu Pecce; podkrkonošská pánev.

Výchozy ploužnického obzoru a prosečenského souvrství se v podkrkonošské pánvi vyskytují jen sporadicky a zkřemenělé zbytky rostlin v nich zachované objeveny nebyly. Nejbohatšími a nejznámějšími místy nálezů v eluviích jsou např. Balka, Stará Paka a Borovnice, resp. okolí obcí Studenec a Horní Branná.

4. Historie výzkumu zkřemenělých stonků

4.1. Vnitrosudetská pánev

V české části vnitrosudetské pánve, v oblasti Jestřebích hor, je výskyt zkřemenělých stonků rostlin znám od pradávna, místní lidé je dobře znali a pro jejich estetickou hodnotu často sbírali. V polovině 19. století se tyto fosílie dostávají do rukou prof. Göpperta z polského Wrocławu, který o nich publikuje první vědeckou práci v roce 1857. Popisuje zde celé území Jestřebích hor s výskytem velkého množství zkřemenělých dřev, která řadí k dvěma druhům: *Araucarites brandlingii* (Lindl. & Hutt.) Göppert a nově popsaný *Araucarites schrollianus* Göppert (Göppert 1857). Oba druhy považuje za konifery. Uvádí, že některé z kmenů dosahují délky přes 6 m a většina má oválný průřez následkem stlačení. Kůra stromů zachována není a suky či větve jen velmi vzácně. Některé kmeny mají až 7 cm širokou centrální dutinu a letokruhy (Göppert 1857, 1858). Renger (1858, 1863) popisuje nálezy mnoha až několik metrů dlouhých, červeně a černě zbarvených kmenů od Radvanic, z nichž některé jsou zachovány ve výchozech (dnes však již neexistujících). Feistmantel (1871, 1872, 1873a, b, c) podává přehled výskytu zkřemenělých dřev v Podkrkonoší, popisuje jejich roztroušené kusy na Jestřebích horách a také dřeva zachovaná v důlních štolách. Makowsky (1878) přibližuje sběr dřev a jejich využívání ke zpevnění cest a dlažby. Purkyně (1927) představuje soubornou zprávu o výskytu zkřemenělých kmenů v Čechách. Výskyt druhu *Araucarites brandlingii* považuje za méně častý než *Araucarites schrollianus* (Purkyně 1927). O dva roky později porovnává nálezy z vnitrosudetské pánve s nálezy z pánví jiných a popisuje zachované dřevní struktury kmenů. Zabývá se také otázkami tafonomickými. Silicifikace stonků musela dle jeho názoru proběhnout ještě před koncem karbonu, neboť z permských uloženin jsou údajně známy nálezy vodou opracovaných a redeponovaných úlomků dřev (Purkyně 1929). Valín zkoumá možnosti využití zkřemenělých dřev z výchozů k rekonstrukcím paleoproudů (Valín 1956, 1960). O existenci zkřemenělých dřev ve vnitrosudetské pánvi se zmiňuje celá řada dalších autorů, např. Jokély (1861, 1862), Krejčí (1877), Stur (1877), Katzer (1892), Schade (1896), Herbing (1904), Petrascheck (1913, 1922, 1924), Walzel (1938), Havlena (1955), Němejc (1963), Tásler *et al*. (1979), Minář (1993), Lokvenc (1985, 1993, 1997), Pešek *et al*. (2001) nebo Jirásek (2003), většinou však jen velmi stručně a bez dalších podrobností. Velkou soubornou práci o výskytu zkřemenělých dřev v Čechách a historii jejich výzkumů sepsala Březinová (1970). Kromě článků Göpperta (1857, 1858) však žádná další práce zabývající se systematikou a klasifikací těchto zkamenělin až donedávna publikována nebyla. V posledních letech se modernímu výzkumu zkřemenělých stonků z hlediska jejich systematiky a paleoekologie věnují Matysová (2004, 2006), Mencl (2007), Matysová *et al*. (2008, 2010) či Mencl *et al*. (2009, 2013a, b – viz přílohy I, III, V).

4.2. Podkrkonošská pánev

Nejstarší zprávou o výskytu zkřemenělých dřev v podkrkonošské pánvi je pravděpodobně zmínka Malocha (viz Heber 1844), popisující dřeva z Pecky a Stupné bez jakýchkoli dalších souvislostí. Göppert krátce po svém výzkumu v oblasti vnitrosudetské pánve navštěvuje také tento region a popisuje dřeva z okolí Nové Paky, Pecky a Kozince jako *Araucarites schrollianus* (Göppert 1858). Jokély (1861, 1862) srovnává dřeva z Jestřebích hor s nálezy podobných kmenů v podkrkonošské pánvi (Pecka, Stupná a Borovnice). Ze sklepení hradu Pecky uvádí několik větších kmenů *Araucarites schrollianus*. Feistmantel (1873a, b, c) popisuje časté nálezy kmenů v arkózách, které mylně považuje za mladší než ony z pánve vnitrosudetské, mezi Novou Pakou, Stupnou a Peckou a na mnoha místech v okolí (Stará Paka, Vidochov, Vrchlabí, Semily). Katzer (1892) upozorňuje na velmi hojný výskyt zkřemenělých dřev u Pecky, Stupné a Kozince, stonků psaronií pak okolo Nové Paky. Frič (1912) uvádí výskyt různých druhů zkřemenělých stonků a rašelin z okolí Nové Paky a Lázní Bělohrad. Ve své práci se zabývá také vrtbami hmyzu, pozorovanými na povrchu některých kmenů, a přítomností epifytických kapradin *Ankyropteris brongniarti* (Renault) Stenzel v kořenových pláštích stromovitých kapradin. Nálezy velkého množství zkřemenělých dřev kolem Nové Paky, volně ležících v terénu, někdy též zachovaných ve výchozech, ale nikdy v jejich růstové pozici, popisuje Purkyně (1927). Stručné zmínky o výskytu zkřemenělých kmenů je možné nalézt v pracech několika dalších autorů, např. Vysockého (1859), Daňka (1902), Hynie (1927), Havleny (1958), Vítka (1986), Dernbacha (1996), Pišla (1996, 1997), Soukupa (1997), Dernbacha *et al*. (2002) aj. Stejně jako v pánvi vnitrosudetské, také zde se však modernímu systematickému výzkumu zkřemenělých dřev věnuje pozornost až v poslední době (např. Sakala *et al*. 2009, Mencl *et al*. 2013a, b, Opluštil *et al*. 2013 – viz přílohy II–V).

5. Systematický přehled zkřemenělých rostlin Podkrkonoší a anatomie jejich stonků

5.1. Plavuňovité rostliny (Lycopodiophyta)

Výtrusné rostliny náležející do monofyletické vývojové skupiny Lycophyta. Ve svrchním paleozoiku patřily k dominantním typům uhlotvorné vegetace (Kvaček *et al*. 2000, Donoghue 2005). Primárně mikrofylní rostliny s nečlánkovaným stonkem typu protostélé, sifonostélé, aktinostélé až plektostélé. Sifonostélické stonky fosilních stromovitých plavuní vytvářely až přes 40 m vysoké, přímé kmeny s dichotomickým až pseudomonopodiálním větvením, v nichž docházelo k tvorbě sekundárního xylému, produkovaného tenkou vrstvou unifaciálního kambia. Druhotného dřeva je však vzhledem k celkovému průměru kmenů velmi málo, největší část jejich objemu tvoří kůra, která je vyztužena silnými prosenchymatickými pláty a lze ji dle typu buněk rozlišit na vnitřní, střední a vnější. Vlastní stonek se skládá z často roztrhané dřeňové dutiny, vně s úzkým kruhem protoxylému a metaxylému, plynule přecházejícího do sekundárního xylému, jehož mocnost dosahuje nanejvýš několika centimetrů. Dřevo je budováno tracheidami, u protoxylému nejčastěji šroubovitě, v případě metaxylému a sekundárního xylému schodovitě ztlustlými. V dolní části stonků vyrůstaly větve, označované jako stigmarie, které nesly kořenové útvary appendices (Němejc 1963, Taylor *et al*. 2009).

Obr. 4: Zkřemenělá rašelina se šišticemi plavuní; podkrkonošská pánev, vzorek P5949 ze sbírky Městského muzea Nová Paka, měřítko = 20 mm.

Ve vnitrosudetské ani podkrkonošské pánvi nebyl výskyt izolovaných zkřemenělých stonků plavuní zatím popsán. V rostlinném detritu, zachovaném v podobě zkřemenělých rašelin (obr. 4), jsou však přítomny stigmarie, výtrusné šištice a části dalších pletiv (Němejc 1963, Opluštil *et al*. 2013 – viz příloha IV).

5.2. Přesličkovité rostliny (Sphenophyta)

Výtrusné rostliny, systematicky řazené do vývojového stupně Euphylophyta, spolu s kapradinami a psilofytními rostlinami náležející do monofyletické skupiny Monilophyta. Jsou typické svým přímým, článkovaným stonkem typu aktinostélé nebo arthrostélé (sifonostélé) a přeslenitým větvením mezi články (v internodiích). Ve svrchním paleozoiku dorůstaly výšky až 20 m a jejich stonek, který mohl dosahovat více než 60 cm v průměru, druhotně tloustl. Patřily k důležitým zástupcům karbonské uhlotvorné květeny (Kvaček *et al*. 2000, Rößler & Noll 2006, 2010, Taylor *et al*. 2009, Rößler *et al*. 2012a). Stonky stromovitých přesliček jsou charakteristické širokou, kruhovitou nebo oválnou dřeňovou dutinou uvnitř článků (tzv. "trubkové kmeny"), vzniklou rozpadem parenchymu. Malé množství parenchymatických buněk bývá zachováno na okrajích dutiny. Pruhy protoxylému kolem dřeňové dutiny se v nadzemních částech rostliny rovněž často roztrhávaly a vznikaly tak další dutiny – karinální kanálky, obklopené schodovitě ztlustlými tracheidami metaxylému. Sekundární xylém je tvořen silnostěnnými tracheidami s žebříčkovitými až retikulátními ztlustlinami a širokými parenchymatickými paprsky, které jsou dvojího typu: širší interfascikulární, oddělující klíny dřeva, a užší fascikulární, jenž se nacházejí uvnitř klínů xylému a oddělují jednotlivé řady tracheid. Po obvodu větších kmenů bývá zachována vnitřní a vnější kůra, tvořená tenkostěnnými parenchymatickými buňkami s pryskyřičnými kanálky. Anatomicky zachované kořeny přesličkovitých rostlin se označují nejčastěji jako *Astromyelon* Williamson a jsou typické absencí článkování a karinálních kanálků. Kolem parenchymatické dřeňové dutiny se rovněž vytváří druhotné dřevo, leč v mnohem menším množství než v nadzemních částech rostliny (Taylor *et al*. 2009).

Obr. 5: Zkřemenělý stonek přesličky *Arthropitys* cf. *bistriata* (výlitek centrální dutiny); podkrkonošská pánev, vzorek P1584 ze sbírky Městského muzea Nová Paka, měřítko = 20 mm.

Dřevo přesliček je možné dělit do 3 fosilních rodů dle typu tracheid a množství parenchymu:

Obr. 6: Zkřemenělý stonek přesličky *Arthropitys* cf. *bistriata* (příčný řez); podkrkonošská pánev, vzorek P1542 ze sbírky Městského muzea Nová Paka, měřítko = 20 mm.

1. *Arthropitys* Göppert (obr. 6): druhotné dřevo s jedním typem tracheid, které jsou uspořádány do zřetelných klínů, oddělených širokými dřeňovými interfascikulárními paprsky s vysokým podílem parenchymu (30–50%), tvořeného poměrně krátkými buňkami kvádrovitého tvaru. Tracheidy se mohou vyskytovat i uvnitř dřeňových paprsků (tzv. interfascikulární dřevo). *Arthropitys* je nejběžnějším typem přesličkovitých stonků (Röβler & Noll 2006, 2010, Röβler *et al*. 2012a).

2. *Calamitea* Cotta nov. emend. Röβler & Noll (dříve ***Calamodendron* Brongn.**, obr. 7): druhotné dřevo fascikulárních paprsků je složeno z 2 typů tracheid různé velikosti, z nichž průměr větších dosahuje přibližně dvojnásobku průměru menších. Zpravidla mají rovněž odlišné zbarvení. Parenchymu, tvořícího interfascikulární paprsky a úzké paprsky v sekundárním dřevu, je výrazně méně než u rodů *Arthropitys* a *Arthroxylon* (Röβler & Noll 2007).

Obr. 7: Část zkřemenělého stonku přesličky *Calamitea striata* (příčný řez); podkrkonošská pánev, vzorek P3173 ze sbírky Městského muzea Nová Paka, měřítko = 10 mm.

3. *Arthroxylon* Reed: vzácně se vyskytující rod. Druhotné dřevo obsahuje, podobně jako u rodu *Arthropitys,* až 50% parenchymu a je tvořeno jedním typem tracheid. Dřeňové paprsky jsou složeny z tenkostěnných, výrazně protažených buněk (Röβler & Noll 2002, 2006).

Dřeva přesliček prvních dvou rodů byla popsána z podkrkonošské pánve, dřeva typu *Arthropitys* také z pánve kladensko-rakovnické (Sakala *et al*. 2009, Mencl *et al*. 2013a – viz přílohy II–III).

5.3. Kapradinovité rostliny

Výtrusné rostliny tradičně řazené do vývojového stupně pteridofytních, dnes do vývojové linie Monilophyta. V podobě zkřemenělých stonků jsou v podkrkonošském permokarbonu zastoupeny 2 skupinami: 1) stromovitými kapradinami řádu Marattiales (rod *Psaronius* Cotta) a 2) drobnějšími formami kapradin řádu Filicales (rod *Ankyropteris* (Stenzel) P. Bertr). Nálezy jiných kapradinovitých rostlin zde dosud nebyly spolehlivě doloženy.

5.3.1. Kapradiny řádu Marattiales

Eusporangiátní stromovité kapradiny, jejichž zástupci přežívají dodnes. Stonky jsou typu složitého diktyostélé se zploštělými, na průřezu podkovovitě prohnutými cévními svazky, svou otevřenou stranou otočenými k ose kmenu a uloženými v základním parenchymu. Ve stoncích kapradin se nevytváří sekundární xylém, stabilitu rostlin zajišťuje mohutný plášť vzdušných kořenů, který lze dělit na vnější a vnitřní. Kořeny ve vnitřním pásu jsou navzájem propleteny, ke stonku připoutány sítí rhizoidních vláken a tvoří tak souvislou vrstvu. Kořeny vnějšího pásu jsou volné, navzájem propletené. Ve fosilním stavu jsou prostory mezi nimi zpravidla vyplněny okolním sedimentem. Cévní svazky vzdušných kořenů mají na průřezu tracheidy zpravidla zformované do čtyř-, pěti-, šesti- až mnohacípého tvaru. Protoxylém je tvořen šroubovitě ztlustlými tracheidami, metaxylém se skládá zejména ze schodovitě ztlustlých tracheid, místy s parenchymem. Cévní svazky jsou koncentricky uloženy, na průřezu patrny jako deskovité lamely. Kolem nich se vytváří korové pletivo složené

Obr. 8: Zkřemenělý stonek stromovité kapradiny *Psaronius* (příčný řez); podkrkonošská pánev, vzorek P1657 ze sbírky Městského muzea Nová Paka, měřítko = 20 mm.

z parenchymu s mnoha slizovými kanálky, které se však zpravidla nezachovávají (Stidd 1971, Ehret & Phillips 1977, Matysová 2009).

Nejznámější a nejrozšířenější karbonský rod *Psaronius* (obr. 8) je užíván pro mineralizované stonky těchto kapradin, které mohly dorůstat výšek až okolo 10 m. Stonky byly nevětvené, pouze s korunou listových vějířů na vrcholu. Nejčastěji je těmto stonkům přiřazováno olistění rodu *Pecopteris* (Brongn.) Sternb. Nálezy psaronií jsou běžné v permokarbonu Francie, Anglie či Německa, u nás se hojně vyskytují v podkrkonošské pánvi (např. Frič 1912, Němejc 1963, Matysová 2004, 2006), vzácně i pánvi kladensko-rakovnické (Dvořák – osobní sdělení 2013, Jech 2014).

5.3.2. Kapradiny řádu Filicales

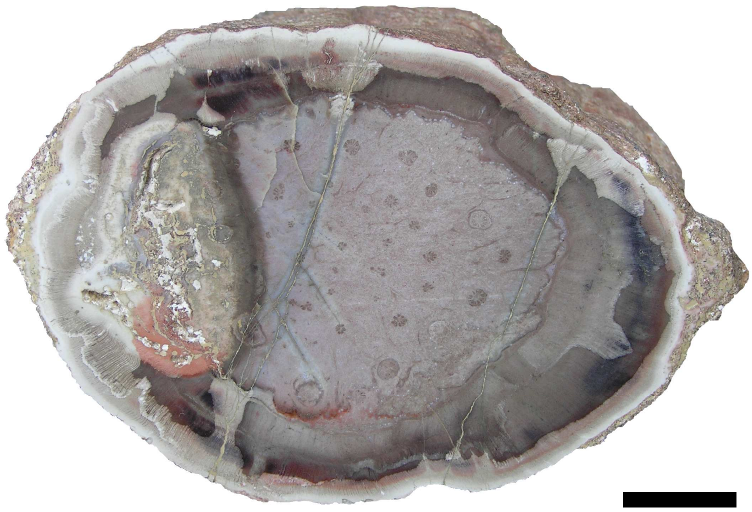
Leptosporangiátní kapradiny známé od karbonu do recentu. V podkrkonošské pánvi byly popsány nálezy popínavých kapradin z čeledi Tedeleaceae (Frič 1912, Němějc 1963). Rostliny z této skupiny jsou známy výhradně ze svrchního paleozoika, od sv. mississippu do sp. permu. Vytvářely obvykle poléhavé či liánovité formy, často epifyticky prorůstající kořenovými plášti stromovitých kapradin. Zdokumentovány jsou i případy jejich obtáčení okolo kmenů přesliček (Libertín & Dašková 2003, Rößler – osobní sdělení 2009). Stonky typu aktinostélé dosahují průměru okolo 2 cm, mají množství adventivních kořínků a jejich cévní svazky jsou na průřezu hvězdicovitě pěticípého tvaru. Primární xylém je tvořen dvěma druhy schodovitě ztlustlých tracheid s jednoduchým skalariformním tečkováním, vnitřních tenčích a vnějších silnějších, oddělenými vrstvou tenkých buněk parenchymu. Fylofory, které nesou listové vějíře a mohou se zanořovat do pláště kořenů stromovitých kapradin, mají cévní svazky s průřezem tvaru H nebo I a často jsou podkovovitě prohnuté. Nejběžnější rod *Ankyropteris* se objevuje v celé euramerické paleoprovincii v karbonu i permu (Němejc 1963, Phillips & Galtier 2005, 2011).

Dle nepotvrzených údajů se v podkrkonošské pánvi vyskytují rovněž drobné stromkovité kapradiny čeledi Anachoropteridaceae, rodu *Tubicaulis* Cotta (Rößler – osobní sdělení 2009), které jsou známé např. z Anglie, Francie či německého Chemnitz (Němejc 1963, Galtier & Phillips 2014).

5.4. Nahosemenné rostliny

5.4.1. Kapraďosemenné rostliny

Skupina vymřelých rostlin známých ze svrchního paleozoika. Rodem nejčastěji nalézaným v českém permokarbonu je *Medullosa* Cotta, patřící do třídy Lyginodendropsida, řádu Medullosales. Objevuje se poprvé ve svrchním mississippu a v permu vymírá (Taylor *et al*. 2009). Jeho zástupci dorůstali do velikosti drobnějších stromků. S těmito stonky jsou nejčastěji spojovány fosilní listové rody *Neuropteris* (Brongn.) Sternb., *Alethopteris* Sternb., *Linopteris* Presl a *O-dontopteris* (Brongn.) Brongn. Jsou to typické manoxylické dřeviny se zcela unikátním typem stonku, který je možné označit jako polysegmentární monostélé. Má složitou stavbu se zvláštním uspořádáním vodivé soustavy, slabým druhotným dřevem a bohatě rozvinutou dření se samostatnými segmenty cévních svazků, jenž vykazují eustélické znaky. Každý ze svazků se skládá z válce primárního xylému s pruhy parenchymu, obklopeného kambiem, které produkuje druhotné dřevo s více řadami dvůrkatě tečkovaných tracheid, až 8 buněk širokými dřeňovými paprsky a sekundárním floémem. Jednotlivé svazky jsou uloženy v parenchymu stonku (Taylor *et al*. 2009). Svazky se někdy po obvodu kmenu spojují a tvoří tlustší souvislý prstenec sekundárního xylému. Kromě hlavních cévních svazků se často objevují i vedlejší menší svazky, které jsou na průřezu kruhové (tzv. *star rings*). Po obvodu kmenů se vytváří poměrně mohutná kůra, vyztužená podélnými pruhy sklerenchymatického pletiva (tzv. sparganová struktura) (Němejc 1963, Stewart & Rothwell 1993). U nás nejběžnější druh *Medullosa stellata* Cotta (obr. 9) je typický uspořádáním centrálních cévních svazků, na příčném řezu dobře patrného hvězdicovitého tvaru, kolem nichž se vytváří válec prvotního a druhotného dřeva. Mezi často nalézané části patří také listové řapíky medullos, označované jako *Myeloxylon* Brongn. Bývají dosti mohutné, s kůrou podobnou kůře stonku se spar-



Obr. 9: Zkřemenělý stonek kapraďosemenné rostliny *Medullosa stellata* (příčný řez); podkrkonošská pánev, vzorek P1729 ze sbírky Městského muzea Nová Paka, měřítko = 20 mm.

ganovou strukturou. Vnitřní pletivo se skládá z parenchymu s velkým množstvím rozptýlených sekrečních kanálků a cévních svazků, četnějších po obvodu řapíku. Jejich druhotné dřevo je složeno ze šroubovitě a schodovitě ztlustlých tracheid. Vzdušné kořeny medullos jsou značně tlusté a obsahují druhotné dřevo a silnou kůru (Němejc 1963, Rößler 2001).

5.4.2. Jehličnaté rostliny (Pinophyta)

Kordaity (Cordaitopsida)

Představitelé třídy Cordaitopsida, tradičně řazení k jehličnatým rostlinám, se objevují v mississippu a vymírají v permu (Taylor *et al*. 2009). Patřili k nejmohutnějším zástupcům svrchnopaleozoické flóry, mohli dorůstat výšky až přes 48 m (Falcon-Lang & Bashforth 2005). Kromě vysokých stromů se však vyskytovaly i drobnější keřovité formy (Stewart & Rothwell 1993). Některé druhy kordaitů osidlovaly prostředí uhlotvorných močálů a trvale zaplavených příbřeží, kde spolu se stromovitými plavuněmi, přesličkami a kapradinovitými rostlinami tvořily smíšené vlhkomilné porosty. O jejich růstu v trvale zamokřeném nebo periodicky zaplavovaném prostředí svědčí nálezy jejich permineralizovaných kořenů *Amyelon* Will., široce a vodorovně rozložených na podkladu (Němejc 1963), nebo typů s chůdovitými kořeny (Taylor *et al*. 2009). Falcon-Lang (2003) však popisuje také suchomilnější typy rostoucí na vyvýšených, dobře odvodňovaných stanovištích v tropických oblastech.

Obr. 10: Dřeňová dutina *Artisia* (podélný řez); vnitrosudetská pánev, vzorek ze sbírky J. Boudného, měřítko = 50 mm.

Stromovité kordaity jsou typické monopodiálně, nepravidelně prostorově, či ve šroubovici větveným kmenem, na vrcholu s korunou velkých pentlicovitých listů. Složené šištice odděleného pohlaví vyrůstaly na koncích listových větévek. Pyl je zpravidla monosakátní, označovaný jako prepolen. Semena jsou bilaterálně souměrná, zploštělá, stonky eustélické, označované jako typ *Agathoxylon* (Rößler *et al*. 2014). Jejich poměrně široká dřeňová dutina (obr. 10) je u většiny kordaitů příčně segmentovaná (*Artisia* Sternb.). U některých kordaitů však toto přihrádkování chybí (např. *Mesoxylon priapi* Trivett & Rothwell). Na okrajích dřeňové dutiny bývají zachovány pruhy primárního xylému.

Pro kordaity i jejich anatomicky zachované stonky (obr. 11) byl v minulosti užíván název *Cordaites* Unger, původně definovaný pro olistění. Dnes jsou tyto fosílie řazeny do několika rodů: stonky s endarchním primárním xylémem nesou označení *Pennsylvanioxylon* D. Vogellehner a *Cordaixylon* Grand'Eury. Jejich vzájemné odlišení je problematické, jsou proto někdy neformálně označovány společným názvem *Cordaixylon-Pennsylvanioxylon* (Taylor *et al*. 2009). Stonky s mesarchním primárním xylémem byly definovány jako *Mesoxylon* Scott & Maslen emend. Trivett & Rothwell. Na rozdíl od rodu *Cordaixylon*, který má vyvinutou sympodiální vodivou soustavu s endarchními listovými stopami, vodivé elementy primárního xylému rodu *Mesoxylon* jsou typicky nesouvislé, nesympodiální. Pro větvičky s listovými jizvami uspořádánými do šroubovice je užíván název *Cordaicladus* Grand'Eury (Trivett & Rothwell 1985, Beck 2010).

Druhotné dřevo kordaitů je, stejně jako u ostatních lignophyt, produkováno bifaciálním kambiem a skládá se z tracheid a paprsčitého (radiálního) parenchymu, tvořeného protáhlými tenkostěnnými buňkami s jednoduchými ztenčeninami. Pryskyřičné kanálky se nevyskytují. Paprsky jsou převážně jednovrstvé a poměrně krátké, jejich výška se pohybuje přibližně v rozmezí 3–20 buněk. Na stěnách tracheid jsou vyvinuté dvojtečky, obvykle uspořádané do několika řad, hustě stěsnané a zformované do šestibokých tvarů a pokrývají celou plochu stěny tracheidy. Na průniku tracheid a dřeňových paprsků lze pozorovat tzv. křížová políčka, typická araukaroidním tečkováním (IAWA Committee 2004).

Konifery (Pinopsida)

Obsáhlá skupina rostlin, známá od svrchního paleozoika do recentu a vytvářející různé růstové formy, od drobných keřů po mohutné stromy. Stonky jsou tvořeny hustým (pyknoxylickým) dřevem s typickými kruhovitými dvojtečkami, primární xylém je endarchní. Listy, obvykle redukované a jehlicovité, vyrůstají ve šroubovici, nebo v přeslenu. Šištice jsou odděleného pohlaví, složené samičí a jednoduché samčí, které produkují ve většině případů sakátní pyl.

Ze svrchního paleozoika Českého masívu jsou známy primitivní jehličnany řádu Voltziales, čeledi Utrechtiaceae. Svým vzhledem a olistěním dnešním blahočetům podobné rostliny se objevují v pennsylvanu a vzácně přežívají až do jury. Charakteristické jsou zejména pro perm, kdy úspěšně osidlovaly sušší, ariditou postižené oblasti. Mají typicky orthotropický (vzpřímený) stonek a plagiotropické (horizontální) větvení v pseudopřeslenech. Pro jejich větévky s jehlicovitým olistěním a samičí šištice jsou nejčastěji užívány názvy *Walchia* Sternb., *Lebachia* Florin, či *Ernestiodendron* Florin (Taylor *et al*. 2009).

Obr. 11: Příčný řez dřevem typu *Agathoxylon* s dobře patrnými nepravými letokruhy; vnitrosudetská pánev, vzorek VS43 ze sbírky autora, měřítko = 20 mm.

Konifery patří mezi rostliny s eustélickým stonkem produkujícím mohutný válec hustého druhotného dřeva. To je tvořeno, podobně jako u kordaitů, tracheidami a protáhlými tenkostěnnými buňkami radiálního parenchymu. Paprsky jsou jednovrstvé až třívrstvé, vysoké 3–20 buněk. Stěny tracheid jsou pokryty dvojtečkami, které jsou na rozdíl od kordaitů zpravidla kruhovité a nepokrývají celou stěnu tracheidy. Pryskyřičné kanálky chybí. Dřeňová dutina s podélným rýhováním nese označení *Tylodendron* C. E. Weiss. Na okrajích dřeňové dutiny bývá zachován primární xylém (Noll *et al*. 2005, Taylor *et al*. 2009).

O rozlišení druhotného dřeva kordaitů a konifer se pokoušelo mnoho badatelů, např. Felix (1882, 1886), Frentzen (1931), Doubinger & Marguerier (1975). Jako kritérium byly nejčastěji uváděny různé typy tečkování na stěnách tracheid a jejich pokrytí tečkami, příp. též tečkování křížových políček. V poslední době se otázkou odlišení dřev kordaitů a konifer zabýval Noll *et al*. (2005). Ve své práci se nezaměřuje pouze na typ tečkování, ale bere v potaz i kombinaci jiných anatomických znaků, např. způsob větvení, charakter listových stop či stavbu primárního xylému (Noll *et al*. 2005, tab. 2). Jako pomocný znak je též možno využít odlišného průřezu tracheid na příčném řezu (Rößler – osobní sdělení 2010). Otázkou rozlišování dřev kordaitů a konifer z českého permokarbonu na základě anatomie sekundárního xylému se zabýval i autor této práce (Mencl 2007, Mencl *et al*. 2009, Mencl *et al*. 2013b – viz přílohy I, V) a další (např. Bureš 2011, 2013, Holeček 2011).

Nomenklatorická problematika týkající se araukaroidního typu dřeva je v odborných kruzích často diskutovanou otázkou. Pro tato dřeva bylo v minulosti užíváno několik různých označení, např. *Dadoxylon* Endlicher, *Agathoxylon* Hartig, *Araucarioxylon* Kraus, *Dammaroxylon* J. Schultze-Motel aj. Dle nejnovějších poznatků je nicméně doporučován název *Agathoxylon* (Rößler *et al*. 2014).

ZNAKY	**KORDAITY (Cordaitales)**	**KONIFERY (Voltziales)**
Radiální stěny tracheid	Dvojtečky hustě stěsnané, zpravidla šestibokého tvaru, pokrývají celou plochu stěny, uspořádány obvykle ve třech až pěti řadách	Dvojtečky rozmístěné dále od sebe, kruhovitého nebo oválného tvaru, nepokrývají celou plochu stěny, uspořádány v jedné, nanejvýš ve dvou řadách
Primární xylém	Do dřeňové dutiny přechází nepravidelně, tvoří zaoblené klíny	Do dřeňové dutiny přechází ve formě pravidelně uspořádaných klínů
Dřeňová dutina	Dřeň horizontálně příčně rozdělená (*Artisia*)	Dřeň podélně rýhovaná, zesílená v místech nasedání větví (*Tylodendron*)
Větvení	Nepravidelně prostorové či spirální	Pseudopřeslenité

Tab. 2: Některé rozlišovací znaky stonků typu *Agathoxylon*. Sestaveno dle Nolla *et al*. (2005).

.

6. Materiál a metody

Materiál

Vlastnímu výzkumu předcházelo několikaleté podrobné mapování výskytu zkřemenělých stonků na území obou pánví a získávání materiálu a dat. Pro výzkum dřev přesliček byly využity exponáty ze sbírek Městského muzea Nová Paka, Muzea východních Čech v Hradci Králové a z Leuckartovy kolekce chemnitzského muzea (*Museum für Naturkunde Chemnitz*). Vzorky dřev nahosemenných rostlin pocházejí ze sbírek Městského muzea Nová Paka, Krkonošského muzea v Jilemnici, několika soukromých sběratelů, či byly získány vlastním sběrem. Za účelem výzkumu byl rovněž konzultován materiál ze sbírek Muzea Českého ráje v Turnově, Přírodovědecké fakulty univerzity Karlovy v Praze, České geologické služby Praha, Krkonošského muzea ve Vrchlabí, Muzea Podkrkonoší v Trutnově a Městského muzea Rtyně v Podkrkonoší. Inventární čísla a signatury jednotlivých vzorků jsou uvedeny v přílohách I–V (Mencl *et al*. 2009; Sakala *et al*. 2009, Mencl *et al*. 2013a, b, Opluštil *et al*. 2013).

Metody

Z vybraných vzorků byly zhotoveny leštěné nábrusy, které byly studovány v odraženém světle pomocí binokulární lupy Leica EZ5. Z nejlépe zachovaných vzorků, pokud nehrozilo jejich zničení či výrazné poškození, byly následně zhotoveny výbrusy, standardně ve třech různých rovinách vůči ose stonku:

1) transversální (příčný řez) kolmo ku ose

2) radiální podélný řez (vedený rovnoběžně s osou středem stonku)

3) tangenciální podélný řez (rovnoběžně s osou mimo střed stonku).

Výbrusy byly poté detailně zkoumány v procházejícím světle s využitím mikroskopů Nikon Eclipse LV100Pol, Olympus BX-51 a Olympus SZX12. Všechny použité fotografie pořídil autor této práce pomocí digitálních fotoaparátů Canon D500, Olympus Camedia 5050 a Olympus DP73. Upravovány byly v programech AnalySIS a NISElements. Pro výpočty a operace se statistickými daty byl využit program Microsoft Excel 2007-2010. Terénní fotografie byly pořízeny fotoaparátem Olympus C765UZ a upravovány v programu GIMP2. Obrázky v textu byly kompletovány pomocí programu CorelDRAW 11. Tabulky byly vytvořeny v programu Microsoft Excel 2007, text práce sepsán v programu Microsoft Word 2007. Odborná terminologie je převzata z prací IAWA Committee (2004), Balabána (1955) a

Němejce (1963), seznam literatury a použité zdroje citovány dle standardu časopisu *Bulletin of Geosciences*.

7. Výsledky

Výskyt zkřemenělých částí rostlin je ve vnitrosudetské i podkrkonošské pánvi velmi hojný, byť je jejich počet neustále snižován intenzívní zemědělskou a sběratelskou činností, a kmeny dosahují délky i několika metrů (např. Mencl 2007, Mencl *et al*. 2009 – viz příloha I). V obou pánvích byl potvrzen výskyt zkřemenělých araukaroidních stonků typu *Agathoxylon*, náležejícím nahosemenným rostlinám třídy Pinophyta, v ploužnickém obzoru podkrkonošské pánve navíc bohatší rostlinné společenstvo obsahující i zbytky dalších typů rostlin. Na základě provedených studií anatomicky zachovaných částí sekundárního xylému a jiných pletiv bylo provedeno přesnější taxonomické zařazení nejčastěji nalézaných stonků, tj. jehličnatých rostlin a stromovitých přesliček. Dle poměrného zastoupení různých rostlinných typů bylo částečně rekonstruováno paleoprostředí v jednotlivých stratigrafických úrovních.

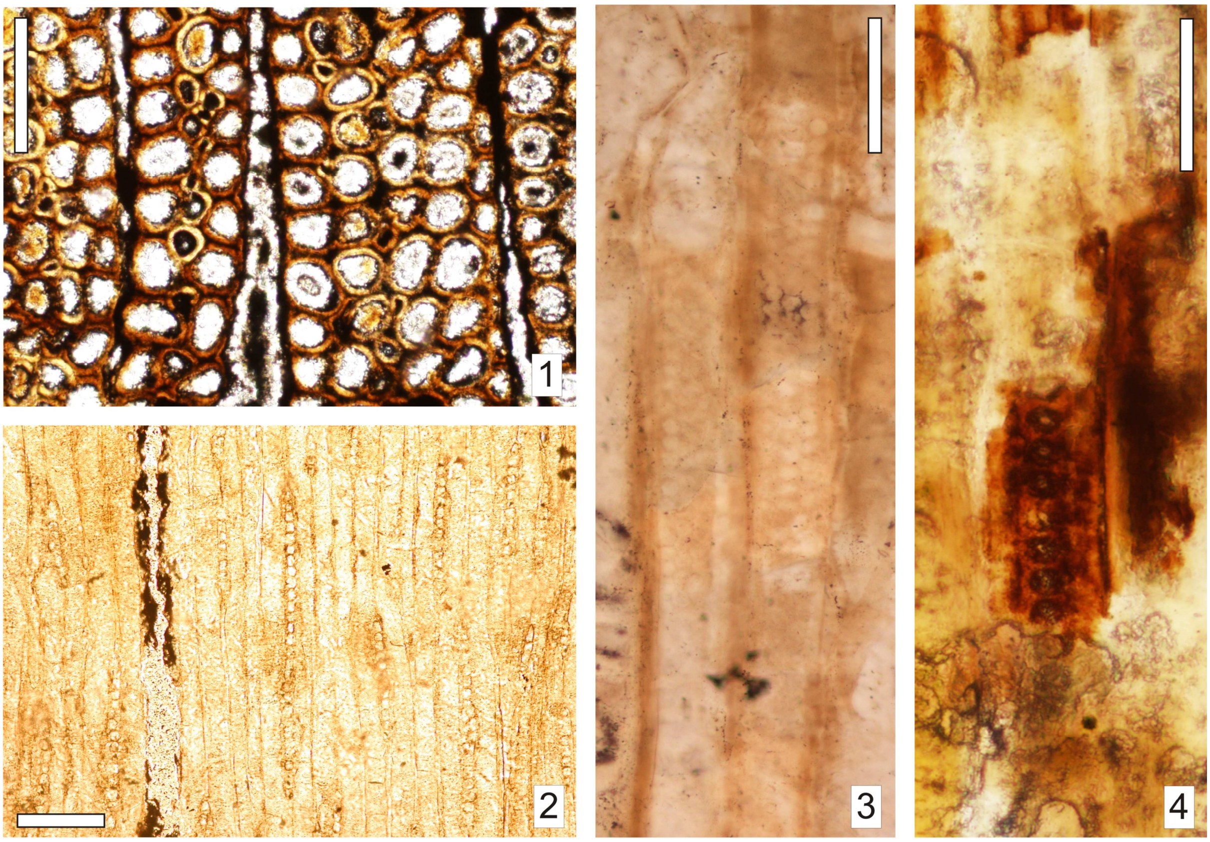
7.1. Vnitrosudetská pánev

7.1.1. Systematika

Zkřemenělá dřeva se v české části vnitrosudetské pánve vyskytují pouze v jediné stratigrafické úrovni, v žaltmanských arkózách odolovského souvrství. Výskyt zkřemenělých dřev v petrovických vrstvách podložního žacléřského souvrství, které zmiňují Tásler *et al*. (1979) a Prouza (osobní sdělení 2007) vlastním terénním výzkumem potvrzen nebyl.

Zkřemenělé zbytky rostlin jsou zachovány výhradně ve formě druhotného dřeva, které je typu *Agathoxylon*. Vzhledem k silnému stupni rekrystalizace dřevní hmoty a špatnému zachování anatomických struktur bylo možné na základě studia dvojteček (obr. 12/3) jednoznačně určit pouze několik vzorků. Všechny byly přiřazeny ke kordaitům (Mencl 2007, Mencl *et al*. 2009 – viz příloha I). Vzácně se u některých větších vzorků objevuje dřeňová dutina typu *Artisia* (obr. 10), nebo suky s pozůstatky větví, odbočujících nepravidelně prostorově z kmene (obr. 13). Tyto makroskopické znaky rovněž odpovídají kordaitům (Noll *et al.* 2005, Mencl *et al*. 2013b – viz příloha V).

Jiný typ zkřemenělých stonků ve vnitrosudetské pánvi není znám.



Obr. 12: Anatomické zachování dřev typu *Agathoxylon.*
1. Tracheidy sekundárního xylému (příčný řez); podkrkonošská pánev, vzorek P1760 ze sbírky Městského muzea Nová Paka, měřítko = 0,25 mm.
2. Jedno- až dvouvrstvé dřeňové paprsky (tangenciální řez); vnitrosudetská pánev, vzorek VS14 ze sbírky autora, měřítko = 0,01 mm.
3. Dvojtečky na stěnách tracheid kordaitu (radiální řez); vnitrosudetská pánev, vzorek VS12 ze sbírky autora, měřítko = 0,05 mm.
4. Dvojtečky na stěnách tracheid konifery (radiální řez); podkrkonošská pánev, vzorek S1 ze sbírky autora, měřítko = 0,05 mm.

7.1.2. Paleoprostředí

Dle Matysové *et al*. (2010) lze prostředí během ukládání žaltmanských arkóz charakterizovat jako fluviální až lakustrinní bez vlivu vulkanismu. Ze studia několika výchozů se zachovanými zkřemenělými kmeny je možné částečně odhadnout podmínky, během nichž k sedimentaci docházelo. Naprostá většina kmenů je uložena vždy při bázi těles výrazně hrubších, ostrou hranicí nastupujících sedimentů (Mencl 2007, Mencl *et al*. 2009 – viz příloha I). Na vybraných lokalitách bylo navíc provedeno měření prostorové orientace kmenů zachovaných ve výchozech, stejně jako sedimentárních struktur v jejich blízkosti. Výsledky ukazují převažující směr přínosu materiálu od Z či JZ a složení hornin odpovídá charakteru říčního toku na pomezí divočící a meandrující řeky (Mencl 2007, Mencl *et al*. 2009 – viz příloha I). Délka transportu sedimentů byla odhadnuta na maximálně několik desítek kilometrů (Martínek – osobní sdělení 2007).

7.2. Podkrkonošská pánev

7.2.1. Systematika

V podkrkonošské pánvi se zkřemenělé části rostlin podařilo nalézt celkem ve 4 stratigrafických úrovních: v brusnických vrstvách a štikovských arkózách kumburského souvrství, v ploužnickém obzoru semilského souvrství a ve svrchní části prosečenského souvrství (Mencl *et al*. 2013b – viz příloha V, tab. 1). V ploužnickém obzoru byly kromě dřev typu *Agathoxylon*, vyskytujících se ve všech čtyřech jednotkách, nalezeny také zkřemenělé zbytky několika dalších typů rostlin. Hojně se zde vyskytují stonky stromovitých přesličkovitých rostlin a kapradin, vzácněji i kapraďosemenných. Části plavuňovitých rostlin jsou známy pouze z tzv. zkřemenělých rašelin, tvořících až přes 1 m velké čočkovité konkrece se zachovaným rostlinným detritem (např. Němějc 1963, Opluštil *et al*. 2013 – viz příloha IV).

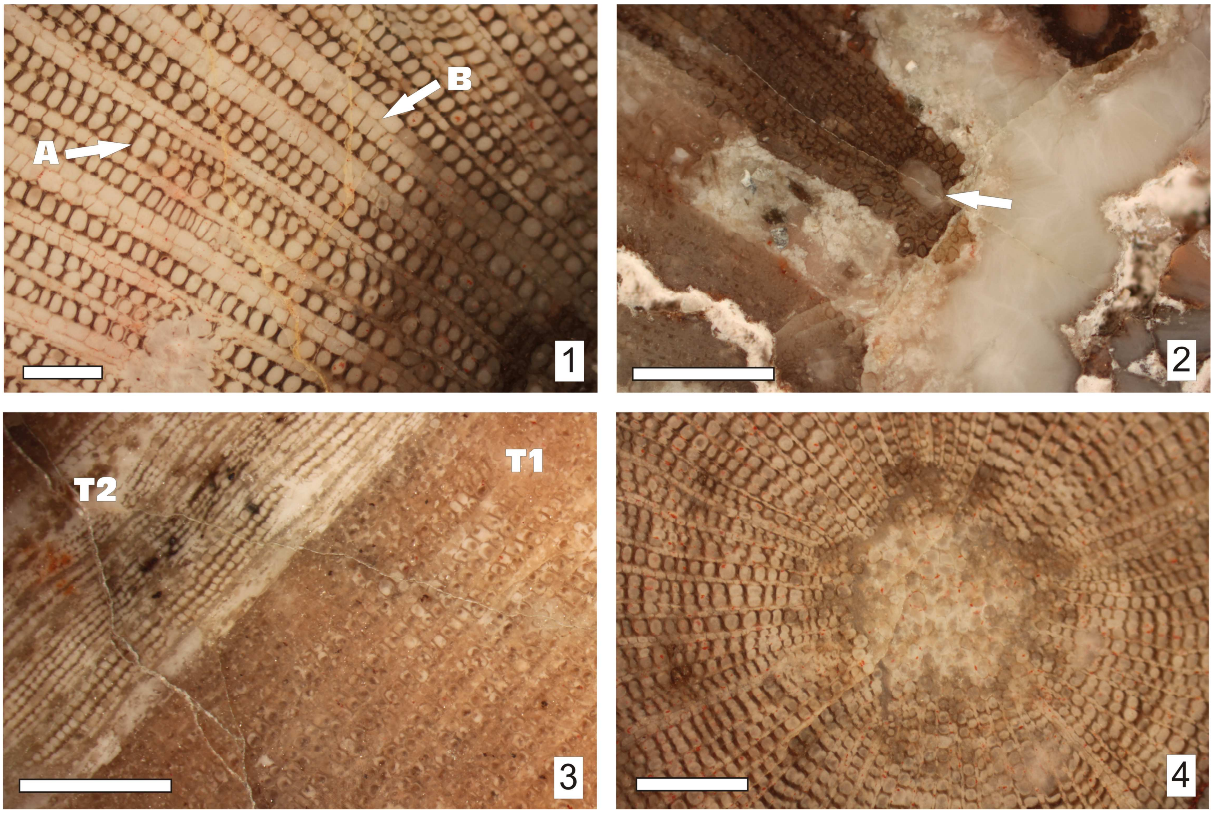
Dřeva kordaitů a jehličnanů

Typ dřeva *Agathoxylon* je v podkrkonošské pánvi nejběžnějším a jednoznačně nejčastěji nalézaným. Známy jsou exempláře až několik metrů dlouhé s průměrem větším než jeden metr (např. Mencl 2007, Mencl *et al*. 2013b – viz příloha V). Podstatná část velkých kmenů je výrazně zploštělá, elipsovitého průřezu, zbarvená organickými pigmenty do tmavohněda až černa, menší část z nich je světlá, načervenalá či béžová, přičemž barva vzorku nemá vliv na kvalitu zachování anatomických znaků. Při mikroskopickém studiu byla zaznamenána přítomnost tracheid sekundárního xylému, někdy s dvojtečkami na jejich radiálních stěnách a dřeňovými paprsky. Žádná primární pletiva ani další struktury pozorovány nebyly. Na základě makroskopických znaků a studia charakteru dvojteček (obr. 12/4) bylo možno vyčlenit dvě formální skupiny, které vykazují znaky blížící se kordaitům, resp. koniferám. Vzácně byly také nalezeny makroskopické struktury, zejména suky (obr. 13) a dřeňová dutina, které rovněž dovolují rozřadit vzorky do těchto skupin (Noll *et al.* 2005, Mencl *et al*. 2013b – viz příloha V).

Obr. 13: Větvení kordaitů a konifer. Nepravidelně odbočující větve kordaitu (vlevo, vnitrosudetská pánev, vzorek VS50 ze sbírky autora, měřítko = 70 mm) a pseudopřeslenité větvení konifery (vpravo, podkrkonošská pánev, vzorek J8766 ze sbírky Krkonošského muzea v Jilemnici, měřítko = 30 mm).

Dřeva přesličkovitých rostlin

Ze zkřemenělých stonků rostlin ploužnického obzoru jsou dřeva přesliček nejčastěji nalézaná. Byly objeveny až přes 1 m dlouhé části stonků těchto rostlin, většinou se však nalézají ve formě drobnějších úlomků, tvořených tmavým, červenohnědě nebo oranžově pigmentovaným, vzácněji i bělavým či šedým křemenem. Kromě úlomků vlastních stonků se výjimečně zachovávají i výlitky jejich dutin typu *Calamites* s nody a stopami po větvení.



Obr. 14: Anatomické zachování dřev přesliček.
1. Tracheidy sekundárního xylému (A) a parenchymatické buňky (B) dřeva druhu *Arthropitys* cf. *bistriata* (příčný řez); podkrkonošská pánev, vzorek H74692 ze sbírky Muzea východních Čech v Hradci Králové, měřítko = 0,5 mm.
2. Detail okraje dřeňové dutiny se zachovanými karinálními kanálky (šipka) dřeva druhu *Arthropitys* cf. *bistriata* (příčný řez); podkrkonošská pánev, vzorek P1992 ze sbírky Městského muzea Nová Paka, měřítko = 0,5 mm.
3. Dvojí typ tracheid (T1, T2) ve dřevu druhu *Calamitea striata* (příčný řez); podkrkonošská pánev, vzorek P3173 ze sbírky Městského muzea Nová Paka, měřítko = 0,5 mm.
4. Dřeňová dutina kořenu *Astromyelon* bez karinálních kanálků (příčný řez); podkrkonošská pánev, vzorek H74697 ze sbírky Muzea východních Čech v Hradci Králové, měřítko = 0,5 mm.

Při mikroskopickém studiu anatomie stonků byly pozorovány tracheidy sekundárního xylému, parenchymatické buňky, vzácně též primární pletiva, karinální kanálky a další struktury (obr. 14). Na základě jejich studia byly popsány dva druhy přesličkovitých rostlin – běžnější *Arthropitys* cf. *bistriata* (Cotta) Göppert emend. Rößler, Feng & Noll a poměrně vzácný *Calamitea striata* Cotta emend. Rößler & Noll. Zajímavostí je, že různé zbarvení dvou typů tracheid u druhu *Calamitea striata*, popsané z Chemnitz, neodpovídá (až na jednu vyjímku) zbarvení téhož dřeva z podkrkonošské pánve, nýbrž je inverzní (Mencl *et al*. 2013a – viz příloha III). Kromě částí stonků byly popsány také kořeny rodu *Astromyelon* (Sakala *et al*. 2009, Mencl *et al*. 2013a – viz přílohy II–III).

7.2.2. Paleoprostředí

Ve dvou stratigrafických úrovních kumburského souvrství byly pozorovány zkřemenělé kmeny zachované ve výchozech velmi hrubých arkózovitých slepenců. Ve zkoumaných výchozech prosečenského ani semilského souvrství takto zachované stonky objeveny nebyly. Poměrné zastoupení konifer vůči kordaitům v jednotlivých stratigrafických úrovních bylo statisticky zpracováno a korelováno s daty zjištěnými v dalších pánví. V porovnání s hodnotami v pánvích středočeských a západočeských se poměry ve stejných stratigrafických úrovních zřetelně liší, což může signalizovat odlišné přírodní poměry během ukládání těchto izochronních jednotek (Mencl *et al*. 2013b – viz příloha V).

Nápadná je variabilita rostlinného společenstva v ploužnickém obzoru. Sedimenty této jednotky jsou spíše jemnější, s vyšším obsahem vulkanoklastik. K jejich ukládání docházelo v nízkoenergetickém prostředí jezer, rašelinišť a zarůstajících močálů (Pešek *et al*. 2001, Stárková *et al*. 2009). Na rozdíl od ostatních fosiliferních stratigrafických úrovní obsahuje tato jednotka velmi málo dřev typu *Agathoxylon*, naproti tomu se zde hojně vyskytují stonky přesliček, kapradin, kapraďosemenných rostlin a petrifikované rašeliny s částmi plavuní. Nálezy z podkrkonošské pánve bylo možné porovnat s dřevy přesličkovitých rostlin z pánví středočeských a západočeských (Mencl *et al*. 2013a – viz příloha III) a také s poněkud mladšími nálezy z tzv. *Permského zkřemenělého lesa* v Chemnitz. Přítomnost dvou druhů *Arthropitys* cf. *bistriata* a *Calamitea striata*, stejně jako jejich poměrné zastoupení přibližně 99:1, odpovídá výsledkům výzkumů v jiných pánvích (např. Röβler & Noll 2006, 2007, 2010, Röβler *et al*. 2012a, b, Holeček 2011).

