MASARYKOVA UNIVERZITA

PŘÍRODOVĚDECKÁ FAKULTA

Ústav geologických věd

Palynologie a její využití pro interpretace přírodního prostředí a jeho změn

Habilitační práce

Nela Doláková

Brno 2018

Bibliografický záznam

Habilitační práce

Autor:	RNDr. Doláková Nela, CSc. Přírodovědecká fakulta, Masarykova univerzita Ústav geologických věd
Název:	Palynologie a její využití pro interpretace přírodního prostředí a jeho . změn.
Počet stran:	296

Klíčová slova: Palynologie, metodika, paleoekologie, neogén, pleistocén, holocén, marinní sedimenty, jeskynní sedimenty, archeologické lokality

Nela Doláková, Masarykova univerzita, 2018

Bibliographic Entry

Author: RNDr. Doláková Nela, CSc.
Faculty of Science, Masaryk University
Institute of Geological Sciences geologických věd
Title: Palynology and its application for the interpretations of natural environments and their changes
Number of pages: 296
Keywords: palynology, methodology, palaeoecology, Neogene, Pleistocene, Holocene, marine sediments, cave sediments, archaeological localities

Poděkování:

Chtěla bych poděkovat všem kolegům i své rodině za trpělivost, pomoc a morální podporu

Abstrakt

Předkládaná práce je zaměřena na problematiku (paleo)palynologie a jejího využití pro interpretace přírodního prostředí a jeho změn.

Informace získané ze studia palynomorf v horninách můžeme využít zejména pro rekonstrukce vegetačního pokryvu v minulosti a jeho změn, interpretace klimatu, paleogeografie nebo stratigrafie. Publikované práce jsou zaměřeny nejen na studium vegetace v terestrických sedimentech, ale i interpretace zachovaných pylových spekter ze sedimentů mořských. V práci je využito 17 autorských publikací.

Práce je rozdělena do několika tematických okruhů. První okruh zahrnuje metodické přístupy a obecnou problematiku palynologie. Náplní této kapitoly jsou principy zachování a degradace palynomorf v horninovém prostředí a s těmito procesy spojená problematika redepozic. V kapitole je rovněž přiblížena tématika přípravy vzorků, principů mikroskopického pozorování, základních příkladů popisu zrn a kvantitativního vyhodnocování pylových spekter. V kapitole jsou využity nejen teoretické principy zobecněné v literatuře, ale i vlastní zkušenosti autorky. Druhý okruh komentovaných palynologických studií se týká interpretace vegetace v sedimentech neogenního stáří. Kapitola je rozdělena do dvou částí. První část je zaměřena na interpretace vegetace a jejích změn v čase, které se odrážejí zejména ve vývoji klimatu. Ve druhé části jsou výsledky palynologie v koordinaci s dalšími paleontologickými, sedimentologickými a geochemickými metodami využity k řešení širší geologické problematiky, zejména charakteru mořských pánví, jejich okrajů a vzájemného ovlivňování s prostředím kontinentu. Kapitola - Palynologie vybraných lokalit kvartéru je věnována problematice interpretace vegetačních poměrů ze studia jeskynních sedimentů a archeologických lokalit. Největším problémem interpretace pylových spekter z jeskynních sedimetů je jejich transport do míst ukládání spojený s možností sekundární selekce zrn. Problematika studia palynologie z archeologických lokalit spojuje nejen změny klimatických charakteristik, ale rovněž změny vegetace v důsledku lidských aktivit.

Abstract

The proposed paper is focused on the (paleo) palynology and its use for the interpretation of natural environment and its changes.

The information obtained from the palynomorph study in the rocks can be used especially for the reconstruction of the vegetation cover in the past and its changes, the interpretation of climate and paleogeography or the stratigraphical determination. The published works are focused not only on the study of vegetation in terrestrial sediments, but also on the interpretations of preserved pollen specter from marine sediments. The work uses 18 author's publications.

The thesis is divided into several thematic scopes. The first round includes methodological approaches and the general problems of palynology. The contents of this chapter are the principles of conservation and degradation of palynomorph in the rock environment and these processes are connected with problems of redepositions. The chapter also deals with the topic of sample preparations, principles of microscopic observations, basic examples of grain descriptions and quantitative evaluation of pollen spectra. The chapter uses not only the theoretical principles generalized in the literature, but also the author's own experience.

The second round of commented palynological studies refers to the interpretation of vegetation in sediments of the Neogene ages. The chapter is divided into two parts. The first part is focused on the interpretation of vegetation and its changes in time, which are reflected mainly in the climate. In the second part, the results of palynology, in coordination with other palaeontological, sedimentological and geochemical methods, are used to resolve broader geological problems, especially the character of the sea basins, their margins and mutual interactions with terrestrial environment.

The chapter on palynology of selected Quaternary localities is devoted to the problem of interpretation of vegetation conditions from the study of cave sediments and archaeological sites. The main problem of interpretation of pollen spectra from cave sediments is their transport to sedimentation places associated with the possibility of secondary grain selection. The scope of palynological study from archaeological sites combines not only changes in climatic characteristics but also changes in vegetation due to human activities.

Obsah:

1. Úvod

Předkládaná práce je zaměřena na problematiku paleopalynologie a jejího využití pro interpretace přírodních procesů a jejich změn.

Palynologie je disciplína, která zkoumá zejména pylová zrna a spory rostlin. Patří sem ovšem i studium dalších mikroobjektů s tzv. acidorezistentními obaly, které se většinou shrnují do skupiny tzv. nepylových objektů. Jedná se např. o mořský i sladkovodní fytoplankton, mikroskopické zbytky hub, živočišné parazity, zbytky srsti nebo těl hmyzu apod. Obecně se pro všechny tyto objekty používá název palynomorfy.

V rámci geologie se často hovoří o paleopalynologii, kdy se studují palynomorfy, které prošly procesem fosilizace.

Rozvoj oboru je umožněn díky velké schopnosti zachování palynomorf, jejich morfologické rozmanitosti a snadnému transportu (větrem, vodou a živočichy). Můžeme je nalézt téměř ve všech typech sedimentárních hornin, a dokonce i v horninách slabě metamorfovaných. Palynomorfy můžeme studovat jak v sedimentech terestrických, tak i marinních, což představuje jednu z mála možností pro korelace těchto vývojů.

Informace získané ze studia palynomorf v horninách můžeme využít zejména pro rekonstrukce vegetačního pokryvu v minulosti a jeho změn, interpretace klimatu i paleogeografie nebo stanovení stratigrafie. Interpretovat můžeme nejen charakter suchozemského prostředí, ale i některé faktory prostředí mořského (např. hloubky, vzdálenost od pobřeží, oxidačně-redukční procesy) a jejich vzájemné ovlivňování – morfologie pobřeží, změny salinity, rozšiřování a ústup mořských pánví.

Jako u každé metody existuje celá řada omezení vypovídací hodnoty studovaných palynospekter. Je proto velmi vhodné kombinovat znalosti z palynologie a dalších metod (např. paleontologie, sedimentologie, geochemie atd.), které při vzájemném doplnění poznatků umožní co nejpřesnější přiblížení se k poznání obrazu minulosti a jeho vývoje.

Předkládaná práce shrnuje výsledky studia palynologie v sedimentech poměrně velkého časového rozsahu. Zahrnuje období v průběhu posledních 22 milionů let (neogén, pleistocén a holocén – více než 80 lokalit). Každý z těchto časových úseků se vyznačuje specifickým vývojem sedimentace a rozličnými ekologickými a tafonomickými podmínkami. Proto byla následující práce rozdělena do několika oddílů, které se po úvodním shrnutí obecné problematiky soustřeďují na dosažené výsledky studia v jednotlivých obdobích. V práci je využito a komentováno celkem 17 autorských publikací. Z důvodů kompaktnosti zvolených tématických celků bylo použito nejen publikací citovaných v databázích WOS a Scopus, (15), ale rovněž 2 prací v recenzovaných časopisech a 1 kapitoly v monografii. Práce, jejichž výsledky se týkají nejen konkrétních palynologických interpretací, ale i zobecňující metodické problematiky, jsou v textu využity v různých kapitolách. Výsledky některých dalších prací jsou pouze citovvány a v krátkosti zmíněny, nejsou však zahrnuty do výčtu komentovaných prací.

Nejzajímavější výsledky týkající se zejména klimatických a paleogeografických změn nebo dopadů lidské činnosti na vegetaci jsou využívány i ve výuce pro studenty geologických a archeologických oborů MU.

2. Metodické přístupy a obecná problematika palynologie

2a) Tafonomické procesy - zachování x degradace palynomorf

Vysoká fosilizační schopnost palynomorf je umožněna díky složení jejich stěn, tvořených tzv. sporopolleninem. Je to organická polymerní látka příbuzná chitinu, která je odolná vůči působení kyselin – proto je označována jako acidorezistentní. Do jisté míry odolává i zvýšené teplotě a tlaku až do účinků slabší metamorfózy (Brooks1971). Pylová zrna a spory se proto vyskytují v sedimentárních, ale i slabě metamorfovaných horninách.

Nejlépe se palynomorfy zachovávají ve vlhkém kyselém prostředí (např. rašeliny), méně v jemně klastických uloženinách mořského, říčního, deltového, jezerního nebo jeskynního prostředí (Moore, Webb, Collinson 1991) a rovněž v některých typech archeologických objektů.

Studium palynomorf v sedimentárních profilech má výhodu zejména v dlouhém časovém záznamu, kdy můžeme sledovat změny jednotlivých faktorů prostředí (např. teplota, vlhkost, povaha substrátu), ale i vymírání, migrace, nebo objevování se nových taxonů. Nevýhodou je (obdobně jako u každého fosilního záznamu) převážně selektivní zachování – výsledným obrazem je tzv. oryktocenóza.

Oproti makrofloristickým nálezům má palynologie několik výhod a naopak nevýhod. Zatímco rostlinné makrozbytky lze většinou determinovat do úrovně rodu i druhu, palynomorfy jsou v mnohých případech určitelné maximálně do úrovně rodu nebo jen čeledi, ve starších obdobích dokonce pouze jako morfotypy. U rostlinných makrozbytků (zejména listů a kutikul) lze i u vymřelých taxonů posuzovat taxonomické zařazení na základě srovnávací anatomie a morfologie. Tato možnost je u palynomorf omezená. Na druhou stranu se makrozbytky uchovávají většinou jen v sedimentech z mokřadních prostředí s nízkou dynamikou vody (kromě archeologických situací), kde jsou zachovány fosílie především z těchto ekologických prostředí a jejich bezprostředního okolí. Taxony a společenstva vyskytující se ve větší vzdálenosti od těchto k fosilizaci vhodných míst mají jen velmi malou možnost uchování (např. taxony suššších nebo horských stanovišť). V oryktocenózach palynomorf se nám díky značné transportní schopnosti dochovávají fosílie rostlin i z prostředí nepříznivých pro zachování fosilních zbytků. Získáváme tedy komplexnější obraz širšího paleoprostředí. Při palynologických interpretacích je ovšem třeba obezřetně řešit i problematiku rozdílné pylové produkce a transportní schopnosti palynomorf jednotlivých rostlin (rostliny hmyzosnubné x větrosnubné), ve fosilních asociacích navíc rozdílnou fosilizační schopnost zrn.

Během transportu a sedimentace palynomorf může vlivem tafonomických procesů docházet k jejich degradaci až zničení, případně ke druhotné akumulaci odolnějších zrn (časté např. u jeskynních a mořských prostředí, viz následující kapitoly). Na degradaci se podílí jak mechanické, tak chemické či biologické, především bakteriální vlivy (např. Havinga, 1964, 1967, 1971). Výsledná oryktocenóza potom může poskytovat značně zkreslený obraz původní vegetace.

Velmi nepříznivě se na zachování palynomorf podílí oxidace. Zvýšená oxidace se projevuje v pórovitých – hrubě klastických horninách (zde navíc silné mechanické poškození vlivem transportu klastik - písky, štěrky). V dobře prokysličeném prostředí vzniká i většina kalcitických sedimentárních hornin (vápence, travertin). Oxidační procesy probíhají i v některých typech sedimentů, jejichž vznik je klimaticky podmíněný (jíly pestrých barev, kaolinit). V těchto typech hornin je možnost zachování palynomorf velmi nepravděpodobná.

V závislosti na chemickém složení a tloušťce sporopylových obalů podléhají palynomorfy různých rostlin rozkladu vlivem oxidace různou rychlostí (např. pylová zrna čeledi Lauraceae se v sedimentech nedochovávají). Experimentálním studiem odolnosti pylových zrn vybraných rostlinných taxonů v závislosti na zvyšující se intenzitě oxidace se zabývali např. Kwiatowski , Lubliner-Mianowska (1957), Havinga (1971), Hopkins, Mc Carthy (2002)

V souvislosti se stupněm zachování palynomorf byly detekovány změny oxidačně-redukčních podmínek i v mořských miocenních sedimentech z karpatské předhlubně na Moravě (**Doláková et al. 2014, Holcová et al. 2015, Nehyba et al. 2016**). Zde bylo v několika vrtech a lokalitách pozorováno periodické střídání palynospekter s pestrými společenstvy a palynospekter, kde převládala pylová zrna jednoho typu. Jednalo se téměř výhradně o pylová zrna konifer (*Pinus*, *Cathaya*, *Picea*, *Cedrus*). Tato zrna se sice díky své schopnosti dalekého doletu mohou akumulovat i v mořských oblastech daleko od břehu, ale podle výsledků studia dalších metod (geochemie, paleontologie, sedimentologie) periodické změny prostoru mořské pánve nebyly předpokládány (viz kap. 3.).

V mořských prostředích s výrazným nedostatkem kyslíku (hypoxické – anoxické) dochází v sedimentu při redukčních procesech k tvorbě mikrokrystalů pyritu. Mohou se tvořit i uvnitř pylových zrn. Po chemické maceraci jsou patrné jako typické drobné krychlovité dutiny, které zůstanou na zrnech viditelné. Mohou být vyvinuty v takovém množství, že způsobí změny morfologie až destrukci zrn (**Doláková, Slamková 2003, Kováčová et al., 2011**).

Z charakteru pylových asociací i morfologických změn na pylových zrnech a sporách lze tedy usuzovat i na změny oxido-redukčního potenciálu sedimentačního prostředí.

Degradace palynomorf mechanickými vlivy je způsobena interakcemi zrn s částicemi sedimentu během intenzivního transportu do místa ukládání. Během těchto procesů se dochovávají jen nejmenší nebo morfologicky nejkompaktnější zrna. Tato jsou potom ve výsledné oryktocenóze druhotně nakumulovaná a pro případné interpretace vegetace nadhodnocená. Proces je typický zejména pro uloženiny v jeskynním prostředí a rovněž pro prostředí chladného klimatu s převažující sedimentací klastik, např. spraší – Asteroideae – hromadění v chladných obdobích (**Doláková 2007, 2014**).

Biologické vlivy se uplatňují především v sedimentačních prostředích vhodných pro činnost mikroorganizmů (např. bakterií). Tento proces je nejintenzivnější při půdotvorných procesech. V půdních horizontech dochází většinou ke kompletní ztrátě palynologických dat.

Při studiu palynologie je vhodné rovněž zaznamenávat a pokud možno determinovat tzv. nepylové objekty. Jejich vypovídací schopnost je zejména v oblasti ekologie a paleoekologie. Jedná se např. o cysty nebo cenobia řas (mořské, sladkovodní, půdní – chladnomilné x teplomilné, oligotrofní x eutrofní), mikroskopické zbytky hub (např. dřevokazné, mykorhizní, koprofilní), organické výstelky foraminifer (tzv. tapeta), obrněnky, vajíčka živočichů (např. cizopasných).

2b) Problematika redepozic

V průběhu opakujícího se procesu sedimentace a zvětrávání nejsou vyloučeny redepozice (přemístění) palynomorf ze sedimentů vzniklých ve starších časových obdobích, do sedimentů mladších, a tím smíšení zrn z různých stratigrafických úrovní. Existence a množství redeponovaných palynomorf závisí na prostředí a typu sedimentace. Nejčastější jsou v sedimentech, které vznikly erozí, transportem a opětovným ukládáním klastik (typicky jeskynní a mělkomořské prostředí). Pokud nelze redeponovaná zrna odlišit od zrn in situ, může docházet k chybným interpretacím stáří i prostředí. Z geologického hlediska mohou být však takovéto redeponované palynomorfy jediným důkazem o původní existenci sedimentů, které byly z daného území kompletně denudovány. Příkladem jsou pylová zrna skupiny Normapolles (skupina vymřelých krytosemenných, rozšířených zejména během křídy), která jsou nalézána v neogenních mořských sedimentech karpatské předhlubně a svědčí o mnohem větším rozšíření křídových sedimentů, než známe z území jižní Moravy dnes (**Doláková, Slamková 2003**).

Jednoznačné odlišení redeponovaných palynomorf je možné pouze v případě determinace typů, které jsou v časovém období reprezentovaném studovaným sedimentem vymřelé nebo pocházejí z prostředí, které neodpovídá procesu sedimentace (např. mořská dinoflagellata v sedimentech spraší). V jiných případech mají redeponovaná zrna odlišný stupeň fosilizace reprezentovaný např. změnou barvy nebo tloušťkou pylových stěn.

Často je však rozlišení redeponovaných zrn velmi obtížné, zejména u smíšení sedimentů z časově blízkých období, která obsahují obdobné typy rostlin - např. u mořských sedimentů jednotlivých miocenních stupňů, odkud jsou běžně známé i další redeponované fosílie (např. foraminifery a vápnitý nanoplankton).

Složitou problematiku představují redepozice v jeskynních sedimentech (**Doláková 2007**). Většina jeskynních sedimentů z moravských krasových oblastí je kvartérního stáří. Mnoho rostlin, jejichž pylová zrna nebo spory v těchto sedimentech můžeme najít, se na našem území vyskytuje od neogénu do současnosti - příkladem jsou stromy jako borovice, jilm, olše, dub, lípa, ale i byliny jako trávy, složnokvěté nebo i některé druhy kapradin a další. Mnohé z nich jsou přitom velmi důležité pro stanovení jednotlivých teplotních fází kvartéru (klimatostratigrafie). Tento fakt velmi ztěžuje přesné a jednoznačné stanovení stáří sedimentů, kdy nemůžeme stoprocentně odlišit terciérní redepozice a sediment se může jevit jako vzniklý v daleko teplejším období. (viz kap. 4a).

Jednou z metod, které mohou přispět k rozlišení redeponovaných pylových zrn, představuje studium ve fluorescenčním mikroskopu. Metody využití UV fluorescence pro determinaci různě starých palynomorf rozpracoval Van Gijzel (1967a ,b, 1971, 1975, 1978) či Yeloff, Hunt (2005). Organický materiál stěny palynomorf vykazuje při působení UV záření autofluorescenci. Spektrum a intenzita fluorescenčních barev závisí na chemickém složení organických stěn. Toto chemické složení se mění s geologickým stářím a při procesech probíhajících v sedimetech – uhelnatění nebo zvětrávání spojené s oxidací a bioerozí. Při redepozicích proto dochází ke změně intenzity a barvy fluorescenčního spektra studovaných taxonů. Praktickým využitím těchto metod na studiu zejména jeskynních, ale i mořských sedimentů se zabývá práce **Doláková, Burešová (2007**). Pylová zrna různých rostlinných taxonů vykazují odlišnou úroveň fluorescence v závislosti na chemickém složení a tloušťce exiny (např. pylová zrna trav jeví nízkou intenzitu fluorescence). Při studiu celého pylového spektra nelze proto z úrovně barev říci, zda některé taxony jsou redeponované a jiné in situ. Pro běžné využití tohoto jevu bez dalších složitých měřících přístrojů je nutné zaměřit se na studium jednoho taxonu (odlišná úroveň fluorescence u zrn v jednom vzorku). Pokud ovšem daný taxon má v UV světle velmi tmavé barvy s velmi nízkou intenzitou, tzn. téměř nesvítí, jedná se velmi pravděpodobně o redepozici. Odolné vůči chemickým procesům jsou organické stěny mikroskopických řas a jejichy cysty – vykazují intenzívní fluorescenci. Naopak zbytky živočišných těl – např. různé typy vajíček, jeví tmavé a málo intenzivní fluorescenční barvy **(Doláková, Burešová 2007**).

Studium fluorescence bylo využito pro detekování případných redepozic u pylových zrn rodu *Carpinus* (habr) z holocenních sedimentů na Pohansku (**Doláková et al., 2010**). Na základě měření stáří metodou ^{14}C byla pylová zrna habru zjištěna v sedimentech nejvyššího stáří na území ČR (8 000 let). Na základě studia fluorescence byly redepozice z tercierních sedimentů v podloží vyloučeny.

Značnou odolnost vůči oxidačním procesům spojeným se zvětráváním, a tudíž i redepozicemi, mají pylová zrna konifer (Kwaitkowski, Lubliner- Mianowska 1957, Havinga 1964, 1967, Brooks 1971, Hopkins, Mc Carthy 2002). Poměr redeponovaných a in situ zrn konifer s létacími vaky byl studován za pomoci UV-fluorescence ve vzorcích z vrtu Oslavany1 (**Nehyba et al. 2016**), kde tato zrna tvořila většinu pylového spektra. Pouze malá část zrn jevila odlišný, velmi nízký stupeň fluorescence. Proto byla většina asociace z tohoto hlediska považována za autochtonní a vysvětlení nadměrného množství konifer mělo jiné příčiny (viz kap. 3a, b**)**.

Dalším tafonomickým jevem je uchování pylových zrn jednoho druhu ve shlucích. Tento jev ukazuje na ukládání v blízkosti původní rostliny, která pyl produkovala. Z geologického hlediska se tedy jedná o depozici in situ, bez výrazného ovlivnění transportem (nízká dynamika vody). Pozorované shluky byly v tercierních sedimentech typické např. pro sedimentaci v pobřežních bažinách, deltových prostředích nebo tzv. marších (Myricaceae, Chenopodiaceae, Caryophyllaceae, Oleaceae, Onagraceae, *Platanus*) (**Doláková et al. 1999, Doláková 2004, Kováčová et al. 2011**).

V kvarterních sedimentech je tento jev zajímavý i z archeologického hlediska, např. v profilu holocenními sedimenty na lokalitě Nad Velkým Jejkalem (Národní park Podyjí) byla identifikována pylová zrna obilí typu pšenice (*Triticum*), která zůstala zachována v nerozpadených prašnících. Tento nález svědčí o pěstování velmi blízko místa uložení. Vzorek z této hloubky (85-94 cm), byl datován radiokarbonovou metodou jako doba římská a období stěhování národů – tyto nálezy mohou indikovat existenci blízkého lidského sídliště, které dosud nebylo archeologicky prokázáno (Šušolová et al. 2016).

2c) Metody studia

2ca) Příprava vzorků

Vzhledem k malým rozměrům palynomorf a jejich rozptýlení v sedimentech je nutné je z těchto hornin separovat a zkoncentrovat. Využívá se různých postupů macerace, kdy je třeba odstranit co nejvíce anorganických minerálních součástí a organickou hmotu koncentrovat a prosvětlit. Macerace představuje kombinace působení chemických procesů a mechanické přípravy založené na rozmělňování, sítování a hmotnostní separaci (využití těžkých kapalin). Kombinace jednotlivých procesů se přizpůsobuje typu horniny. Nejčastěji používanou metodou jetzv. Erdtmanova metoda acetolýzy (Erdtman1960). Soubor postupů podle různých autorů s přizpůsobeními pro jednotlivé typy hornin shrnuly např. Pacltová 1963, Gabrielová 1986. Alternativní metody macerací, kde jde zejména o vyloučení práce s kyselinou fluorovodíkovou, publikovali Riding, Kyffin-Hughes (2006). V naší praxi se prozatím tyto metody neosvědčily.

Nejpoužívanější standardní palynologická macerace pro sedimenty terciéru a kvartéru je založená na těchto principech:

1. Odstranění karbonátů pomocí kyseliny chlorovodíkové (HCl)
2. Odstranění silikátů - kyselina fluorovodíková (HF)
3. Odstranění vytvořených fluoridových gelů (HCl)
4. Hmotnostní separace minerálního rezidua a zkoncentrování pylonosné frakce za pomoci těžké kapaliny ($ZnCl_2$, $BrCl_2$) - hustota = $2 g/cm^3$

5a) U uhelných sedimentů je třeba ještě provést zesvětlení zuhelnatělých palynomorf pomocí oxidace: HNO_3, KOH

5b) U palynomorf z mladých – holocenních sedimentů, kde ještě nedošlo ke kompletní fosilizaci, je třeba prosvětlit palynomorfy a jejich organický obsah pomocí tzv. acetolýzy - H_2SO_4 + acetanhydrid kyseliny octové (CH_3COOH). Vynechání acetolýzy u pleistocenních a starších sedimentů naopak umožní odlišení kontaminace recentními pylovými zrny a sporami např. při průsaku srážkové vody po puklinách nebo kořenech rostlin (zůstane zachována cytoplazma).

Hmotnost zpracovávaných vzorků a volba metody macerace závisí na typu horniny. Odebírá se od několika gramů až po půl kilogramu. Nejvyšší koncetrace a nejlepší zachování palynomorf lze očekávat v sedimentech, které vznikaly v prostředí bez přístupu kyslíku nebo druhotných oxidačních procesů a snížené dynamiky, kde dochází k hromadění organické hmoty (např. rašeliny, sedimenty jezerní, deltové, pobřežních lagun a bažin, slepých ramen řek apod.).

1. rašeliny - pomalé ukládání sedimentu, nízká nebo žádná minerální příměs -vysoká koncentrace palynomorf - malé vzorky (cca 20g);
2. sediment s velkou příměsí minerálního materiálu – vysoká rychlost akumulace sedimentu, nízká koncentrace palynomorf - větší vzorky (500g), např. povodňové hlíny nebo spraše

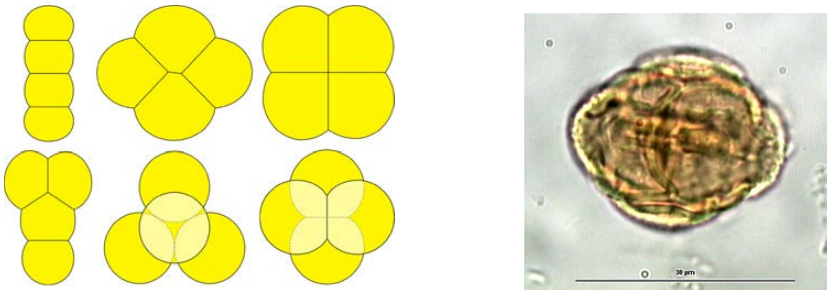
Při uchovávání a dalším studiu vymacerovaných palynomorf je nutné zamezit další oxidaci. Výsledný macerát se proto uchovává ve směsi glycerínu, ethanolu a vody.

Mikroskopická pozorování lze provádět přímo v tomto tekutém médiu – pylové zrno je možné posunovat a otáčet. Potřebujeme-li preparáty trvalé (uchování preparátu po delší čas), používá se většinou tzv. glycerinová želatina nebo kanadský balzám.

2cb) Mikroskopické techniky, základní principy popisu zrn

Palynomorfy se převážně determinují v biologických prosvěcovacích mikroskopech na základě jejich morfologické rozmanitosti. Běžně je používáno zvětšení 200x, 400x a 1000x - imerzní objektiv). Výhodou biologických mikroskopů je posuvný stolek, kde je možné za pomoci dvou na sobě kolmých měřítek zaznamenat přesnou polohu zrna v preparátu.

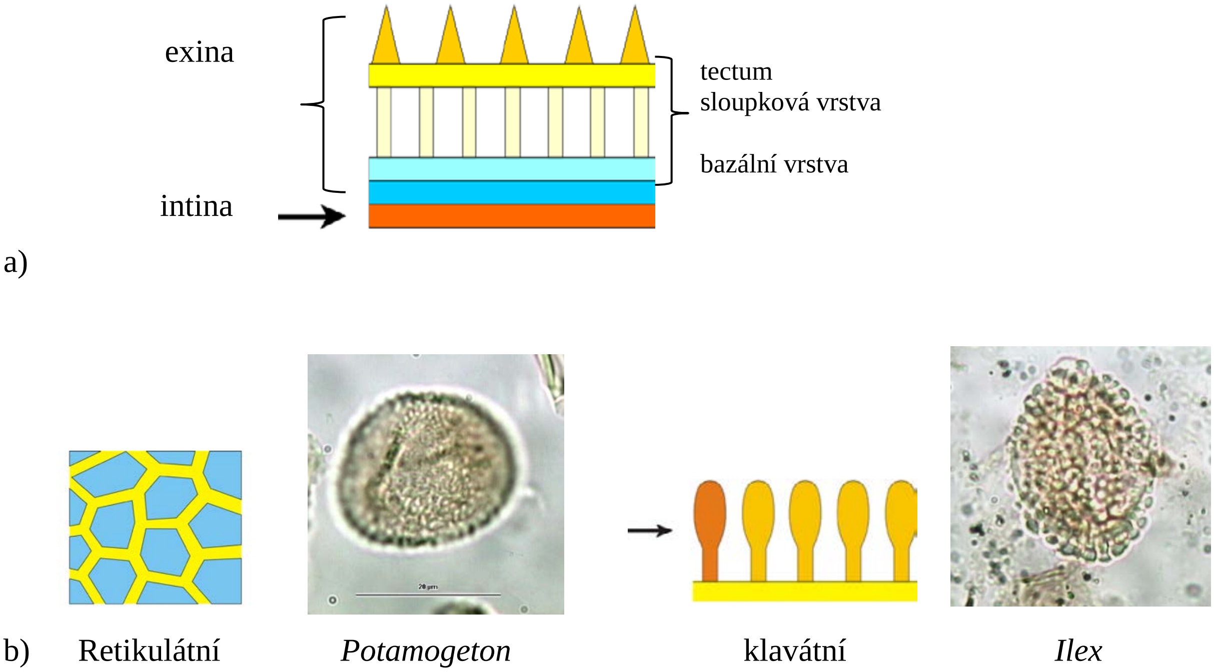
K popisu a determinaci pylových zrn byla vytvořena ustálená terminologie založená především na morfologii zrn. Nejdůležitější znaky souvisejí s postavením zrna v tetrádě, vnějším tvarem a velikostí, skulptuře a struktuře stěny, stavbou germinálního aparátu. První souborný atlas morfologických znaků sestavil Erdtman (1957). Nejnovější shrnutí palynologické termilogie představuje práce Punt et al. (2007). Příklady morfologických znaků jsou znázorněny na obr. 1- 5.



a) b) *Caluna* sp.

Obr 1. a) Základní tvary tetrád spor a pylových zrn (upraveno Punt et al. 2007)
b) tetráda pylového zrna rodu *Calluna* (foto autorka)

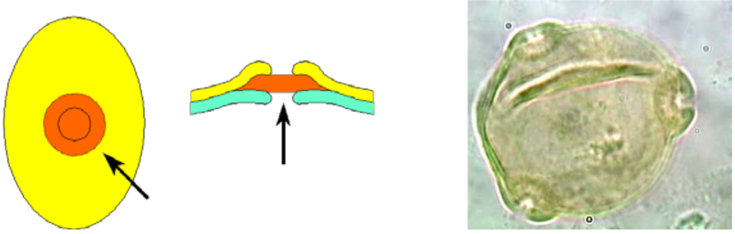
Obr. 2. Rozdíly velikostí pylových zrn: a) pylové zrno rodu *Abies*, b) pylové zrn rodu *Castanea* (foto autorka)



Obr. 3. a) Členění vnějšího obalu pylových zrn a spor

b) Příklady skulptury a ornamentace povrchu zrn: retikulátní - *Potamogeton* klavátní - *Ilex* (upraveno Punt et al. 2007, foto autorka)

a) pór *Poa* *Engelhardia* *Carya*



b) anulus *Betula*

Obr. 4. Příklady hlavních typů apertur (klíčních štěrbin), jejich umístění a kombinací:

a) Pór - pylová zrna s 1 pórem - *Poa*, 3 póry v různém unítění - *Engelhardia*, *Carya*
b) Příklad vnitřní stavby póru - anulus, pylové zrno s anulem - *Betula*
(upraveno Punt et al. 2007, foto autorka)

a) Kolpa *Quercus* *Galium*

b) Kombinace póru a kolpy *Cornus – Mastixia* *Sapotaceae*

Obr. 5 Příklady hlavních typů apertur (klíčních štěrbin), jejich umístění a kombinací:

a) Kolpa - zrno se 3 kolpami – *Quercus*, se 6 kolpami – *Galium*
b) Kombinace póru a kolpy: 3x - *Cornus* - *Mastixia* typ, 4x Sapotaceae
(upraveno podle Punt et al. 2007, foto autorka)

U současných taxonů rostlin jsou pylová zrna a spory dostatečně prostudované k tomu, aby se u jmen palynomorf mohlo využít systematické jméno odpovídajícího rostlinného taxonu.

U fosilních palynomorf bohužel v mnohých případech konkrétní botanickou příslušnost determinovaného taxonu stanovit nelze, protože část taxonů je vymřelých, některé taxony exotické nejsou z hlediska pylové morfologie dostatečně prostudovány nebo některé fosilní taxony mají vyšší morfologickou variabilitu, než je známa u taxonů recentních.

Proto byla pro účely determinace fosilních palynomorf vytvořena umělá systematika, kde jsou názvy taxonů založené na morfologických znacích pylových zrn a spor. Tato systematika je využívána zejména ve starších pracích (např. Krutzsch 1966, 1971, Pacltová 1958, Nagy 1969, 1985, Planderová 1971, 1990). Morfotaxony se používaly i u názvů zrn, jejichž botanická příslušnost byla nesporná. Část palynologů se naopak snaží pojmenovávat pylové taxony podle botanické příslušnosti, zejména na základě detailnější morfologie založené na studiu v elektronových mikroskopech (např. Zetter 1989, www.paldat.org). V současné době se část specialistů palynologů snaží držet principu priority a používat pro pylová zrna a spory modifikované názvy morfotaxonů (např. Stuchlik et al. 1994, 2014), i když je botanická souvislost s originálními rostlinami jasná. Jako příklad můžeme uvést různá synonyma pro pylová zrna rodu *Juglans* (ořešák): *Multiporopollenites maculosus* (Potonié) Thomson & Pflug, *Juglans* Linne, *Jugnlanspollenites juglandoides* (Kohlman-Adamska). V detailních systematických pracích mívají proto pylové taxony velmi rozsáhlou část synonymiky.

Z důvodů přesnější taxonomické determinace některých sporných palynomorf se v poslední době často studují objekty v elektronovém mikroskopu. Využívá se zejména pro determinaci a stanovení příbuznosti taxonů a hledání recentních ekvivalentů dosud neurčených tercierních taxonů na základě morfologie povrchu pylových zrn a spor. Tyto morfologické prvky nebývají v mikroskopech světelných zřetelné. Terminologii využívanou pro morfologické charakteristiky při studiu v elektronovém mikroskopu (SEM) sestavil kolektiv autorů Halbitter et al. (2006) v rámci databáze PALDAT (www.paldat.org). Je ovšem nutné využít kombinaci studia daného objektu v prosvěcovacím mikroskopu (pohled dovnitř zrna a vnitřní stavba terminálního aparátu) a téhož objektu v SEM (podrobná vnější morfologie bez vnitřního pohledu). Metodiku tohoto studia rozpracoval Zetter (1989). Tato metoda však vyžaduje speciální optické mikroskopy, které mají přídavnou optiku pro vytvoření stranově nepřevráceného obrazu. Navíc je zde nutné objekty dále přenášet na vodivé měděné terče, což neumožňuje opětovné pozorování ve světelném mikroskopu.

Na ÚGV PřF MU je k dispozici elektronový mikroskop JEOL JSM – 649 OLV, který umožňuje vkládat studované objekty přímo na podložním skle. Pro palynologická studia jsme s kolegyní M. Kováčovou (UK Bratislava) rozpracovaly metodiku přizpůsobenou tomuto elektronovému mikroskopu s možností zpětného prohlížení v mikroskopu optickém (Doláková, Kováčová připraveno do tisku).

Studia palynomorf založená na kombinované metodě LM/SEM byla využita zejména pro detreminace palynomorf neogenního stáří. Poprvé bylo použito na zařazení morfotaxonu *Monocirculipollis* Krutzsch a jeho přiřazení k čeledi Caryophyllaceae (**Doláková 2004**). Metod LM/SEM bylo použito i pro řešení identifikace problematických morfotaxonů čeledi Fagaceae: *Tricolpopollenites liblarensis***,** *Tricolporopollenites cingulum oviformis.* Na základě studia v SEM bylo zjištěno, že tato v optickém mikroskopu téměř identická zrna mohou mít různou botanickou příslušnost – *Castanea* x *Castanopsis* x *Trigonobalanopsis*. Jejich rozlišení je možné na základě morfologie povrchu zrn (**Dolákova et al 2011**). Upřesnění identifikace na základě LM/SEM bylo provedeno i u rodů: *Quercus*, *Platanus, Tamarix*, zástupců čeledí Caryophyllaceae a Rutaceae, rozlišení rodů *Pinus* x *Cathaya*. Identifikace byla prováděna na základě srovnání s literárními údaji a rovněž na základě studia recentních pylových zrn - *Castanea sativa*, *Tamarix gallica*, *Citrus limon* (**Doláková et al. 2011, Kováčová et al. 2011**)

2cc) Kvantitativní vyhodnocování - tvorba pylových diagramů

Soubor pylů a spor v jednom vzorku, které pod mikroskopem determinujeme a kvantitativně vyhodnocujeme, se označuje jako pylové spektrum.

Pylová spektra z chronologicky odebraných vzorků se znázorní v pylovém diagramu. Získáme tak obraz časových změn vegetace na studovaném místě. Nejčastější vyhodnocování pylových spekter se provádí na základě procentuálního zastoupení jednotlivých palynomorf nebo jejich skupin. Nejmenší suma palynomorf v jednom vzorku, ze kterých se pylový diagram vytváří, je 100 determinovaných zrn při minimálním množství 15 determinovaných taxonů. Menší množství není pro interpretaci vegetace dostatečně reprezentativní.

Pro kvantitativní (semikvantitativní) vyhodnocování pylových spekter a tvorbu pylových diagramů existuje několik softwarových programů. Jsou založené na procentuálním zastoupení determinovaných taxonů v jednotlivých vzorcích. V mé práci bylo využíváno především programu POLPAL polských autorů Walanus, Nalepka (1999). Tento program umožňuje jednoduše a operativně vložit do tvorby pylových diagramů i zkušenosti palynologa. Tohoto využívám např. při kombinování taxonů s ekologicky podobnými nároky do jedné křivky tzv. syntetického diagramu, což v mnoha případech umožní názornější vizualizaci ekologických charakteristik prostředí (např. **Doláková et al. 2010, 2014**). Toto kombinování má ovšem svá omezení, protože ne vždy se podaří dané taxony determinovat až do úrovně druhu, což může způsobit nepřesnosti u těch taxonů, které mají různé ekologické nároky pro různé druhy (např. *Quercus* – dub – sušší stanoviště nebo lužní lesy, existence stálezelených druhů v tercierních palynospektrech). Ještě složitější je to u taxonů tercierních, kde u některých morfotaxonů není stoprocentně objasněná botanická příslušnost, a tudíž ekologická charakteristika.

Pylové taxony, které jsou v asociaci výrazně nadhodnocené (akumulují se v důsledku vysoké pylové produkce a tafonomických procesů), a tudíž by výrazně změnily poměr jednotlivých rostlin, je možné vyloučit z celkové sumy 100%. Graf je potom možné sestavit ze dvou částí. Levá část znázorňuje procentuální zastoupení jednotlivých taxonů nebo jejich skupin, kde se za celkovou sumu počítá součet všech pylových zrn s vyloučením nadhodnoceného taxonu. Pravá strana grafu znázorňuje poměr zastoupení původně vyloučeného taxonu k celkové sumě všech determinovaných zrn. Botanikové používají tento princip pro odstranění vlivu ekologicky výrazného stanoviště nad celkovým charakterem širšího okolí (např. převaha Cyperaceae, Polypodiaceae). V mé praxi se tento princip osvědčil pro interpretaci pylových spekter zejména jeskynních nebo mořských sedimentů, kde dochází k selektivním změnám v důsledku tafonomických procesů (**Doláková 2014, Doláková et al. 2014**).