8. Diskuze

Stonky zkřemenělých rostlin se ve studovaných pánvích nacházejí ve čtyřech různých statigrafických pozicích, z nichž většina vykazuje podobné litologické složení, tj. hrubé arkózovité pískovce až slepence. Vyjímkou je pouze ploužnický obzor, tvořený spíše jemnějšími klastiky s významným podílem tufů a tufitů (Martínek 1997, Pešek *et al*. 2001). Ve všech statigrafických úrovních byl prokázán výskyt zkřemenělých dřev typu *Agathoxylon*. Rostliny s tímto typem stonku podle Falcon-Langa & Scotta (2000) osidlovaly spíše méně vlhké prostředí. Ačkoli dle Opluštila & Cleala (2007) spadají jednotky s výskytem zkřemenělých stonků převážně do aridnějších a sušších klimatických fází (tab. 1), nápadná variabilita vlhkomilného společenstva ploužnického obzoru a výrazný úbytek araukaroidních dřev v této jednotce zřejmě indikuje krátkou, humidnější epizodu ve vývoji pánve, kdy rostlinné společenstvo svým složením odpovídalo spíše hydrofilní bažinné flóře. Zachování odlišných typů rostlin však může také být důsledkem jiného litologického složení této jednotky a velmi krátkého transportu ukládaného materiálu (Stárková *et al*. 2009), který byly kromě sekundárního xylému schopny přečkat i méně odolné části rostlin, či přítomností vulkanoklastik jako potenciálního zdroje velkého množství křemitých roztoků impregnujících organické zbytky (např. Matysová *et al*. 2010, Mencl *et al*. 2013a – viz příloha III). Přijetí některé z těchto teorií by však nevysvětlovalo absenci dřev typu *Agathoxylon*, která jsou v ostatních fosiliferních jednotkách běžná.

Taxonomická klasifikace studovaných přesliček a nahosemenných rostlin byla provedena především na základě charakteru sekundárního xylému. Jiná rostlinná pletiva jsou zachována zcela výjimečně. Poměrné vzájemné zastoupení dvou popsaných druhů přesličkovitých rostlin přibližně odpovídá hodnotám zjištěným v jiných pánvích (např. Rößler & Noll 2006, 2007, 2010). Poměr kordaitů vůči koniferám se v jednotlivých stratigrafických úrovních vnitrosudetské a podkrkonošské pánve v porovnání se středočeskými a západočeskými pánvemi někdy značně liší. Tyto variace v procentuálním zastoupení obou typů rostlin (Mencl *et al*. 2013b – viz příloha V) mohou odrážet poněkud odlišné životní podmínky, které v daných oblastech panovaly. Předpoklad, že během svrchního paleozoika následkem zvyšující se aridity (např. Pešek *et al*. 1998, 2001) přibývá konifer na úkor kordaitů, se vzhledem k nedostatečnému množství dat s určitostí prokázat nepodařilo. Navíc celkový pohled na rostlinné společenstvo, rekonstruované výhradně z fosilního záznamu v říčních náplavech, může být značně zkreslený, neboť jeho druhové složení může být ovlivněno tím, že jsou zde zachovány především rostliny žijící v blízkosti vodních toků, kde důležitou roli hraje jejich stabilita a odolnost vůči vysoce energetickému vodnímu toku (např. Falcon-Lang 2003, Falcon-Lang & Bashforth 2005, Martín-Closas & Galtier 2005).

U žádných ze studovaných vzorků dřev nebyly identifikovány pravé letokruhy. Případné zóny s různým průměrem tracheid jsou zcela nepravidelné a zřejmě odrážejí pouze dočasné, neperiodické změny teploty a humidity v dané lokalitě. Hodnoty měření těchto elementů mohou však být někdy zavádějící, neboť ve většině případů byly k dispozici pouze drobné úlomky sekundárního xylému z různých částí stonků. Výkyvy v rozměrech tracheid a tloušťce jejich stěn tedy mohou být způsobeny např. jejich stářím a vzdáleností od kambia (Falcon-Lang 2005) nebo nepravidelnostmi v růstu rostliny, např. vznikem tlakového dřeva (Schweingruber 2007) atd. Pravidelné přírůstové zóny však nebyly pozorovány ani na žádném z několika větších studovaných vzorků. Na některých exemplářích jsou nápadné deformace struktury pletiv, vzniklé zřejmě stlačením dřeva a jeho slabou diagenezí krátce po pohřbení v sedimentu ještě před začátkem procesů silicifikace (Matysová 2006, Mencl 2007).

Stonky rostlin ze všech studovaných pánví prodělaly zřejmě podobný proces fosilizace pomocí křemitých roztoků. Dle Matysové (2006) a Matysové *et al*. (2008, 2010) byly tyto roztoky zejména produktem chemického zvětrávání živců a slíd, v případě ploužnického obzoru (a v menší míře i jiných jednotek) mohlo být navíc jejich množství pozitivně ovlivněno vulkanickými procesy. Ve všech případech jsou však zkřemenělé stonky uloženy v sedimentech tvořených transportovaným (přeplaveným) materiálem, tj. ve fluviálních až lakustrinních uloženinách (Stárková *et al.* 2009) Křemitá hmota impregnující stonky ve vnitrosudetské a podkrkonošské pánvi je složena z převážně nízkoteplotního α-křemene a nejlépe zachované části pletiv tvoří mikrokrystalický, polyblastický nebo oligoblastický křemen, který respektuje buněčné struktury jednotlivých elementů (Matysová 2006, Matysová *et al*. 2008). Ačkoli je každý nález specifický, obecně lze uvést, že je materiál dřev z vnitrosudetské pánve nápadně více rekrystalizovaný a jejich anatomické znaky mnohem hůře zachovány než u dřev z pánve podkrkonošské (Mencl 2007, Mencl *et al*. 2009 – viz příloha I). Ještě lepší zachování vykazují při vzájemném porovnání nálezy z pánví středočeských a západočeských (Holeček 2011, Mencl *et al*. 2013b – viz příloha V). Zajímavostí je fakt, že v Českém masívu jsou někdy lépe zachovaná dřeva z prostředí bez vlivu vulkanismu než z prostředí přímo ovlivněného vulkanickou činností. To je situace zcela odlišná např. od *Zkřemenělého lesa* v Chemnitz, francouzského Autunu či brazilského Araguaina, odkud bylo z vulkanoklastických sedimentů popsáno množství zkřemenělých rostlin *in situ* s dokonale zachovanou anatomií (např. Dernbach *et al.* 2002, Röβler & Noll 2006, 2007, 2010, Röβler *et al*. 2012a, b). Stupeň zachování tudíž zřejmě nesouvisí s původem a množstvím křemitých roztoků v sedimentu, ale spíše s typem a velikostí krystalů křemene vyplňujícího buňky rostlinných pletiv a počtem fází krystalizace (Matysová 2006, Matysová *et al.* 2008).

Ze studia charakteru žaltmanských arkóz vnitrosudetské pánve ve výchozech se zachovanými kmeny vyplývá, že jejich větší části byly zřejmě do pánve přinášeny za zvýšeného stavu hladiny řeky, zejména při povodních, kdy energie vodního proudu mohla přenášet, příp. i vyvracet z kořenů stromy rostoucí v blízkosti břehů nebo na vyvýšeninách v blízkém okolí. Transportu na poměrně velkou vzdálenost by odpovídalo i značné poničení kmenů před jejich uložením, např. dekortikace a absence dalších extraxylárních pletiv (Mencl 2007, Mencl *et al*. 2009 – viz příloha I). Podobné podmínky ukládání zřejmě panovaly po většinu svrchnopaleozoického období i v pánvi podkrkonošské. Dosud neobjasněna však zůstává zdrojová oblast přinášeného a ukládaného materiálu žaltmanských arkóz, zřejmě větší těleso granitoidních hornin. Vzhledem k naměřeným směrům přínosu materiálu do vnitrosudetské pánve by nejbližším pravděpodobným zdrojem materiálu mohl být středočeský pluton (Prouza – osobní sdělení 2007).

9. Závěr

Ve svrchnopaleozoických pánvích vnitrosudetské a podkrkonošské byl zmapován hojný výskyt silicifikovaných stonků rostlin v několika stratigrafických úrovních, které přibližně odpovídají jejich výskytu v pánvích středočeských a západočeských. Ve všech úrovních byla zjištěna přítomnost stonků typu *Agathoxylon*, v ploužnickém horizontu semilského souvrství (sp. gzhel) je navíc přítomno bohaté společenstvo několika různých typů zkřemenělých stonků, které nejčastěji náležejí přesličkovitým rostlinám. Části rostlinných pletiv bývají také zachovány v podobě zkřemenělých rašelin. Z důvodu chybějících výchozů hornin některých jednotek bylo stratigrafické zařazení nálezů z eluvií provedeno na základě staršího geologického mapování. Ve vnitrosudetské pánvi se na několika výchozech se zachovanými zkřemenělými kmeny podařilo změřit jejich prostorovou orientaci. Žádný z kmenů se nenacházel ve vzpřímené růstové pozici, všechny byly po transportu uloženy v pozicích subhorizontálních, většinou v hrubých arkózovitých sedimentech fluviálního původu. U většiny kmenů je zřetelně patrné značné předfosilizační poškození a zachován z nich téměř výlučně jen sekundární xylém, který je u velkého procenta vzorků zcela rekrystalizován a jeho detailní anatomické studium tudíž nemožné.

Výzkum byl zaměřen na nejčastěji se vyskytující dřeva přesliček a nahosemenných rostlin. Detailní studium zachovaných anatomických struktur druhotného dřeva přesliček prokázalo výskyt druhů *Arthropitys* cf. *bistriata* a *Calamitea striata*. Zachované anatomické znaky dřev typu *Agathoxylon* umožnily vymezit 2 skupiny, z nichž jedna vykazuje vlastnosti kordaitů, a druhá se svým charakterem blíží spíše koniferám. Paleoekologické interpretace vyplývající z různého poměrného zastoupení těchto dvou skupin je však nutné vzhledem k malému množství získaných dat považovat jen za velmi přibližné.

10. Literatura

BALABÁN, K. 1955. *Anatomie dřeva*. 216 pp. SZN, Praha.

BECK, C. B. 2010: *An introducing to plant structure and development*. 441 pp. Cambridge University Press, Cambridge.

BŘEZINOVÁ, D. (1970): *Přehled dosavadních nálezů fosilních dřev na území Československa zpracovaných na základě literárních pramenů*. Rukopis, Národní muzeum, Praha.

BUREŠ, J. 2011. Zkřemenělé kordaity a konifery v sedimentech líňského souvrství plzeňské karbonské pánve. *Erica 18*, 179–198.

BUREŠ, J. 2013. Morfologicko-anatomický průzkum dvou mohutných kmenů pyknoxylických dřev (kordaitů) z období stephanu plzeňské karbonské pánve. *Erica 20*, 179–190.

DANĚK, J. J. 1902. Studie o permském útvaru v Čechách. *Archiv pro přírodovědecké prozkoumání Čech XI (6)*.

DERNBACH, U. 1996. The petrified forest of Nová Paka. In: DERNBACH, U. (ed.): *Petrified Forests*. D'ORO Publishers, Heppenheim.

DERNBACH, U., TIDWELL, D. W., BARTHEL, M., GALTIER, J., JUNG, W., KERP, H., NOLL, R., RÖßLER, R., ROTHWELL, W. G., SELMEIER, A., STOCKEY, A. R., WILDE, V., WRIGHT, W. W. 2002. *Secrets of Petrified Plants, Fascination from Millions of Years.* D'ORO Publishers, Heppenheim.

DONOGHUE, M. J. 2005. Key innovations, convergence, and success: macroevolutionary lessons from plant phylogeny. *Paleobiology 31 (2)*, 77–93.

DOUBINGER, J. & MARGUERIER, J. 1975. Paléoxylologie: Étude anatomique comparée de *Scleromedulloxylon aveyronense* nov. gen. nov. sp. du Permien de St-Affrique (Aveyron, France); considérations taxinomiques et stratigraphiques. *Géobios 8 (1)*, 25–59.

EHRET, D. L. & PHILLIPS, T. L 1977. Psaronius root systems – morphology and development. *Paleontographica B, 161*, 147–164.

FALCON-LANG J. H. & SCOTT C. A. 2000. Upland ecology of some Late Carboniferous cordaitalean trees from Nova Scotia and England. *Palaeogeography, Palaeoclimatology, Palaeoecology 156 (3–4)*, 225–242.

FALCON-LANG, J. H. 2003. Late Carboniferous Tropical Dryland Vegetation in an Alluvial-plain Setting, Joggins, Nova Scotia, Canada. *Palaios V, 18*, 197–211.

FALCON-LANG, J. H. 2005. Intra-tree variability in wood anatomy and its implications for fossil wood systematics and palaeoclimatic studies. *Palaeontology 48 (1),* 171–183.

FALCON-LANG, J. H. & BASHFORTH, R. A. 2005. Morphology, anatomy, and upland ecology of large cordaitalean trees from the Middle Pennsylvanian of Newfoundland. *Review of Palaeobotany and Palynology 135 (3–4),* 223–243.

FEISTMANTEL, O. 1871. Über die Steikohlenflora der Ablagerung am Fusse des Riesengebirges. *Sitzungsberichte der königlichen böhmischen Gesellschaft der Wissenschaften 1*, 87–105.

FEISTMANTEL, O. 1872. O floře kamenouhelného uložené na úpatí hor krkonošských. *Vesmír*, 215.

FEISTMANTEL, O. 1873a. Geologische Stellung und Verbreitung der Verkieselten Holzer in Böhmen. *Verhandlung der Kaiserlich Königlichen Geologischen Reichsanstalt, Jg. 168, Nr. 6*, 108–112.

FEISTMANTEL, O. 1873b. Über die Verbreitung ung geologische Stellung der verkieselten Araucariten-Stämme in Böhmen. *Sitzungsberichte der königlichen böhmischen Gesellschaft der Wissenschaften 5,* 204–220.

FEISTMANTEL, O. 1873c. O zkřemenělých kmenech v permském útvaru českém. *Vesmír*, 176–178, 190–192, 208.

FELIX, J. 1882. Über die versteinerten Hölzer von Frankenberg in Sachsen. *Sitzungsberichte der Gesellschaft Naturforschender Freunde zu Leipzig 9, 9*, 5–9.

FELIX, J. 1886. Untersuchungen über den inneren Bau westfälischer Carbonpflanzen. *Abhandlungen der Königlich Preussischen Geologischen Landesanstalt 7, 3,* 56–58.

FRENTZEN, K. 1931. Studien über die fossilen Hölzer der Sammelgattung *Dadoxylon* Endl. *Abhandlung der Heidelberger Akademie der Wissenschaften 16,* 1–67.

FRIČ, A. 1912. Studie v oboru českého útvaru permského. *Archiv pro přírodovědecké prozkoumání Čech 15,* 18–23.

GALTIER, J. & PHILLIPS, T. L. 2014. Evolutionary and ecological perspectives of Late Paleozoic ferns. Part III. Anachoropterid ferns (including Anachoropteris, Tubicaulis, the Sermayaceae, Kaplanopteridaceae and Psalixochlaenaceae). *Review of Palaeobotany and Palynology 205,* 31–73.

GÖPPERT, H. R. 1857. Ueber den versteinerten Wald von Radowenz bei Adersbach in Böhmen und über den Versteinungsprocess überhaupt. *Jahrbuch der Kaiserlich Königlichen Geologischen Reichsanstalt, Bd. 8,* 725–738.

GÖPPERT, H. R. 1858. Ueber die versteinten Wälder im nördlichen Böhmen und in Schlesien. *Jahres-Bericht der Schlesischen Gesellschaft für Vaterländische Cultur 36,* 41–49.

HAVLENA, V. 1955. Vývoj stratigrafie permokarbonských uhelných oblastí Čech a Moravy. *Knihovna ÚÚG, sv. 28,* 32–43.

HAVLENA, V. 1958. Studie o geologii a stratigrafii permokarbonského synklinoria v Podkrkonoší. *Rozpravy Čsl. akademie věd, řada MPV 68 (7).*

HEBER, F. A. 1844. *Böhmens Burgen, Vesten und Bergschlösser 2.* C. M. Medau, Praha.

HERBING, J. 1904. *Über Steinkohlenformation und Rotliegendes bei Landshut, Schatzlar und Schwadowitz. Zur Geologie der böhmisch-schlesischen Grenzgebirges*. Wrocław.

HOLEČEK, J. 2011. *Svrchnokarbonská zkřemenělá dřeva západní části kladensko-rakovnické pánve.* Diplomová práce. Karlova univerzita, Praha.

HYNIE, O. 1927. Dosavadní výsledky mého mapování v permu podkrkonošském. *Věstník Státního geoogického ústavu Čsl. republiky III (6).*

IAWA COMMITTEE 2004. IAWA List of microscopic features for softwood identification. *IAWA J, 25,* 1–70.

JECH, F. 2014. Tak trochu jiný očihovský oddíl. *Zkamenělá dřeva a jiné křemité hmoty, www.zkamenela-dreva.cz.*

JIRÁSEK, V. 2003. *Ve znamení mlátku a želízka I.* Bor, Liberec.

JOKÉLY, J. 1861. Verbreiterung der Araucariten-Stämme im Rothliegenden Böhmens. *Jahrbuch der Geologischen Reichsanstalt 2 (1861–1862),* 392–395.

JOKÉLY, J. 1862. Uebersicht über die Lagerungsverhältnisse des Rothliegenden und der Kreidebildungen im nördlichen Theile des Königgrätzer Kreises in Böhmen. *Verhandlung der Kaiserlich Königlichen Geologischen Reichsanstalt (1861–1862),* 169–175.

KATZER, F. 1892. *Geologie von Böhmen*. Praha.

KREJČÍ, J. 1877. *Geologie čili nauka o útvarech zemských.* Praha.

KVAČEK, Z., FATKA, O., FEJFAR, O., HOLCOVÁ, K., KOŠŤÁK, M., KRAFT, P., MAREK, J., PEK, I. 2000. *Základy systematické paleontologie I.* Karolinum, Praha.

LIBERTÍN, M. & DAŠKOVÁ, J. 2003. The floristic assemblage from the pyroclastics rocks of the Tlustice Relict, Bolsovian, Czech Republic. *Abstract book, 14 International Workshop on Plant Taphonomy*, 5.

LOKVENC, T. 1985. Za tajemstvím zkamenělého lesa. *Krkonoše 18, č. 6*, 16–17.

LOKVENC, T. 1993. Araukarity Jestřebích hor. *Rodným krajem 6*, 22–24.

LOKVENC, T. 1997. Araukarity. In *Malé Svatoňovice, příroda a lidé pod Jestřebími horami*, 91–94. Malé Svatoňovice.

MAKOWSKY, A. 1878. Der „versteinerten Wald“ bei Radowenz in Böhmen. *Verhandlung des naturforschenden Vereines in Brünn 17*, 57–64.

MARTÍN-CLOSAS, C. & GALTIER, J. 2005. Plant Taphonomy and Paleoecology of Late Pennsylvanian Intramontane Wetlands in the Graissessac-Lodève Basin (Languedoc, France). *Palaios 20*, 249–265.

MARTÍNEK, K. in BLECHA ET AL. 1997. *Změny prostředí na rozhraní karbonu a permu a jejich dopad na společenstva organismů ve fosiliferních obzorech podkrkonošské pánve.* Závěrečná zpráva za grant GAČR. MS Archív ČGS, Praha.

MATYSOVÁ, P. 2004. *Zkřemenělá permokarbonská dřeva v oblasti vnitrosudetské a podkrkonošské pánve.* Bakalářská práce. Karlova univerzita, Praha.

MATYSOVÁ, P. 2006. *Permokarbonská silicifikovaná dřeva z vnitrosudetské a podkrkonošské pánve: Systematika a instrumentální analýza*. Diplomová práce. Karlova univerzita, Praha.

MATYSOVÁ, P. 2009. Psaronie, královny permokarbonu aneb Kapradiny trochu jinak. *Vesmír 88*, 380–385.

MATYSOVÁ, P., LEICHMANN, J., GRYGAR, T., RÖSSLER, R. 2008. Cathodoluminescence of silicified trunks from the Permo-Carboniferous basins in eastern Bohemia, Czech Republic. *European Journal of Mineralogy 20*, 217–231.

MATYSOVÁ, P., RÖSSLER, R., GÖTZE, J., LEICHMANN, J., FORBES, G., TAYLOR, E.L., SAKALA, J., GRYGAR, T. 2010. Alluvial and volcanic pathways to silicified plant stems (Upper Carboniferous-Triassic) and their taphonomic and palaeoenvironmental meaning. *Palaeogeography, Palaeoclimatology, Palaeoecology 292*, 127–143.

MENCL, V. 2007. *Svrchnokarbonská zkřemenělá dřeva vnitrosudetské pánve: Systematika a paleoprostředí.* Diplomová práce. Karlova univerzita, Praha.

MENCL, V., MATYSOVÁ, P., SAKALA, J. 2009. Silicified wood from the Czech part of the Intra Sudetic Basin (Late Pennsylvanian, Bohemian Massif, Czech Republic): systematics, silicification and palaeoenvironment. Neues *Jahrbuch für Geologie und Paläontologie – Abhandlungen, Band 252*, 269–288.

MENCL, V., HOLEČEK, J., ROESSLER, R., SAKALA, J. 2013a. First anatomical description of silicified calamitalean stems from the upper Carboniferous of the Bohemian Massif (Nová Paka and Rakovník areas, Czech Republic). *Review of Palaeobotany and Palynology 197,* 70–77.

MENCL, V., BUREŠ, J., SAKALA, J. 2013b. Summary of occurrence and taxonomy of silicified *Agathoxylon*-type of wood in late Paleozoic basins of the Czech republic. *Folia Musei rerum naturalium Bohemiae occidentalis. Geologica et Paleobiologica 47, 1–2,* 14–26.

MINÁŘ, P. 1993. Vrcholy Jestřebích hor. *Rodným krajem 7,* 17.

NĚMEJC, F. 1963. *Paleobotanika II, III.* ČSAV, Praha.

NOLL, R., RÖßLER, R., WILDE, V. 2005. 150 Jahre *Dadoxylon* – Zur Anatomie fossiler Koniferen- und Cordaitenhölzer aus dem Rotliegend des euramerischen Florengebietes. *Veröffentlichungen des Museums für Naturkunde Chemnitz 28*, 29–48.

OPLUŠTIL, S. & CLEAL, C. J. 2007. A comparative analysis of some Late Carboniferous basins of Variscan Europe. *Geological Magazine 144 (3)*, 417–448.

OPLUŠTIL, S., ŠIMŮNEK, Z., ZAJÍC, J., MENCL, V. 2013. Climatic and biotic changes around the Carboniferous/Permian boundary recorded in the continental basins of the Czech Republic. *International Journal of Coal Geology 119*, 114–151.

PEŠEK, J., OPLUŠTIL, S., KUMPERA, O., HOLUB, V., SKOČEK, V., DVOŘÁK, J., PROUZA, V., TÁSLER, R. 1998. *Paleogeographic atlas, Late Paleozoic and Triassic Formations, Czech Republic.* ČGS, Praha.

PEŠEK, J., HOLUB, V., JAROŠ, J., MALÝ, L., MARTÍNEK, K., PROUZA, V., SPUDIL, J., TÁSLER, R. 2001. *Geologie a ložiska svrchnopaleozoických limnických pánví České republiky*. Český geologický ústav, Praha.

PETRASCHECK, W. 1913. *Erläuterungen zum geologische Karte Josefstadt und Náchod.* Wien.

PETRASCHECK, W. 1922. Zur Entstehungsgeschichte der sudetischen Karbon- und Rotliegendablagerungen. *Zeitschrift der Deutschen Geologischen Gesellschaft 74 (1923)*, 244–262.

PETRASCHECK, W. 1924. *Kohlengeologie der österreichischen Teilstaaten I.* Wien.

PHILLIPS, T. L. & GALTIER, J. 2005. Evolutionary and ecological perspectives of Late Paleozic ferns. Part I. Zygopteridales. *Review of Palaeobotany and Palynology 135*, 165–203.

PHILLIPS, T. L. & GALTIER, J. 2011. Evolutionary and ecological perspectives of late Paleozoic ferns. Part II. The genus *Ankyropteris* and the Tedeleaceae. *Review of Palaeobotany and Palynology 164*, 1–29.

PIŠL, M. 1996. *Praprales*. Presstar, Turnov.

PIŠL, M. 1997. Zkamenělé dřevo – němý svědek minulosti. *Minerál 5*, 151–158.

PURKYNĚ, C. 1927. O nalezištích zkřemenělých kmenů araukaritových v Čechách, zvláště v Podkrkonoší. *Časopis Národního muzea CI*, 113–131.

PURKYNĚ, C. 1929. Karbon a perm v západním Podkrkonoší. *Rozpravy české akademie věd 38, 19*, 1–34.

RENGER, K. 1858. Skamenělé kmeny v Čechách. *Živa 6*, 254.

RENGER, K. 1863. O skamenělém lese Radvanickém blíže Abrspachu a o spůsobech skamenění vůbec. *Živa 11*, 362–375.

RÖßLER, R. 2001. *The Petrified Forest of Chemnitz*. Museum für Naturkunde Chemnitz.

RÖßLER, R. & NOLL, R. 2002. Der permische versteinerte Wald von Araguaina/Brasilien. Geologie, Taphonomie and Fossilführung. *Veröffentlichungen des Museums für Naturkunde Chemnitz 25,* 5–44.

RÖßLER, R. & NOLL, R. 2006. Sphenopsids of the Permian (I): the largest known anatomically preserved calamite, an exceptional find fromthe petrified forest of Chemnitz, Germany. *Review of Palaeobotany and Palynology 140*, 145–162.

RÖßLER, R. & NOLL, R. 2007. *Calamitea* Cotta, the correct name for calamitean sphenopsids currently classified as *Calamodendron* Brongniart. *Review of Palaeobotany and Palynology 144*, 157–180.

RÖßLER, R. & NOLL, R. 2010. Anatomy and branching of *Arthropitys bistriata* (Cotta) Göppert - new observations from the Permian petrified forest of Chemnitz, Germany. *International Journal of Coal Geology 83*, 103–124.

RÖßLER, R., FENG, Z., NOLL, R. 2012a. The largest calamite and its growth architecture - *Arthropitys bistriata* from the Early Permian petrified forest of Chemnitz. *Review of Palaeobotany and Palynology 185*, 64–78.

RÖßLER, R., ZIEROLD, T., FENG, Z., KRETZSCHMAR, R., MERBITZ, M., ANNACKER, V., SCHNEIDER, J. W. 2012b. A snapshot of an early Permian ecosystem preserved by explosive volcanism: new results from the Chemnitz Petrified Forest, Germany. *Palaios 27,* 814–834.

RÖßLER, R., PHILIPPE, M., VAN KONIJNENBURG-VAN CITTERT, J. H. A., MCLOUGHLIN, S., SAKALA, J., ZIJLSTRA, G. 2014. Which name(s) should be used for Araucaria-like fossil wood? Results of a poll. *Taxon 63*, 177–184.

SAKALA, J., MENCL, V., MATYSOVÁ, P. 2009. Nové poznatky o svrchně karbonských prokřemenělých stoncích stromovitých přesliček z Novopacka. *Zprávy o geologických výzkumech v roce 2008,* 111–113.

SCHADE, J. 1896. Über *Araucarites Schrollianus* Göppert. *Das Riesengebirge in Wort und Bild 16, 3–4,* 70–71.

SCHWEINGRUBER, F. H. 2007. *Wood Structure and Environment.* 279 pp. Springer, Berlin.

SOUKUP, J. 1997. Silicifikovaná dřeva v západním Podkrkonoší. *Minerál 5,* 180–182.

STÁRKOVÁ, M., ŠIMŮNEK, Z., MARTÍNEK, K. 2009. Připravovaný výzkum ploužnického obzoru semilského souvrství, jeho geneze a paleoekologické podmínky v době sedimentace. *Acta Musei Turnoviensis 4*, 120–124.

STEWART, N. W. & ROTHWELL, W. G. 1993. *Paleobotany and the Evolution of Plants*. Cambridge University Press, Cambridge.

STIDD, B. M. 1971. Morphology and anatomy of the frond *Psaronius*. *Paleontographica B, 134*, 87–123.

STUR, D. 1877. Zwei Notizen über die Araucariten in nordöstlichen Bohmen. *Verhandlung der Kaiserlich Königlichen Geologischen Reichsanstalt*, 237–240.

TÁSLER, R., ČADKOVÁ, Z., DVOŘÁK, J., FEDIUK, F., CHALOUPSKÝ, J., JETEL, J., KAISEROVÁ-KALIBOVÁ, M., PROUZA, V., SCHOVÁNKOVÁ-HRDLIČKOVÁ, D., STŘEDA, J., STŘÍDA, M., ŠETLÍK, J. 1979. *Geologie české části vnitrosudetské pánve.* ÚÚG, ČSAV, Praha.

TAYLOR, T. N., TAYLOR, E. L., KRINGS, M. 2009. Paleobotany, *The Biology and Evolution of Fossil Plants, 2nd edition.* 1230 pp. Elsevier Academic Press, Amsterdam.

TRIVETT, M. L. & ROTHWELL, G. W. 1985: Morphology, Systematics, and Paleoecology of Paleozoic Fossil Plants: Mesoxylon priapi, sp. nov. (Cordaitales). *Systematic Botany 10 (2)*, 205–223.

VALÍN, F. 1956. Hydrodynamické podmínky během sedimentace žaltmanských arkóz. *Zprávy o geologických výzkumech v roce 1956*, 182–183.

VALÍN, F. 1960. Litologie souvrství žaltmanských arkóz. *Sborník ÚÚG 26*, 409–437.

VÍTEK, J. 1986. Araukarity v Nové Pace. *Přírodní vědy ve škole 37 (5)*, 175.

VYSOCKÝ, P. 1859. Některé poměry permského útvaru v severozápadních Čechách. *Živa VII*, 211–218.

WALZEL, F. 1938. Versteinerter Wald von Radowenz. *Firgenwald 11*, 30–31.

11. Seznam publikovaných článků

Práce je předkládána jako konvolut níže uvedených článků. Práce č. I, III a IV byly publikovány v mezinárodních impaktovaných časopisech, práce č. II a V v časopisu zařazeném do Seznamu recenzovaných neimpaktovaných periodik schváleného Radou vlády pro výzkum, vývoj a inovace. Řazeno chronologicky.

Seznam článků	
I.	Mencl, V., Matysová, P., Sakala, J., 2009. Silicified wood from the Czech part of the Intra Sudetic Basin (Late Pennsylvanian, Bohemian Massif, Czech Republic): systematics, silicification and palaeoenvironment. Neues Jahrbuch für Geologie und Paläontologie - Abhandlungen Band 252, 269–288.
II.	Sakala, J., Mencl, V., Matysová, P., 2009. New data on Upper Carboniferous silicified stems of calamites from the Nová Paka region. Geoscience Research Reports for 2008, 111–113.
III.	Mencl, V., Holeček, J., Roessler, R., Sakala, J. 2013a. First anatomical description of silicified calamitalean stems from the upper Carboniferous of the Bohemian Massif (Nová Paka and Rakovník areas, Czech Republic). Review of Palaeobotany and Palynology 197, 70–77.
IV.	Opluštil, S., Šimůnek, Z., Zajíc, J., Mencl, V. 2013. Climatic and biotic changes around the Carboniferous/Permian boundary recorded in the continental basins of the Czech Republic. International Journal of Coal Geology 119, 114–151.
V.	Mencl, V., Bureš, J., Sakala, J. 2013b: Summary of occurrence and taxonomy of silicified *Agathoxylon*-type of wood in late Paleozoic basins of the Czech republic. Folia Musei rerum naturalium Bohemiae occidentalis. Geologica et Paleobiologica 47, 1–2, 14–26.

12. Přílohy

Příloha I

N. Jb. Geol. Paläont. Abh.
2009, vol. 252/3, p. 269–288, Stuttgart, June 2009, published online 2009

Silicified wood from the Czech part of the Intra Sudetic Basin (Late Pennsylvanian, Bohemian Massif, Czech Republic): systematics, silicification and palaeoenvironment

Václav Mencl, Petra Matysová and **Jakub Sakala,** Prague

With 13 figures and 2 tables

Mencl, V., Matysová, P. & Sakala, J. (2009): Silicified wood from the Czech part of the Intra Sudetic Basin (Late Pennsylvanian, Bohemian Massif, Czech Republic): systematics, silicification and palaeoenvironment. – N. Jb. Geol. Paläont. Abh., **252**: 269–288; Stuttgart.

Abstract: Silicified trunks, colloquially called "*araukarity*", are plentiful plant fossils of the Late Pennsylvanian in the Czech part of the Intra Sudetic Basin (ISB) in NE Bohemia. They are predominantly embedded in Žaltman Arkoses, a unit of fluvial sediments deposited during Barruelian, Late Carboniferous. This unit is a part of the Odolov Formation with the richest outcrops in the area of "Jestřebí hory" (Hawk Mts.). Since Goeppert (1857) firstly described these fossils as species *Araucarites brandlingii* and *A. schrollianus*, interpreting both as conifer woods close to the Araucariaceae, they have later never been re-examined or studied as a whole by any modern analytical methods. As the original material of Goeppert was unavailable to our study, we re-evaluated the previous taxonomical assignments on the basis of newly collected material and supplemented a detailed description of their mineral matter (petrography, mineralogy). Following the modern classification, *A. brandlingii* (= *Dadoxylon brandlingii*) describes the wood of cordaites, and *Araucarites schrollianus* (= *Dadoxylon saxonicum* syn. *Dadoxylon schrollianum*) is a name of conifer wood, but our systematical study proves only the presence of cordaites. The pycnoxylic stems were silicified in alluvia without apparent influence of volcanic material. Data from sedimentary structures were used for reconstructions of palaeostreams. The weathering of feldspars is presumed as a source of silicification amplified by the oscillation of water table under seasonally arid periods within Late Pennsylvanian/Early Permian long climate cycles. This mode of permineralization is responsible for frequently poor preservation and high recrystallization of these fossils. Their mineral mass consists of pure highly crystalline quartz without other SiO_2 phases. Cathodoluminescence (CL) microscopy and spectroscopy revealed a polyphase process of silicification including influence of thermal fluids which healed cracks in previously silicified mass. It is possible that all these facts responsible for poor preservation of anatomical features of *Dadoxylon* wood type have precluded its more detailed taxonomical study for more than one century.

Key words: silicified wood, *Dadoxylon*, α-quartz, petrography, cathodoluminescence, imaging, Late Pennsylvanian, Intra Sudetic Basin, arkoses, fluvial sediments.

1. Introduction

1.1. Historical insight

In the area of Jestřebí hory (Hawk Mountains, Czech part of the Intra Sudetic Basin – ISB), silicified trunks colloquially called "*araukarity*" (in *Czech*) have been known for a long time. The first scientific description was done by Heinrich Robert Goeppert, a famous palaeontologist from the University of Wroclaw. He once received several samples from Benedikt Schroll,

DOI: 10.1127/0077-7749/2009/0252-0269 0077-7749/09/0252-0269 $ 5.00

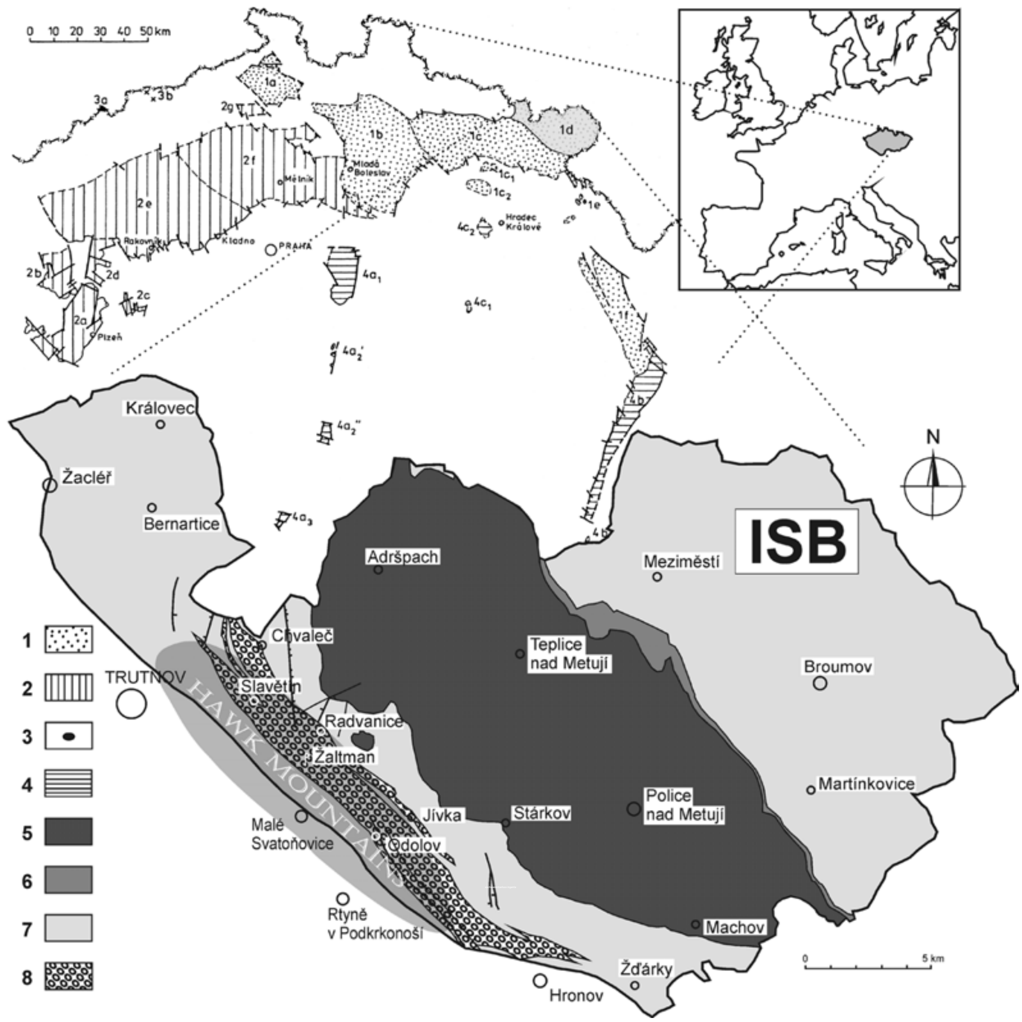


Fig. 1. 1-4: Permo-Carboniferous basins of the Czech Republic with the position of the Intra Sudetic Basin (1 – Lugic Basins with '1d' as the Czech part of the Intra Sudetic Basin; 2 – Central and Western Bohemian basins, 3 – Upper Palaeozoic of the Krušné Mts., 4 – furrows). 5-8: Simplified geological map of the Czech part of the Intra Sudetic Basin with a highlighted area of the Hawk mountains (5 – Upper Cretaceous, 6 – Triassic, 7 – Permo-Carboniferous, 8 – Žaltman Arkoses (Odolov Fm.), some tectonic faults or grabens marked) modified after Report (1994) and Pešek et al. (2001).

a local mine and factory owner living in the area of Hawk Mts., and accepted his invitation. Schroll as an amateur geologist and collector possessed several pieces of local silicified fragments and recognized xylem structures within them. Goeppert came to the Hawk Mts. for the first time in 1856. He explored the whole region and specified that silicified woods occurred in the area of about 30 x 7.5 kilometres (Goeppert 1858). The biggest amount of trunks was found on the Slavětín hill and in a neighbourhood of Brendy village. He named this place "Radvanice fossil forest" (*Versteinerter Wald bei Radowenz*) and considered it to be of a world uniqueness. In the area of the Hawk Mts., he estimated the total mass of woods to almost 1700 tonnes. The length of stems reached about 6 m in some cases and average thickness varied between 40 and 50 cm. Some stems were circular in cross-section but most of them were oval because of compression. On the surface of all stems there were obvious striae but bark was not preserved or only very exceptionally (Goeppert 1858). On some logs, knots with fragments of branches with a maximum length of 45 cm were discovered. The largest trunks had cavities up to 7 cm in diameter and reportedly also growth

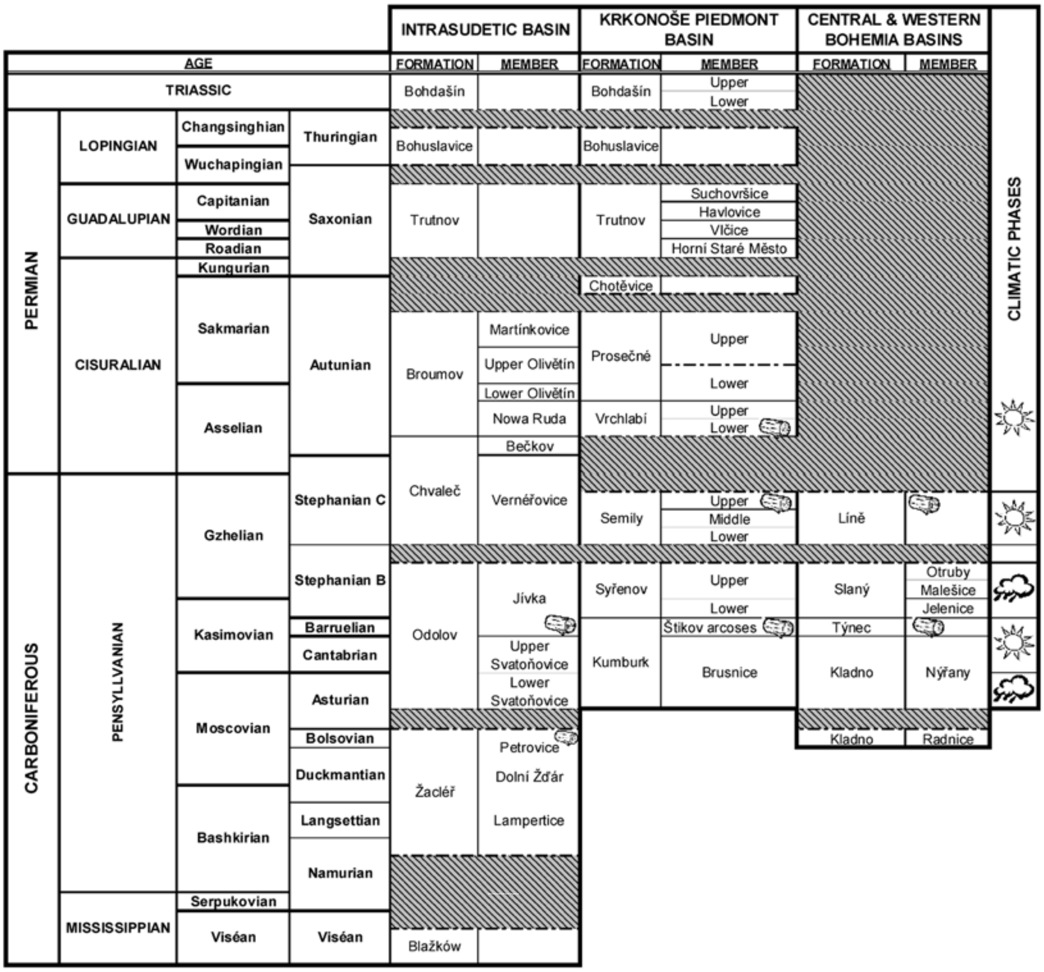


Fig. 2. Stratigraphy of the Intra Sudetic Basin in comparison with the Krkonoše-Piedmont and Central and Western Bohemian basins; positions of the fossil wood (small log) and supported climatic phases marked, compiled after Skoček (1970), Tásler et al. (1979), Pešek et al. (2001), Roscher & Schneider (2005), and Opluštil & Cleal (2007). Notes to pictures: cloud – humid or seasonally humid climate, sun – seasonally dry to seasonally arid climate.

rings, 2.5 to 8 cm wide. Goeppert (1857, 1858) considered light-grey chalcedony and chert as the main components forming the permineralized stems. After a microscopic study based on the similarity to the wood of modern *Araucaria*, Goeppert (1857, 1858) classified these silicified woods to two following species: the previously described *Araucarites brandlingii* (Lindl. & Hutt.) Goepp., and his newly erected *Araucarites schrollianus* Goepp. (Goeppert 1857). He interpreted both species as belonging to a group of conifers (type *Araucarites*). Furthermore, he described the fossiliferous rock Žaltman Arkoses (*Sandsteinfelsen*) as the Upper Carboniferous part of a black coal bearing unit (*Steinkohlenformation*). Goeppert's works raised attention of a lot of scientists and amateur collectors. An unwanted consequence was that most of deposits had been spoiled or destroyed during following years. The locality followed the unlucky fate of once famous silicified *Dadoxylon* wood formed in very similar facies in the Kyffhäuser Massif in Germany (Rössler 2002).

Although many authors (e.g., Stur 1877; Makowsky 1878; Katzer 1892; Petrascheck 1924; Purkyně 1927; Březinová 1970) wrote about this area and its silicified wood in general, nobody has studied both wood anatomy and systematics in detail since Goeppert.

1.2. Current research

In this contribution, we focused on newly discovered silicified trunks, still very common in the studied area (Mencl 2007). Silicified trunks are found almost in all large Late Palaeozoic basins in the Czech Republic shown in Fig. 1 (Pešek 1968; Holub et al. 1975; Tásler et al. 1979; Report 1994; Pešek et al. 2001). They are mostly embedded in very similar sedimentary sandstones or arkosic units (Skoček 1970; Tásler et al. 1979; Pešek et al. 2001; Matysová 2006; Mencl 2007; Opluštil & Cleal 2007 and references therein; Fig. 2) that correspond to drier intervals from the Stephanian to the Early Permian mentioned by Opluštil & Cleal (2007). Contrary to other Permocarboniferous basins in the world with variable types of fossil wood/plants (e.g., Falcon-Lang & Scott 2000; Falcon-Lang & Bashforth 2005; Rössler 2006; Uhl 2006; Wagner & Mayoral 2007), only one type of wood (*Dadoxylon*) is considered to be present in the Czech part of the Intra Sudetic Basin. Fossils are very recrystallized, probably preserved without any direct influence of volcanism, and fit to Barruelian sedimentary units (Fig. 2).

The systematical study of the newly collected material presents only one aspect of our work; we paid attention to geological setting and orientations of trunks in fluvial deposits (Valín 1960; Liu & Gastaldo 1992; Bridge 2003; Gastaldo & Degges 2007), furthermore to mineralogical, petrographical and instrumental analyses in the sense of the work done by Matysová (2006) and Matysová et al. (2008). Microscopic studies as well as geochemical analyses were undertaken on polished thin slides or sections. For petrograhic description of SiO_2 the international classification was used (Flörke et al. 1991). For textures of SiO_2 crystals in permineralized plants we used terminology published by Weibel (1996) and references therein. Cathodoluminescence microscopy and spectroscopy (CL) proved very useful in qualitative and quantitative analysis of mineral matter creating the fossil trunks (Götze & Rössler 2000; Götze & Zimmerle 2000; Götze et al. 2001; Matysová et al. 2008) or just various mineral grains (e.g., Götte & Richter 2006). All new gathered data served as a clue for upgraded framing such fossils into basinal history and palaeoenvironment.

2. Geological setting

The Czech part of the Intra Sudetic basin is situated in the NE part of the Czech Republic (Fig. 1). Its stratigraphical range of deposits is the widest among all Czech Late Palaeozoic basins. The sedimentation was continuous (except for several hiatuses) from the Mississippian to the Middle Triassic (Pešek et al. 2001; Opluštil & Cleal 2007). The maximum thickness of deposits is about 3500 m (Chlupáč et al. 2002). The whole set is divided into 8 formations with a well established correlation to European stratigraphical units (after Tásler et al. 1979; Tásler et al.

Table 1. List of selected representative permineralized samples of *Dadoxylon* sp. from the Hawk Mts. (Intra Sudetic Basin). Cathodoluminescence measurements (CL) of chosen samples marked by *i* (imaging) and *s* (spectroscopy). Abbreviations: VS (*in Czech*) means Intra Sudetic Basin, *OdFm* – Odolov Formation (Žaltman Arkoses), *s.a.d.* – secondary alluvial deposits, * – without stratigraphic assignment, *qtz* – quartz (SiO_2), *K-fld* – K-feldspars.

Sample	Description of deposit	Stratigraphy	Mineralogy	CL
VS1	fragment from a memorial – unknown origin	*	qtz	*i*
VS2	fragment from a bigger trunk – on a road	*s.a.d.*	qtz	*i*
VS3	outcrop – Žaltman	*OdFm*	qtz	*i*
VS4	weathered on surface	*s.a.d.*	qtz	*i*
VS6	freely in a stream	*s.a.d.*	qtz	*i, s*
VS7	on a track in wood	*s.a.d.*	qtz	*i, s*
VS10	weathered material – marshland	*s.a.d.*	qtz	
VS11	artificial assemblage	*	qtz	
VS12	surface of a field	*s.a.d.*	qtz	
VS13	artificial assemblage	*	qtz	
VS14	artificial assemblage	*	qtz	
VS21	in a stream	*s.a.d.*	qtz + K-fld	*i*
VS34	in a stream	*s.a.d.*	qtz	
VS35	in a stream	*s.a.d.*	qtz	

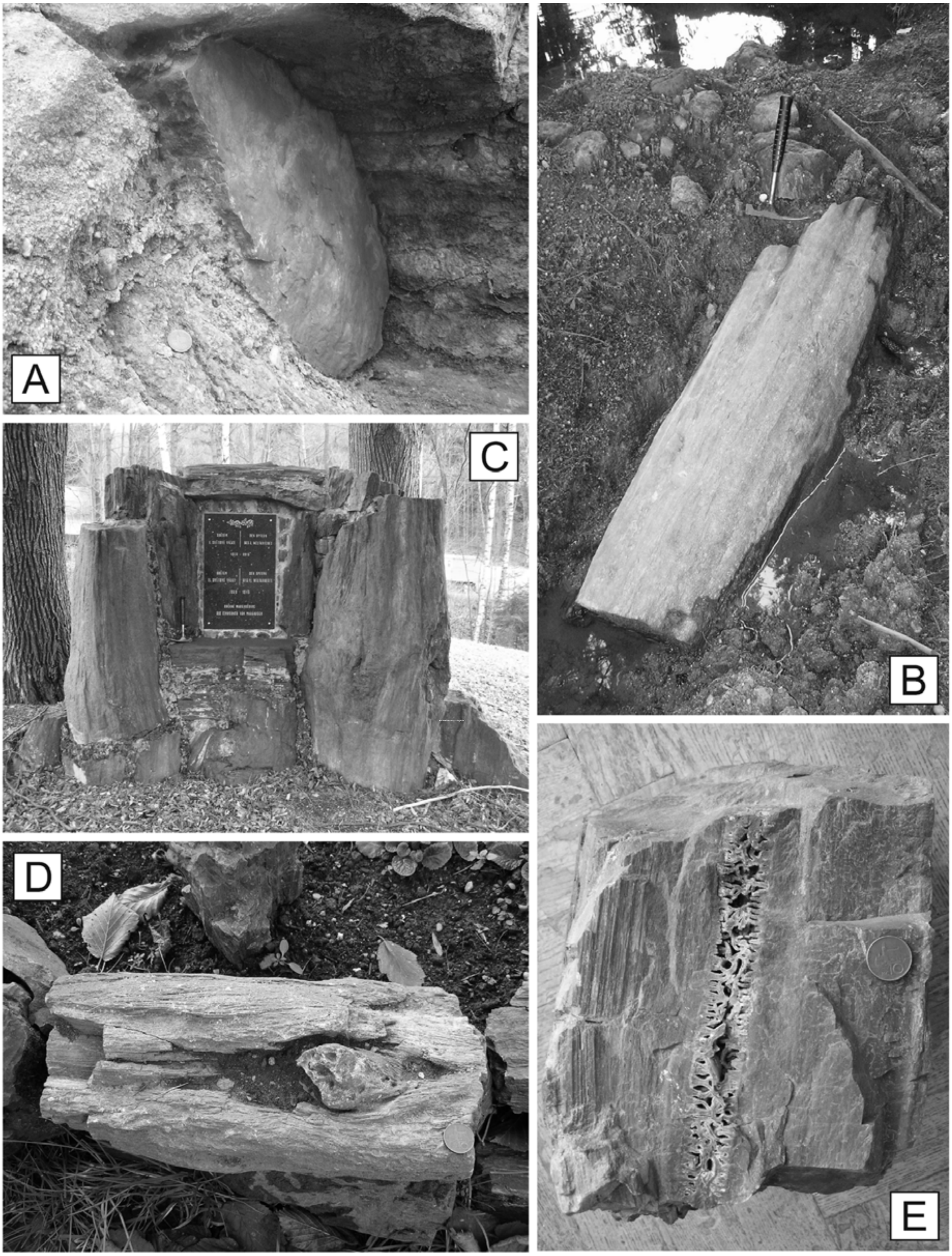


Fig. 3. *Dadoxylon* sp. (macroscopic photos). **A** – Silicified trunk in allochthonous position, Hronov locality. **B** – Silicified trunk secondary embedded in Quaternary deposits, U Studánky locality. **C** – Silicified wood in monument, Markoušovice. **D** – Fragment of silicified stem with a branch remain. **E** – Silicified trunk with a central pith of *Artisia*-type.