3. Palynologie neogénu

Studium palynologie v sedimentech neogenního stáří (mladší terciér) tvoří největší část mé palynologické práce. Publikované výsledky se soustřeďují na 2 vzájemně propojená témata:

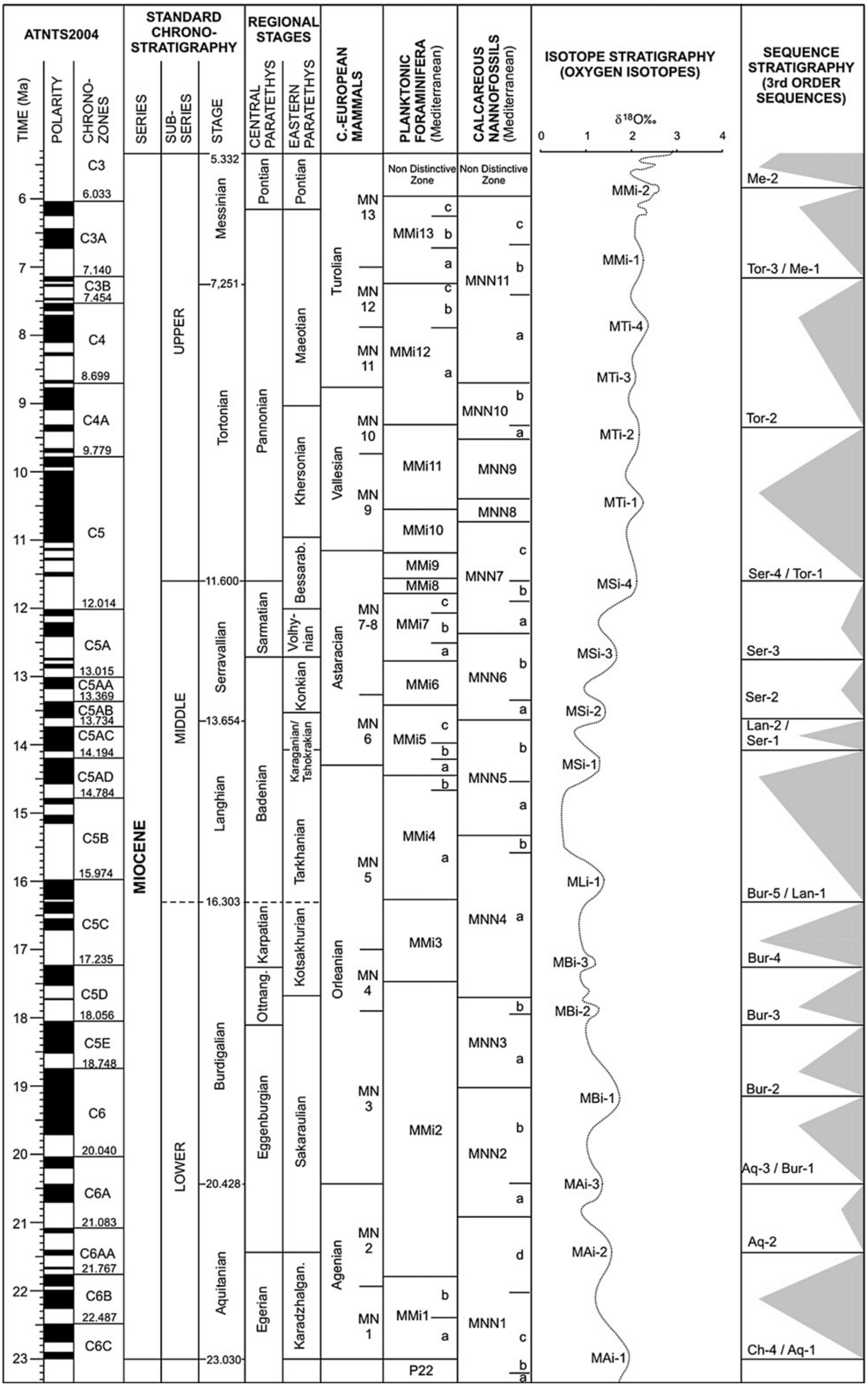
3a) rekonstrukci vegetačních poměrů v jednotlivých časových úsecích, a na jejich základě interpretace paleoekologických charakteristik a stratigrafických údajů;

3b) interpretaci širších geologických charakteristik na základě koordinace výsledků dalších paleontologických, sedimentologických a geochemických metod. Tyto práce se snaží interpretovat poměry v sedimentačních pánvích a řešit vzájemné vztahy kontinentálního a mořského prostředí.

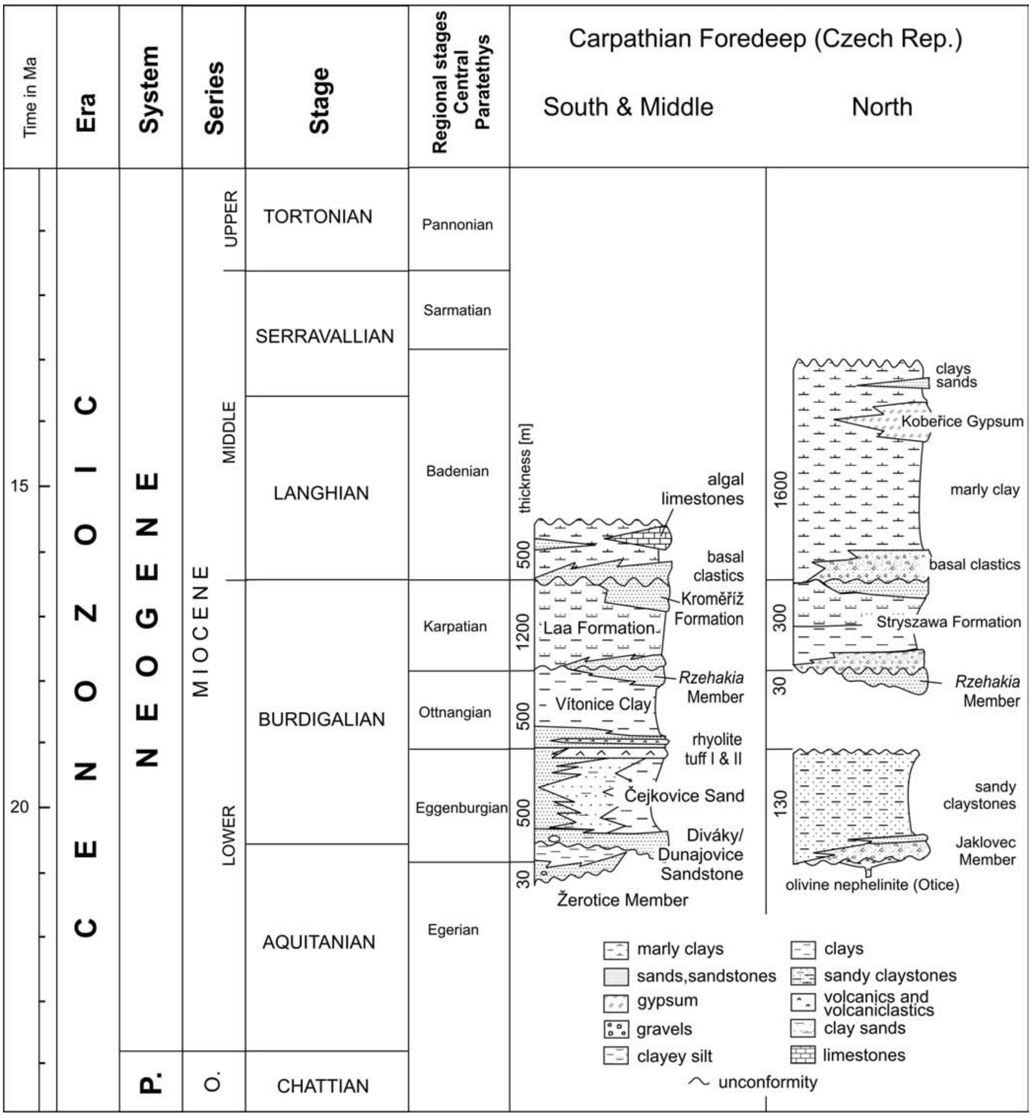
Studované lokality patří k velmi geologicky velmi dynamickému území, které je situováno na hranici mezi východními svahy tektonicky klidné Evropské platformy (reprezentované českým masívem) a okrajem tektonicky aktivních, zvyšujících se horských řetězců Západních Karpat. Během neogénu bylo toto teritorium pokryto širokým výběžkem epikontinentální mořské oblasti Centrální Paratethydy. Území mělo během studovaného období velmi komplikovanou geodynamickou historii (Kováč 2000, **Kováčová et al. 2011**). Vývoj morfologie krajiny se zásadním způsobem projevoval i ve změnách vegetace zobrazené v pylových spektrech. Díky velké prostorové distribuci palynomorf lze pylová spektra studovat i v mořských sedimetech a využít je ke korelaci kontinentálního a mořského prostředí.

Publikované výsledky byly soustředěny na lokality geodynamicky odlišných lokálních pánví Centrální Paratethydy: karpatské předhlubně, vídeňské pánve a jihoslovenské a modrokameňské pánve na Slovensku.

Studovaný časový interval zahrnuje stupně standardní chronostratigrafické stupnice burdigal až torton, které jsou na území Centrální Paratethydy označovány jako eggenburg až pannon (obr. 6). Stratigrafické členění a hlavní typy sedimentů v karpatské předhlubni na Moravě jsou uvedeny na obr.3**.** Sedimenty, ve kterých byla palynospektra studována, zahrnují prostředí mořská, nebo různé okrajové vývoje mořské pánve s brakickou až sladkovodní sedimentací, případně delty velkých řek i sedimenty tufitů. Výhodou studia palynospekter v mořských sedimentech je jejich přesná chronostratigrafická datace na základě mořských mikroorganizmů (foraminifera, Ca-nannoplankton). Toto datování potom umožňuje korelace s klimatickými změnami pozorovatelnými v terestrických vývojích.



Obr. 6. Chronostratigrafie a biostratigrafie miocénu (Harzhauser, Piller 2007)



Obr. 7. Regionální stratigrafické členění neogénu karpatské předhlubně na Moravě (Rasser et al. 2008)

Období mladšího terciéru – neogén je charakteristické řadou globálních i lokálních klimatických změn. Změny globálního charakteru jsou zaznamenány především na izotopových hodnotách kyslíku ze schránek organizmů z hlubokomořských vývojů. Přechod z paleogénu do neogénu (oligocén- miocén) je vyznačený krátkou chladnou oscilací známou jako event Mi-1, který byl zaznamenaný před 23,7 mil let (Zachos et al. 2001). Po tomto ochlazení po celou dobu spodního miocénu teploty opět vzrostly. Menší klimatické oscilace odpovídají vrcholům hodnoty izotopů kyslíku (Mi - eventy), které byly zaznamenány opakovaně (Miller et al. 1991, Shackleton et al. 1999). Další teplotní maximum je známé jako Mid-Miocene Climatic Optimum (MMCO), datované do období před 17 až 14,5 miliony let kolem hranice spodního a středního miocénu (Zachos et al. 2001). Toto období představovalo nejteplejší časový interval za posledních 35 mil. let. Po něm následovala celosvětově zaznamenaná fáze přechodného klimatu známá jako Middle Miocene Climatic Transition (MMCT), které se projevovalo v rámci převládajícího globálního klimatu před 16 a 14.8 mil. let jako krátkodobé oscilace klimatu, objemu Východoantarktického ledovcového štítu (EAIS), hladiny světového oceánu a hlubokooceánské cirkulace. V pozdější fázi, od 14,8 - 12,9 mil. let, klimatický vývoj zahrnoval velký vzrůst EAIS spojený s ochlazením Antarktidy, znatelný růst teplotního gradientu, rozsáhlé výkyvy mořské hladiny následované globálním snížením hladiny oceánu a významné změny hlubokomořské cirkulace (Flower and Kennett 1994). V mělkomořských okrajových vývojích byl klimatický záznam kromě globálních podmínek ovlivněn i lokálními geomorfologickými podmínkami a vulkanickou aktivitou během vývoje Alpsko-karpatského horského pásma a rovněž průniky chladných nebo teplých oceánských vod (**Holcová et al. 2015**, Kováč et al. 2017).

Terestrická vegetace tyto změny odráží velmi výrazně. Stratigrafie kontinentálních vývojů (kde chybí indexové fosílie) střední Evropy je proto do značné míry založena na studiu těchto klimatických změn (klimatostratigrafie).

3a) Interpretace vegetace a klimatických změn

V palynospektrech z území ČR bylo v období neogénu zachyceno mnoho klimatických výkyvů, které jsou typické pro centrální Evropu. Jejich interpretací v terestrických ekosystémech a stratigrafickým zařazením se zabývala a zabývá celá řada autorů (např. Mai 1981, 1991, Planderová 1990, **Planderová et al. 1993a**,b, Sadowska 1989, 1993, Stuchlik 1992, Stuchlik et Ważynska 1993, Mosbruggeret Utescher 1997, Böhme 2003, Böhme et al. 2006, **Bruch et al. 2004**, 2007, **Kvaček et al. 2006, Kováčová et al. 2011**)

Celkový charakter klimatu, zejména kombinace teplotních a srážkových poměrů, je zobrazen v tzv. zonální vegetaci (odráží hlavní klimatickou zonaci – tropické deštné lesy, opadavé lesy mírného pásma apod.). Obraz místních paleoekologických a paleogeografických poměrů, často závislých na charakteru substrátu, vyjadřují společenstva azonální (intrazonální x extrazonální, např. vegetace lužních lesů, slaniska, horská vegetace). Azonální vegetační prvky mohou být v palynospektrech lokálně značně nabohacené a mohou zastírat celkový zonální charakter. Lze z nich ovšem interpretovat lokální poměry daného regionu a rovněž vztahy mezi mořským a kontinentálním prostředím (zasolování pobřeží, ingrese sladkých vod, mírný nebo diferencovaný reliéf pobřeží - vznik pobřežních bažin, horská vegetace). Odlišit je navíc třeba, pokud možno i taxony nabohacené v důsledku rozdílné transportní schopnosti palynomorf a tafonomických vlivů (viz kap. 2a,b). Další problém v interpretaci vegetačního pokryvu a klimatických faktorů představují morfotaxony, u nichž je dosud botanická příslušnost systematicky nejistá. Pro interpretace palynospekter proto není možné bezvýhradně využít aktualistických údajů. Pro přesnější představy o paleoprostředí jsou nutné poznatky dalších paleontologických, sedimentologických a geochemických metod.

Změny klimatických i dalších paleekologických charakteristik se projevují nejvíce ve vzájemném poměru zastoupení méně teplotně náročných rostlin (reprezentovaných zejména opadavými dřevinami a jehličnany) – tzv. arktotercierních geofloristických prvků (A) a rostlin s vyššími klimatickými nároky (stálezelené velkolisté taxony rostoucí v podmínkách tropického a subtropického pásma) – tzv. flóry paleotropických geofloristických prvků (P). Tento princip jako první navrhl Mai (1981, 1991). Palynologická společenstva charakterizující jednotlivé klimatické změny označil jako pylové obrazy. Stuchlik et al. (1994) rozdělili arktoterciérní taxony (A) na teplé mírné (A1) a chladné mírné (A2). Paleotropické elementy (P) dělí na prvky klimatické zóny tropické (P1) a subtropické (P2). U taxonů, které dosud nemají determinovanou botanickou příbuznost, posuzují ekologickou náročnost na základě celkové charakteristiky společenstev, v nichž se tyto taxony vyskytují (Stuchlik et al. 1993, 1994, 2014).

První komplexní interpretace a charakterizace klimatických změn na základě vegetačních poměrů pobřeží Centrální Paratethydy byla shrnuta v pracích pod editorstvím E. Planderové (Planderová et al. 1993a,b). K těmto výsledkům přispěly práce mnohých autorů z jednotlivých území např. Konzalová (1976), Konzalová, Stuchlik (1983, 1992), Nagy (1969, 1985), Planderová (1971, 1984 1990), Sadowská (1989, 1993), **Zdražílková (1993)** a další. Autoři vymezili v miocenu Centrální Paratethydy čtyři výrazná paleoklimatická období.

První interval zahrnující svrchní eger, eggenburg a ottnang je charakterizovaný tropicko – subtropickým klimatem se stále přetrvávající flórou paleogenního charakteru, s typickými paleogenními taxony *Cicatricosisporites chattensis*, *Plicatopollis plicatus*, vyskytujícími se jen v jižních oblastech Centrální Paratethydy. V severních oblastech byly nalezeny paleotropické prvky ze skupiny P1 (*Dicolpopollis kockeli*, *Fususpollenites fusus*, *Sapotaceoidaepollenites*), ale bez paleogenních elementů. Kromě zmíněných rozdílů se pylová společenstva na celém území příliš nelišila. Tato shoda byla nejspíše způsobena paleogeografickou situací území.

Druhý interval zahrnuje karpat a spodní baden. Jsou pro něj typické velmi hojné paleotropické prvky a vyšší taxonomická diferenciace. Početné jsou taxony P1 i P2. Spodní baden znamenal pro některé charakteristické tropické elementy jejich poslední výskyt (Sapotaceae, Symplocaceae, Schizacaceae).

Třetí interval charakterizuje svrchní baden a sarmat. Paleoflóra se stává jednotnou, docházelo k promíchávání flóry nížin s flórou Paratethydy, což mělo za následek rozšíření arktoterciérních prvků na jihu a vzrůstem paleotropických elementů skupiny P2 na severu.

V sedimentech z období svrchního sarmatu severně od Karpat převládá močálová teplomilná vegetace s příznivými podmínkami pro tvorbu uhlí. Míšení flór mizí během postupné regrese moře, paleotropická vegetace migruje na jih. Od tohoto období dominují severně od Karpat prvky arktoterciérní.

Čtvrtý interval představují stupně pannon a pont. V tomto časovém úseku docházelo k expanzi arktoterciérní flóry a dále ke vzrůstu kvantity chladnomilných taxonů v severní části Paratethydy. Klimatické podmínky v pontu jsou mírné humidní a vegetace se vyznačuje převážně listnatými lesy rozprostírajícími se u břehů teplých vod (Planderová et al. 1993).

Na tyto práce navazovaly některé další komplexní publikace, které problematiku rozšiřovaly a upřesňovaly (např. Stuchlik et al. 1994, Nagy 1999).

V současnosti jednou z nejvyužívanějších metod pro interpretace paleoklimatu na základě terestrických rostlinných společenstev je tzv. „koexistenční přístup“ - „coexistence approach (CA)“ - který poprvé publikovali Mosbrugger, Utescher (1997). Rozsáhlou diskusi jeho aplikací a problematiku využití zpracovali Utescher et al. (2014). Tato metoda je založená na aktualistickém předpokladu, že terciérní taxony rostly v podobných podmínkách jako jejich nejbližší žijící příbuzní (NLR – „nearest living relatives“). U těchto recentních zástupců jsou definované hlavní ekologické faktory (ekologická valence), které jsou shrnuty do databáze CLIMBOT (zahrnuje více než 800 terciérních rostlinných taxonů v podobě výtrusů, pylových zrn, semen, listů a dřev, jejich nejbližší recentní příbuzné a jejich klimatické parametry). Klimatická charakteristika jednotlivých taxonů vyjadřuje 10 hlavních parametrů - průměrná roční teplota (MAT), průměrná teplota v nejteplejším měsíci (WMT), průměrná měsíční teplota v nejchladnějším měsíci (CMT), průměrné roční srážky (MAP), minimální průměrné roční srážky (MinAP), maximální měsíční srážky (MmaP), minimální měsíční srážky (MmiP), srážky v nejteplejším měsíci (WMP), relativní vlhkost (RH), index aridity (AI). Výsledkem tohoto modelu je získání intervalových hodnot u jednotlivých parametrů (teplotních, srážkových), v rozmezí kterých mohou determinované taxony na určitém místě růst ve společné asociaci (koexistovat). Pro získání koexistenčních intervalů byl navržen program CLIMSTAT (Mosbrugger, Utescher 1997). Jedny z prvních konkrétních výsledků interpretací klimatických charakteristik a jejich vývoje během posledních 25 mil. let vývoje klimatu na základě CA z oblasti SZ Německa publikovali Utescher et al. (2000).

Databáze Palaeoflora (http://www.palaeoflora.de/) je neustále rozšiřována a je součástí mezinárodního programu NECLIME - Neogene Climate Evolution in Eurasia, který byl založen v roce 2000 **(http://www.neclime.de/).** Výsledky této rozsáhlé spolupráce odborníků na neogénní terestrické ekosystémy jsou neustále publikovány a rozšiřovány (např. Bruch et al. 2007, Utescher et al. 2011, Louis et al. 2017).

Jednou z prvních syntetizujících prací v rámci tohoto programu byla publikace **Bruch et al. 2004**. Výsledkem CA analýz z mnoha lokalit střední a jižní Evropy z období časného středního miocénu a časného svrchního miocénu byla rekonstrukce klimatického gradientu. V obou těchto obdobích byl konstatován pouze mírný šířkový gradient. Tento jev patrně souvisel s obrovským plošným rozsahem epikontinentální mořské oblasti Centrální Paratethydy, která klimaticky ovlivňovala suchozemské oblasti ve svém okolí. Detailnější klimatické interpretace související např. s rozdílnou paleogeografií v důsledku zvyšujících se oblastí alpsko karpatského horského pásma jsou patrně studovanou metodou nezachytitelné.

Z prostředí karpatské předhlubně byla do klimatických modelů zahrnuta lokalita Židlochovice, kde byly na několika palynospektrech z bodových vzorků vypracovány základní klimatické charakteristiky. Tato lokalita reprezentuje hypostratotyp spodního badenu, a byla proto zpracována podrobněji ve dvou 20 metrových vrtech z paleontologického i sedimentologického hlediska a rovněž metodou CA (**Doláková et al. 2014**) viz níže.

Jako každá interpretační metoda má i CA ve fosilním záznamu svá omezení. Je založena pouze na přítomnosti nebo nepřítomnosti určitého taxonu v paleoasociaci. Nezohledňuje kvantitativní zastoupení některých prvků a vlivy tafonomie – nedochování se taxonů s rychleji rozložitelnou stěnou, nebo taxonů, které se vlivem menší schopnosti distribuce palynomorf nedostanou do studovaného sedimentu, např. mořského prostředí. U terciérních palynospekter, kde je vždy určitý podíl pouze morfologicky determinovaných taxonů, je navíc interval koexistence značně široký. Chyby v interpretaci mohou být u terciérních taxonů rovněž způsobeny nepřesným přiřazením nejbližšího příbuzného, případně změnami ekologické valence některých taxonů - např. určitý druh se vyskytoval v odlišných asociacích než dnes – refugia. Příkladem může být rod *Craigia.* Tento rod je v současné době zastoupený v asociaci širolistých stálezelených smíšených lesů blízkých tropům, se sezónními zvýšenými srážkami z Číny a severního Vietnamu. V miocenních oryktocenózách se však ve vyšších frekvencích vyskytoval v asociacích pobřežních až uhlotvorných bažin v asociaci opadavých dřevin (s převažujícími Taxodioideae). (Kvaček et al. 2002, 2004, Zetter et al. 2002). V těchto asociacích se pylová zrna rodu *Craigia* vyskytovala hojně i ve spodním miocénu karpatské předhlubně na Moravě **(Doláková 2004, Kováčová et al. 2011)**

Práci, která propojuje poznatky vegetačních poměrů a geodynamického vývoje z prostoru Centrální Paratethydy, představuje publikace **Kvaček et al. (2006).** Pro interpretaci a zobrazení vegetačních a paleogeografických poměrů bylo využito digitálního elevačního modelu (DEM). Tento model umožňuje zobrazit představu krajiny na palinspastických mapách s rekonstruovanou orografií vývoje karpatského horstva a okolních sedimentačních pánví.

Model vegetace kontinentálního prostředí v okolí Centrální Paratethydy využívá zjednodušený systém vegetačních jednotek (formací), které jsou postačující pro získání předběžného obrazu paleovegetace v prostoru.

V rámci mezinárodního týmu byly (na základě studia listové flóry, semen, plodů a palynomorf) pro rekonstrukci rostlinného pokryvu navrženy základní zonální, intrazonální a extrazonální formace (vegetační jednotky). Tyto formace sdružují jednotlivé elementy flóry na základě autekologie jejich nejbližších žijících příbuzných (NLR) a rovněž metod listové fyziognomie. Rostlinná společenstva referenčních fosilních lokalit často obsahovala taxony rozdílných vegetačních formací, z nichž zonální prvky byly použity pro tvorbu map rekonstrukcí fosilní vegetace.

Charakteristika formací byla založena na diverzitě a vzájemném poměru zonálních elementů: stálezelených, opadavých, sklerofylních a leguminozních dřevin. Kromě zonální vegetace byly shrnuty i základní typy vegetace azonální (intrazonální, extrazonální).

<u>Zonální formace</u> – procentuální zastoupení je poměr ke všem determinovaným zonálním krytosemenným.

1. Temperátní listnatý (širolistý) opadavý les - (Warm-) temperate Broad-leaved Deciduous Forest) s velmi nízkým poměrem stálezelených dřevin, obsahující více než 80% opadavých zonálních krytosemenných dřevin (*Parrotia, Zelkova, Ostrya, Acer angustilobum* atd).

2. Temperátní smíšený mezofytní les (Warm) - temperate Mixed-Mesophytic Forest - zahrnující méně než 80% zonálních opadavých krytosemenných dřevin, méně než 30%

stálezelených krytosemenných dřevin, méně než 20% sklerofylních a leguminozních (malolistých) typů s pravidelnou příměsí *Tetraclinis salicornioides* a dalších teplomilných prvků, méně než 30% zonálních bylin)

3. Subtropický širolistý stálezelený les - Subtropical Broad-leaved Evergreen Forests, zahrnující tzv. mastixiovou flóru “Younger Mastixioid Floras” sensu Mai (1981), obsahující 30 % nebo více listnatých stálezelených teplomilných elementů, reprezentovaných zejména čeleděmi Lauraceae, Theaceae, Mastixiaceae, Symplocaceae, Sapotaceae, *Engelhardia*, a stálezelené členy čeledi Fagaceae (v pylovém spektru reprezentované morfologickými druhy *Castaneoideoipollenites pusillus, Quercoidites henrici, Quercoidites microhenrici*) a méně než 25% zonálních bylin.

4. Subtropický a subhumidní sklerofytní les - Subtropical sub-humid Sclerophyllous Forest, obsahující více než 20 % sklerofylních taxonů (*Quercus mediterranea, Quercus drymeja*) a leguminozních malolistých dřevin

Azonální formace – význačné množství těchto prvků ve společenstvech může zastřít celkový charakter klimatických zón - tzv. faciálně ovlivněná společenstva, nejsou vyjádřená v mapách pomocí vzorců, ale pouze bodově u referenčních lokalit.

Intrazonální formace:

5. Bažinný les a uhlotvorný močál - Swamp forest and coal-forming mire, kde dominantní postavení mají elementy uhlotvorných dřevin a bylin (*Glyptostrobus* adalších Taxodioideae, *Byttneriophyllum, Nyssa, Myrica, Calamus, Spirematospermum*).

6. Močálová a akvatická vegetace - Marsh and aquatic vegetation, zastoupená dominantně vodními bylinami a halofyty (Cyperaceae, *Typha, Potamogeto*n, *Stratiotes* atd.).

7. Opadavý lužní les - Deciduous riparian forest, tvořený především dřevinami vlhkých substrátů (*Taxodium, Alnus, Salix, Populus, Fraxinus, Acer tricuspidatum*)

Extrazonální formace

8. Horské jehličnaté lesy - Mountain conifer-rich forest reprezentované především rody *Cedrus, Tsuga, Picea, Cathaya* etc. Tato formace je v mapách znázorněná, je založená většinou na záznamu pylových zrn.

Na základě těchto typů vegetace byly výsledky floristických studií analyzovány ve 3 časových intervalech miocénu s odlišnou flórou a paleogeografií a byl z nich vytvořen paleobiogeografický model pro areál Centrální Paratethydy a její periferii. Jednalo se o inervaly : karpat/spodní baden, svrchní baden/spodní sarmat a spodní panon.

Limity modelu spočívají v tom, že nebere v úvahu hojnost výskytů, což bylo způsobeno nepravidelným fosilním záznamem. Nicméně procentuálně vyjádřená diverzita je prozatím nejobjektivnější charakteristika rostlinných společenstev. Na paleogeografických podkladech úzkých časových úseků lépe vynikne dynamika vegetace a její vývoj, i když je pro daný čas malý počet referenčních lokalit. Problematická byla transformace palynologických diagramů, ve kterých zůstává stále určitý počet taxonů s pouze morfologickými determinacemi do jednotlivých vegetačních formací, které byly vytvořeny na základě zejména listové fyziognomie. Pokud to bylo možné, byly starší palynologické údaje revidovány, aby se rozšířilo množství taxonů přiřazených do botanického systému. Mnohá zpřesnění ovšem zůstávají otázkou pro budoucí výzkumy.

3ab) Charakteristika vegetace v jednotlivých časových úsecích

Prozatím nejnovější kompletaci a interpretaci palynologických údajů doplněnou o literární údaje makrofloristické z území ČR a SR a srovnání s vývojem flóry v sousedních oblastech představuje pulikace **Kováčová, Doláková a Kováč (2011)**. Práce se zaměřila na vegetační a paleoklimatickou analýzu dvou oblastí Centrální Paratethydy a jejího okolí s různým geodynamickým vývojem: karpatské předhlubně na Moravě a vídeňské pánve na Moravě a na Slovensku. Shrnuje výsledky dosavadních výzkumů zaměřených na vegetaci miocénu studovaných areálů **(Doláková 2004, Doláková et al. 1999, Doláková, Kováčová 2008, Doláková et al. 2011, Doláková, Slamková 2003).** Výsledky pylové analýzy vycházejí ze semikvantitativního hodnocení palynospekter na základě proporcionálního poměru paleotropických a arktotercierních prvků (sensu Mai 1981, 1991, Stuchlik et al. 1994, Neclime koncept NLR.), které jsou vyjadřovány pomocí pylových diagramů. Reprezentují vývoj vegetace a klimatu ve sledovaných stratigrafických intervalech. Interpretace výsledků vychází z konceptu prací **Kvaček et al. (2006),** Kovar-Eder et al. (2008a, b).

Na změnách pylových spekter se kromě klimatického vývoje projevují i změny paleogeografické, jako např. rozšiřování a restrikce mořských pánví – transgrese a regrese spojené se zarovnáváním reliéfu nebo silnou erozí kontinentu, vznik a vzájemné propojování lokálních okrajových pánví, prostředí delt s míšením mořské a sladké vody a přínosem organické hmoty z pevniny, zvyšování reliéfu v důsledku orogeneze, dosouvání karpatských příkrovů – nedochování okrajových facií apod. (Kováč 2000, Nehyba et al. 2008).

Z konceptu práce **Kováčová, Doláková, Kováč (2011)** vyplynuly peleovegetační chjarakteristiky stratigrafických úseků miocénu a byly doplněné údaji z některých starších i novějších vlastních publikací.

Základní taxony, které jsou zahrnuty do zonální vegetace skupiny teplomilných stálezelených dřevin (P), jsou - Sapotaceae, Palmae, *Engelhardia, Platycarya,* stálezelené členy čeledi Fagaceae (morfotaxony *Quercoidites microhenrici* a *Quercoidites henrici, Trigonobalanopsis*), *Symplocos,* Cornaceae - Mastixiaceae, *Tricolpopollenites liblarensis,* Araliaceae, Rutaceae, Reevesia, *Alangium,* Theaceae, Styracaceae, *Parthenocissus,* atd. Základní prvky opadavých dřevin – arktoterciérní (A) vegetace jsou: *Quercus, Acer, Carpinus, Betula, Juglans, Tilia, Celtis, Carya, Zelkova, Ostrya, Eucommia*.

Extrazonální horská vegetace je reprezentována rody: *Cedrus, Tsuga, Picea, Cathaya, Keteleeria.*

Azonální vegetace ovlivňovaná edafickými faktory je reprezentována:

1. prvky lužního lesa: *Alnus, Salix, Ulmus, Fraxinus, Pterocarya, Platanus, Liquidambar, Cercidiphyllum;*
2. pobřežních bažin: Taxodioideae (*Glyptostrobus*), Myricaceae, Cyrillaceae, Nyssa, *Craigia, Sciadopitys, Decodon, Ilex;*
3. vodní a příbřežní vegetace: Cyperaceae, Oenotheraceae, *Sparganium, Typha, Potamogeton, Nelumbo, Azolla;*
4. vegetací otevřených ploch se zástupci heliofyt: stromovitých *Olea,* bylinných (Poaceae, Caryophyllaceae, Asteraceae, *Artemisia, Salvia*) a keřovitých (Ericaeae, *Buxus,* Rosaceae, *Ephedra*) a pobřežních slanisek (Chenopodiaceae – *Salicornia* and *Gypsophilla, Tamarix*)
5. kapraďorosty – teplomilné: *Lygodium, Pteris,* Schizeaceae, Davaliaceae,
   ostatní: Polypodiaceae, *Osmunda, Selaginella.*

Prostředí spodnomiocenních stupňů eggenburg – ottnang (obr. 6,7) zachycené v sedimentech jz. části karpatské předhlubně bylo mimořádně variabilní (např. vrty Miroslav, Jezeřany, Šafov, Čejkovice). Sedimentace probíhala v subtropickém klimatu v příbřežní mořské oblasti s velmi morfologicky diferencovaným reliéfem pobřeží – mořské facie se střídaly v čase i prostoru s faciemi lagun a delt (brakické až sladkovodní prostředí)**.** Změny mořského prostředí byly spojené se změnami mořské hladiny, změnami dynamiky, prosvětlení, obsahu kyslíku a salinity a rovněž rychlostí akumulace sedimentů. Tyto změny se projevily jak v mořských ekosystémech, tak i v charakteru pobřežní terestrické vegetace (**Doláková et al. 1999,** Nehyba et al. 1995, 1997, **Doláková 2004).** Palynospektra měla charakter subtropického klimatu. V porovnání s mladšími obdobími miocénu jižní části karpatské předhlubně byla typická pravidelná přítomnost pylových zrn čeledi Rutaceae, hojněji byl zastoupený subtropický rod *Symplocos* a ojediněle byla zjištěna pylová zrna rodu *Alangium*. Ve facii lužních lesů byl zastoupený hojněji rod *Platanus* než *Alnus*. Vegetace otevřených ploch se zástupci heliofyt (Poaceae, Caryophyllaceae, Asteraceae, Ericaeae, *Buxus, Ephedra*) a pobřežních slanisek (Chenopodiaceae až 37% ve vzorku, patrně rod *Salicornia, Tamarix*) se v profilech střídala s převahou rostlin pobřežních bažin (Taxodioideae, Myricaceae, Cyrillaceae, *Decodon*) s hojným podílem teplomilných kapradin. Např. rod *Lygodium* (až 5 %), Pteridaceae, Gleicheniaceae, vranečky *Selaginella* a jatrovkou *Ricci*a. Flóra rostoucí na okrajích sladkých vod (*Sparganium, Potamogeton, Nelumbo*, Cyperaceae) byla rovněž charakteristická a častěji zastoupená než ve spektrech karpatu a badenu. Typická pro palynospektra eggenburgu byla přítomnost formálního rodu *Monocirculipollis*, který nebyl zjištěn v mladších sedimentech karpatské předhlubně. Na základě studia v elektronovém mikroskopu byl přiřazen čeledi Caryophyllaceae (zmíněno v kapitole 2cb), morfologicky podobnému pylovým zrnům rodu *Gypsophilla*. Vysoká frekvence jehličin čeledi Pinaceae zahrnující nejčastěji rody *Pinus, Cathaya* a méně *Cedrus, Picea, Abies* prokazovala velmi diferenciovaný reliéf pořeží. Rod *Tsuga* byl na rozdíl od mladších sedimentů zjištěn pouze velmi ojediněle.

Nálezy palynologie podpořily dřívější závěry studia makroflóry, která je ve studované oblasti poměrně vzácná. Ojedinělou oryktocenózu ze Znojma a Přímětic determinoval Knobloch (1982, 1984). Interpretoval několik ekologicky odlišných asociací: a) keřovito-bylinnou heliofilní vegetaci se zástupci stálezelených sklerofylních dřevin podobnou mediteranním společenstvům tzv. macchie; b) bažinnou vegetaci *Glyptostrobus, Myrica*; c) akvatickou flóru se *Salvinia, Potamogeton, Nymphaea* a pobřežní společenstvo s *Typha, Decodon, Sparganium*. Popsal rovněž akumulaci plodů rodu *Limnocarpus*, který roste na okrajích brakických vod.

Interpretace charakteru vegetace obsažené v sedimentech karpatu byla zpracovávána zejména v rámci mezinárodního projektu Reedice stratotypu Karpatu. Závěry tohoto projektu byly shrnuty v monografii **Brzobohatý et al. (2003)**. Palynospektra byla mimo dalších vrtů a lokalit studována i na stratotypových lokalitách Slup, Hevlín a Dolní Dunajovice (**Doláková**, **Slamková 2003, Doláková et al. 2003)**.

Podle palynologických údajů i dalších geologicko-paleontologických studií (Brzobohatý et al. 2003, **Kvaček et al. 2006**) byla pobřežní oblast Centrální Paratetydy charakteristická nízkým zarovnaným reliéfem, který představoval příznivé podmínky pro tvorbu hojných bažin v příbřežním a deltovém režimu. Během karpatu nebyla na základě paleobotanického studia patrná výrazná šířková ani výšková vegetační zonace v celé karpato - panonské oblasti

Základní charakter zonálních společenstev vyjádřený v poměru teplomilných paleotropických prvků vůči prvkům arktoterciérním se oproti eggenburgu a ottnangu výrazně nezměnil. Převažující formaci tvoří subtropické listnaté lesy s vysokým nebo středním podílem stálezelených dřevin. Některé taxony jako *Symplocos,* Rutaceae a *Platanus* byly oproti předchozímu období nalézány sporadičtěji. Oryktocenózy bažinných facií (Myricaceae, Taxodioideae, *Craigia*, Pteridaceae, Polypodiaceae) a lužních porostů (*Alnus*, Ulmaceae, Lythraceae) se vyskytovaly běžně a často tvořily převažující složku palynospekter. Velmi typické byly asociace s výrazným zastoupením rodu *Craigia*. Obdobné oryktocenózy byly pozorovány v cyprisových jílovcích ze Severočeské pánve pod formálním taxonem *Intratriporopollenites insculptus* Mai (Konzalová (1976) a v karpatských sedimentech lokality Korneuburg (Hofmann et al. 2002).

Zástupci bylinné a keřovité vegetace otevřených stanovišť byli daleko méně zastoupeni než v období předcházejícím. Typické mořské sedimenty - tzv. "šlír" - byly charakteristické vysokým podílem jehličin, zejména rody *Pinus* a *Cathaya,* které se díky velkému doletu pylových zrn těchto větrosnubných rostlin často hromadí v mořských sedimentech (viz kap. 2). Rody *Tsuga* a *Abies* jako zástupci extrazonální vegetace rostoucí převážně ve výše položených oblastech se začínají objevovat v sedimetech z mladších období studovaného intervalu. Dokumentují počátek výzdvihu karpatského orogénu (**Doláková et al. 2003, Kvaček et al. 2006, Kováčová et al. 2011**).

Vyskytovali se rovněž zástupci mořských dinofyt a cysty zelených řas skupiny Prasinophyta, které byly místy nalézány v masovém množství. Tyto akumulace mohly být projevem vodního květu, který se vytváří v důsledku omezené cirkulace a stratifikace vodního sloupce. Pylová zrna a spory byly často degradovány a obsahovaly shluky krychlových dutin (pozůstatky po mikrokrystalech pyritu), které svědčí o existenci prostředí se sníženým obsahem kyslíku (viz kap. 2).

Existence subtropického humidního klimatu byla podpořena i makrofloristickými nálezy na stratotypových lokalitách Slup a Dolní Dunajovice. Asociace byly tvořeny převahou fosilních listů čeledi Lauraceae (pylová zrna této čeledi se nedochovávají ve fosilním stavu) a nízkým zastoupením opadavé flóry (Knobloch 1967, 1982, Kvaček 2003). Azonální vegetace byla reprezentována bažinnými a lužními lesy s dominancí rodů *Glyptostrobus* a *Myrica*. Zjištěny byly i další prvky totožné s nálezy pylových zrn včetně rodu *Craigia*.

Sedimenty spodního miocénu ottnang - karpat byly z palynologického hlediska studovány i z území Modrokameňské pánve na Slovensku (**Doláková 2004**). Charakter oryktocenóz převážně odpovídal pylovým spektrům z karpatské předhlubně. Nejvýraznější rozdíl představovalo zastoupení formálního rodu *Pentapollenites* Krutzsch, který v palynospektrech z území Moravy nebyl zjištěn. Asociace palynomorf poněkud chladnějšího klimatu reprezentovaného zvýšením poměru arktotercierních dřevin popsané z konce ottnangu a počátku karpatu ze sousedních oblastí např. Slovenska, Polska (Planderová 1990, **Planderová et al.1993a**,b, Ważyńska 1998), nebyly v karpatské předhlubni zaznamenány. Tato palynospektra mají ovšem převahu azonálních prvků a změny mohly být odrazem lokálních paleogeografických poměrů (vyšší diferenciace reliéfu).

Velmi obdobný charakter karpatských palynospekter byl publikován ze sedimentů pohoří Mecsek z Maďarska (Nagy 1999). Palynospektra z karpatských sedimentů Korneuburgské pánve v Rakousku vykazovala obdobný charakter zejména azonálních formací. Vysoké poměrné zastoupení palem a nálezy rodu *Avicenia*, který představuje ojedinělý prvek mangrovových porostů v oblasti Centrální Paratethydy, interpretují autoři Hofmann et al. (2002) jako důsledek průniku teplých vod z oblasti Tethydy.

Podle nejnovějších studií a statistického vyhodnocení palynospekter pomocí CA (Doláková et al in prep, jsou na pylových diagramech pozorovatelné cyklické změny poměrného zastoupení teplomilných a arktotercierních prvků. Tato periodicita pokračuje i v následujícím stupni baden.

Ve středním miocénu, který je na území karpatské předhlubně zastoupený stupněm baden, byl vývoj krajiny ovlivněný zejména postupným výzdvihem horských oblastí Západních Karpat a současnou subsidencí přilehlých nížinných oblastí. V palynospektrech je patrný nástup výrazné výškové vegetační zonace (**Kováčová et al. 2011**).

Interpretace vegetace v sedimentech spodního badenu karpatské předhlubně byla publikována zejména v pracích (**Doláková 2004, Doláková et al. 2011, 2014, Kováčová et al. 2011).**

Palynologická data dokumentují subtropické klima v období doznívajícího miocenního klimatického optima (MMCO) a dominancí zonální formace stálezelených širolistých lesů (až přes 30% - *Engelhardia, Platycarya*, stálezelené typy Fagaceae: *Castanopsis, Trigonobalanopsis*). Podíl prvků formace temperátního smíšeného mezofytního lesa a širolistého opadavého lesa byl nižší (např. *Quercus, Carya, Celtis, Juglans*). Oproti palynospektrům spodního miocénu byl zaznamenaný mírný úbytek některých teplomilných prvků (P1 - Sapotaceae, Palmae, Mastixiaceae, Lygodiaceae).

V pylových spektrech byla pozorovaná vyšší diverzita pylových zrn stálezelených i opadavých dubů a nárůst podílu pylových zrn rodu *Platanus*.

Kolísání podílu prvků lužního lesa a pobřežních močálových biotopů a místně zvýšený podíl bylin a heliofytních rostlin vyskytujících se na sušších otevřených areálech byl důsledkem změn humidity. Toto zjištění odpovídá i studiím makrofloristickým. V porovnání s nálezy makroflóry (Knobloch et Kvaček, 1996) indikují palynologické údaje poněkud teplomilnější charakter vegetace. Tento rozdíl může být ovšem způsoben tafonomickými procesy v mořských sedimentech, kde se zejména listová flóra hůře dochovává. Zajímavý fenomén představuje poměrně pravidelná přítomnost rodu *Cercidiphyllum*, který ve starších sedimentech karpatské předhlubně nebyl dokumentován.

Občasné nálezy rostlin typických pro okraje sladkých vod, jako např. *Potamogeton, Sparganium* a kolonie řas (*Botryococcus*), dokumentují přítok sladkých vod do mořské pánve.

Největší pozornost byla věnována lokalitě Židlochovice. Jako na první lokalitě ze studovaného prostoru byly statisticky spočítány na několika bodových vzorcích výsledky CA (**Bruch et al. 2004).** Lokalita reprezentuje hypostratotyp sedimentů spodního badenu a byla proto zpracována nověji z co nejširšího paleontologického (foraminifery, CA nanoplankton, otolity, měkkýši, červené řasy, mechovky, palynomorfy) a sedimentologického hlediska (**Doláková et al. 2014**). Problematika změn paleobiologických, paleoklimatických a sedimentologických podmínek byla pro tuto lokalitu zpracována kontinuálně ve dvou vrtech. Pylová spektra s bohatým a diferencovaným obsahem palynomorf byla zpracována za pomoci CA. Ne všechny studované vzorky byl ovšem k účelům statistického zhodnocení vhodné (viz kap. 2)

Na lokalitě Židlochovice byly ve dvou studovaných vrtech provedeny výpočty teplotních a vlhkostních charakteristik za pomoci CA. Zvyšující se kolísání klimatických charakteristik (zejména teploty a humidity, zvyšující se sezonalita) v rámci subtropické kontinentální vegetace představují finální fázi vrcholícího miocenního klimatického optima (MMCO) a nastupující středně miocenní přechodnou klimatickou fázi (MMCT) (**Doláková et al. 2014**, **Holcová et al 2015**, 2018**)** ve smyslu Zachos et al. (2001), Flower , Kennet (1994). Palynologická studia a studium asociací červených řas napomohla rovněž k indikování prvního šířkového teplotního gradientu od spodního badenu v rámci pobřeží Paratethydy (**Doláková et al. 2008**). Do tohoto období je předpokládána uniformita charakteru klimatu v rámci celé střední Evropy (**Bruch et al 2004**).

Pro studium palynospekter svrchní části středního miocénu (**svrchní baden, sarmat**) nebyly dosud v moravské části karpatské předhlubně (sedimentace končí ve spodním badenu) ani vídeňské pánve nalezeny sedimenty vhodné k zachování pylových zrn a spor. Všechny dosud zkoumané sedimenty byly palynologicky sterilní.

Podstatný nárůst taxonů horské vegetace (*Picea, Abies, Tsuga, Cedrus*), zvýšení podílu arktoterciérní flóry (*Quercus, Ulmus, Carya*) a úbytek subtropických taxonů (*Platycarya, Engelhardia, Myrica, Distylium*, teplomilné Fagaceae, Sapotaceae) v palynospektrech svrchního badenu byl dokumentován na lokalitách Slovenské části vídeňské pánve. Tyto změny jsou interpretovány jako důsledek vzrůstu výškového gradientu souvisejícího s výzdvihem horského oblouku Západních karpat (Kováč et al. 1998, **Doláková et al. 2011**, **Kováčová et al. 2011**).

Studovaná palynospektra svrchního miocénu moravské části Paratethydy pocházela ze sedimentů panonu vídeňské pánve. Vlivem paleogeografických změn se během svrchního miocénu začalo postupně uzavírat spojení s mořskou oblastí Paratethydy. Severní část vídeňské pánve byla postupně vyplňována progradujícími deltovými a říčními faciemi, které přinášely materiál z vyzdvihujících se karpatských horstev. Prostředí se postupně změlčovalo a vyslazovalo (Kováč et al. 1998a,b, 2017). Tento proces byl patrný i ze studia palynologie, kde sporadické výskyty dinoflagelát a zelených řas čeledi Tasmanaceae indikují ještě mořské až brakické prostředí. Místy hojné kolonie rodu *Botryococcus* se mohou vyskytovat jak v brakické, tak sladké vodě. Ovšem kolonie rodu *Pediastrum*, cysty *Mougeotia*, sporangia s glochidii vodní kpradiny *Azolla*, a pylová zrna pobřežních vodních rostlin jako *Nelumbo*, *Nymphaea*, *Myriophyllum*, *Sparganium*, *Potamogeton* reprezentují prostředí sladkých vod (**Doláková, Kováčová 2008, Kováčová et al. 2011)**.

Sedimenty pannonu jsou známé bohatými makrofloristickými nálezy (Knobloch 1962, 1963, 1968, 1969, 1972, 1981, 1985), proto jim byla z hlediska palynologie věnována pozornost již v dřívějších výzkumech (Gabrielová 1966, Kalvoda 1979, Lázničková 2006, Konzalová 2005). V palynospektrech pannonských sedimentů byla oproti spodnímu a střednímu miocénu zaznamenána výrazná změna vegetačního pokryvu. V důsledku paleogeografických změn a klimatických oscilací se množství termofilních taxonů začalo snižovat a některé z tohoto prostoru zcela ustoupily do jižnějších oblastí. Morfologicky pestrý reliéf horských pásem v okolních oblastech vytvořil podmínky pro rozšíření temperátních smíšených mezofytních lesů (*Quercus, Celtis, Tilia, Carya, Zelkova, Ostrya, Carpinus, Juglans)* s minimálním přimíšením stálezelených subtropických taxonů (*Engelhardia*, *Castanea*, stálezelené Fagaceae) a extrazonální horskou vegetaci s jehličnany

Cedrus, Tsuga, Picea (**Doláková, Kováčová 2008, Doláková et al. 2010, Kováčová et al. 2011)**.

V tomto období se lokálně začínají objevovat areály otevřené krajiny se stepním charakterem, tzv. „open woodland“ – „open grassland“, které se projevují zvýšeným procentem výskytu bylinných prvků (10 až 14 % složení spekter) - Poaceae, *Artemisia*, Chenopodiaceae, Asteraceae, Lamiaceae, *Polygonum*, Daucaceae, Caryophyllaceae, *Thalictrum, Rumex, Valeriana*, Dipsacaceae, *Galium, Ranunculus*) a keřovitých forem (*Buxus*, Ericaceae, *Ephedra*). Zjištěny byly rovněž lianovité formy Vitaceae, *Lonicera*, Rosaceae typ *Rubus*) a halofyty (Chenopodiaceae) indikující existenci lokálně zasolených substrátů.

Azonální vegetace se v jednotlivých sekvencích velmi rychle střídaly v čase i prostoru. Pylová spektra tvoří různé facie intrazonálních společenstev, jako např. zasolené příbřežní louky tzv. marše s Chenopodiaceae, Ericaceae, Poaceae, *Tamarix*) lužní lesy (*Alnus, Salix, Betula, Liquidambar, Myrica, Nyssa*), pobřežní močály s Taxodioideae, *Nyssa, Myrica* střídající se s asociacemi otevřených až stepních ploch (tzv. artemisiové stepi).

Na základě pylových společenstev byly za pomoci CA analýzy ze slovenské části vídeňské pánve vypočítány klimatické faktory prostředí (**Doláková, Kováčová 2008**).

Obdobná palynospektra (redukované pobřežní močály a izolovaná sladkovodní jezera obklopená stepními porosty (s dominantním pelyňkem *Artemisia*) s řídkými dřevinami popsala ze slovenské části Podunajské pánve Planderová (1972, 1990). Ve srovnání s palynospektry z Maďarska konstatovala na slovenském území chladnější a sušší klima (Nagy 1985, 2005, Planderová 1990). Pylová společenstva bohatá na zastoupení bylin popsali ze svrchního pannonu Štýrské pánve Hoffmann, Zetter (2005).

3b) Širší problematika neogénu v korelaci palynologie a dalších paleontologických, sedimentologických a geochemických metod výzkumu

Výhodou studia palynologie v mořských sedimentech je možnost korelace palynologických interpretací s paleoklimatickými a paleogeografickými údaji, které vycházejí ze studia dalších paleontologických, sedimentologických, nebo geochemických metod. Proto je poslední dobou práce širšího kolektivu autorů zaměřena na komplexní zpracování studovaných lokalit a tvorbu modelů mořského a terestrického prostředí a jejichvzájemného ovlivňování.

Prozatím nejpodrobnějším studiím byly podrobeny sedimenty spodního badenu nannoplanktonové zóny MNN 5 (obr. 6.). Výsledky palynologického studia byly začleněny do celkového pohledu na vývoj prostředí. Interpretace palynospekter i tafonomické procesy se odrazily nejen ve změnách charakteru vegetace, klimatu a morfologie kontinentu, ale i v interpretacích režimu a morfologie mořské pánve (změny obsahu kyslíku, proudění, hloubky, salinity (**Doláková et al. 2014, Holcová et al. 2015, Nehyba et al. 2016**). Výsledky palynologických studií přispěly i k interpretaci vzniku karbonátových těles mořského původu, které samy jsou palynologicky sterilní. Z hlediska palynologie byly v delších časových profilech zobrazených v sedimentech z vrtných jader patrné periodické sekvence s bohatým obsahem palynomorf (místy s patrnými pseudomorfózami po mikrokrystalech pyritu), střídající se s faciemi s naprostou převahou pylových zrn konifer doprovázenými cystami mořských dinofyt s pouze výjimečně dochovanými dalšími palynomorfami. Tato sekvence bývá následována sedimenty palynologicky sterilními, případně sedimentací vápencových těles. K akumulaci pylových zrn konifer může docházet v důsledku ekologických i tafonomických jevů. Většina pylových zrn konifer má pylová zrna přizpůsobená přenosu větrem (vzdušné vaky). Hromadí se proto v mořských sedimetech vzálených od pobřeží, kam se pylová zrna hmyzosnubných rostlin netransportují. Mohou být navíc doneseny z morfologicky vyvýšených terénů, kde mají některé rody areál původního výskytu (*Tsuga, Cedrus, Picea, Ketelleria*). Pylová zrna konifer jsou rovněž odolnější vůči oxidickým podmínkám v mořské vodě i v sedimentu (Kwiatkowski, Lubliner Mianowska 1957, Havinga 1964, 1967, Brooks 1971, Hopkins, Mc Carthy 2002). Hojnost a diversita palynomorf v sedimentech je v přímé závislosti na oxidačně - redukčním potenciálu (Martin, Drew 1970, Heusser 1978). Akumulace konifer je typická pro oligotrofní podmínky mořské pánve a zvyšující se klimatické výkyvy. Tato klimatická nestabilita (cyklické změny teplot, a humidity) je předpokládaným počátkem středně miocenní klimatické přechodné fáze (MMCT) **(Doláková et al. 2014, Holcová et al. 2015, Nehyba et al. 2016).**

Výsledkem komplexního výzkumu badenských sedimetů je představa režimu pánve ve vzájemných vztazích s podmínkami na přilehlé pevnině (**Holcová et al. 2015, Nehyba et al. 2016)**. Změna režimu v okrajových částech pánve byla v zóně MNN-5 zaznamenána v časovém intervalu mezi posledním výskytem (LO) druhu *Helicosphaera waltrans* (14,36 mil. let) a posledním výskytem druhu *Sphenolithus heteromorphus* (Ca- nanoplankton).

V intervalu pod LO *H. waltrans* vznikaly ve studovaném území pouze siliciklastické sedimenty, režim mořské vody byl více eutrofní - se značným obsahem živin, klima bylo subtropické, poměrně vyrovnané, cyklicita pozorovatelná na mořských organizmech, sedimentech i vegetaci byla nevýrazná. Palynospektra byla diversifikovaná a dobře dochovaná (příklady vrtů Vyškov, Ivaň).

V intervalu nad LO *H. waltrans* byly patrné cyklické změny mořského režimu i klimatu na kontinentu. Sedimentace siliciklastik byla doprovázena v okrajových částech pánve vznikem karbonátových komplexů. Zaznamenány byly cyklické změny mořské hladiny (transgrese, regrese) související s mírou cirkulace vody (dobré prokysličení/ stratifikace vodního sloupce), přínosu živin i teploty (zvyšování sezonality, zvyšování salinity v připovrchových vodách související s aridizací klimatu). Každý cyklus začíná poměrně náhlým oteplováním následovaným postupným ochlazováním. Kromě cyklických změn v zastoupení teplomilných a akrtotercierních prvků spolu s místně zvýšeným zastoupením heliofytních, suchomilných prvků (*Olea, Buxus, Ephedra,* Poaceae, Asteraceae, Caryophyllaceae, Chenopodiaceae) se projevila cyklicita i ve stupni zachování palynomorf. V periodách zvýšené cirkulace vody a dobrého prokysličení se vyskytovala spektra s nadhodnocením Pinaceae. V tomto období byl rovněž na palynospektrech patrný rozdíl v zastoupení vysokohorských prvků na opačných stranách mořské pánve. Na lokalitách bližších k pasivnímu okraji českého masívu bylo zastoupení konifer poměrně monotónní, bez výrazného poměru vysokohorských prvků. Tyto byly naopak častěji přítomné na okraji pánve směrem k orogeneticky aktivnímu horstvu Západních Karpat, což je dokumentováno na řadě lokalit např. Židlochovice, Lomnice, Rebešovice, Chrlice, Otmarov, Opatovice, Oslavany **(Doláková et al. 2014, Holcová et al. 2015, Nehyba et al. 2016)**.

Vznik karbonátového komplexu byl označen jako karbonátový event. (Holcová et al. 2015). Byl doprovázený snížením přínosu terestrického materiálu během transgrese, spojený s oligotrofním režimem, rozšířením tzv. podmořských luk a aridizací klimatu. Siliciklastické vrstvy materiálu uvnitř karbonátů byly palynologicky sterilní.

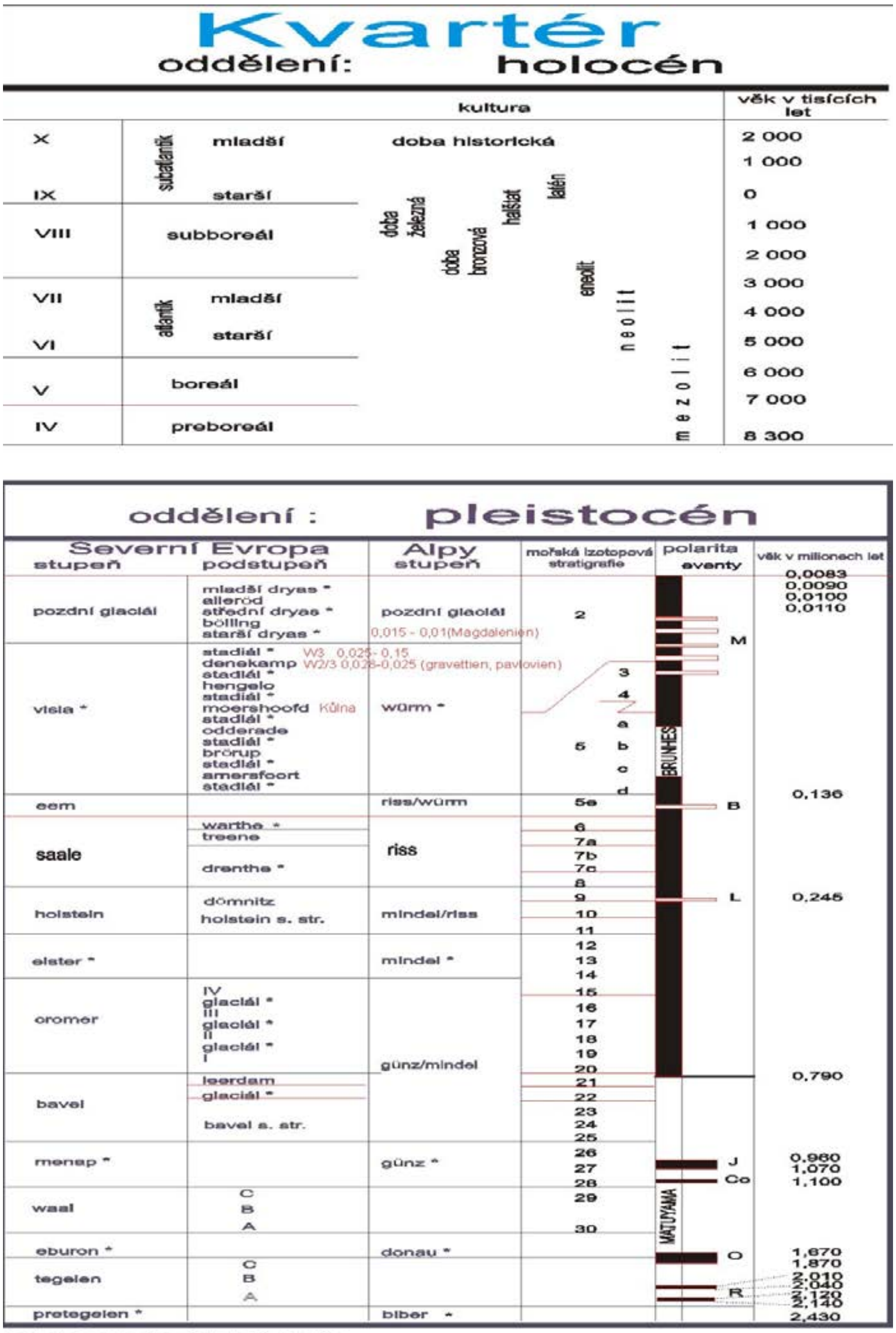
Podle těchto posledních výzkumů z karpatské předhlubně (**Doláková et al. 2014, Holcová et al. 2015, Nehyba et al. 2016)** lze tedy biostratigraficky korelovat zónu vápnitého nanoplanktonu MNN5 Zone nad LO (=Last Occurrence) *Helicosphaera waltrans* 4,6-13,9 mil. let s počátteční fází MMCT. Z dosavadních studií lze předpokládat, že cyklicita mořské sedimentace byla vyvolána klimatickými změnami počátku MMCT.

4. Palynologie vybraných lokalit kvartéru

Vegetace kvartéru (obr. 8) je ovlivněna výraznými klimatickými výkyvy střídajících se chladných a suchých období (glaciálů) a teplejších humidních fází (interglaciálů).

Vegetační pokryv krajiny, který se zobrazuje v pylových spektrech uchovaných v sedimentech z archeologických lokalit, se vyznačuje různě intenzívním dopadem lidské činnosti. V období pleistocénu a raného holocénu ještě nedocházelo k ovlivnění krajiny lidskou činností v masivním měřítku. Základní charakter vegetace souvisel se změnami přírodních podmínek. Pouze v těsném okolí lidských sídlišť byl rostlinný pokryv pozměněn např. v důsledku intenzivněji ošlapávaných ploch nebo přibývající dotací dusíkatých látek v důsledku životní činnosti. V mladších obdobích – počínaje kulturním obdobím neolitu – začal člověk měnit krajinu zásadním způsobem zejména v důsledku zemědělství (odlesňování a s ním spojený proces zvýšené půdní eroze a zvýšení intenzity povodňových sedimentů, domestikace rostlin, extenzívní pěstování kulturních plodin, šíření plevelů, změny původních areálů). Základní problematiku změn kvartérní vegetace v čase shrnují v evropském měřítku zejména práce Firbas 1949, Lang 1994, Litt et al. 2008, Ložek 2007. Problematikou vývoje vegetace z hlediska palynologie na území ČR se zabývali např. Rybníčková (1974, 1985), Jankovská (1971, 1987), Svobodová (1990, 1991). V současné době je studium změn vegetace (zejména od období konce posledního glaciálu) velmi aktuální v souvislosti s porozuměním současnému vývoji a věnuje se mu celá řada mladých specialistů.

V palynologických společenstvech z kvartérních sedimentů se pro zařazení jednotlivých taxonů používá botanický systém.



Kvartér

oddělení: holocén

			kultura	věk v tisících let
X	subatlantik	mladší	doba historická	2 000 1 000
IX		starší	doba železná halštat latén	0
VIII	subboreál		doba bronzová	1 000 2 000
VII	atlantik	mladší	eneolit	3 000 4 000
VI		starší	neolit	5 000
V	boreál		mezolit	6 000 7 000
IV	preboreál			8 300

oddělení : pleistocén

Severní Evropa stupeň	Severní Evropa podstupeň	Alpy stupeň	mořská izotopová stratigrafie	polarita eventy	věk v milionech let
pozdní glaciál	mladší dryas * alleröd střední dryas * bölling starší dryas *	pozdní glaciál 0,015 - 0,01(Magdalenien)	2	M	0,0083 0,0090 0,0100 0,0110
visla *	stadiál * W3 0,025- 0,15 denekamp W2/3 0,028-0,025 (gravettien, pavlovien) stadiál * hengelo stadiál * moershoofd Kůlna stadiál * odderade stadiál * brörup stadiál * amersfoort stadiál *	würm *	3 4 5 a b c d	BRUNHES	
eem		riss/würm	5e	B	0,136
saale	warthe * treene drenthe *	riss	6 7a 7b 7c 8		
holstein	dömnitz holstein s. str.	mindel/riss	9 10 11	L	0,245
elster *		mindel *	12 13 14		
cromer	IV glaciál * III glaciál * II glaciál * I	günz/mindel	15 16 17 18 19 20		0,790
bavel	leerdam glaciál * bavel s. str.		21 22 23 24 25		
menap *		günz *	26 27 28	J Co	0,960 1,070 1,100
waal	C B A		29 30	MATUYAMA	
eburon *		donau *		O	1,670
tegelen	C B A			R	1,870 2,010 2,040 2,120 2,140
pretegelen *		biber *			2,430

* chladné nebo stepní období, glaciály

Obr. 8. Stratigrafie kvartéru (Musil in Přichystal et al. 1996)

4a) Jeskynní sedimenty

Palynologická studia jeskynních sedimentů jsou ztížena tafonomickými problémy v uchování a transportu palynomorf. Proto bylo těmto typům sedimentů na území ČR věnováno pouze málo prací. Palynologickým studiem jeskynních sedimentů se do konce devadesátých let zabývala pouze Svobodová (Svobodová 1988, 1992, Svobodová in Seitl et al. 1986, Svobodová in Svoboda 1991). Jednalo se však vždy o sedimenty jeskynních vchodů a otevřených prostor komunikujících s povrchem.

Hlavním problémem studia palynologie ve vnitřních částech jeskyní je, že rostlinné zbytky zde nejsou uloženy v blízkosti původního stanoviště, ale jsou do jeskynních prostor druhotně transportovány (prosakující voda, spolu se sedimenty nebo v srsti a potravě živočichů). Jedná se proto vždy o oryktocenozu vzniklou smíšením zbytků rostlin z různých míst z povrchu jeskynních systémů. Často dochází i k redepozici a smíšení palynomorf ze sedimentů uložených v různých časových obdobích. V sedimentech moravských krasových oblastí dochází nejčastěji ke smíšení kvartérních a terciérních palynomorf. Značná část rostlinných taxonů se ovšem na našem území vyskytovala v obou těchto útvarech (např. borovice, jilm, olše, dub, lípa ale i byliny jako trávy, složnokvěté nebo i některé druhy kapradin). Jejich přítomnost a rovněž množství v palynospektrech jsou přitom velmi důležité pro stanovení klimatostratigrafie. Během transportu navíc dochází ke korozi a degradaci zrn, a tudíž ani stav zachování a fosilizace nemusí být spolehlivým rozlišovacím znakem. Tento fakt velmi ztěžuje přesné a jednoznačné stanovení stáří sedimentů, ale i interpretace vegetace na povrchu jeskynních systémů. Jednou z možností odlišení různě starých palynomorf představuje studium ve fluorescenčním mikroskopu (viz kap. 2b)

Dalším problémem typickým pro jeskynní palynofacie je selekce palynomorf způsobená odlišnou rezistencí sporopylových obalů vůči transportu (mechanické interakce s horninovými klasty) a chemismu prostředí během sedimentačních pochodů. Tento fakt se projevuje zejména druhotným selektivním nahromaděním odolnějších pylových zrn a spor. Je proto velmi obtížné stanovit, zda palynofacie s převahou určitých prvků ve spektrech odpovídají původnímu ekologickému charakteru prostředí nebo vznikly v důsledku mechanických a chemických procesů během sedimentace. Z moravských krasových území byly zjištěny nadhodnocené akumulace různých pylových zrn a spor. Je evidentní, že existuje několik faktorů ovlivňující tyto akumulace. Prvním z nich je klimaticky podmíněný typ sedimentačního procesu. V příznivějších klimatických fázích se během transportu akumulují zejména pylová zrna lípy a hladké monoletní spory kapradin čeledi Polypodiaceae (dokumentováno např. z jeskyně Ochozské). Drobná pylová zrna podčeledi Asteroideae se naopak kumulují v sedimentech vznikajících během chladného klimatu, např. lokality Sloupsko-Šošůvské, Podhradní, Balcarka, Javoříčko (**Doláková 2007, 2014**)

Další zajímavý tafonomický jev popsali Navarro et al. (2001) z jeskynních sedimentů Španělska. Autoři zjistili, že pylová zrna anemofilních rostlin (zejm. rod *Pinus*), která bývají díky dobrému transportu větrem a velké pylové produkci v povrchových pylových spektrech silně nadhodnocena, ubývají v palynospektrech z jeskynních sedimentů v závislosti na vzdálenosti od jeskynního vchodu. Naopak pylová zrna rostlin zoofilních se směrem do hloubky jeskyní na složení palynospekter podílejí mnohem častěji. Podle španělských autorů se může jednat o transport způsobený živočichy (pylová zrna zoofilních rostlin bývají morfologicky přizpůsobena ke snadnému zachycování na tělech živočichů).

V moravských jeskyních se tento jev podařilo dokumentovat v jeskyni Za hájovnou v Javoříčském krasu (**Doláková 2007**), kde byla studována palynospektra ze dvou míst jedné vrstvy. Sedimenty z profilu v Narozeninové chodbě, které byly situovány ve větší blízkosti k původnímu jeskynnímu vchodu, obsahovaly převahu pylových zrn borovice a poměrně hojné zastoupení lísky (větrosnubné). Naproti tomu oryktocenózy z téže vrstvy profilu Kostnice II, který byl v pozici vzdálenejší, jsou o tato pylová zrna výrazně ochuzená a naopak silně nadhodnocená o zástupce podčeledi Asteroideae. Spektrum bylo celkově výrazně monotónnější.

Faktorem podílejícím se na zachování pylových zrn nepříznivě je vlhkost sedimentu, protože v tomto prostředí se vyskytuje množství hub a bakterií, které rozkládají organickou hmotu, a tudíž i pylová zrna (Navarro et al. 2001).

Z uvedených poznatků vyplývá, že pylová spektra z jeskynních sedimentů nelze jednoduše porovnávat se standardními spektry platnými pro jednotlivá období kvartéru z povrchových sedimentů (např. z rašelinišť). Jejich přesná determinace vyžaduje další studia, zejména tafonomická, a neobejde se bez sedimentologického a paleontologického nebo archeologického výzkumu. Podle studií autorů Carrión et al. (1999) lze za dostatečně vypovídající o charakteru prostředí vně jeskynních sytémů považovat taková, kde bylo determinováno více než 15 taxonů při minimálním počtu 200 pylových zrn a spor ve vzorku.

V rámci mé práce byla palynologická studia prováděna v sedimentech Moravského krasu (jeskyně Ochozská, Balcarka, Sloupsko- Šošůvská a Kůlna, Pod hradem, Dagmar, Barová, Tereza, kaverny lomu Mokrá), Javoříčského krasu (Za Hájovnou) a Hranického krasu (Hranická propast). Studované sedimenty byly kvartérního (holocén, pleistocén) i terciérního stáří (**Doláková 2007, Doláková 2014).**

V Ochozské jeskyni byly studovány 2 profily, které měly obdobný charakter palynospekter. Z palynologického hlediska se daly rozdělit do dvou částí. Ve spodní části profilů převládala pylová zrna a spory vegetace chladné stepi (rody *Helianthemum, Thalictrum, Selaginella selagineloides, Saxifraga, Ephedra*) spolu s teplotně nenáročnými dřevinami, odolnými vůči chladu (*Pinus cembra, Betula, Salix*) a mokřinnými rostlinami (Cyperaceae, *Potamogeton, Botryococcus, Pediastrum*). Nálezy cenobií zelené řasy druhu *Pediastrum kawraiskyi* dokumentují existenci velmi chladného klimatu (Jankovská, Komárek 1982). Tyto části profilů vznikaly s největší pravděpodobností v některé z chladných fází pozdního glaciálu.

Svrchní partie obou profilů byly typické jednotvárnými palynospektry s vysokou akumulací pylových zrn lípy (*Tilia*) a hladkými monoletními sporami čeledi osladičovitých Polypodiaceae. Přes tento vyselektovaný charakter palynospekter prokazují přítomná zrna lípy charakter některého z teplejších klimatických období. Radiometrické datování sintrové polohy v nadloží profilů detekovalo stáří vrstev sedimentů jako vyšší než 28 000 let (Kadlec et al. 2000). Vylučuje tedy holocenní stáří těchto sedimentů s teplomilnějším charakterem vegetace. Velmi obdobná palynospektra byla zjištěna ve stalagmitech z belgické jeskyně Han - sur - Lesse, která byla datována do období 37 000 BP Bastin et al. (1987).

Profily, ve kterých byly patrné střídající se klimatické fáze posledního glaciálu (wisla) byly zjištěny i v jeskyni Balcarka. Palynologická studia byla prováděna v zámci záchranného archeologického výzkumu. Vchodové partie jeskyně jsou známy jako sídliště magdalenských lovců (13 000 – 11000 BP) (Nerudová et al. 2010). Spodní části profilů z vnitřních částí jeskynního systému obsahovaly oryktocenózy s převažujícími heliofytními stepními rostlinami (Asteroideae, *Artemisia,* Poaceae, Ranunculaceae, *Delphinium, Chrysosplenium*) a málo četnými dřevinami (*Pinus, Betula*, *Alnus*), které patrně odpovídají chladné fázi pozdního glaciálu.

Nadložní sedimenty obsahovaly vyšší zastoupení dřevin s převahou lísky (*Corylus),* hojnou borovicí (*Pinus)*, břízou (*Betula)*, olší (*Alnus)*, lípou (*Tilia)* a sporadicky smrkem (*Picea*). Tyto sedimenty pravděpodobně vznikaly během teplejších výkyvů posledního glaciálu nebo během raného holocénu (boreál). K bližší charakterizaci by ovšem bylo třeba dalších tafonomických, sedimentologických a archeologických výzkumů.

Palynologické studium spodních částí opěrného profilu ve vchodové části jeskyně Kůlna poskytlo možnost srovnání s palynospektry vzorků odebíraných ve vnitřních částech Sloupsko-Šošůvských jeskyní, které jsou s Kůlnou propojené. Opěrný profil v jeskyni Kůlna byl podrobně zpracován z hlediska archeologického i paleontologického. Obsahuje sedimenty, které se uložily v době od závěrečných fází saalského glaciálu (vrstva 14), přes interglaciál eem (vrstvy 13,12,11a,c), poslední glaciál würm (wisla) (9b, 8a, 7a, b, c, 6) a holocén (1-5) (Valoch et al. 1988). Jeho nejsvrchnější vrstvy palynologicky zpracovala Svobodová (1988, 1992**).** Vrstvy 1- 4 klasifikovala jako holocenní, paleovegetace vrstvy 6 odpovídala chladné oscilaci pozdního glaciálu. Předmětem mého studia byly vrstvy 14 - 7. Z palynologického hlediska bylo možné pozorovat klimatické oscilace, které se odrážely ve vývoji vegetace. Palynospektra spodní části profilu dokumentovala zalesněnější krajinu s mírnějším klimatem. Vrstva 14 indikovala oteplování v období závěru saalského (riss) glaciálu. Vrstva 13 optimum a vrstva 11 zhoršení podmínek na konci interglaciálu eem.

Svrchní části profilu (vrstvy 9b - 7a, vrstva 7c byla radiometricky datována do období 45 000 BP) prokazovaly parkovitý charakter krajiny, kde se chladná stepní vegetace (*Selaginella selaginoides, Thalictrum, Ephedra, Botrychium*) střídala s nehojnými lesními porosty s nenáročnými dřevinami a častými mokřinami (Cyperaceae, *Sphagnum*). Mírně teplejší charakter klimatu byl pozorován ve vrstvách 8a a 7c (sporadické nálezy taxonů *Tilia, Acer, Teucrium, Centaurea scabiosa*). Mírné odchylky v charakteru vegetace a nálezech fauny drobných savců mohly být způsobeny lokálními podmínkami v morfologicky členitém povrchu Moravského Krasu. Vzorky z vnitřních partií Sloupsko – Šošůvských jeskyní obsahovaly převahu bylinné stepní vegetace a byly korelovatelné s chladnějšími obdobími z vrchní části profilu v Kůlně (würm až počátek holocénu). Tyto interpretace potvrdily i nálezy části koster jeskynních medvědů (*Ursus spelaeus*).

Nejstarší studovaná palynospektra kvartérních sedimentů byla zjištěna v jeskyni Za Hájovnou v Javoříčském krasu (**Doláková 2007, 2014**). Převážná většina studovaných sedimentů byla paleontologicky i radiometricky datována jako interglaciál holstein (Musil 2005, Musil et al. 2014). Palynospektra byla studována z několika profilů převážně suťových kuželů v různé vzdálenosti od původního jeskynního vchodu i z několika jeskynních komínů. Palynologická studia potvrdila mírný charakter klimatu, optimální pro růst smíšených lesů (*Carpinus, Hedera, Acer, Tilia, Corylus).* Ojediněle byla nalézána pylová zrna rodů *Pterocarya* a *Ilex*, která představují prvky vegetace typické pro naše území v neogénu. Tyto rody přežívají ve střední Evropě nejstarší kvartérní zalednění a opětně migrují na naše území v teplejších obdobích. Představují vegetaci typickou pro klimatické optimum holsteinského interglaciálu (Dyjakowska 1952, Vodičková-Kneblová 1961, Břízová 1994, Bińka et al. 1997, Reille et al. 2000, Urban, Sierralta 2012). Jejich poslední výskyt je dokumentován právě v interglaciálu holstein (Lang 1994, Litt et al. 2008, Roucoux et al. 2008).

Jediná pylová spektra, která měla odlišný charakter, pocházela z jeskynního komínu. Spektrum obsahovalo akumulaci pylových zrn podčeledi Asteroideae a nálezy vlhkomilných prvků. V souhlasu s výsledky studia drobných savců vznikaly tyto sedimenty v podmínkách chladnějšího klimatu a vegetační pokryv tvořila chladná step.

Změny palynospekter napomohly i interpretacím sedimentologickým, např. rozdělení suťového kužele do dvou úrovní, které bylo podmíněno klimaticky. V profilech byla pozorována i selekce, degradace a sekundární akumulace odolnějších pylových zrn v důsledku chemickýcch, mechanických i mikrobiologických vlivů (viz výše).

4b) Archeologické lokality – vliv člověka na prostředí

Záchranný archeologický výzkum lokality Brno-Štýřice III zachytil v rámci střední Evropy poměrně ojedinělý záznam lidského osídlení (epigravettien) v období krátce po skončení posledního glaciálního maxima (LGM; 21 000 ± 2000 cal. BP). Interpretace klimatu se opíraly o studia malakologie, palynologie a antrakologie (**Nerudová et al. 2016**).

Výsledky paleobotanické i malakologické analýzy dokumentovaly glaciální charakter okolní krajiny s převládající světlomilnou vegetací charakteru travnaté stepi až keřovité tundry (Poaceae, *Helianthemum, Ephedra*). Zjištěny byly otevřené lesní porosty břízy, vrby a střemchy (*Prunus padus*), které byly podmíněny existencí příznivějšího mikroklimatu a vlhčích stanovišť v okolí velkého vodního toku (Svratka). Lokalita představuje příklad mikroklimaticky příznivějšího refugia pro lidské sídliště z období konce svrchního paleolitu. Toto období je charakteristické absencí archeologické evidence ve značné části Evropy (Feurdean et al. 2014, Heiri et al. (2014) potvrzující dekolonizaci obrovských, dříve osídlených území vlivem extrémních klimatických podmínek předcházejících osídlení magdalénienu (**Nerudová et al. 2016**).

V rámci vědeckovýzkumného záměru MSM0021622427 „Interdisciplinární centrum výzkumů sociálních struktur pravěku až vrcholného středověku“ byly od roku 2005 z komplexního přírodovědného hlediska studovány zejména 2 významné archeologické lokality: Těšetice a Pohansko.

Lokalita Těšetice je významné archeologické naleziště s polykulturním osídlením zahrnujícím především sled hlavních neolitických kultur s dominantní starší fází moravské malované keramiky (MMK), dále osadu únětického lidu a posléze i intenzívní osídlení horákovské kultury doby halštatské (Podborský 1988). Od roku 1967 zde probíhá systematický archeologický výzkum. Rozkládá se severozápadně od obce Těšetice a jihozápadně od osady Kyjovice v nadmořské výšce 265-290 m v údolí potoka Únanovka. Zatímco osada starší fáze MMK je situována na vyšších místech svahu, sídliště únětické a halštatské je posunuto níže po svahu východním směrem. Na vrcholku táhlého návrší lokality byl objeven rondel lidu s MMK (Podborský 1988).

Dřívější paleobotanický výzkum lokality prováděl Opravil (1961). Studován byl především materiál uhlíků. Největší část vzorků pocházela z halštatských objektů, jen málo z objektů doby bronzové a neolitu. Podle Opravila (1961) se vegetace těšetického halštatu vyznačovala početným zastoupením světlomilných dřevin, hlavně křovin, rostoucích obyčejně na volných prostranstvích, okrajích lesů anebo tvořících podrost ve světlých lesích. Nejrozšířenější lesní společenstva byla svazu *Quercion pubescentis*. Vedle uhlíků byly nalezeny v mazanici sídelních objektů otisky obilek a plev ovsa (*Avena*) (Opravil 1961).

V rámci výzkumného záměru bylo na lokalitě provedeno 5 mělkých vrtů (do10 m), které většinou obsahovaly palynomorfy jen velmi sporadicky. Jediný vrt, který poskytl bohaté palynologické asociace, byl vrt T4 situovaný v nivě říčky Únanovky cca 500 m jv. od vlastní lokality. Výsledky tohoto vrtu byly propojeny s výsledky dalšího vrtu z nivy Únanovky pod sídlištěm Staré zámky a společně publikovány (**Petřík et al. 2014).**

Sedimenty z obou vrtů v nivních sedimentech poskytly data z významné části období holocénu (v rozmezí 5211-5008 cal. BC po současnost). Vrty by studovány za pomoci metod sedimentologie, palynologie, makrozbytkové analýzy, malakozoologie, datování ^{14}C. Etapy lidského osídlení byly konfrontovány s vývojem nivní sedimentace. Báze tvorby sedimentace nivy byla zaznamenána na počátku neolitu. Okolní prostředí odpovídalo smíšenému lesu s převahou dubu – Quercetum mixtum (*Quercus, Tilia, Carpinus, Pinus*), s keřovitým podrostem (*Corylus, Cornus*). Bylinná složka byla tvořena zejména trávami a ostřicemi (Poaceae, Cyperaceae). Na konci neolitu a počátku eneolitu se začínají v pylových spektrech objevovat zrna obilovin. Klimatické změny během přechodu neolit/ eneolit a vzrůstající intenzita lidské činnosti v souvislosti se zemědělstvím (odlesňování, orba, zvyšující se pěstování kulturních plodin, zejména obilí) vedly i k výrazné akumulaci sedimentů v nivě. Zvyšující se intenzita civilizačního impaktu byla patrná v průběhu celého eneolitu. Ve spektrech se začínají objevovat rostliny typické pro ruderalizovaná stanoviště (*Artemisia, Chenopodium*).