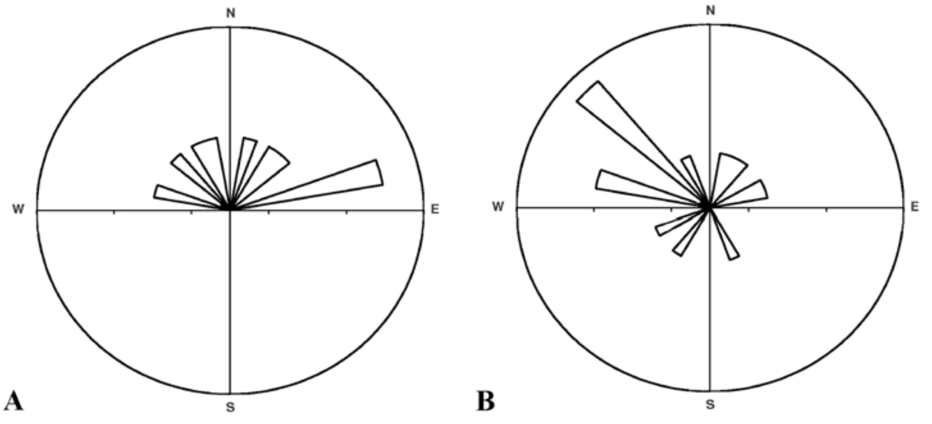


Fig. 4. Palaeoflow directions (A) and directions of the longest axes of stems (B).

in Pešek et al. 2001; Fig. 2). The axis of the basin is oriented in NE–SW direction congruently with the centre lines of the other Late Carboniferous limnic basins of the Bohemian Massif. The Intra Sudetic Basin joins on the SW edge the Krkonoše Piedmont Basin, from which it is separated only by the Hronov-Poříčí Fault. The basin is interlaced by numerous tectonic faults of a variable extent (Fig. 1).

Except for the very oldest part, the filling of the basin is purely continental. Sediments have mostly a fluvial or proluvial character, in some levels with finer deposits of temporary lakes or swamps. Volcanic material is present in several units. Silicified wood can either be found directly embedded in the arkosic sediments of Barruelian age (Jívka Member of Odolov Formation), which are called Žaltman Arkoses (Fig. 2), or spread in neighbouring fields, meadows or forests in the form of fragments or trunks. Their best outcrops are in the area of the Hawk Mts. where the Žaltman Arcoses rise up to the surface. These strata are mainly composed of more or less coarse arkosic conglomerates and sandstones, deposited by river streams (Valín 1956, 1960) and they lack any compressions of leaves or reproductive organs.

3. Materials and methods

In the area of the Hawk Mts. we collected several hundreds of samples of silicified stems, and the databases of photos and information for palaeoecological reconstructions have been improved considerably (Table 1; Mencl 2007) Results gained from samples belonging to the National Museum in Prague (Matysová 2006) were also considered. For the trunks embedded in the original sediment, a standard geological compass was used to measure their azimuth and inclination and the surrounding stream structures (bedforms) in order to reconstruct the direction of palaeostreams, and the reaction of the wood during its sedimentation. The values were corrected using the software STEREONETT 2.02 and the results were subsequently plotted in the geological map with the help of the programme ArcGIS 9 (application ArcMAP 9.2). Several tens of the best preserved samples were selected to make thin sections and study them with microscopic and other instrumental techniques. Each chosen sample of silicified wood was cut in 3 directions: transverse, tangential and radial. Systematic parameters were finally processed by Anova programme.

For microscopic observations of standard (polished) thin sections in transmitted light (PPL) and polarized light (XPL) optical microscopes Olympus BX-51 and Olympus BX-60 were used. Microscope Leica with fluorescence regime in UV spectral scale was used for observations of transverse polished sections in reflected light. Cathodoluminescence imaging was performed with a "hot cathode" CL microscope Simon-Neuser HC2-LM (Masaryk University, Brno, Czech Republic), which enables both light microscopy and cathodoluminescence microscopy without sample readjustment. The electron gun was operated at 14 keV with a current density 10-40 $\mu A \cdot mm^{-2}$ in vacuum (10^{-6} bars). The luminescence images were taken by a digital camera Olympus C-5060. CL spectral measurements were carried out on a "hot cathode" CL microscope HC1-LM (TU Bergakademie Freiberg, Germany) under the same experimental conditions as to imaging in MU Brno. EG&G digital triple-grating spectrograph with CCD detector, which was attached to the CL microscope by a silica fibre guide, served to gain CL spectra. Thin sections were carbon coated before CL measurements to prevent build-up of electrical charge. Spectra were firstly processed by Microsoft Office Excel 2003 and subsequently evaluated in OriginPro 7.5 (OriginLab, USA). Spectral deconvolution to Gaussian components & examination of 2nd derivatives of smoothed spectra was used to find maxima of luminescence

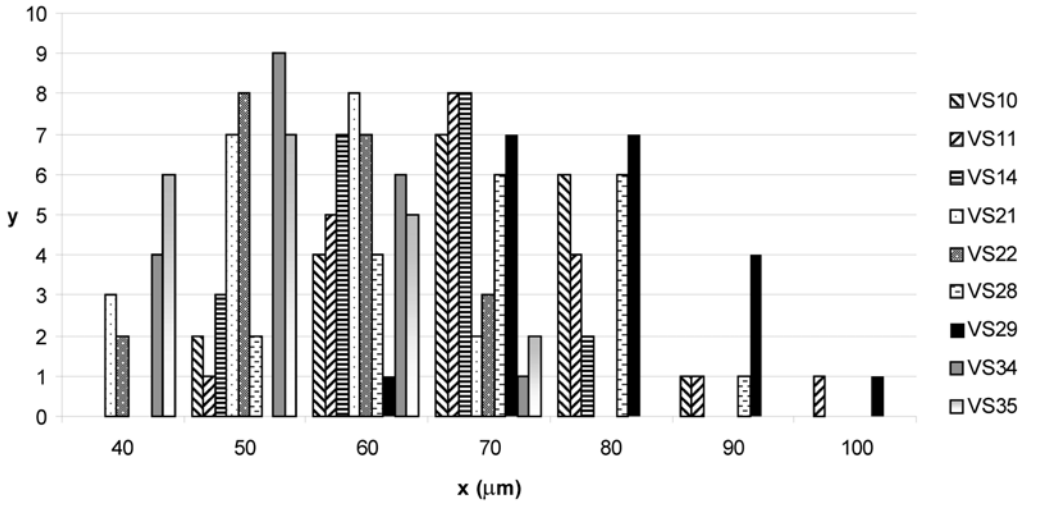


Fig. 5. Radial tracheid diameter in transverse section; x – diameter (μm), y – number of tracheids.

bands. Selected one-sided planar remains from cutting of samples were measured by X-ray diffraction (XRD) to identify mineral matrix of the permineralized samples using Siemens D5005 diffractometer. Diffractograms were processed using PANalytical HighScore search/match programme.

4. Results

4.1. Sedimentology

Three main types of occurrences of the fossil trunks have been recognized in the field: sedimented horizontally as allochthonous material and embedded in fluvial sediments (Fig. 3A); in secondary alluvia without any relation to the original sediment (Fig. 3B), and artificially removed in relation to human activities (monuments, communal town decorations; Fig. 3C). Valín (1956, 1960) described 17 outcrops of the first category, which can be directly used to measure the orientation of the trunks. Unfortunately, most of them are destroyed nowadays. Nevertheless, we have discovered several other useful outcrops. Finally, we selected 8 localities with 14 stems em-

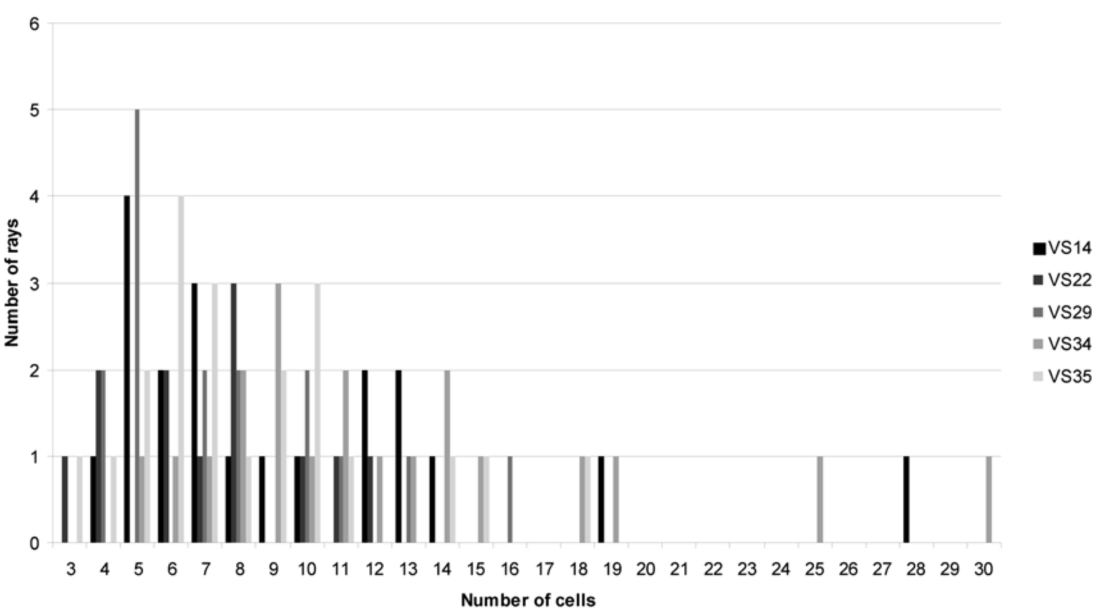


Fig. 6. Histogram of height of rays in tangential longitudinal section.

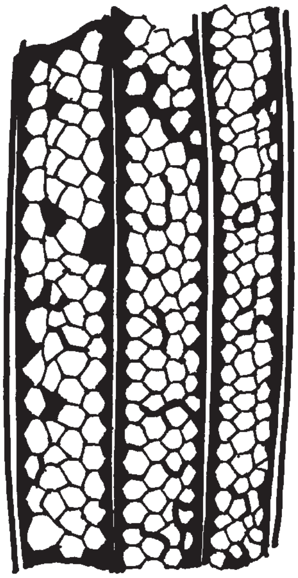


Fig. 7. Sketch of bordered pits in a radial wall of tracheids in the specimen VS12 – cordaite type.

bedded in sedimentary strata. The orientation of the trunks themselves was studied as well as the sedimentary structures in their neighbourhood to recognize the direction of palaeostreams.

The fossil logs are mostly oriented in NW or WNW directions. Fossil trunks are relatively short, preserved without bark or branches, often damaged or split into pieces that are surely due to the transport in torrential rivers together with gravel and sand. The logs are shorter than axes of bedforms, which are in our case utmost about 10 m that, in accordance with the observations by BRIDGE (2003), means that the logs laid almost perpendicularly to the palaeostream (Fig. 4). Moreover, the logs are embedded on the bottom of sandy channels with very coarse residual gravel that indicate their transport during extreme floods. The river behaviour can be interpreted as an intermediate type between braided and meandering (MARTÍNEK, pers. comm.).

4.2. Palaeobotany

Gymnosperms
Dadoxylon ENDLICHER
Dadoxylon sp.

Specimens: VS10, VS11, VS12, VS13, VS14, VS21, VS22, VS28, VS29, VS34, VS35.

Description: Transverse section (Figs. 5, 8A, B) – Growth rings indistinct. Tracheids thin-walled, round or oval in cross-section or irregular in shape when compressed, placed in deformed radial lines. Radial diameter 40-100 μm (mean 63 μm, n = 180). Axial parenchyma absent.

Tangential longitudinal section (Figs. 6, 8C, D) – Tracheid pits not observed. Rays mostly uniseriate (74 %), partly biseriate (25 %) or triseriate (1%) and generally medium (9) in height sensu IAWA COMMITTEE (2004) with total extent of 3-30 cells. Ray cells round to oval in section. The density of rays varies between 3 to 9 (mean 5) rays per tangential mm.

Radial longitudinal section (Figs. 7, 8E, F) – Tracheid pitting in radial walls (preserved only in 6 samples VS10, VS12, VS13, VS21, VS34, VS35) 2-3(-4) seriate and alternate (araucarioid). Pits bordered, hexagonal, crowded, covering all width of a tracheid wall. Pit diameter 10-12 (-20) μm. Cross-field pitting not observed.

All here described specimens are characterized only by the structure of the secondary xylem, the features of primary xylem as well as pith are lacking. The wood is homoxylous pycnoxylic without axial parenchyma and resin canals, traumatic or normal. Its age (Late Pennsylvanian, Barruelian) and the overall "araucarioid" character (alternate multiseriate tracheid pitting in radial walls with uniseriate rays and no parenchyma) allow its safe attribution to the morphogenus *Dadoxylon* ENDLICHER. However, a more accurate attribution on a specific level remains problematic because the stems are strongly recrystallized by highly crystalline quartz (see 4.3.1. below). Some of the features cannot be detected (cross-field pitting), some of them only rarely and in a bad state, e.g. pits in radial tracheid walls are visible only rarely thanks to pigmentation that highlights their outlines. Therefore, we prefer to leave our woods in open nomenclature, designate them as *Dadoxylon* sp. We used this generic name following VOGELLEHNER's (1964) concept as the only correct name for an araucarioid type of secondary xylem where neither primary xylem nor pith is present. Nomenclatural discussions, e.g., priority of *Pinites* LINDLEY & HUTTON over *Dadoxylon* ENDLICHER (see BAMFORD & PHILIPPE 2001), are beyond the scope of this paper.

The fossil record of this case exists only in forms of decorticated trunks or thicker branches; bark, small branches and other co-occurring plants remains (leaves, reproductive organs etc.) that could facilitate the systematic attribution of the fossil wood are absent. The only exception is represented by two extraordinary specimens that we had an opportunity to study during our field-work. They possessed other unique macroscopic features: the first one (Fig. 3D) has one solitary rest of a branch preserved without any

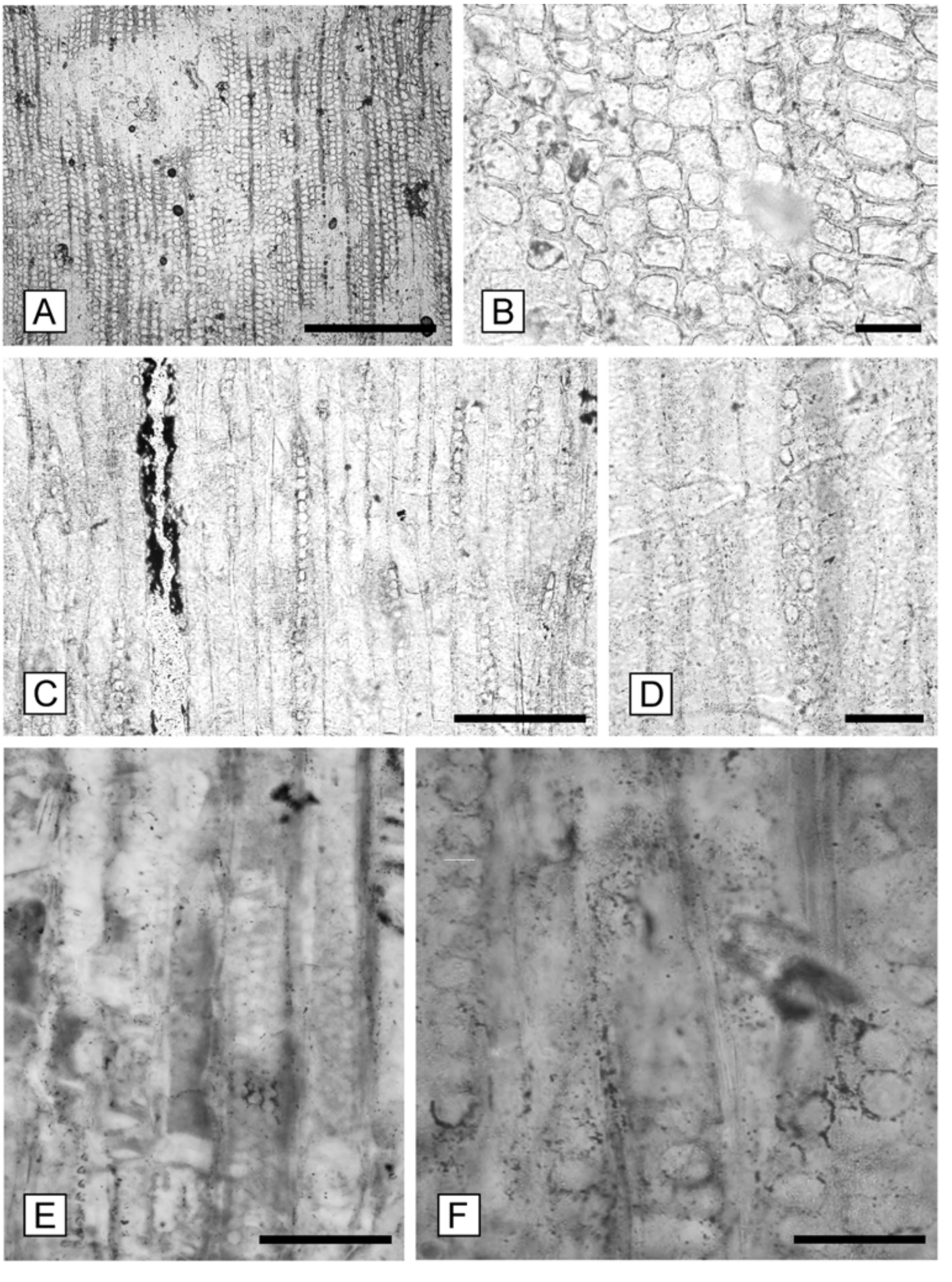


Fig. 8. *Dadoxylon* sp. (microscopic photos). **A –** Transverse section, VS12, scale bar 1 cm. **B –** Transverse section, thin-walled tracheids, VS14, scale bar 50 µm. **C** – Tangential longitudinal section, uniseriate rays, VS14, scale bar 100 µm. **D –** Tangential longitudinal section, biseriate ray, VS12, scale bar 50 µm. **E** – Radial longitudinal section, alternate (araucarioid) pitting, VS12, scale bar 100 µm. **F** – Radial longitudinal section, araucarioid pitting, VS35, scale bar 25 µm.

indication of the branch in the close proximity, the second one (Fig. 3E) shows the pith of *Artisia*-type. Both these features are considered to belong to cordaitaleans (e.g., NOLL et al. 2005).

4.3. Geochemistry

4.3.1. Mineralogy and petrography

All samples from ISB (Table 1) are mainly permineralized by pure α-quartz (α-SiO_2) of a high crystal-

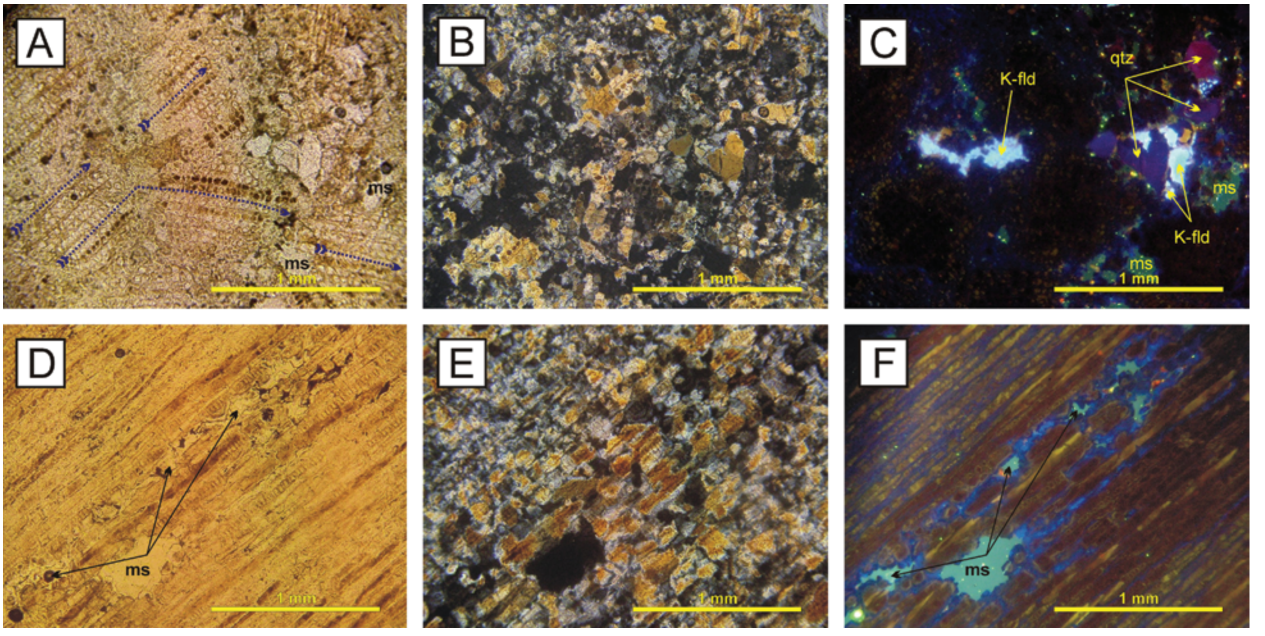


Fig. 9. Demonstration of particular mineralogy of *Dadoxylon* sp. From left: Normal light (PPL), polarized light (XPL) and cathodoluminescence (CL) pictures of sample VS21. **A-C –** Transverse section, **D-F** – tangential (longitudinal) section. Dotted line in A indicates strong fragmentation of secondary xylem, surrounded by allochthonous sedimentary grains (viz C). Short-lived blue CL in C and F as a secondary overprint of silicification. E shows preferred orientation of qtz grains respecting anatomy of tracheids. Yellow CL in F is attributed to hydrothermal quartz. Abbreviations: *K-flds* – K-feldspars (stable bright blue CL), *qtz* – allochthonous crystals of quartz, also of volcanic origin (violet CL), *ms* – visible microscope slide. Further explanation in the text.

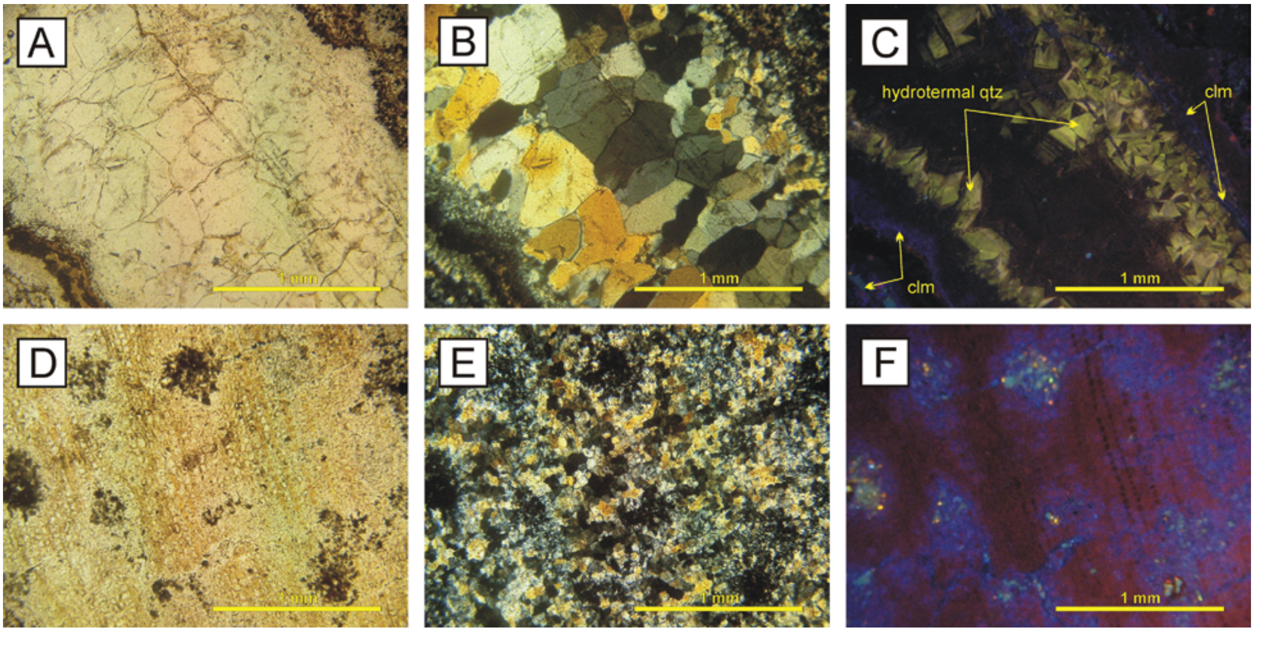


Fig. 10 (Legend see p. 279)

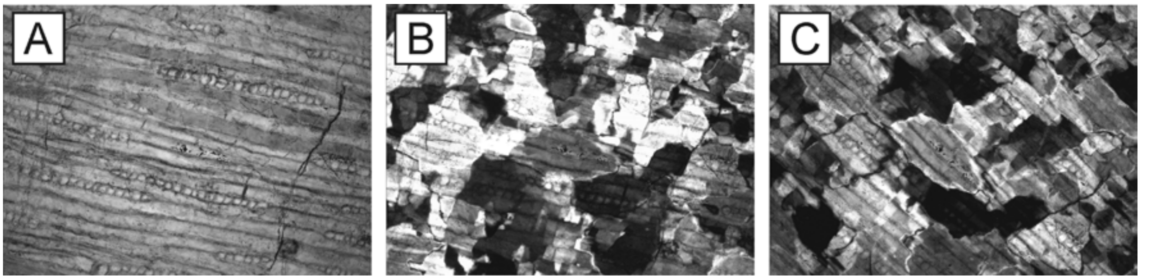


Fig. 11. Illustration of particular petrography in tangential longitudinal section (VS21): A (PPL), B (XPL), C (XPL shift 30º). Megaquartz grains are arranged in domains that respect the former anatomy of tracheids (secondary xylem) in the longitudinal direction.

linity as was proven by XRD in bulk samples and petrography microscope in a microscopic scale. Furthermore, fragments of wood are often "contaminated" by allochthonous sediment, such as polymict quartz grains, K-feldspars, or clay minerals, mainly kaolinite, as was analytically proved by XRD or visualized by CL (Fig. 9A-C). The absolute majority of the samples are highly recrystallized. Although the rough anatomical features are more or less visible, tiny anatomical details such as pits or cross fields are mostly unreadable (see 4.2 above). Wood is very often unevenly pigmented by Fe_xO_y, and sometimes this pigmentation helps to highlight/preserve particular tiny anatomical details, such as tracheids and pits. Obviously, the residual coalified organic matter is almost or completely missing. In petrographical terms used to classify SiO_2 polymorphs (Flörke et al. 1991) and quartz textures in silicified plants (e.g., Weibel 1996; Matysová 2006; Matysová et al. 2008, and references therein), the best preserved parts of secondary xylem were mostly permineralized by microcrystalline quartz ("microquartz", 5-20 µm in diameter) mainly being arranged in polyblastic textures. On the other hand, the presence of macrocrystalline quartz ("megaquartz", 20-2000 µm across) is by far more frequent in our samples, particularly in hyperblastic textures not respecting former anatomical arrangement of plant tissues. These types of silica crystals vary in both size and shape through the whole collection of thin sections. It is interesting that XPL pictures of transverse and longitudinal cuts are very different. An apparently chaotic arrangement of SiO_2 crystals in recrystallized transversal cuts (Figs. 9B, 10E) looks in longitudinal sections as megaquartz crystals elongated along the tracheids (Figs. 9E, 11A-C). These samples were often heterogeneous, broken by abundant fissures of a various size, passing across the secondary xylem, and frequently the "fragmentation" of the former plant tissue produced a misoriented mosaic of preserved wood in a purely inorganic non-templated secondary silica mass (Fig. 9A). The cracks were often filled by large idiomorphic megaquartz crystals, agate-like structures of microquartz, or palisades of fibrous quartz (Fig. 10B). Different silica arrangements in cracks etc. mark later steps of permineralization, probably thanks to tectonic movements that caused mechanical breakage of plant fossils (see part 2).

Due to high SiO_2 crystallinity, coarseness, large recrystallized parts and frequent fissures, silicified samples of *Dadoxylon* type from ISB are often heterogeneous, incompact, and frequently mechanically disintegrated. Therefore, their thin section processing was not easy, and on some of them a microscope slide is obvious through (Fig. 9D-F).

4.3.2. Cathodoluminescence

CL microscopy was used on 7 samples marked in Table 1. CL imaging revealed conspicuous heterogeneity of siliceous mass that seemed to be uniform at

Fig. 10. Demonstration of particular mineralogy of *Dadoxylon* sp. on transverse sections. From left: Normal light (PPL), polarized light (XPL) and cathodoluminescence (CL) pictures of samples VS6 (A, B, C) and VS7 (D, E, F). **A-C** – Secondary fissure inside the wood sample fulfilled by well-zoned hydrothermal quartz, bordered by reduction line consisted of clay minerals and Fe_xO_y; **D-F** – conspicuous geochemical patterns in wood structure. Complicated mechanism of silicification proved by different CL shades (F) of uniform siliceous mass (D, E). Abbreviations: *qtz* – quartz, *clm* – clay minerals (stable blue CL). Further explanation in text.

Table 2. Results of spectral CL measurements and their assignment. For spectra see Figs. 12-13.

Shade CL	Cathodoluminescence maximum [nm]		Assignment
	VS6	VS7	
short-lived blue (initial)	451	447	450 nm
stable blue (initial)	–	438	
yellow (initial)	585	–	580 nm
(after 60/120/180 sec)	(637/641/643)		
stable red	649	640	620-650 nm

first sight in transmitted light (PPL, XPL). Silicification proceeded in several distinct environments under a varying temperature and chemical composition, and the silicification resulted in silica mass in wood that is rich in microscopic impurities, substitution of Si, and abundant defects in the crystal lattice. Some of so called intrinsic or extrinsic defects are CL activators.

Prevailing CL shades in the silicified fossils from ISB are: stable red – typical for primary siliceous mass, les commonly stable blue; and short-lived blue CL – typical for secondary overprints, which passes into stable red CL after longer exposition (see also Matysová et al. 2008). Some of these shades alternate through thin sections, sometimes are not anticipated, sometimes reflect domains of recrystallization, where already the appearance of SiO_2 in PPL seemed to be different (Fig. 10D-F).

CL spectroscopy was performed on two representative thin sections, VS6 and VS7. It served to a detailed spectral study of prevailing CL shades that are not megascopic. It was supposed that every CL shade corresponds to a particular CL activator in the crystal lattice. Acquired CL spectra show several CL emission bands (Figs. 12-13; Table 2). Time dependent short-lived blue CL around 450 nm in α-quartz (see Figs. 12A, 13A; Table 2) is supposed to be typical in quartz crystallized from hydrothermal solutions (Götze 2000; Götze et al. 2001a, b; Witke et al. 2004; Boggs & Krinsley 2006). The typical change from initial blue to final brown CL colours (Fig. 12A) is caused by the rapid decrease of the CL emission bands just below 400 nm and about 450 nm and the associated increase of the red emission band at about 650 nm.

Transient yellow CL unexpectedly appeared in samples VS1, VS6 and VS21. It was detected for the first time in Czech samples of silicified wood. In VS6 (Fig. 12B; Table 2) it was observed particularly in large fissures healed by idiomorphic quartz grains (Fig. 10C) whereas in VS1 or VS21 the yellow CL appeared in patches of silica mass with wood structures (see Fig. 9F). During the measurement transient yellow CL passed to stable red CL with the same emission maximum as in the case of short-lived blue CL (Table 2).

CL also very well displayed some allochthonous sedimentary grains, such as clay minerals (blue CL along fissure healed by hydrothermal quartz in Fig. 10C), grains of K-feldspars (bright blue CL of angular grains) or detritus quartz grains (plutonic? qtz – darker blue CL, qtz of supposed volcanic origin – violet-reddish CL). CL intensity of these admixtures was so high that it overshadowed CL of wood (Fig. 9C).

5. Discussion

5.1. Taxonomical assignment, taphonomy and their importance

The wood of *Dadoxylon*-type generally represents both cordaites and conifers and their distinction based only on the anatomy of secondary xylem is not easy. Doubinger & Marguerier (1975: 40) distinguished three groups (*Dadoxylon* of type I-III) in which the first group belongs to cordaites and the second one to primitive conifers of *Walchia*-type. Distinctive features are outlines of tracheids in cross-section, presence of growth rings, tracheid pitting in radial walls, cross-field pitting and height of rays. Most recently, the wood of *Dadoxylon*-type was reviewed in detail by Noll et al. (2005). Authors specified the following features, which help to distinguish the wood of cordaites from that of conifers: arrangement and outlines of bordered pits in radial tracheid walls of secondary xylem, a shape of the transition between the primary xylem and the pith, external and internal disposition of the pith, leaf traces and branching. It is obvious that Noll et al. (2005) contrary to Doubinger & Marguerier (1975) used not only the secondary xylem but also other parts of fossilized stems that, however, are rarely present.

In spite of rather bad preservation of our specimens, we could definitely use the character which is common to both classifications: pitting in radial tracheid walls. The bordered pits observed in PPL in radial sections of several specimens have a typical hexagonal outline and they alternate in 2-4 rows, covering almost the entire width of the radial tracheid wall (Figs. 7, 8E, F). Moreover, Anova programme on radial tracheid diameter and height of rays (Figs. 5, 6) showed results with insignificant deviation that means that samples of wood are very similar to each other. Consequently we interpret these woods as belonging to cordaites. Another evidences confirm our observations; the piece of the stem possessing the solitary knot, which has no indication of a branch in the close proximity meaning the absence of pseudo-verticillate branching (Fig. 3D), and the typically fragmented pith of *Artisia*-type (Fig. 3E). Both such findings further indicate a cordaitalean affinity (Noll & Wilde 2002; Noll et al. 2005), even if we could not analyse secondary xylem of these two samples due to their insufficient preservation. Unfortunately, the co-occurring plant remains as leaves or reproductive structures that could facilitate the systematic attribution of the fossil wood are absent in the whole Jívka Member. Summarizing this part we can say that our new observations of petrified stems cannot confirm the presence of conifers contrary to Goeppert's (1857, 1858) observations, which point to both groups in the Radvanice fossil forest – cordaites and conifers; Goeppert's *Araucarites brandlingii* (Lindley & Hutton) Goeppert, known today as *Dadoxylon brandlingi* (Lindley & Hutton) Frentzen, corresponds to the wood of cordaites and his *Araucarites schrollianus* Goeppert = *Dadoxylon schrollianum* (Goeppert) Frentzen is the wood of conifers. Moreover, we never found growth rings in our samples as Goeppert (1857, 1858) described (compare 1.1. vs. 4.2.); we only observed the so called "false" growth rings (IAWA Committee 2004: 16) or ring-like structures that appear in secondary xylem for instance due to diagenetic mechanical compaction (Noll & Wilde 2002; Noll et al. 2005; Matysová et al. 2008).

The poor preservation of plant tissues and fragmentary preservation of silicified decorticated stems represent a typical problem met in analyses of Late Palaeozoic *Dadoxylon* wood type, and, maybe, the general reason of unsatisfactory taxonomical assignment of silicified stems found in alluvial facies. The differentiation between cordaites and conifers is, however, of great importance with respect to a global environmental change around Carboniferous/Permian boundary. While cordaites had flourished in equatorial Pangean uplands during the Westphalian (e.g. Falcon-Lang & Scott 2000; Falcon-Lang & Bashforth 2005), the Permian upland flora consisted mostly of conifers (Noll & Wilde 2002; Diéguez & López-Gómez 2005; Uhl 2006), e.g. of *Walchia*-type (Wagner & Mayoral 2007). A similar pattern was recorded by the preserved specimens of *Dadoxylon*-type of wood. Doubinger & Marguerier (1975: 42) traced the stratigraphical significance of the fossil record of their "*Dadoxylon de type I-III*" from the Euramerican province, starting with *Dadoxylon* of type I (cordaites), the most frequently found type in Namurian, Westphalian and Stephanian times while *Dadoxylon* of type II (conifers) started in the Stephanian with a maximum during the Stephanian/ Early Permian, and *Dadoxylon* of type III (probable conifers) occurred mostly in the Late Permian. A systematic occurrence in favour of cordaites in the case of the Žaltman Arkoses (Barruelian or Stephanian A) where conifer stems were not yet confirmed can not be excluded. In this respect, an exact re-assignment of the silicified wood of *Dadoxylon*-type of Westphalian D/Stephanian age from the Central and Western Bohemia Late Palaeozoic basins (Skoček 1960; Pešek 1968) will be of particular interest in the future. Another possible explanation of a virtual lack of conifers in our fossil wood record can be in taphonomy. DiMichele et al. (2001) in their extensive review of floral development in Late Carboniferous/Early Permian flora as supposed that during the Bolsovian-Westphalian D (Middle Pennsylvanian) conifers persisted in seasonally dry climate periods in uplands, which influenced the possibility being preserved in fossil record. In river systems, alluvial deposits gave more chance to preserve plants, which grew closer to the river. Such a way of fossilization could have preferred the cordaites from riparian or transitional (piedmont) environments, rather than more distant and 'xerophilous' conifers from uplands (mountain areas).

Due to size and shape of pebbles in fossiliferous layers we consider that transport of wood could process in the distance of utmost 100 km (Martínek, pers. comm.). This rather long transport probably resulted in highly selected preservation of hard pycnoxylic wood only thanks to high resistance of stems:

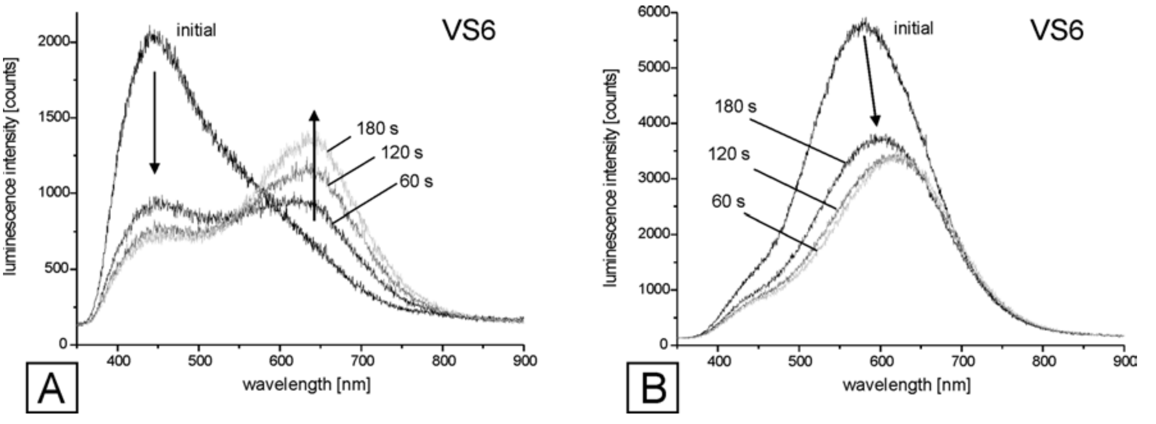


Fig. 12. Time dependent spectra (VS6) of short-lived blue CL (A) passing into stable red CL, and short-lived yellow CL (B). Numerical CL spectral data in Table 2.

other remnants of plants or charcoals were not maintained, they should have been damaged during the rapid transport in high energetic water stream systems among coarse gravels and rock fractions. Most fossil logs are oriented perpendicularly to the palaeostream direction (Fig. 4). These logs must have been deposited after their damage and breakage into pieces smaller than approximately 10 m. The dominant palaeostream directions were hence from the SW to the NE, which corresponds with older observations on other localities in the same basin (Valín 1956, 1960; Pešek et al. 2001). Thanks to the compactness of the *Dadoxylon* kind of wood, no pebbles, cobbles or boulders could be found enclosed in our samples and therefore we could not for example do provenance analysis as was done by Liu & Gastaldo (1992), or Gastaldo & Degges (2007).

5.2. Cathodoluminescence, petrography, and silicification

The aim of petrographic and cathodoluminescence analyses was to understand the actual silicification pathway of petrified trunks because this multiphase and complicated process has still remained puzzling (viz 5.3. below). We proved high crystallinity of the SiO_2 in the stems by XRD, pure α-quartz can be an inevitable consequence of aging the metastable forms (see Moxon 2002). Sometimes quartz was accompanied by minor allochthonous admixtures, also visualized by CL (Fig. 9C). No other phases of SiO_2, such as opal-A, opal-CT, or moganite (e.g. Březinová et al. 1994; Witke et al. 2004), were found. Similar conclusions were reached by Matysová et al. (2008).

CL imaging and CL spectroscopy revealed more generations of SiO_2 by contrasting structures of reddish and blue shades, and occasionally yellow shades of CL (viz 4.3.2.). The preserved plant tissues (the 1st generation of quartz) have usually a dark red (620-650 nm) or stable blue CL (Figs. 10F, 12A, 13B; Table 2). The second or further generations, showing transient blue (~450 nm) and yellow CL (~580 nm; see Fig. 12B), are mainly present in cracks and fissures in the silica mass. Interestingly, in specimens from Krkonoše Piedmont Basin the short-lived blue CL was less common than in ISB, and yellow was absent (Matysová et al. 2008). These short-lived blue CL and especially yellow CL shades point most probably to hydrothermal SiO_2 (Götze 2000; Götze et al. 2001a, b; Boggs & Krinsley 2006). Götze et al. (1999) detected the yellow CL emission predominantly in agates and hydrothermal vein quartz with high contents of oxygen vacancies (E' centres) and Si-substituting elements, and also in Permian silicified wood from Chemnitz, Germany (Götze et al. 2001a, b; Witke et al. 2004). It could be explained by increased temperatures due to burial or tectonic dislocations in the basin that caused first mechanical ruptures and fragmentation and then healing the cracks by the second generation of quartz (Fig. 10C).

CL can help to distinguish alluvial and volcanic environment of silicification, because the latter produced more plentiful mineral phases with more intense luminescence, which is obvious in comparison of our current and already published results (Matysová et al. 2008), and with results published by

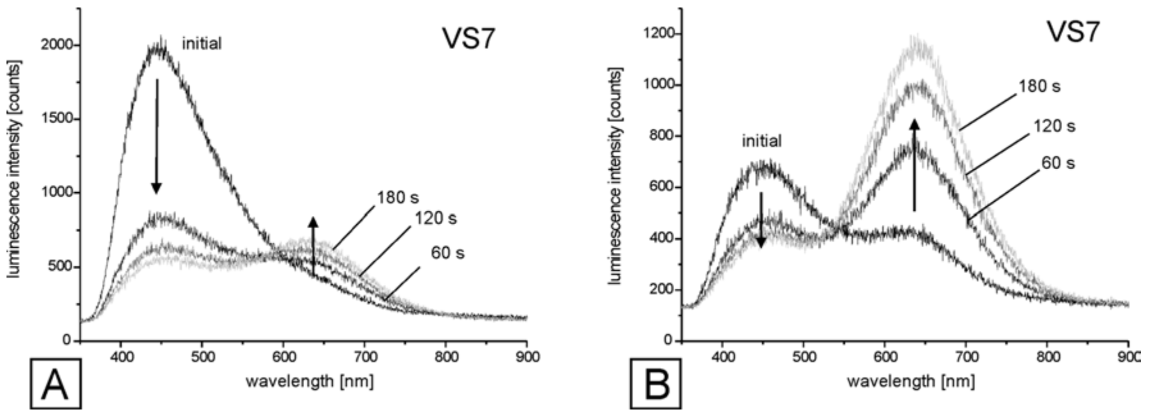


Fig. 13. CL spectra of sample VS7. Stable blue CL (A), short-lived blue CL passing into stable red much faster than stable blue (B). Numerical CL spectral data in Table 2.

Götze & Rössler (2000), Götze et al. (2001b), and Witke et al. (2004). Besides, fossil plants from volcanic strata are in most cases much better preserved including tiny anatomical details than those from alluvia. Even if the mechanism of the silicification process was studied a lot in the past (e.g., Landmesser 1994, 1995; Weibel 1996; Landmesser 1999), we still cannot say whether quartz crystals in wood were formed straight from solution of H_4SiO_4 or through various hydrated SiO_2 phases (Opal-A, Opal-CT, moganite etc.) because those were not detected in our samples.

CL and XPL revealed that silicification must have proceeded through tracheids because the specific distinct CL patterns/generations of SiO_2 (Fig. 9F, 10F) reflect the only permeable route how silicic species could pass through the wood with partly silicified cellular walls. They passed via tracheids, and the pits, which joined them, also took part in the transport. Furthermore, XPL pictures domains of equally oriented crystals (Fig. 11) which also support this hypothesis.

CL and PPL can also visualize parts in wood with different preservation of organic matter: so called bleaching due to locally increased organic matter consumption by fungi (e.g., Diéguez & López-Gómez 2005) under simultaneous action of repeating changes of water table produced alterations of oxidative and reductive conditions. The resulting different physico-chemical conditions likely caused different quartz structural defects and hence different shades of CL.

Because the *Dadoxylon* type of wood has quite uniform and simple structure (Noll et al. 2005, Schweingruber et al. 2006) it might have influenced the specific way of arrangement of quartz crystals within the stem. Abundance of hyperblastic "megaquartz" so typical of secondary overprint (Fig. 9E, 10B) is followed by tiny "microquartz", which appears in very well preserved tracheids as subordinated to former uniform anatomy of secondary xylem. It can also be seen in common recrystallized parts. Such petrographical patterns, very often reflecting a high level of recrystallization, are very similar to those published by Skoček (1970), Weibel (1996), and Matysová et al. (2008).

Material from ISB is mostly pigmented by ferrous oxides that are dispersed through the stems irregularly and thanks to that, some of tiny anatomical details were preserved/visible (pits, tracheids). Weathering of arkoses is supposed to be the source of Fe_xO_y, the important pigment. The presence of Fe oxides (instead of sulfides) clearly indicates the resulting oxidation conditions during the final stage of wood silicification.

5.3. Silicification process and paleoenvironmental interpretation

Already in 1970, Skoček discussed a possible palaeoenvironmental aspect of the formation of silicified wood (Skoček 1970). In the Central and Western Bohemian basins he noticed its presence in the boundaries between the formations and attributed it to periods of unstable humidity conditions, namely aridization of climate (Skoček, pers. comm.). Certainly, at least seasonal humidity was required to the growth of large trees. On the other hand, seasonally arid climate prevented stems from fast rot and total decay of organic matter and simultaneously provided ground water supplying silicic acid. Fluctuating water table was supposed as a prerequisite to wood silicification in alluvial formations also by Weibel (1996), Parrish & Falcon-Lang (2007) and Wagner & Mayoral (2007). Climate instability during Pennsylvanian and earliest Permian times was attributed to instability (glacials/interglacials) of the South Gondwana ice sheet (Scheffler et al. 2006). These South Gondwanian deglacial cycles were correlated to global climatic cycles in equatorial Pangaea (Izart et al. 2003; Roscher & Schneider 2005; Schneider et al. 2006). On shorter time scales, Milankovitch-like climate cycles were also acting during extensive Gondwanian glaciation.

Before any palaeoenvironmental interpretation of the occurrences of silicified wood in basinal sediments can be provided, it is necessary to distinguish two main modes of silicification. The first one, silicification after a volcanic material fall out (tephra burial) – Chemnitz, Germany (Rössler 2006), or silicification obviously closely influenced by volcanism – Balka, Czech Republic (Pešek et al. 2001) – mirrors the palaeoenvironment by almost completely preserved plant morphotaxa, often preserved in an excellent way. Such silicified assemblages can represent a nearly complete fossilized biome, usually including numerous hygrophilous elements as if the simultaneous presence of lakes was essential for silicification (Wagner & Mayoral 2007). In the second mode, there is riparian or upland vegetation preserved in river alluvia, usually containing chemically unweathered minerals, such as feldspars and dark minerals. Among others, subsequent weathering of these minerals in seasonally arid environment is supposed to produce silicic acid to successive permineralization (Skoček 1970; Matysová 2006; Matysová et al. 2008). Such deposits were studied in this work, and similar deposits were also found in the stratigraphic equivalent positions in other Czech basins (Fig. 2) and in the Early Autunian Nová Paka Sandstone of the Vrchlabí Formation (Pešek et al. 2001; Matysová 2006; Matysová et al. 2008) and other localities as Kyffhäuser in Germany (Rössler 2002). Furthermore, allochthonous trunks from alluvia possess complicated taphonomy because they surely underwent transport to various extent during which they were often damaged to a certain degree (decortication, fragmentation etc.).

The alluvial occurrence of redeposited trees producing araucarites in the Czech Massif was reported in three to four stratigraphic levels (Fig. 2), that can be correlated with four intraglacial/glacial cycles recorded in S Gondwana (Scheffler et al. 2006). Silicified wood from the Petrovice Member (Bolsovian) was mentioned only in one reference (Tásler et al. 1979). The other three stratigraphic levels with silicified wood are confirmed by more references, museum collections and by our own fieldwork. The absence of regular growth rings in *Dadoxylon* wood of the Barruelian age is worth mentioning. Between the second silicified-wood-bearing strata in the Barruelian (reported in this work) and the third one (Stephanian C) there was a mid-Stephanian B humidity period (Pešek et al. 2001; Opluštil & Cleal 2007). During that humid period a large lake was formed across all basins in the Bohemian Massif with a very rich flora in its watershed and chiefly kaolinite-quartz siliciclastic sediment – components indicating very intense chemical weathering (Holub et al. 1975; Lojka et al., submitted). This climate alteration clearly proves a palaeoenvironmental significance of *Dadoxylon* type of wood preserved in alluvia of unstable rivers as indicators of seasonally arid climate supposed for Barruelian. Unfortunately, any detailed palaeoenvironmental analysis has not yet been undertaken in the studied area. Concerning the presence of growth rings, Brison et al. (2001) concluded that even in Mesozoic it could also be taxonomically controlled. The authors instigate not to make conclusions from anatomical features alone because it might be in some cases false and misleading; in other words they claim that some taxa cannot make any growth rings even if they grew in highly seasonal climates. Therefore, the lack of clear indications of growth rings in the Upper Carboniferous *Dadoxylon* wood could not necessarily mean a lack of seasonality. The similar explanation was also given by Falcon-Lang & Scott (2000). Their work deals with cordaites found as permineralizations or charcoals in the Westphalian of Nova Scotia, Canada and England. Their studied material also lacked regular growth rings even if trees were supposed to grow in seasonal climates (proved by calcrete fragments in channel units etc.); it follows that cordaites had to possess wood with a low sensitivity to climatic seasonality. Moreover, we either agree with the fact that cordaite logs being found in fluvial sandstone units and such trees might grow in so called streamside niches where local environmental anomalies could sometimes exist as irregular drought periods, which might be recorded on anatomical level as "false" growth rings.