V následujícím období jsou změny v sedimentárním záznamu a vegetaci jen velmi málo zřetelné. Od doby bronzové byla niva pokrytá zejména nitrofilní vegetací. Ačkoli na studovaném území nejsou známé archeologické doklady pro období římské a stěhování národů, v pylovém záznamu dokumentovaném C14 datováním (1320 BC - 1050 BC), jsou z tohoto období zaznamenána zrna obilovin, která lidskou činnost v této době dokládají. Ve vzorcích byla rovněž viditelná převaha bylin nad dřevinami, která by v tomto areálu bez lidského zásahu nebyla pravděpodobná. Zvýšený podíl zaznamenala rovněž líska (*Corylus*), vyskytující se v prosvětlených oblastech lesních okrajů, která mohla být i lidmi záměrně šířená. Výrazná změna sedimentace i palynospekter byla viditelná od středověku. Podle radiokarbonového datování byly tyto změny patrné od doby hradištní (230 - 410 AD). Dřeviny ze spekter téměř vymizely, zastoupeny byly pouze v podobě lužních porostů v zaplavovaném prostředí nivy (*Alnus, Salix*). Výrazné odlesnění se proto projevilo zejména v sušších, pro pěstování plodin vhodných místech. Dominantní vegetace měla charakter nitrifikovaných stanovišť (*Sambucus*, Chenopodiaceae, Cichorioideae, *Urtica*, *Polygonum aviculare*). V sedimentačním záznamu od období vrcholného středověku do současnosti byla intenzívní lidská činnost patrná z akcelerace eroze a akumulace v nivě doprovázená zvýšenou koncentrací fosfátů (**Petřík et al. 2014**).

Lokalita Pohansko u Břeclavi představuje jedno z center raně středověkého slovanského osídlení – Velkomoravské říše (9. století). Velkomoravské hradisko Břeclav-Pohansko patří i v evropském měřítku k nejlépe prozkoumaným a zpracovaným raně středověkým lokalitám svého druhu (Dresler, Macháček 2013). Systematické archeologické výzkumy katedry prehistorie FF MU v Brně pod vedením prof. dr. Františka Kalouska a prof. dr. Bořivoje Dostála zde byly zahájeny v roce 1958 (Vignatiová 1992). Pro vědecké účely zde byla do roku 1990 odkryta, zdokumentována a vědecky vyhodnocena plocha větší než 137 380 m^2 (Macháček 2000).

Lokalita je situována v nadloží neogenních sedimentů vídeňské pánve. Kvartérní sedimenty, ve kterých se nacházejí archeologické doklady, patří soutokové oblasti, v dnešní době až několik kilometrů široké společné údolní nivě Dyje, Moravy a Kyjovky. Jedná se o litologicky pestré říční (povodňové hlíny, jíly, fluviální písky, štěrky) a eolické sedimenty (váté písky, spraše) a subfosilní půdy (Havlíček 2001**, Macháček et al. 2007**). Oblast je jedním z nejníže situovaných areálů ČR. Nachází v nadmořské výšce 155-157 m. Kromě velkomoravského osídlení je lokalita je známá jako stará sídelní oblast s archeologickými doklady od mezolitu, přes neolit, eneolit, dobu bronzovou, dobu železnou reprezentovanou hlavně obdobím laténu, dobu římskou a dobu stěhování národů, která zahrnuje nejmladší předslovanské osídlení. V období Velkomoravské říše je známá jako jedno ze tří hlavních sídelních center (Macháček 2005).

Širší okolí lokality byla centrem zájmu řady paleobotanických výzkumů zahrnujících rekonstrukce vývoje vegetace údolní nivy Dyje a Moravy (Břízová and Havlíček (2002), Jankovská et al. (2003), Opravil (1962, 1978, 1983b), Rybníček and Rybníčková (2001).

Rybníček a Rybníčková (2001) předpokládali během raného atlantiku v území nivy vývoj travnatých subxerofylních doubrav a smíšených dubo-lipových lesů s jedlí na středně vlhkých stanovištích. Vegetace byla intenzivně měněna vlivem odlesňování, pěstování kulturních plodin a pastvy už během doby bronzové a starší doby železné.

Podle Ložka (2007) a Opravila (1999) způsobilo zvýšení srážek ve spodním atlantiku zvýšení eroze a první zarovnávání níže položených nik v území údolní nivy. Od této doby krajina postupně nabývá moderního charakteru. Podle Opravila (1978, 1983b, 1999, 2000) měla vegetace v okolí raně středověkých hradišť oproti dnešnímu stavu vyšší diverzitu a jiné kvantitativní proporce v důsledku vyšší morfologické rozrůzněnosti stanovišť. Vegetační pokryv údolní nivy byl tvořen převážně lužními lesy a vlhkými loukami.

Jediné dřívější palynologické zpracování pocházející přímo ze sedimentů areálu Pohanska publikovala Svobodová (1990). Ve studovaném profilu zdokumentovala zvyšující se lidský impakt na vegetaci: odlesňování, přítomnost synantropních prvků (jako např. *Artemisia, Plantago lanceolata, Convolvulus arvensis, Centaurea cyanus*, Viciaceae) a kulturních rostlin (zejména obilniny Cerealia). Ve srovnání s dalším velkomoravským centrem Mikulčice, které mělo charakter městské aglomerace s velkým zemědělským zázemím, bylo Pohansko obklopeno smíšenými dubovými lesy. Bohužel, studovaný profil neobsahoval archeologické záznamy, které by zpřesňovaly polohy s vlastním slovanským osídlením.

V současné době představuje lokalita Pohansko jednu z nejdetailněji palynologicky studovaných lokalit. Palynologická studia probíhala v rámci společného výzkumného záměru a grantů Ústavu geologických věd PřF MU a Ústavu archeologie pravěku a středověku FF. Bylo prostudováno 13 vrtů do 20m, 12 kopaných nebo zarážených sond, 2 bagrované profily, 11 profilů objekty, 21 vzorků z hrobových jam a více než 15 jednotlivých vzorků.

Největší pozornost byla v součinnosti s archeology věnována profilům v rámci archeologického řezu valem (profil před opevněnín, pod ním a na vnější straně, vzorky z výplně mezi kameny valu). Nejnovější výsledky jsou v současné době odeslány nebo připravovány do tisku v rámci interdisciplinárních výzkumů. Dosud publikované palynologické výzkumy byly shrnuty zejména do prací **Macháček et al. 2007** a **Doláková et al. 2010.** Protože ne všechny profily a vrty poskytly kontinuální palynologická data, byla část výsledků stratigraficky kompilována podle litologických charakteristik a C14 datování.

Nejspodnější části některých mělkých průzkumných vrtů zasáhly do svrchnomiocenních sedimentů (pannon) vídeňské pánve, která tvoří podloží kvartérních sedimentů. Jejich palynologický obsah byl diskutován v kapitole 3ab. V jejich nadloží byly místy zachovány sedimenty pleistocenní v podobě hrubozrnných štěrků, které neposkytly palynologické doklady. Největší část studovaných sedimentů patřila holocénu.

Nejstarší sedimenty datované metodou C14 pocházely z období mezolitu (14C in 8240 cal BP), nejmladší ze 16. století. Změny v proporcionálním zastoupení jednotlivých rostlinných typů, které byly pozorovatelné v pylových diagramech, byly způsobené zejména změnami povahy substrátu v závislosti na změnách humidity a rovněž lidskou aktivitou (odlesňování, pěstování plodin, pastva).

Na bázi studovaných holocenních sedimentů byly palynologicky zdokumentovány tafocenózy původních lesních porostů s nízkým ovlivněním lidskou činností. V pylových spektrech převažovaly habrové doubravy s lípou (*Quercus* tvořil dominantní složku), které se v čase i prostoru střídaly s lužními lesy (s převahou *Alnus*, méně *Ulmus, Fraxinus, Salix* and *Populus*). Křoviny byly zastoupené méně, pravidelněji byla přítomná líska (*Corylus*). Dřeviny ve spektrech převažovaly nad bylinami, ale krajina nebyla zcela zalesněná.

Nejstarší výrazný úbytek dřevin současně s nálezy pylových zrn obilnin (Cerealia) i polních plevelů jako *Polygonum aviculare* (rdesno ptačí), (*Centaurea cyanus*) chrpa modrák a druhotných antropogenních ukazatelů jako: jitrocel kopinatý (*Plantago lanceolata)* , šťovík kyselý (*Rumex acetosella),* chmel/konopí (*Humulus*/*Cannabis)* a merlíkovité (Chenopodiaceae) prokázaly zemědělskou činnost už v období neolitu (S1: 127cm: 7050 BC - 6450 BC). Protože byly tyto pylové asociace nalezeny ve vrstvách z těsného podloží spodních povodňových sedimentů, jeví se tento výrazný lidský zásah do krajiny jako pravděpodobná příčina zvýšeného výskytu povodní a akumulace povodňových hlín. Výrazné lidské ovlivnění krajiny bylo dokumentováno rovn ěž v palynospekterch ze sedimentů datovaných do období hallstattu (O1: 820 BC - 520 BC). Částečná rejuvenace lesních porostů v nadložních sedimentech poukazuje na snížení intenzity lidského působení. Tato obnova lesa byla potom následována nejvýraznějším odlesněním pozorovaným v období existence velkomoravské aglomerace a vzniku jejího opevnění studovaného zejména ve vzorcích z kultruní vrstvy vytyčené archeologickými nálezy. V nejmladších povodňových sedimentech nad velkomoravskou vrstvou byla pozorována částečná rejuvenace dřevin v podobě zvýšení nálezů zejména pionýrských porostů borovic a břízy (*Pinus, Betula*). Došlo tedy ke snížení lidského impaktu.

V rámci palynologického studia na Pohansku bylo zjištěno několik zajímavých problematik. V pylových spektrech se poměrně často objevovala pylová zrna ořešáku (*Juglans*). Tato dřevina není na našem území původní. Místní nabohacení v pylových spektrech umožňuje předpoklad záměrného pěstování, i když prozatím nebylo doloženo makrobotanickými nálezy. Existence palynomorf vodních a vlhkomilných rostlin vně a v těsném podloží opevnění a naopak jejich absence ve stejně starých sedimentech z vnitřní strany valu mohou poukazovat na možnos, že opevnění fungovalo jako ochrana nejen proti úočníkům, ale jako ochrana při povodních. Podporu pro toto tvrzení přinesl samotný řez valem, kdy během intenzivních jarních povodních v r. 2007 došlo k zatopení velké části vnitřní strany plochy hradiska. Výskyt pylových zrn habru (*Carpinus*) v sedimentech datovaných do raného Atlantiku indikuje jeho dřívější šíření na území jižní Moravy, než je tradičně předpokládáno pro území ČR jako celku (Firbas 1949), a podporuje tak interpretace Opravila (1983a) a Rybníčkové (1985). Redepozice těchto pylových zrn z miocenních sedimentů byly vyloučeny na základě studia autofluorescence.

Použitá literatura:

Bastin B., Deflandre G., Quinif Y., (1987): Mise en évidence d'un réchauffement majeurau sein de la derniére glaciation, enregistré dans un plancher stalagmitique de la Grotte du Pére Noė (Han-sur-Lesse, Belgique). - Colloque international de sedimentologie karstique. Han-Sur-Lesse Belgique, 518-522.

Bińka K., Lindner L., Nitychoruk J. (1997): Geologic-floristic setting of the Mazovian Interglacial sites in Wilczyn and Lipnica in southern Podlasie (eastern Poland) and their palaeogeographic connections. - Geological Quarterly, 41, 3, 381-394.

Břízová E. (1994): Vegetation of the Holsteinian Interglacial in Stonava - Horní Suchá (Ostrava region). - Sbor. Geol. věd, Anthropozoikum, 21, 29-56.

Břízová E., Havlíček P. (2002): Několik poznámek k pylové analýze kvartérních sedimentů z Mikulčic na jižní Moravě. - Zpr. Geol. Výzk. v r. 2001, 124-126.

Böhme M. (2003): Miocene Climatic Optimum: evidence from Lower Vertebrates of Central Europe. – Palaeogeography, Palaeoclimatology, Palaeoecology, 195, 389-401.

Böhme M., Ilg A., Ossig A., Küchenhoff H. (2006): New method to estimate paleoprecipitation using fossil amphibians and reptiles and the middle and late Miocene precipitation gradients in Europe. - Geology, 34, 6, 425-428.

Brooks J. (1971): Some chemical and geochemical studies on sporopollenin: - In: Brooks J., Grant P.R., Muir M., van Gijzel P., Shaw G. (Eds.), Sporopollenin. Academic Press, London. 351-407.

Bruch A. A., Uhl D., Mosbrugger V. (2007): Miocene Climate in Europe - Patterns and Evolution. – a first synthesis of NECLIME. Palaeogeogr., Palaeoclimat., Palaeoecol. 253, 1-7.

Bruch A. A. Utescher T., Alcade Olivares C., **Dolakova N.,** Ivanov D., Mosbruger V. (2004): Middle and Late Miocene spatial temperature patterns and gradients in Europe - preliminary results based on paleobotanical climate reconstructions. - Cour.forsch.-Inst. Senckenberg, 249, 15-27.

Bruch A. A., Utescher T., Mosbrugger V., NECLIME members (2010): Precipitation patterns in the Miocene of Central Europe and the development of continentality. - Palaeogeography, Palaeoclimatology, Palaeoecology. 304, 202-211.

Brzobohatý R., Cicha I., Kováč M., Rögl F. (2003): The Karpatian a Lower Miocene stage of the Central Paratethys. - Masaryk University Brno, 360p.

Carrión J. S., Munuera M., Navarro C., Burjachs F., Dupré M., Walke, M. J. (1999): The palaeoecological potential of pollen records in caves: the case of Mediterranean Spain. - Quaternary Science Reviews, 18, 1061-1073.

Doláková N. (2002): Palynologické studium sedimentů Šošůvské části Sloupsko – Šošůvských jeskyní a spodní části opěrného profilu v jeskyni Kůlna - Acta Mus. Moraviae, Sci. geol., LXXXVII, 275-288.

Doláková N. (2004): Discussion on some Thermophile palynomorphs from the Miocene sediments in the Carpathian Foredeep (Czech Republic) and Modry Kamen basin (Slovakia). - Acta Palaeobotanica 44, 1, 79-85.

Doláková N. (2007): Palynological studies in the Cave sediments from the Moravian, Javoříčko and Hranice Karsts - Czech Republic. - Scripta Fac. Sci. Natur. Universitatis Masarykianae Brunensis. 2007, Geology,. 35, 47-53.

Doláková N. (2014): Palynological analysis of Sediments from Za Hájovnou Cave. - Acta Musei Nationalis Pragae, Series B - Historia Naturalis, 70 (1-2), 35-42.

Doláková N., Burešová A. (2007): Use of fluorescent microscopy in the study of redeposited palynomorphs in the cave and marine sediments of Moravia (Czech Republic). - Acta Palaeobotanica, 47, 1., 275-279.

Doláková N., Brzobohatý R., Hladilová Š., Nehyba S. (2008): The red-algal facies of the Lower Badenian limestones of the Carpathian Foredeep in Moravia (Czech Republic). - Geologica Carpathica 59, 2, 133-146.

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

Doláková N., Hladilová Š., Petrová P., Švábenická L., Zlinská A., Halásová E., Andreyeva-Grigorovich A. S., Kvaček Z **(2003):** Hypostratotypes of the Karpatian Stage. - In: Brzobohatý R., Cicha I., Kováč. M., Rögl F. eds.: The Karpatian a lower Miocene stage of the Central Paratethys. Masaryk University Brno, 21-26.

Doláková N., Holcová K., Nehyba S., Hladilová Š., Brzobohatý R., Zagoršek K., Hrabovský J., Seko M., Utescher T. (2014**):** The Badenian parastratotype at Židlochovice from the perspective of the multiproxy study. - Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, Stuttgart, E. Schweitzerbartsche Verlagsbuchhandlun, 271, 2, 169-201.

Doláková N., Kováčová M. (2008): Pannonian vegetation from the northern part of Vienna basin. - Acta Musei Nationalis Pragae Series B - Historia Naturalis 64 (2-4), 63-171.

Doláková N., Kováčová M., Basistová P. (2011): Badenian (Langhian – Early Serravallian) palynoflora from the Carpathian Foredeep and Vienna Basin (Czech and Slovak Republics). - Acta Musei Nationalis Pragae, Series B - Historia Naturalis 67 (1-2), 51-59.

Doláková N., Roszková A., Přichystal A. (2010): Palynology and Natural Environment in the Pannonian to Holocene sediments of the Early Medieval Centre Pohansko near

Břeclav (Czech Republic). - Journal of Archaeological Science, USA/UK 37, 10, 2538-2550.

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

Dresler P., Macháček J. (2013): Vývoj osídlení a kulturní krajiny dolního Podyjí v raném středověku. - Archeologické rozhledy LXV, 4, 663-705.

Dresler P., Macháček J. (2009): Břeclav-Pohansko: Stav zpracování výzkumů předhradí. In Archeologie doby hradištní v České a Slovenské republice. - Masarykova univerzita Brno.

Dyjakowska J. (1952): Róstlinność plejstocénska w Nowinach Żukowskich [Pleistocene flora of Nowiny Żukowskie on the Lubin Upland]. – Biul. Inst. Geol., 67, 115-181.

Erdtman G. (1957): Pollen and Spore Morphology. Plant Taxonomy. Gymnospermae, Pteridophyta, Bryophyta. Almquist and Wiksell, Stockholm, 151 pp.

Erdtman G. (1960): The acetolysis method, a revised description. - Svensk Bot. Tidskr., 54, 561pp.

Feurdean A, Perşoiu A, Tanţău I et al. (2014): Climate variability and associated vegetation response throughout Central and Eastern Europe (CEE) between 60 and 8 ka. - Quaternary Science Reviews 106, 206-224.

Firbas F. (1949): Spät- und nachzeitliche Waldgeschichte Mitteleuropas nördlich der Alpen. I. Allgemeine Waldgeschichte, Jena. 480pp.

Flower B. P., Kennett J. P. (1994): The middle Miocene climatic transition: East Antarctic ice sheet development, deep ocean circulation and global carbon cycling. - Palaeogeography, Palaeoclimatology, Palaeoecology, 108, (3-4), 537-555.

Gabrielová N. (1966): Preliminary report about palynological research at the locality Poštorná. (in Czech) - Zpr. geol. výzk. 1966, 285-286.

Gabrielová N. (1986): Laboratorní metody v mikropaleontologii. - Ústřední ústav geologický. Metodická příručka Ústředního ústavu geologického. Praha, 63 s.

Halbritter H., Weber M., Zetter R., Frosch-Radivo A., Buchner R., Hesse M. (2006). PalDat – Illustrated Handbook on Pollen Terminology. - Univ. Vienna, 61pp.

Harzhauser M., Piller E.W. (2007): Benchmark data of changing sea – Palaeogeography, Palaeobiogegraphy and events in the Cenral Paratethys during the Miocene. Palaeogeography, Palaeoclimatology, Palaeoecology, 253**,** 8-31.

Havinga A. J. (1964): Investigation into the differential corrosion susceptibility of pollen and spores. - Pollen et Spores, 6, 621-635.

Havinga A. J. (1967): Palynology and pollen preservation. - Review of Paleobotany and Palynology, 2, 81-98.

Havinga A. (1971): An experimental investigation into the decay of Pollen and spores in various soil types. - In: Brooks J., Grant, P. R., Muir, M., van Gijzel, P., Shaw, G. (eds.), Sporopollenin, Academic Press, London, 446-478.

Havlíček P. (2001): Geologická stavba velkomoravského mocenského centra Břeclav Pohansko a jeho okolí. - Zpr. Geol. Výzk. v roce 2000, 71-73.

Heiri O., Brooks S. J., Renssen H. et al. (2014): Validation of climate model-inferred regional temperature change for late-glacial Europe. - Nature Communications 5: 4914.

Heusser L. (1978): Spores and pollen in the marine realm.- In: Haq, B. U. & Boersma A. (Eds.): Introduction to marine micropaleontology, Elsevier Science, 327–339.

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

Hofmann Ch. Ch., Zetter R. (2005): Reconstruction of Different Wetland plant Habitats of the Pannonian Basin System (Neogene, Eastern Austria). - Palaios, 20, 266-279.

Holcová K., **Doláková N.,** Vass D., Zágoršek K., Zelenka J. (1996): Morský vývoj v spodnom badene v strhársko-trenčskej prepadline z pohľadu foraminiferových, machovkových a ostrakódových spoločenstiev a palynológie. - Mineralia Slovaca, 28, 99-119.

Holcová K., Hrabovský J., Nehyba S., Hladilová Š., **Doláková N**., Demeny, A. (2015): The Langhian (Middle Badenian) carbonate production event in the Moravian part of the Carpathian Foredeep (Central Paratethys): a multiproxy record . - Facies, 61, 1, 3-17.

Hopkin, J. A., Mc Carthy F. M. G. (2002): Post-depositional palynomorph degradation in Quaternary shelf sediments a laboratory experiment studying the effects of progressive oxidation. - Palynology, 26, 167-184.

Jankovská V. (1971): The development of vegetation on the western slopes of the Bohemian-Moravian Uplands during the late holocene period. A study on based on pollen and macroscopic analyses. - Folia Geobot. Phytotax., 6, 281-302.

Jankovská V. (1987): Entwicklung des Moores Mokré Louky bei Třeboň im Postglazial (paläoökologische Studie). - Follia Geobot. Phytotax., 22, 199-216.

Jankovská V., Kaplan M., Poláček L. (2003): Pollenanalytische Forschung in Mikulčice in Poláček, L., (Ed.): Studien zum Burgwall von Mikulčice. - Spisy Archeologického ústavu AV ČR Brno, 39-74.

Jankovská V., Komárek J. (1982): Das Vorkommen einiger Chlorokokkalalgen in böhmischen Spätglazial und Postglazial. - Folia Geobot. Phytotax., 17/2, 165–195.

Kadlec J., Pruner P., Venhodová D., Hercman H., Nowicki T. (2000): Stáří a geneze sedimentů v Ochozské jeskyni. - Geol.výzk. Mor. Slez. v r. 1999, 19-24.

Kalvoda J. (1979): Microflora of the Upper Miocene at the locality Poštorná. - MS, Rigorous thesses. PřF MU, Brno (in Czech).

Knobloch E. (1962): Preliminary report about paleobotanical researches in moravian Teritiary. - Zpr. geol. výzk. 1961, 215-217.

Knobloch E. (1963): Die Floren des südmährischen Neogens. - N. Jb. Geol. Paläont. Mh., 1: 1-11.

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

Knobloch E. (1968): The plant association in Czechoslovakian Teritary. - Čas. mineral. geol., 13 (1): 109-118 (in Czech, German summary).

Knobloch E. (1969): Tertiäre Floren von Mähren. - Moravské muzeum a Muz. spol. Brno., 1- 309, Brno.

Knobloch E. (1972): Die gegenseitigen Beziehungen der tschechoslowakischen und ungarischen Teritiärfloren. - Földt. Közlöny, Bull. Of the Hungarian Geol.soc., 102, 246-259.

Knobloch E. (1981): Micropaleobotanical research of Pannonian and Potian in Moravia and Slovakia. (in Czech, German summary). - Zem. Plyn Nafta, XXVI, 4, 741-757.

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

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

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

Knobloch E., Kvaček Z. (1996): Miozäne floren der südbohemischen Becken. - Sbor. Geol. věd., Paleontologie, 33, 39-77.

Komárek J., Jankovská V. (2001): Review of the Green Algal Genus *Pediastrum*; Implication for Pollenanalytical Research. - Gebrüder Borntraeger, Berlin, 127pp.

Konzalová M. (1976): Microbotanical (palynological) research of the lower miocene of Northern Bohemia. - Rozpr. Čes. Akad. Věd, 86, 12, 1-75.

Konzalová M. (2005): Upper Miocene (Pannonian, Pontian) palynomorphs from the south Moravian extension of the Vienna Basin (Czech Republic). - Documenta Naturae, 155, 5, 1-51.

Konzalová M., Stuchlik L. (1983): Micropaleontological research of the sediments overlaying the Main brown-coal seam in the Cheb Basin (Miocene, West Bohemia). - Čas. Miner. Geol. 28, 4, 363-376.

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

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

Kováč M., Baráth I., Kováčová-Slamková M., Pipík R., Hlavatý I., Hudáčková N. (1998a): Late Miocene paleoenvironments and sequence stratigraphy: Northern Vienna basin. - Geologica Carpathica, 49, 6, 445-458.

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

Kováč M., Hudáčková N., Halásová E., Kováčová M., Holcová K., Oszczypko-Clowes M., Báldi K., Less G., Nagymarosy A., Ruman A., Klučiar T., Jamrich M. (2017): The Central Paratethys palaeoceanography: a water circulation model based on microfossil proxies, climate, and changes of depositional environment. Acta Geologica Slovaca, 9, 2, 75-114.

Kováčová M., **Doláková N**., Kováč M. (2011): Miocene vegetation pattern and climate change in the Northwestern Central Paratethys domain (Czech and Slovak Republic). - Geologica Carpathica, 62, 3, 251- 266.

Kovar-Eder, J., Jechorek, H., Kvaček Z., Parashiv V. (2008): The integrated plant record: An essential tool for reconstructing Neogene zonal vegetation in Europe. - Palaios 23, 97- 111.

Kovar-Eder J., Suc J.-P., Kvaček Z. (2008): Definition of relevant botanical terms and vegetation units. - www.neclime.de

Krutzsch W. (1966): Zur Kenntnis der präquartären periporaten Pollenformen. - Geologie, 15, 55. Berlin.

Krutzsch W. (1971): Atlas der mittel- und jungtertiären dispersen Sporen und Pollen sowie der Microplankton formen des nördlichen Mitteleuropas. - Lief. VI, 234pp., Jena.

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

Kvaček Z., Dvořák Z., Mach K., Sakala J. (2004): Třetihorní rostliny severočeské uhelné pánve. - Granit Praha, 160s.

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

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

Kwaitowski A, Lubliner-Mianowska L (1957): Badanie skladu chemicznego pylku II Badania blon pylkowich.- Acta Societatis Botanicorum Polonae, 26, 501-514.

Lang G. (1994): Quartäre Vegetationsgeschichte Europas. - Gustav Fischer Verlag, Jena-Stuttgart-New York, 462 pp.

Lázničková J. (2006): Palynological study of selected localities in Upper Miocene of theMoravian part of theVienna Basin. (in Czech, with English summary). - MS Diploma thesses, MU Brno, 72s.

Litt T., Shmincke H. U., Frechen M., Schluchter Ch. (2008): Quaternary. - In: McCann, T. (ed.): The Geology of Central Europe. Vol. 2 Mezozoic and Cenozoic. - Geologic Society London, 1288–1340.

Louis F., Bruch A., Utescher T., Spicer R.A, Spicer T. (2017): Reconstructing Cenozoic vegetation from proxy data and models - A NECLIME synthesis (Editorial). - Palaeogeography, Palaeoclimatology, Palaeoecology, 467, SI, 1-4.

Ložek V. (2007): Zrcadlo minulosti. Česká krajina v kvartéru. - Dokořán, 196 s., Praha.

Macháček, J. (2000): Pohansko u Břeclavi po roce 1990. Příspěvek ke čtyřicátému výročí zahájení archeologických výzkumů. - Archaeologia mediaevalis Moravica et Silesiana I. Masarykova univerzita v Brně. Brno, 9-19.

Macháček J. (2005): Raně středověké Pohansko u Břeclavi – munitio, palatium nebo emporium moravských panovníků? (Early Medieval centre in Pohansko near Břeclav/

Lundenburg:munitio, emporium or palatium of the rulers of Moravia?). - Archeologické rozhledy LVII, 100-138.

Macháček J., **Doláková N.,** Dresler P., Havlíček P., Hladilová Š., Přichystal A., Roszková A., Smolíková L. (2007): Raně středověké centrum na Pohansku u Břeclavi a jeho přírodní prostředí. - Archeologické rozhledy LIX, 2, 278-314.

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

Mai H. D. (1991): Palaeofloristic changes in Europe and the confirmation of theArctotertiary - Palaeotropical concept. - Review of Palaeobotany and Palynology, 68, 1, 29-36.

Martin P. S., Drew C. M. (1970): Additional Scanning Electron Photomicrographs of Southwestern Pollen Grains. - Journal of the Arizona Academy of Science. 6, 2, 140-161.

Miller K. G., Wright J. D., Fairbanks R. G. (1991): Unlocking the icehouse: Oligocene–Miocene oxygen isotopes, eustasy, and margin erosion.- J. Geophys. Res., 96, 6, 829-848.

Moore J. D., Webb J. A., Collinson M. E. (1991): Pollen analysis. - Blackwell Scientific public. London - Edinburgh - Boston - Melbourne - Paris - Berlin - Vienna, 216 pp.

Mosbrugger V., Utescher T. (1997): The coexistence approach - a method for quantitative reconstructions of Tertiary terrestrial palaeoclimate data using plant fossils. - Palaeogeography, Palaeoclimatology, Palaeoecology, 134, 61-86.

Musil R. (2005): Jeskyně Za Hájovnou, výjimečná lokalita Javoříčského krasu [Za Hájovnou Cave, exceptional locality of Javoříčko Karst, Moravia]. - Přír. stud. Muz. Prostějovska. 8: 9–42. (in Czech)

Musil R., Sabol M., Ivanov M., **Doláková N**. (2014): Middle Pleistocene stratigraphy of the Deposits in Za Hájovnou cave (Javoříčko Karst, Northern Moravia, Czech Republic) - Acta Musei Nationalis Pragae, Series B - Historia Naturalis, 70 (1–2), 107–119.

Nagy E. (1969): Palynological elaborations the Miocene layers of the Mecsek Mountains. - A. Magyar Áll. Földt. Int. Évk. II, 2, 237-537.

Nagy E. (1985): Sporomorphs of the Neogene in Hungary. - Geologica Hungarica 47, Ser. paleont., 235pp.

Nagy E. (1999): Palynological Correlation of the Neogene of the Central Paratethys. - Geol. Inst. of Hungary Budapest, Budapest, 126pp.

Nagy E. (2005): Palynological evidence for Neogene climatic change in Hungary. - Occassional papers of the Geol. Inst. of Hungary Budapest vol. 205, Budapest, 120.

Navarro C., Carrión J. S., Munuera M., Prieto A. R. (2001): Cave surface and the palynological potential of karstic cave sediments in palaecology. - Rev. Paleobot. Palynol., 117, 4, 245-265.

Nehyba S., **Doláková N**., Hladilová Š., Petrová P. (2008): Carpathian Foredeep - western part (CzechRepublic). - In: Mc CannT. (ed) The Geology of Central Europe, vol2. Paleogene and Neogene, 1st edn.The Geological Society, London, 1081-1083.

Nehyba S., Hladilová Š., **Zdražílková N.** (1995): Sedimenty spodního miocénu v širším okolí Miroslavi. - in Hamršmíd B., ed.: Nové výsledky v terciéru Západních Karpat II. - Knih. Zem. Plyn Nafta, 16, 85-95.

Nehyba S., Hladilová Š., **Doláková N.** (1997): Vývoj sedimentace a fosilních společenstev ve spodním miocénu jz. části karpatské předhlubně na Moravě. - in ed- Hladilová Š.: Sborník příspěvků - Dynamika vztahů marinního a kontinentálního prostředí, Grantový projekt GAČR 205/95/1211, 47-58, Brno

Nehyba S., Holcová K., Gedl P., **Doláková N.** (2016): The Lower Badenian transgressive-regressive cycles – a case study from Oslavany (Carpathian Foredeep, Czech Republic). - N. Jb. Geol. Paläont. Abh. 279, 2, 209-238.

Nerudová ed. (2010): Jeskyně Balcarka v Moravském krasu. - Anthropos, MZM, 31, 23, 117s.

Nerudová Z., **Doláková, N.,** Novák J. (2016): New Information Augmenting the Picture of Local Environment of the LGM/LGT in the Context of the Middle Danube Region. - Holocene, 26, 9, 1345-1354.

Opravil E. (1961): Vegetační poměry Znojemska v době halštatské. - Acta Musei Moraviae, Scientiae geologicae, 46, 81-99.

Opravil E. (1962): Paleobotanický výzkum slovanského hradiska Na valech u Mikulčic. - Arch. Rozhledy, 24, 475 - 482.

Opravil E. (1978): Rostlinná společenstva v okolí Mikulčic v období předvelkomoravském a velkomoravském. - Arch. Rozhledy 30, 67-75.

Opravil E. (1983a): Habr obecný (*Carpinus betulus* L.) v československém kvartéru. - Čas. Slez. Muz. Opava (A). 32, 67-82.

Opravil E. (1983b): Údolní niva v době hradištní. (ČSSR - povodí Moravy a Poodří). - Academia, Praha. 77s.

Opravil E. (1999): Umweltentwicklung in der Talaue der March (Ober- und Untermarch). - in: Poláček, L., Dvorská, J. (Eds.): Probleme der mitteleuropäischen Dendrochronologie und naturwissenschaftliche Beiträge zur Talaue der March. Internationale Tagungen in Mikulčice V, Brno, 165-180.

Opravil E. (2000): Archäobotanische Funde aus dem Burgwall Pohansko bei Břeclav. - In: Poláček, L., (Ed.): Studien zum Burgwall von Mikulčice IV, Brno, 165-169.

Pacltová B. (1958): Rostlinné mikrofosílie (hlavně sporomorphy) z lignitových ložisek u Mydlovar v Českobudějovické pánvi. - Sbor. Ústř. Úst. geol., XXV, paleont., Praha.

Pacltová B. (1990): Základy mikropaleobotaniky. - SPN, Praha 171 s.

PalDat – a palynological database (2000 onwards), www.paldat.org), Division of Structural and Functional Botany, University of Vienna.

Petřík J., Petr L., Šabatová K., **Doláková N.,** Lukšíková H., Dohnalová A., Koptíková L., Blaško D. (2015): Reflections of Prehistoric and Medieval human activities in floodplain deposits of the Únanovka Stream, South Moravia, Czech Republic. - Zeitschrift für Geomorphologie, 59, 3 393-412.

Planderová E. (1971): Palynologistische Charakteristik of Eggenburger Schichtengruppe. - in: Steininger F. - Seneš J.: Chronostratigraphie und Neostratotypen, M1 Eggenburgien. - SAV Bratislava, 778-806.

Planderová E. (1984): Sporomorphs and Plankton of the Karpathian from Locality Dežerice. - Západné karpaty, sér. paleont., 9, 111-130.

Planderová E. (1990): Miocene Microflora of Slovak Central Paratethys and its Biostratigraphical Significance. - Geol. Inst. D. Štúra. Bratislava. 144pp.

Planderová E., Ziembińska-Tworzydło, Grabowska I., Kohlman-Adamska A., Konzalová M., Nagy E., Pantić N., Ryłova T., Sadowska A., Słodkowska B., Stuchlik L., Syabraj S., Ważyńska H., **Zdražílková N.** (1993a): On paleofloristic and paleoclimatic changes during the Neogene of Eastern and Central Europe on the basis of palynological research. - Proceedings of the International Symposium: Paleofloristic and paleoclimatic changes during Cretaceus and Tertiary. September 14-20, 119-129, Dionýz Štúr Institute of Geology in Bratislava.

Planderová E., Ziembińska-Tworzydło, Grabowska I., Kohlman-Adamska A., Sadowska A., Słodkowska B., Stuchlik L., Ważyńska H. (1993b): Wahania klimatyczne w Neogenie Europy Środkowej na podstawie zmiennego udziału w palinoflorze składników paleotropikalnych i arktycznotreciorzędowych. - Przeglad Geologićny. Państw. Inst. Geol. 41, 12, 829-834. Warszawa.

Podborský V. (1988): Těšetice-Kyjovice 4. Rondel osady lidu s moravskou malovanou keramikou. - Univerzita J. E. Purkyně. Brno, 311 pp.

Přichystal A., Hladilová Š., **Doláková N**., Brzobohatý R., Musil R. (1996): Morava a Slezsko v geologické minulosti. - MZM Brno 42s.

Punt W., Hoen P., Blackmore S., Nilsson S., Le Thomas A. (2007): Glossary of Pollen and Spore Terminology. - Review of Palaeobot. and Palynol. 143, 1–2, 1-81.

Rasser M.W., Harzhauser M., Anistratenko O.Y., Anistratenko V.V., Bassi D., Belak M., Berger J.-P., Bianchini G., Čičić S., Ćosović V., **Doláková N**., Drobne K., Filipescu S., Gürs K., Hladilová Š., Hrvatović H., Jelen B., Kasińsk, J.R., Kováč M., Kralj P., Marjanac T., Márton E., Mietto P., Moro A., Nagymarosy A., Nebelsick J.H., Nehyba S., Ogorelec B., Oszczypko N., Pavelić D., Pavlovec R., Pavšič J.,Pavšič J., Petrová P., Piwocki M., Poljak M., Pugliese N., Redžepović R., Rifelj H., Roetzel R., Skaberne D., Sliva L., Standke G., Tunis G., Vass D., Wagreich M., Wesselingh F. (2008): Palaeogene and Neogene . - In: McCann T., ed. (2008): The Geology of Central Europe. Central Europe Volume 6, 2, 1031-1139. The Geological Society, London.

Reille M., de Beaulieu J.- L., Svobodova H., Andrieu-Ponel V., Goeury C. (2000): Pollen analytical biostratigraphy of the last five climatic cycles from a long continental sequence from the Velay region (Massif Central, France). - Journal of Quaternary Science, 15, 665–685.

Riding J. B., Kyffin-Hughes J. E. (2006): Further Testing of a Non-Acid Palynological Preparation Procedure . - Palynology, 30,1, 69-87.

Roucoux K. H., Tzedakis P. C., Frogley M. R., Lawson I. T., Preece R. C. (2008): Vegetation history of the marine isotope stage 7 interglacial complex at Ioannina, NW Greece. – Quaternary Science Reviews, 27, 1378-1395.

Rybníček K., Rybníčková, E. (2001): Vegetace a přírodní prostředí jako pozadí archeologických kultur ČR, 28 000 – 1 000 BP. - In: Podborský, V., (Ed.): 50 let archeologických výzkumů Masarykovy Univerzity na Znojemsku. MU Brno, 301-310.

Rybníčková E., 1974: Die Entwicklung der Vegetation und Flora im sudlichen Teil der Böhmisch-Mährischen Höhe während des Spätglazials und Holozäns. - Vegetace ČSSR A7. 65, Academia Praha.

Rybníčková E. (1985): Dřeviny a vegetace Československa v nejmladším kvartéru (paleobotanická studie). MS Ústav experimentální fytotechniky ČSAV, 125, Brno.

Sadowska A. (1989): Miocene palynostratigraphy of the Silesian part of the Paratethys Basin..- Courier Forsch. Inst. Senkenberg 109, 229-235.

Sadowska A. (1993): The stratigraphical table of the Neogene floras from Poland. - Proceedings of the International Symposium: Palaeofloristic and palaeoclimatic changes during Cretaceous and Tertiary. Dionýz Štúr Institute of Geology, Bratislava, 133-139.

Seitl L., Svoboda J., Ložek V., Přichystal A., Svobodová H. (1986): Das Spätglazial in der Barová-Höhle im Mährischen Karst. – Archäologisches Korrespondenzblatt, 16, 393-398.

Shackleton N. J., Crowhurst S. J., Weedon G. P., Laskar J. (1999): Astronomical calibration of Oligocene - Miocene time. - Philos. Trans. R. Soc. Lond., A, 357, 1907-1929.

Stuchlik L. (1992): Correlation of the Neogene Floras of Transcaucasia, Ukrainian Carpathians, South Poland and Czechoslovakia. - Paleontologia I Evolució, 24-25, 483 - 488.

Stuchlik L. (ed.) (1994): Neogene Pollen Flora of Central Europe. Part 1. - Acta Palaeobotanica, Suppl.1, 1-56.

Stuchlik L., Ważynska H. (1993): Wahania klimatyczne w Neogenie Europy Środkowej na podstawie zmiennego udziału w palinoflorze składników paleotropikalnych I arktycznotreciorzędowych. – Przegled Geologićny Państw. Inst. Geol., 41(12), 829-834.

Stuchlik L., Ziembińska-Tworzydło M., Kohlman-Adamska A., Grabowska I., Słodkowska B., Worobiec.E., Durska E. (2014): Atlas of Pollen and Spores of the Polish Neogene, Vol. 4, Angiosperms (2). - W. Szafer Inst. of Botany, Polish Academy of Science, Krakow. 466 pp.

Svoboda J., (1991): Neue Erkentnisse zur Pekárna-Höhle im Mährischen Karst. - Archäologisches Korrespondenzblatt 21, 39-43.

Svobodová H. (1988): Pollenanalytische Untersuchung des Schichtkomplexes 6-1 vor der Kůlna-Höhle. – In: Valoch, K. (ed): Die Erforschung der Kůlna Höhle 1961-1976. Anthropos, 24, 205-210.

Svobodová H. (1990): Vegetace jižní Moravy mezi 500-1000 A.D. - Arch. Rozhledy, 42, 170-205.

Svobodová H., (1991): Pollen analysis of the Upper Paleolithic triple burial at Dolní Věstonice. - Anthropozoikum 43, 505-515.

Svobodová H. (1992): Palaeobotanical evidence on the Late Glacial in the Moravian Karst. – In: Eder-Kovar, J. (ed.): Palaeovegetational Development in Europe and Regions relevant to its Palaeofloristic Evolution. Proceedings of the Pan- European Palaeobotanical Conference Vienna, Museum of Natural History Vienna, Vienna, 19 -23.

Šušolová J., **Doláková N.**, Gregerová M., Dundek P., Hadacz R. (2016): Nové poznatky k půdám na území Národního parku Podyjí se zaměřením na výskyt humolitů**.** - Acta Mus. Moraviae, Sci. Geol., 199-125.

Utescher T., Böhme M., Mosbrugger V. (2011): The Neogene of Eurasia: Spatial gradients and temporal trends – the second synthesis of NECLIME. - Palaeogeography, Palaeoclimatology, Palaeoecology, 304, 196-201.

Utescher T., Bruch A. A., Erdei B., François L., Ivanov D., Jacques F.M.B.,. Kern A. K Liu Y.-S.(C.), Mosbrugger V., Spicer R.A. (2014): The Coexistence Approach - Theoretical background and practical considerations of using plant fossils for climate quantification. - Palaeogeography, Palaeoclimatology, Palaeoecology 410, 58-73

Utescher T., Mosbrugger V., Ashraf A. R. (2000): Terrestrial Climate Evolution in Northwest Germany Over the last 25 Million Years. - Palaios 15, 5, 430-449.

Urban B., Sierralta M. (2012): New palynological evidence and correlation of Early Paleolithic sites Schöningen 12 B and 13II, Schöningen Open Lignite Mine. - In: Behre, K.- E. (ed.): Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen, Römisch-Germanisches Zentralmuseum, Mainz, 77-96.

Valoch K. et al., (1988): Die Erforschung der Kůlna Höhle 1961-1976. - Anthropos, 24 (N. S. 16).

Van Gijzel P. (1967a): Palynology and flourescence microscopy . - Review of Palaeobotany and Palynology, 2, 49-79.

Van Gijzel P. (1967b): Autofluorescence of fossil pollen and spores with special reference to age determination and coalification. - Leidse Geol. Meded., 40, 263-317.

Van Gijzel P. (1971): Review of the UV-fluorescence microphotometry of fresh and fossil exines and exosporia - In: Brooks J., Grant P. R., Muir M., van Gijzel P. & Shaw G. (eds) Sporopollenin. - Academic Press, London - New York, 659-685.

Van Gijzel P. (1975): Polychromatic UV-fluorescence microphotometry of fresh and fossil plant substances, with special reference to the location and identification of dispersed organic material in rocks: - In: Alpern B. (ed.) Colloque International Petrographie de la Matiere Organique des Sediments, Paris. 67-91.

Van Gijzel P. (1978): Recent developments in the application of quantitative fluorescence microscopy in palynology and paleobotany. - Annales des Mines de Belgique, 7-8: 836-851.

Vignatiová J. (1992): Břeclav-Pohansko. II, Slovanské osídlení jižního předhradí. - Vyd. 1. Masarykova univerzita, Brno, 9-12.

Vodičková-Kneblová V. (1961): Entwicklung der vegetation im Elster-Saale-Interglazial im Suchá-Stonava-Gebiet (Ostrava-Gebiet). - Anthropozoikum, 9 (1959): 129-174.

Walanus A., Nalepka D. (1999): POLPAL. Program for counting pollen grains, diagrams plotting and numerical analysis. - Acta Paleobot. 2, 659-661.

Ważyńska H. (Ed.) 1998: Palynology and paleogeography of the Neogene in the Polish Lowlands. - Pr. Panstw. Inst. Geol., 1-160.

Yeloff D. E., Hunt C. O. (2005): Fluorescence microscopy of pollen and spores: a tool for investigating environmental change. - Review of Palaeobotany and Palynology, 133, 203-219.

Zachos J., Pagani M., Sloan L., Thomas E. & Billups K. (2001): Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present. - Science 292 (5517), 686-693.

Zdražílková N. (1993): Paleopalynology of the lower Miocene in Moravia. - Paleofloristic and Paleoclimatic changes during Cretacous and Tertiary. - Proceedings of the international symposium September 1-20, 145-147. Dionýz Štúr Institute of Geology in Bratislava.

Zetter R. (1989): Methodik und Bedeutung einer routinemässig kombinierten Lichtmikroskopischen und Rasterelktronenmikroskopischen Untersuchung fossiler Mikrofloren. - Cour. Forsch.-Inst Senckenberg, 109, 51-50.

Zetter R., Weber M., Hesse M., Pingen M. (2002): Pollen, Pollenkitt, and Orbicules in *Craigia Bronnii* Flower Buds (Tilioideae, Malvaceae) from the Miocene of Hambach. - Germany Int. J. Plant Sci. 163, 6, 1067-1071.

Přílohy:

Seznam přiložených publikací:

1. Bruch A. A., Utescher T., Alcade Olivares C., **Doláková N.,** Ivanov D., Mosbruger V. (2004): Middle and Late Miocene spatial temperature patterns and gradients in Europe – preliminary results based on paleobotanical climate reconstructions. – Cour.forsch.-Inst. Senckenberg, 249: 15-27.
   Použito pro kapitolu: 3a

2. **Doláková N**. (2004): Discussion on some Thermophile palynomorphs from the Miocene sediments in the Carpathian Foredeep (Czech Republic) and Modry Kamen basin (Slovakia). – Acta Paleobotanica 44 (1), 79-85.
   Použito pro kapitoly: 2, 3a

3. **Doláková, N.** (2007): Palynological studies in the Cave sediments from the Moravian, Javoříčko and Hranice Karsts - Czech Republic. - Scripta Fac. Sci. Natur. Universitatis Masarykianae Brunensis. 2007, Geology, 35, 47-53
   Použito pro kapitoly: 2 4a

4. **Doláková, N.** (2014): Palynological analysis of Sediments from Za Hájovnou Cave. - Acta Musei Nationalis Pragae, Series B – Historia Naturalis, 70 (1–2), 35–42.
   Použito pro kapitoly: 2, 4a

5. **Doláková N**., Burešová A. (2007): Use of fluorescent microscopy in the study of redeposited palynomorphs in the cave and marine sediments of Moravia (Czech Republic). - Acta Palaeobotanica, 47, 1, 275-279.
   Použito pro kapitoly: 2,4ab

6. **Doláková N**., Hladilová Š., Nehyba S., (1999): Development of Sedimentation, molluscs and palynospectra in the Lower Miocene of the south-western Part of the Carpathian Foredeep in Moravia (Czech Republic). - Acta Palaeobotanica, Suppl. No. 2, W. Szafer Institute of Botany, Polish Academy of Sciences, Krakow, 269-278.
   Použito pro kapitoly: 2,3a

7. **Doláková N.,** Holcová K., Nehyba S., Hladilová Š., Brzobohatý R., Zagoršek K. Hrabovský J., Seko M., Utescher T. (2014): The Badenian parastratotype at Židlochovice from the perspective of the multiproxy study. - Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 271, 2, 169-201.
   Použito pro kapitoly: 2,3a

8. **Doláková N.,** Kováčová M. (2008): Pannonian vegetation from the northern part of Vienna basin. - Acta Musei Nationalis Pragae Series B - Historia Naturalis 64, 2–4, 163–171
   Použito pro kapitolu: 3a

9. **Doláková, N.,** Roszková, A. Přichystal, A. (2010): Palynology and Natural Environment in the Pannonian to Holocene Sediments of the Early Medieval Centre Pohansko near Breclav (Czech Republic). - Journal of Archaeological Science, USA/UK : Elsevier, 37, 10, 2538-2550.
   Použito pro kapitoly: 2, 4b

10. **Doláková N**., Kováčová M., Basistová, P. (2011): Badenian (Langhian – Early Serravallian) palynoflora from the Carpathian Foredeep and Vienna Basin (Czech and Slovak Republics). - Acta Musei Nationalis Pragae, Series B - Historia Naturalis 67 (1–2): 51-59.
    Použito pro kapitoly: 2,3a

11. **Doláková N**., Slamková M. (2003): Palynological characteristics of Karpatian sediments. - In: Brzobohatý R., Cicha I., Kováč. M., Rögl F. (Eds.) : The Karpatian a lower Miocene stage of the Central Paratethys. Masaryk University Brno. 325-346.
    Použito pro kapitoly: 2,3a

12. Holcová K., Hrabovský J., Nehyba S., Hladilová Š., **Doláková N.,** Demeny A (2015): The Langhian (Middle Badenian) carbonate production event in the Moravian part of the Carpathian Foredeep (Central Paratethys): a multiproxy record . - Facies, 61, 1, Article Number: 419
    Použito pro kapitolu: 3b

13. Kováčová M., **Doláková N**., Kováč M. (2011): Miocene vegetation pattern and climate change in the Northwestern Central Paratethys domain (Czech and Slovak Republic). - Geologica Carpathica, 62, 3, 251—266
    Použito pro kapitolu: 3a

14. Kvaček Z., Kováč M., Kovar-Eder J., **Doláková N.,** Jechorek H., Parashiv V., Kováčová M., Sliva, Ľ. (2006): Miocene evolution of landscape and vegetation in the Central Paratethys. - Geologica Carpathica, 57, 4, 295-310.
    Použito pro kapitolu: 3

15. **N**ehyba S., Holcová K., Gedl P., **Doláková N.** (2016): The Lower Badenian transgressive-regressive cycles – a case study from Oslavany (Carpathian Foredeep, Czech Republic). - Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, Stuttgart, 279, 2, 209-238.
    Použito pro kapitolu: 3b

16. Nerudová Z., **Doláková, N.,** Novák, J. (2016): New information augmenting the picture of local environment of the LGM/LGT in the context of the Middle Danube Region. - The Holocene, 26(9), 1345–1354.
    Použito pro kapitolu: 4b

17. Petřík J., Petr L., Šabatová K., **Doláková N**., Lukšíková H., Dohnalová A., Koptíková L., Blaško D. (2015): Reflections of prehistoric and Medieval human activities in floodplain deposits of the Únanovka stream, South Moravia, Czech Republic. - Zeitschrift für Geomorphologie, 59, 3, 393-41.
Použito pro kapitolu: 4b

Cour. Forsch.-Inst. Senckenberg | 249 | 15–27 | 4 Figs, 5 Tabs | Frankfurt a. M., 16. 08. 2004

Middle and Late Miocene spatial temperature patterns and gradients in Europe – preliminary results based on palaeobotanical climate reconstructions

With 4 figs, 5 tabs

Angela A. Bruch[1], Torsten Utescher[2], Cristina Alcalde Olivares[3], Nela Dolakova[4], Dimiter Ivanov[5], Volker Mosbrugger[1]

Abstract

As a first attempt to provide proxy data for the quantification of Neogene latitudinal temperature gradients, fossil plant associations of the early Middle Miocene and early Late Miocene from Central and South Europe have been analysed for climate reconstruction by using the Coexistence Approach. In both time intervals the temperature gradients within the study area are weak when compared to the Present, and in some cases are below the resolution limit of the method. Slightly higher values for the Late Miocene indicate the tendency towards a higher spatial differentiation of the climate during late Neogene. In comparison with the Recent situation it becomes evident that major climatic changes must have occurred after the early Late Miocene in Central Europe.

Key words: palaeotemperature maps, Miocene, Europe, coexistence approach

Kurzfassung

Für eine erste Quantifizierung neogener latitudinaler Temperaturgradienten wurden Pflanzenassoziationen aus dem frühen Mittelmiozän und dem frühen Spätmiozän Europas paläoklimatisch mit Hilfe des Koexistenz-Ansatzes ausgewertet. Obwohl in beiden Zeitintervallen die beobachteten Gradienten im Untersuchungsgebiet erheblich geringer sind als im Rezenten und teilweise unterhalb der methodischen Auflösung liegen, zeigen sich für das Spätmiozän leicht erhöhte Werte, die die Tendenz zu einer verstärkten räumlichen Differenzierung des Klimas gegen Ende des Neogen andeuten. Der Vergleich mit der rezenten Situation belegt jedoch, dass die grundlegenden klimatischen Umwälzungen erst nach dem frühen Spätmiozän stattgefunden haben.

Schlüsselworte: Paläotemperaturkarten, Miozän, Europa, Koexistenz-Ansatz

---

Authors' addresses: [1]corresponding author: Institute of Geosciences, Sigwartstr. 10, 72076 Tübingen, Germany; <angela.bruch@uni-tuebingen.de>
[2]Geological Institute, Nußallee 8, D-53115 Bonn, Germany
[3]Escuela Técnica Superior de Ingenieros de Montes, Universidad Politécnica de Madrid, Spain
[4]Institute of Geological Sciences, Masaryk University, Kotlarska 2, 61137 Brno, Czech Republic
[5]Bulgarian Academy of Sciences, Institute of Botany, 23, Acad. G. Bontchev Str., BG 1113 Sofia, Bulgaria

Introduction

For the understanding of global circulation patterns in the Neogene and its development towards the Recent situation it is crucial to obtain quantitative proxy data especially from the terrestrial environment not only in temporal but also in sufficient spatial resolution. One main aspect of the climate system is its regional differentiation reflecting the three-dimensional character of the atmospheric circulation. Today, temperature patterns in Europe show strong gradients both, latitudinally and longitudinally. The gradient from North to South is part of the global pole-to-equator temperature differentiation, which is one of the most important factors responsible for the intensity of atmospheric circulation, thus influencing the transport of heat and water vapour (e.g., Manabe & Bryan 1985, Bice & Marotzke 2000). The strong longitudinal differentiation observed today is due to the marine influence of the Gulf Stream (Atlantic Ocean) on the climate of the western part of Europe causing mild winters and a reduced annual range of temperature. Towards the East, the climate becomes increasingly continental with a higher seasonality of temperature and cold winters. Moreover, in the East temperature patterns denote a stronger latitudinal differentiation than in the western part of Europe.

These patterns are well known and understood for the Recent situation, but little is known yet about the terrestrial temperature differentiation in Europe during substantially warmer climate conditions like in the Neogene. Besides former qualitative comparisons of floras from different latitudes (e.g. Suc 1989, Mai 1995), this study is a first attempt to provide quantitative proxy data for the quantification of spatial patterns and latitudinal gradients of temperatures for the early Middle Miocene and the early Late Miocene of Europe.

Materials and methods

To obtain a spatial picture of temperatures in the two time intervals of interest, published flora lists have been compiled and analysed with the coexistence approach (CA) after Mosbrugger & Utescher (1997). All analysed floras are listed in tables 1 and 2. Only floras with a sufficient number of climatically relevant taxa and a reliable age control are chosen. For the time interval of early Middle Miocene 19 localities have been accepted that are dated as Langhian, early Badenian, or equivalents. For early Late Miocene the stratigraphic ages of 30 localities are early Tortonian, Vallesian (MN9-10), or Pannonian. Therefore,

Table 1: List of early Middle Miocene localities.

Locality	Region	Type of Flora	Logitude	Latitude	no. of taxa with climate data	Stratigraphy	Reference
Belorado	Spain	pollen	–3,17	42,43	25	Langhian	Valle et al. (1995)
C-136A/301.0	Bulgaria	pollen	28,25	43,45	14	Tarchanian	Ivanov (Appendix 1)
Fabrègues 1	France	pollen	6,23	43,63	36	late Langhian – early Serravallian	Bessedik (1984)
Glinsko 1	Ukraine	leaves	24,03	49,83	12	early Badenian	Shvareva (1983)
Hambach Mine 6C	Germany	fruits and seeds	6,47	50,92	10	Reinbekian	Gross et al. (1989)
Hoktemberyan 2	Armenia	pollen	44,12	40,15	49	Tshokrakian	Manukyan (1977), (1978), (1980)
Kortumov 1	Ukraine	leaves	24,03	49,83	23	early Badenian	Shvareva (1983)
La Motte d'Aigues	France	pollen	5,55	43,73	15	late Langhian – early Serravallian	Bessedik (1984)
La Rierussa 2	Spain	pollen	1,87	41,45	16	Langhian	Bessedik (1984)
Lisboa-Almada	Portugal	pollen	–9,17	38,68	31	Langhian	Pais (1979), Pais (1981)
Oder 2a	Germany	leaves	12,18	49,32	17	early Badenian	Knobloch & Kvacek (1976)
Ponholz 1	Germany	fruits and seeds	12,1	49,15	22	early Badenian	Knobloch & Kvacek (1976)
Randecker Maar	Germany	fruits and seeds	9,55	48,55	22	MN5 (16.0-16.8 Ma)	Gregor (1986)
Rittsteig 1	Germany	Pollen	12.00	48.50	38	MN5	Seitner (1987)
Rubí	Spain	leaves	2,03	41,48	15	Langhian	Sanz de Siria (1988)
Tuzla 1	Bosnia	leaves	18,7	44,55	11	early Badenian	Pantic et al. (1988)
Ukraine A	Ukraine	leaves	25,1	48,33	26	early Badenian	Shvareva (1983)
Vilovi 1	Spain	pollen	1,8	41,2	24	late Langhian – early Serravallian	Bessedik (1984)
Zidlochovice 1	Czech R.	pollen	16,63	49,04	34	NN5	Dolakova (Appendix 2)

Table 2: List of early Late Miocene localities that are not given in Bruch et al. (in press).

Locality	Region	Type of Flora	Logitude	Latitude	no. of taxa with climate data	Stratigraphy	Reference
Abezames	Spain	pollen	–5,80	41,60	42	Vallesian	Salvador de Luna (1984), Valle, H. & Salvador de Luna (1985a, b)
Burgos	Spain	pollen	–3,70	41,60	35	Vallesian	Rivas Carballo & Valle (1990)
Massenhausen	Germany	leaves	11,65	48,35	18	early Pannonian	Jung (1963)
Povoa	Portugal	leaves	–8,90	39,20	22	Vallesian	Pais (1981,1986), Antunes & Mein (1977)
Rudabanya	Hungary	leaves	20,62	48,38	29	MN 9	Kretzoi et al. (1976)
Samos	Greece	pollen	26,70	37,70	19	K/Ar age 11.2Ma	Chryssanthi & Solounias (1985)
Sé	Hungary	leaves	16,36	47,15	13	late Pannonian	Horváth (1972)
Sivas Gemerek	Turkey	pollen	37,00	38,00	15	late Sarmatian to earliest Pannonian	Kayseri & Akgün (2002)
Wörth	Austria	leaves	15,75	47,02	8	Pannonian D	Kovar-Eder & Krainer (1990)
Zukunft Mine 7A	Germany	fruits and seeds	6,47	50,92	39	early Tortonian	Utescher et al. 2000

Table 3: Results of CA analysis for early Middle Miocene floras.

Locality		MAT [°C]			CMT [°C]			WMT [°C]	
	left border		right border	left border		right border	left border		right border
Belorado	13.30	15.85	18.40	-0.10	6.20	12.50	22.80	25.25	27.70
C-136A/301.0	13.60	14.95	16.30	1.80	4.40	7.00	23.60	25.70	27.80
Fabrègues 1	15.60	17.20	18.80	6.40	8.00	9.60	24.70	26.20	27.70
Glinsko 1	13.90	15.25	16.60	2.70	4.25	5.80	25.70	26.05	26.40
Hambach Mine 6C	15.70	16.85	18.00	9.60	10.65	11.70	25.20	26.75	28.30
Hoktemberyan 2	15.70	17.00	18.30	5.00	6.55	8.10	25.40	26.55	27.70
Kortumov 1	13.90	14.75	15.60	2.70	3.55	4.40	25.70	26.05	26.40
La Motte d'Aigues	15.60	17.55	19.50	5.00	9.15	13.30	24.70	26.40	28.10
La Rierussa 2	15.60	17.05	18.50	6.40	9.45	12.50	26.60	27.15	27.70
Lisboa-Almada	15.70	17.25	18.80	2.90	8.00	13.10	25.70	26.70	27.70
Oder 2a	15.90	16.25	16.60	5.00	5.40	5.80	26.60	26.65	26.70
Ponholz 1	14.40	14.95	15.50	2.90	3.70	4.50	25.70	26.75	27.80
Randecker Maar	15.60	16.10	16.60	5.60	5.90	6.20	25.00	26.45	27.90
Rittsteig 1	15.70	16.40	17.10	6.20	6.60	7.00	25.60	26.20	26.80
Rubí	20.60	20.95	21.30	5.60	12.50	19.40	27.20	27.65	28.10
Tuzla 1	15.30	17.25	19.20	10.00	10.85	11.70	26.50	27.30	28.10
Ukraine A	13.90	14.75	15.60	2.70	3.55	4.40	25.70	26.05	26.40
Vilovi 1	15.60	17.05	18.50	7.70	8.65	9.60	24.70	26.20	27.70
Zidlochovice 1	15.70	17.05	18.40	5.00	8.75	12.50	24.70	26.40	28.10

Table 4: Results of CA analysis for early Late Miocene floras of table 2.

Locality		MAT [°C]			CMT [°C]			WMT [°C]	
	left border		right border	left border		right border	left border		right border
Abezames	15.60	16.10	16.60	5.00	7.30	9.60	25.30	26.50	27.70
Burgos	15.60	16.30	17.00	6.40	8.35	10.30	24.70	25.50	26.30
Massenhausen	13.30	13.55	13.80	-0.10	2.00	4.10	25.60	26.00	26.40
Povoa	13.70	15.35	17.00	2.50	5.40	8.30	23.30	24.85	26.40
Rudabanya	15.60	15.65	15.70	5,00	5,05	5,10	25,60	25,95	26,30
Samos	16.50	17.95	19.40	9.60	9.60	9.60	26.00	26.95	27.90
Sé	12.50	14.10	15.70	-0.10	2.50	5.10	21.60	24.15	26.70
Sivas Gemerek	17.20	18.20	19.20	4.30	10.45	16.60	24.90	26.60	28.30
Wörth	13.30	15.30	17.30	-0.70	3.15	7.00	25.70	26.20	26.70
Zukunft Mine 7A	15.30	15.40	15.50	6.60	7.25	7.90	25.70	25.80	25.90

both intervals comprise a time span of around three million years. The whole procedure of the selection of floras, the application of the CA, and the processing of the data with the *inverse distance weighted* method (IDW) to obtain interpolated climate maps follows the procedure described in detail in BRUCH et al. (in press). To avoid an overinterpretation of the resulting maps, we clearly indicate within these maps the underlying data points, i.e. localities. All maps are exclusively meant as a visualisation of the data given in tables 3 and 4.

Although the CA and the PALAEOFLORA database (www.palaeoflora.de) provide information about 15 different climate parameters, in this study only the temperature related parameters, i.e. mean annual temperature (MAT), mean temperature of the coldest month (CMT), and mean temperature of the warmest month (WMT) have been calculated by the CA. In addition, the mean annual range of temperature (MART) as the difference between WMT and CMT has been taken into consideration.

Results and discussion

All quantitative climate data obtained from early Middle Miocene and early Late Miocene localities are given in tables 3 and 4, respectively. These data together with data published by BRUCH et al. (in press) are visualised in figs 1 to 4. In general, values for early Middle Miocene are higher than those for early Late Miocene, reflecting the general Neogene cooling trend. For Middle Miocene, none of the temperature parameters does indicate any clear spatial patterns nor a latitudinal gradient. The Late Miocene data for MAT and CMT point to a slight geographical differentiation with cooler values in the Central Europe and warmer values in the south-eastern, south-western, and north-western parts of the study area (fig. 3). Due to the fact that there are no data available from Italy and France, the interpolation shows a strong southward shift of cooler temperatures in Central Europe, which is obviously artificial.

In many cases the obtained coexistence intervals of temperature parameters are overlapping and calculated gradients are within the range of resolution of the method. Yet, significantly lower temperatures are calculated for the localities Massenhausen in South Germany (MAT and CMT) and Sé in Hungary (CMT) while higher MATs and CMTs result for the eastern Mediterranean sites Samos and Sivas Gemerek (tab. 4). These small latitudinal patterns in CMT and MAT together with very homogenous WMTs lead to a resulting differentiation of seasonality of temperatures (MART, fig. 4). Thus, MART pattern are very similar to the distribution of MATs and CMTs. Nevertheless, overall latitudinal gradients are week compared to present-day conditions.

To quantify the latitudinal gradients within the data sets, temperature values of the northernmost and southernmost localities are arranged in table 5. Supporting the impression given by the maps, these data document no significant differentiation of temperatures between North and South for both, early Middle and early Late Miocene localities. In some cases even opposite trends underline the fact that the very low latitudinal temperature gradients in most cases are below the resolution of the method. However, it is interesting to note that even with these weak temperature gradients near the resolution limit of the method applied, a latitudinal differentiation for early Late Miocene data becomes evident in fig. 3 expressing the development towards a more differentiated climate system during Neogene. In addition, Recent temperature data in table 5 record a strong modern latitudinal gradient with a difference in MAT from NW Germany to Crete of 9°C. Also a longitudinal gradient from marine climate conditions in the West (Portugal) to continental climate in the East (Armenia) is clearly evident today; especially reflected in the seasonality of temperature (Recent gradient of MART of 17°C). Some of these climate patterns observed today are also found in Miocene data on a regional scale. When comparing the Present and early Late Miocene temperatures in northwest Germany and the Vienna Basin it is evident that gradients of MAT and CMT are of similar magnitudes. On the other hand, the strong Recent gradients between Central and Southern Europe are not yet developed in early Tortonian. This seem to imply a regional differentiation of latitudinal gradients and their development since Late Miocene, with a more intense and uniform cooling in the northern part of Europe. Nevertheless, data are insufficient for an advanced interpretation.

Comparing MART values, even the more continental aspect of the climate in the Vienna Basin today (tab. 5) is denoted in fig. 4 for early Tortonian. The fact that these patterns are not as pronounced in the Miocene data as today can be explained firstly by the generally low differentiation of temperatures in the area, and secondly by the large extent of the Paratethian water body suppressing the establishment of continental climate conditions in Europe during Miocene (cf. FLUTEAU et al. 1999, BRUCH et al. in press). The fact that these patterns are visible at all in Late Miocene data implies, on the other hand, a development towards the Recent climatic and atmospheric structure.

Nevertheless, it seems to be evident that climate situations with higher temperatures are associated with a lower spatial differentiation. If at all, these gradients are better reflected in winter temperatures than in summer temperatures.

In general, our data indicate that during the Miocene large scale atmospheric temperature gradients were very low compared to present-day, but increased slightly from Middle to Late Miocene. Accordingly, the main global heat transport must have been achieved in a different way; possibly by an increased water cycle moving latent heat from low to high latitudes and/or by increased tropospheric circulation as supposed by BICE & MAROTZKE (2000). Apparently, major climatic changes towards the Recent situation must have taken place later than early Late Miocene in Central Europe.

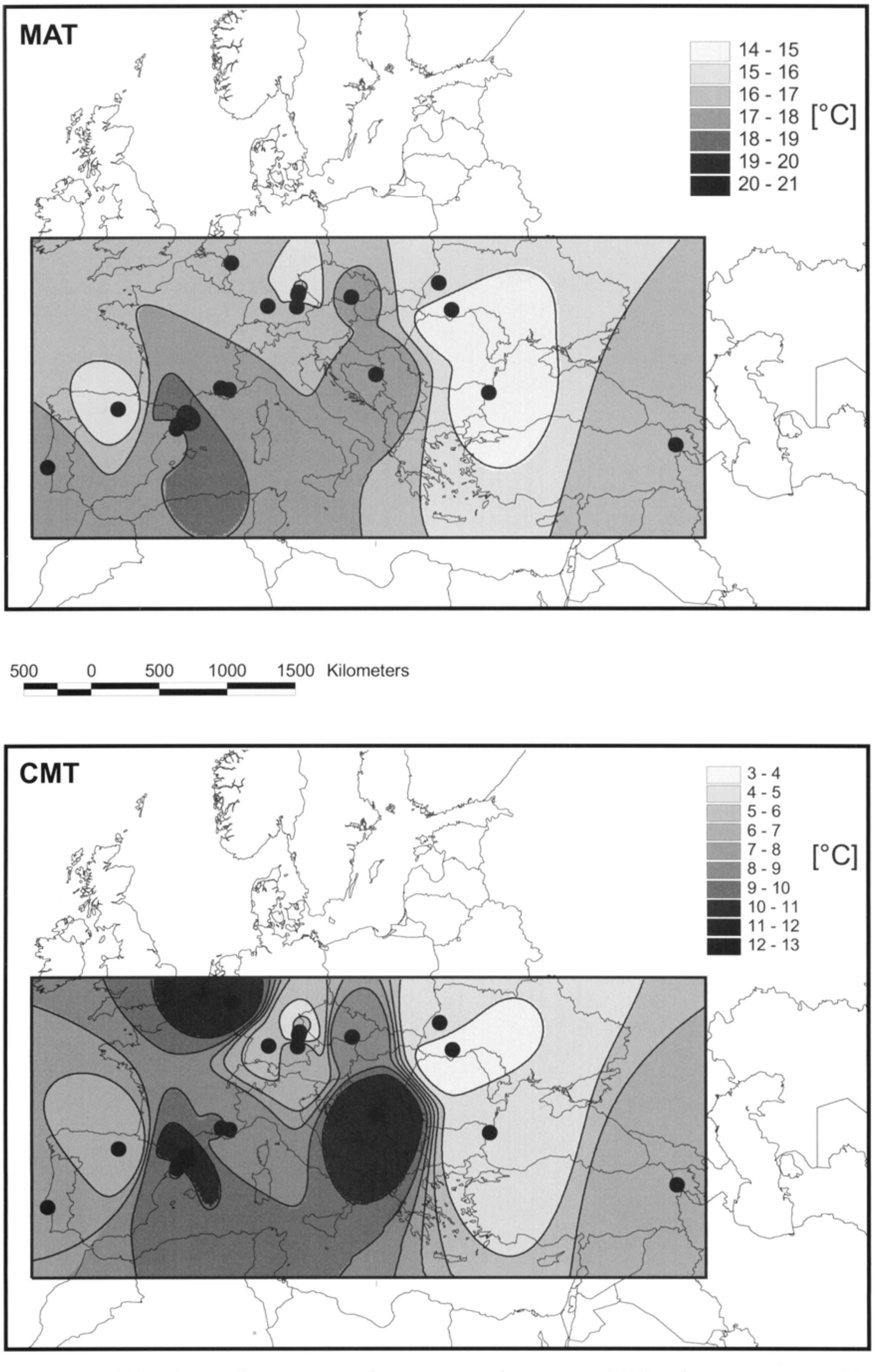


Fig. 1: Early Middle Miocene climate reconstructions: mean annual temperature (MAT) and mean temperature of the coldest month (CMT) (middle values of coexistence intervals, IDW interpolated).

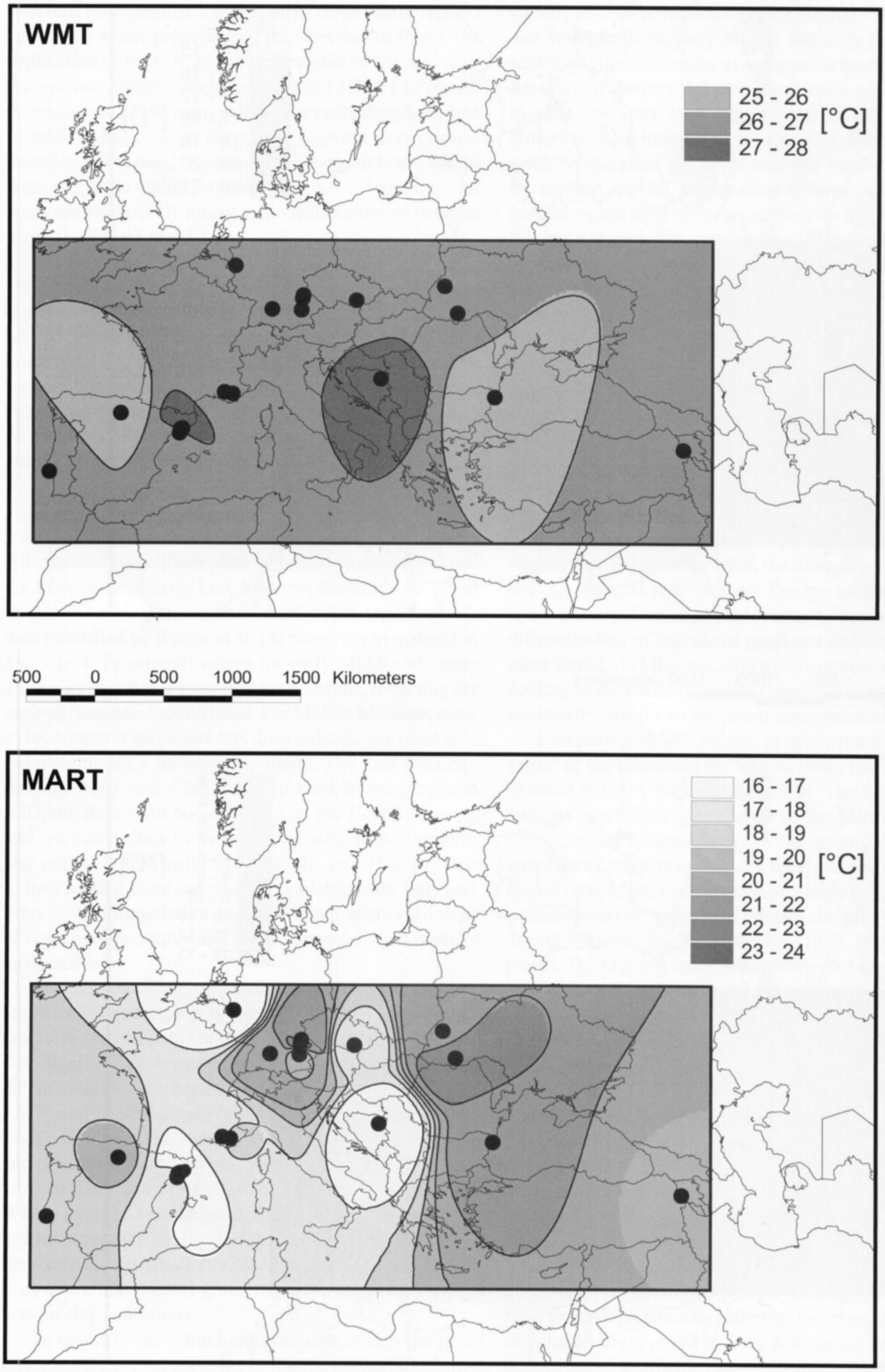


Fig. 2: Early Middle Miocene climate reconstructions: mean temperature of the warmest month (WMT) and mean annual range of temperature (MART) (middle values of coexistence intervals, IDW interpolated).

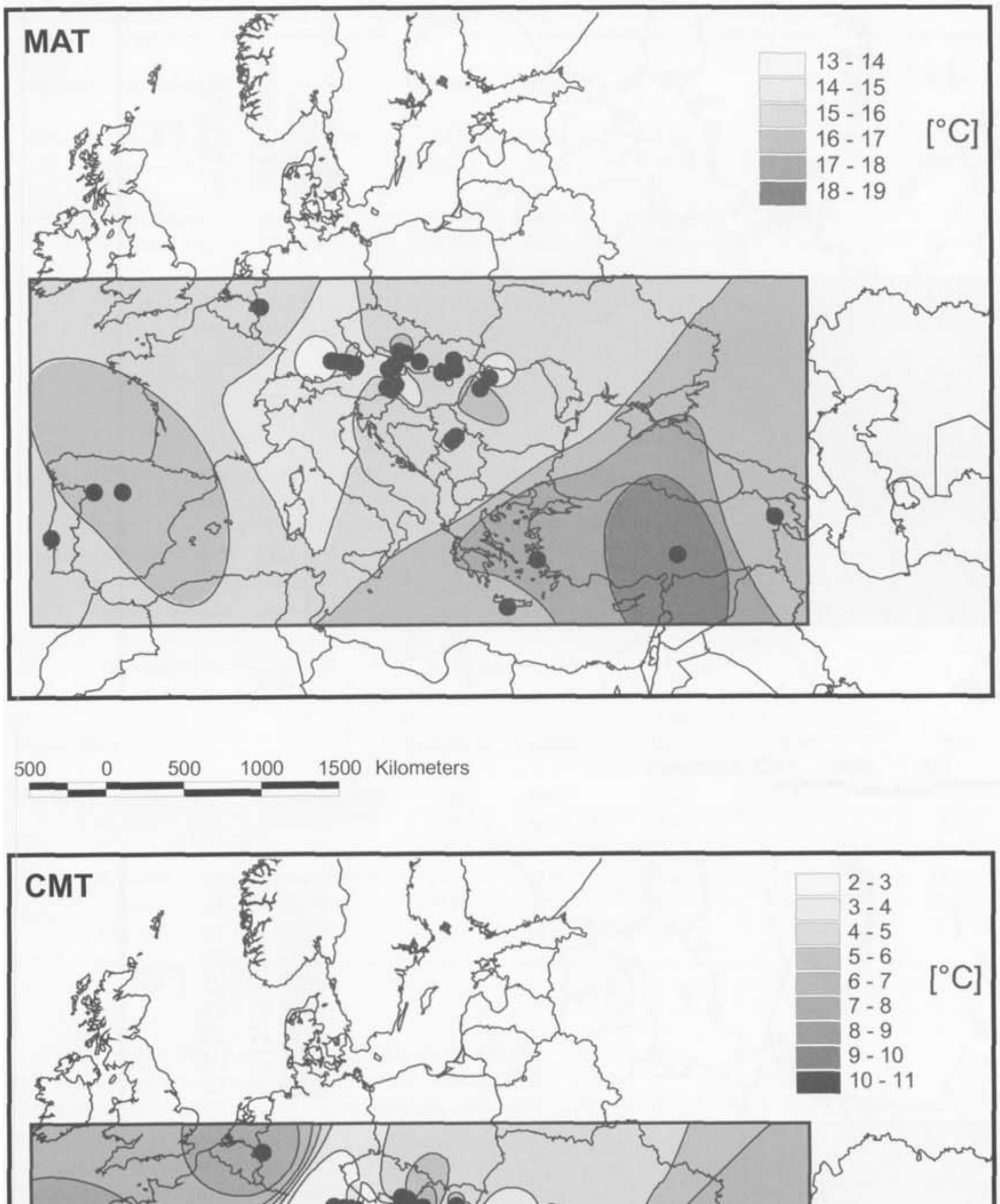


Fig. 3: Early Late Miocene climate reconstructions: mean annual temperature (MAT) and mean temperature of the coldest month (CMT) (middle values of coexistence intervals, IDW interpolated).