6. Conclusions

Silicified wood is still very common in the Late Pennsylvanian of the Hawk Mts. (Intra Sudetic Basin, Czech Republic), although many localities were destroyed or damaged. Trunks or their remains can be attributed systematically, they indicate seasonally arid climate because crystal lattice of quartz reflects specific environmental conditions, and should be considered by geologists and palaeontologists as an important stratigraphic indicator. The trunks are purely allochthonous, embedded in fluvial arkosic sediments, preserved in their original position of sedimentation, in outcrops mostly weathered, decorticated. Nowadays, it is not very easy to find such stems; we discovered only 14 pieces. In addition to these stems there is a big amount of stems or fragments dispersed in the landscape or even pieces stored in gardens, monuments, museums etc. From several hundred stems we selected several tens of well preserved specimens to make thin sections for systematic assignment, but tissue structures suitable for correct determination were found only on seven specimens.

Even if absolute majority of stems are very poorly preserved due to recrystallization of α-quartz, our detailed study proved that there is only one type of homoxylic wood in the study area – *Dadoxylon* sp. On several specimens we found microscopical bordered pits in radial tracheid walls typical of cordaites. Furthermore, one trunk presents the *Artisia*-like pith, the other has branching rather typical of cordaites. Other suitable features were not preserved. All stems are without bark, roots, small branches or any other parts or plant organs that might be found in the same stratigraphic level.

The allochthonous logs were embedded in fluvial deposits crosswise or perpendicularly to the river streams and in coarse-grained parts of the deposits. Therefore, the stems were transported and embedded only during increased level of rivers or during extreme floods. A quite long and high-powered transport damaged and split the stems, other parts of plant bodies or less resistant plants were destroyed. The river system into which the logs were deposited can be interpreted as an intermediate type between braided and meandering.

Detailed petrographical analysis revealed variable permineralization in the former plant tissue, particularly thanks to strong recrystallizations (almost no organic remains left). Cathodoluminescence microscopy and spectroscopy exposed a multiphase process of silicification and distinct defects in the structure of silica crystal lattice. Hydrothermal quartz in veins proved an important influence of higher temperatures after burial or difficult genesis of wood due to tectonic activity in the Intra Sudetic Basin. Those processes as well as complicated taphonomy of the wood were not favourable to wood preservation thanks to which the wood is difficult to assign to particular species. Finally, the specific silicification of the wood in alluvial formation was possible thanks to a fluctuating water table caused by a seasonally arid climate. This generally agrees with a dry climate phase supposed for this time span (Barruelian).

Acknowledgements

We are thankful to V. Prouza, K. Martínek, and V. Skoček (Czech Geological Survey, Prague) for help in field works, V. Gryc (Mendel University of Agriculture and Forestry in Brno) for special microscopy hours and statistical data proceeding, R. Rössler (Museum für Naturkunde, Chemnitz) for palaeobotanic professional advise, J. Pešek and S. Opluštil (Charles University, Prague) for fruitful discussions on palaeoenvironment. We would like to acknowledge particularly J. Leichmann (Masaryk University, Brno) and J. Götze (TU Bergakademie Freiberg) for cathodoluminescence microscopy and spectral analysis, respectively. T. Grygar (Institute of Inorganic Chemistry, ASCR, Řež) deserves our thanks for the evaluation of the data from analytical methods (CL spectra and XRD processing) and for the help with the manuscript finishing. Our last thanks belong to both referees, H. Falcon-Lang and R. Rössler whose critical comments helped to improve the manuscript. The present research was possible thanks to the financial support of the following grants: KJB301110704, IAA300460510, and MSM0021620855.

References

Bamford, M. K. & Philippe, M. (2001): Jurassic–Early Cretaceous Gondwanan homoxylous woods: a nomenclatural revision of the genera with taxonomic notes. – Review of Palaeobotany and Palynology, **113**: 287-297.

Boggs, S. & Krinsley, D. (2006): Application of cathodoluminescence imaging to the study of sedimentary rocks. – 176 pp.; New York (Cambridge University Press).

Bridge, J. S. (2003): Rivers and floodplains: forms, processes, and sedimentary record. – 491 pp.; Oxford (Blackwell).

Brison, A.-L., Philippe, M. & Thevenard, F. (2001): Are Mesozoic wood growth rings climate-induced? – Paleobiology, **27**: 531-538.

Březinová, D. (1970): Overview of existing findings of fossil wood in Czechoslovakia elaborated on the base of literature sources. – 130 pp.; unpublished Manuscript in Czech, deposited in the National Museum in Prague, Prague.

Březinová, D., Holý, F., Kužvartová, A. & Kvaček, Z. (1994): A silicified stem of *Podocarpoxylon helmstedtianum* Gottwald, 1966 from the Palaeogene site Kučlín (NW Bohemia). – Journal of the Czech Geological Society, **39**: 221-234.

Chlupáč, I., Brzobohatý, R., Kovanda, J. & Stráník, Z. (2002): Geological past of the Czech Republic. – 436 pp.; Prague (Academia). (In Czech)

Diéguez, C. & López-Gómez, J. (2005): Fungus-plant interaction in a Thuringian (Late Permian) *Dadoxylon* sp. in the SE Iberian Ranges, eastern Spain. – Palaeogeography, Palaeoclimatology, Palaeoecology, **229**: 69-82.

DiMichele, W. A., Pfefferkorn, H. W. & Gastaldo, R. A. (2001): Response of Late Carboniferous and Early Permian plant communities to climate change. – Annual Review of Earth and Planetary Science, **29**: 461-87.

Doubinger, J. & Marguerier, J. (1975): Paléoxylologie: Étude anatomique comparée de *Scleromedulloxylon aveyronense* nov. gen. nov. sp. du Permien de St-Affrique (Aveyron, France); considérations taxinomiques et stratigraphiques. – Géobios, **8**: 25-59.

Falcon-Lang, H. J. & Scott, A. C. (2000): Upland ecology of some Late Carboniferous cordaitalean trees from Nova Scotia and England. – Palaeogeography, Palaeoclimatology, Palaeoecology, **156** (3-4): 225-242.

Falcon-Lang, H. J. & Bashforth, A. R. (2005): Morphology, anatomy, and upland ecology of large cordaitalean trees from the Middle Pennsylvanian of Newfoundland. – Review of Palaeobotany and Palynology, **135**: 223-243.

Flörke, O. W., Graetsch, H., Martin, B., Röller, K. & Wirth, R. (1991): Nomenclature of microcrystalline and noncrystalline silica minerals, based on structure and microstructure. – Neues Jahrbuch für Mineralogie, Abhandlungen, **163**: 19-42.

Gastaldo, R. A. & Degges, C. W. (2007): Sedimentology and paleontology of a Carboniferous log jam. – International Journal of Coal Geology, **69** (1-2): 103.

Goeppert, H. R. (1857): Über den versteinerten Wald von Radowenz bei Adersbach in Böhmen und über den Versteinerungsprocess überhaupt. – Jahrbuch der kaiserlich-königlichen geologischen Reichsanstalt, **8**: 725-738.

Goeppert, H. R. (1858): Ueber die versteinerten Wälder im nördlichen Böhmen und in Schlesien. – Jahresberichte der Schlesischen Gesellschaft für vaterländische Cultur, **36**: 27-38.

Götte, T. & Richter, D. K. (2006): Cathodoluminescence characterization of quartz particles in mature arenites. – Sedimentology, **53**: 1347-1359.

Götze, J. (2000): Cathodoluminescence microscopy and spectroscopy in applied mineralogy. – 128 pp.; Freiberg (Technische Universität Bergakademie Freiberg, Germany).

Götze, J. & Rössler, R. (2000): Kathodolumineszenz-Untersuchungen an Kieselhölzern. I. Silifizierungen aus dem Versteinerten Wald von Chemnitz (Perm, Deutschland). – Veröffentlichungen des Museums für Naturkunde Chemnitz, **23**: 35-50.

Götze, J. & Zimmerle, W. (2000): Quartz and silica as guide to provenance in sediments and sedimentary rocks. – Contributions to Sedimentary Geology, **21**: 91 pp.; Stuttgart (Schweizerbart).

Götze, J., Plötze, M., Fuchs, H. & Habermann, D. (1999): Defect structure and luminescence behaviour of agate – results of electron paramagnetic resonance (EPR) and cathodoluminescence (CL) studies. – Mineralogical Magazine, **63** (2): 149-163.

Götze, J., Plötze, M. & Habermann, D. (2001a): Origin, spectral characteristics and practical applications of the cathodoluminescence (CL) of quartz – a review. – Mineralogy and Petrology, **71** (3-4): 225-250.

Götze, J., Rössler, R. & Dietrich, D. (2001b): Cathodoluminescence studies of Permian silicified wood from Chemnitz, Germany. Cathodoluminescence in geosciences: new insights from CL in combination with other techniques, Freiberg, Germany: 46-47.

Holub, V., Skoček, V. & Tásler, R. (1975): Palaeogeography of the Late Palaeozoic in the Bohemian Massif. – Palaeogeography, Palaeoclimatology, Palaeoecology, **18**: 313-332.

IAWA Committee (2004): IAWA list of microscopic features for softwood identification. – IAWA J, **25**: 1-70.

Izart, A., Stephenson, R., Vai, G. B., Vachard, D., Le Nindre, Y., Vaslet, D., Fauvel, P. J., Suss, P., Kossovaya, O., Chen, Z. Q., Maslo, A. & Stovba, S. (2003): Sequence stratigraphy and correlation of late Carboniferous and Permian in the CIS, Europe, Tethyan area, North Africa, Arabia, China, Gondwanaland and the USA. – Palaeogeography, Palaeoclimatology, Palaeoecology, **196**: 59-84.

Katzer, F. (1892): Geologie von Böhmen. – 1606 pp.; Prag.

Landmesser, M. (1994): Zur Entstehung von Kieselhölzern. – ExtraLapis, **7**: 49-80.

– (1995): "Mobility by Metastability" in sedimentary and agate petrology: Applications. – Chemie der Erde-Geochemistry, **58** (1-2): 1-22.

– (1999): Die Genese der Kieselhölzer aus der Sicht der physikalisch-chemischen Mineralogie. – In: Edle Steine aus Holz, 29-41; Idar-Oberstein (Deutsches Edelsteinmuseum e.V.)

Liu Y. J. & Gastaldo, R. A. (1992): Characteristics and provenance of log-transported gravels in a Carboniferous channel deposit. – Journal of Sedimentary Petrology, **62** (6): 1072-1083.

Lojka, R., Drábková, J., Zajíc, J., Sýkorová, I., Franců, J., Bláhová, A. & Grygar, T. (submitted): Climate variability in the Stephanian B based on environmental record of the Mšec Lake deposits (Kladno-Rakovník Basin, central Bohemia).

MAKOWSKY, A. (1878): Der „versteinerte Wald“ bei Radowenz in Böhmen. – Verhandlungen des naturforschenden Vereines in Brünn, **17**: 57-64.

MATYSOVÁ, P. (2004): Silicified Permo-Carboniferous trunks from Intra-Sudetic and Krkonoše-Piedmont Basins. – 48 pp.; Bachelor Thesis, Faculty of Science, Charles University, Prague. (In Czech).

– (2006): Permo-Carboniferous silicified trunks from the Intra-Sudetic and the Krkonoše-Piedmont Basins: taxonomy and instrumental analysis. – 195 pp.; Master Thesis, Faculty of Science, Charles University in Prague. (In Czech)

MATYSOVÁ, P., LEICHMANN, J., GRYGAR, T. & RÖSSLER, R. (2008): Cathodoluminescence of silicified trunks from the Permo-Carboniferous basins in eastern Bohemia, Czech Republic. – European Journal of Mineralogy, **20**: 217-231.

MENCL, V. (2007): Late Pennsylvanian silicified woods of the Intra-Sudetic Basin: systematics and palaeoenvironment. – 106 pp.; Master Thesis, Faculty of Science, Charles University in Prague. (In Czech).

MOXON, T. (2002): Agate: a study of ageing. – European Journal of Mineralogy, **14** (6): 1109-1118.

NOLL, R., RÖSSLER, R. & WILDE, V. (2005): 150 Jahre Dadoxylon – Zur Anatomie fossiler Koniferen – und Cordaitenhölzer aus dem Rotliegend des euramerischen Florengebietes. – Veröffentlichungen des Museums für Naturkunde Chemnitz, **28**: 2-48.

NOLL, R. & WILDE, V. (2002): Conifers From the “Uplands” – Petrified Wood From Central Germany. – In: DERNBACH, U. & TIDWELL, W. D. (Eds.): Secrets of Petrified Plants. Fascination from Millions of Years, 88-103; Heppenheim (D’Oro Verlag).

OPLUŠTIL, S. & CLEAL, C. J. (2007): A comparative analysis of some Late Carboniferous basins of Variscan Europe. – Geological Magazine, **144** (3): 417-448.

PARRISH, J. T. & FALCON-LANG, H. J. (2007): Coniferous trees associated with interdune deposits in the Jurassic Navajo Sandstone Formation, Utah, USA. – Paleontology, **50** (4): 829-843.

PEŠEK, J. (1968): To importance of araucarites for stratigraphy of sediments in Plzeň Basin. –Časopis pro mineralogii a geologii, **13**: 213. (In Czech)

PEŠEK, J., HOLUB, V., JAROŠ, J., MALÝ, L., MARTÍNEK, K., PROUZA, V., SPUDIL, J. & TÁSLER, R. (2001): Geology and deposits of Upper Palaeozoic limnic basins of the Czech Republic. – 244 pp.; Prague (Czech Geological Survey). (In Czech)

PETRASCHECK, W. (1924): Kohlengeologie der österreichischen Teilstaaten, Teil I; Wien (Verlag für Fachliteratur).

PURKYNĚ, C. (1927): About deposits of silicified araucarite trunks in Bohemia, especially in Krkonoše Piedmont. – Časopis Národního muzea, **101**: 113-131. (In Czech)

REPORT OF THE WORKING GROUP FOR REGIONAL GEOLOGICAL CLASSIFICATION OF THE BOHEMIAN MASSIF AT THE FORMER CZECHOSLOVAK STRATIGRAPHIC COMMISSION (1994): Regional geological subdivision of the Bohemian Massif on the territory of the Czech Republic. – Journal of the Czech Geological Society, **39** (1): 127-144.

RÖSSLER, R. (2002): The petrified trees from the Kyffhäuser, Germany. – In: DERNBACH, U. & TIDWELL, W. D. (Eds.): Secrets of petrified plants. Fascination from millions of years, 48-53; Heppenheim (D’Oro Verlag).

RÖSSLER, R. (2006): Two remarkable Permian petrified forests: correlation, comparison and significance. – In: LUCAS, S. G., CASSINIS, G. & SCHNEIDER, J. W. (Eds.): Non-Marine Permian biostratigraphy and biochronology. – Geological Society, Special Publication, **265**: 39-63.

ROSCHER, M. & SCHNEIDER, J. W. (2005): An annotated correlation chart for continental Late Carboniferous and Permian basins and the marine scale. – In: LUCAS, S. G. & ZEIGLER, K. E. (Eds.): The Nonmarine Permian. – New Mexico Museum of Natural History and Science, Bulletin, **30**: 282-291.

SCHEFFLER, K., BUEHMANN, D. & SCHWARK, L. (2006): Analysis of late Palaeozoic glacial to postglacial sedimentary successions in South Africa by geochemical proxies – Response to climate evolution and sedimentary environment. – Palaeogeography, Palaeoclimatology, Palaeoecology, **240**: 184-203.

SCHNEIDER, J. W., KÖRNER, F., ROSCHER, M. & KRONER, U. (2006): Permian climate development in the northern peri-Tethys area – The Lodève Basin, French Massif Central, compared in a European and global context. – Palaeogeography, Palaeoclimatology, Palaeoecology, **240**: 161-183.

SCHWEINGRUBER, F. H., BÖRNER, A. & SCHULTZE, E. D. (2006): Atlas of woody plant stems, evolution, structure, and environmental modifications. – 229 pp.; Heidelberg & Berlin (Springer).

SKOČEK, V. (1970): Silicified wood in the Central Bohemian Permo-Carboniferous. – Věstník Ústředního ústavu geologického, **45**: 87-94. (In Czech)

STUR, D. (1877): Zwei Notizen über die Araucariten im nordöstlichen Böhmen. – Verhandlungen der kaiserlich-königlichen geologischen Reichsanstalt, **1877**: 237-240.

TÁSLER, R., ČADKOVÁ, Z., DVOŘÁK, J., FEDIUK, F., CHALOUPSKÝ, J., JETEL, J., KAISEROVÁ-KALIBOVÁ, M., PROUZA, V., SCHOVÁNKOVA-HRDLIČKOVÁ, D., STŘEDA, J., STŘÍDA, M. & ŠETLÍK, J. (1979): Geology of the Czech Part of the Intrasudetic Basin; Prague (Central Geological Institute, Akademia Prague). (In Czech)

UHL, D. (2006): Some considerations on the taphonomy of conifer remains from the Late Permian of Europe. – Neues Jahrbuch für Geologie und Paläontologie, Monatshefte, **2006**: 483-502.

VALÍN, F. (1956): Hydrodynamic conditions during sedimentation of Žaltman Arkoses. – Zprávy o geologických výzkumech v r., **1956**: 182-183. (In Czech)

– (1960): Litology of the Žaltman Arkoses group. – Věstník Ústředního ústavu geologického, **26**: 409-437. (In Czech).

VOGELLEHNER, D. (1964): Zur Nomenklatur der fossilen Holzgattung *Dadoxylon* ENDLICHER 1847. – Taxon, **13**: 233-237.

WAGNER, R. H. & MAYORAL, E. J. (2007): The Early Permian of Valdeviar in Sevilla province, SW Spain: basin history and climatic/palaeogeographic implications. – Journal of Iberian Geology, **33** (1): 93-124.

WEIBEL, R. (1996): Petrified wood from an unconsolidated sediment, Voervadsbro, Denmark. – Sedimentary Geology, **101**: 31-41.

WITKE, K., GÖTZE, J., RÖSSLER, R., DIETRICH, D. & MARX, G. (2004): Raman and cathodoluminescence spectroscopic investigations on Permian fossil wood from Chemnitz – a contribution to the study of the permineralisation process. – Spectrochimica Acta, (A), **60**: 2903-2912.

Manuscript received: July 3rd, 2008.
Revised version accepted by the Stuttgart editor: October 20th, 2008.

Addresses of the authors:

VÁCLAV MENCL, Institute of Geology and Palaeontology, Faculty of Science, Charles University, Albertov 6, 128 43 Prague 2, Czech Republic & Municipal Museum Nová Paka, Treasury of Gem stones, F. F. Procházky 70, 509 01 Nová Paka, Czech Republic;
e-mail: vaclavmencl@seznam.cz

PETRA MATYSOVÁ (corresponding author), Institute of Geology and Palaeontology, Faculty of Science, Charles University, Albertov 6, 128 43 Prague 2, Czech Republic & Department of Geochemistry, Institute of Rock Structure and Mechanics, ASCR, v.v.i., V Holěsovičkách 41, 182 09 Prague 8, Czech Republic;
e-mail: pmatysova@email.cz

JAKUB SAKALA, Institute of Geology and Palaeontology, Faculty of Science, Charles University, Albertov 6, 128 43 Prague 2, Czech Republic;
e-mail: rade@natur.cuni.cz

Příloha II

menším pro vagrantní bentos. Tento nesoulad lze však také vysvětlit redepozicí alespoň části zbytků fauny krátce po odumření organismů z nestabilního svahu pánevního dna do anoxického prostředí. Souvislejší zbytky trilobitů včetně možných exuvií jsou však s touto alternativou v rozporu. Nález polohy intraformační brekcie uvnitř sekvence je naopak jednoznačnou indikací pro alespoň krátkodobý sedimentační neklid. Ačkoli většina nalezené fauny patří k infauním, kvaziinfauním či vagrantně bentickým prvkům, nebyly zjištěny žádné ichnofosilie (snad s výjimkou některých konkrecí upomínajících na ichnorod *Thalassinoides* isp., viz také Röhlich et al. 2008). Jako možnou příčinu lze připustit i úplné promíšení substrátu (R. Mikuláš, ústní sdělení). Některé polohy jílovců ovšem jeví náznaky laminace, což by tuto možnost vylučovalo.

Závěr

Lokalita patří zřejmě do relativně hlubokovodnějšího vývoje (viz Havlíček a Vaněk 1990) střední části bohdaleckého souvrství a je zřejmě partií starší než polyteichový obzor i celá „polyteichová“ (michelská) facie. Ta má v blízkém okolí studované lokality v Praze-Michli i typické lokality svého vývoje, které však byly zjištěny nejblíže ve Vyskočilově ulici a dále k JV (Havlíček in Králík, red. 1983, Röhlich 2006).

Příspěvek byl podpořen projekty VaV MKČR DE08P04OMG002 a GAAV IAA301110908. Děkujeme RNDr. Š. Mandovi za laskavé poskytnutí mapky výskytu ordoviku v oblasti Barrandienu.

Literatura

BUDIL, P. (2000): Zpráva o zajímavé paleontologické lokalitě ve východní části Prahy. – Zpr. geol. Výzk. v Roce 1999, 122–123.

HAVLÍČEK, V. – VANĚK, J. (1990): Ordovician invertebrate communities in black-shale lithofacies (Prague Basin, Czechoslovakia). – Věst. Ústř. Úst. geol., 65, 4, 223–236. Praha.

KRÁLÍK, F., red. (1983): Základní geologická mapa ČSSR 1 : 25 000, list 12-243 Praha-sever. – Ústř. úst. geol. Praha.

MANDA, Š. (2008): *Trocholites* Conrad, 1838 (Nautiloidea, Tarphycerida) in the Middle Ordovician of the Prague Basin and its palaeobiogeographical significance. – Bull. Geosci., 83, 3, 327–334.

RÖHLICH, P. (2006): O takzvané polyteichové facii v bohdaleckém souvrství (ordovik, střední Čechy). – Zpr. geol. Výzk. v Roce 2005, 40–42.

RÖHLICH, P. – BUDIL, P. – STEINOVÁ, M. (2008): Fauna: bohdaleckého souvrství z dočasného odkryvu v Praze 4. – Zpr. geol. výzk. v Roce 2007, 132–133.

STRAKA, J. (1985): Základní geologická mapa ČSSR 1 : 25 000, list 12-244 Praha-východ. – Ústř. úst. geol. Praha.

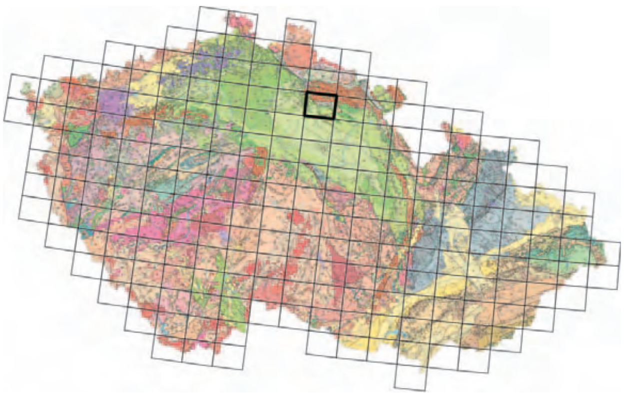
Nové poznatky o svrchně karbonských prokřemenělých stoncích stromovitých přesliček z Novopacka

New data on Upper Carboniferous silicified stems of calamites from the Nová Paka region

JAKUB SAKALA [1] – VÁCLAV MENCL [1, 2] – PETRA MATYSOVÁ [1, 3]

[1] *Ústav geologie a paleontologie, Přírodovědecká fakulta, Univerzita Karlova v Praze, Albertov 6, 128 43 Praha 2; rade@natur.cuni.cz*
[2] *Městské muzeum Nová Paka, Klenotnice drahých kamenů, F. F. Procházky 70, 509 01 Nová Paka; VaclavMencl@seznam.cz*
[3] *Ústav struktury a mechaniky hornin AV ČR, v. v. i., V Holešovičkách 41, 182 09 Praha 8; pmatysova@email.cz*

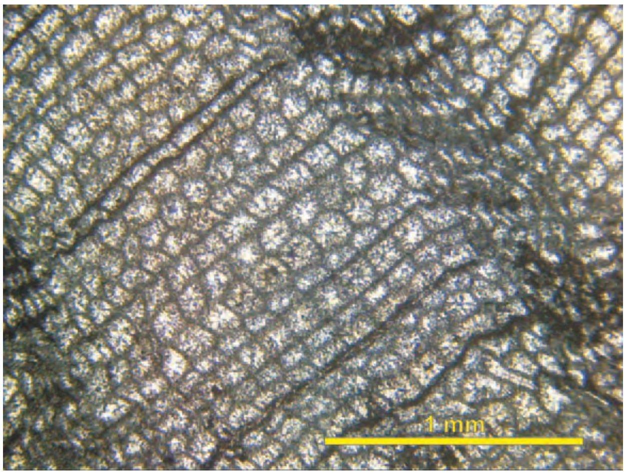
(03-43 Jičín)



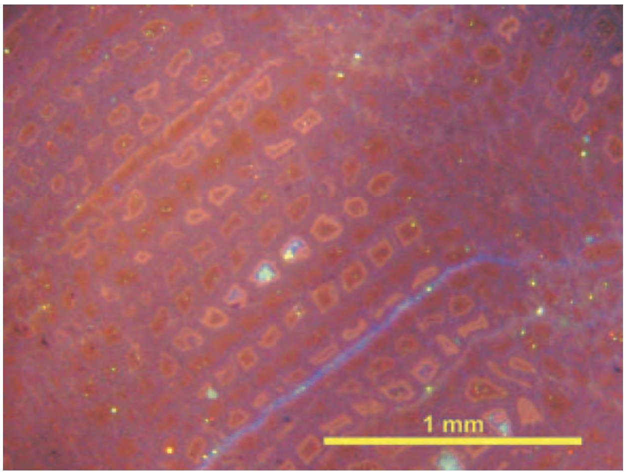
Key words: Upper Carboniferous, calamite stems, palaeobotany, cathodoluminescence, -quartz, Ploužnice Horizon, Krkonoše Piedmont Basin

Abstract: The described silicified stems of calamites come from sediments near the town Nová Paka, which are of the Stephanian C age. All of them are characterized by an alternation of interfascicular rays and fascicular wedges with only one type of tracheids and important amount of parenchyma, so they belong to the form genus *Arthropitys* Goeppert. Cathodoluminescence analysis shows quite well preservation of a specific pattern, which might point to a volcanic influence during silicification. Based on the presence of hygrophilous elements, the paleoenvironment and climatic conditions of the site where the plants originally grew can be considered as rather humid and swampy.

Podkrkonošská pánev je obecně známa četnými nálezy zkamenělých dřev. Vedle tzv. araukaritů (dřev jehličnatých rostlin typu *Dadoxylon*) a částí stonků stromovitých kapradin rodu *Psaronius* jsou to především stonky rostlin přesličkovitých. V příspěvku přinášíme první výsledky mezioborového studia prokřemenělých dřev stromovitých přesliček z okolí Nové Paky, především pak z lokality Balka.



Obr. 1. Výbrus č. 6b – XPL (# E6296, Národní muzeum). Část sekundárního xylému, kde jsou řady tracheid i dlouhých paprsků uspořádány diagonálně. V dolní části snímku je doprovází tenká tmavá trhlina (téměř není rozeznatelná). Buňky ve zdánlivé přírůstkové zóně zde vypadají velmi smáčknuté a objevují se v levé dolní a v pravé horní části snímku; transverzální řez.



Obr. 2. Výbrus č. 6b – CL (# E6296, Národní muzeum). Popis CL barev je uveden v textu. Dlouhá tenká trhlina podél dřevního paprsku, která vyzařuje jasně modrou CL, se hákovitě uhýbá doprava, a to v zóně sekundárního xylému, která byla postižena kompakcí a makroskopicky se na průřezu tedy jeví jako „falešný letokruh“. Drobounká žlutá svítivá zrnka jsou zbytky diamantového leštidla.

Geologická situace

Podkrkonošská pánev (PKP) je součástí komplexu svrchnopaleozoických kontinentálních pánví Českého masivu. Studované území leží v okolí Nové a Staré Paky a s největší pravděpodobností je úzce spjato s výskytem tzv. ploužnického obzoru, který stratigraficky náleží do střední části semilského souvrství, stáří gzhel (stephan C). Ploužnický obzor je znám pouze z j. části PKP, v s. části mu stratigraficky odpovídá obzor štěpanicko-čikvásecký. Vystupuje v úzkém pásu táhnoucím se v.-z. směrem od Borovnice a Pecky do s. okolí Nové Paky a pokračuje přes Starou Paku a Syřenov až k vrchu Tábor. V ploužnickém obzoru lze vyčlenit dvě polohy, jejichž mocnost se pohybuje od 10 do 60 m. Je tvořen převážně pestře zbarvenými vápnitými prachovci a jílovci s vložkami tufů, tufitů, tufitických a vulkanodetritických jemnozrnných pískovců a lakustrinních vápenců. Meziloží těchto poloh je mocné obvykle 10–30 m a tvoří jej červenohnědé aleuropelity a pískovce (Pešek et al. 2001). Zejména ve spodní poloze ploužnického obzoru se často vyskytují čočkovité vrstvičky a hlízky karneolu a zkřemenělých dřev různých typů: vedle zkřemenělých stonků přesliček to jsou stromovité kapradiny (typu *Psaronius*) a kapraďosemenné rostliny (typu *Medullosa*) (Matysová 2004). K historicky známým nalezištím patří Borovnice, Lísek a Balka (s. od Nové Paky). Kvůli absenci výchozů ploužnického obzoru se na těchto lokalitách dosud nepodařilo nalézt zkřemenělá dřeva v jejich původní pozici ve fosiliferním sedimentu, tj. *in situ*. Nalézané stonky jsou většinou druhotně uloženy v kvartérním aluviu, vyvětralé díky své vyšší odolnosti a přenesené sem z původních lokalit (Matysová 2006).

Systematicko-paleobotanický popis

Z několika vzorků byly vybrány ty, jejichž stav zachování umožnil mikroskopický popis na základě studia leštěných výbrusů. Na všech je přítomna dřeňová dutina, druhotně vyplněná sedimentem. Na příčném řezu je na vzorcích patrné střídání fascikulárních oblastí, charakterizovaných primárním dřevem s typickými karinálními kanálky, přecházejícím směrem vně do dřeva sekundárního s úzkými dřeňovými paprsky, s oblastmi interfascikulárními se širokými dřeňovými paprsky. Tento typ rozdělení společně s výrazným podílem parenchymu, pouze jediným typem tracheid a typickým uspořádáním na podélném tangenciálním řezu (viz Taylor – Taylor – Krings 2009 na str. 351) umožňuje zařazení vzorků do formálního rodu *Arthropitys* Goeppert (Rößler – Noll 2006, 2007). Přítomnost formálního rodu *Calamitea* Cotta (dříve *Calamodendron* Brongniart) udávaného z Nové Paky (např. Rössler – Noll 2007 na str. 169) se tak na základě studia dostupného materiálu zatím nepotvrdila. Třetí typ zkamenělého dřeva stromovitých přesliček (formální rod *Arthroxylon* Reed) není z Novopacka znám.

Geochemicko-mineralogický popis

V pletivech přesliček *Arthropitys* bylo charakterizováno několik mineralogických forem SiO_2, které jsou vůči sobě různě uspořádány a odrážejí tak anatomické znaky dnes již neexistující rostliny. V sekundárním xylému se ve většině případů nachází mikrokrystalický křemen, ve větších tracheidách (jejich lumenech) i makrokrystalický, který někdy vytváří mozaiky (obr. 1). Sférolitický chalcedon se vyskytuje jen někdy, zejména ve vzorcích popsaných z okolí Staré Paky, patrně ze staropackých pískovců (Matysová 2006). Katodoluminiscenční analýza jednoznačně ukazuje, že vzorky z Balky mají svůj vlastní „chemický mód“ a odlišují se tak od jiných vzorků z jiných lokalit podobného stáří (např. Chemnitz v Německu, Autun ve Francii, oblast Huqf v Ománu). Nejvíce se podobají fosiliím, u kterých je znám vliv vulkanismu během silicifikace (Matysová nepubl. data).

Mezi základní CL (horká katodová luminiscence) odstíny SiO_2 hmoty v *Arthropitys* patří odstíny červené v primární hmotě/pletivu (mikro- a makrokrystalický křemen), růžové (sférolity chalcedonu) a krátce žijící modré (rekrystalizace, další fáze silicifikace – obr. 2). Při větším zvětšení je CL schopná zachytit i vícevrstevnou buněčnou stěnu tracheid přesličky, kde má každá vrstva trochu jiný CL odstín a anatomie buněčné stěny je tak zřetelnější než při mikroskopii v normálním světle. Tento jev pravděpodobně souvisí s přítomností různých CL aktivátorů v jednotlivých sektorech. Obecně je zatím předmětem diskuse, jaké konkrétní aktivátory se podílejí na tom kterém CL odstínu a zda se jedná o vnitřní defekty v krystalové struktuře nebo o nepatrné příměsi konkrétních prvků (např. Al^{3+} centra – modrá CL, viz Witke et al. 2004).

Diskuse

V pánvích středočeských, západočeských, podkrkonošské a vnitrosudetské existují ekvivalentní barruelské horizonty s téměř totožným výskytem silicifikovaných dřev typu *Dadoxylon* (Mencl 2007, Matysová et al. 2008, Mencl et al. 2009). V okolí Balky u Nové Paky v PKP jsou o něco mladší výskyty fosilních dřev druhově mnohem pestřejší. Katodoluminiscenční provenienční analýza ukazuje, že fenomény jako tektonická aktivita, vulkanismus nebo termální prameny mohly mít za následek několikastupňovou rekrystalizaci fyzikálně odlišnými minerálními roztoky (vulkanismus, epiči termální roztoky). Obecně se zdá, že na Balkách mohlo existovat i v rámci celkově suchého klimatického období (Mencl et al. 2009) místní společenstvo s převahou vlhkomilných prvků, např. v prostředí jezerním či bažinném, jak tomu nasvědčují zde popisované zbytky přesliček typu *Arthropitys* či nálezy silicifikovaných rašelin.

Práce je součástí juniorského grantu Grantové agentury Akademie věd České republiky č. KJB 301110704. Výzkum byl rovněž podpořen granty IAA300460510 a MSM0021620855. Autoři děkují V. Prouzovi a Z. Šimůnkovi za kritické posouzení článku.

Literatura

MATYSOVÁ, P. (2004): Zkřemenělá permokarbonská dřeva v oblasti vnitrosudetské a podkrkonošské pánve. Bakalářská práce. – 48 str., MS Přírodověd. fak. Univ. Karl. Praha.

MATYSOVÁ, P. (2006): Permokarbonská silicifikovaná dřeva z vnitrosudetské a podkrkonošské pánve: Systematika a instrumentální analýza. Diplomová práce. – 195 str., MS Přírodověd. fak. Univ. Karl. Praha.

MATYSOVÁ, P. – LEICHMANN, J. – GRYGAR, T. – RÖSSLER, R. (2008): Cathodoluminescence of silicified trunks from the Permo-Carboniferous basins in eastern Bohemia, Czech Republic. – Eur. J. Mineral., 20, 217–231.

MENCL, V. (2007): Svrchnokarbonská zkřemenělá dřeva vnitrosudetské pánve: Systematika a paleoprostředí. Diplomová práce. – 106 str., MS Přírodověd. fak. Univ. Karl. Praha.

MENCL, V. – MATYSOVÁ, P. – SAKALA, V. (2009): Silicified wood from the Czech part of the Intra Sudetic Basin (Late Pennsylvanian, Bohemian Massif, Czech Republic): systematics, silicification and palaeoenvironment. – Neu. Jb. Geol. Paläont., Abh., 252, 269–288.

PEŠEK, J. – HOLUB, V. – JAROŠ, J. – MALÝ, L. – MARTÍNEK, K. – PROUZA, V. – SPUDIL, J. – TÁSLER, R. (2001): Geologie a ložiska svrchnopaleozoických limnických pánví České republiky. – 244 str., Čes. geol. služba. Praha.

RÖSSLER, R. – NOLL, R. (2006): Sphenopsids of the Permian (I): The largest known anatomically preserved calamite, an exceptional find from the petrified forest of Chemnitz, Germany. – Rev. Palaeobot. Palynol., 140, 145–162.

RÖSSLER, R. – NOLL, R. (2007): *Calamitea* Cotta, the correct name for calamitean sphenopsids currently classified as *Calamodendron* Brongniart. – Rev. Palaeobot. Palynol., 144, 157–180.

TAYLOR, T. N. – TAYLOR, E. L. – KRINGS, M. (2009): Paleobotany: The Biology and Evolution of Fossil Plants, Second Edition. – 1230 str., Elsevier Acad. Press. Burlington.

WITKE, K. – GÖTZE, J. – RÖSSLER, R. – DIETRICH, D. – MARX, G. (2004): Raman and cathodoluminescence spectroscopic investigations on Permian fossil wood from Chemnitz – a contribution to the study of the permineralisation process. – Spectrochim. Acta, Part A, 60, 2903–2912.

Příloha III

Review of Palaeobotany and Palynology 197 (2013) 70–77

Contents lists available at ScienceDirect

Review of Palaeobotany and Palynology

journal homepage: www.elsevier.com/locate/revpalbo

Research paper

First anatomical description of silicified calamitalean stems from the upper Carboniferous of the Bohemian Massif (Nová Paka and Rakovník areas, Czech Republic)

Václav Mencl [a,b,*], Jakub Holeček [a], Ronny Rößler [c], Jakub Sakala [a]

[a] Charles University in Prague, Faculty of Science, Institute of Geology and Palaeontology, Albertov 6, 128 43 Praha 2, Czech Republic
[b] Municipal Museum Nová Paka, Treasury of Gem Stones, F. F. Procházky 70, 509 01 Nová Paka, Czech Republic
[c] DAStietz, Museum für Naturkunde, Moritzstraße 20, D-09111 Chemnitz, Germany

ARTICLE INFO

Article history:
Received 14 December 2012
Received in revised form 5 May 2013
Accepted 6 May 2013
Available online 16 May 2013

Keywords:
Arthropitys bistriata
Calamitea striata
stem anatomy
late Carboniferous
Czech Republic

ABSTRACT

Silicified stems are very abundant in the upper Palaeozoic basins of the Czech Republic. The results of an anatomical study of the silicified calamitalean stems from the Krkonoše Piedmont and Kladno–Rakovník basins are presented here for the first time. In the Krkonoše Piedmont Basin, there are various silicified plant remains, but the presence of calamitalean wood is restricted to only one stratigraphic unit, to the so-called "Ploužnice Horizon". Only a few data on the systematics of permineralised or petrified stems from the Kladno–Rakovník Basin are available, anatomical descriptions are largely lacking and fossilised calamitalean stems were unknown. The fossils can be attributed to two species: the common *Arthropitys* cf. *bistriata* and the rare *Calamitea striata*; the occurrence of the latter is limited to the Krkonoše Piedmont Basin.

1. Introduction

The Carboniferous–Permian of the Krkonoše Piedmont area is historically well known for its abundant fossil stems. Their frequency and aesthetic value attracted the attention of local and foreign researchers (Březinová, 1970), but a modern systematic overview is still lacking. One might even say that in the past decades only collectors have shown their interest. The fossil stems were illustrated in several popular books on fossil plants (e.g., Dernbach, 1996; Dernbach et al., 2002). Only Matysová and Mencl in their MSc theses (Matysová, 2006; Mencl, 2007) and three consecutive papers (Matysová et al., 2008; Mencl et al., 2009; Matysová et al., 2010) presented the first detailed systematical and geochemical data, mainly focused on the "*Dadoxylon*" type of wood. Holeček in his MSc thesis (Holeček, 2011) studied the succession in the Kladno–Rakovník Basin in Central/Western Bohemia, which also contains abundant fossil wood and can be correlated with the succession in the Krkonoše Piedmont area.

The present contribution summarises new and old evidences of silicified calamite stems from the upper Carboniferous of the Czech Republic and provides the first anatomical description with special emphasis on the Krkonoše Piedmont Basin as well as the Kladno–Rakovník Basin, from which calamite stems were previously unknown. We apply the taxonomic concept recently developed for calamitaleans from the early Permian petrified forest of Chemnitz, Germany (Rößler and Noll, 2006, 2007, 2010; Rößler et al., 2012a).

2. Historical research

2.1. Krkonoše Piedmont Basin

Silicified stems in the Nová Paka region (Fig. 1A) were mentioned by many authors, probably first by Maloch (see Heber, 1844). The first scientific descriptions of silicified plant remains from localities such as Nová Paka, Pecka and Kozinec are by Goeppert (1858), who described the conifer wood *Araucarites schrollianus* (=*Dadoxylon saxonicum*; synonym: *Dadoxylon schrollianum*), *Calamites* and *Psaronius*. Frič (1912) noticed several types of silicified stems from Nová Paka and Lázně Bělohrad (stem types *Medullosa*, *Psaronius* and "*Dadoxylon*") and silicified peat. He paid special attention to insect borings on the woods, and to small axes of the climbing fern *Ankyropteris brongniartii*, which were preserved inside the root mantle of *Psaronius* trunks. Common findings of silicified wood in the Nová Paka and Pecka surroundings were also mentioned by Jokély (1861), Feistmantel (1873a,b,c) and Purkyně (1927). Several pieces of silicified stems ("*Dadoxylon*", *Psaronius*, *Medullosa*) were found in the village of Pecka; mostly as loose pieces but some of them in outcrops, although not in upright position (Purkyně, 1927). The age of these findings was initially considered

* Corresponding author at: Charles University in Prague, Faculty of Science, Institute of Geology and Palaeontology, Albertov 6, 128 43 Praha 2, Czech Republic.
E-mail addresses: vaclavmencl@seznam.cz (V. Mencl), holda29@gmail.com (J. Holeček), roessler@naturkunde-chemnitz.de (R. Rößler), rade@natur.cuni.cz (J. Sakala).

0034-6667/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.revpalbo.2013.05.001

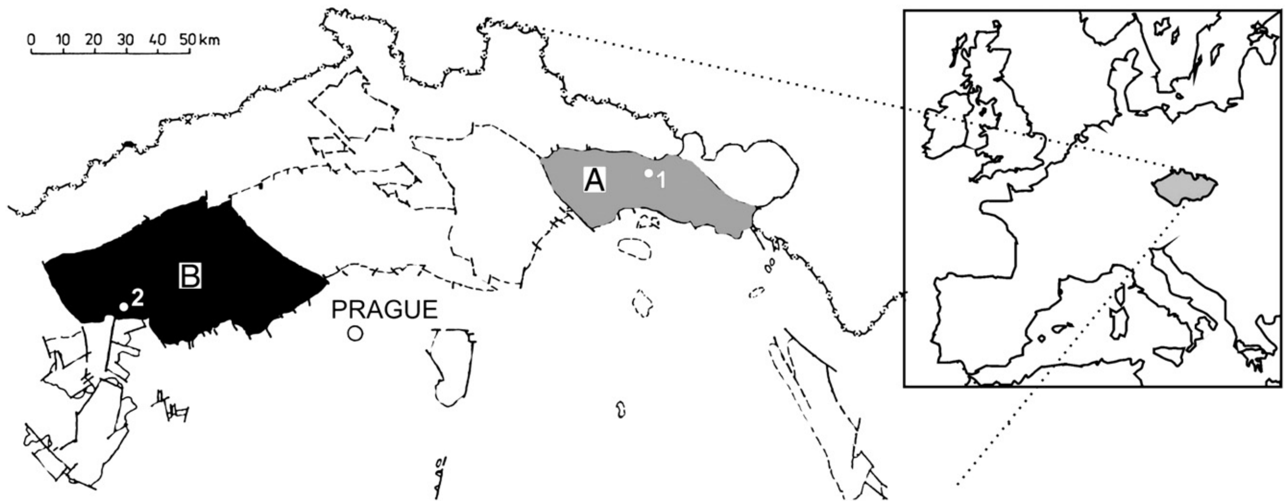


Fig. 1. Carboniferous–Permian basins of the Czech Republic with the position of the Krkonoše Piedmont Basin (A) and Kladno–Rakovník Basin (B) and two studied localities Nová Paka (1) and Bílenec (2) with most abundant fossil wood.

to be early Permian (Feistmantel, 1873a,b,c), but is now regarded to be Kasimovian–Gzhelian (Matysová, 2006; Mencl, 2007; Mencl et al., 2009). No detailed anatomical descriptions of calamitalean stems were published to date, only the historical report by Goeppert (1858), some photos by Němejc (1963, Plates XXXII–XXXIII), a few notes by local collectors (e.g., Soukup, 1997) and a short note by Sakala et al. (2009).

2.2. Kladno–Rakovník Basin

Findings of silicified wood in the Kladno–Rakovník Basin (Fig. 1B) are not as common as in the Krkonoše Piedmont Basin. The first study was carried out by Feistmantel (1873b). He described silicified wood from localities such as Rakovník, Lubná, Hředle, Řevničov, Klobuky and Krušovice as *Araucarites schrollianus* and *Psaronius*. Frič (1912) mentioned sandy strata with silicified wood near Kněževes. Purkyně (1927) provided a summary of findings from Bohemia, including the new localities Očihov and Kryry; he also mentioned an occurrence of black silicified wood from Slaný Formation. The most recent petrological study was performed by Skoček (1970), who divided the petrified wood in two categories: dark wood with organic matter and lighter wood without organic matter. Skoček (1970) assumed that the dark wood was deposited in swamps or marshes in a wet climate regime, while the more common pale-coloured wood was regarded as being deposited under dry climatic conditions. Finally, a short note about the silicified peat and fossil wood in the Kloubuky area was recently published by local collectors (Dvořák and Švancara, 2003). It can be said that the research in the Kladno–Rakovník Basin was not as thorough as in the Krkonoše Piedmont Basin.

3. Geological settings

3.1. Krkonoše Piedmont Basin

The Krkonoše Piedmont Basin is situated in the northern part of the Czech Republic, at the foot of the Krkonoše–Jizerské hory crystalline complex (Fig. 1A) and belongs to a system of post-orogenic extensional/transtensional basins of the Bohemian Massif. Continental deposits in the Krkonoše Piedmont Basin are early Moscovian (Asturian) to Early (or even Middle) Triassic. The maximum thickness of the succession is about 1800 m (Pešek et al., 2001). Despite the fact that occurrences of "*Dadoxylon*" type of wood are confirmed from three stratigraphic levels (Mencl et al., 2009), silicified remains of calamitaleans (*Arthropitys*, *Calamitea*), ferns (*Psaronius*) and seed-ferns (*Medullosa*) are restricted to a single stratigraphic level — the so-called "Ploužnice Horizon" (Fig. 2, right column).

The Ploužnice Horizon belongs to the middle part of the Semily Formation and is Gzhelian (Stephanian C) in age. It is known from the southern part of the basin, only from a number of localities that are situated approximately around Syřenov, Stará Paka, Nová Paka (with the well-known Balka locality), Borovnice and Pecka. This unit is usually up to 100 m thick and sediments are mostly lacustrine (Pešek et al., 2001). They consist of fine-grained, reddish mudstones and siltstones with limestone-enriched horizons, calcareous and silicic concretions, and intercalations of tuff and tuffitic sandstones that were deposited as bedload (Stárková et al., 2009). Common occurrences of silicified wood and nodules of carnelian are restricted to the lower part of the Ploužnice Horizon. Silicified stems in growth position have never been observed. They are very rarely found in outcrops, but they are always transported and redeposited in lacustrine and fluvial sediments. Most of fossil trunks are split into pieces and found in eluvial sediments.

3.2. Kladno–Rakovník Basin

The Kladno–Rakovník Basin is situated in the central and northwestern part of the Czech Republic (Fig. 1B). It was also formed as part of a post-orogenic extensional/transtensional basin of the Bohemian Massif. The oldest sediments are early Moscovian and the youngest are Gzhelian in age. These mostly lacustrine sediments are usually divided into four formations, i.e. the Kladno, Týnec, Slaný and Líně formations. Silicified wood is usually found in all formations, but it is most abundant in the Týnec and Líně formations (Fig. 2, left column).

The Týnec Formation (Kasimovian) is typified by coarse-grained reddish sediments, without or with little volcanic material. Up to 10 m long silicified trunks were described from this formation by Pešek et al. (2001). The Týnec and the Líně formations are separated by a hiatus. The Líně formation (Gzhelian) was deposited in a drier environment and primarily consists of reddish to crimson-coloured siltstones and claystones. Tuffs and tuffites are more common than in the underlying Týnec Formation. Three horizons can be distinguished within the Líně Formation: the Zdětín, Klobuky and Stránka horizons (Pešek et al., 2001). Unfortunately, there are no outcrops of this formation in the Kladno–Rakovník Basin and all fossil trunks have been found in eluvium. Whole trunks are extremely rare, petrified wood is often fragmented into small pieces without branches. Therefore, we suppose that the trees were transported by rivers and eventually buried far from their original place of growth.

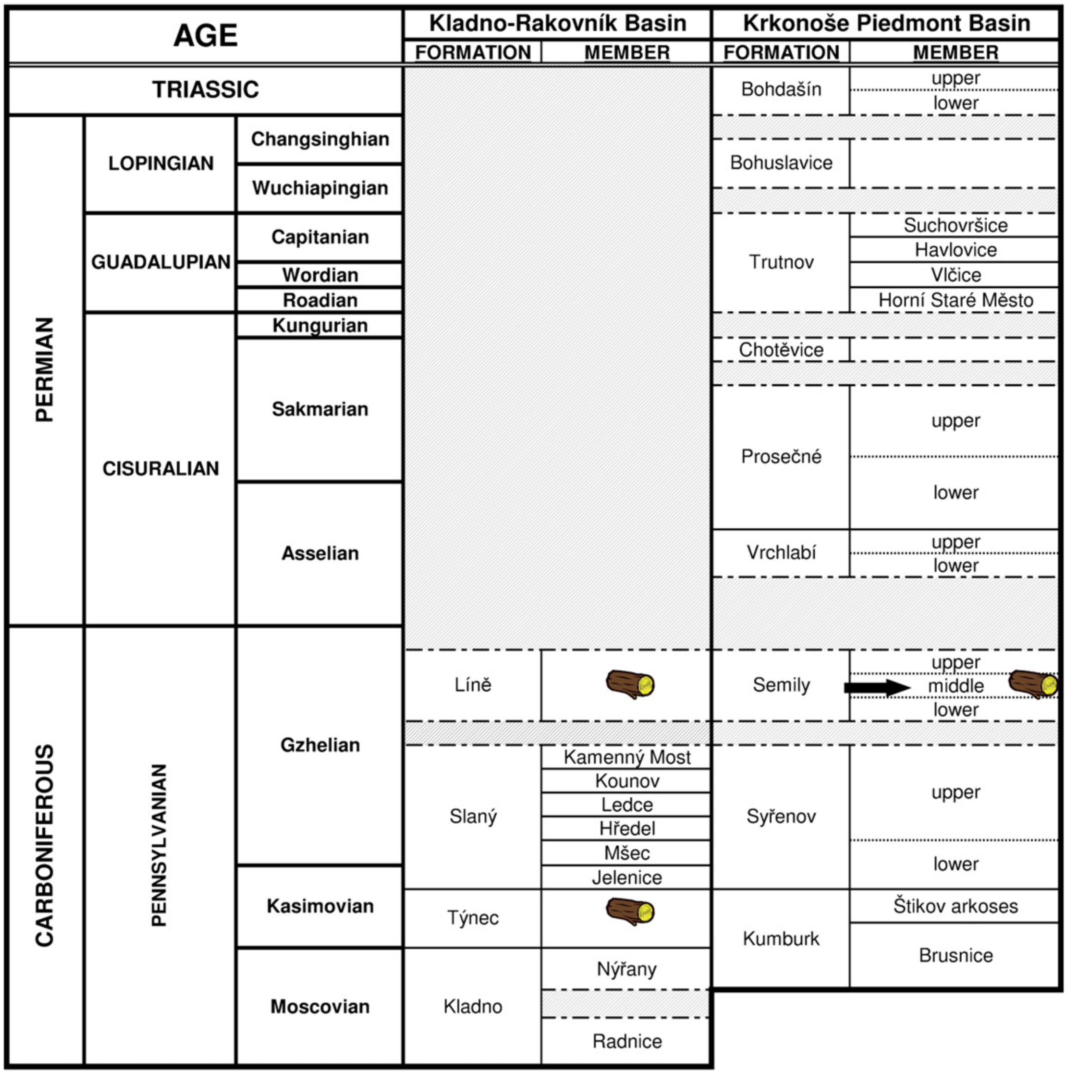


Fig. 2. Stratigraphy of the Kladno–Rakovník Basin in comparison with the Krkonoše Piedmont Basin; positions of the silicified calamitalean stems are figured by three small logs, the arrow shows the position of the Ploužnice Horizon.

4. Materials and methods

The samples from the Krkonoše Piedmont Basin are either from the palaeontological collections of the Municipal Museum Nová Paka, which have been collected during the last 100 years (signature P) and the Museum of Eastern Bohemia in Hradec Králové (abbreviation H), or by a private collector (specimen DVO5/XLVI). One specimen of *Calamitea striata* is from the Leuckart collection at Museum für Naturkunde Chemnitz (signature K). The samples from the Kladno–Rakovník Basin were provided exclusively by private collectors (abbreviations SVE, REH, ZAJ, DVO).

Only the best preserved samples were selected for further study. Cross sections of several dozens of well-preserved samples were polished and examined in reflected light with a Leica EZ 5 stereomicroscope and a Nikon Eclipse LV100Pol microscope. Several samples were selected for thin sectioning and transverse, tangential longitudinal and radial longitudinal sections were studied microscopically in transmitted light.

Thin sections were studied with an Olympus BX-51 microscope. Images were made with Olympus Camedia 3030 and Canon D500 digital cameras and processed with imaging software AnalySIS and NIS-Elements, with the help of Microsoft Excel 2007–2010.

5. Results

5.1. Systematics

Class: Sphenopsida.
Order: Equisetales.
Family: Calamitaceae.

Arthropitys Goeppert.
Arthropitys cf. *bistriata* (Cotta) Goeppert emend. Rößler, Feng and Noll (Fig. 3; Plates I, II).
Material: P1584, P1591, P1952, P1992, P3207, P4672, P5072, P5657, P5956, H74692, H74697 and DVO5/XLVI from the Krkonoše Piedmont Basin and SVE001/1, SVE002/1, SVE003/1, SVE004/1, SVE005/1, REH002/1, ZAJ004/1 and DVO5/XXXIII from the Kladno–Rakovník Basin.

Macroscopic description: all samples are small; pieces are only several centimetres long. Samples from the Krkonoše Piedmont Basin are dark, red-brown or orange (Plate I, 5; Plate II, 3, 6), only few are beige or whitish. On the other hand, samples from the Kladno–Rakovník Basin are mostly beige to greyish (Plate II, 1, 4), with one exception (ZAJ004/1) that is brown-yellow. Some samples (P1584, DVO5/XLVI) show nodes and another one (SVE005/1) nodes and a branch trace.

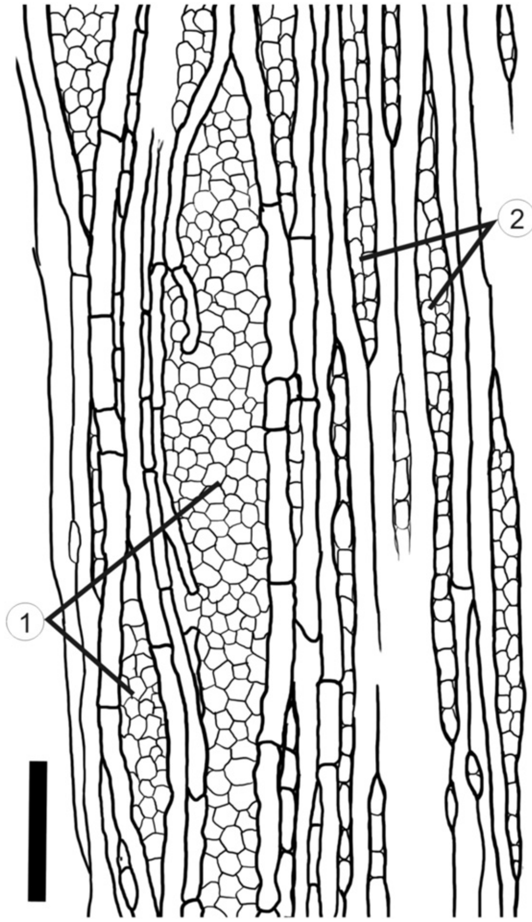


Fig. 3. Drawing showing the zones of wider interfascicular rays (1) and narrower fascicular rays (2), see Plate I/7 (specimen ZAJ004/1, Kladno–Rakovník Basin). Scale bar = 0.5 mm.

Microscopic description: well-preserved secondary xylem tracheids separated by interfascicular rays were observed in all studied samples (Plate II, 5). Sometimes also the primary vascular system with carinal canals and poorly preserved metaxylem in the external part of the pith cavity is preserved (Plate I, 2, 3, 6). The amount of parenchyma is about 46%. Interfascicular rays are distinguishable through the whole secondary xylem thickness (Plate I, 7; Fig. 3).

All specimens show one type of tracheid; tracheids are arranged in radial rows, slightly varying in size and shape in each row (Plate II, 5). Tracheids close to the pith are usually oval, square or brick-shaped in cross-section, and slightly elongated in radial direction; they are 25–100 μm (mean 56 μm) in diameter in radial direction and 22–76 μm (mean 44 μm) in tangential direction. Parenchyma cells in the fascicular rays are usually oval, square or brick-shaped, 22–108 μm (mean 57 μm) in diameter. Tracheids are arranged in five to eighteen files separated by interfascicular rays. These rays are distinguishable to the very edge of the specimens and consist of one to seven rows of parenchyma cells, rectangular, brick-shaped and obviously elongated in radial direction. Tracheids in the external parts of the stems are slightly widened compared to those in the internal part, which are 50–100 μm (mean 70 μm) radially and 45–60 μm (mean 51 μm) wide tangentially. Scalariform pitting is visible in radial longitudinal sections (Plate I, 4). The pits are bordered and the distance between two neighbouring ones is 2–4 μm. Carinal canals and the surrounding metaxylem are sometimes preserved next to the pith cavity (Plate I, 6). Carinal canals are usually circular in transverse section, and 105–171 μm (mean 140 μm) in diameter. Metaxylem elements are rectangular, arranged in two to three rows surrounding the carinal canals and are 15–57 μm (mean 27 μm) in diameter. The samples interpreted as roots lack carinal canals and have pith parenchyma cells preserved (Plate II, 2ab).

Discussion: thin sections were prepared from specimens P4672, P5956, SVE001/1, SVE002/1, REH002/1 and ZAJ004/1. They all show the same anatomical characteristics. There is only one type of tracheid; all tracheids are oval, square to brick-shaped in transverse section and some of them have bordered scalariform pits in their radial walls as illustrated in Marguerier (1970). Generally, fascicular and interfascicular rays consist of parenchyma cells and almost 50% of the secondary body consists of parenchyma. Moreover, it is possible to distinguish fascicular and interfascicular zones up to the periphery of the wood and the tracheids have scalariform pitting (Röβler and Noll, 2006, 2010; Röβler et al., 2012a). After a detailed comparison with the Chemnitz material, we think that all samples belong to the most common calamitalean *Arthropitys bistriata*. However, because the typical branching pattern of this species (Röβler et al., 2012a) is not recognised in our material, we identify our fossils as *Arthropitys* cf. *bistriata*.

Calamitea Cotta emend. Rößler and Noll.
Calamitea striata Cotta (Plate III).
Material: P3173, P2660A, P2660C, and K2121, all from the Krkonoše Piedmont Basin.
Macroscopic description: only small parts of secondary xylem with badly preserved external portions of the central pith and carinal canals are present. Other parts of plant tissues (e.g., phloem, cortex) are not preserved. The colour of all specimens varies from dark, red-brown or orange to light, whitish or beige. The size of the samples ranges from 50 to 100 mm.
Microscopic description: the secondary xylem consists of two different types of tracheids, one having a larger diameter than the other (Plate III, 5, 6). Both tracheid types are arranged in radial files and are separated by thin continuous rays. The tissues are sometimes deformed during fossilisation. Wide tracheids (SX1) are present in front of the carinal canals and alternate with zones of narrow tracheids (SX2) which the fill lateral parts of secondary xylem fascicles. The two types of tracheids differ in colour (Plate III, 1–4); note that wide (SX1) and narrow (SX2) tracheids correspond to “large-diameter tracheids” and “small-diameter tracheids” sensu Rößler and Noll (2007).
Type 1: wide tracheids are mostly in dark, brown-red. This part of secondary xylem has more parenchyma than the Type 2, but the exact shape and size of these parenchyma cells forming fascicular rays cannot be estimated due to poor preservation. Tracheids are variously polygonal with circular to oval lumen in transverse section; the radial rows are usually less deformed. Tracheid diameters vary from 39 to 173 μm (mean 61 μm) radially and from 49 to 120 μm (mean 67 μm) tangentially. Brick-shaped parenchyma cells are mostly poorly preserved (Plate III, 6).
Type 2: these narrow tracheids are usually preserved as lighter parts of secondary xylem and occur on both sides of the Type 1 tracheids toward the interfascicular ray; they are arranged in regular, often deformed radial rows (Plate III, 6). The tracheids are polygonal in transverse section and slightly elongated in radial direction; their diameter varies from 26 to 54 μm (mean 38 μm) radially and from 24 to 51 μm (mean 36 μm) tangentially.
Tracheid pitting in radial walls has not been observed due to the poor preservation.
Interfascicular rays are usually 11–37 μm (mean 25 μm) wide and are composed of one to four rows of cells. Rays are enlarged from the pith to the periphery of the wood cylinder, often deformed and visible as darker zones in the middle of the lighter portions of the secondary xylem Type 2 (see Plate III, 7). Rectangular, thick-walled cells of interfascicular rays are obviously elongated in radial direction. Their diameter varies from 31 to 73 μm (mean 42 μm) in radial direction and from 11 to 22 μm (mean 17 μm) tangentially.
Discussion: only small pieces of secondary tissues were available, but two types of tracheids and ray parenchyma cells are conspicuous. More delicate details like tracheid pitting in radial walls could not

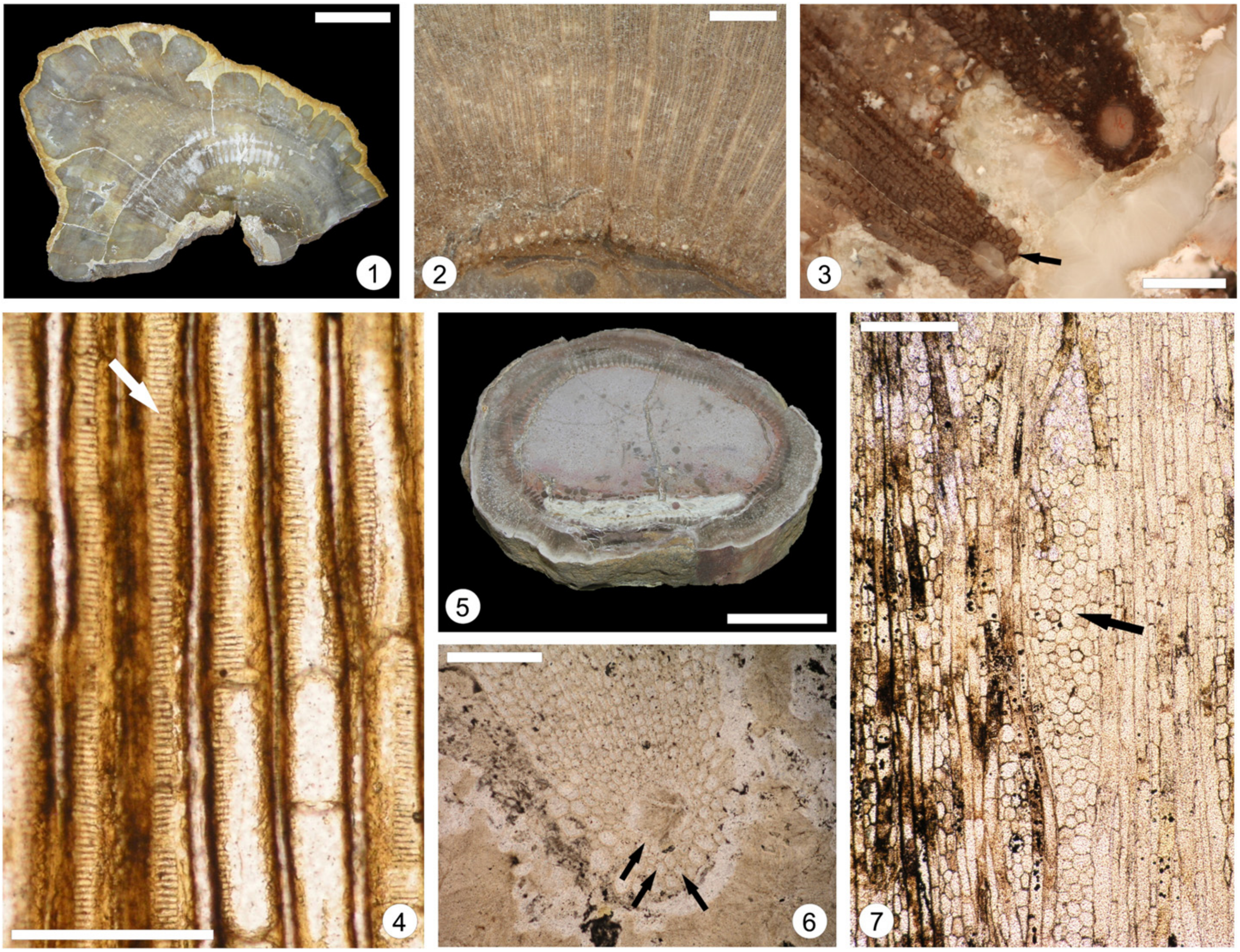


Plate I. *Arthropitys* cf. *bistriata* from the Kladno–Rakovník Basin and the Krkonoše Piedmont Basin.

1. General view of one of the biggest specimens from the Kladno–Rakovník Basin, TS (specimen DVO5/XXXIII). Scale bar = 40 mm.
2. Pith periphery surrounded by secondary xylem composed of fascicular wedges and interfascicular rays, TS (specimen SVE004/1, Kladno–Rakovník Basin). Scale bar = 2 mm.
3. Detail of the central pith secondary filled, TS (specimen P1992, Krkonoše Piedmont Basin), showing pith periphery, detail of innermost interfascicular ray, fascicular secondary xylem and two carinal canals surrounded by badly preserved tracheids of metaxylem (arrow). Scale bar = 0.5 mm.
4. Tracheids of secondary xylem with scalariform bordered pitting (arrow), RLS (specimen ZAJ004/1, Kladno–Rakovník Basin). Scale bar = 0.2 mm.
5. Large central pith secondary filled surrounded by a narrow secondary xylem composed of fascicular wedges and interfascicular rays, TS (specimen P5956, Krkonoše Piedmont Basin). Scale bar = 30 mm.
6. Detail of the previous picture with a carinal canal surrounded by three rows of metaxylem tracheids (arrows). Scale bar = 0.3 mm.
7. A multiseriate interfascicular ray (arrow) among tracheids and fascicular rays, TLS (specimen ZAJ004/1, Kladno–Rakovník Basin). Scale bar = 0.5 mm.

TS = transverse section; TLS = tangential longitudinal section; RLS = radial longitudinal section.

be studied due to the poor preservation of the specimens and low contrast of the structures when observed with stereomicroscope; in fact, it was not possible to make additional thin longitudinal sections because of the rarity of the museum specimens. However, all observed features, mainly the differences in shape of various types of tissue and thickness of their walls, are typical of *Calamitea striata* (Rößler and Noll, 2007). The samples from the Krkonoše Piedmont Basin differ in colour from those of the Permian petrified forest of Chemnitz; all samples from the Krkonoše Piedmont Basin typically show wide, dark-coloured tracheids, whereas narrow tracheids are lighter. On the other hand, the samples from the type locality Chemnitz (except for sample MfNC K 5204: Rößler and Noll, 2007, Plate I, 6) are coloured reversely: narrow tracheids are dark and wide tracheids are light (Rößler and Noll, 2007). This is probably caused by different conditions during taphonomic processes.

5.2. Taphonomy

The silicification of trees represents a very complex process, which involves both the filling of pore spaces in the wood (permineralization) and the replacement of the organic cellular tissue with SiO_2 under various conditions (Ballhaus et al., 2012) and its complete understanding and detailed description are over the scope of the present paper. According to Matysová et al. (2010) silicification can take place in four different palaeoenvironments: (1) in fluvial sediments, (2) in fluvial facies with volcanic influence, (3) in lacustrine facies with volcanic influence, and (4) in environments under direct influence of diverse volcanic emplacement events.

In the Krkonoše Piedmont Basin, silicified stems occur in at least four stratigraphic levels, but only one, the Ploužnice Horizon, shows volcanic influence. According to Matysová et al. (2010) this unit can

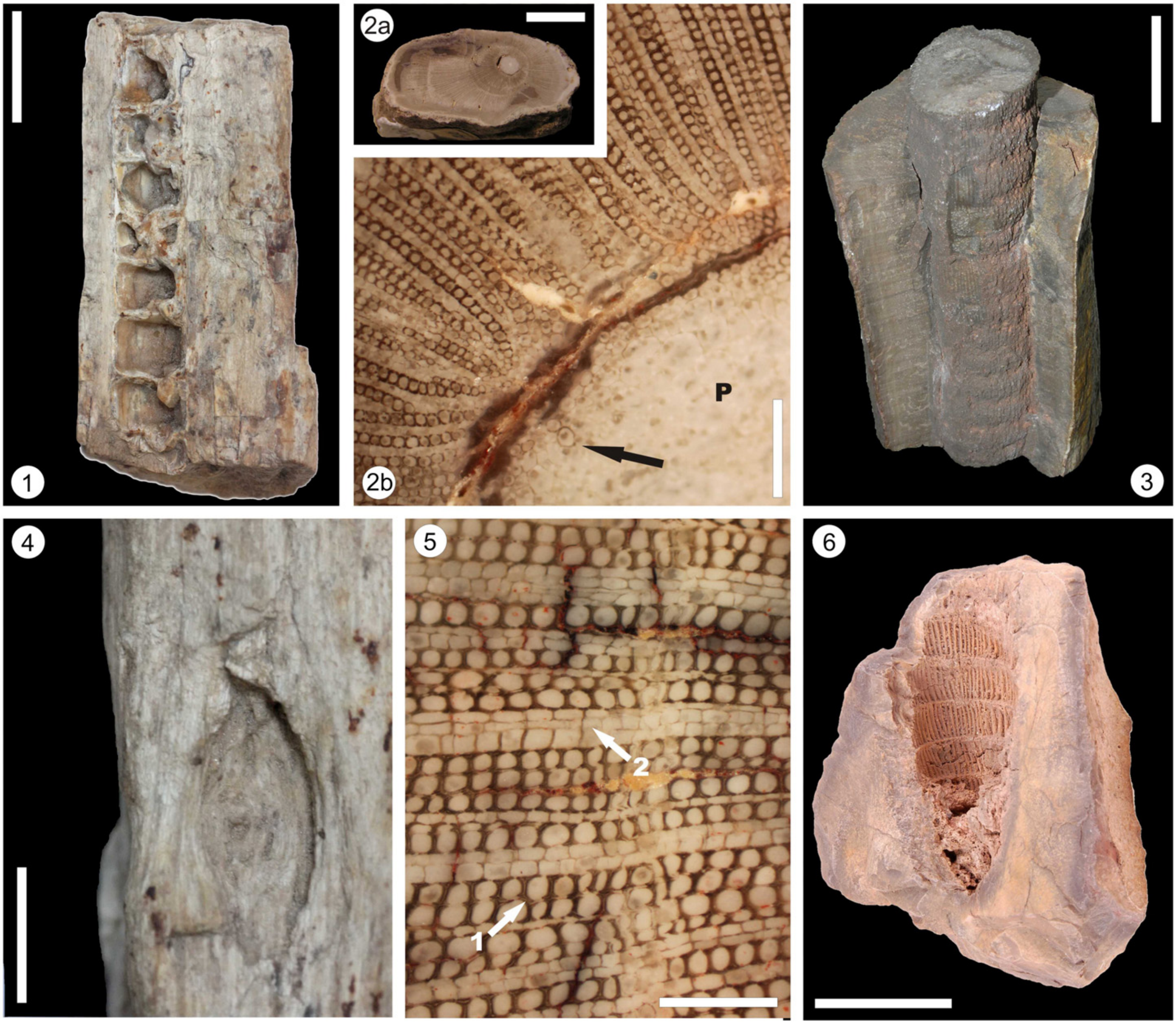


Plate II. *Arthropitys* cf. *bistriata* from the Kladno–Rakovník Basin and the Krkonoše Piedmont Basin.

1. Pith cavity with short internodes and diaphragms at levels of nodes (specimen SVE005/1, Kladno–Rakovník Basin). Scale bar = 30 mm.
2. Small root — general view (a) and detail (b) of its central, solid parenchymatous pith (P), showing parenchyma inside (arrow), and pith periphery without carinal canals but with curved both rays and rows of secondary xylem tracheids, TS (specimen H74692, Krkonoše Piedmont Basin). Scale bars in 2a = 10 mm and in 2b = 0.5 mm.
3. Unusual sample showing both well preserved pith cast and secondary xylem (specimen P1584, Krkonoše Piedmont Basin). Scale bar = 30 mm.
4. Single branch scar as seen on reverse side of the specimen illustrated in Plate II, 1 (specimen SVE005/1, Kladno–Rakovník Basin). Scale bar = 5 mm.
5. Detail of circular-shaped tracheids of secondary xylem (1) and elongated, rectangular parenchyma cells (2) of multiseriate interfascicular rays, TS (specimen H74697, Krkonoše Piedmont Basin). Scale bar = 0.5 mm.
6. Well preserved pith cavity with longitudinal striation of short internodes and transverse diaphragms of a basal tapering portion of the vertical stem (specimen P5657, Krkonoše Piedmont Basin). Scale bar = 50 mm.

TS = transverse section.

be interpreted as a lacustrine environment with influence of volcanism. This horizon contains a much more varied assemblage of silicified stems than the other strata, but the preservation of anatomical detail is often rather poor. The sediments of the Kladno–Rakovník Basin do not contain significant amounts of volcanic material and the fossiliferous sediments are purely lacustrine to fluvial. Silicified stems are known from several units and their anatomy is usually much better preserved than in the specimens from the Krkonoše Piedmont Basin or the Intra Sudetic Basin (Mencl, 2007; Mencl et al., 2009). Finally, the Chemnitz Petrified Forest can be mentioned as comparative example of an environment under direct influence of volcanism. Surprisingly, there is a very high percentage of well-preserved petrified trunks, although there was a direct influence of explosive and therefore destructive volcanic events (Rößler et al., 2012b).

6. Conclusions

Silicified calamitalean stems are reported from two Carboniferous–Permian basins in the Czech Republic.

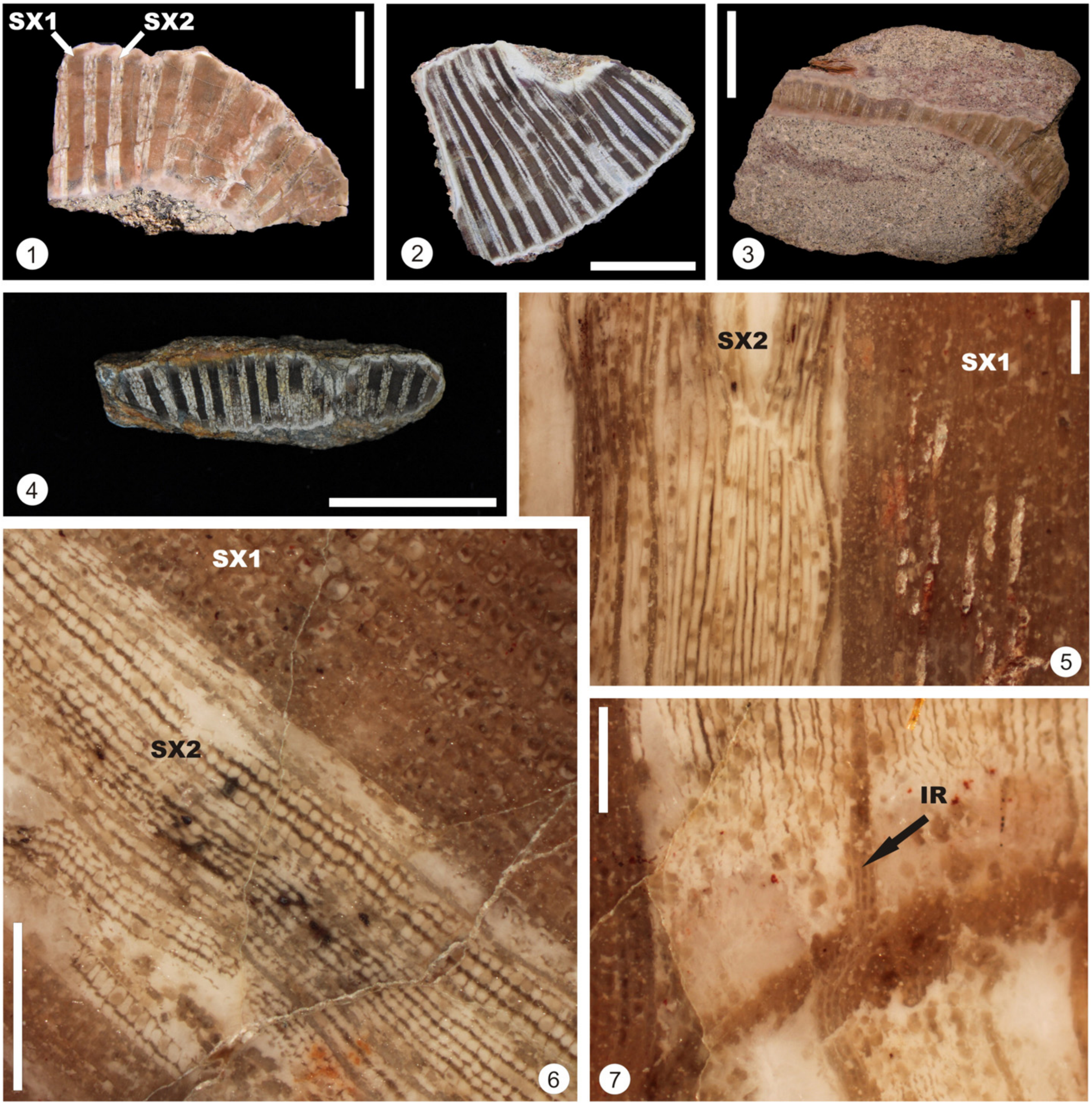


Plate III. *Calamitea striata* from the Krkonoše Piedmont Basin.

1.–4. General view showing the difference in colouration of darker wide (SX1) and lighter narrow (SX2) tracheids, TS (specimens P3173, P2660A, P2660C, K2121). Scale bars in 1 = 10 mm and in 2, 3 and 4 = 20 mm.
5. Detail showing difference between wide (SX1) and narrow (SX2) tracheids, TLS (specimen P3173). Scale bar = 0.25 mm.
6. Detail showing two types of tracheids (SX1, SX2), arranged in slightly deformed rows, TS (specimen P3173). Scale bar = 0.5 mm.
7. Rectangular parenchyma cells of interfascicular ray (IR), TS (specimen P3173). Scale bar = 0.25 mm.

TS = transverse section; TLS = tangential longitudinal section.

In the Krkonoše Piedmont Basin, several hundred specimens have been found, but only few were suitable for anatomical studies. After an evaluation of all available samples we recognise two taxa. *Arthropitys* cf. *bistriata* is very common, whereas *Calamitea striata* is rather rare. The attribution of the former is based on the similarity in parenchyma ratio, the presence of scalariform pitting and interfascicular rays running continuously through the entire wood. The latter was identified on the basis of the two types of tracheids found in the secondary xylem and the small proportion of parenchyma. This type represents only about 1% of all calamitalean stems in the Krkonoše Piedmont Basin, but is also very rare in other coeval fossil forests. Contrary to the "*Dadoxylon*" type of wood, silicified stems of calamitaleans and other "pteridophytes" are in the Krkonoše Piedmont Basin strictly limited to a single stratigraphic unit that contains volcanics. The fossils are usually fragmented and preserved without branchlets or extraxylary tissues, but are less damaged than "*Dadoxylon*" stems in other stratigraphic levels. They were probably transported by rivers and streams as bedload before they were deposited. Moreover, most of the woody tissue is strongly recrystalised and cell structures are damaged considerably.

In the Kladno–Rakovník Basin, calamitalean stems, although being the second most abundant after the common "*Dadoxylon*" type, are quite rare; other types, such as *Psaronius* or *Medullosa* are very scarce. Stems can mainly be found in two stratigraphic levels, but most of them are found in the Týnec Formation. Both stratigraphic levels are without any volcanic content. The trunks are usually fragmented without branches or extraxylary tissue. They were probably transported and finally embedded in fluvial sediments. Calamitaleans are rarer than "*Dadoxylon*" stems; bigger specimens are not mentioned in literature. The fragmentary nature of the specimens can be related to the nature of the wood that was parenchyma-rich, soft and therefore more prone to destruction. However, we cannot exclude that calamitalean wood remains unidentified in private collections. All samples were found in the field in eluvium. Therefore, the stratigraphic position of the source strata is assumed from the general geological situation.

The present contribution fills a gap in giving the first anatomical description of silicified calamitalean stems from the upper Carboniferous of the Bohemian Massif, which represents a classical area of palaeobotanical interest, well studied both in the past and present, but without a modern systematic overview on fossil wood and petrified stems in general.

Acknowledgements

First of all, we are grateful to our colleagues S. Štamberg and J. Juráček (Museum of Eastern Bohemia) as well as private collectors for providing us with the fossil wood material and information regarding its geological setting, namely to J. Svejkovský, M. Řehoř, J. Zajíček, Z. Dvořák and B. Zasadil. We also thank D. Pons, Paris for her valuable comments and suggestions. Finally, we gratefully acknowledge R. Noll, Tiefenthal, and J. Steinbinder, Freiberg, for the loan of comparative specimens in their care and scientific discussion. The manuscript was improved by the thorough reviews of J. Galtier and an anonymous reviewer as well as by detailed suggestions of the editor. The research was supported by the grants GAUK 303411, MSM0021620855, and the project I/84638 by Volkswagen Foundation.

References

Ballhaus, C., Gee, C.T., Bockrath, C., Greef, K., Mansfeldt, T., Rhede, D., 2012. The silicification of trees in volcanic ash — an experimental study. Geochimica et Cosmochimica Acta 84, 62–74.

Březinová, D., 1970. An overview of the fossil wood record from the territory of Czechoslovakia on the basis of the literature. Manuscript, National Museum in Prague, Czech Republic (in Czech).

Dernbach, U., 1996. The petrified forest of Nová Paka. In: Dernbach, U. (Ed.), Petrified Forests. D'ORO Publishers, Heppenheim, pp. 116–117.

Dernbach, U., Tidwell, D.W., Barthel, M., Galtier, J., Jung, W., Kerp, H., Noll, R., Rößler, R., Rothwell, W.G., Selmeier, A., Stockey, A.R., Wilde, V., Wright, W.W., 2002. Secrets of Petrified Plants, Fascination from Millions of Years. D'ORO Publishers, Heppenheim.

Dvořák, Z., Švancara, M., 2003. Naleziště zkamenělých stromů u Slaného. Minerál 11, 403–406.

Feistmantel, O., 1873. O zkřemenělých kmenech v permském útvaru českém. Vesmír 208, 176–178 190–192.

Feistmantel, O., 1873. Über die Verbreitung und geologische Stellung der verkieselten Araucariten-Stämme in Böhmen. Sitzungsberichte d. k. b. Ges. d. Wiss. 5, 204–220.

Feistmantel, O., 1873. Geologische Stellung und Verbreitung der Verkieselten Hölzer in Böhmen. Verhandlungen der k. k. Geologischen Reichsanstalt 168 (6), 108–112.

Frič, A., 1912. Studie v oboru českého útvaru permského. Arch. Přírodov. Prozk. Země Čes. 15, 18–23.

Goeppert, H.R., 1858. Ueber die versteinerten Wälder im nördlichen Böhmen und in Schlesien. Jahres-Bericht der Schlesische Gesellschaft fuer vaterlandische Cultur 36, 41–49.

Heber, F.A., 1844. Böhmens Burgen, Vesten und Bergschlösser 2. C. M. Medau, Praha.

Holeček, J., 2011. Late Carboniferous Silicified Wood from the Western Part of the Kladno–Rakovník Basin. (MSc Thesis) Charles University in Prague, Faculty of Science, Czech Republic (in Czech).

Jokély, J., 1861. Bemerkungen über die Verbreiterung der Araucaritenstämme. Jahrbuch der GeoloGischen Reichsanst 2, 392–395.

Marguerier, J., 1970. Sur les différents types cellulaires ponctués chez les Equisétales fossiles. C.R. 92e Congrès nat. Soc. sav., Strasbourg et Colmar, 1967, Sci., 3, pp. 77–92.

Matysová, P., 2006. Permocarboniferous Silicified Woods from the Intra Sudetic and Krkonoše Piedmont Basins: Taxonomy and Instrumental Analysis. (MSc Thesis) Charles University in Prague, Faculty of Science, Czech Republic (in Czech).

Matysová, P., Leichmann, J., Grygar, T., Rössler, R., 2008. Cathodoluminescence of silicified trunks from the Permo-Carboniferous basins in eastern Bohemia, Czech Republic. European Journal of Mineralogy 20, 217–231.

Matysová, P., Rössler, R., Götze, J., Leichmann, J., Forbes, G., Taylor, E.L., Sakala, J., Grygar, T., 2010. Alluvial and volcanic pathways to silicified plant stems (Upper Carboniferous–Triassic) and their taphonomic and palaeoenvironmental meaning. Palaeogeography Palaeoclimatology Palaeoecology 292, 127–143.

Mencl, V., 2007. Upper Carboniferous Silicified Wood of the Intra Sudetic Basin: Systematics and Palaeoenvironment. (MSc Thesis) Charles University in Prague, Faculty of Science, Czech Republic (in Czech).

Mencl, V., Matysová, P., Sakala, J., 2009. Silicified wood from the Czech part of the Intra Sudetic Basin (Late Pennsylvanian, Bohemian Massif, Czech Republic): systematics, silicification and palaeoenvironment. Neues Jahrbuch für Geologie und Paläontologie - Abhandlungen Band 252, 269–288.

Němejc, F., 1963. Paleobotanika II. Nakladatelství ČSAV, Praha.

Pešek, J., Holub, V., Jaroš, J., Malý, L., Martínek, K., Prouza, V., Spudil, J., Tásler, R., 2001. Geologie a ložiska svrchnopaleozoických limnických pánví České republiky. Český geologický ústav, Praha.

Purkyně, C., 1927. O nalezištích zkřemenělých kmenů araukaritových v Čechách, zvláště v Podkrkonoší. Časopis Národ. muzea 51, 113–131.

Rößler, R., Noll, R., 2006. Sphenopsids of the Permian (I): the largest known anatomically preserved calamite, an exceptional find from the petrified forest of Chemnitz, Germany. Review of Palaeobotany and Palynology 140, 145–162.

Rößler, R., Noll, R., 2007. *Calamitea* Cotta, the correct name for calamitean sphenopsids currently classified as *Calamodendron* Brongniart. Review of Palaeobotany and Palynology 144, 157–180.

Rößler, R., Noll, R., 2010. Anatomy and branching of *Arthropitys bistriata* (Cotta) Goeppert — new observations from the Permian petrified forest of Chemnitz, Germany. International Journal of Coal Geology 83, 103–124.

Rößler, R., Feng, Z., Noll, R., 2012. The largest calamite and its growth architecture — *Arthropitys bistriata* from the Early Permian petrified forest of Chemnitz. Review of Palaeobotany and Palynology 185, 64–78.

Rößler, R., Zierold, T., Feng, Z., Kretzschmar, R., Merbitz, M., Annacker, V., Schneider, J.W., 2012. A snapshot of an early Permian ecosystem preserved by explosive volcanism: new results from the Chemnitz Petrified Forest, Germany. Palaios 27, 814–834.

Sakala, J., Mencl, V., Matysová, P., 2009. New data on Upper Carboniferous silicified stems of calamites from the Nová Paka region. Geoscience Research Reports for 2008, pp. 111–113 (in Czech).

Skoček, V., 1970. Silicifikovaná dřeva ve středočeském permokarbonu. Vestnik Ustredni ustav geologicky 45, 87–92.

Soukup, J., 1997. Silicifikovaná dřeva v západním Podkrkonoší. Minerál 5, 180–182.

Stárková, M., Šimůnek, Z., Martínek, K., 2009. Prepared research of Ploužnice horizon — Semily Formation; genesis and paleoecology of lacustrine facies. Acta Musei Turnoviensis 4, 120–124.

Příloha IV

International Journal of Coal Geology 119 (2013) 114–151

Contents lists available at ScienceDirect

International Journal of Coal Geology

journal homepage: www.elsevier.com/locate/ijcoalgeo

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

Stanislav Opluštil [a,*], Zbyněk Šimůnek [b], Jaroslav Zajíc [c], Václav Mencl [d]

[a] Charles University in Prague, Faculty of Science, Albertov 6, 128 43 Praha 2, Czech Republic
[b] Czech Geological Survey, Klárov 3/131, 118 21 Praha 1, Czech Republic
[c] Institute of Geology AS CR, v. v. i., Rozvojová 269, CZ-165 00 Prague 6, Lysolaje, Czech Republic
[d] Municipal Museum Nová Paka, Treasury of Gemstones, F. F. Procházky 70, 509 01 Nová Paka, Czech Republic

ARTICLE INFO

Article history:
Received 30 April 2013
Received in revised form 11 July 2013
Accepted 15 July 2013
Available online 19 July 2013

Keywords:
Carboniferous–Permian transition
Biotic change
Continental basin
Bohemian Massif

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.

* Corresponding author. Tel.: +420 221951502.
E-mail addresses: oplustil@natur.cuni.cz (S. Opluštil), zbynek.simunek@geology.cz (Z. Šimůnek), zajic@gli.cas.cz (J. Zajíc), vaclav.mencl@natur.cuni.cz (V. Mencl).

0166-5162/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.coal.2013.07.014

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).

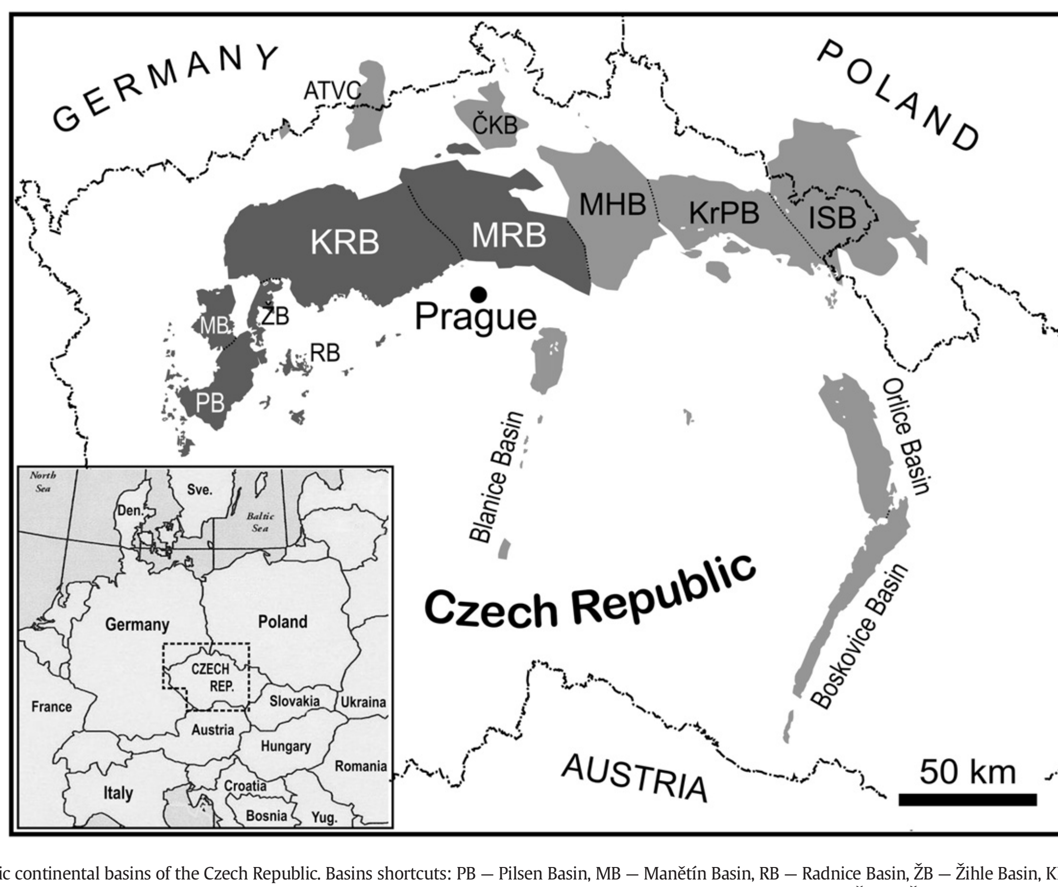


Fig. 1. Late Palaeozoic continental basins of the Czech Republic. Basins shortcuts: PB — Pilsen Basin, MB — Manětín Basin, RB — Radnice Basin, ŽB — Žihle Basin, KRB — Kladno–Rakovník Basin, MRB — Mšeno–Roudnice Basin, MHB — Mnichovo Hradiště Basin, KrPB — Krkonoše Piedmont Basin, ISB — Intra-Sudetic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

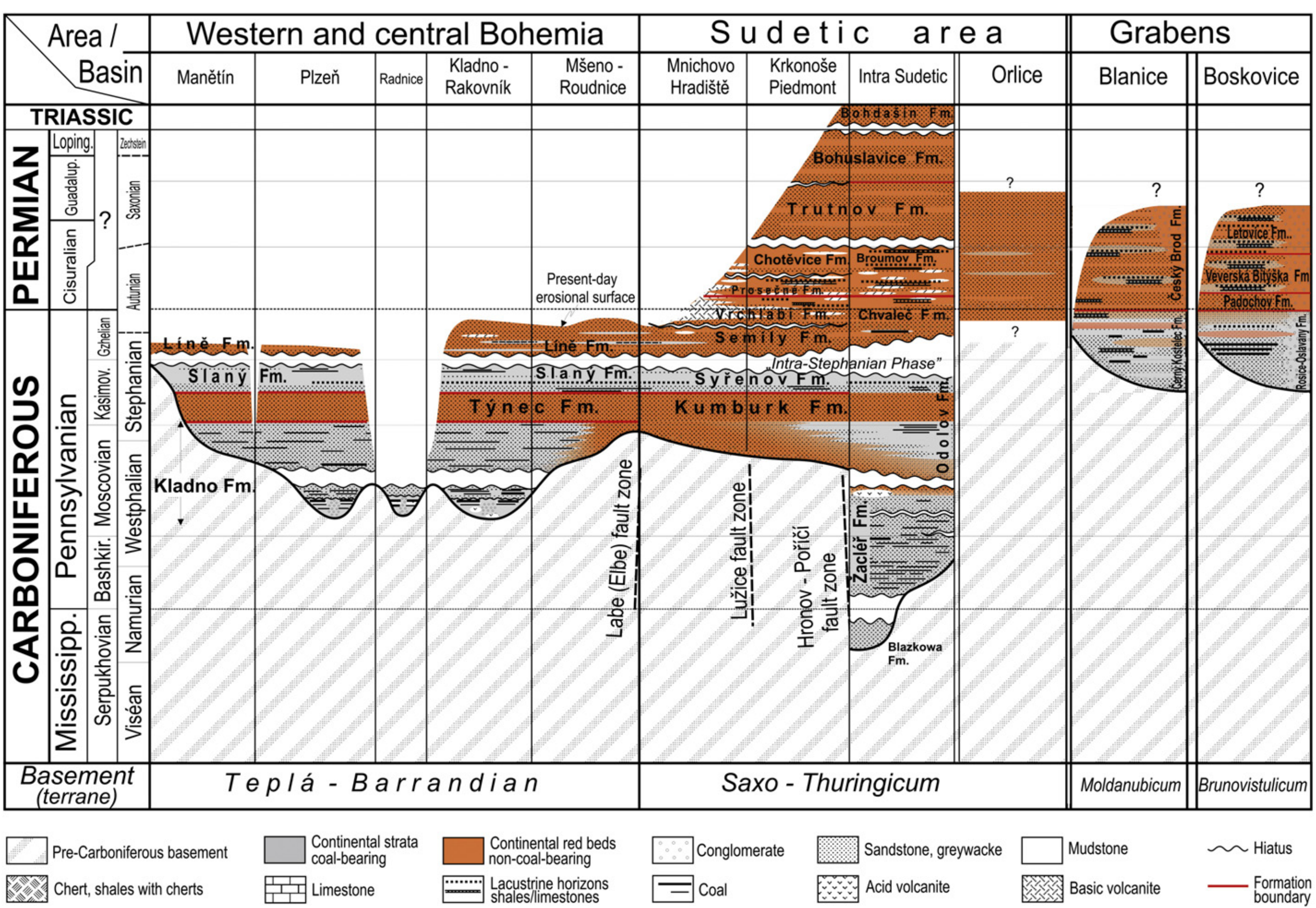


Fig. 2. Stratigraphy of the continental basins of the Czech Republic.