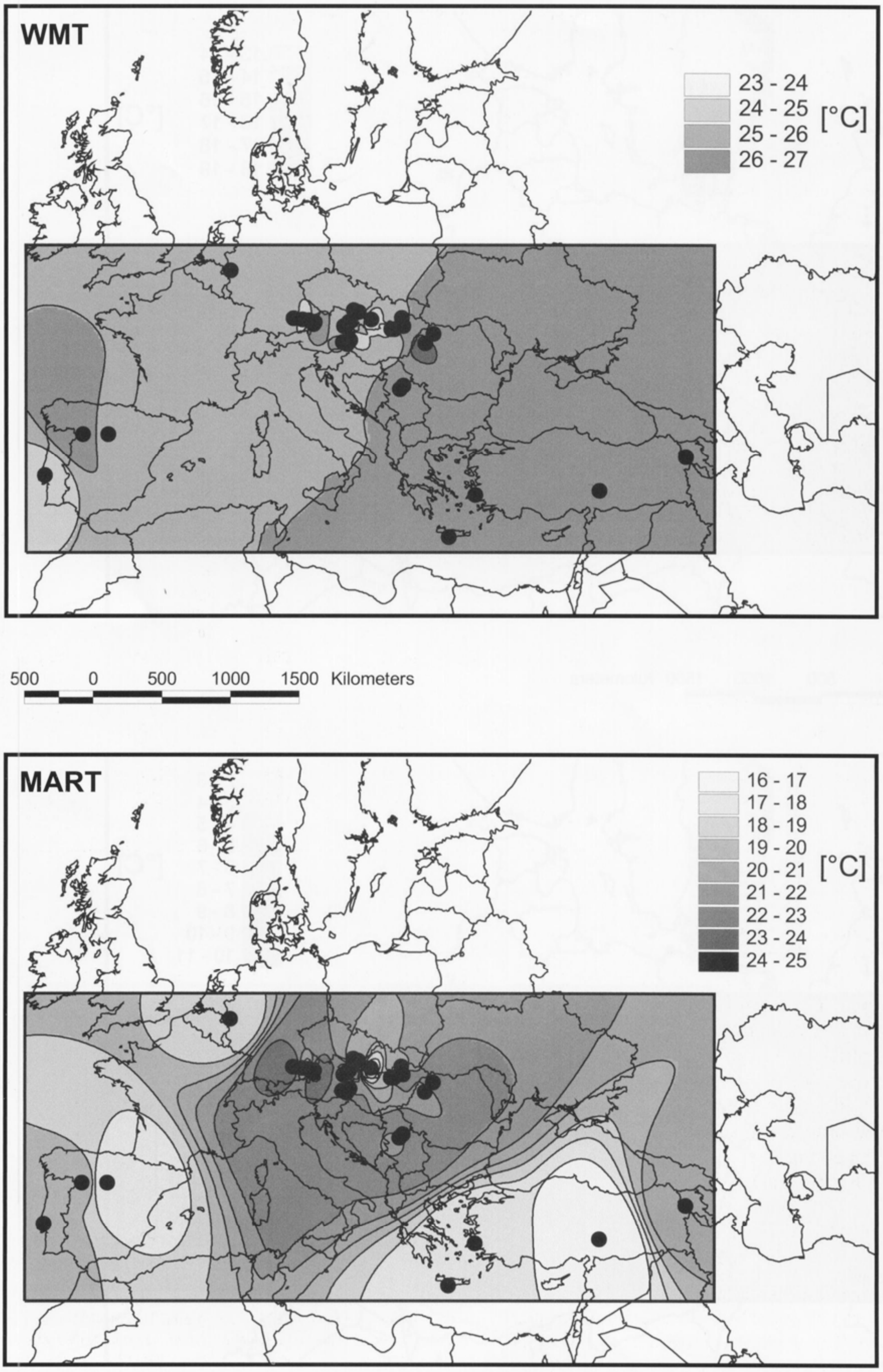


Fig. 4: Early Late Miocene climate reconstructions: mean temperature of the warmest month (WMT) and mean annual range of temperature (MART) (middle values of coexistence intervals, IDW interpolated).

Table 5: Temperature gradients of early Middle Miocene, early Late Miocene, and Recent climate data.

Langhian/early Badenian			**Longitude**	**Latitude**	**MAT**	**CMT**	**WMT**	**MART**
North	Hambach Mine 6C	NW Germany	6.47	50.92	16.85±1.15	10.65 ±1.05	26.75 ±1.55	16.10
	Zidlochovice 1	Czech Rep.	16.63	49.04	17.05±1.35	8.75 ±3.75	26.40 ±1.70	17.65
South	Lisboa-Almada	Portugal	-9.17	38.68	17.25±1.55	8.00 ±4.10	26.70 ±1.00	18.70
	Hoktemberyan 2	Armenia	44.12	40.15	17.00±1.30	6.55 ±1.55	26.55 ±1.15	20.00
	latitudinal distance ca. 1500 km							
early Tortonian/Pannonian			**Longitude**	**Latitude**	**MAT**	**CMT**	**WMT**	**MART**
North	Zukunft Mine 7A	NW Germany	6.45	50.93	15.40 ±0.10	7.25 ±0.65	25.80 ±0.10	18.55
	WIEN E-F	Austria (Vienna Basin)	16.65	48.80	16.10 ±0.40	4.65 ±1.75	25.60 ±1.80	20.95
	Moravian Basin	Czech Rep. (Vienna Basin)	17.05	48.70	16.05 ±0.45	5.70 ±0.10	26.05 ±0.35	20.35
South	Triopetra	Greece (Crete)	24.50	34.88	16.80 ±1.20	8.75 ±3.75	26.50 ±1.80	17.75
	Povoa	Portugal	–8.68	39.25	15.35 ±1.65	5.40 ±2.90	24.85 ±1.55	19.45
	Hoktemberyan 5	Armenia	44.15	40.18	16.50 ±0.90	6.35 ±1.35	26.75 ±1.05	20.40
	latitudinal distance ca. 1800 km							
Recent data			**Longitude**	**Latitude**	**MAT**	**CMT**	**WMT**	**MART**
North	Cologne	NW Germany	7.08	50.87	9.6	1.2	18.2	17.0
	Vienna	Austria	16.37	48.25	9.8	-1.5	19.9	21.4
South	Heraklion	Greece (Crete)	25.13	35.35	18.6	12.3	25.6	13.3
	Lisboa	Portugal	-9.15	38.72	16.6	10.8	22.5	11.7
	Yerevan	Armenia	44.47	40.13	11.6	-4.0	25.1	29.1

Beside all the shortcomings concerning the quality of data in terms of stratigraphy, taxonomy etc. that are not fully avoidable in such a compilation, there are only very few quantitative climate data obtained by standardised methods yet and only within a relatively restricted area. That makes it difficult to completely understand the temperature patterns observed for the European Miocene. Future studies will enlarge and enhance the dataset in time and space to obtain a better resolution and to quantify also the very low temperature gradients of the Middle Miocene by covering a larger geographical area.

Acknowledgements

The authors like to thank all colleagues and NECLIME members for providing publications and published flora lists for analysis. This work is a contribution to the program "*Neogene Climate Evolution in Eurasia* – NECLIME" and ESF program "Environments and Ecosystem Dynamics of the Eurasian Neogene (EEDEN)".

References

Antunes, M.T. & Mein, P. (1977): Contributions à la Paléontologie du Miocène moyen continental du Bassin du Tage. III – Mammifères, Póvoa de Santarém, Pero Filho et Chões (Secorio). Conclusions générales. – Ciências da Terra, **3**: 143-165.

Bessedik, M. (1984): The early Aquitanian and upper Langhian-lower Serravallian environments in the northwestern Mediterranean region. – Paléobiologie Continentale, **14**(2): 153-179.

Bice, K.L.& Marotzke, J. (2000): Warm climate dynamics. – GFF, **122**: 29-30.

Bruch, A.A., Utescher, T., Mosbrugger, V., Gabrielyan, I. & Ivanov, D. (in press): Late Miocene climate in the circum-Alpine realm – a quantitative analysis of terrestrial palaeofloras. – Paleogeography, Palaeoclimatology, Palaeoecology.

Chryssanthi, I. & Solounias, N. (1985): A radiometrically dated pollen flora from the Upper Miocene of Samons Island, Greece. – Revue de Micropaléontologie, **28**: 197-204.

Fluteau, F., Ramstein, G. & Besse, J. (1999): Simulating the evolution of the Asian and African monsoons during the past 30 Myr using an atmospheric general circulation model. – Journal of Geophysical Research, Atmospheres, D10, **104**: 11995-12018.

Gregor, H.J. (1986): Zur Flora des Randecker Maares (Miozän, Baden-Württemberg). – Stuttgarter Beiträge zur Naturkunde, B 5, **122**: 1-29.

Gross, G., Mosbrugger, V., Schäfer, A., & Wutzler, B. (1989): Niederrheinische Braunkohle. Exkursion in den Tagebauen der Rheinbraun AG in der südlichen Niederrheinischen Bucht. – 59. Jahrestagung der Paläontologischen Gesellschaft, Excursion Guide: 44; Bonn (Bonn University).

Horváth, E. (1972): Beiträge zur Kenntnis der pliozänen Flora Westungarns. – Savaria, Vas megyei Múzeumok Értesítoje **5-6**: 23-73.

Jung, W. (1963): Blatt- und Fruchtreste aus der OSM von Massenhausen, MN8. – Palaeontographica, **B 112**: 119-166.

Kayseri, M.S. & Akgün, F. (2002): Palynostratigraphic correlations of the Miocene sediments with lignites and their depositional environments in the Central Anatolia, Turkey. – 6th European Palaeobotany Palynology Conference, Abstracts volume: 217-218; Athens (University of Athens).

Knobloch, E. & Kvacek Z. (1976): Miozäne Blätterfloren vom Westrand der Böhmischen Masse. – Rozpravy Ustredniho Ustavu Geologickeho, **42**: 1-131.

Kovar-Eder, J. & Krainer, B. (1990): Faziesentwicklung und Florenabfolge des Aufschlusses Wörth bei Kirchberg/Raab (Pannon, Steirisches Becken). – Annalen Naturhistorisches Museum Wien, **A 1991**: 7-38.

Kretzoi, M., Krolopp, E., Lőrincz, H. & Pálfalvy, I. (1976): Flora, fauna, and stratigraphic position of the lower Pannonian pre-hominid locality of Rudabanya, northeastern Hungary. – Annual Report of the Hungarian Geological Institute, **1974**: 365-394.

Mai, D. H. (1995): Tertiäre Vegetationsgeschichte Europas. – 1-691; Jena (Gustav Fischer).

Manabe, S. & Bryan, Jr., K. (1985): CO_2-induced change in a coupled ocean-atmosphere model and its palaeoclimatic implications. – Journal of Geophysical Research, **90**: 11,689-11,707.

Manukyan, L.K. (1977): The Miocene Flora and Vegetation of the Hoktemberyan Depression on Palaeopalinological Data (in Russian). – Akademia Nauk Armianskoy SSR. Biolog. Zhurnal Armeniy (The Academy of Sciences of Armenian SSR. Botanical Magazine of Armenia), **30**(12): 9-15.

Manukyan, L.K. (1978): The Flora and Vegetation of the Hoktemberyan Depression (South-West part of Armenian SSR) on the Palaeopalinological Data (in Russian). – Abstract of the Theses of Candidate of Biological Science: 1-25; Yerevan (Armenian Academy of Sciences).

Manukyan, L.K. (1980): The List of the Fossil Pollen Flora of the Tertiary (Miocene) Deposits of the South-West Armenia (in Russian). – Akademia Nauk Armianskoy SSR. Biolog. Zhurnal Armeniy (Academy of Sciences of Armenian SSR. Botanical Magazine of Armenia), **33**(5): 509-514.

Mosbrugger, V. & Utescher, T. (1997): The coexistence approach – a method for quantitative reconstructions of Tertiary terrestrial palaeoclimate data using plant fossils. – Paleogeography, Palaeoclimatology, Palaeoecology, **134**: 61-86.

Pais, J. (1979): La végétation de la Basse Vallèe du Tage (Portugal) au Miocène. – Annales Geologiques des Pays Helleniques, Hors série, **2**: 933-942.

Pais, J. (1981): Contribuição para o conhecimento da vegetação miocénica da parte ocidental da bacia do Tejo. – Dissertação de Doutoramento: 1-328; Lisboa (Universidad de Nova de Lisboa).

Pais, J. (1986): Évolution de la végétation et du climat pendant le Miocène au Portugal. – Ciências da Terra, **8**: 179-191.

Pantic, N., Mihajlovic, D. & Vrabac, S. (1988): Badenian Fossil Flora from Tuzla Area. – Annales Geologiques de la Peninsula Balkanique, **51**: 321-327.

Rivas Carballo, M.R. & Valle, M.F. (1990): Estudio del polen, esporas y palinomorfos del paleógeno y neógeno de la provincia de Burgos. – In: Blanca, G. et al. (eds.): Polen, esporas y sus aplicaciones. – VII. Simposium de Palinología. 445-451; Salamanca (Asociación de Palinólogos de Lengua Españgola).

Salvador de Luna, J.V. (1984): Análisis esporopolínico en el borde suroccidental y nororiental del Neógeno de la Cuenca del Duero (Abezames, Zamora, y Castrillo del Val, Burgos). – Tesis de licenciatura: 1-168; Salamanca (Universidad de Salamanca).

Sanz de Siria, A. (1988): Los vegetales miocénicos de Rubí (Barcelona). – Paleontologia i Evolució, **22**: 71-76.

Seitner, L. (1987): Miozäne Mikrofloren aus Sedimenten der Süssbrackwassermolasse und der oberen Süsswassermolasse Süddeutschlands. – unpubl. Dissertation: 1-352; Munich (Ludwig-Maximilians-University).

Shvareva, N.Y. (1983): Miotsenovaya flora Predkarpatya (The Miocene Precarpathian Flora – in Russian). – 1-160; Kiev (Naukova Dumka Kiev).

Suc, J.-P. (1989): Distribution latitudinale et étagement des associations végétales au Cenozoique supérieur dans l'aire oust-mediterranéenne. – Bulletin de la Société géologique de France, série 8, **5**(3): 541-550.

Utescher, T., Mosbrugger, V., Ashraf, A.R., 2000. Terrestrial Climate Evolution in Northwest Germany Over the Last 25 Million Years. – Palaios, **15**(5): 430-449.

Valle, H. & Salvador de Luna, J.V. (1985a): Palinología del Neógeno de la cuenca del Duero, Castrillo del Val (Burgos). – Estudios Geológicos, **41**(3-4): 237-241.

Valle, M.F. & Salvador de Luna, J.V. (1985b): Resultados palinológicos en el borde sur-occidental de la cuenca del Duero. Abezames (Zamora). – Estudios Geológicos, **41**(1): 69-45.

Valle, M.F., Alonso-Gavilán, G. & Rivas Carballo, M.R. (1995): Analyse palynologique préliminaire du Miocene dans le NE de la depression du Duero (aire de Belorado, Burgos, España). – Geobios, **28**(4): 407-412.

Manuscript submitted 2004 – 05 – 30
Manuscript accepted 2004 – 07 – 29

Appendix 1: Taxa list of C-136A/301.0, Bulgaria (D. Ivanov).

Taxa	**NLR**
Laevigatosporites sp	unknown
Retitriletes reticuloides reductoides Krutzsch	Lycopodiaceae – *Lycopodium*
Osmundacidites primarius (Wolff) Nagy	Osmundaceae – *Osmunda*
Corrugatisporites cf. *pseudovallatus* Nagy	Pteridaceae – *Pteris*
Monoleiotriletes gracilis Krutzsch	
Pityosporites labdacus (Pot.) Th. & Pf.	Pinaceae – *Pinus sylvestris* type
Pityosporites microalatus (Pot.) Th. & Pf.	Pinaceae – *Pinus haploxylon* type
Tsugaepollenites sp. div.	Pinaceae – *Tsuga*
Sciadopityspollenites serratus (Pot. & Venitz) Raatz	Sciadopitaceae – *Sciadopitys*
Inaperturopollenites hiatus (Pot.) Th. & Pf.	Taxodiaceae
Sequoiapollenites polyformosus Thierg.	Taxodiaceae – *Sequoia*
Cupressacites sp.	Cupressaceae
Aceripollenites striatus (Pflug) Thiele-Pfeifer	Aceraceae – *Acer*
Ilexpollenites iliacus (Pot.) Thiergart ex Potonié	Aquifoliaceae – *Ilex*
Araliaceoipollenites euphorii (Pot.) Pot. ex Potonié	Araliaceae
Corylopollis coryloides (Pflug) **Ziembinska-Tworzydlo**	Betulaceae – *Corylus*
Caprifoliipites sambucoides Nagy	Caprifoliaceae
Cornaceaepollis major (Stuchlik) Stuchlik	Cornaceae – *Cornus*
Cyperaceaepollis sp.	Cyperaceae
Ericipites sp. div.	Ericaceae
Quercoidites sp. div.	Fagaceae – *Quercus*
Liquidambarpollenites orientaliformis Nagy	Hamamelidaceae – *Liquidambar*
Caryapollenites simplex (Pot.) Raatz	Juglandaceae – *Carya*
Pterocaryapollenites stellatus (Potonié) Thiergart	Juglandaceae – *Pterocarya*
Juglandipollis maculosus (Pot.) Kohlman-Adamska	Juglandaceae – *Juglans*
Nyssapollenites kruschi (Pot.) Nagy	Nyssaceae – *Nyssa*
Symplocoipollenites vestibulum (Pot.) Potonié	Symplocaceae – *Symplocos*
Thalictrum sp.	Thalictraceae – *Thalictrum*
Ulmipollenites undolosus Wolff	Ulmaceae – *Ulmus*

Appendix 2: Taxa list of Zidlochovice 1, Czech Republic (N. Dolakova).

Taxa	**NLR**
Triplanosporites sinuosus Pf. ex Th.et Pf.	unknown
Laevigatosporites haardti (R. Pot. & Ven.) Th. & Pf	unknown
Leiotriletes wolffi wolffi Krutzsch	Lygodiaceae – *Lygodium*
Leiotriletes sp.	Lygodiaceae
Segmentizonosporites paucirugosus (Nagy) Stuchlik	Pteridaceae
Polypodiaceoisporites muricinguliformis Nagy	Pteridaceae – *Pteris*
Polypodiaceoisporites corrutoratus Nagy	Pteridaceae – *Pteris*
Pinus – haploxylon and diploxylon types	Pinaceae
Cathaya	Pinaceae – *Cathaya*
Keteleeria	Pinaceae – *Keteleeria*
Picea	Pinaceae – *Picea*
Abies	Pinaceae – *Abies*
Cedrus	Pinaceae – *Cedrus*
Tsuga	Pinaceae – *Tsuga*
Sciadopitys	Sciadopitaceae – *Sciadopitys*
Inaperturopollenites hiatus (Pot.) Th. & Pf.	Taxodiaceae
Glyptostrobus type	Taxodiaceae – *Glyptostrobus*
Ephedra	Ephedraceae – *Ephedra*
Acer	Aceraceae – *Acer*
Ilexpollenites margaritatus (Pot.) Potonié	Aquifoliaceae – *Ilex*
Ilexpollenites propinquus (Pot.) Raatz	Aquifoliaceae – *Ilex*
Tricolporopollenites pseudocingulum (Pot.) Th. & Pf.	Anacardiaceae – *Rhus*
Alnus	Betulaceae – *Alnus*
Betula	Betulaceae – *Betula*
Buxus	Buxaceae – *Buxus*
Chenopodiaceae.	Chenopodiaceae
Tricolporopollenites megaexactus (Pot.) Th.& Pf.	Cyrillaceae
Ericipites ericius (Potonié) Potonié	Ericaceae
Castaneoideaepollis oviformis (Potonié) Grabowska	Fagaceae
Castaneoideaepollis pusillus (Potonié) Grabowska	Fagaceae
Quercoidites henrici (Potonié) Potonié	Fagaceae
Quercoidites microhenrici (Potonié) Potonié	Fagaceae
Quercoidites granulatus (Nagy) Slodkowska	Fagaceae – *Quercus sp.*
Ouercoidites asper (Pflug &Thomson) Slodkowska	Fagaceae – *Quercus sp.*
Quercoidites sp.	Fagaceae – *Quercus sp.*
Q. ilex type	Leguminosae – Fagaceae
Tricolporopollenites falax (Potonié) Krutzsch	Leguminosae – Fagaceae
Tricolporopollenites liblarensis (Thomson) Grabowska	Leguminosae – Fagaceae
Tricolporopollenites quisqualis (Potonié) Krutzsch	Leguminosae – Fagaceae
Liquidambar	Hamamelidaceae – *Liquidambar*
Tricolporopollenites indeterminatus (Rom.) Ziemb.-Tworz.	Hamamelidaceae – *Distylium*
Carya	Juglandaceae – *Carya*
Pterocaryapollenites	Juglandaceae – *Pterocarya*
Juglanspollenites	Juglandaceae – *Juglans*
Engelhardia	Juglandaceae – *Engelhardia*
Platycarya	Juglandaceae – *Platycarya*
Myrica	Myricaceae – *Myrica*
Oleaceae	Oleaceae
Platanus	Platanaceae – *Platanus*
Sapotaceae	Sapotaceae
Symplocos	Symplocaceae – *Symplocos*
Intratriporopollenites insculptus Mai	Tiliaceae – Brownloideae
Intratriporopollenites instructus (Pot.) Th. & Pf	Tiliaceae – Brownloideae
Ulmus	Ulmaceae – *Ulmus*
Zelkova	Ulmaceae – *Zelkova*

Celtis	Ulmaceae – *Celtis*
Tamarix	Tamaricaceae – *Tamarix*
Tricolporopollenites spp. - indet.	
Poaceae	Poaceae
Arecaceae	Arecaceae
Butomus	Butomaceae – *Butomus*

Acta Palaeobotanica 44(1): 79–85, 2004

Discussion of some thermophile palynomorphs from the Miocene sediments in the Carpathian Foredeep (Czech Republic) and Modrý Kamen basin (Slovakia)[*]

NELA DOLÁKOVÁ

Institute of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic;
e-mail: nela@sci.muni.cz

Received 14 March 2003; accepted for publication 16 February 2004

ABSTRACT. The sediments from the southern part of the Carpathian Foredeep in Moravia (Czech Republic) and the Modrý Kamen basin from Slovakia were studied. The sediments are of Eggenburgian to Lower Badenian ages and of marine or brackish origin. The marine facies rapidly changes with lagoonal and deltaic facies during the Eggenburgian–Ottnangian. The palynospectra have warm-subtropical character. Saltmarsh vegetation (37% Chenopodiaceae) interchanged with swamp vegetation. In the Karpatian palynospectra marsh facies occur more uniformly. Marked azonal associations, for example marsh palm forest, riparian forest or the associations with Taxodiaceae and Tiliaceae (*Craigia*), are typical. The Ottnangian–Karpatian palynospectra from the Modrý Kamen basin were typical in the occurrence of pollen of *Pentapollenites* sp. The studied Lower Badenian sediments represent the fully marine conditions. The palynospectra were poor in pollen and spores (except Pinaceae) and rich in Dinoflagellata. At this time the climate was not extremely warm.

KEY WORDS: palynology, Miocene, Carpathian Foredeep, Czech Republic

INTRODUCTION

The sediments from the southern part of the Carpathian Foredeep in Moravia (Czech Republic) were studied palynologically. Palynomorphs have been described from many boreholes and outcrops with the sediments of the Eggenburgian to Badenian age. Palynological studies were compared primarily with sedimentological and palaeontological investigations. The studies were directed firstly on the relationship between the terrestrial and marine ecosystems. Palynological results were compared with the ones from the Modrý Kamen basin in the southern part of the Slovak Republic.

RESULTS

The sediments are of Eggenburgian to the Lower Badenian age, and are marine or brackish in origin. As a whole, the palynospectra indicate a warm-subtropical character of climate. Sapotaceae, Palmae, *Engelhardia*, *Platycarya*, Castaneoideae, *Tricolporopollenites liblarensis* (Th.) Th. & Pf., thermophile oaks, *Lygodium*, and Pteridaceae are frequent. *Symplocos*, *Reevesia*, Cornaceae, *Parthenocissus*, *Tricolporopollenites pseudocingulum* (Pot.) Th. & Pf., and families Araliaceae and Rutaceae occur regularly but in lower quantities. *Alangium* and *Neogenisporis neogenicus* Krutzsch are represented by sporadic occurrences only. Arctotertiary elements are slightly less frequent. Practically all of the palynospectra are strongly influenced by sedimentological

---

[*] This study was supported by the Grant Agency of the Czech Republic, grant no. 05/00/0550.
This paper was presented on the EEDEN Workshop, Kraków 28 June – 1 July 2002

facies. This fact is reflected in the proportional changes between the palaeotropic and arctotertiary elements, and it is very difficult to specify any trends in the climate development from these data. Higher percentages of the arctotertiary elements were observed locally, for example:

– Chenopodiaceae, Oleaceae, Ericaceae, *Salix*, *Potamogeton*, Ulmaceae, Taxodiaceae – in the sediments of the Eggenburgian–Ottnangian,

– *Alnus*, Ulmaceae, *Osmunda*, Polypodiaceae, Lythraceae, *Sparganium* – in the Karpatian sediments.

In the pollen diagrams of the studied Miocene sediments, no explicit climatic changes are visible. The author cannot specify at the present time if the observed changes are influenced climatologically or caused by the development of the sedimentary basin and adjacent areas.

The environment of the studied part of the Carpathian Foredeep was extraordinarily variable during the Eggenburgian–Ottnangian. The marine transgression penetrated the sea coast with highly differentiated relief configurations. The marine facies interchanged rapidly with those of lagoons and deltas. Sediments and molluscs show rapid changes in salinity, dynamics and depths, light and evaporation. The palynospectra reflected many of these changes (Nehyba et al. 1997).

Due to oscillations in salinity and occasional higher levels of evaporation halophilous vegetation grew on the coast (up to 37% Chenopodiaceae, Pl. 1, fig. 9). In some places these were accompanied with higher number of *Ephedra* and Buxaceae. Ericaceae are frequent in the facies manifesting a low salinity.

Pollen grains of the species cf. *Monocirculipollis zahnaensis* Krutzsch (Pl.1, figs 1–4) in one case even in pollen conglomerate, which most probably contradicts the redeposition from older sediments, were typical for the sediments of the Eggenburgian age. These pollen were found in all the Eggenburgian boreholes and they were absent in younger sediments. Krutzsch (1966) described these pollen types from the Palaeocene and Eocene sediments and he considered them as extinct members of the family Buxaceae. Similar pollen types were found also in the Miocene sediments from Turkey (Nurdan Yavus, pers. comm.). According to data in the literature, the pollen type seem to be similar to some members of the families Caryophyllaceae or Amaranthaceae. It is necessary to test this opinion with SEM observations on the detailed features of the pollen.

Even the presence of small tri- or tetracolporate grains of Rutaceae is typical for some localities. A large amount of *Platanus* pollen was also observed in some samples.

Saltmarsh vegetation developed in time and space to the various growth stages of the swamp and riparian vegetation. For example facies with *Myrica* pollen (Pl. 1, fig. 13) overlapping 40%, or Taxodiaceae approaching values of 50% are visible. The freshwater flora with *Nelumbo*, *Potamogeton*, *Sparganium*, and Cyperaceae has been ascertained. *Lygodium* (Pl.1, fig.14) was also frequent, in one locality its frequency reached more than 5%.

Later on, the character of the coast development changed, with the relief becomming flatter. The transgression stage follows in the Ottnangian, the sea probably penetrated further to the north into the area. The sediments include the so called *Rzehakia* beds (Nehyba et al. 1997). Facies with moorland and marginal swamp appeared in the palynospectra. Taxodiaceae are also frequent. The climate at this time appears to be more humid. Pollen spectra contain a larger amount of spores of thermophile ferns as *Lygodium*, Pteridaceae, Gleicheniaceae together with *Riccia* and *Selaginella* (Pl. 1, fig. 10). *Ilex* is relatively plentiful. The higher representation of *Symplocos* pollen is interesting in the samples of Ottnangian age.

Striking members in some palynospectra are the higher proportions of *Selaginella* (up to 6%), their occurrence being visible in the Eggenburgian/Ottnangian and Ottnangian/Karpatian border sediments. They are accompanied by an increased frequency of other pteridophytes. The humid climate was probably connected with the transgression.

The Karpatian sedimentation began by gradual transgression on the relatively flat coast, which was connected with anoxic conditions. The frequent alteration of palynomorphs caused by precipitation and growth of pyrite is visible. Later on, fully marine conditions with schlieric sediments developed. In the Karpatian palynospectra the marsh facies occur more uniformly than in the Eggenburgian–Ottnangian. Pollen and spores also confirm a warm to warm-temperate climate.

The markedly azonal associations, for example marsh palm forest with Palmae (Pl. 2, figs 9,10), Poaceae, *Lygodium*, *Sparganium*, and *Potamogeton*; riparian forest with *Alnus*, (Pl. 2, fig. 4), Myricaceae (Pl. 2, fig. 3), Lythraceae (Pl. 2, figs 1,2), or *Selaginella* (Pl. 2, fig. 13) are frequent in Karpatian sediments. The associations with Taxodiaceae, *Intratriporopollenites insculptus* Mai (Pl.2, figs 6,7) and Pteridaceae (up to 10%) are typical. According to recent investigations (Kvaček et al. 2002) *Intratriporopollenites insculptus* belongs to the genus *Craigia* (Malvaceae–Tilioideae). Very similar associations were also described from the lower Miocene of Northern Bohemia (Konzalová 1976). These pollen types were found also in the Eggenburgian sediments of the Carpathian Foredeep. In all the cases they are accompanied with high amount of other hygrophilous elements (except the ones mentioned above also Ericaceae and *Salix*).

Assotiations of markedly colder climatic conditions, known from the adjacent areas (e.g. Slovakia, Austria) from the end of the Ottnangian and the lower Karpatian (Hochuli 1978, Planderová 1990) have not been found. Proportional changes between palaeotropical and arctotertiary elements seems to be influenced by facies in all of the samples studied.

The schlieric sediments, representing marine conditions, contain a large amount of Pinaceae and an increasing amount of Oleaceae (Pl. 2, figs 8,12). Sapotaceae have not been found in the uppermost studied Karpatian sediments. Arctotertiary elements increased slightly. However, there are not sufficient data to enable a more exact interpretation of this as representing a colder climate interval.

Conglomerations of pollen (*Monocirculipollis*, Chenopodiaceae, *Platanus*, Oenotheraceae, Myricaceae, *Alnus*, and others) were found in some facies from the whole of the Lower Miocene. Their presence confirms the low-flow water dynamics and short transport distances to the place of sedimentation.

The studied sediments from the Modrý Kamen basin include the *Rzehakia* beds and the schlieric layers (Ottnangian–Karpatian). The palynospectra are similar to the ones from the Carpathian Foredeep. The biggest difference is based on the typical occurence of pollen of the formal genus *Pentapollenites* (Pl. 2 fig. 14–16) which after Krutzsch (1962) is characteristic for Palaeogene. These pollen have also been described from Miocene sediments by Planderová (1990) and Nagy (1985). Planderová interprets these types of pollen as typical for the coal facies of the Slovakian Lower Miocene. However, the author has not observed these pollen types in the Carpathian Foredeep. According to the recent literature (Reille 1995) part of our material is very close to the genus *Haplophyllum* (Rutaceae). Hofmann and Zetter (2001) described this pollen from the Palaeocene/Eocene of Austria and considered them belonging within the Simarubaceae.

The studied Lower Badenian sediments represent the development of fully marine conditions with a high oxygen content. The palynospectra are generally poor in pollen and spores (except for Pinaceae), and are comparatively rich in Dinoflagellata. The tapeta of foraminifers have also been identified. It is probable that the conifer pollen accumulated in these marine sediments due to their wind dispersal properties.

The environment on the seashore was probably rather wet as noted by the presence of spores of Fungi, Polypodiaceae, pollen of *Alnus* and *Ulmus* and ranging up to swampy as represented by the pollen of Taxodiaceae and Myricaceae. There are visible only slight changes in the pollen diagrams between the Karpatian and Lower Badenian pollenspectra. In the Badenian a decreasing number of some thermophilous members, such as *Engelhardia*, *Platycarya*, *Tricolpopollenites henrici* (Pot.) Th. & Pf. and *T. microhenrici* (Pot.) Th. & Pf., and Castanoideae are observed. Oleaceae were also less frequent, although Taxodiaceae regularly have a higher representation while *Alnus* has steadily lower percentages. In the Badenian palynospectra the higher differentiation of the pollen of thermophilous forms of oaks such as *Tricolpopollenites henrici* (Pot.) Th. & Pf. and *T. microhenrici* (Pot.) Th. & Pf. or forms probably similar to the *Quercus ilex* as well as deciduous ones, are observed (Pl. 2, figs 18–19).

The present author cannot currently specify if the changes observed are influenced climatologically or are caused by the development of the sedimentation basin and its adjacent areas.

REFERENCES

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

HOFMANN Ch.Ch. & ZETTER R. 2001. Palynological investigation of the Krappfeld area, Palaeocene/Eocene, Carinthia (Austria). Palaeontographica, B, 259 (1–6): 47–64.

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

KRUTZSCH W. 1962. Mikropaläontologische (sporenpaläontologische) Untersuchungen in der Braunkohle des Geiseltales. II. Die Formspezies der Pollengattung *Pentapollenites* Krutzsch 1958. Paläont. Abh., 1(2): 75–103.

KRUTZSCH W. 1966. Zur Kenntnis der präquartären periporaten Pollenformen. Geologie, 15(55): 16–71.

KVAČEK Z., MANCHESTER S.R., ZETTER R. & PINGEN M. 2002. Fruits and seeds of *Craigia bronni* (Malvaceae-Tilioideae) and associated flower buds from the late Miocene Inden Formation, Lower Rhine Basin, Germany. Rev. Palaeob. Palyn., 119: 311–324.

NAGY E. 1985. Sporomorphs of the Neogene in Hungary. Geologica Hungarica, ser. Palaeont., 47: 1–470.

NEHYBA S., HLADILOVÁ Š. & DOLÁKOVÁ N. 1997. Sedimentary evolution and changes of fossil assemblages in the SW part of the Carpathian Foredeep in Moravia during the Lower Miocene. In: Hladilová Š. (ed.) Dynamika vztahů marinního a kontinentálního prostředí. Sborník příspěvků. Grantový projekt GAČR 205/95/1211. Masarykova univerzita: 40–58. Brno. (In Czech with English summary).

PLANDEROVÁ E. 1990. Miocene Microflora of Slovak Central Paratethys and its Biostratigraphical Significance. Geol. Inst. D. Štúra, Bratislava.

REILLE M. 1995. Pollen et Spores d' Europe et d' Afrique du Nord, (I,II). Marseille.

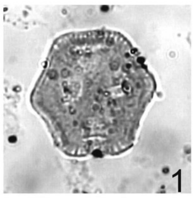
PLATES

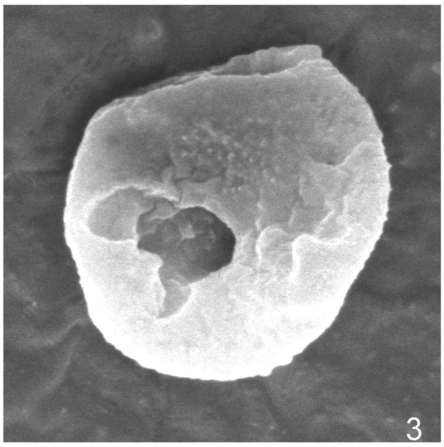
Plate 1

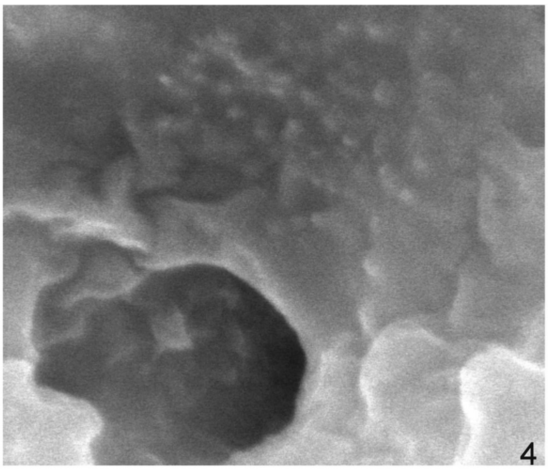
Sporomorphs of Eggenburgian – Ottnangian

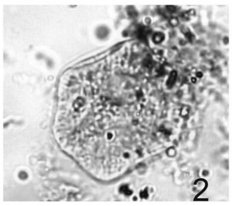
× 1000, except figs 3,4 and 13

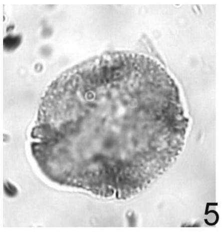
1–4. *Monocirculipollis zahnaensis* Krutzsch, Čejkovice 176.8 m, Eggenburgian–Ottnangian
3. SEM × 2300
4. SEM × 5500
5. *Reevesiapollis triangulus* (Mamczar) Krutzsch, Líšeň, Ottnangian
6. *Sapotaceoidaepollenites* sp., Miroslav 78.4 m, Eggenburgian–Ottnangian
7, 8. *Rutaceaepollenites* sp., Šafov 12, 17.5 m
9. *Chenopodipollis multiplex* (Weyl. & Pf.) Krutzsch, pollen conglomerate, Miroslav 78.4 m, Eggenburgian–Ottnangian
10. *Echinatisporis miocenicus* Krutzsch & Sontag in Krutzsch, Trboušany 65.8 m, Eggenburgian–Ottnangian
11. *Symplocoipollenites vestibulum* (Potonié) Potonié, Líšeň, Ottnangian
12. *Potamogetonpollenites* sp., Líšeň, Ottnangian
13. *Myricipites* sp., pollen conglomerate, Trboušany 49.7 m, Eggenburgian–Ottnangian, × 500
14. *Leiotriletes maxoides maximus* (Pflug) Krutzsch, Trboušany 49.7 m, Eggenburgian–Ottnangian


1


3

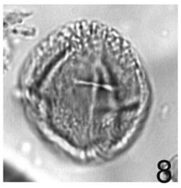

4

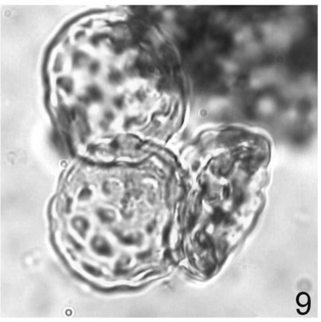

2

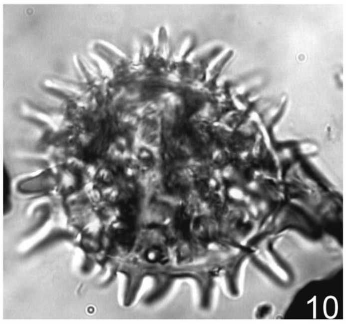

5

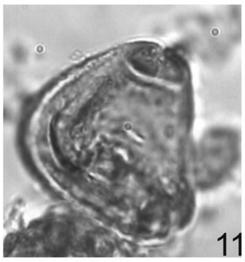

6

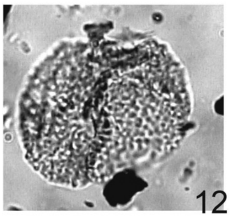

7


8


9


10


11


12


13

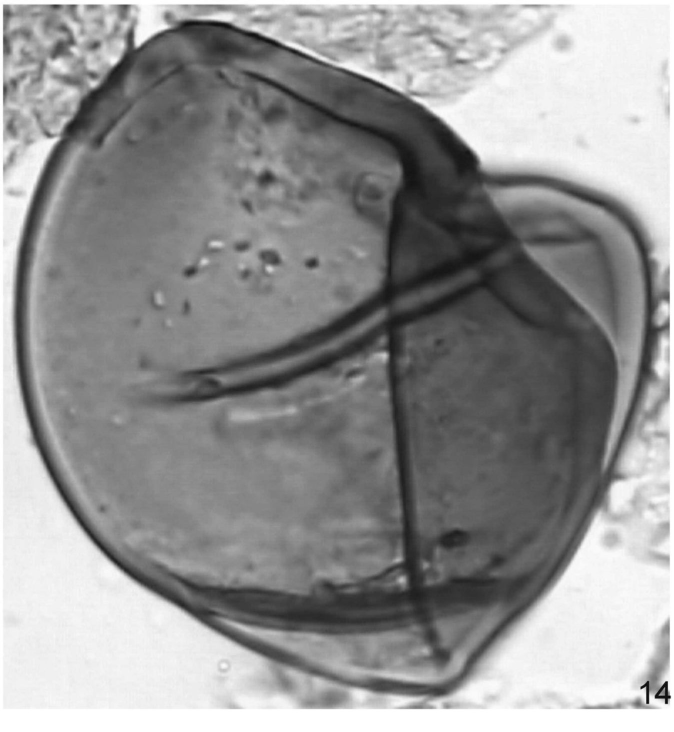
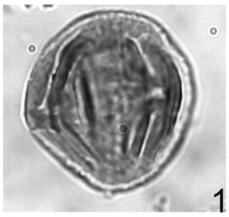

14

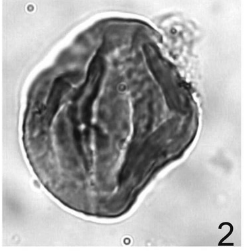
Plate 2

Sporomorphs of Ottnangian–Karpatian–Badenian

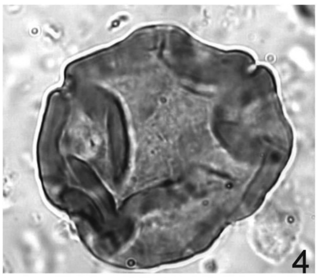
× 1000

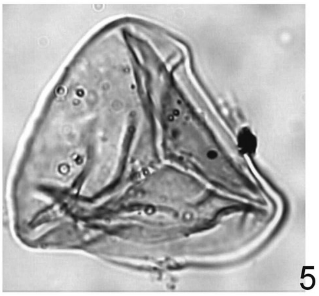
1,2. *Lythraceaepollenites* sp., Ždánice 67, 780–785 m
3. *Myricipites rurensis* (Pf.& Th.) Nagy, Ždánice 67, 780–785 m, Karpatian
4. *Alnipollenites verus* Potonié, Ždánice 67, 785–790 m, Karpatian
5. *Leiotriletes wolffii wolffii* Krutzsch, Nosislav 3, 323 m, Karpatian
6,7. *Intratriporopollenites insculptus* Mai, Ždánice 68, 815–820 m, Karpatian
8,12. *Oleoidearumpollenites* microreticulatus (Th. & Pf.) Ziembińska-Tworzydło, Nosislav 3, 280.8 m, Karpatian
9,10. *Sabalpollenites areolatus* (Potonié) Potonié, Ždánice 67, 795–800 m, Karpatian
11. *Potamogetonpollenites* sp. Ždánice 67, 795–800 m, Karpatian
13. *Echinatisporis miocenicus* Krutzsch & Sontag in Krutzsch, Nosislav 3, 343 m, Karpatian
14. *Pentapollenites* fsp. 1, Modrý Kamen Basin, N91, 345 m, Ottnangian–Karpatian
15, 16. *Pentapollenites* fsp. 2, Modrý Kamen Basin, N91, 345 m, Ottnangian–Karpatian
17. Marine Dinophyta, Židlochovice, Badenian
18. *Quercoidites granulatus* (Nagy) Słodkowska, Židlochovice, Badenian
19. *Quercoidites* sp. 1 – *Quercus ilex* type, Židlochovice, Badenian
20. *Cercidiphyllites minimireticulatus* (Trevisan) Ziembińska-Tworzydło, Židlochovice, Badenian
21. *Platanipollis ipelensis* (Pacltová) Grabowska, Lysice, Badenian
22. *Polypodiaceoisporites corrutoratus* Nagy, Židlochovice, Badenian
23. *Inaperturopollenites hiatus* (Potonié.) Th & Pf. – *Glyptostrobus* type, Ždánice 68, 815–820 m, Karpatian