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

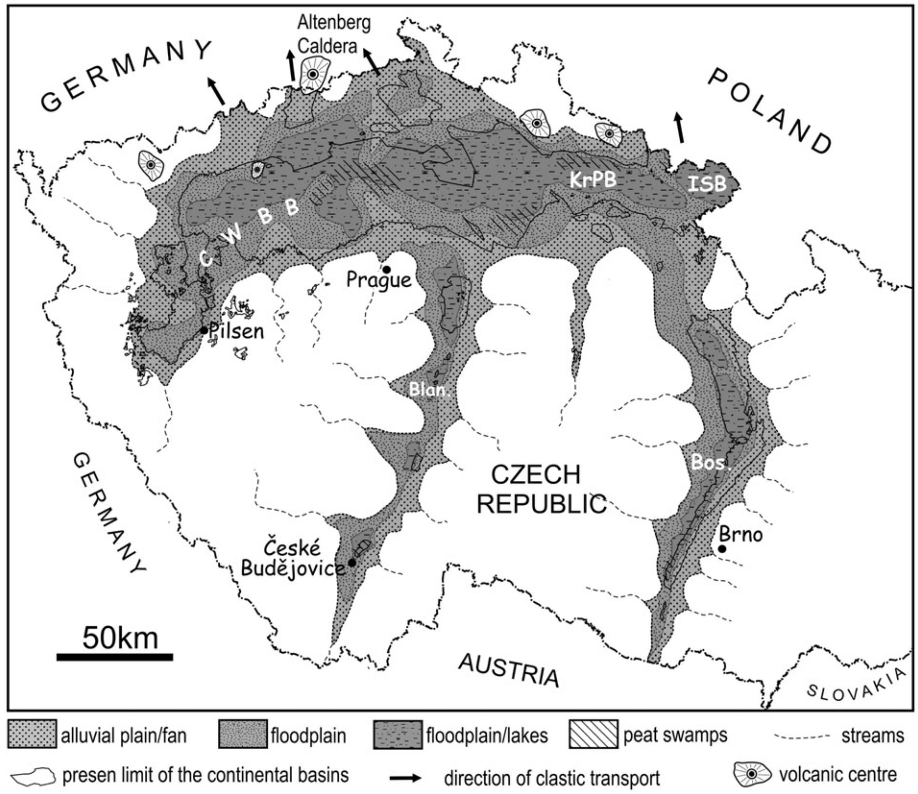


Fig. 3. Palaeogeographic map of the Czech Republic during the latest Stephanian and early Autunian (after Pešek et al., 1998). Different environments were established on percentage sand–gravel content within the corresponding lithostratigraphic units described in the text: alluvial plain/fan (>70% sand-gravel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

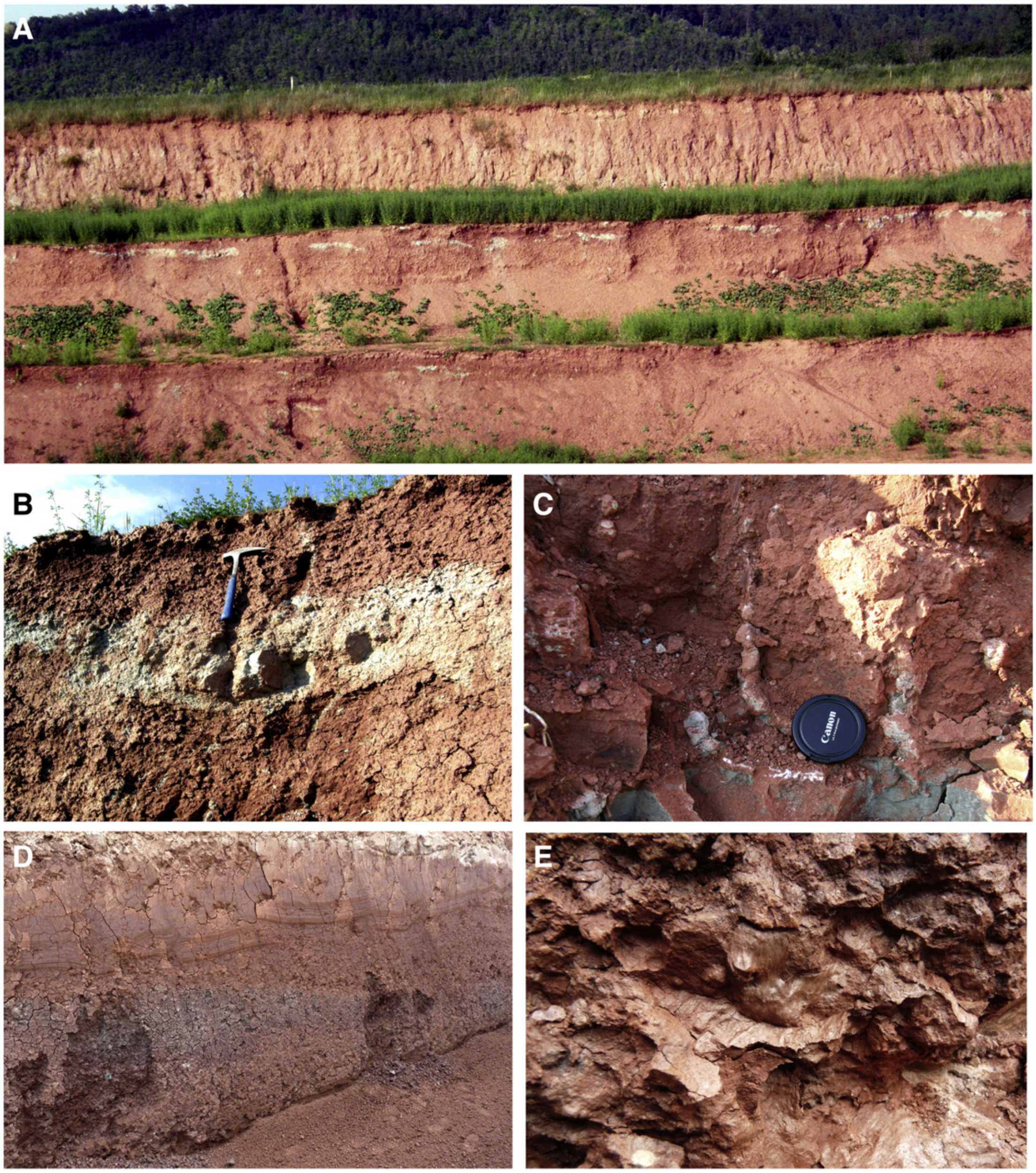


Fig. 4. Líně Formation: A — Red beds exposed in a brick-pit near the village of Kryry in the KRB. Note the discontinuous whitish horizon which indicates position of pedogenic calcretes. B — Detail of calcrete horizon (vertic calcisol) from the Fig. 3A. C — Vertical to sub-vertical rhizoliths in red angular 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

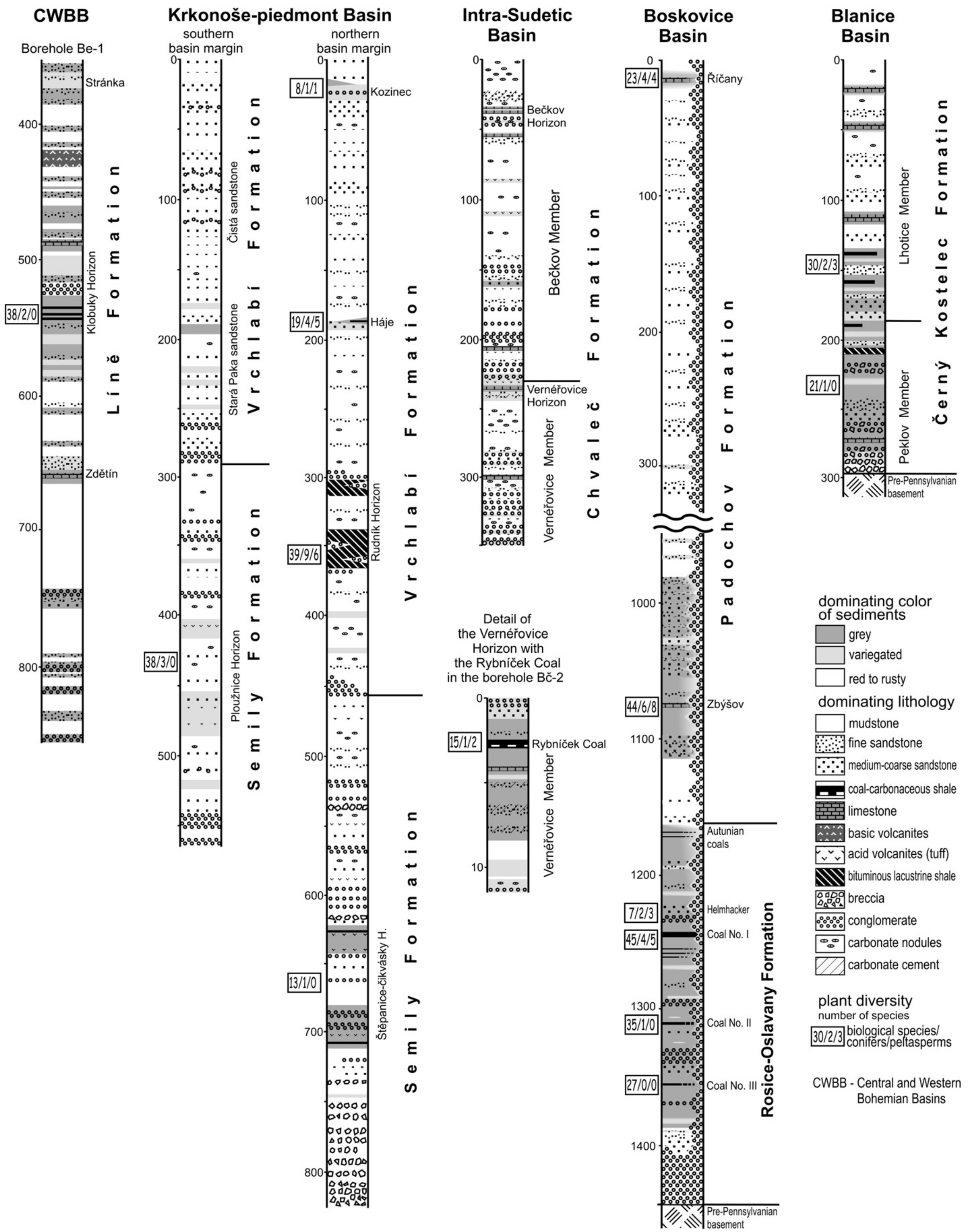


Fig. 5. Examples of basin sections described in detail in the text. Redrawn from Tásler et al. (1979) and Pešek (1994, 2004). Numbers in rectangle indicate plant diversity of particular horizons. The first number refers to the estimated number of biological species, the second number points to conifer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

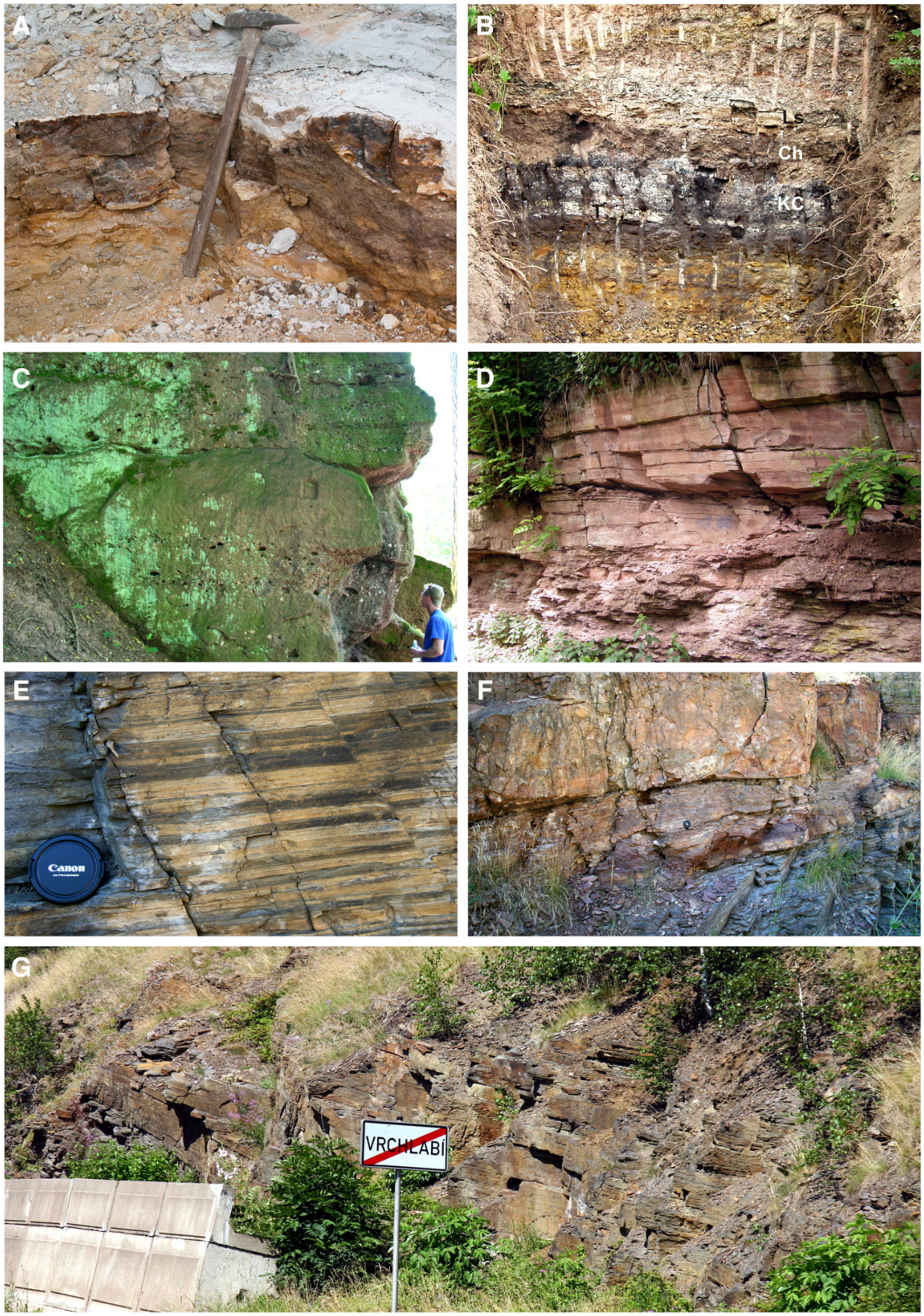


Fig. 6. A — Chert in lacustrine sediments of the Klobuky Horizon (Líně Fm.) exposed in a road cut near Panenský Týnec, KRB. B — Part of the lacustrine succession of the Klobuky Horizon exposed near the village of Klobuky in the KRB. Rusty and poorly laminated nearshore mudstones followed by thin high-ash 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

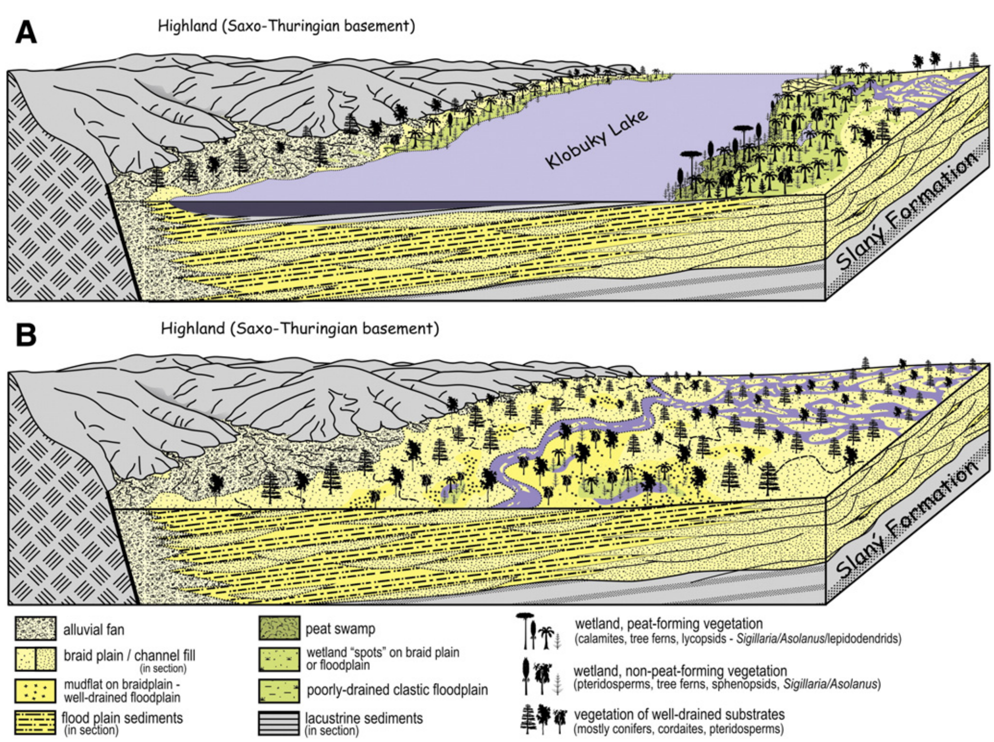


Fig. 7. Landscape reconstruction of the Líně Formation in contrasting stages of climatic oscillations. (A) Humid period characterised by increased precipitation promoted development of lacustrine environment (Klobuky Lake) with coastal wetlands and local peat swamps dominated by tree ferns with sub-dominant 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*

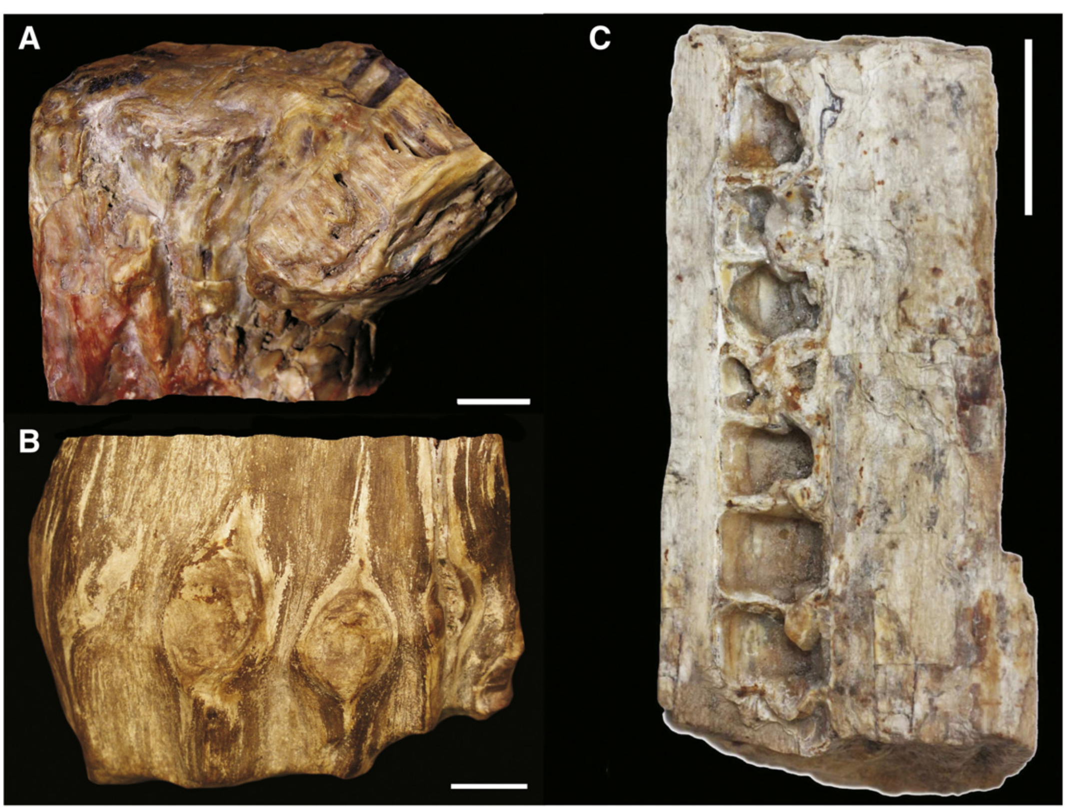


Fig. 8. Silicified stems from fluvial red beds of the Líně Formation. A — Cordaitalean stem with exposed pith of the *Artisia* type (sample FP00066, West Bohemian Museum in Pilsen), Líně near Pilsen, Pilsen Basin. B — Silicified wood of walchian conifer showing position of branches (sample FP00067, West 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.

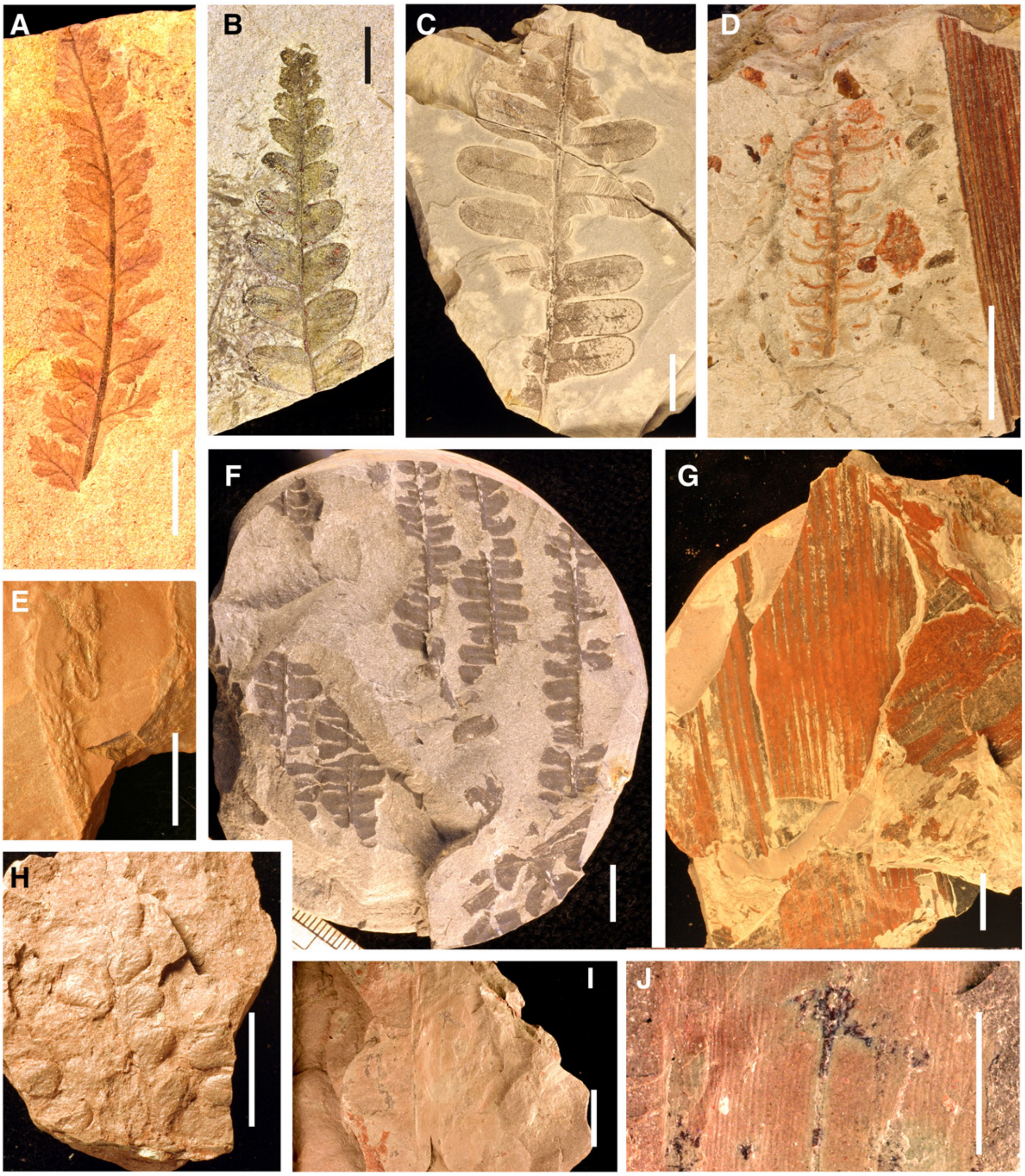


Fig. 9. Flora of the Líně Formation. A — *Dicksoniites plukenetii*, loc. Klobuky, grey mudstone beneath the coal. B — *Odontopteris schlotheimii*, loc. Klobuky, grey mudstone beneath the coal. C — *Alethopteris zeilleri*, loc. Klobuky, grey mudstone beneath the coal. D — *Ernestiodendron filiciforme*, 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

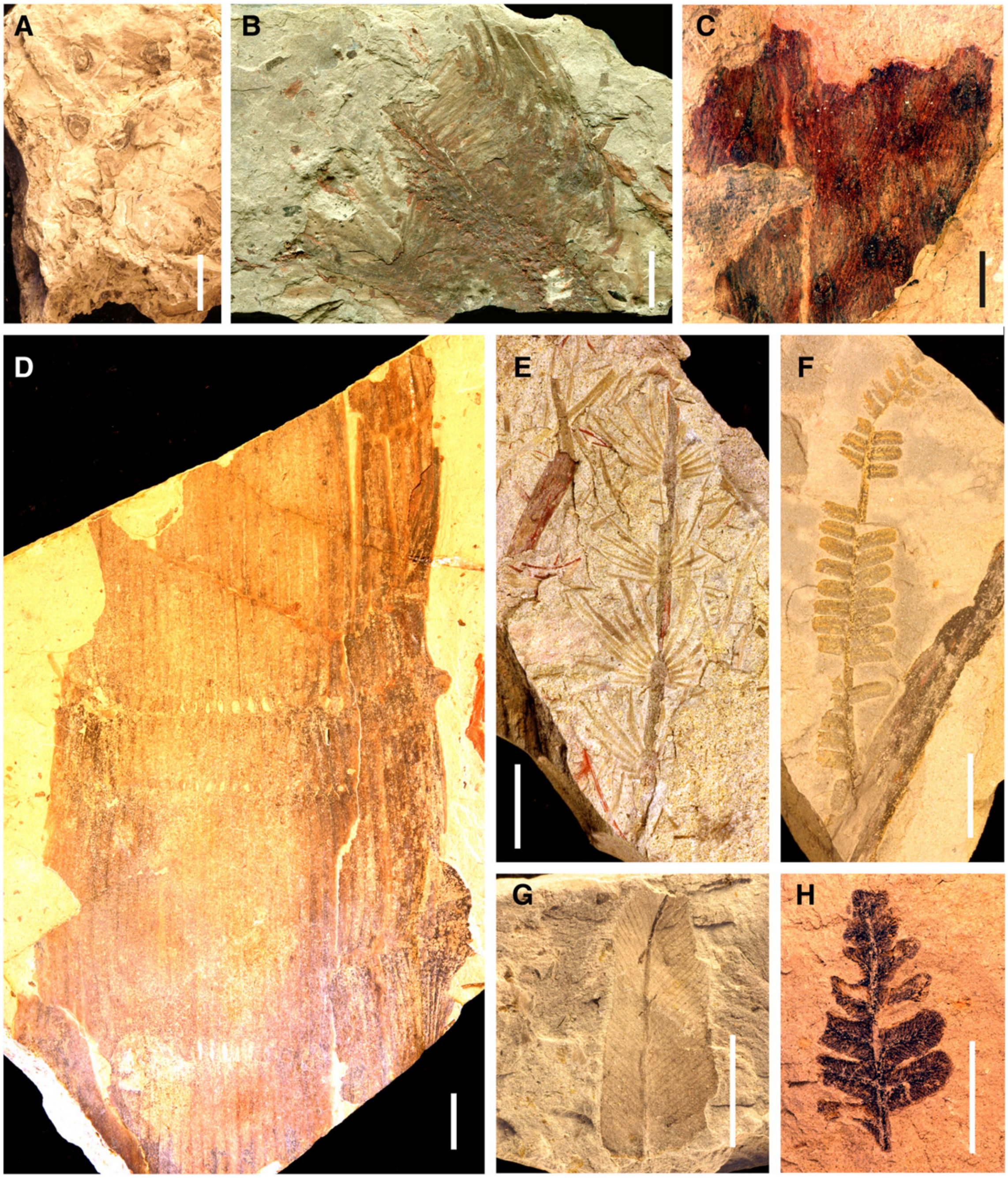


Fig. 10. Flora of the Klobuky Horizon (Líně Formation) from the type area near Klobuky village in the KRB. A — *Stigmaria ficoides* in mudstone just beneath the Klobuky Coal. B — *Lepidostrobus* sp., muddy limestone above the Klobuky Coal, coll. Obrhel. C — *Asollanus camptotaenia*, muddy limestone above 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
Asterophyllites equisetiformis	X		X	X				X	X	X		X	X		X
Asterophyllites 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.

	Krkonoše-piedmont Basin					
	CWBB		Vrchlabí Formation			ISB
Taxon	Líně Fm.	Semily Formation	Rudník H.	Háje H.	Kozinec H.	Vernéřovice 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

Table 2 (*continued*)

	Krkonoše-piedmont Basin					
	CWBB		Vrchlabí Formation			ISB
Taxon	Líně Fm.	Semily Formation	Rudník H.	Háje H.	Kozinec H.	Vernéřovice M.
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*)

Taxon	Krkonoše-piedmont Basin					
	CWBB		Vrchlabí Formation			ISB
	Líně Fm.	Semily Formation	Rudník H.	Háje H.	Kozinec H.	Verneřovice 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

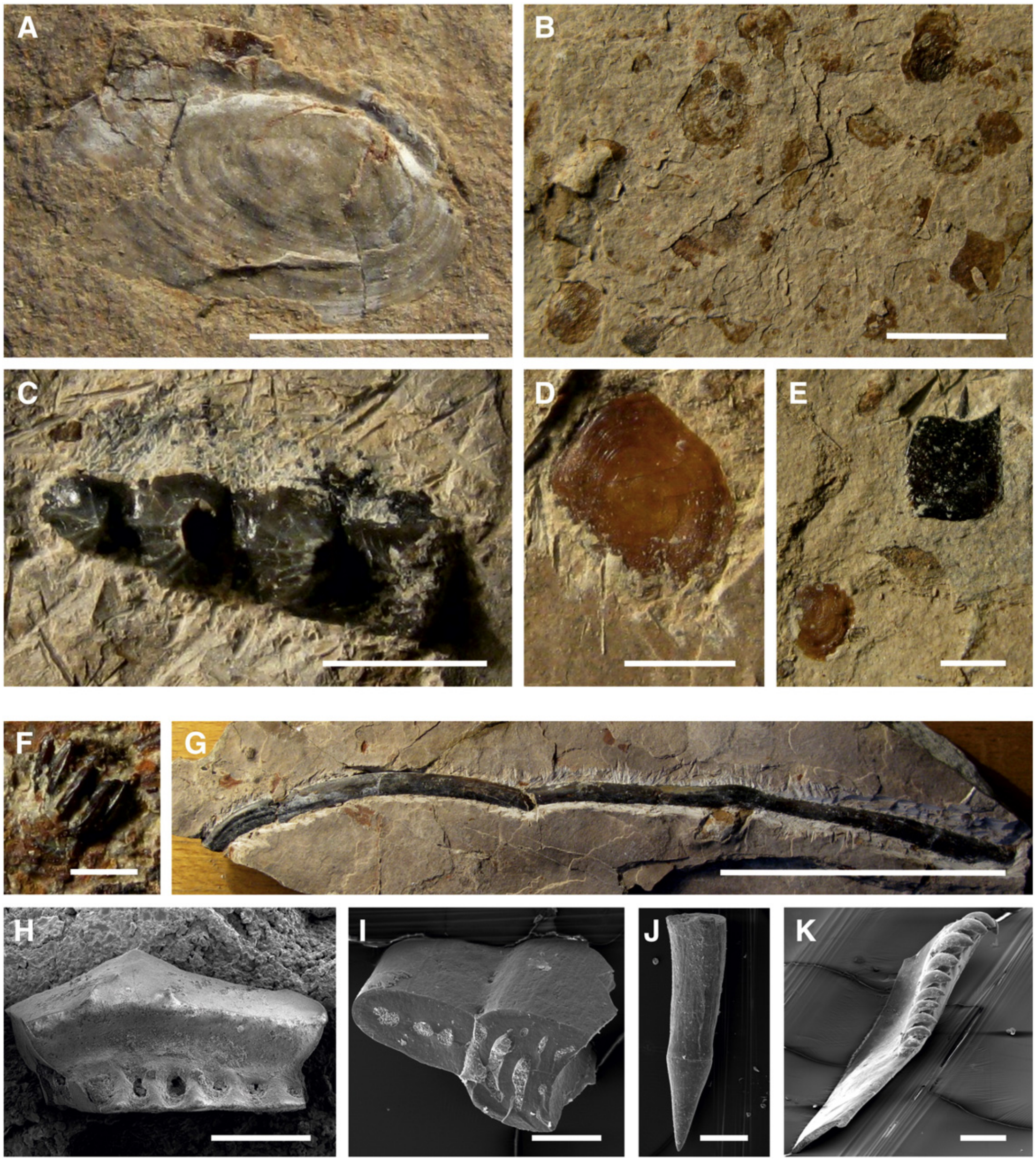


Fig. 11. Fauna of the Kladno–Rakovník Basin (CWBB), Klobuky Horizon, Klobuky locality. Photos by Zajíc. A — *Anthraconaia* sp., scale bar equals 5 mm. B — Lioestheriidae indet., scale bar equals 5 mm. C — *Sphenacanthus carbonarius*, tooth in coronal view, scale bar equals 3 mm. D — *Sphaerolepis kounoviensis*, 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

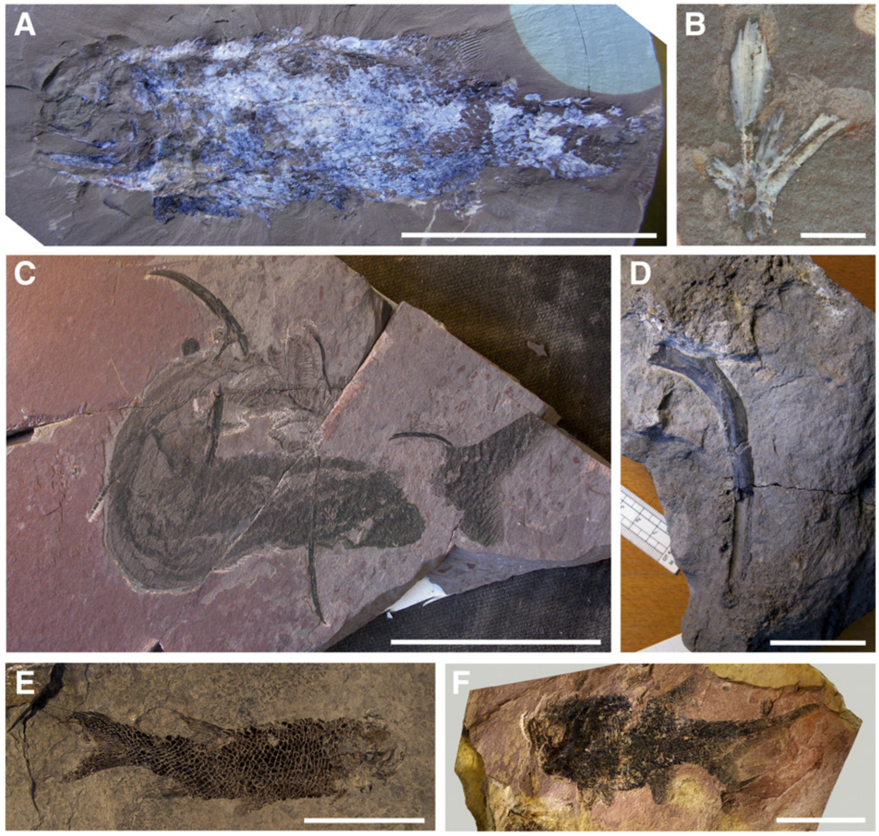


Fig. 12. A — Actinopterygii indet., articulated specimen, Mšeno–Roudnice Basin (CWBB), red sequence of the Líně Formation between the Klobuky and Stránka Horizons, Lib-1 Liběchov borehole, scale bar equals 30 mm. B — *Sphaerolepis kounoviensis*, incomplete parasphenoid, KrPB, Ploužnice Horizon, Ploužnice 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, Košťálov 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.
		no fauna																										
Líně Formation	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

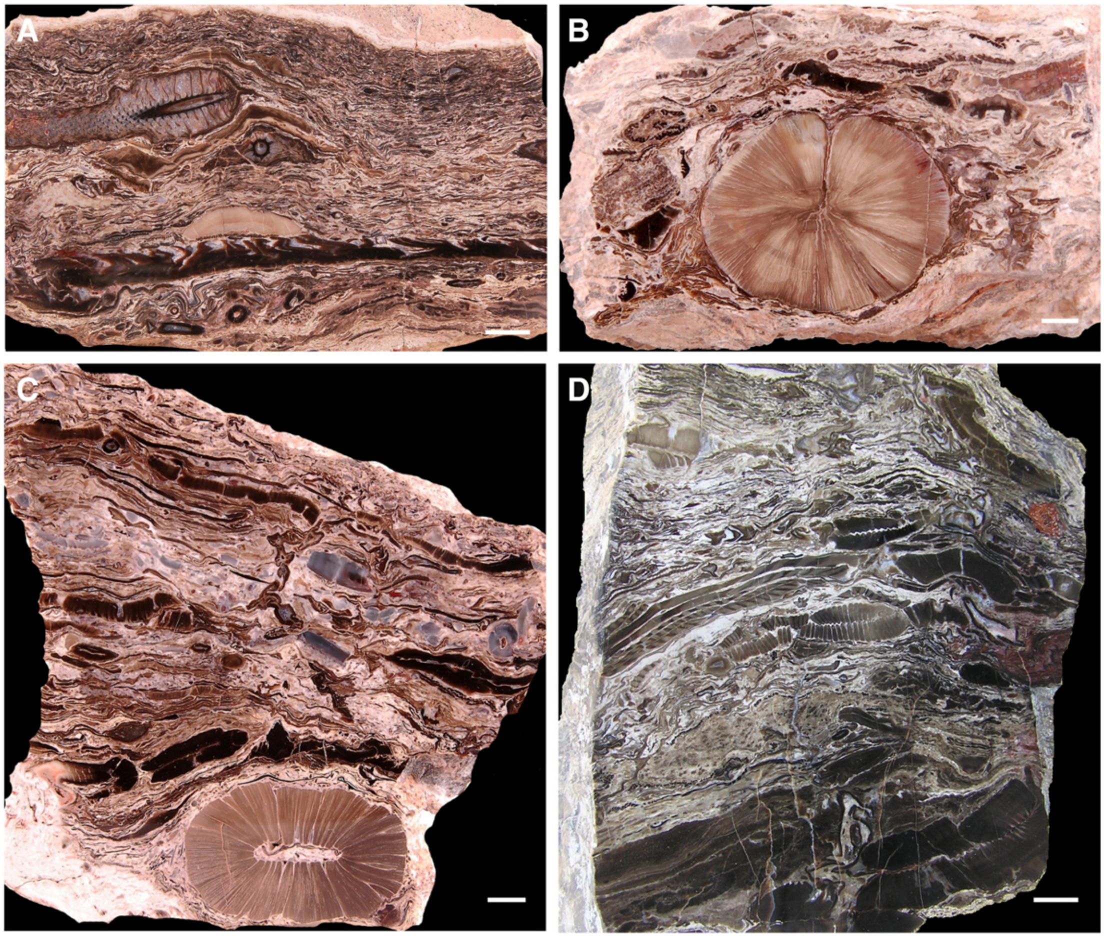


Fig. 13. Silicified peat from the Ploužnice Horizon (Semily Formation) in the KrPB. A — Part of a lycopsid cone. B — Woody cylinder of lycopsid axes (?*Stigmaria* sp.). C — Cross section of the secondary xylem cylinder of *Stigmaria* sp. D — Calamite stems showing wedges of secondary xylem. Scale bars 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

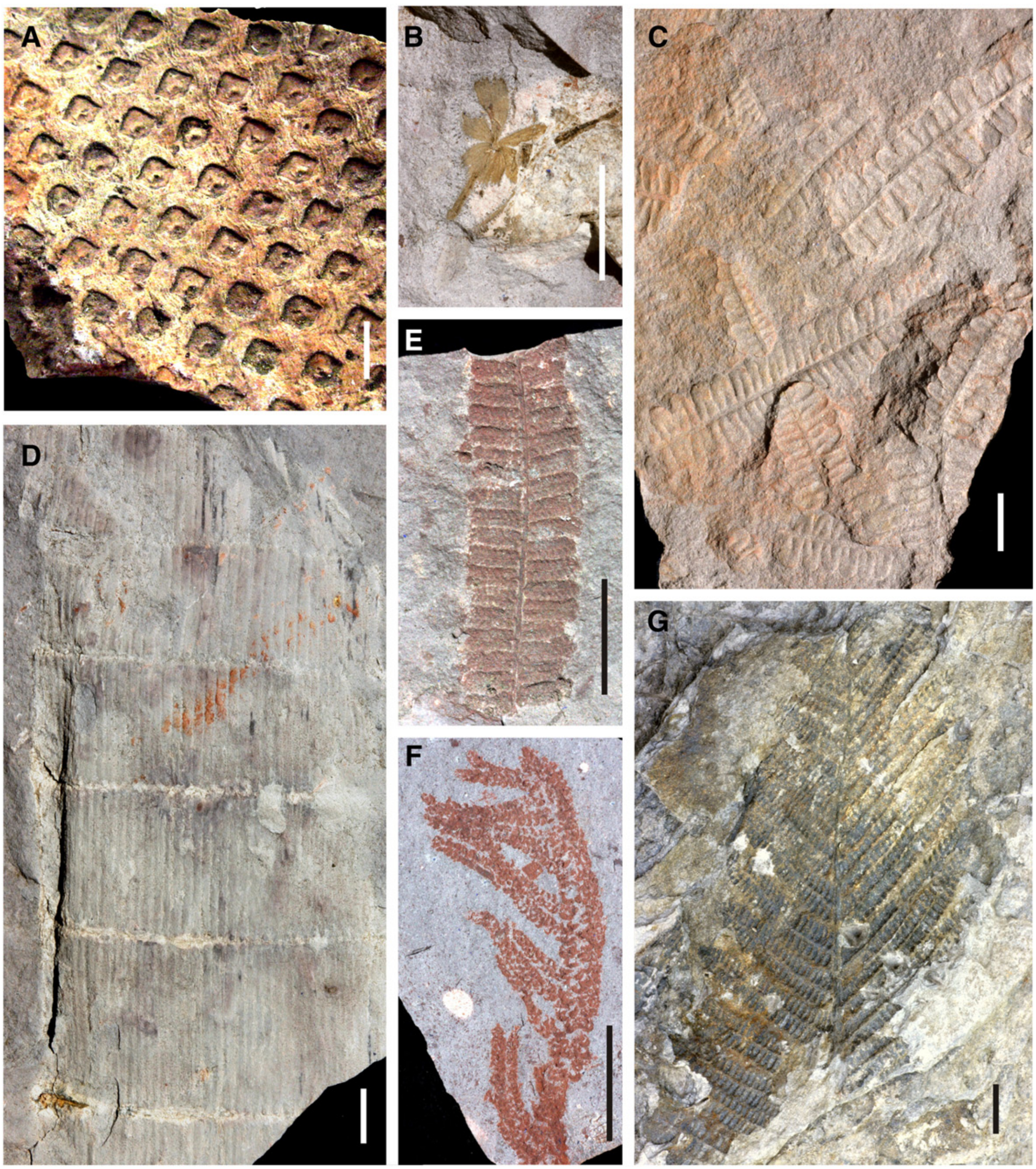


Fig. 14. Flora from the Ploužnice and Štěpanice–Čikvásky Horizons (Semily Fm.) in the KrPB. A — *Sigillaria brardii*, carbonaceous mudstone, Ploužnice Horizon, loc. Ploužnice, coll. Benda, Lomnice Museum. B — *Sphenophyllum oblongifolium*, carbonaceous mudstone, Ploužnice Horizon, loc. Ploužnice, coll. 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.

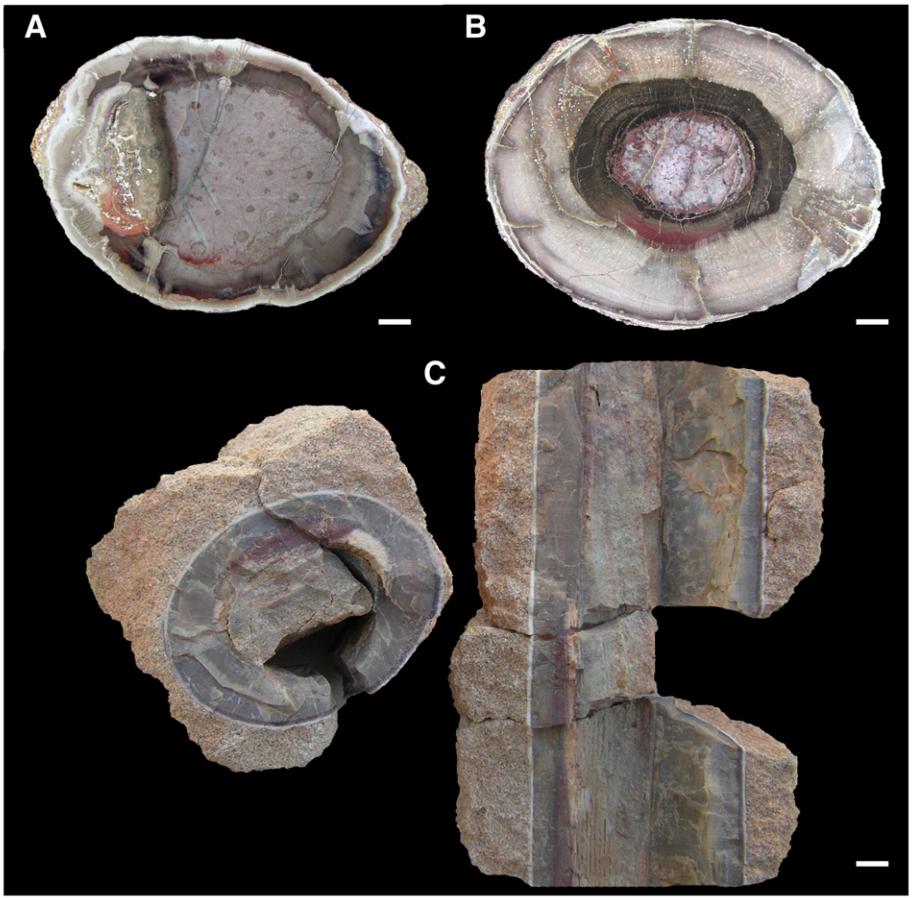


Fig. 15. Silicified stems from sandstone above the Ploužnice Horizon (Semily Fm.) in the KrPB. A — Medullosan stem. B — Calamite stem with thick woody tissues. C — Calamite stems preserved in sandstone. Scale bars 1 cm. All photos: V. Mencl.
Collection of the Municipal Museum Nová Paka.

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

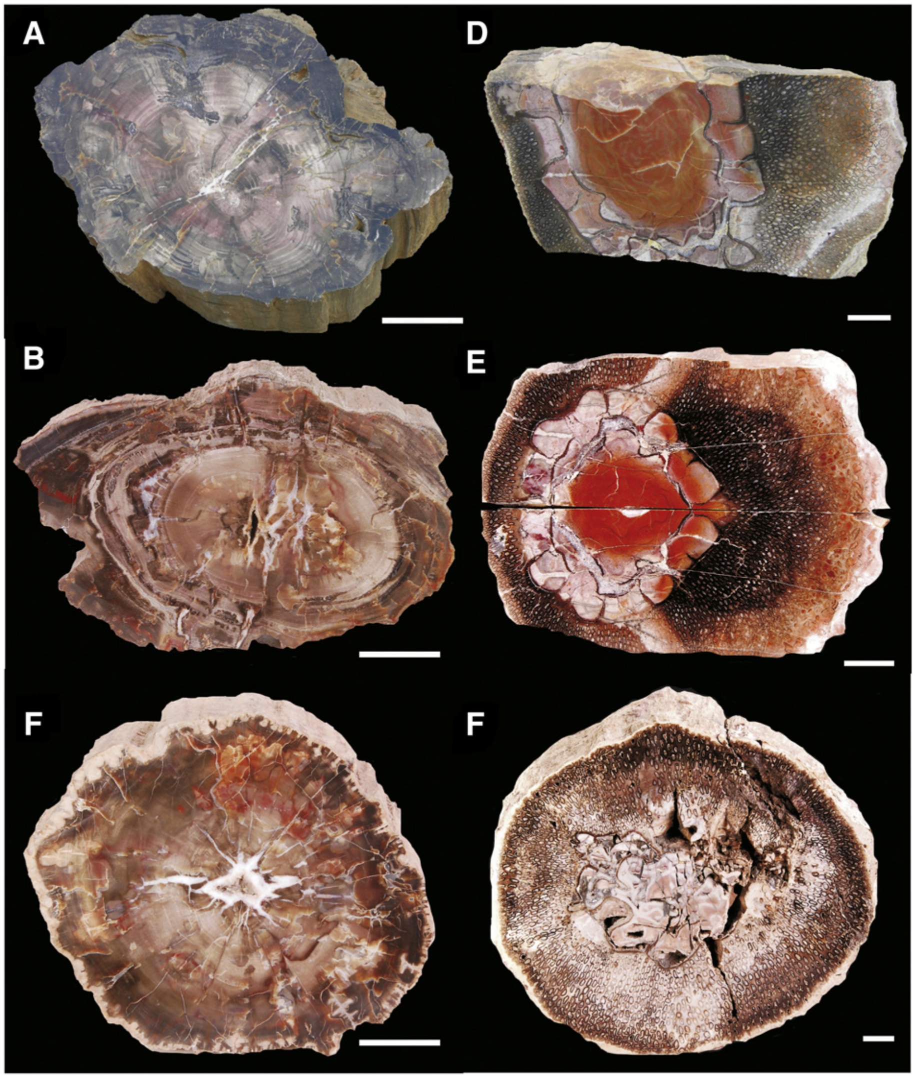


Fig. 16. Silicified stems from sandstone above the Ploužnice Horizon (Semily Fm.) in the KrPB. A–C — gymnospermous woods (Scale bars 5 cm). D–F — *Psaronius* stems (Scale bars 2 cm). All photos: V. Mencl.
Collection of the Municipal Museum Nová Paka.

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*

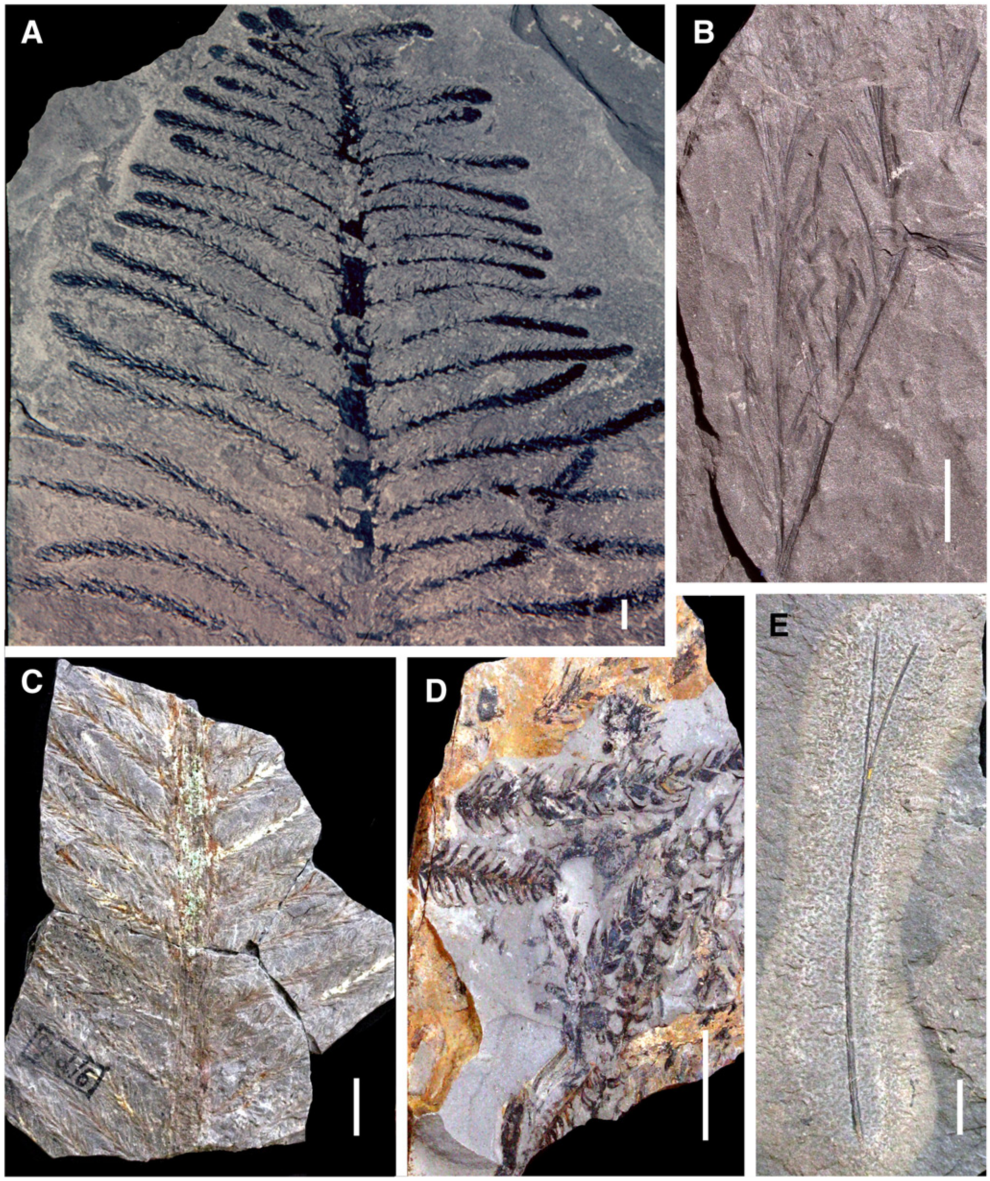


Fig. 17. Flora of the Rudník and Kozinec Horizons (Vrchlabí Formation) in the KrPB. A — *Walchia goeppertiana*, bituminous shale, loc. Vrchlabí — road cut section, Rudník Horizon — upper part. B — cf. *Dichophyllum flabelliferum*, bituminous shale, loc. Valtěřice, Rudník Horizon. C — *Walchia piniformis*, 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 near-shore 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

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

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.

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).

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*"

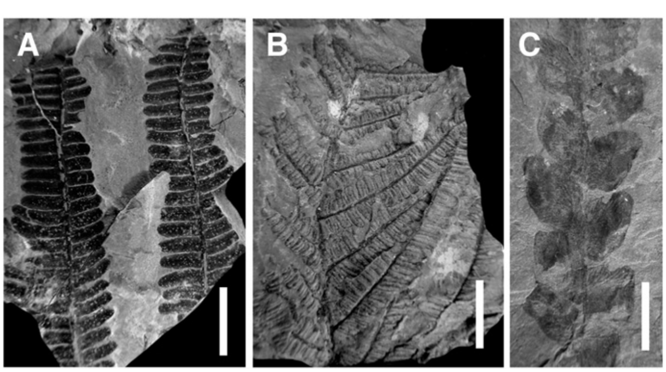


Fig. 19. Flora of the Oslavany group of coals (Oslavany Formation) from the Oslavany section, Boskovice Basin. A — *Pecopteris cyathea*, mudstone parting in the No. 1 Coal. B — *Pecopteris cyathea*, mudstone parting in the No. 1 Coal. C — *Odontopteris schlotheimii*, roof of the No. 1 Coal. Scale bars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

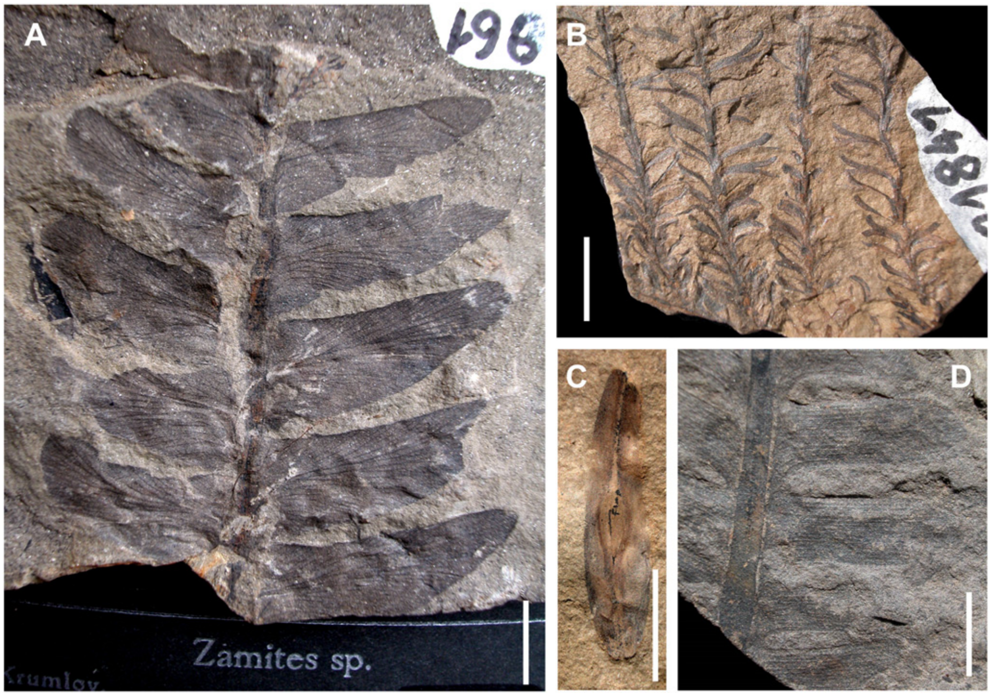


Fig. 20. Flora from the Zbýšov Horizon of the Padochov Formation, Boskovice Basin. A — *Zamites* sp., loc. Moravský Krumlov (No. 21961). B — *Carpentieria marocana*, loc. Moravský Krumlov, Augusta and Němejc orig. (No. 21841). C — *Samaropsis helmhackeri*, loc. Moravský Krumlov (No. 21904). D — *Pterophyllum* 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

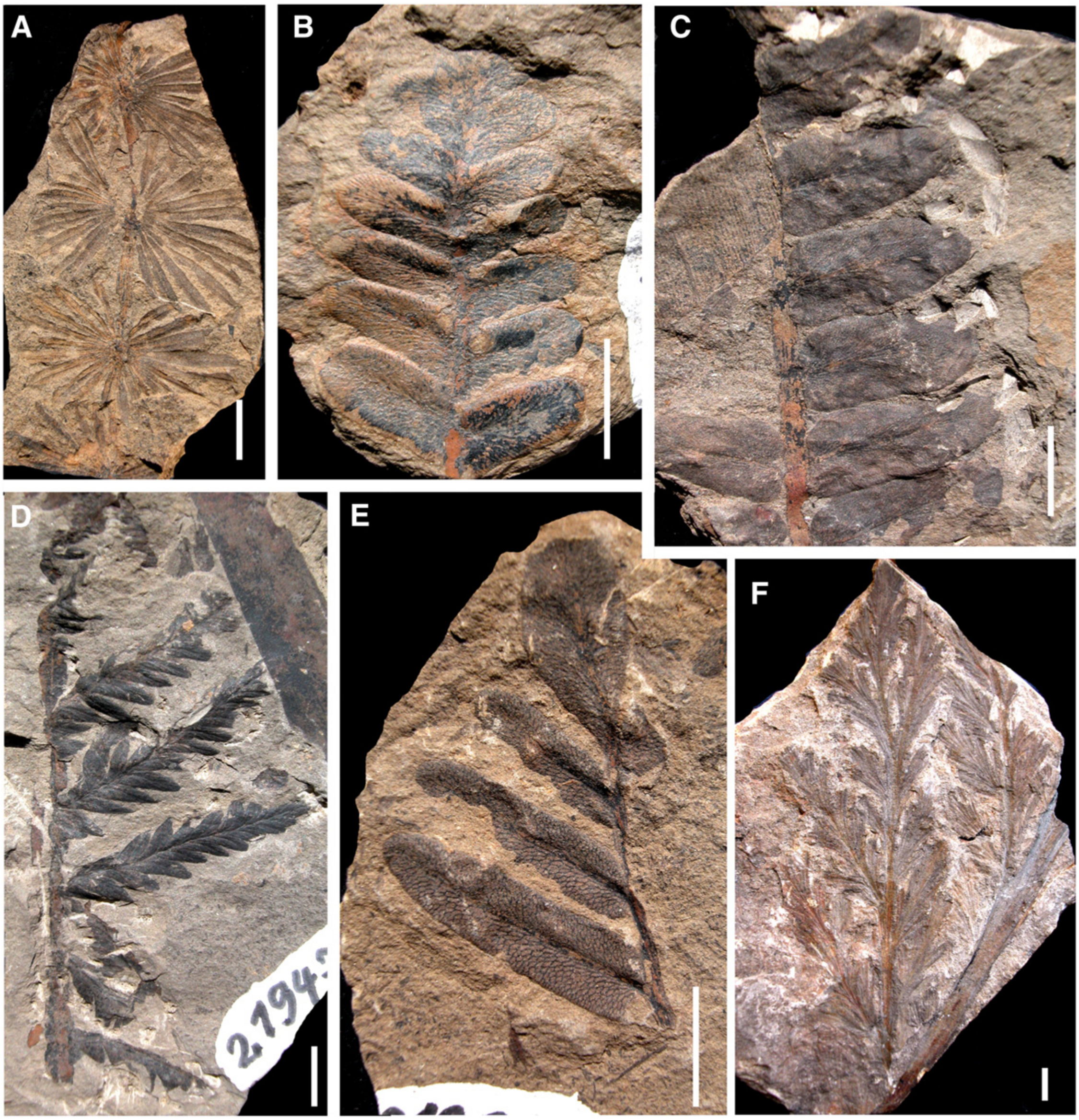


Fig. 21. Flora from the Zbýšov Horizon of the Padochov Formation, Boskovice Basin. A — *Annularia stellata*, loc. Moravský Krumlov (No. 21901). B — *Neurocallipteris neuropteroides*, loc. Moravský Krumlov (No. 21940). C — *Neurocallipteris planchardii*, loc. Moravský Krumlov (No. 21932). D — *Autunia 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

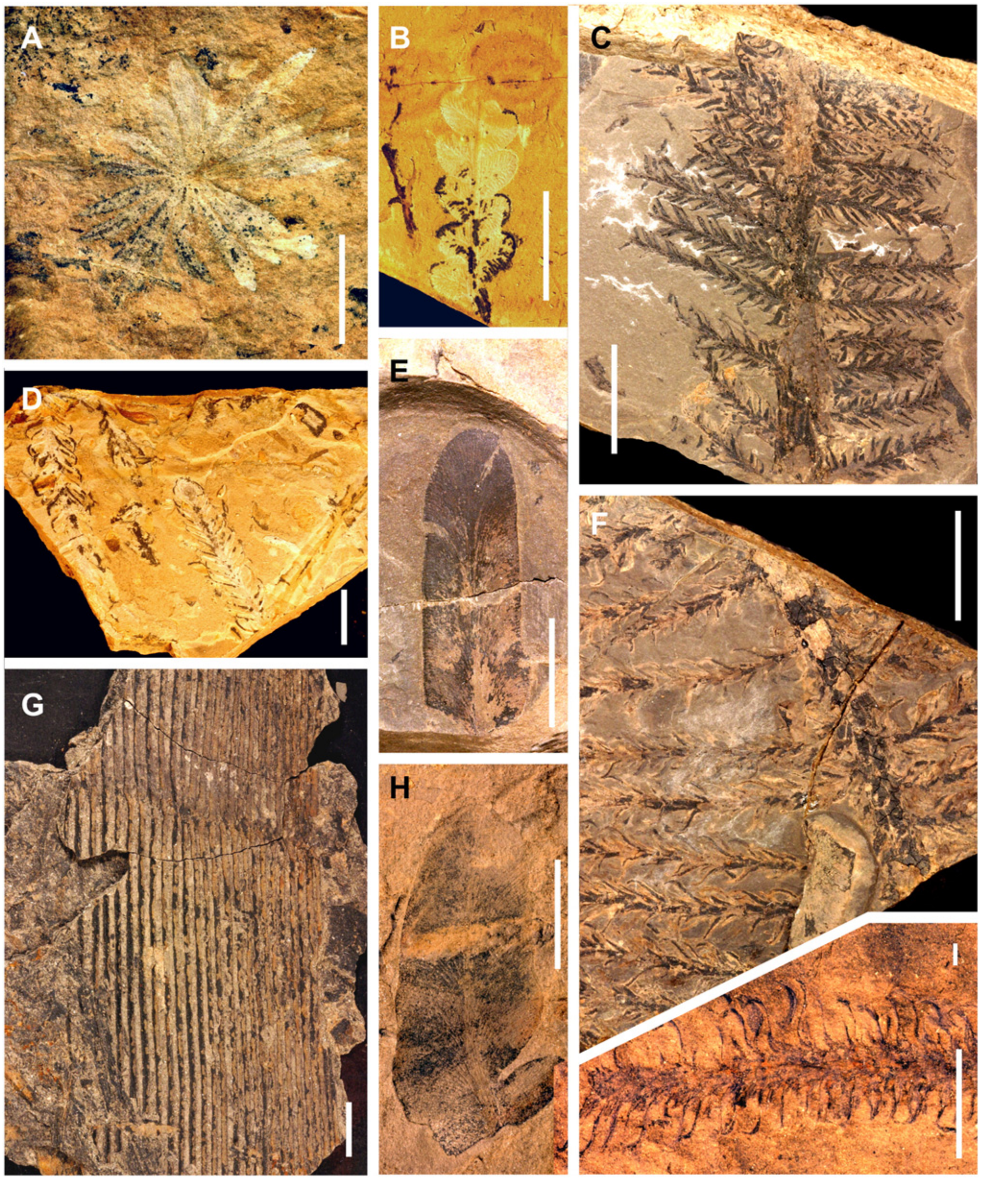


Fig. 22. Flora from the Říčany Horizon of the Padochov Formation, Boskovice Basin. A — *Annularia stellata*, pile from house foundation on NE edge of Veverské Knínice village. B — *Remia pinnatifida*, outcrop behind the house, Veverské Knínice loc. C — *Culmitzschia frondosa* v. *zeilleri*, outcrop behind 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.	*Moraviptera 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.
Říčany 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	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

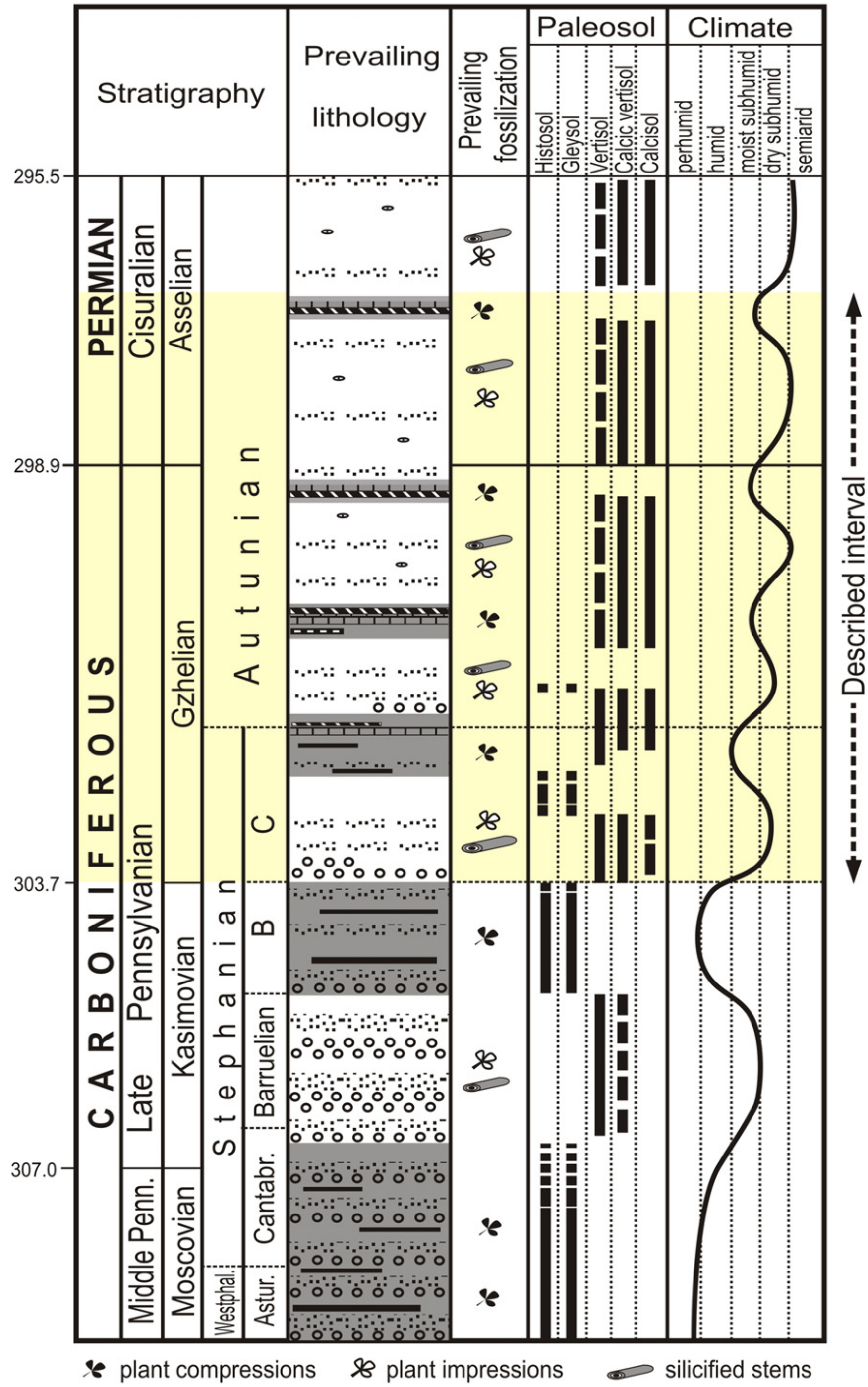


Fig. 25. Generalised section of the Stephanian C/early Autunian strata in the basins of the Czech Republic with climatic indicators and interpreted climatic changes during the Late Pennsylvanian–early Permian. For explanation of lithological symbols see Fig. 5.

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.

Acknowledgement

The paper is a contribution to the currently running projects P210/12/2053 and P210/11/1431 supported by the Grant Agency of the Czech Republic (GAČR). One of the authors (JZ) was supported by the Institutional project Z 3013 0516 (Institute of Geology AS CR, v. v. i.). The authors are very grateful to J. Bureš from the West Bohemian Museum in Pilsen who kindly provided snaps of silicified woods depicted on Fig. 5A, B, and to S. Štamberg from the Museum of Eastern Bohemia at Hradec Králové for some photographs kindly rendered.

The authors are thankful to Scott Elrick (Illinois State Geological Survey, Champaign-Urbana) and one anonymous reviewer for their constructive and comprehensive suggestions for improving the content of the paper. Special thanks of the authors belong to William DiMichele, (Smithsonian Institution, Washington), who did a language correction of the manuscript and also contributed by his suggestion in a manuscript improvement.

References

Augusta, J., 1937. Über die Arten der Gattung *Callipteris* Bgt. aus dem Oberkarbon des Steinkohlenbeckens von Rosice und Oslavany in Mähren (Tschechoslowakei). Zentralblatt für Mineralogie, Teil II, Abteilung B 5, 223–229.

Barthel, M., 2011. Der Farnsamer *Odontopteris schlotheimii* Brongniart aus der Manebach-Formation des Thüringer Wald Beckens. Semana 26, 13–24.

Birgenheier, L.P., Fielding, C.R., Rygel, M.C., Frank, T.D., Roberts, J., 2009. Evidence for dynamic climate change on sub-10^6-year scales from the Late Paleozoic glacial record, Tamworth Belt, New South Wales, Australia. Journal of Sedimentary Research 79, 56–82.

Blecha, M., Martínek, K., Mihaljevič, M., 1999. Sedimentary and geochemical record of the ancient Kalná Lake, Lower Permian, Krkonoše Piedmont Basin, Czech Republic. Acta Universitatis Carolinae 43 (4), 657–665.

Bourouz, A., Doubinger, J., 1977. Report on the Stephanian–Autunian Boundary and on the contents of upper Stephanian and Autunian in their stratotypes. In: Holub, V.M., Wagner, R.H. (Eds.), Symposium on Carboniferous Stratigraphy. Ústřední ústav Geologicky, Praha, pp. 147–169.

Broutin, J., Doubinger, J., Farjanel, G., Freytet, P., Kerp, H., Langiaux, J., Lebreton, M.L., Sebban, S., Satta, S., 1990. Le renouvellement des flores au passage Carboniférе–Permian: approche stratigraphique, biologique, sédimentologique. Comptes Rendus de l'Académie des Sciences Paris II 311, 1563–1569.

Bureš, J., 2011. Silicified cordaite and conifers wood in the sediments of the Líně Formation of the Pilsen Carboniferous Basin (In Czech with English abstract). Erica 18, 179–198.

Cecil, C.B., 2003. The concept of autocyclic and allocyclic controls on sedimentation and stratigraphy, emphasizing the climatic variable. In: Cecil, C.B., Edgar, T.N. (Eds.), Climate Controls on StratigraphySEPM Special Publication 77, 13–20.

Cecil, C.B., Dulong, F.T., West, R.R., Stamm, R., Wardlaw, B.A., Edgar, N.T., 2003. Climate controls on stratigraphy of a Middle Pennsylvanian cyclothems in North America. SEMP Special Publication 77, 151–180.

Cleal, C.J., Opluštil, S., Thomas, B.A., Tenchov, Y. (Eds.), 2010. Late Moscovian terrestrial biotas and palaeoenvironments of Variscan EuramericaNetherlands Journal of Geosciences 88 (4), 181–278.

Corda, A.J., 1867. Flora Protogaea, Beiträge zur Flora der Vorwelt. S. Calvary & Co., Berlin (128 pp.).

Dallmeyer, R.D., Franke, W., Weber, K. (Eds.), 1995. Pre-Permian Geology of Central and Eastern Europe. Springer, Berlin.

DiMichele, W.A., Gastaldo, R.A., Pfefferkorn, H.W., 2005. Plant biodiversity partitioning in the Late Carboniferous and Early Permian and its implications for ecosystem assembly. Proceedings of the California Academy of Sciences 4 (56 (Suppl. I)), 32–49.

DiMichele, W.A., Chaney, D.S., Nelson, W.J., Lucas, S.G., Looy, C.V., Quick, Wang, J., 2007. A low diversity, seasonal tropical landscape dominated by conifers and peltasperms: Early Permian Abo Formation, New Mexico. Review of Palaeobotany and Palynology 145, 249–273.

DiMichele, W.A., Kerp, H., Tabor, N.J., Looy, C.V., 2008. Revisiting the so-called "Paleophytic–Mesophytic" transition in equatorial Pangea: vegetational integrity and climatic tracking. Palaeogeography, Palaeoclimatology, Palaeoecology 268, 152–163.

DiMichele, W.A., Montañez, I.P., Poulen, C.J., Tabor, N.J., 2009. Climate and vegetational regime shift in the late Palaeozoic Ice Age Earth. Geobiology 7, 200–226.

DiMichele, W.A., Cecil, B.C., Montañez, I.P., Falcon-Lang, H.J., 2010. Cyclic changes in Pennsylvanian paleoclimate and effects on floristic dynamics in tropical Pangaea. International Journal of Coal Geology 83, 329–344.

Driese, S.G., Ober, E.G., 2005. Paleopedologic and paleohydrologic records of precipitation seasonality from Early Pennsylvanian "underclay" paleosols, U.S.A. Journal of Sedimentary Research 75, 997–1010.

Feistmantel, K., 1883. Die Hornsteinbank bei Klobuk. Sitzungsberichte der Königl. Böhmischen Gesellschaft der Wissenschaften in Prag 2, 176–193.

Fielding, C.R., Frank, T.D., Isbell, J.L., 2008. The Late Paleozoic Ice Age — a review of current understanding and synthesis of global climate patterns. In: Fielding, C.R., Frank, T.D., Isbell, J.L. (Eds.), Resolving the Late Paleozoic Ice Age in Time and SpaceGeological Society of America, Special Paper 441, 343–354.
Franke, W., 2000. The mid-European segment of the Variscides: tectonostratigraphic units, terrane boundaries and plate tectonic evolution. Geological Society of London, Special Publication 179, 35–61.
Franke, W., 2006. The Variscan orogene in Central Europe: construction and collapse. In: Gee, D.G., Stephenson, R.A. (Eds.), European Lithosphere DynamicsMemoirs. Geological Society of London 32, 333–343.
Frič, A., 1912. Studien im Gebiete der Permformation Böhmens. Archiv für die naturwissenschaftliche Landesdurchforschung Böhmens 15 (2), 1–52.
Gastaldo, R.A., Demko, T.M., 2010. The relationship between continental landscape evolution and plant-fossil record: long term hydrologic controls on preservation. In: Allison, P.A., Bottjer, D.J. (Eds.), Taphonomy: Processes and Bias Throughout Time. Topics in Geobiology 32, 249–285.
Havlena, V., 1957. Stratigrafico-paleontologické výzkumy v okolí Semil a Košťálova (Listy spec. Mapy Vrchlabí – 3755 a Turnov – 3754). Zprávy o geologických výzkumech v roce 1956, pp. 60–61.
Havlena, V., 1964. Geologie uhelných ložisek II,. Nakladatelství Československé Akademie Věd, Praha (437 pp.).
Havlena, V., Jindřich, J., 1975. Nález valounů karbonského materiálu v usazeninách červené jaloviny v okolí Slaného. Časopis pro Mineralogii a Geologii 1, 293.
Havlena, V., Špinar, Z.V., 1955. Stratigrafico-paleontologické výzkumy v okolí Vrchlabí v Podkrkonoší. Zprávy o. geologických výzkumech v roce 1954, pp. 43–44.
Holub, V., 1972. The Permian of the Bohemian Massif. In: Falke, H. (Ed.), Rotliegend; Essays on European Lower Permian. E. J. Brill, Leiden, pp. 137–188.
Holub, V., 1982. Explanatory notes to the lithotectonic profiles of Paleozoic molasses, 26. Blanice Furrow. (Profile and comment to Annex 26). Veröffentlichungen. Zentralinstitut für Physik der Erde Potsdam 66.
Holub, V., Tásler, R., 1981. Geologie mšenské pánve a černouhelného ložiska mezi Mělníkem a Benátkami nad Jizerou. Sborník geologických věd, ložisková geologie 22, 7–87.
Jindřich, V., 1963. Nový nález flóry ze svrchních červených vrstev na Slánsku. Časopis pro Mineralogii a Geologii, 8, pp. 82–85.
Kalibová, M., 1970. Spores from the Upper Red Formation, upper Palaeozoic, overlain by the Bohemian Cretaceous in the Kladno–Rakovník basin. Věstník Ústředního ústavu Geologického 45, 7–16.
Katzer, F., 1895. Vorbericht über eine Monographie der fossilen Flora von Rossitz in Mähren. Sitzungsberichte der Königl. Böhmischen Gesellschaft der Wissenschaften in Prag 24 (1895), 1–26.
Katzer, F., 1904. Der Hořensko-Kostialower Steinkohlenzug bei Semil in Nordböhmen. Verhandlungen der Keiserlichen-Königlichen geologischen Reichsanstalt, Wien 150–189.
Kerp, H., 1988. Aspects of Permian palaeobotany and palynology. X. The West- and Central European species of the genus *Autunia* Krasser emend. Kerp (Peltaspermaceae) and the form-genus *Rhachiphyllum* Kerp (Callipterid foliage). Review of Palaeobotany and Palynology 54, 249–360.
Kerp, H., 1996. Post-Variscan late Palaeozoic Northern Hemisphere gymnosperms: the onset to the Mesozoic. Review of Palaeobotany and Palynology 90, 263–285.
Kerp, H., Fichter, J., 1985. Die Macrofloren des saarpfälzischen Rotliegenden (?Ober-Karbon – Unter-Perm; SW-Deutschland). Mainzer Geowissenschaftliche Mitteilungen 14, 159–286.
Klembara, J., Steyer, J.S., 2012. A new species of *Sclerocephalus* (Temnospondyli: Stereospondylomorpha) from the Early Permian of the Boskovice Basin (Czech Republic). Journal of Paleontology 86 (2), 302–310.
Kopecký, L., Malkovský, M., 1958. O nálezech melafyru v kladensko-rakovnickém permokarbonu. Věstník Ústředního ústavu geologického 37, 217–232.
Kotková, J., Parrish, R., 2000. Evidence for high exhumation rate in central European Variscides: U–Pb ages of granulite metamorphism of clasts deposited in Upper Visean conglomerates. Geolines 10, 41–42.
Krejčí, J., 1877. Geologie čili nauka o útvarech zemských ze zvláštním ohledem na krajiny československé.- Praha.
Krs, M., Pruner, P., 1995. Palaeomagnetism and palaeogeography of the Variscan formations of the Bohemian Massif, comparison with other European regions. Journal of the Czech Geological Society 40, 3–36.
Kukal, Z., 1984. Granitoid plutons were the main source of feldspar of Permo-Carboniferous sediments (in Czech with English summary). Časopis pro Mineralogii a Geologii 29, 193–196.
Linnemann, U., McNaughton, N.J., Romer, R.L., Gehmlich, M., Drost, K., Tonk, C., 2004. West African provenance for Saxo-Thuringia (Bohemian Massif): did Armorica ever leave pre-Pangean Gondwana? U/Pb-SHRIMP zircon evidence and the Nd-isotopic record. International Journal of Earth Sciences 93, 683–705.
Lojka, R., Drábková, J., Zajíc, J., Sýkorová, I., Franců, J., Bláhová, A., Grygar, T., 2009. Climate variability in the Stephanian B based on environmental record of the Mšec Lake deposits (Kladno–Rakovník Basin, Czech Republic). Palaeogeography, Palaeoclimatology, Palaeoecology 280, 78–93.
Lojka, R., Sýkorová, I., Laurin, J., Matysová, P., Matys Grygar, T., 2010. Lacustrine couplet-lamination: evidence for Late Pennsylvanian seasonality in central equatorial Pangaea (Stephanian B, Mšec Member, Central and Western Bohemian basins). Bulletin of Geosciences 85 (4), 709–734.
Martínek, K., Blecha, M., Daněk, V., Franců, J., Hladíková, J., Johnová, R., Uličný, D., 2006. Record of palaeoenvironmental changes in a Lower Permian organic-rich lacustrine succession: integrated sedimentological and geochemical study of the Rudník member, Krkonoše Piedmont Basin, Czech Republic. Palaeogeography, Palaeoclimatology, Palaeoecology 230 (1–2), 85–128.
Matte, P., 1986. Tectonics and plate tectonics model for the Variscan Belt of Europe. Tectonophysics 126, 329–374.
Matte, P., 2001. The Variscan collage and orogeny (480–290 Ma) and the tectonic definition of the Armorica microplate: a review. Terra Nova 13, 122–128.
Matysová, P., Leichman, J., Grygar, T., Rössler, R., 2008. Cathodoluminescence of silicified trunks from the Permo-Carboniferous basis in eastern Bohemia, Czech Republic. European Journal of Mineralogy 20, 217–231.
Matysová, P., Rössler, R., Götze, J., Leichmann, J., Forbes, G., Taylor, E.L., Sakala, J., Grygar, T., 2010. Alluvial and volcanic pathways to silicified plant stems (Upper Carboniferous–Triassic) and their taphonomic and palaeoenvironmental meaning. Palaeogeography, Palaeoclimatology, Palaeoecology 292, 127–143.
Mazur, S., Aleksandrowski, P., Kryza, R., Oberc-Dziedzic, T., 2006. The Variscan Orogen in Poland. Geology & Quaternary 50 (1), 89–118.
Mencl, V., Matysová, P., Sakala, J., 2009. Silicified woods from the Czech part of the Intra Sudetic Basin (Late Pennsylvanian, Bohemian Massif, Czech Republic): systematics, silicification and palaeoenvironment. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen 252/3, 269–288.
Mencl, V., Holeček, J., Rößler, R., Sakala, J., 2013. First anatomical description of silicified calamitalean stems from the upper Carboniferous of the Bohemian Massif (Nová Paka and Rakovník areas, Czech Republic). Review of Palaeobotany and Palynology 197, 70–77.
Mikuláš, R., Martínek, K., 2006. Ichnology of the non-marine deposits of the Boskovice Basin (Carboniferous-Permian, Czech Republic). Bulletin of Geosciences 81 (1), 81–91.
Montañez, I.P., Tabor, N.J., Niemeir, D., DiMichele, W.A., Frank, T.D., Fielding, C.R., Isbell, J.I., 2007. CO_2-forced climate and vegetation instability during Late Palaeozoic deglaciation. Science 315, 87–91.
Němejc, F., 1953. Úvod do floristické stratigrafie kamenouhelných oblastí ČSR. Akademia, Praha 173.
Němejc, F., 1932. Předběžná zpráva o paleobotanicko-stratigrafických studiích v podkrkonošském mladším paleozoiku. Věstník Státního Geologického ústavu 8 (1), 29–35.
Němejc, F., 1951. K výskytu Callipteridů v obzoru slojí rosicko-oslavanských a k otázce stáří tohoto slojového pásma. Sborník Ústředního ústavu Geologického 18, 425–436.
Nordt, L., Orosz, M., Driese, S., Tubbs, J., 2006. Vertisol carbonate properties in relation to mean annual precipitation: implications for paleoprecipitation estimates. Journal of Geology 114, 501–510.
Obrhel, J., 1959. Svrchní červené souvrství a klobucká sloj v okolí Klobuk v Čechách (severně od Slaného). Časopis Národního muzea. Oddíl přírodovědný, 128, pp. 61–65.
Obrhel, J., 1965. Klobucké souslojí u Slaného. Věstník Ústředního ústavu Geologického 40, 365–368.
Opluštil, S., 2005. Evolution of the Middle Westphalian river valley drainage system in central Bohemia (Czech Republic) and it palaeogeographic implication. Palaeogeography, Palaeoclimatology, Palaeoecology 222, 223–258.
Opluštil, S., 2013. Flora from the Líně Formation (Czech Republic) as an example of floristic dynamics around thé Carboniferous/Permian boundary. In: Lucas, S.G., et al. (Ed.), The Carboniferous–Permian TransitionNew Mexico Museum of Natural History and Science, Bulletin 60, 314–321.
Opluštil, S., Cleal, C.J., 2007. A comparative analysis of some Late Carboniferous basins of Variscan Europe. Geological Magazine 144, 417–448.
Opluštil, S., Martínek, K., Tasáryová, Z., 2005. Facies and architectural analysis of fluvial deposits of the Nýřany Member and the Týnec Formation (Westphalian D–Barruelian) in the Kladno–Rakovník and Pilsen basins. Bulletin of Geosciences 80 (1), 45–66.
Pašek, J., Urban, M., 1990. The tectonic evolution of the Plzeň basin (Upper Carboniferous, West Bohemia): a review and reinterpretation. Folia Musei Rerum Naturalium Bohemiae Occidentalis, Geologica 32, 1–56.
Pešek, J., 1994. Carboniferous of Central and Western Bohemia (Czech Republic). Czech Geological Survey, Prague (61 pp.).
Pešek, J., 2004. Late Palaeozoic limnic basis and coal deposits of the Czech Republic. Folia Musei Rerum Naturalium Bohemiae Occidentalis, Geologica 1, 1–188.
Pešek, J., Skoček, V., 1999. Alluvial–lacustrine red beds in Upper Paleozoic continental basins, Bohemian Massif, Czech Republic. Czech Geological Survey Special Paper 11, 1–28.
Pešek, J., Opluštil, S., Kumpera, O., Holub, V., Skoček, V., 1998. Paleogeographic Atlas, Late Paleozoic and Triassic Formations, Czech Republic. Czech Geological Survey, Prague (53 pp.).
Pešek, J., Holub, V., Jaroš, J., Malý, L., Martínek, K., Prouza, V., Spudil, J., Tásler, R., 2001. Geologie a ložiska svrchnopaleozoických limnických pánví České republiky. Český Geologický ústav, Praha (243 pp., 59 pls, 23 maps).
Petrascheck, W., 1904. Zur neuesten Literatur über da böhmiche Grenzgebiet. Jahrbuch der Kaiserlichen-königlichen Geologischen Reichsanstalt, 54, pp. 511–540.
Purkyně, C., 1927. O nalezištích zkřemenělých kmenů araukaritových v Čechách, zvláště v Podkrkonoší. Časopis Národního muzea, Oddíl přírodovědný 101, 113–133.
Purkyně, C., 1929. Karbon a Perm v západním Podkrkonoší. Rozpravy Československé Akademie věd 38 (19), 1–34.
Remy, W., Havlena, V., 1960. Prinzipien der stratigraphischen Gliederung im terrestrish-limnish entwickelten Raum deseuramerischen Florenbereiches im Jungpaläozoikum Europas. Monatsberichte der Deutschen akademie der Wissenschaften zu Berlin, 2 (3/4), pp. 230–235.
Remy, W., Havlena, V., 1962. Zur floristischen Abgrenzung von Devon, Karbon und Perm im terrestrisch-limnisch entwickelten Raume des euramerischen Florenbereichs in Europa. Fortschritte in der Geologie von Rheinland und Westfalen 3 (2), 735–752.
Rieger, Z., 1958. Stručné výsledky paleobotanických studií v západní části podkrkonošského permokarbonu. Věstník Ústředního ústavu Geologického 33, 212–213.

Rieger, Z., 1965. Nové fytopaleontologické nálezy v rosicko-oslavanské oblasti. Časopis pro Mineralogii a Geologii 10 (1), 89–91.
Rieger, Z., 1968. Fytopaleontologicko-stratigrafický výzkum stefanu a autunu podkrkonošské pánve. Věstník Ústředního ústavu Geologického 43 (6), 449–457.
Rieger, Z., 1971. Zhodnocení dosavadních fytopaleontologických sběrů z rudnického obzoru podkrkonošské pánve. MS archiv ÚÚG, Praha (47 str.).
Schneider, J.W., Korner, F., Roscher, M., Kroner, U., 2006. Permian climate development in the northern peri-Tethys area — Lodeve basin, French Massif Central, compared in a European and Global context. Palaeogeography, Palaeoclimatology, Palaeoecology 243, 92–117.
Schulmann, K., Konopásek, J., Janoušek, V., Lexa, O., Lardeaux, J.M., Edel, J.B., Štípská, P., Ulrich, S., 2009. An Andean type Palaeozoic convergence in the Bohemian Massif. Comptes Rendus Geoscience 341, 266–286.
Šetlík, J., 1951. Paleontologicko-stratigrafické výzkumy ve stefanienu středních Čech a Moravy. Sbornik Ústředního ústavu Geologického 18, 437–448.
Šetlík, J., 1977. Results on recent investigation on the Carboniferous flora of Bohemia. In: Holub, V., Wagner, R.H. (Eds.), Symposium on Carboniferous Stratigraphy. Czechoslovakian Geological Survey, Prague, pp. 315–340.
Šetlík, J., Rieger, Z., 1970. Fytopaleontologie svrchního červeného souvrství. MS. Archiv of the Czech Geological Survey Prague, Praha 32.
Sheldon, N.D., 2005. Do red beds indicate paleoclimatic conditions?: A Permian case study. Palaeogeography, Palaeoclimatology, Palaeoecology 228, 305–319.
Sheldon, N.D., Tabor, N.J., 2009. Quantitative paleoenvironmental and paleoclimatic reconstruction using paleosols. Earth Science Review 95, 1–52.
Šimůnek, Z., Drábková, J., 1997. Palaeobotany and palynology of the Háje Horizon (Autunian) in the Krkonoše Piedmont Basin, Czech Republic. Mededelingen Nederlands Institut voor Toegepaste Geowetenschappen. Proceedings 4th EPPC, 58. TNO, Heerlen, pp. 53–63.
Šimůnek, Z., Martínek, K., 2009. A study of Late Carboniferous and Early Permian plant assemblages from the Boskovice Basin, Czech Republic. Review of Palaeobotany and Palynology 155 (3–4), 275–307.
Šimůnek, Z., Zajíc, J., Drábková, J., 1988. Stratigraficko-paleontologický výzkum lokality Klobuky. MS. Archív Českého Geologického ústavu, Praha 37.
Šimůnek, Z., Martínek, K., Zajíc, J., Drábková, J., Mikuláš, R., Valentová, D., 2009. Paleontology, sedimentary environments and climatic indices of the Klobuky Horizon (Líně Formation, Upper Pennsylvanian, Kladno–Rakovník Basin, Czech Republic). XXXI Symposium on Geology of Coal-bearing Strata of Poland, Proceedings. Krakow, pp. 69–78 (ISBN 978-83-919850-5-9).
Skoček, V., 1969. Some silicification phenomena and their stratigraphical importance in the Permo-Carboniferous of central Bohemia. Věstník Ústředního ústavu Geologického 44, 293–300 (In Czech with English abstract).
Skoček, V., 1970. Silicifikovaná dřeva ve středočeském permokarbonu. Věstník Ústředního Ústavu Geologického 45, 87–93.
Skoček, V., 1974. Climate and diastrophism, the principal factors controlling Late Paleozoic sedimentation in central Bohemia. Časopis pro Mineralogii a Geologii 19 (1), 27–45.
Skoček, V., 1990. Stephanian lacustrine–deltaic sequence in central and northeast Bohemia. Sborník Geologických věd, Geologie 45, 91–122 (in Czech with English abstract).
Skoček, V., 1993. Fossil calcretes in the Permo-Carboniferous sequences; Bohemian Massif, Czechoslovakia. Věstník Českého geologického ústavu 68 (2), 45–51.
Skoček, V., Holub, V., 1968. Origin, age and characteristics of fossil Late Palaeozoic weathering residues in the Bohemian Massif. Sborník Geologických věd, Řada Geologie 14, 3–46.
Štamberg, S., 2010a. A new aeduellid actinopterygian from the Lower Permian of the Krkonoše Piedmont Basin (Bohemian Massif) and its relationship to other Aeduellidae. Bulletin of Geosciences 85 (2), 183–198.
Štamberg, S., 2010b. Taxonomic remarks on *Rhabdolepis saarbrueckensis* Gardiner, 1963 (Osteichthyes: Actinopterygii) and its relationships to some actinopterygians from the Late Carboniferous of the Bohemian Massif, Czech Republic. Journal of the National Museum (Prague), Natural History Series 179 (15), 153–170.
Štamberg, S., 2012. Permian actinopterygian fishes and their use to correlate outcrops of the significant fossiliferous horizons of the Krkonoše Piedmont Basin. Zprávy o geologických výzkumech v roce 2011, pp. 149–150 (in Czech).
Štamberg, S., Zajíc, J., 2008. Carboniferous and Permian Faunas and their Occurrence in the Limnic Basins of the Czech Republic. Muzeum Východních Čech v Hradci Králové, Hradec Králové.
Tabor, N.J., Poulsen, J.P., 2008. Palaeoclimate across the Late Pennsylvanian–Early Permian tropical palaeolatitudes: a review of climate indicators, their distribution, and relation to palaeophysiographic climate factors. Palaeogeography, Palaeoclimatology, Palaeoecology 268, 293–310.
Tásler, R., Skoček, V., 1964. Geology and lithology of the Manětín Basin. Sborník Geologických věd, Geologie 6, 7–64.
Tásler, R., Skoček, V., 1980. Permokarbon in Südteil des Krkonoše-Vorlandbecken und seine Parallelisierung mit anderen Gebieten. Věstník Ústředního ústavu Geologického 55, 309–321.
Tásler, R., Čadková, Z., Dvořák, J., Fediuk, F., Chaloupský, J., Jetel, J., Kaiserová-Kalibová, M., Prouza, V., Schovánková-Hrdličková, D., Středa, J., Střída, M., Šetlík, J., 1979. Geology of the Bohemian Part of the Intra-Sudetic Basin (In Czech with English Summary). Academie, Praha (296 s).
Tásler, R., Havlena, V., Prouza, V., 1981. New lithostratigraphical division of the central and western part of the Krkonoše Piedmont Basin. Věstník Ústředního Ústavu Geologického 56, 129–143 (in Czech with English Abstr).
Valterová, P., 1987. Palynologický výzkum bituminózních pelitů. Sborník Geologických věd, Geologie.MS, Geoindustria archiv, Praha.
Wagner, R.H., 1984. Megafloral zones of the Carboniferous. Compte rendu 9e Congrès International de Stratigraphie et de Géologie du Carbonifère (Washington, 1979), 2, pp. 109–134.
Weithofer, K.A., 1896. Die geologischen Verhältnisse des Bayer-Schachtes und benachbarten Teiles der Pilsner Kohlenmulde. Österreiche Zeitschrift für Berg- und Hüttenwesen 44 (317–21, 331–5, 345–9, 355-7).
Weithofer, K.A., 1902. Geologische Skizze des Kladno-Rakonitzer Kohlenbeckens. Verhandlungen der Geologischen Reichsanstalt 399–420.
Zajíc, J., 2000. Vertebrate zonation of the non-marine Upper Carboniferous–Lower Permian basins of the Czech Republic. Courier Forschungsinstitut Senckenberg 223, 563–575.
Zajíc, J., 2004. Vertebrate biozonation of the Permo-Carboniferous lakes of the Czech Republic — new data. Acta Musei Reginaehradecensis, Series A: Scientiae Naturales 30, 16–17.
Zajíc, J., 2007. Carboniferous fauna of the Krkonoše Piedmont Basin. Acta Musei Reginaehradecensis, Series A: Scientiae Naturales 32, 11–16.
Zajíc, J., 2012. Contribution to the question of age of the uppermost part of the Líně Formation (Mšeno-Roudnice Basin, Bohemian Massif) — new circumstantial evidence from the Be-1 Bechlín borehole. Zprávy o geologických výzkumech v roce 2011, pp. 59–62 (in Czech).
Zajíc, J., Milner, A.R., Klembara, J., 1990. The first partially articulated amphibian (Temnospondyli: Dissorophoidea) from the Líně Formation (Stephanian C, central Bohemia). Věstník Ústředního ústavu Geologického 65 (6), 329–337.
Zajíc, J., Martínek, K., Šimůnek, Z., Drábková, J., 1996. Permo-Carboniferous of the excavation for the extension of the Transit Pipeline in the Boskovice Furrow. Zprávy o geologických výzkumech v roce 1995, pp. 158–159 (in Czech).
Zikmundová, J., Holub, V., 1965. Valouny silurských a devonských vápenců v permokarbonu na Mladoboleslavsku. Věstník Ústředního ústavu geologického 40, 185–187.
Zulauf, G., Bues, C., Dörr, W., Vejnar, Z., 2002. 10 km Minimum throw along the West Bohemian shear zone: evidence for dramatic crustal thickening and high topography in the Bohemian Massif (European Variscides). International Journal of Earth Science 91, 850–864.

Příloha V

SUMMARY OF OCCURRENCE AND TAXONOMY OF SILICIFIED *AGATHOXYLON*-TYPE OF WOOD IN LATE PALEOZOIC BASINS OF THE CZECH REPUBLIC

Václav Mencl[1,2*], Jan Bureš[3] & Jakub Sakala[2]

[1] Municipal Museum Nová Paka, F.F. Procházky 70, 50901 Nová Paka, Czech Republic; mencl@muzeum.cz
[2] Charles University in Prague, Faculty of Science, Albertov 6, 128 43 Praha 2, Czech Republic; rade@natur.cuni.cz
[3] Palaeontology Department, West Bohemian Museum in Pilsen, Kopeckého sady 2, 30100 Plzeň, Czech Republic; rallus@seznam.cz
* Corresponding author

Abstract: *The late Paleozoic deposits in several basins in the Czech Republic are well known for their abundance of silicified stems. Despite the fact they have been known since 19th century, there are few modern works of this material. The stems have been known to occur at several stratigraphic levels. During the course of recent field work such material has been found at additional levels. Most of them belong to the genus* Agathoxylon*, divided here into two types: cordaitalean plants and conifers. Based on previous data from Intra Sudetic and Pilsen Basins, and new material from Krkonoše Piedmont and Kladno-Rakovník Basins, this work compiles and compares the occurrence, anatomical features and taxonomy of silicified* Agathoxylon*-type of stems through four studied areas. The various cordaitalean – conifer ratio among all basins reflect different palaeoenvironment in each of them.*

Key words: silicified wood, stem anatomy, *Agathoxylon*-type of wood, cordaitaleans, conifers, late Paleozoic, Czech Republic.

1. INTRODUCTION

Silicified araucarioid wood is an important element of the floras from the late Paleozoic Czech basins. There are several papers which recently described this type of wood from different parts of the Bohemian Massif (e.g., Matysová, 2006; Mencl, 2007; Mencl et al., 2009; Holeček, 2011; Bureš, 2011, 2013; Opluštil et al., 2013).

The nomenclature of araucarioid wood has been often discussed, and several various names have been applied to this wood over time (e.g., *Dadoxylon* Endlicher, *Agathoxylon* Hartig, *Araucarioxylon* Kraus, and *Dammaroxylon* J. Schultze-Motel). Present palaeoxylologists generally prefer the use of term *Agathoxylon* for such wood (Rößler et al., in press) and we follow this usage herein.

2. HISTORICAL INSIGHT

2.1. Krkonoše Piedmont Basin

Silicified plant remains in area of Nová Paka (Figure 1) have been known for many years. Their occurrence was first mentioned, as far as we can ascertain, by Maloch (1844) (see Heber, 1844) who described stems in the villages of Pecka and Stupná. Goeppert (1858) presented the first scientific description of the conifer wood *Araucarites schrollianus* (= *„Dadoxylon“ saxonicum*; synonym: *„Dadoxylon“ schrollianum*), as well as calamitalean wood and stems of ferns from Kozinec, Nová Paka and Pecka. Occurrences of *Medullosa, Psaronius* and *Agathoxylon* stems and the existence of silicified peats in Nová Paka and Lázně Bělohrad were described by Frič (1912). In his work, special attention was paid to insect borings on the stem surface, and to the presence of small axes of the climbing fern *Ankyropteris brongniartii*, occasionally preserved in the root mantle of *Psaronius* stems. Vysocký (1859), Jokély (1861), Stur (1877), Makowsky (1878), Katzer (1892), Daněk (1902), Petrascheck (1924) and Hynie (1927) reported on the silicified stems from around Nová Paka. In the Nová Paka region, stems are most often found as lag on hillsides as loose pieces, less commonly they

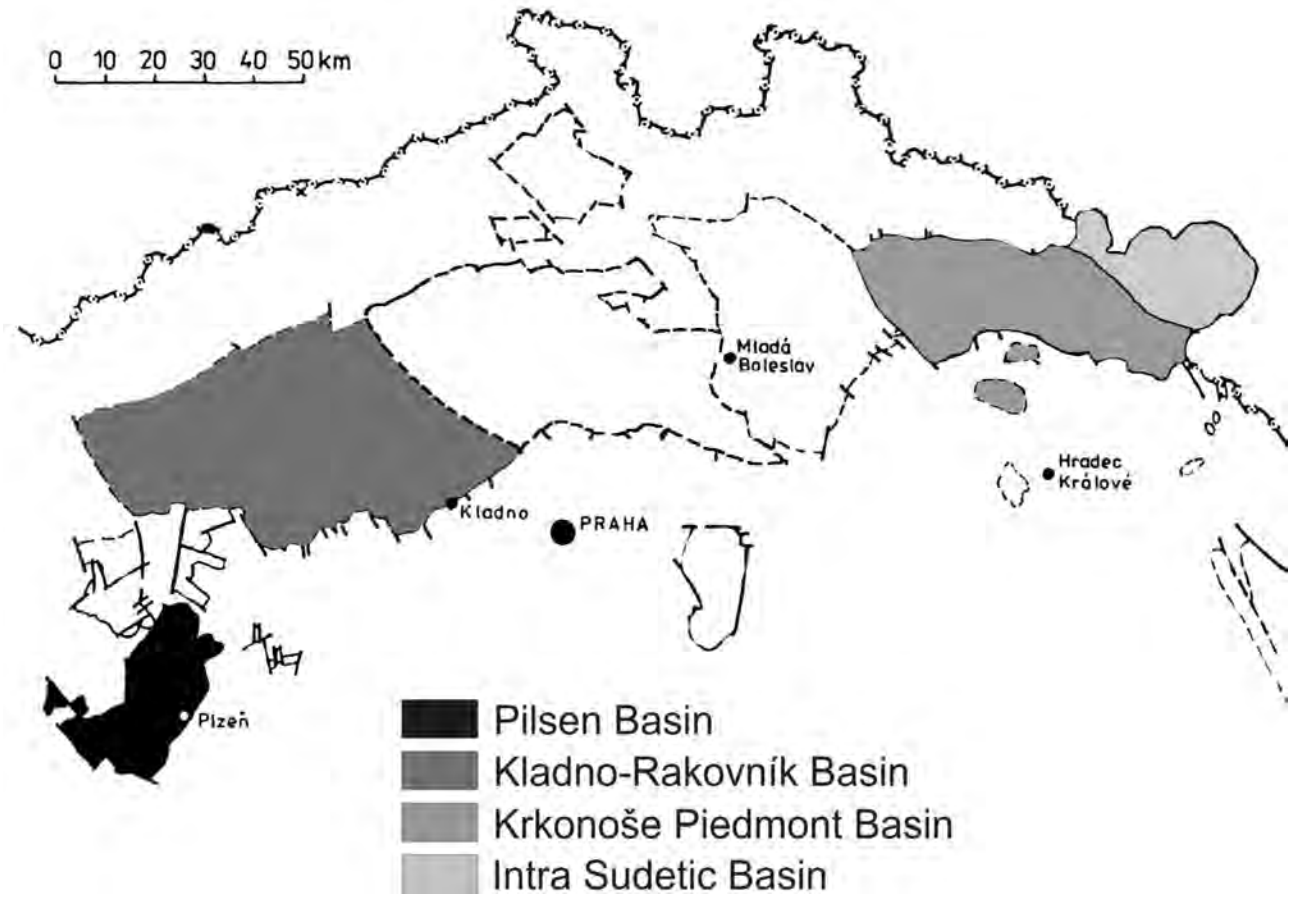


Figure 1. *Late Paleozoic basins of the Czech Republic. Studied areas are highlighted. After Pešek et al. (2001).*

have been found in outcrops, but never in upright position (Purkyně, 1927). Some specimens preserve bark and leaf scars (Renger, 1858, 1863). Feistmantel (1873a, b, c) generally considered silicified stems from the Nová Paka to be early Permian, but recent research indicates that they are of late Pennsylvanian (Kasimovian – Gzhelian) age (Pešek et al., 2001; Matysová, 2006; Mencl, 2007; Mencl et al., 2009; Mencl et al., 2013; Opluštil et al., 2013). The most recent general summary of silicified stem localities in Czech Republic was presented by Březinová (1970). Most recently short notes on the material from the Krkonoše Piedmont Basin have been published by Havlena (1955, 1958), Vítek (1986), Soukup (1997), Dernbach (1996) and Dernbach et al. (2002). Subsequent to Goeppert (1858) no detailed anatomical study of the *Agathoxylon*-type wood has been published.

2.2. Intra Sudetic Basin

In the Czech part of the Intra Sudetic Basin (Figure 1) silicified wood have been known for a long time. The first scientific descriptions were presented by Goeppert (1857, 1858) based on silicified wood in the Jestřebí hory region; an area about 30 x 7.5 kilometres.

The length of stems reaches up to 6 m, and diameter varies between 40 and 50 cm. Most are oval in cross-section due to compression. Some logs have preserved growth rings and knots with stubs of branches, and all lack bark (Goeppert, 1858). Systematically these fossils were interpreted as conifers and attributed to the species *Araucarites brandlingii* (Lindl. & Hutt.) Göpp. and *Araucarites schrollianus* Göpp. (Goeppert, 1857, 1858).

Occurrences of silicified stems in the Intra Sudetic Basin mentioned also many other authors, e.g., Stur (1877), Makowsky (1878), Katzer (1892), Petrascheck (1924), Purkyně (1927), Březinová (1970) and Tásler et al. (1979). The most modern research was performed by Matysová (2006), Mencl (2007) and Mencl et al. (2009) who interpreted this material as cordaitalean wood.