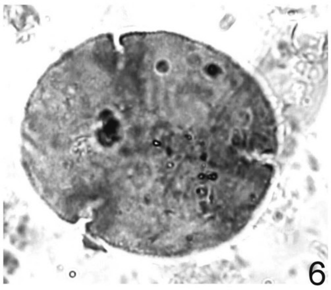

1

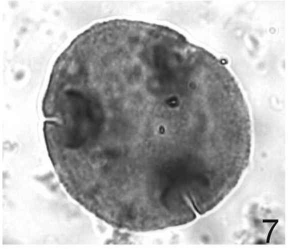

2


3


4

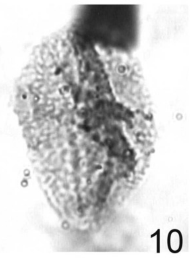

5

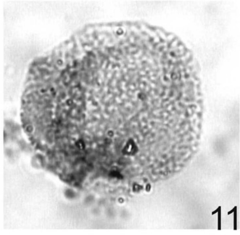

6

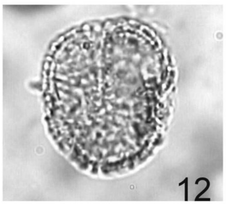

7

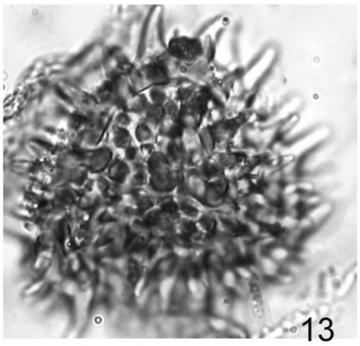

8

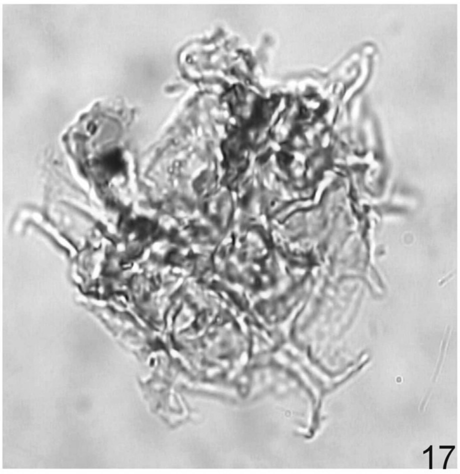

9

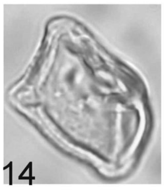

10

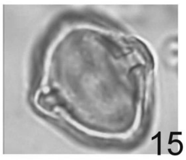

11

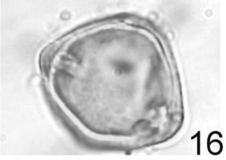

12

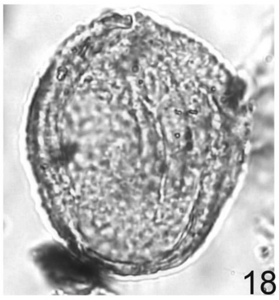

13

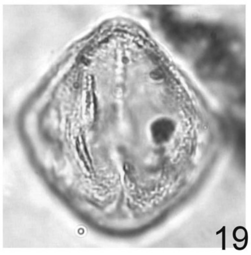

17

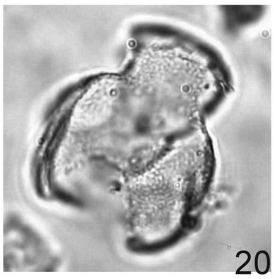

14


15

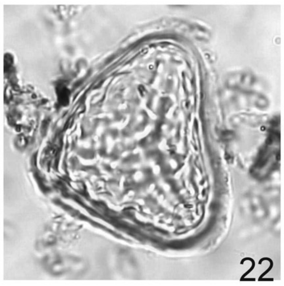

16

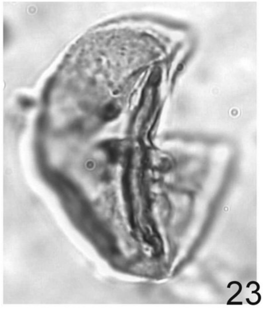

18


19


20


21


22


23

Palynological studies in the Cave sediments from the Moravian, Javoříčko and Hranice Karsts – Czech Republic

Nela Doláková

Department of Geological Sciences, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic;
e -mail: nela@sci.muni.cz

Key words: Palynology, cave sediments, Holocene, Pleistocene, Miocene

Abstract

The sediments of the karstic formations from the Moravian part of the Czech Republic (Moravian, Javoříčko and Hranice Karsts) were investigated from the palynological point of view. They were of Holocene, Pleistocene and Miocene ages. The mixing of the palynomorphs of different ages - especially Quaternary and redeposited Tertiary ones - and their selections and secondary accumulations due to their different resistances causes problems complicating the ages determinations and reconstructions of the original vegetation.

Introduction – problematics of pollen spectra interpretation in the cave sediments

The palynospectra were studied from three karstic formations: Moravian Karst (caves – Barová, Kateřinská, Pekárna, Býčí Skála, Ochoz, Kůlna, Sloup-Šošůvka, and Balcarka) Javoříčko Karst (the cave Za Hájovnou) and Hranice Karst (the karstic caverns in the Hranice quarry). The sediments were of Early Holocene, Pleistocene and Miocene ages. Palynological investigations were made in the collaboration with further geological and archeological disciplines.

The typical feature of the palynological studies in the caves is, that the sediments do not contain the plant rests in their original positions. Palynomorphs are transported to the sedimentation places with sedimentary particles or through the activity of animals. This fact causes several problems complicating the exact ages determinations and reconstruction of the general vegetation character outside the caves. The possibility of different ages components mixing as well as the selection of palynomorphs due to their varied resistances are commonplace (Doláková & Nehyba, 1999, Doláková, 2000, Doláková, 2002, Svobodová in Svoboda, 1991).

The mixing of the different ages components – especially Quaternary and redeposited Tertiary ones – is frequent (primarily the Moravian Karst surface was covered by Miocene marine sediments of the Carpathian Foredeep). Their preservation states may be different or similar. Sometimes it is very difficult to distinguish the age of palynomorphs known from both Quaternary and Tertiary (i.e. *Pinus, Ulmus, Alnus, Quercus, Corylus, Betula, Tilia*). In the Ochoz cave 300 Quaternary a 80 verifiable Tertiary palynomorphs were determined in one sample. Observations under fluorescence microscopy offer a possibility to detect the reworked palynomorphs. After van Gijzel (i.e. 1971) with increasing age, coalification and corrosion, the colours shift from blue-green, white or yellow and strong fluorescence to orange, red or brown and weak fluorescence. Verifiably redeposited palynomorphs from the Moravian Quaternary karstic sediments have typical dark brown colours with a very low intensity of fluorescence. Good identification of redepositions is possible (from the different colours) in the mixture of specimens of several ages belonging to the same genus i.e. *Pinus* (Doláková, Burešová in print).

Other problems are connected with selection and secondary accumulation of palynomorphs due to their different resistances to the chemical and mechanical processes during the transport and sedimentation. It is difficult to say, whether the accumulations of the individual elements were caused by ecological character of the landscape or by special conditions during the sedimentation. There are known more or less monotonous oryctocoenoses with prevailing small pollen of Asteroideae (Asteraceae/ Tubiflorae) – caves: Balcarka, Za Hájovnou, Sloup-Šošůvka cave (up to overlap 60 %), *Corylus* (Balcarka, Za Hájovnou caves) or *Tilia* (Ochoz cave), and smooth monolete spores of Polypodiaceae (Ochoz cave – in several samples the only pollen) - Doláková (1999, 2000, 2002, 2005). These pollen types are small and compact and are known as the mechanically resistant (Jankovská, 1971, Draxler, 1992). Navarro et al. (2001) found out from the Spanish caves the decreasing amount of the anemophilous pollen (f.e. *Pinus*) and increasing amount of the zoophilous ones (Asteraceae/Liguliflorae) in the direction from the cave entrance. They presume that the anemophilous pollen often overestimted in surface samples due to massive pollen production and big flying range decreased into the caves due to their mechanical properties. Conversely, the anemophilous pollen grains (with morphological adaptations to easy catching in the animals hair) participate more frequently in the pollen spectra from the deeper parts of the caves. This fact may be caused by transport of pollen grains by the animals. In the Ramesh cave (about 2,000 m above see level, sediments dated 64,000 – 32,000 ka) Draxler (1986) interpreted the existence of pollen of the climatically demanding plants among others as a consequence of the cave bear nourishment (honey).

Palynological results from the individual caves: Moravian Karst

The first palynological study of the cave sediments from the Moravian Karst was published by Svobodová (Seitl et al., 1986, Svobodová, 1992) from the Barová cave. The evidence from this cave section reflects the oscillating climate from the cold Würm-Pleniglacial one to a temperate one; this was followed by an erosion and resedimentation period and a colder steppic phase. The temperate oscillation in the roof sediments may reflect the Magdalénian events, as opposed to the Bölling and the next cooling with Dryas II. The upper layer yielded a pollen spectrum comparable to Alleröd (Epimagdalenian), and the uppermost layer could correspond to the colder and moister Dryas III.

One sample was palynologically studied from the Pekárna cave (Svobodová in Svoboda et al. 2000), the palynospectra confirm the Late Glacial conditions. Single pollen grains were found in the caves 559 – Lipovec and 565 – Jedelská ventarola. They indicate a cold climate throughout the Last Glacial (Svobodová, 1992).

The layer with archeological findings of the linear ceramic were palynologically studied in the entrance of Kateřinská cave. The author (Svobodová in Geislerová et al. 1986) interpreted the age of these sediments as Early Holocene (Atlantikum). The palynoassociation reflects the warmer and humid period with the thermophilic folious trees without human influence.

The character of vegetation from the speleothem („ slacked lime“) from the Býčí skála cave indicate the spreading of the meadows and clearance of the lanscape by the human activity. The anthropogenic indicators as the *Secale cereale, Plantago lanceolata* occurred (Svobodová, 1993). This layer covered the archeological findings of the Halstatt burial (800 – 450 B.C.).

Ochoz cave

From the Ochoz cave the samples from two profiles were studied: I. – the main dome – palaeostream (Doláková and Nehyba, 1999), II. – at the Zkamenělá Řeka (Doláková, 2000, Kadlec, 2000). Both profiles were of a similar character being divided in two parts from the palynological point of view. There were predominating members of the cold steppe vegetation in the lower part of the profiles (i.e. *Helianthemum, Thalictrum, Selaginella selagineloides, Saxifraga, Ephedra*) together with cold resistant wood plants (*Pinus cembra, Betula, Salix*) and hydrophilous plants and alges (Cyperaceae, *Potamogeton, Botryococcus, Pediastrum*). Findigs of the species *Pediastrum kawraiskyi* demonstrate the cold climate (Jankovská and Komárek,1982). These parts of the profiles belong most likely to one of the Late Glacial cold phases.

For the upper parts of the profiles, high amounts of the genus *Tilia* and smooth monolete spores of Polypodiaceae are typical. The pollen of *Tilia*, and smooth monolete spores of Polypodiaceae seemed to be overestimated. The redeposition of *Tilia* pollen and spores of Polypodiaceae cannot be excluded. The same conclusions published Draxler (1992) from the Nixloch cave. This oryctocenosis represents probably the warmer climate. The radiometric dating of the speleothem layer above the profiles in the Main Domes indicate the age of underlaying fluvial sediment as older than 28,000 years (Kadlec et al. 2000). This fact eliminated the Holocene ages of the palynospectra. Very similar palynospectra were described by Bastin et al. (1987) in the stalagmite from Belgian cave Han - sur - Lesse dated as 37,000 BP.

Balcarka cave

The entrance of the Balcarka cave is known as a settlement of the Magdalenian hunters (13,000 - 11,000 BP). Palynological studies were done from the profiles 2 and 3 in the cave part „Muzeum“ (Doláková, 2004). In the lower part of the profiles (K, F, E) taphocenoses with the prevailing heliophilous steppes plants (Asteroideae, *Artemisia*, Poaceae, Ranunculaceae, *Delphinium*, *Chrysosplenium*) and less frequent trees (*Pinus, Betula, Alnus*) are present. This part of the profile belongs probably to some of the Late Glacial colder phases. The overlaying sediments (samples D, Ca, Cb, B) contained a greater amount of trees with prevailing *Corylus*, frequent *Pinus*, *Betula*, *Alnus*, *Tilia* and sporadic *Picea*. Without a detailed knowledge of sedimentology, paleontology, archeology as well as palynomorphs taphonomy in the Balcarka cave it is very difficult to specify the age of the studied layers more exactly. They probably originated in some warmer parts of the last Glacial or during Early Holocene (Boreal).

Kůlna and Sloup–Šošůvka caves

Palynological studies were made in the lower part of the supporting profile in the entrance part of the Kůlna cave and in individual samples from the Šošůvka part of the Sloup-Šošůvka cave connected with Kůlna cave (northern part of the Moravian Karst).

The sediments from the Kůlna cave were exactly archeologically and paleontologically dated (Valoch et al.1988, Zelinková, 1998). The palynological results are comparable with the results of other paleontological methods confirming the presence of similar ecosystems. Differences were probably in the local ecological conditions. Palynospectra from the Kůlna cave might be used for the comparison with the ones from the inner parts of the Šošůvka cave.

Svobodová (in Valoch et al. 1988, Svobodová, 1992) studied the upper part of this profile (layers 1-6) from the palynological point of view. She classified the upper layers (1-4) as the Holocene. The paleovegetation from layer 6 was interpreted as the grassy steppe corresponding with some of the Late Glacial cold oscillations.

Doláková (2002) studied the underlying layers (7-14). The sediments originated from the final phase of the Saale Glacial (14) through the Eem Interglacial (13, 12, 11a, 11c) to the lower part of the Würm Glacial (9b, 8a, 7a, 7b, 7c).

These layers were divided into two parts from the palynological point of view.

The lower part of this profile (14, 13, 12, 11a, 11c) contained a great amount of wood elements (with exception of sample 11a), such as genera *Pinus*, *Picea*, *Betula*, *Alnus*, *Corylus*, *Tilia*, *Acer*. The layer 14 signalized warming in the terminating Saale (Riss) glacial. The layer 13 represented an optimum, and 11 deterioration in the end of the Eem interglacial. All the samples frequently contained water algae *Botryococcus* and *Pediastrum*, and moss spores of *Sphagnum*. This fact documented the existence of the quiet water and marshes.

The upper part (samples 9b – 7a, the layer 7 was radiometrically dated as 45,000 years) contained steppe and wood-steppe associations. In some samples elements of the cold steppe occur (*Selaginella selaginoides, Thalictrum*, *Ephedra*, *Botrychium*) with frequent wetlands (Cyperaceae, *Sphagnum*). The layers 8a and 7c exhibited a relatively warmer character (presence of *Tilia*, *Acer*, more frequent *Teucrium*, *Centaurea scabiosa*). After faunistic and macrofloristic results the layer 7c had a relatively warmer character - Kůlna interstadial (Musil, 1997, Valoch et al. 1998). The palynological results (except the sample 9b) are comparable with the results of other paleontological methods confirming the presence of similar ecosystems. Discrepancies were probably caused by the local ecological conditions.

From the Šošůvka cave only individual samples of the sediments were studied. The herbs predominate over trees in all the studied samples, no human indicators were found. *Sphagnum* and algal colonies of *Botryococcus* were found.

The richest sample was found in the dark lens 72.5 m from the contemporary cave entrance. Due to the excellent state of the preservation a short transport through the cave stack can be presumed. The palynoassociations had steppe and wood-steppe character containing heliophilous herbs as *Centaurea, Campanula, Thalictrum, Galium,* Asteraceae and sporadic tree pollen *Pinus Betula, Tilia, Alnus, Corylus.* In the immediately underlying layer Pleistocene fauna was found. The palynological character was quite similar, but Asteroideae were accumulated there. We cannot exclude that both the sediments are of the same age but they underwent different modes of transport (causing the secondary accumulation of Asteroideae).

Analogous character of the pollen oryctocoenoses was found in most of the studied samples. Calciphyta as *Knautia, Scabiosa* and *Teucrium* were also found. The cranium and bones of the *Ursus spelaeus* were found in the layers from which the samples 8 and 18 were picked up. These bones confirm the Pleistocene age. A different character of palynoassociations represented the sample number 4 in which cold steppes elements (*Selaginella selaginoides)* were found. The majority of the palynospectra from the Šošůvka cave are similar to the layers 7c and 8a from the Kůlna cave thus their ages might be probably similar (Middle Würm to the Lower Holocene).

Javoříčko karst – Za Hájovnou cave

At present the cave Za Hájovnou is explored and studied. Two profiles - from the Charnelhouse and Birthdays corridor – were analysed from the palynological point of view. The applicable palynological results originated from the upper parts of both mentioned profiles. They were paleontologically dated as Holstein interglacial (Musil, 2005). The palynospectra confirmed the mild character of the climate with the frequent members of the woods during the sediment deposition (*Carpinus, Hedera, Acer, Tilia, Corylus).* The single pollen of *Pterocarya*, as the surviving member of Tertiary floras (up to Holstein) were found. Asteroideae were accumulated in most of samples.

After paleontological results, the layers 2a and 2b were running in the upper parts of both mentioned profiles. The pollen diagram from these layers indicates the decreasing number of Pinaceae (anemophilous) and most of the trees pollen, and increasing number of the herbs pollen (primarilly Asteroideae – zoophilous) in the direction into the inner cave parts (Doláková, 2005). These facts are most likely related with the type of transport (by wind or by animals – see above Navarro et al., 2001) as well as with the resistance of the pollen exines to chemical and transport conditions.

Hranice Karst – Mokrá quarry

The Hranice karst represented the tropical type of pre-Neogene paleokarst. The Lower Miocene up to Lower Badenian (Langhian) sediments were found in the karstic cavities in the quarry Hranice. In the Tertiary pollen association redeposited Cretaceous palynomorphs were observed – in one case even in pollen conglomerate (*Normapolles*).

The typical thermophile elements such as Sapotaceae, *Engelhardia, Platycarya* were found. The pollen and spores were accompanied by abundant marine Dinoflagellata.

The comparison of the palynospectra from the cave with the ones from the surface confirms a good correspondence. Only the small tricolporate pollen grains are more frequent in the cave. This morphological type of pollen is probably more resistant to the transport and chemical processes similar to the Asteroideae in the Quaternary sediments.

References

Bastin B., Deflandre G. and Quinif Y. (1987): Mise en évidence ďun réchauffement majeurau sein de la derniére glaciation, enregistré dans un plancher stalagmitique de la Grotte du Pére Noė (Han-sur-Lesse, Belgique).: abstract: Colloque international de sedimentologie karstique. Han-Sur-Lesse Belgique, 18.-22.5. 1987.

Doláková, N. and Nehyba, S. (1999): Sedimentologické a palynologické zhodnocení sedimentů z Ochozské jeskyně. Geol. výzk. Mor. Slez. v r. 1998, 7-10. Brno.

Doláková, N. (2000a): Palynologické zhodnocení sedimentů z Ochozské jeskyně. Část 2.- Profil u Zkamenělé řeky. - Geol.výzk. Mor. Slez. v r. 1999, 5-9. Brno.

Doláková, N. (2000b): Palynological studies from the Ochozská Cave and from the Šošůvka part of the Sloupsko-šošůvská Cave (Moravian Karst). - Geolines 11, 172-174.

Doláková, N. (2002): Palynologické studium sedimentů Šošůvské části Sloupsko – Šošůvských jeskyní a spodní části opěrného profilu v jeskyni Kůlna. – Acta Mus. Moraviae, Sci. geol., LXXXVII, 275-288. Brno ISSN 1211-8796.

Doláková, N. (2004): Palynologické výzkumy v jeskyni Balcarka. Geol.výzk. Mor. Slez. v r. 2003, 2-4. Brno

Doláková, N. (2005): Palynologická studia v jeskyni „Za Hájovnou", Javoříčský kras.– Přír. stud. Muz Prostějovska. 8, 83-88.

2007

Doláková, N. and Burešová, A. (in print): Use of fluorescent microscopy in the study of redeposited palynomorphs in the cave and marine sediments of Moravia (Czech Republic). - Acta Palaeobotanica vol.47, No. 1.

Draxler, I. (1992): Palynologische Untersuchungen von Höhlensedimenten im Nixloch bei Losenstein – Ternberg (Oberösterreich). – Mitt Komm. Quartärforsch. 8: 21-29. Wien

Geislerová, K., Seitl, L., Svoboda, J. and Svobodová, H. (1986): Záchranný výzkum před Kateřinskou jeskyní. - Regionál. sbor. okresu Blansko. 8, 64-72.

Jankovská, V. (1971): The development of vegetation on the western slopes of the Bohemian-Moravian Uplands during the late holocene period. A study on based on pollen and macroscopic analyses. - Folia Geobot. Phytotax., 6, 281-302.

Jankovská, V. and Komárek J. (1982): Das Vorkommen einiger Chlorokokkalalgen in böhmischen Spätglazial und Postglazial. - Folia Geobot. Phytotax., 17/2, 165-195.

Kadlec, J., Hlaváč, J., Pruner, P., Venhodová D., Svobodová, H. and Beneš, V. (2000): Studium krasových sedimentů v jižní části Moravského krasu.MS ČAV. Praha.

Musil, R. (1997): Klimatická konfrontace terestrických a marinních pleistocenních sedimentů. In: Hladilová Š. ed.: Dynamika vztahů marinního a kontinentálního prostředí. Grant. projekt GAČR 205/95/1211. Brno

Musil, R. (2005): Jeskyně „Za Hájovnou", výjimečná lokalita v Javoříčském krasu. Přír. stud. Muz Prostějovska. 8, 9 - 42.

Navarro, C., Carrión, J.S., Munuera, M. and Prieto A.R. (2001): Cave surface and the palynological potential of karstic cave sediments in palaecology. – Rev. Paleobot. and Palynol., 117, 4, 245-265.

Seitl, L., Svoboda, J., Ložek, V., Přichystal A. and Svobodová, H. (1986): Das Spätglazial in der Barová-Höhle im Mährischen Karst. - Archäologisches Korrespondenzblatt 16, 393-398. Mainz.

Svobodová, H. (1992): Palaeobotanical evidence on the Late Glacial in the Moravian Karst. In: Eder-Kovar j. (Ed.): Palaeovegetational Development in Europe and Regions relevant to its Paleofloristic Evolution. - Proceedings of the Pan - European Palaeobotanical Conference Vienna, 19-23 September 1991, Museum of natural History Vienna.

Svobodová, H. (1993): Pylová analýza vypáleného vápence v jeskyni Býčí skála v Moravském krasu. –Acta mus. Moraviae. Vědy společenské. LXXVIII. Brno

Valoch, K. et al. (1988): Die Erforschung der Kůlna Höhle 1961-1976. Anthropos, Band 24 (N.S. 16), Brno.

Van Gijzel, P. 1971. Review of the UV-fluorescence microphotometry of fresh and fossil exines and exosporia: 659-685. In: Brooks J., Grant P.R., Muir M., van Gijzel P.& Shaw G. (eds) Sporopollenin. Academic Press, London - New York.

Zelinková, M., 1998: Osteologický materiál z vnitřních prostor jeskyně Kůlny. – Acta Mus. Moraviae, Sci. Geol., LXXXIII, 147-157.

SBORNÍK NÁRODNÍHO MUZEA V PRAZE
Řada B – Přírodní vědy • sv. 70 • 2014 • čís. 1–2 • s. 35–42

ACTA MUSEI NATIONALIS PRAGAE
Series B – Historia Naturalis • vol. 70 • 2014 • no. 1–2 • pp. 35–42

PALYNOLOGICAL ANALYSIS OF SEDIMENTS FROM ZA HÁJOVNOU CAVE

NELA DOLÁKOVÁ
Masaryk University, Faculty of Sciences, Institute of Geological Sciences, Kotlářská 2, 611 37, Brno, the Czech Republic;
e-mail: nela@sci.muni.cz

Doláková, N. (2014): Palynological analysis of sediments from Za Hájovnou Cave, Javoříčko Karst. – Acta Mus. Nat. Pragae, Ser. B, Hist. Nat, 70(1-2): 35–42, Praha. ISSN 1804-6479.

Abstract. The sediments of profiles ZH P-2, 5, 7, 8b, 9, 10 and 11 from Za Hájovnou Cave (Javoříčko Karst) were studied from a palynological point of view. Most of layers (except layer 1c/ZH P-10, layer 7e /ZH P-2) were paleontologically dated as Holsteinian Interglacial. The palynospectra confirmed the mild character of the climate during sediment deposition (*Carpinus, Hedera, Acer, Tilia, Corylus,* single *Pterocarya* and *Ilex*). The proportion of individual elements as well as relationship between trees and herbs varied. Changes in number of morphologically different pollen grains (primarily Pinaceae, Asteroideae) in correlated layers (2a, 2b/ ZH P-5 and 2,2b/ZH P-8b, and layer 4 – debris cone) from profiles ZH P-10, ZH P-11and ZH P-8b were recorded in the direction towards the cave interior. This phenomenon is most likely related to the resistance of the pollen grains to chemical and mechanical conditions during transport.

■ Javoříčko karst, Za Hájovnou Cave, Quaternary, Palynology

Received January 20, 2014
Issued October, 2014

Introduction

Palynological study of sediments from Za Hájovnou Cave (Javoříčko karst) was carried out within the framework of a complex multiproxy study of this area headed by Prof. R. Musil.

Results of earlier palynological studies of Moravian (the eastern part of the Czech Republic) karstic areas were published by Seitl et al. (1986), Svobodová (1988), Svoboda (1991), Svobodová (1992), Doláková and Nehyba (1999), Doláková (2002, 2004, 2005, 2007).

Pollen spectra from cave sediments are typified by the absence of in situ plant remains. Palynomorphs are transported into the caves together with sedimentary particles by percolating water or through the activity of animals. Selection, degradation and secondary accumulation of various palynomorphs is clearly due to their different resistances to chemical and mechanical processes, and microbial attack during transport and sedimentation (Elsik 1971, Havinga 1971, Jankovská 1971, Draxler, 1992, Carrión et al. 1999, Doláková and Nehyba 1999, Navarro et al. 2001, Doláková 2002, 2007). The mixing of different age components – especially Quaternary and redeposited Tertiary elements – is also well known (eg. Doláková and Nehyba 1999, Doláková 2002, 2007). This phenomenon causes complications in interpretation of the original surface vegetation. Comparison with the results from other paleontological and geological methods is necessary.

Material and methods

About 50 samples of cave sediments from Za Hájovnou Cave were studied from a palynological point of view. The palynological samples were treated with HCl (20%), HF, KOH and HCl (10%) and heavy liquid ZnCl$_2$ (density = 2g/cm^3) for standard maceration. The omission of acetolyse enabled clearer identification of pollen contamination eg by percolating water. The final residue from each sample was mounted in preparation for biological microscopy, and diluted with glycerol.

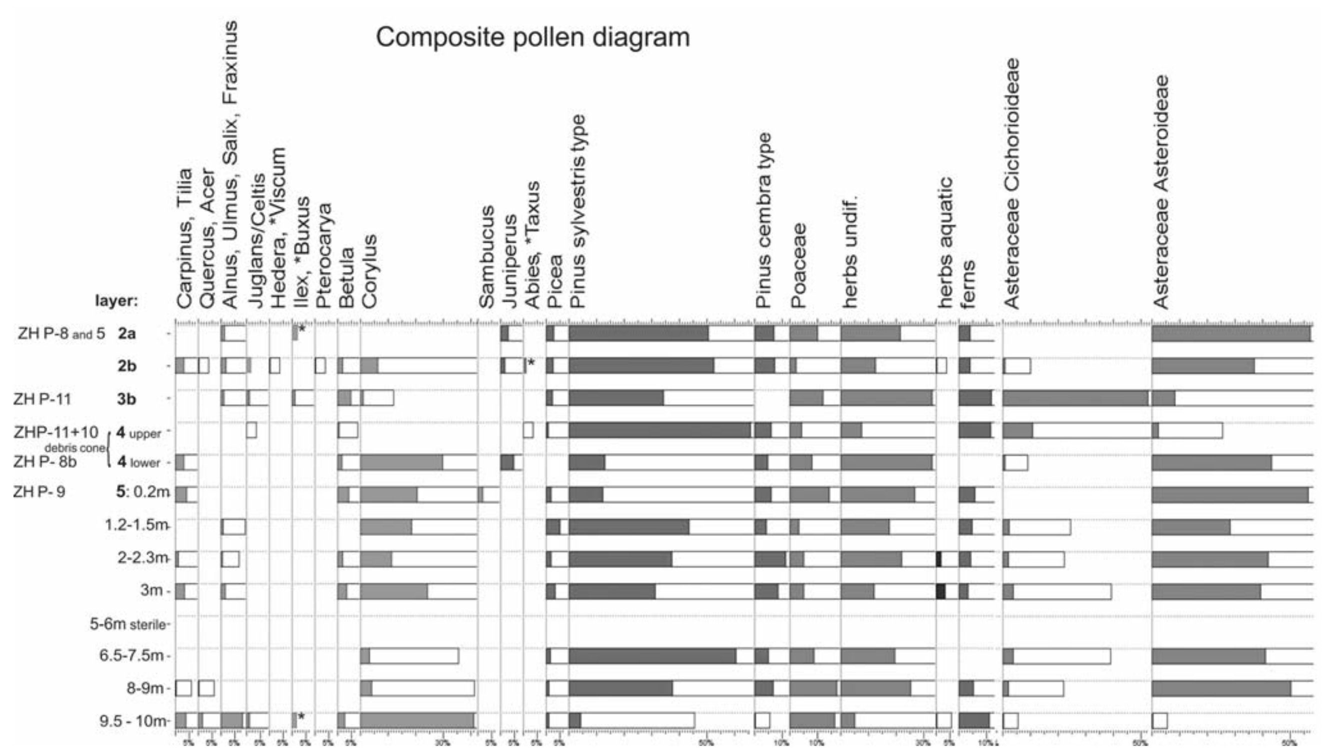
The pollen diagram was calculated from the total of a minimum of 100 determined pollen grains and spores (minimally from 15 taxons) using the POLPAL programme (Walanus and Nalepka 1999). Several plant types were combined according to their ecological grouping (*Carpinus* + *Tilia*, *Quercus* + *Acer*, herbs undif., herbs aquatic, flood plain forest – *Alnus*, *Ulmus*, *Fraxinus*, *Salix*, ferns + *Sphagnum*).

The pollen diagram was separated into two parts due to the over-representation of Asteraceae: in the left section was the pollen sum (100%), excluding Asteraceae. The right section showed the proportion of Asteraceae and was calculated from the sum of all the determined pollen grains. This form of presentation offers clearer visualisation of the basic character of the vegetation changes.

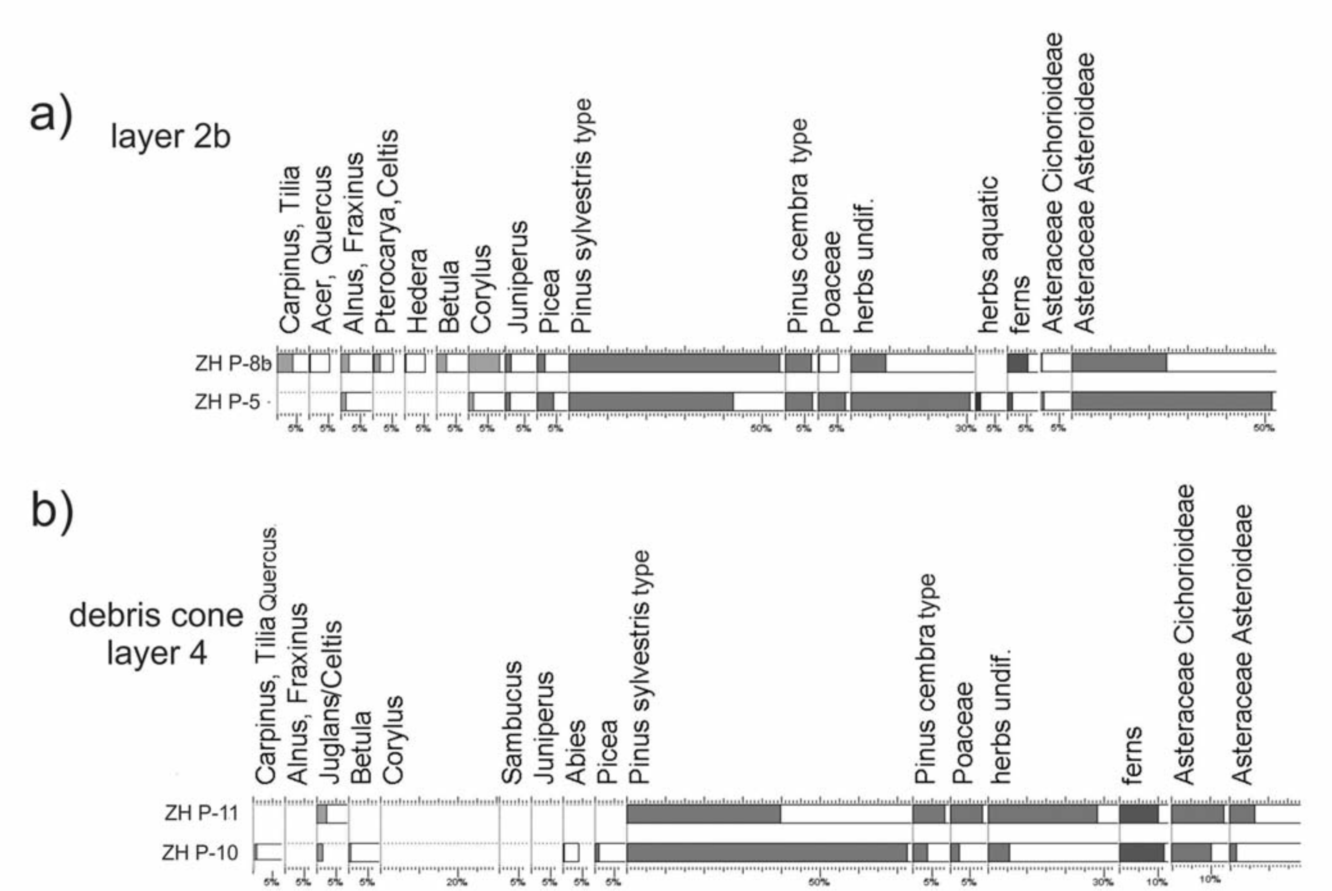
A composite pollen diagram (Text-fig. 1) was constructed on the basis of average representation of elements from single layers (arithmetic mean of samples collected from several places within 1 layer). Other diagrams (Text-figs 2a, b) indicate differences among the palynospectra collected from different spots within a single layer.

Results

The samples from profiles: ZH P-2 (Velikonoční jeskyně (= Easter corridor): Komín I (= Chimney I), ZH P-5 (Vykopaná chodba (= Excavated corridor): Kostnice II



Text-fig. 1. Composite pollen diagram.



Text-fig. 2. Pollen diagram. a – layer 2b from ZH P-5 correlating with 2b of ZH P-8 nd 9; b – layer 4 (debris cone) of profiles ZH P-10 and ZH P-11.

(Charnelhouse II), ZH P-7 (Chodba naděje (=Corridor of Hope)), ZH P-8b and 9 (Spojovací chodba/Narozeninová chodba (=Connection Passage/Birthday corridor)), ZH P-10 and 11 (Narozeninová chodba) were analysed from palynological point of view. Profile descriptions are presented in the contribution by Musil (2014). The first palynological study from Za Hájovnou Cave was published by Doláková (2005, 2007). Not all the palynospectra contained a sufficient number of pollen grains and spores for analysis. Some of the samples were almost sterile, another part contained only a small number of palynomorphs. Samples with the most abundant palynospectra came from profiles ZH P-8b and 9. Only layer 4 of profiles ZH P-10 and ZH P-11 and layers 2a and 2b from profile ZH P-5 contained enough pollen grains and spores to construct a pollen diagram.

Most of the palynologically studied sediments (except ZH P-1, layer1c and ZH P-2, layer 7e) were dated as Holsteinian Interglacial (Musil 2005, Lundberg et al. 2014).

Sample ZH P-10, layer 1c was assigned as a melange of Holocene and older sediments (Musil 2014). It contained only a small amount of pollen from *Pinus*, Asteraceae, Daucaceae and Ranunculaceae.

The sample from layer 7e of ZH P-2 was the only one from the Komín I profile in which palynomorphs were found. There was a large over-estimation of small Asteroideae. Pollen from *Chrysosplenium*/*R.trichophylus* type typical for damp places had also accumulated here along with some other herbs (Poaceae, *Galium*, Ranunculaceae). No pollen from trees or large sized pollen grains were observed. This oryctocoenoses provides evidence of mechanical selection during transport with sediment flow. According to a personal study of cave sediments (Balcarka – Doláková 2004, Pod Hradem – personal data of the author) such palynospectra could support the paleozoological interpretation of development in a colder steppe environment (Musil 2005, Ivanov 2005).

The palynospectra from other studied samples of layer 4 (debris cone) from profiles: ZH P-10 and 11, ZH P-5: layers 2a, 2b and the whole ZH P-8a similarly confirmed the mild character of the climate during sediment deposition, by virtue of the abundant wood elements (*Carpinus*, *Tilia*, *Juglans*, *Quercus*, sporadic *Acer*, single *Hedera*, *Pterocarya*, *Ilex* - Tab.1).

Pterocarya and *Ilex* are the surviving members of Tertiary floras. The presence of *Pterocarya* continued to the Holsteinian Interglacial in Europe. It dissapeared from the palynological record during the Saalian complex Stage and it is not known from any younger warmer phases (Lang 1994, Litt et al. 2008, Roucoux et al. 2008).

The above mentioned plants created the typical vegetation of the climatic optimum of the Holsteinian Interglacial (Dyjakowska 1952, Vodičková-Kneblová 1961, Břízová 1994, Lang 1994, Bińka et al. 1997, Reille et al. 2000, Urban and Sierralta 2012).

The general character of most studied pollen spectra is quite similar, however the proportions of individual elements fluctuate. Composite pollen diagrams indicate changes among pollen spectra in recognised layers (Text-fig. 1). The relationship between trees and herbs varied, herbs mostly prevail. Dominance of arboreal pollen was observed in layers: 2b and 5: 1.2–1.5 m and 9.5–10 m from ZH P-8b and 9, and in part of the debris cone: layer 4 upper. *Pinus sylvestris* type or *Corylus* formed the highest proportion of them. Elements of flood plain forest such as *Alnus*, *Ulmus*, *Fraxinu*s, *Salix* were mostly rare. *Betula*, *Picea* and ferns and *Sphagnum* are observed continuously but at a low percentage. Nonarboreal pollen dominated in most samples. Asteraceae prevailed in these cases. Poaceae were also common. The occurrence of other herbs was also recorded: *Artemisia*, Brassicaceae, *Campanula*, *Galium*, Lamiaceae, Liliaceae, Ranunculaceae, *Delphinium* type, Silenaceae, *Urtica* and single specimens of other herbs. Hygrophilous herbs such as *Chrysosplenium/Ranunculus trichophylus* type and *Valeriana* were common. Pollen from aquatic flora (*Sparganium*, *Potamogeton*) were rare. Ferns mostly represented by the smooth spores of Polypodiaceae, rarely *Polypodium vulgare* and *Pteridium*. Algae such as *Botryococcus*, *Mougeotia* and a single *Pediastrum* were found locally. Algae were absent in samples from the debris cone (layer 4).