2.3. Kladno-Rakovník Basin and Pilsen Basin

The occurrence of petrified stems in the Kladno-Rakovník and Pilsen Basins (Figure 1) has been known for about 150 years. Such fossil material is less common in this basin than in the Krkonoše Piedmont area. The first mention of such material in the Pilsen Basin was by Miksch (1853) who described stems up to 7.5 m in length from locality Chotíkov. The first anatomical studies of silicified stems were performed by Feistmantel (1873a, b, c), who described many stems from the Kladno-Rakovník Basin (localities Rakovník, Lubná, Hředle, Řevničov, Klobuky and Krušovice). He assigned different wood types to the conifer *Araucarites schrollianus* (= *„Dadoxylon" saxonicum*; synonym: *„Dadoxylon" schrollianum*), and fern *Psaronius* (Feismantel, 1873b). These stems are without bark, some have growth rings, knots and pith cavities (Feistmantel, 1873c). First taxonomic description of silicified stems from both basins was provided by Feistmantel (1883). He determined one well-preserved piece of wood from Mutějovice (Kladno-Rakovník Basin) to belong to *Araucarioxylon schrollianus,* several loose-pieces from Lochotín as the cordaitalean wood *Araucarioxylon brandlingi* (Lindl. & Hutt.) Göpp., and from Líně and Červený Újezd he identified wood as the conifer *Araucarites schrollianus* Göpp. (Feistmantel, 1883). Frič (1912) described silicified wood from a sandstone near Kněževes, and one stem uniquely preserved in outcrop of whitish sandstone near Klobuky. Purkyně (1927) provided a summary of petrified stems from Bohemia, including the new localities; Očihov, Kryry and Slaný; where black coloured silicified wood was found. He attempted stratigraphic correlations based on the occurrence of fossil wood (Purkyně, 1912). The possible applications of the silicified wood for stratigraphic correlations were also discussed by Němejc (1953), Pouba and Špinar (1954), and Pešek (1968). Subsequently Skoček (1970) divided petrified wood in two taphonomic types: dark which organic matter is present (deposited in swamps and partly humified), and light which lacks organic matter, which were deposited under dry climatic conditions (Skoček, 1970). Short notes about silicified stems were mentioned by several other authors, e.g., Němejc (1953), Pouba and Špinar (1954), Havlena (1964), Březinová (1970), Obrhel (1977), Řehoř and Řehoř (2005) and Svejkovský (2009). A short note about the silicified peat and fossil wood in the Kloubuky area was published by local collectors (Dvořák and Švancara, 2003). A palaeoichnological study was performed by Mikuláš and Zasadil (2008), who described silicified stems with insect boreholes and fungal traces from Kněževes, Hředle, Bílenec, Očihov a Stachov. The newest systematic work on silicified stems from the Kladno-Rakovník Basin summarised the occurrences of various types of stems and described their anatomy was done by Holeček (2011). Silicified conifer and cordaitalean stems from the Pilsen Basin and their anatomical features were described by Bureš (2011, 2013).

3. GEOLOGICAL SETTINGS

3.1. Krkonoše Piedmont Basin

The Krkonoše Piedmont Basin is situated in the northern part of the Czech Republic, at the foot of the Krkonoše-Jizerské hory crystalline complex (Figure 1) and belongs to a system of post-orogenic extensional/transtensional basins of the Bohemian Massif. Purely continental deposits in the Krkonoše Piedmont Basin are early Moscovian (Asturian) to early (or even middle) Triassic in age (Figure 2). The sediment fill of this basin reaches a maximum thickness about 1800 m (Pešek et al., 2001).

Previous geologic mapping indicates that silicified *Agathoxylon*-type stems are known from two stratigraphic levels: the Štikov Arkoses (Kumburk Formation) and the Ploužnice Horizon (Semily Formation) (Pešek et al., 2001). More recently this wood has been found in both the Brusnice Member (lower Kumburk Formation) and the lower Prosečné Formation. Stems, when found in place are horizontal on bedding planes; no upright stems have been observed.

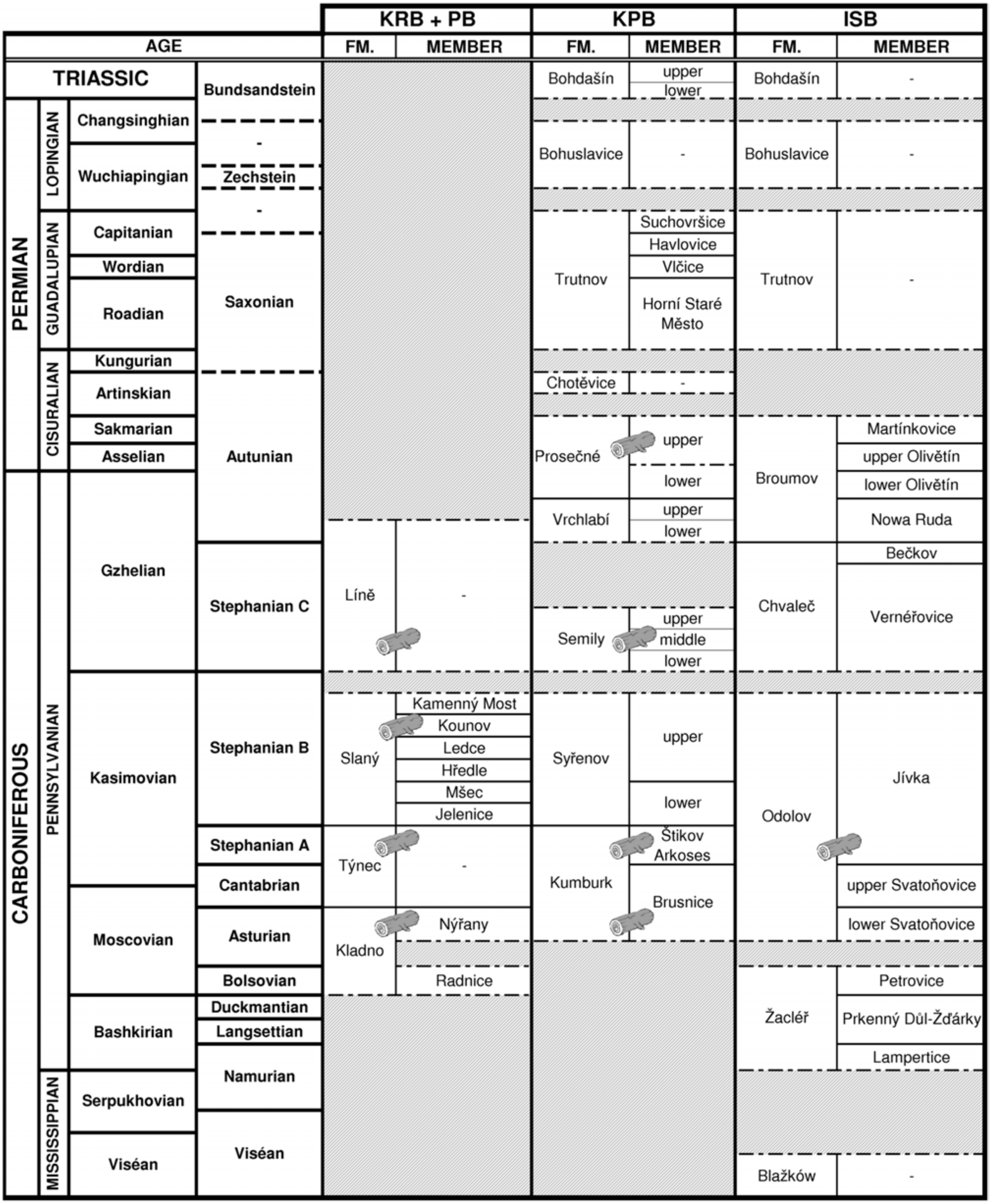


Figure 2. *Comparison of stratigraphy of the Kladno – Rakovník Basin (KRB), Pilsen Basin (PB), Krkonoše Piedmont Basin (KPB) and Intra Sudetic Basin (ISB). Stratigraphical positions of the silicified stems are illustrated by small logs. Compiled after Mencl et al. (2009), Holeček (2011) and Gradstein et al. (2012).*

3.1.1. Kumburk Formation

Brusnice Member (lower Kumburk)

This unit is upper Moscovian – lower Kasimovian (Asturian – Cantabrian) in age. It consists mostly of reddish aleuropelites with common, several metre thick intercalations of greyish, middle- to coarse-grained, semi-rounded to rounded, siliciclastic conglomerates (Pešek et al., 2001). This unit is only known to occur in the southern part of the Krkonoše Piedmont Basin. It was deposited in lacustrine and fluvial environments with no volcanic component (Matysová et al., 2010). Silicified stems are rare and have not yet been described from this unit. A single silicified stem was observed in horizontal position in an outcrop of coarse-grained conglomerate by one of the present authors (V. Mencl).

Štikov Arkoses (upper Kumburk)

This unit is Kasimovian (Stephanian A) in age. Deposits are middle- to coarse-grained, light grey, reddish and pinkish sandstones that may laterally become conglomeratic with rounded cobbles up to 10 centimetres in diameter (Pešek et al., 2001), probably deposited in lacustrine and/or fluvial environment without any volcanic influence (according to Matysová et al., 2010). Silicified *Agathoxylon* stems are very abundant and often preserved in outcrops. The longest log, which has been ever found in this area, was more than 8 metres long and about 1 metre in diameter.

3.1.2. Semily Formation

Ploužnice Horizon (middle Semily)

This unit is Gzhelian (Stephanian C) in age. The sediments have a mostly lacustrine character (Pešek et al., 2001). They consist of fine-grained, reddish mudstones and siltstones with thin carbonate banks, calcareous and chert concretions. There is a volcanic component represented by intercalated tuffs and tuffitic sandstones which were deposited by traction mechanisms, mostly by river streams (Stárková et al., 2009). Silicified remnants of plants are, for the most part, restricted to the lower part of the Ploužnice Horizon. This unit has yielded *Agathoxylon*-type of wood, silicified stems of the fern *Psaronius*, the calamitaleans (*Arthropitys* and *Calamitea*), and the seed-fern (*Medullosa*) as well as nodules of carnelian (Sakala et al., 2009; Mencl et al., 2013; Opluštil et al., 2013). Due to the lack of outcrops, the silicified stems are usually found as lag. This unit was deposited in a lacustrine environment with influence of volcanism (according to Matysová et al., 2010).

3.1.3. Prosečné Formation

The Prosečné Formation is Asselian - Sakmarian (Autunian) in age. It is only known from the central and western part of the Krkonoše Piedmont Basin. It is a very fine-grained lacustrine deposit with numerous interbedded tuffs, tuffites and limestones. The uppermost part of the Prosečné Formation is composed of pinkish arkoses and arkosic sandstones (Pešek et al., 2001). The usually dark-coloured silicified stems are very common in some localities, but found as lag only. This unit was deposited in a lacustrine environment with influence of volcanism (according to Matysová et al., 2010).

3.2. Intra Sudetic Basin

The Czech part of the Intra Sudetic Basin is in the north-eastern Czech Republic (Figure 1). Its sediments have the greatest stratigraphic range among the late Paleozoic basins of the Bohemian Massif, ranging from Viséan to the Middle Triassic (Pešek et al., 2001; Opluštil and Cleal, 2007; Opluštil et al., 2013) (Figure 2). Strata are divided into eight formations (Tásler et al., 1979; Pešek et al., 2001). The Intra Sudetic Basin is separated from the Krkonoše Piedmont Basin by the Hronov-Poříčí Fault. Sediments in the Intra Sudetic Basin are continental, with the exception of the Mississippian (Viséan) deposits that are partly marine. All other deposits have fluvial, proluvial or lacustrine character. A volcanoclastic component is present in several units (Pešek et al., 2001). Silicified wood is known only from one stratigraphic level called the Žaltman Arkoses in the Odolov Formation. The presence of silicified stems in the Petrovice Member (Bolsovian) that were mentioned by Tásler et al. (1979) was not confirmed (Mencl, 2007; Mencl et al., 2009). The Žaltman Arkoses is Stephanian A in age and composed of fluvial arkosic conglomerates and sandstones (Pešek et al., 2001, Valín, 1956, 1960). Stems are very rarely found in outcrops (e.g. *Kryštofovy kameny*), they are allochthonous and never found in upright position. They lack bark, roots, branches or any other extraxylary tissue (Mencl et al., 2009). Most are found as loose pieces in the field. They are most common in the area of the Jestřebí Hory (Matysová, 2006; Mencl, 2007; Mencl et al., 2009).

3.3. Kladno-Rakovník Basin and Pilsen Basin

The Kladno-Rakovník and Pilsen Basins are situated in the central and south-western part of the Czech Republic (Figure 1). They were formed by an extension/transition during the Variscan orogeny in the Bohemian Massif. The oldest sediments are early Moscovian and the youngest are Gzhelian in age (Figure 2), with a maximum thickness about 1440 metres. These mostly lacustrine sediments are divided into four formations, i.e. the Kladno, Týnec, Slaný and Líně Formations. Silicified wood is known to occur in all formations (Holeček, 2011), but is most common in the Týnec and Líně Formations (Pešek et al., 2001). Exposures of these formations are extremely poor or lacking thus all fossil wood has been found as fragments in eluvium. Some however have been recovered from kaolin mines in the Pilsen Basin. Whole trunks are very rare, petrified wood is often fragmented into small pieces, knots and remnants of branches are very scarce.

3.3.1. Kladno Formation

The Kladno Formation is Moscovian (Bolsovian – Cantabrian) in age and is composed of the Radnice and Nýřany members separated by a hiatus. Both are typified by dark-coloured, greyish and reddish fluvial deposits, mostly claystones, siltstones, sandstones and conglomerates in the Radnice Member, and arkoses, arkosic sandstones and siltstones in the Nýřany Member. Both units contain coal beds and common volcanic intercalations. The very scarce silicified stems in the Kladno Formation are mostly black in colour.

3.3.2. Týnec Formation

The Týnec Formation is lower Kasimovian (Barruelian) and is typified by coarse-grained reddish sediments, without or only with little volcanic intercalations. Petrified stems are very common in this unit and usually light-coloured. Trunks, up to 10 m long, have been described from this formation by Pešek et al. (2001). Two types of wood are present: *Agathoxylon*-type and calamitalean (Mencl et al., 2013).

3.3.3. Slaný Formation

Slaný Formation is Kasimovian (Stephanian B) in age, divided into six members that are composed of mostly grey-coloured sediments. Silicified stems, known only from the Kounov Member (upper part of the Slaný Formation, Fig. 2), are quite rare and usually dark-coloured. The Kounov Member is typified by fluvial and lacustrine deposits, mostly white to greyish arkoses, arkosic sandstones and aleuropelites with coal beds and tuffitic interbeds.

3.3.4. Líně Formation

The Líně Formation is Gzhelian (Stephanian C) in age and separated from the Slaný Formation by a hiatus. It consists primarily of reddish to crimson-coloured silt and claystones. Tuffs and tuffites are more common than in the underlying Slaný Formation, and are can be distinguished within three units (horizons), i.e. the Zdětín, Klobuky and Stránka Horizons (Pešek et al., 2001). Silicified *Agathoxylon*-type stems are very common in arkosic deposits of the lower part of the Líně Formation. Stems are found there as loose pieces in the field, except one unique specimen, which was preserved in outcrop and described by Frič (1912). From this stratigraphic position were also described calamitalean stems (Mencl et al., 2013). In the Klobuky area, there are also known silicified peats (e.g., Dvořák and Švancara, 2003).

4. MATERIAL AND METHODS

The samples from the Krkonoše Piedmont Basin are either from the palaeontological collections of the Municipal Museum Nová Paka (signature P), the Krkonoše Museum in Jilemnice (abbreviation J), or were provided by V. Mencl and private collectors (abbreviations BA, C, HB, JA, PE, S, SH). The samples from the Kladno–Rakovník Basin were collected by J. Holeček and are now housed in the West Bohemian Museum in Pilsen (abbreviations RAK, ZAS), or provided by private collectors (abbreviation ZAJ). The samples from the Pilsen Basin were provided by the West Bohemian Museum in Pilsen (signature FP), or came from the collection of the Municipal Museum Nová Paka (signature P).

Cross sections of several tens of specimens were polished and examined in reflected light with a Leica EZ 5 and Olympus SZx12 stereomicroscopes. The best preserved were thin-sectioned in the standard transverse, tangential longitudinal and radial longitudinal sections, and studied using transmitted light under either an Olympus BX-51 or SZX12 microscope. Images were made with Olympus Camedia 3030 and 5050 digital cameras and processed with imaging software AnalySIS, NIS-Elements and Quick Photo Industrial. The data were analysed with Microsoft Excel 2007–2010.

5. RESULTS

The specimens from the Krkonoše Piedmont and Intra Sudetic Basins are characterised only by the structure of the secondary xylem. A few specimens have knots with stubs of branches. The wood is homoxylous pycnoxylic. Resin canals and axial parenchyma have not been observed. Radial sections rarely show alternate „araucaroid" pitting in tracheid walls. Due to a considerable amount of recrystallisation, other features can only very rarely (e.g. cross-field pitting) be seen. Samples from both basins underwent the same process of recrystallisation, but samples from the Krkonoše Piedmont Basin in much less intensive way than coeval ones from the Intra Sudetic Basin (Mencl, 2007, Mencl et al., 2009).

The specimens from the Kladno-Rakovník and Pilsen Basins show better preservation being less recrystallised. However, they also have preserved the secondary xylem only. Radial sections show alternate „araucaroid" pitting. Knots and pith are rare.

5.1. *Agathoxylon* sp. 1

Specimens: BA1, C1, P1760, P1786, P1793, P1831, P2697, S4, SH1, VS10, VS11, VS12, VS13, VS14, VS21, VS22, VS28, VS29, VS34, VS35, FP00066, FP00068, FP00069, FP00083, FP00098, FP00107, FP00112, FP00125, FP00126, FP00129, RAK004/1, RAK004/2, RAK004/3, RAK005/1, RAK005/2, RAK006/1, RAK008/1, RAK008/2, VS100, VS101, ZAJ002/1.

Microscopic description:
Transverse section: Growth rings not observed. Tracheids, radial diameter 20 – 162 μm (mean 60 μm), tangential diameter 23 – 149 μm (mean 65 μm) (Table 1), are mostly round to oval, organized in radial lines (Plate I/2). Axial parenchyma is not present.
Tangential longitudinal section: Tracheid pits not detected. Rays range from 2 to 45 cells in hight (Table 1), mostly uniseriate, partly biseriate, rarely triseriate. Rays cells are mostly round (Plate I/5).

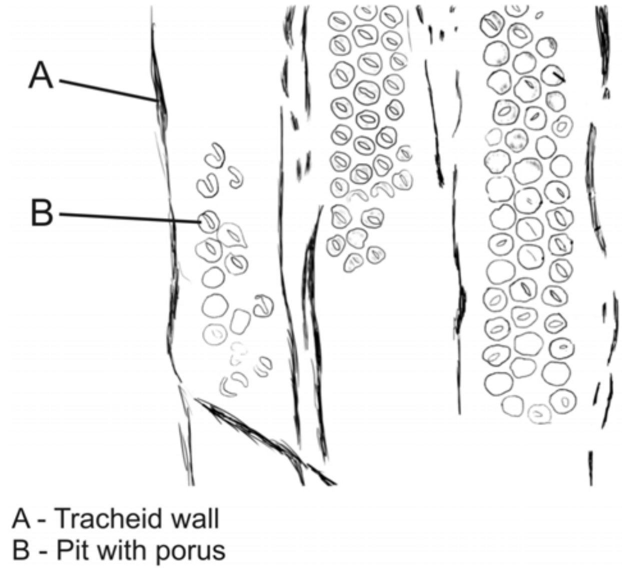


Figure 3. *Sketch of the radial longitudinal section of the specimen RAK004/1 – Agathoxylon sp. 1 (after Holeček, 2011).*

Radial longitudinal section: Tracheid pitting 1 – 4 columns usually covering the entire width of the tracheid wall and arranged in an alternating („araucarioid") pattern for maximum number of pits/cell (Plate I/6). Pits are bordered, mostly hexagonal, polygonal or oval; pores are oval or round (Figure 3). Pit diameter varies from 6 to 37 μm (Table 1). Cross-field pitting is araucarioid sensu IAWA Committee (2004) and only rarely observed. Cross-field pits are bordered, hexagonal to oval, with round to oval pores, and usually three or four in each field (Plate I/4).

Macroscopic description:
Several specimens show macroscopic features: irregular branching (solitary branches without other branches in close proximity), and an *Artisia*-type of pith (Plate I/7). These features allow them to be identified as *Agathoxylon* sp. 1. Thin sectioning of these specimens was not allowed by the keepers of the Nová Paka and Krkonoše Museums, and the private collectors.

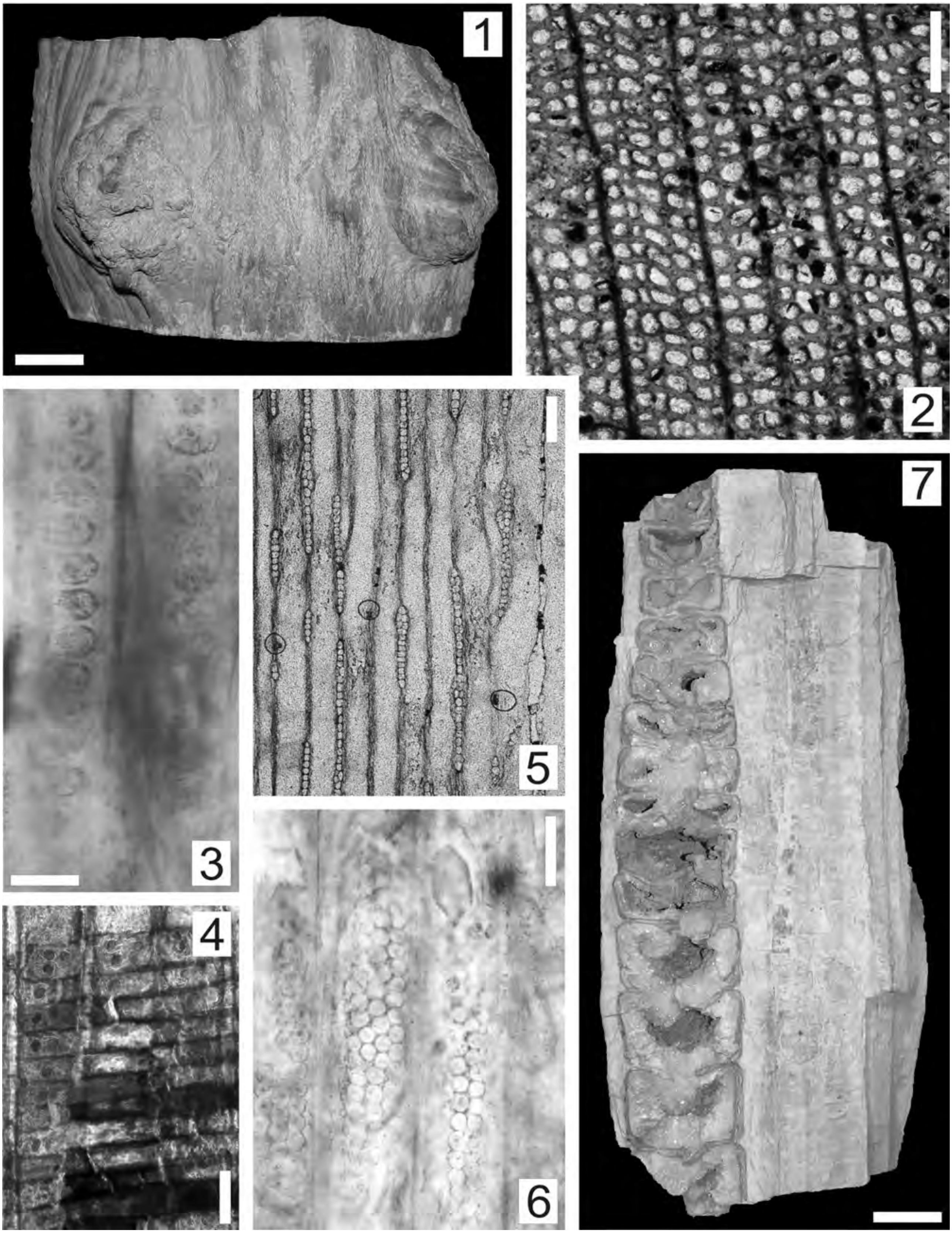
5.2. *Agathoxylon* sp. 2

Specimens: HB1, J8766, J8767, JA1, P302, P1478, P1798, P2960, P5113, PE1, S1, S3, S5, S6, S7, FP00067, FP00071, FP00073, FP00077, FP00093, FP00095, FP00100, FP00101, FP00103, FP00106, FP00115, FP00116, FP00118, FP00127, RAK003/2, ZAJ003/1, ZAS001/2, ZAS002/1, ZAS003/1.

Table 1. Attributes of anatomical features of studied specimens with their stratigraphical positions, and their assumed systematical affiliation. Stratigraphy: I = upper Moscovian, II = Kasimovian, III = lower Gzhelian, IV = upper Gzhelian, V = Sakmarian; 1 = Kladno-Rakovník and Pilsen basins, 2 = Krkonoše Piedmont Basin, 3 = Intra Sudetic Basin. x = attributes not detectable.

SECTION	TRANSVERSAL						LONGITUDINAL RADIAL						LONGITU. TANGENTIAL				STRATIGRAPHIC POSITION	*Agathoxylon* sp.
FEATURE	TRACHEID DIAMETER						PITTING						RAYS					
	radial direction			tangential direction			series			pit diameter			height			series		
SPECIMEN	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	max		
BA1	49	142	80,5	44	129	87	3	5	4	11	25	17,9	x	x	x	x	IV/2	1
HB1	72	121	92,3	54	148	84,3	1	1	1	9	31	16	x	x	x	x	V/1	2
JA1	36	60	45	34	55	43	x	x	x	x	x	x	4	26	14	2	II/2	2
P1760	34	84	57,4	47	90	62,1	2	3	2	8	16	11,5	x	x	x	x	II/2	1
P2697	45	162	97,4	34	149	98,2	2	4	4	6	12	8	10	23	19	2	IV/2	1
P2960	x	x	x	x	x	x	1	1	1	10	14	11,6	x	x	x	x	V/1	2
PE1	x	x	x	x	x	x	1	1	1	8	14	10	x	x	x	x	II/2	2
S1	x	x	x	x	x	x	1	1	1	11	25	16,7	5	22	8	2	V/1	2
S3	18	41	26,8	21	40	29,9	1	1	1	8	12	10	4	14	9	2	V/1	2
S4	x	x	x	x	x	x	1	2	1,2	9	15	12,8	x	x	x	x	V/1	1
S5	x	x	x	x	x	x	1	1	1	6	12	8,3	5	20	11	2	V/1	2
S6	x	x	x	x	x	x	1	2	1,1	12	20	16,3	x	x	x	x	V/1	2
S7	33	73	49	38	109	72,7	1	1	1	8	34	23	x	x	x	x	V/1	2
SH1	20	58	38,8	27	52	37,3	2	2	2	16	37	21,8	x	x	x	x	I/2	1
VS10	60	90	70	60	100	72,5	2	3	2	18	25	23	5	21	16	3	II/3	1
VS11	60	100	71	70	110	78,5	x	x	x	x	x	x	2	9	6	2	II/3	1
VS12	x	x	x	x	x	x	3	4	3,8	7	13	9,6	8	23	19	2	II/3	1
VS13	x	x	x	x	x	x	2	3	2,2	10	20	15	7	16	10	2	II/3	1
VS14	50	80	64,5	55	80	66	x	x	x	x	x	x	4	28	10	2	II/3	1
VS21	40	60	54,5	40	75	61,5	x	x	x	x	x	x	x	x	x	x	II/3	1
VS22	40	70	55,5	50	80	65	x	x	x	x	x	x	3	11	7	2	II/3	1
VS28	60	90	71	60	100	78	x	x	x	x	x	x	x	x	x	x	II/3	1
VS29	60	100	78,5	60	100	85	x	x	x	x	x	x	4	16	8	2	II/3	1
VS34	40	70	52	50	90	75	2	3	2,3	12	21	17	6	30	13	2	II/3	1
VS35	40	70	51,5	40	80	58,5	1	3	2,5	11	25	14	3	18	8	1	II/3	1
P5113	13	30	21,2	16	38	27,3	1	2	1,2	11	16	13,3	x	x	x	x	IV/1	2
FP00071	45	50	47,5	x	x	x	1	2	1,1	18	18	18	6	6	6	1	IV/1	2
FP00073	30	35	32,5	x	x	x	1	1	1	12	15	13	x	x	x	x	IV/1	2
FP00077	40	50	44,7	x	x	x	1	1	1	15	20	18	6	14	9	1	IV/1	2
FP00083	70	80	73,3	x	x	x	2	4	3,1	10	12	11	7	7	7	1	IV/1	1
FP00093	45	50	46,7	x	x	x	1	2	1,1	12	15	13	x	x	x	x	IV/1	2
FP00095	40	50	46,7	x	x	x	1	1	1	17	18	17,3	16	16	16	1	IV/1	2
FP00098	55	65	60	x	x	x	1	2	1,7	12	12	12	6	29	18	1	IV/1	1
FP00100	40	40	40	x	x	x	1	2	1,1	15	15	15	x	x	x	x	IV/1	2
FP00101	40	50	46,7	x	x	x	2	4	2,9	15	15	15	4	5	5	1	IV/1	2
FP00103	30	40	33,3	x	x	x	1	2	1,8	10	15	13	x	x	x	x	IV/1	2
FP00106	40	50	45	x	x	x	1	2	1	15	15	15	x	x	x	x	IV/1	2
FP00107	50	50	50	x	x	x	1	1	1	18	18	18	7	10	9	1	IV/1	1
FP00112	40	50	45	x	x	x	1	2	1,7	12	12	12	x	x	x	x	IV/1	1
FP00115	50	60	55	x	x	x	1	3	1,8	15	15	15	7	9	8	1	IV/1	2
FP00116	50	50	50	x	x	x	1	3	2	15	15	15	15	25	20	1	IV/1	2
FP00118	40	40	40	x	x	x	1	1	1	15	18	17	7	7	7	1	IV/1	2
FP00125	50	50	50	x	x	x	2	3	2,4	10	10	10	x	x	x	x	IV/1	1
FP00126	45	50	48,3	x	x	x	2	4	2,4	10	10	10	7	12	9	1	IV/1	1
FP00127	40	50	43,3	x	x	x	1	1	1	12	12	12	x	x	x	x	IV/1	2
FP00129	50	50	50	x	x	x	1	3	2	12	12	12	9	12	10	1	IV/1	1
RAK003/2	42	65	51,3	34	69	50,8	2	2	2	14	16	15,6	x	x	x	x	III/1	2
RAK004/1	36	85	59,7	40	75	56,5	1	4	3	10	12	10,9	2	23	9	2	II/1	1
RAK004/2	32	61	48,7	30	59	44,4	1	3	2	10	13	11,4	2	30	9	3	II/1	1
RAK004/3	28	61	42,9	23	52	39	1	3	2	10	13	12	3	22	7	2	II/1	1
RAK005/1	41	79	63,6	39	71	54,1	1	3	3	15	16	15,7	2	35	11	2	II/1	1
RAK005/2	56	79	65,6	52	87	72,2	2	4	3	13	16	14	3	45	13	2	II/1	1
RAK006/1	40	72	53,8	38	80	59,1	1	2	2	12	17	14	3	22	11	2	II/1	1
RAK008/1	51	90	66,2	40	67	55,4	2	3	2	10	15	13,4	3	27	14	3	II/1	1
RAK008/2	30	61	47,1	32	71	49,3	1	2	1	13	14	13,7	2	30	14	1	II/1	1
ZAJ002/1	x	x	x	x	x	x	x	x	x	x	x	x	4	26	12	2	IV/1	1
ZAJ003/1	x	x	x	x	x	x	1	2	1	15	23	19	2	26	9	2	IV/1	2
ZAS001/2	x	x	x	x	x	x	1	2	1	12	20	15,7	x	x	x	x	IV/1	2
ZAS002/1	x	x	x	x	x	x	1	2	1	11	14	13,4	x	x	x	1	IV/1	2
ZAS003/1	x	x	x	x	x	x	1	2	1	9	14	11,1	x	x	x	x	IV/1	2

Plate I.



Microscopic description:
Transverse section: Growth rings were not observed. Tracheids are round or oval, rarely irregular, arranged in radial lines, radial diameter 13 – 121 μm (mean 44 μm), tangential diameter 16 – 148 μm (mean 51 μm) (Table 1). Axial parenchyma was not observed.
Tangential longitudinal section: Tracheid pits were not detected. Rays are uni- to biseriate, 2 – 26 cells in height (Table 1). Ray cells are round to slightly oval.
Radial longitudinal section: Tracheid pitting is mostly uniseriate, locally biseriate. Pits are bordered, round, diameters 6 – 37 μm (Table 1), and do not cover the total width of a tracheid wall (Table 1). Pores are round or slightly oval. Cross-field pitting not observed.

Macroscopic description:
Some of specimens of group *Agathoxylon* sp. 2 have preserved knots with the bases of branches. Branching pseudo-verticillate; with the branches arranged round the stem in the same orthogonal plane (Plate I/1).

6. DISCUSSION

6.1. Taxonomy

Only the characters of the secondary xylem are known for all specimens studied, the primary xylem and other tissues are lacking. Wood is homoxylous pycnoxylic without resin canals and axial parenchyma. Regular growth rings were not observed. Based on the known general characters (alternate pitting, lack of axial parenchyma) is possible to classify all the wood from the four basins as *Agathoxylon* sp. (Rößler et al., in press). However, due to strong recrystallisation of the quartz and the effect that has on the details visible in the wood it is not possible to make a more precise determination. Two groups (*Agathoxylon* sp. 1 and *Agathoxylon* sp. 2) are recognized based on the nature of the pitting in radial walls of the tracheids. All other features of the secondary xylem were either not discernable due to recrystallisation of the quartz or only hardly visible because of the poor preservation.

There is however a few well-preserved macroscopic features that permit the assignment, with reservations, of the two groups of *Agathoxylon* to higher levels of classification. *Agathoxylon* sp. 1 is probably assignable to the cordaitaleans, and *Agathoxylon* sp. 2 can possibly be assigned to the conifers (sensu Doubinger and Marguerier, 1975 and Noll et al., 2005).

6.2. Summary of stratigraphic and geographic occurrence

Using available palaeobotanical data and the occurrence of silicified stems we are able to partially reconstruct floral assemblages at various stratigraphic levels in the four studied basins.

6.2.1. Upper Moscovian (Asturian)

The Nýřany Member of the Kladno Formation (Kladno-Rakovník and Pilsen Basins) and the Brusnice Member of the Kumburk Formation (Krkonoše Piedmont Basin) were deposited during this time interval. Silicified stems of this age are not known from the Intra Sudetic Basin. Specimens from the Kladno-Rakovník and Pilsen Basins were collected in the Lišany and Lužná as loose pieces in fields (Holeček, 2011). Unfortunately, their preservation is very poor and any further classification of them is not possible. Two specimens are known from the Krkonoše Piedmont Basin near Šárovcova Lhota. Both of them were collected from outcrops and have been classified as cordaitalean wood (see Table 1).

Plate I.
1. Part of a stem with pseudo-verticillate branching (specimen J8766, Krkonoše Piedmont Basin). Scale bar = 30 mm; 2. General view of tracheids of secondary xylem, transversal section (specimen P2697, Krkonoše Piedmont Basin). Scale bar = 1 mm; 3. Detail of tracheid pitting of *Agathoxylon* sp. 2, radial longitudinal section (specimen S1, Krkonoše Piedmont Basin). Scale bar = 30 μm; 4. Detail of cross-field pitting of *Agathoxylon* sp. 1, radial longitudinal section (specimen RAK006/1, Kladno-Rakovník Basin). Scale bar = 50 μm; 5. Detail of tangential longitudinal section showing mostly uniseriate but locally biseriate rays (specimen RAK005/2, Kladno-Rakovník Basin). Scale bar = 0.1 mm; 6. Detail of tracheid pitting of *Agathoxylon* sp. 1, radial longitudinal section; note crowded hexagonal pits (specimen FP00098, Pilsen Basin). Scale bar = 50 μm; 7. General view of the unique specimen with preserved pith of *Artisia*-type (specimen C1, Kladno-Rakovník Basin). Scale bar = 20 mm.

6.2.2. Kasimovian (Stephanian A)

Silicified stems of this age are very common and are known from all four studied basins. Most of the specimens from the Kladno-Rakovník and Pilsen Basins (Týnec Formation) are cordaitaleans (Holeček, 2011). Specimens from the Krkonoše Piedmont Basin (Štikov Arkoses, Kumburk Formation) are mostly conifers. From the Intra Sudetic Basin (Žaltman Arkoses, Odolov Formation) seven, well preserved specimen can be assigned to the cordaitaleans (Mencl, 2007, Mencl et al., 2009).

6.2.3. Upper Kasimovian (Stephanian B)

Specimens of this age are known only from the Kladno-Rakovník Basin. The only identifiable specimen is possibly cordaitalean (Holeček, 2011).

6.2.4. Lower Gzhelian (Stephanian C)

The Kladno-Rakovník, Pilsen and Krkonoše Piedmont Basins have a rich stem flora of this age, while lacking in the Intra Sudetic Basin. The Líně Formation, localities of Zbůch, Tlučná and Chotíkov, stems are 2/3 conifers and 1/3 cordaitaleans (Bureš, 2011). In the Krkonoše Piedmont Basin, the Ploužnice Horizon (Semily Formation) is well known for occurrence of several types of silicified stems, e.g., calamitaleans, ferns, pteridosperms and gymnosperms (Matysová, 2006; Matysová et al., 2008; Matysová et al., 2010; Mencl et al., 2013). All studied specimens from the Balka and Lísek localities are cordaitaleans.

6.2.5. Asselian - Sakmarian (Autunian)

Specimens from the Krkonoše Piedmont Basin are the only ones know from this age, with most probably assignable to the conifers.

CONCLUSIONS

During our research we studied several dozen of silicified *Agathoxylon*-type of stems from the Kladno-Rakovník, Pilsen, Krkonoše Piedmont and Intra Sudetic late Paleozoic basins. Based on previous studies and new field research, silicified stems are now known to be present at five stratigraphic levels. All of them are always decorticated with secondary xylem only. They are rarely preserved in outcrops, but never in upright position. More often are found in alluvial deposits or as loose pieces in fields. Because of lack of outcrops, the assigning of these specimens to their stratigraphic positions can be done according to a detailed field-work in combination with the previous geological mapping data. The preservation of anatomical features is generally poor due to high recrystallisation of the quartz and destruction of the organic matter. The best preserved specimens are from the Kladno-Rakovník and Pilsen Basins, and the most poorly preserved from the Intra Sudetic Basin. Our studies of the secondary xylem resulted in the assignment of the specimens into two groups, *Agathoxylon* sp. 1 and *Agathoxylon* sp. 2. *Agathoxylon* sp. 1 exhibits features indicative of the cordaitaleans, while the homologous features in *Agathoxylon* sp. 2 are indicative of the conifers. The most significant contribution to the understanding of the floras of this time is that the cordaitaleans – conifer ratio in Western Bohemia basins is obviously different that in the Krkonoše Piedmont Basin. This fact is probably a reflection of differing palaeoenvironments.

ACKNOWLEDGEMENTS

We would like to thank J. Luštinec and other employees of the Krkonoše Museum in Jilemnice, J. Šimurda (Krkonoše Museum in Vrchlabí) and T. Řídkošil (Czech Paradise Museum Turnov) as well as private collectors J. Červenka, J. Svejkovský, J. Zajíček and B. Zasadil for kind provide samples of their collections. Many thanks to V. Prouza (Czech Geological Survey) and J. Holeček (Radioactive Waste Repository) for their help with field works and fruitful discussion, and F. Tichávek for thin-sectioning. The manuscript was improved by the thorough reviews of S. Opluštil and Z. Kvaček, and detailed linguistic and scientific correction by D. Chaney. The research was supported by the project MSM0021620855, PRVOUK P44, SVV261203, UU09/2011 and FRL 2013.

REFERENCES

Březinová, D. 1970. Přehled dosavadních nálezů fosilních dřev na území Československa zpracovaných na základě literárních pramenů. Manuscript, National Museum, Prague.

Bureš, J. 2011. Silicified cordaite and conifers wood in the sediments of the Líně Formation of the Pilsen Carboniferous Basin. *Erica 18*, 179 - 198. Plzeň (in Czech).

Bureš, J. 2013. Morphological-anatomical research of two large trunks of pycnoxylic woods (cordaitalean plants) from the Stephanian of Pilsen basin. *Erica 20*, 179 - 190. Plzeň (in Czech).

Daněk, J. J. 1902. Studie o permském útvaru v Čechách. *Archiv pro přír. prozk. Čech XI (6).*

Dernbach, U. 1996. The Petrified Forest of Nová Paka. In Dernbach, U. (ed.) *Petrified Forests,* 116 - 117. D'ORO Publishers, Heppenheim.

Dernbach, U., Tidwell, D. W., Barthel, M., Galtier, J., Jung, W., Kerp, H., Noll, R., Rößler, R., Rothwell, W. G., Selmeier, A., Stockey, A. R., Wilde, V., Wright, W. W. 2002. *Secrets of Petrified Plants, Fascination from Millions of Years*. 232 pp. D'ORO Publishers, Heppenheim.

Doubinger, J., Marguerier, J. (1975). Paléoxylologie: Étude anatomique comparée de Scleromedulloxylon aveyronense nov. gen. nov. sp. du Permien de St-Affrique (Aveyron, France); considérations taxinomiques et stratigraphiques. *Géobios 8*, 25 - 59.

Dvořák, Z., Švancara, M., 2003. Naleziště zkamenělých stromů u Slaného. *Minerál 11*, 403 - 406.

Feistmantel, K. 1883. Über Araucarioxylon in der Steinkohlenablagerung von Mittel-Böhmen. *Abh. d. k. b. Ges. d. Wiss. 6 (12)*, 1 - 24.

Feistmantel, O. 1873a. O zkřemenělých kmenech v permském útvaru českém. *Vesmír 2*, 176 - 178, 190 - 192, 208. Praha.

Feistmantel, O. 1873b. Über die Verbreitung und geologische Stellung der verkieselten Araucariten - Stämme in Böhmen. *Sitzungsberichte d. k. b. Ges. d. Wiss. 5,* 204 - 220.

Feistmantel, O. 1873c. Geologische Stellung und Verbreitung der Verkieselten Hölzer in Böhmen. *Verhandlung der k.k. geologische Reichsanstalt. 168 (6),* 108 - 112.

Frič, A. 1912. Studie v oboru českého útvaru permského. *Arch. přírodov. prozk. země čes. 15*. Praha.

Goeppert, H. R. 1857. Über den versteinerten Wald von Radowenz bei Adersbach in Böhmen und über den Versteinungsprocess überhaupt. *Jahrbuch k. k. geologische Reichanstalt 8,* 725 - 738.

Goeppert, H. R. 1858. Ueber die versteinerten Wälder im nördlichen Böhmen und in Schlesien. *Jahresber. d. Schles. Ges. für vaterländ. Cultur 36,* 41 - 49.

Gradstein, F. M., Ogg, J. G., Schmitz, M. D., Ogg, G. M. 2012. *The Geologic Time Scale*, 603 - 679. Elsevier, Amsterdam.

Havlena, V. 1955. Vývoj stratigrafie permokarbonských uhelných oblastí Čech a Moravy. *Knihovna ÚÚG 28.* Praha.

Havlena, V. 1958. Studie o geologii a stratigrafii permokarbonského synklinoria v Podkrkonoší. *Rozpravy Čsl. akademie věd, řada MPV 68 (7).* Praha.

Havlena, V. 1964. *Geologie uhelných ložisek 2*. ČSAV Praha. 440 pp.

Heber, F. A. 1844. *Böhmens Burgen, Vesten und Bergschlösser 2*. C. M. Medau Praha.

Holeček, J. 2011. Late Carboniferous silicified wood from the western part of the Kladno-Rakovník Basin. 135 pp. Master thesis, Charles University, Prague (in Czech).

Hynie, O. 1927. Dosavadní výsledky mého mapování v permu podkrkonošském. *Věstník Stát. geol. ústavu Čsl. republiky III (6).* Praha.

IAWA Committee 2004. IAWA list of microscopic features for softwood identification. *IAWA J, 25*, 1 - 70.

Jokély, J. 1861. Bemerkungen über die Verbreiterung der Araucaritenstämme. *Jahrbuch d. geol. Reichsanstalt 2,* 392 - 395.

Katzer, F. 1892. *Geologie von Böhmen.* 1606 pp. Praha.

Makowsky, A. (1878): Der „versteinerte Wald" bei Radowenz in Böhmen. *Verhandlungen des naturforschenden Vereines in Brünn, 17*, 57-64.

Matysová, P. 2006. Permocarboniferous silicified woods from the Intra Sudetic and Krkonoše Piedmont Basins: taxonomy and instrumental analysis. 195 pp. Master thesis, Charles University, Prague (in Czech).

Matysová, P., Leichmann, J., Grygar, T., Rössler, R., 2008. Cathodoluminescence of silicified trunks from the Permo-Carboniferous basins in eastern Bohemia, Czech Republic. *European Journal of Mineralogy 20*, 217 - 231.

Matysová, P., Rössler, R., Götze, J., Leichmann, J., Forbes, G., Taylor, E. L., Sakala, J., Grygar, T. 2010. Alluvial and volcanic pathways to silicified plant stems (Upper Carboniferous–Triassic) and their taphonomic and palaeoenvironmental meaning. *Palaeogeogr. Palaeoecl. 292*, 127 - 143.

Mencl, V. 2007. Upper Carboniferous silicified wood of the Intra Sudetic Basin: systematics and palaeoenvironment. 105 pp. Master thesis, Charles University, Prague (in Czech).

Mencl, V., Matysová, P., Sakala, J. 2009. Silicified wood from the Czech part of the Intra Sudetic Basin (Late Pennsylvanian, Bohemian Massif, Czech Republic): systematics, silicification and palaeoenvironment. *N. Jb. Geol. Paläont. Abh. 252*, 269 - 288.

Mencl, V., Holeček, J., Roessler, R., Sakala, J. 2013. First anatomical description of silicified calamitalean stems from the upper Carboniferous of the Bohemian Massif (Nová Paka and Rakovník areas, Czech Republic). *Rev. Palaeobot. Palynol. 197*, 70 - 77.

Miksch, J. 1853: Vorkommen fossile Hölzer bei Pilsen. *Korrespondenzblatt des zool.-miner. Vereins in Regensburg,* 7 - 14.

Mikuláš, R., Zasadil, B. 2008. Paleontologický význam dutin ve fosilních dřevech permokarbonského stáří středočeských a západočeských kamenouhelných pánví. *Zprávy o geologických výzkumech v roce 2007*, 124 - 127.

Němejc, F. 1953. *Úvod do floristické stratigrafie kamenouhelných oblastí v ČSR*. 173 pp. ČSAV, Praha.

Noll, R., Rössler, R., Wilde, V. 2005. 150 Jahre *Dadoxylon* – Zur Anatomie fossiler Koniferen- und Cordaitenhölzer aus dem Rotliegend des euramerischen Florengebietes. *Veröffentlichungen des Museums für Naturkunde Chemnitz 28,* 29 – 48. Chemnitz.

Obrhel, J. 1977. Několik paleontologických nálezů ve svrchním karbonu kladensko-rakovnické pánve. *Časopis Národního muzea 146*, 41 - 42.

Opluštil, S., Cleal, C. J. 2007. A comparative analysis of some Late Carboniferous basins of Variscan Europe. *Geological Magazine 144 (3)*, 417 - 448.

Opluštil, S., Šimůnek, Z., Zajíc, J., Mencl, V. 2013. Climatic and biotic changes around the Carboniferous/Permian boundary recorded in the continental basins of the Czech Republic. *International Journal of Coal Geology 119*, 114 - 151.

Pešek, J. 1968. K významu araukaritů pro stratigrafii sedimentů plzeňské pánve. *Časopis pro mineralogii a geologii 13*, 213.

Pešek, J., Holub, V., Jaroš, J., Malý, L., Martínek, K., Prouza, V., Spudil, J., Tásler, R. 2001. Geologie a ložiska svrchnopaleozoických limnických pánví České republiky. 244 pp. Český geologický ústav Praha.

Petrascheck, W. 1924. *Kohlengeologie der österreichischen Teilstaaten, Teil I*. Wien.

Pouba Z., Špinar Z. 1954: Stratigrafické poměry okolí kaolínového ložiska u Chlumčan (jižní část plzeňské pánve). *Věstník ÚÚG 29*, 145 - 158. Praha.

Purkyně, C. 1927. O nalezištích zkřemenělých kmenů araukaritových v Čechách, zvláště v Podkrkonoší. *Časopis Národ. muzea 51*, 113 - 131.

Řehoř, M., Řehoř, V. 2005. Pozoruhodný nález zkamenělého dřeva na lokalitě Očihov. *Minerál 3/ 2005*, 178 - 180.

Renger, K. 1858. Skamenělé kmeny v Čechách. *Živa VI,* 254.

Renger, K. 1863. O skamenělém lese radvanickém blíže Abrspachu a o způsobech skamenění vůbec. *Živa 4*, 362 - 375.

Rößler, R., Philippe, M., van Konijnenburg-van Cittert, J. H. A., McLoughlin, S., Sakala, J., Zijlstra, G. & al. in press. Which name(s) should be used for Araucaria-like fossil wood? Results of a poll. *Taxon,* doi: http://dx.doi.org/10.12705/631.7.

Sakala, J., Mencl, V., Matysová, P. 2009. New data on Upper Carboniferous silicified stems of calamites from the Nová Paka region. *Geoscience Research Reports for 2008*, 111 - 113 (in Czech).

Skoček, V. 1970. Silicifikovaná dřeva ve středočeském permokarbonu. *Věst. Ústř. ústavu geol. 45*, 87 - 92.

Soukup, J. 1997. Silicifikovaná dřeva v západním Podkrkonoší. *Minerál 5 (3)*, 180 - 182.

Stárková, M., Šimůnek, Z., Martínek, K. 2009. Prepared research of Ploužnice Horizon – Semily Formation; genesis and palaeoecology of lacustrine facies. *Acta Musei Turnoviensis 4*, 120 - 124.

Stur, D. 1877: Zwei Notizen über die Araucariten in nordöstlichen Bohmen. *Verhandlung der k. k. geologische Reichsanstalt,* 237 - 240.

Svejkovský, J. 2009. *Geologie Podbořanska*. 78 pp. Sdružení MAC spol. s.r.o. Praha.

Tásler, R., Čadková, Z., Dvořák, J., Fediuk, F., Chaloupský, J., Jetel, J., Kaiserová-Kalibová, M., Prouza, V., Schovánková-Hrdličková, D., Středa, J., Střída, M., Šetlík, J. 1979. *Geologie české části vnitrosudetské pánve.* 296 pp. ÚÚG Praha.

Valín, F. 1956. Hydrodynamické podmínky během sedimentace žaltmanských arkóz. *Zprávy o geologických výzkumech v r. 1956*, 182 - 183. Praha.

Valín, F. 1960. Litologie souvrství žaltmanských arkóz. *Sborník ÚÚG 26*, 409 - 437. Praha.

Vítek, J. 1986. Araukarity v Nové Pace. *Přír. vědy šk. 37 (5)*, 175.

Vysocký, P. 1859. Některé poměry permského útvaru v severozápadních Čechách. *Živa VII,* 211 - 218.