The greatest difference in pollen picture was observed in layer 5, the deepest studied layer: 9.5-10 m in profile ZH P-9. Trees prevailed over herbs (67:33%) with the most abundant being *Corylus* together with *Carpinus*, *Tilia* and *Alnus*. *Juglans* also occurred here. In this layer was the lowest proportions of *Pinus* and Asteroideae from all the samples. Only Poaceae represented the more abundant herbs. This palynospectrum probably represented the vegetation of deciduous woodland with only a small admixture of conifers. In the overlying samples there was an increased proportion of *Pinus*, Asteroideae and other herbs and a decrease in *Corylus*, *Alnus* and *Tilia* until they became absent at the 6.5–7.5 m level. It is difficult to decide whether this phenomenon is a result only of climate deterioration or also due to taphonomic reasons.

The highest percentage of *Pinus* (over 60%) together with a minority of other trees was recorded in the upper part of the debris cone (layer 4 upper). The pollen picture in the lower part of the debris cone differs with *Pinus* representing only 10% of the pollen found, *Corylus* over 25%, *Carpinus* and *Tilia* also occured, but more herbs were common (Text-fig. 1). This difference could indicate climatic variations during deposition of the debris cone.

According to paleontological results, layers 2a and 2b from ZH P-5 correlate with 2a and 2b from ZH P-8b. The pollen diagram from these layers indicates a decreasing number of Pinaceae and dominance of tree pollen, and increasing number of herb pollen (mainly Asteroideae) in the direction towards the cave interior (Doláková 2005) (Text-fig. 2a). These facts are most likely related to the resistance of the pollen exines to chemical and mechanical conditions during transport. A similar phenomenon was observed in layer 4 (the debris cone) of the profiles ZH P-10 and ZH P-11 (Text-fig. 2b). Differences in the pollen picture were probably caused by mixing of sedimentary material transported through the former cave entrance and near the chimney. A difference in pollen record between samples of layer 4 (the debris cone) collected from ZH P-10 and ZH P-11 compared to ZH P-8b is evidence enough to indicate that sedimentation of this layer occured over a longer time span during slight climatic oscillation. Therefore the layer was divided into 2 sublayers: layer 4 upper and the underlying: layer 4 lower (Text-fig. 1).

Discussion

Navarro et al. (2001) established that the amount of the anemophilous pollen (eg. *Pinus*) decreased and that the amount of zoophilous pollen (Asteraceae/Cichorioideae) increased in the direction from the cave entrance into the inner parts. They presumed that the anemophilous pollen, often overestimated in surface samples due to massive pollen production and extensive flight range, decreased inside the caves due to their mechanical properties. Conversely, the anemophilous pollen grains (with morphological adaptations for easier attachment to animal hair) more frequently form part of the pollen spectra from the deeper parts of caves. This fact may be caused by transport of pollen grains by animals. In the Ramesh Cave (about 2000 m above sea level, sediments dated 64–32 ka), Draxler (1992) interpreted the existence of pollen from climatically demanding plants among other types to be a consequence of the cave bear nourishment (honey). The decrease in *Pinus* pollen recorded there is in clear agreement with our results from Za Hájovnou Cave (see above, Text-figs 2a, b). An overestimation of Cichorioideae was visible only in layer 3ba (Text-fig. 1). Asteroideae together with *Pinus* prevailed in most of the studied samples from Za Hájovnou Cave.

According to Carrión et al. (1999) the pollen spectra from cave sediments reflect the surface environment reliably only when several requirements are fulfilled: a) taxonomic diversity reliably above 15 taxons per sample, b) pollen counts of more than 200 grains excluding Asteraceae, c) less than 20% indeterminable pollen.

From cave sediments from the Moravian karstic areas not only is the prevailing pollen from the Asteroideae but also a more or less monotonous oryctocoenoses with over-representation of smooth monolete Polypodiaceae spores, *Tilia* and *Corylus* are also known (Doláková 2000, 2002, 2004, 2005). These pollen types are small and compact and are known to be both mechanically and chemically resistant (Havinga 1971, Jankovská 1971, Draxler 1992).

According to this information , the most reliable pollen spectra which reflected the vegetation cover outside the caves came from layers 2a and 2b (ZH P-8b and ZH P-5), the debris cone, layer 4 (ZH P-10), and layer 5: 9-10m (ZH P-8b and 9). Care must be taken in interpretation of the vegetation and climatic character of other studied palynospectra. In some other site even a single common pollen grain could provide useful information.

The wide variety and selectivity of the palynological record from Za Hájovnou Cave did not allow accurate reconstruction of changes in vegetation. The general character of the pollen pictures corresponds to the climatic optimum of the Holsteinian interglacial when compared to studies of several localities in Central Europe (eg. Dyjakowska 1952, Vodičková-Kneblová 1961, Břízová 1994, Lang 1994, Kondratienė and Šeirienė 2003, Urban et al. 2011, Bittmann 2012, Urban and Sierralta 2012). The findings of *Pterocarya* (often taken as a marker for the Holsteinian) in the upper parts of the profile observed after deterioration of the climate as reflected in the section of layer 5: 6.5–9 m from ZH P-9 (Text-fig.1) also support this interpretation.

The samples from layer 5: 9.5–10 m of profile ZH P-9 and layer 4 lower of ZH P-8b support the *Corylus* expansion described by Urban et Sierralta 2012 from Schöningen lignite mine profile 12B LPAZ R 3b (MIS 9). The limited palynological results from Za Hájovnou Cave do not provide sufficient data to clearly differentiate if the sediments could be related to MIS 11 or MIS 9; the assumption that they are Holsteinien is a topical theme for discussion (eg. Geyh and Müller 2005, Scourse 2006, Nitychoruk et al. 2006, Roe et al. 2009, Bittmann 2012, Urban and Sierralta 2012).

The overall characteristics of the environment and stratigraphic position based on other paleontological methods is discussed in detail in a contribution by Musil et al. (2014). According to faunistic and sedimentological characteristics, the studied sediments can be divided into two groups. Sediments older than the debris cone contained bones which were nearly always complete, never weathered, and often even in the correct anatomical positions. In sediments above the debris cone the bones were invariably fragmentary, many of them covered by sinter crusts. No fossils except palynomorphs have been found inside the debris cone. The difference between the palynospectra from the upper and lower parts of the debris cone sediments could indicate climatic variations during deposition of the debris cone (see above, Text-fig. 1). Pollen spectra from lower layers and the debris cone contained a limited number of Tertiary pollen relics such as *Pterocarya*, *Ilex*, *Celtis*, which were not observed in the older part of the sediments. These data are in clear agreement with other Holsteinian localities (see above).

Conclusions

About 50 samples from profiles: ZH P-2, 5, 7, 8 and 9, 10 and 11 from Za Hájovnou Cave were assessed palynologically.

The pollen spectrum of layer 7e is without any tree pollen but with an accumulation of Asteroideae and several hygrophilous herbs and thus may support the paleozoological results suggesting development in a colder steppe environment.

The general character of other palynospectra confirmed the mild character of the climate during the Holsteinian Interglacial due to the occurence of plants such as *Carpinus*, *Hedera*, *Tilia*, *Pterocarya* and *Ilex* which are typical for the climatic optimum of this time span. Such a pollen picture is in clear accordance with other similar localities from Central and Western Europe.

The difference in pollen record inside the debris cone (layer 4) prompts division of layer 4 into 2 sublayers (layer 4 upper and layer 4 lower) which developed during varying climatic conditions.

Detailed reconstruction of vegetations cover, their changes and development is difficult to interpret from the cave sediments. Selection, degradation and secondary accumulation of various palynomorphs, due to their different resistances to chemical and mechanical processes and microbial attack during transport, were recorded. This phenomenon was documented by numerical changes in the different pollen grains from several spots within a single layer in a direction towards the inner cave parts (primarily a decrease in Pinaceae, and increase in Asteroideae).

The overall characteristics of the environment and stratigraphic position based on other paleontological methods will be discussed in the contribution Musil et al. (2014)

References

Bińka, K., Lindner, L., Nitychoruk, J. (1997): Geologic-floristic setting of the Mazovian Interglacial sites in Wilczyn and Lipnica in southern Podlasie (eastern Poland) and their palaeogeographic connections. – Geological Quarterly, 41(3): 381–394.

Bittmann, F. (2012): Die Schöninger Pollendiagramme und ihre Stellung im Mittleeuropäischen Mittelpleistozän. – In: Behre, K.-E. (ed.), Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen, Römisch-Germanisches Zentralmuseum, Mainz, pp. 97–111.

Břízová, E. (1994): Vegetation of the Holsteinian Interglacial in Stonava- Horní Suchá (Ostrava region). – Sborník geologických věd, Anthropozoikum, 21: 29–56.

Carrión, J.S., Munuera, M., Navarro, C., Burjachs, F., Dupré, M., Walker, M.J. (1999): The palaeoecological potential of pollen records in caves: the case of Mediterranean Spain. – Quaternary Science Reviews, 18: 1061–1073.
http://dx.doi.org/10.1016/S0277-3791(98)00002-X

Doláková, N. (2000): Palynologické zhodnocení sedimentů z Ochozské jeskyně. Část 2. Profil u Zkamenělé řeky. – Geologické výzkumy na Moravě a ve Slezsku v roce 1999: 5–9. (in Czech)

Doláková, N. (2002): Palynologické studium sedimentů Šošůvské části Sloupsko -Šošůvských jeskyní a spodní části opěrného profilu v jeskyni Kůlna [Palynological studies of the sediments from the Šošůvka part of the Sloup-Šošůvka cave and from the lower part of the supporting profile in the Kůlna cave (Moravian Karst)]. – Acta Musei Moraviae, Scientiae geologicae, 87: 275–288. (in Czech, with English summary)

Doláková, N. (2004): Palynologické výzkumy v jeskyni Balcarka [Palynological studies in the Balcarka cave (Moravian Karst)]. – Geol.výzk. Mor. Slez. v r. 2003: 2–4. (in Czech)

Doláková, N. (2005): Palynologická studia v jeskyni „Za Hájovnou“, Javoříčský kras [Palynological studies in the “Za Hájovnou” Cave, Javoříčko Karst, Moravia]. – Přírodovědné studie Muzea Prostějovska, 8: 83–88. (in Czech)

Doláková, N. (2007): Palynological studies in the Cave sediments from the Moravian, Javoříčko and Hranice Karsts - Czech Republic. – Scripta Facultatis Scientiarum Naturalium UniversitatisMasarykianae Brunensis., Geology, 35: 47–53.

Doláková, N., Nehyba, S. (1999): Sedimentologické a palynologické zhodnocení sedimentů z Ochozské jeskyně [Sedimentological and palynological evaluation of the sediments from the Ochozská jeskyně cave]. – Geologické výzkumy na Moravě a ve Slezsku v roce 1998: 7–10. (in Czech)

Draxler, I. (1992): Palynologische Untersuchungen von Höhlensedimenten im Nixloch bei Losenstein – Ternberg (Oberösterreich). – Mitt. Komm. Quartärforsch., 8: 21–29.

Dyjakowska, J. (1952): Róstlinność plejstocénska w Nowinach Żukowskich [Pleistocene flora of Nowiny Żukowskie on the Lubin Upland]. – Biul. Inst. Geol., 67: 115–181. (in Polish)

Elsik, W. C. (1971): Microbiological degradation of Sporopollenin. – In: Brooks, J., Grant, P. R., Muir, M., van Gijzel, P., Shaw, G. (eds), Sporopollenin, Academic Press, London, pp. 480–511.
http://dx.doi.org/10.1016/B978-0-12-135750-4.50023-7

Geyh, M. A., Müller, H., (2005): Numerical 230Th/U dating and a palynological review of the Holsteinian/Hoxnian interglacial. – Quaternary Science Reviews, 24: 1861–1872.
http://dx.doi.org/10.1016/j.quascirev.2005.01.007

Havinga, A. (1971): An experimental investigation into the decay of Pollen and spores in various soil types. – In: Brooks J., Grant, P. R., Muir, M., van Gijzel, P., Shaw, G. (eds), Sporopollenin, Academic Press, London, pp. 446–478.
http://dx.doi.org/10.1016/B978-0-12-135750-4.50022-5

Ivanov, M. (2005): Obojživelníci a plazi lokality Za Hájovnou - Javoříčský kras [Amphibians and reptiles from the “Za Hájovnou” Cave, Javoříčko Karst, Moravia]. – Přírodovědné studie Muzea Prostějovska. 8: 89–108. (in Czech)

Jankovská, V., (1971): The development of vegetation on the western slopes of the Bohemian-Moravian Uplands during the Late Holocene period. A study based on pollen and macroscopic analyses. – Folia Geobot. Phytotax., 6: 281–302.

Kondratienė, O., Šeirienė, V. (2003): Vegetation and climate of the Butėnai Interglacial (Holsteinian) in Lithuania. – Geological Quaterly, 47(2): 139–148.

Lang, G. (1994): Quartäre Vegetationsgeschichte Europas. – Gustav Fischer Verlag, Jena-Stuttgart-New York, 462 pp.

Litt, T., Shmincke, H. U., Frechen, M., Schluchter, Ch. (2008): Quaternary. – In: McCann, T. (ed.), The Geology of Central Europe. Vol. 2 Mezozoic and Cenozoic, Geologic Society London, pp. 1288–1340.

Lundberg, J., Musil, R., Sabol, M. (2014): Sedimentary history of Za Hájovnou Cave (Moravia, Czech Republic): A unique Middle Pleistocene palaeontological site. – Quaternary International, 339-340: 11–24.
http://dx.doi.org/10.1016/j.quaint.2013.04.006

Musil, R. (2005): Jeskyně Za Hájovnou, výjimečná lokalita Lavořičského krasu [Za Hájovnou Cave, exceptional locality of Javoříčko Karst, Moravia]. – Přírodovědné studie Muzea Prostějovska. 8: 9–42. (in Czech)

Musil, R., Sabol, M., Ivanov, M., Doláková, N. (2014): Middle Pleistocene stratigraphy of the deposits in Za Hájovnou Cave (Javoříčko Karst, northern Moravia, Czech Republic). – Acta Musei Nationalis Pragae, Ser. B., Historia Naturalis, 70(1-2): 107–119.

Navarro, C., Carrión, J. S., Munuera, M., Prieto A. R. (2001): Cave surface and the palynological potential of karstic cave sediments in palaecology. – review of Paleobotany and Palynology, 117(4): 245–265.
http://dx.doi.org/10.1016/S0034-6667(01)00095-1

Nitychoruk, J., Bińka, K., Ruppert, H., Schneider J. (2006): Holsteinian Interglacial = Marine Isotope Stage 11?. – Quaternary Science Reviews, 25: 2678–2681.
http://dx.doi.org/10.1016/j.quascirev.2006.07.004

Reille, M., de Beaulieu, J.-L., Svobodova, H., Andrieu-Ponel, V., Goeury, C. (2000): Pollen analytical biostratigraphy of the last five climatic cycles from a long continental sequence from the Velay region (Massif Central, France). – Journal of Quaternary Science, 15: 665–685. http://dx.doi.org/10.1002/1099-1417(200010)15:7<665::AID-JQS560>3.0.CO;2-G http://dx.doi.org/10.1002/1099-1417(200010)15:7<665::AID-JQS560>3.3.CO;2-7

Roe, H. M., Coope ,G. R., Devoy, R. J. N., Harrison, C. J. O., Penkman, K. E. H., Preece, R. C., Schreve, D. C. (2009): Differentiation of MIS 9 and MIS 11 in the continental record: vegetational, faunal, aminostratigraphic and sea-level evidence from coastal sites in Essex, UK. – Quaternary Science Reviews, 28: 2342–2373. http://dx.doi.org/10.1016/j.quascirev.2009.04.017

Roucoux, K. H., Tzedakis, P.C., Frogley, M.R., Lawson, I.T., Preece, R.C. (2008): Vegetation history of the marine isotope stage 7 interglacial complex at Ioannina, NW Greece. – Quaternary Science Reviews, 27: 1378–1395. http://dx.doi.org/10.1016/j.quascirev.2008.04.002

Scourse, J. (2006): Comment on: Numerical 230Th/U dating and a palynological review of the Holsteinian/Hoxnian Interglacial by Geyh and Müller. – Quaternary Science Reviews, 25: 3070–3071. http://dx.doi.org/10.1016/j.quascirev.2006.03.006

Seitl, L., Svoboda, J., Ložek, V., Přichystal, A., Svobodová, H. (1986): Das Spätglazial in der Barová-Höhle im Mährischen Karst. – Archäologisches Korrespondenzblatt, 16: 393–398.

Svoboda, J. (1991): Neue Erkentnisse zur Pekárna-Höhle im Mährischen Karst. – Archäologisches Korrespondenzblatt, 21: 39–43.

Svobodová, H. (1988): Pollenanalytische Untersuchung des Schichtkomplexes 6-1 vor der Kůlna-Höhle. – In: Valoch, K. (ed), Die Erforschung der Kůlna Höhle 1961–1976. Anthropos, 24, Brno, pp. 205–210.

Svobodová, H. (1992): Palaeobotanical evidence on the Late Glacial in the Moravian Karst. – In: Eder-Kovar, J. (ed.), Palaeovegetational Development in Europe and Regions relevant to its Palaeofloristic Evolution. Proceedings of the Pan- European Palaeobotanical Conference Vienna, Museum of Natural History Vienna, Vienna, pp. 19–23.

Urban, B., Sierralta, M. (2012): New palynological evidence and correlation of Early Paleolithic sites Schöningen 12 B and 13II, Schöningen Open Lignite Mine. – In: Behre, K.-E. (ed.), Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen, Römisch-Germanisches Zentralmuseum, Mainz, pp. 77–96.

Urban, B., Sierralta, M., Frechen, M. (2011): New evidence for vegetation development and timing of Upper Middle Pleistocene interglacials in Northern Germany and tentative correlations. – Quaternary International, 241: 125–142. http://dx.doi.org/10.1016/j.quaint.2011.02.034

Vodičková-Kneblová, V. (1961): Entwicklung der vegetation im Elster-Saale-Interglazial im Suchá-Stonava-Gebiet (Ostrava-Gebiet). – Anthropozoikum, 9(1959): 129–174.

Walanus, A., Nalepka, D. (1999): POLPAL - Program for counting pollen grains, diagram plotting and numerical analysis. – Acta Paleobotanica, 2: 659–661.

Explanations of the plate

PLATE 1

Typical pollen grains (all magnifications 1 000 x)

1. *Hedera* sp. - layer 2b, profile ZH P-8b.
2. *Pterocarya* sp. - layer 2b, profile ZH P-8b.

3., 4. *Tilia* sp. - layer 5–9.5 m, profile ZH P-9.

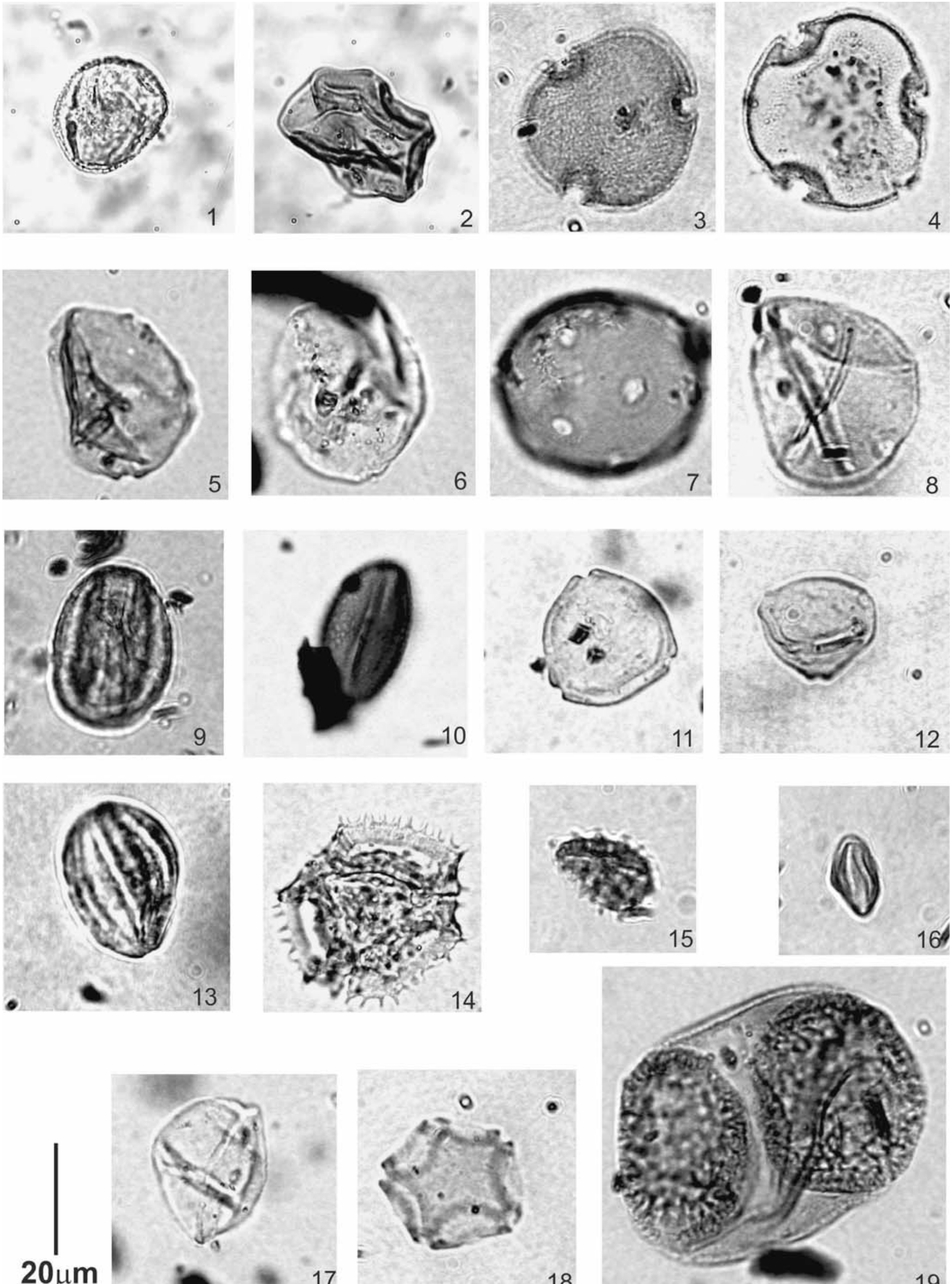
5., 6. *Carpinus* sp. - layer 5–9.5 m, profile ZH P-9.

7. *Juglans* sp. – layer 4, profile ZH P-11.
8. *Celtis* sp. - layer 5–9.5 m, profile ZH P-9.
9. *Quercus* sp. - layer 4, profile ZH P-10.
10. *Salix* sp. - layer 5–10 m, profile ZH P-9.

11., 12. *Corylus* sp. - layer 5–9.5 m, profile ZH P-9.

13. *Galium* sp. - layer 3ba, profile ZH P-11.
14. Asteraceae Cichorioideae - layer 3b, profile ZH P-11.
15. Asteraceae Asteroideae - layer 2b, profile ZH P-8b.
16. *Chrysosplenium*/*Ranunculus trichophyllum* type - layer 5–8.5 m, profile ZH P-9.
17. Poaceae - layer 5–9.5 m, profile ZH P-9.
18. *Alnus* sp. - layer 5–9.5 m, profile ZH P-9.
19. *Pinus sylvestris* type - layer 4, profile ZH P-11.

PLATE 1



Acta Palaeobotanica 47(1): 275–279, 2007

Use of fluorescent microscopy in the study of redeposited palynomorphs in the cave and marine sediments of Moravia (Czech Republic)

NELA DOLÁKOVÁ[1] and ALENA BUREŠOVÁ[2]

[1,2] Institute of Geological Sciences, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic;
e-mail: nela@sci.muni.cz

Received 23 Jube 2006; accepted for publication 13 February 2007

ABSTRACT. Reworked palynomorphs occur in the cave sediments of the Moravian karstic areas as well as in marine sediments of the Carpathian Foredeep (Czech Republic). Their preservation states may be different or similar under the light microscope. The mutual distinguishing features of primarily Quaternary and Tertiary ones, or of the palynomorphs from particular Miocene stages are therefore often very difficult to determine. Observation under the fluorescent microscope can help to determine the reworked palynomorphs in Quaternary as well as Miocene sediments.

KEY WORDS: fluorescent microscopy, redeposited palynomorphs, Miocene, Quaternary, Czech Republic

INTRODUCTION

It is not necessary for palynological studies to be done only in autochthonous sediments (i.e. of organic and chemical development). The sediments develop mostly through disintegration, transport and resedimentation of older rocks. Therefore we can often find the older redeposited palynomorphs in younger sediments.

The occurrence of reworked palynomorphs is typical for cave sediments. These sediments do not contain plant remains in their original positions. Palynomorphs are transported to the sedimentation places with sedimentary particles or through the activity of animals. These facts create the possibility of mixing components of different ages as well as selection of palynomorphs due to their varied degrees of resistance (Doláková & Nehyba 1999, Doláková 2000, 2002). The preservation state of the redeposited grains can be similar to the grains that are contemporary to the development of the sediments and therefore it is frequently difficult to mutually distinguish them.

Very similar problems arise in the Miocene marine sediments from the Carpathian Foredeep. Several transgression and regression cycles occurred in this region. The redepositions of foraminifers and calcareous nannoplankton from the older Miocene stages into the younger ones are commonly known from this area (Brzobohatý et al. 2003). Thus, the occurrence of redeposited palynomorphs is likewise possible. The decision about whether some pollen and spores typical for the climatic zonations are *in situ* or not is therefore of great importance. It is even important to diagnose the potential amounts of redepositions within frequent usual species, because the high percentage of such redeposition could change the image of palaeovegetation.

Observation under fluorescence microscopy introduces a possibility to detect the reworked palynomorphs. These methods were elaborated mostly by van Gijzel (1967a, b, 1971, 1975, 1978).

All our macerated sediments were rich in clays; they were partly calcareous, and for the most part not coalified. For the maceration, HCl, HF (not heating) and heavy liquid $ZnCl_2$ were used. Pure glycerine was mostly used as the observation medium. Part of the samples (especially from the cave sediments) were microscopically studied directly in $ZnCl_2$ due to the exclusion of further dilution of mostly very small palynomorph amounts.

RESULTS

The sediments of the karstic formations from the Moravian part of the Czech Republic (Moravian, Javoříčko and Hranice Karsts) are of Holocene, Pleistocene and Miocene ages (Doláková 2000, 2002, 2004a, b, Doláková & Nehyba 1999). The mixing of components of different ages – especially Quaternary and redeposited Tertiary – is common in these areas. Observed under the light microscope, their preservation states can be very similar. It is therefore often very difficult to distinguish the ages of individual palynomorphs known both from the Quaternary and Tertiary e.g. *Pinus*, *Ulmus*, *Alnus*, *Quercus*, *Corylus*, and *Betula*, which consequently causes complications in age determination and climatic reconstructions. For example, 300 Quaternary and 80 verifiable Tertiary palynomorphs were determined in one sample from Ochoz cave (Doláková & Nehyba 1999), their preservation states being very alike (Pl. 1, fig. 3a, b).

Similar problems arise in the Miocene marine sediments from the Carpathian Foredeep. The occurrence of redeposited Cretaceous palynomorphs is quite usual and well detected. Under the optical microscope, the existence of palynomorphs redeposited from the older Miocene stages is often not possible to prove. We try to use the observations under the fluorescent microscope to detect some redeposited palynomorphs (Burešová 2005).

Van Gijzel (1967a, b, 1971, 1975, 1978) focused his attention on the methods of determining the properties of UV-fluorescence on fresh and fossil pollen and spores. He found that the fluorescence spectra are closely related to the chemical composition of palynomorphs. They also depend on the different levels of resistance to geological age, corrosion and coalification of pollen and spore walls. Similarly, weathering redepositions connected with the oxidization of rocks and activities of bacteria and fungi also change the intensity and colours of the studied pollen and spores (van Gijzel 1971). These characteristics are then significant for determining the systematics and age of palynomorphs. Most of these methods require a lot of complicated measuring and equipment (van Gijzel 1967a, b, 1975) for routine palynological studies. For the orientational detection of the reworked palynomorphs, the relative observation of the colour spectra seem to be convenient. It is necessary to attentively observe the change in colour for a single type of palynomorph. With increasing age, coalification and corrosion, the colours shift from blue-green, white or yellow and strong fluorescence to orange, red or brown and weak fluorescence. Thus, each type of secondary pollen shows a larger variation in fluorescent colours than the autochthonous material (van Gijzel 1971). New data about the effect on fluorescence of the physical processes associated with peat erosion and re-sedimentation in reservoirs during the Holocene were provided by Yeloff and Hunt (2005).

According to van Gijzel (1967b), the maceration methods may also cause variation in fluorescence (the use of hydrofluoric acid can shift fluorescent colours of pollen to the red end of the spectrum and darker). From our experience, glycerine gelatine was found not to be a suitable mounting medium for the study of fluorescence. In a short time, the gelatine changes colour (develops a dark circle) and the palynomorphs fade. Glycerine as well as $ZnCl_2$ seem to be suitable. The studied objects have sufficiently stable colours for the duration of observation.

The autochthonous pollen grains (except grasses), both from the studied Quaternary cave (Pl.1, fig.1a, b, 3a, b, 5a, b) and Miocene marine sediments (Pl. 1, fig 2a, b), have light colours (white, light-yellow, light-orange) and intensive fluorescence during UV observation. The pollen grains in the brackish more coalified material from the Lower Miocene sediments manifest shifts of colour towards brownish-orange and a decreasing intensity of fluorescence (Pl. 1, fig.6).

Verifiably redeposited palynomorphs from the Moravian Quaternary karstic sediments have typical dark brown colours with a very low intensity of fluorescence (i.e. pollen grains of Taxodiaceae – Pl. 1, fig. 3a, b). It is therefore possible to assume the grains of similar colours to also be redeposited (Pl. 1, fig. 1a, b).

Good identification of redeposition is possible (from the different colours) in the mixture of specimens of several ages of the one genus e.g. *Pinus* from the Quaternary (Pl. 1) and from the Miocene (Pl. 1, fig. 2) palynospectra. The detection of single unusual pollen grains and spores brought out more difficulties. Some types of palynomorphs have primarily low fluorescence or their exines are easier disintegrated than others (i.e. Poaceae, *Lygodium*); therefore, the redepositions are very hard to confirm or eliminate.

Other interesting observations are connected with the different colours of the algal bodies. After Brooks (1971) and Yeloff and Hunt (2005) the sporopollenin content of lower plants is chemically different from that of higher plants. The rate of corrosion of the algal remains and fungal spores is different from that of spores and pollen grains (van Gijzel 1971); therefore, they differ considerably in fluorescence from the other plant remains in the fossil material. In the studied Quaternary sediments (cave sediments, soils), the cenobia of *Botryococcus* and *Pediastrum* show striking blue-green colours (Pl. 1, figs 7, 8a, b). In the Miocene sediments these were yellowish-white with a very high intensity (Pl. 1, fig. 6). These phenomena enable the detection of even small parts of algae among other plant remains.

ACKNOWLEDGEMENT

We would like to express our thanks to Dr. P. Pokorný and Dr. S. Sarkar (University Brno) for their remittance to issues of fluorescence microscopy. This study was supported by Grant Agency of the Czech Republic, Grant 205/04/1021.

REFERENCES

BROOKS J. 1971. Some chemical and geochemical studies on sporopollenin: 351–407. In: Brooks J., Grant P.R., Muir M., van Gijzel P. & Shaw G. (eds) Sporopollenin. Academic Press, London – New York.

BRZOBOHATÝ R., CICHA I., KOVÁČ M. & RÖGL F. 2003. The Karpatian a Lower Miocene stage of the Central Paratethys. Masaryk University, Brno.

BUREŠOVÁ A. 2005 (unpubl.). Paleobotanické výzkumy v sedimentech pleistocénu a raného holocénu na Moravě. (Paleobotanical researches in the sediments of the Pleistocene and Early Holocene in Moravia). Archives of the Masaryk University Brno. (in Czech).

DOLÁKOVÁ N. 2000. Palynological studies from the Ochozská Cave and from the Šošůvka part of the Sloup-Šošůvská Cave (Moravian Karst). Geolines, 11: 172–174.

DOLÁKOVÁ N. 2002. Palynologické studium sedimentů Šošůvské části Sloupsko-Šošůvských jeskyní a spodní části opěrného profilu v jeskyni Kůlna. (summary: Palynological studies of the sediments from the Šošůvka part of the Sloup-Šošůvka Cave and from the lower part of the supporting profile in the Kůlna cave (Moravian Karst). Acta Mus. Moraviae, Sci. Geol., 87: 275–288.

DOLÁKOVÁ N. 2004a. Palynologická studia jeskynních sedimentů moravských krasových oblastí. Česká speleologická společnost. 3. národní speleologický kongres, Sloup: 13–15. Sloup. (in Czech).

DOLÁKOVÁ N. 2004b. Palynological studies in the Cave sediments from the Moravian, Javoříčko and Hranice Karsts – Czech Republic. 11th In ternational Palynological Congress, Granada 2004, Acstract. Polen, 14: 269–270.

DOLÁKOVÁ N. & NEHYBA S. 1999. Sedimentologické a palynologické zhodnocení sedimentů z Ochozské jeskyně. (Sedimentological and Palynological value of the sediments from the Ochozská jeskyně cave). Geol.Výzk. Mor. Slez. in 1998: 7–10. Brno. (in Czech).

Van GIJZEL P. 1967a. Palynology and flourescence microscopy. Rev. Palaeobot. Palynol., 2:49–79.

Van GIJZEL P. 1967b. Autofluorescence of fossil pollen and spores with special reference to age determination and coalification. Leidse Geol. Meded., 40: 263–317.

Van GIJZEL P. 1971. Review of the UV-fluorescence microphotometry of fresh and fossil exines and exosporia: 659–685. In: Brooks J., Grant P.R., Muir M., van Gijzel P. & Shaw G. (eds) Sporopollenin. Academic Press, London – New York.

Van GIJZEL P. 1975. Polychromatic UV-fluorescence microphotometry of fresh and fossil plant substances, with special reference to the location and identification of dispersed organic material in rocks: 67–91. In: Alpern B. (ed.) Colloque International Petrographie de la Matiere Organique des Sediments, Paris.

Van GIJZEL P. 1978. Recent developments in the application of quantitative fluorescence microscopy in palynology and paleobotany. Ann. Mines Belgique, 7–8: 836–851.

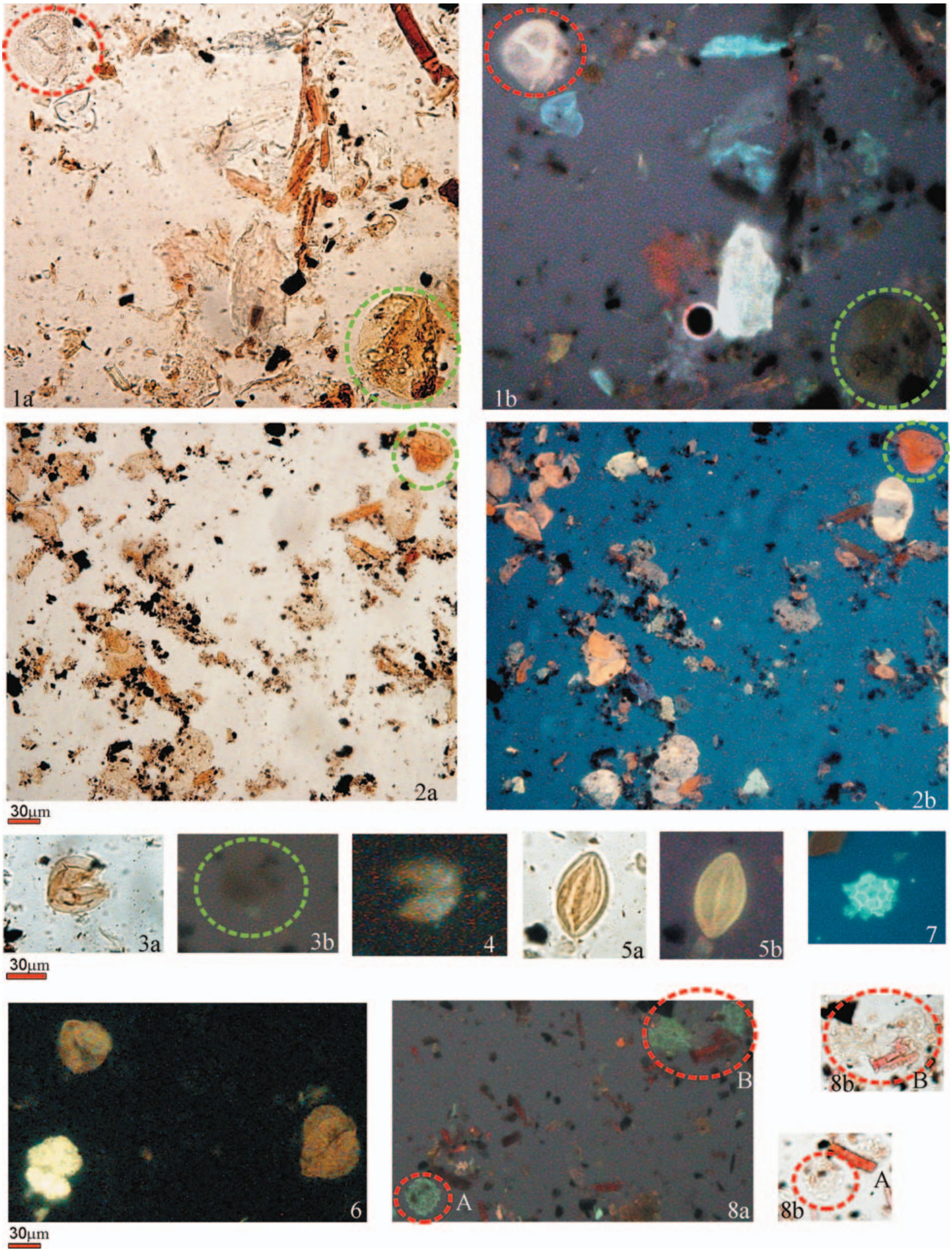
YELOFF D.E. & HUNT C.O. 2005. Fluorescence microscopy of pollen and spores: a tool for investigating environmental change. Rev. Palaeobot. Palynol., 133: 203–219.

PLATE

Plate 1

1a. Part of pollen spectrum of the Late Glacial cave sediments – light microscope – red circle *Pinus* sp. autochthonous, green circle *Pinus* sp. redeposited, Ochoz cave
1b. The same under the fluorescent microscope (UV light)
2a. Part of pollen spectrum from the Badenian marine sediments – light microscope – green circle redeposited *Pinus* sp. (the cubic caves in the grain are caused by crystallization of pyrite in the anoxic marine environment), Židlochovice
2b. The same under the fluorescent microscope (UV light)
3a. Redeposited Taxodiaceae from the Late Glacial cave sediments – light microscope, Ochoz cave
3b. The same under the fluorescent microscope (UV light)
4. Taxodiaceae from the Badenian marine sediments, the fluorescent microscope (UV light), Židlochovice
5a. *Helianthemum* sp. from the Late Glacial cave sediments – light microscope, Ochoz cave
5b. The same under the fluorescent microscope (UV light)
6. *Pinus* and *Botryococcus* sp. from Eggenburgian brackish sediments, the fluorescent microscope (UV light), Trboušany
7. Cenobium of *Pediastrum* sp., fluorescent microscope, late Pleistocene, Krumlov Forest
8a. A – cenobium of *Pediastrum* sp. and B – several parts of another *Pediastrum*, fluorescent microscope, late Glacial cave sediments, Ochoz cave
8b. A, B part of the same under the light microscope

Plate 1



Acta Palaeobot. Suppl. 2: 269–277, 1999 — Proceedings 5th EPPC

DEVELOPMENT OF SEDIMENTATION, MOLLUSCS AND PALYNOSPECTRA IN THE LOWER MIOCENE OF THE SOUTH-WESTERN PART OF THE CARPATHIAN FOREDEEP IN MORAVIA (CZECH REPUBLIC)

NELA DOLÁKOVÁ, ŠÁRKA HLADILOVÁ and SLAVOMÍR NEHYBA

Department of Geology and Palaeontology, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic;
e-mail: nela@gap.muni.cz

ABSTRACT. The environment in the south-western part of the Carpathian Foredeep in Moravia (surroundings of Znojmo and Miroslav) in the Lower Miocene (Eggenburgian, Ottnangian) was extraordinarily variable. Marine facies interchanged with those of lagoons and deltas. Sedimentation took place in a subtropical climate and in the inshore zone. Changes of the marine environment in this area were connected primarily with sea level changes (fluctuations in water depth and dynamics, light, aeration, salinity) and with variable rates and intensities of sediment accumulation. The flora and fauna reflect all these environmental changes with great occuracy.

KEY WORDS: sedimentology, palaeontology – molluscs, palynology, Lower Tertiary, Carpathian Foredeep, Czech Republic

INTRODUCTION

The boundary between marine and terrestial environments can be studied in the Lower Miocene sediments (Eggenburgian, Ottnangian) in the south-western part of the Carpathian Foredeep in Moravia, in the neighbourhoods of Znojmo and Miroslav. Information about the character of the marine environment was gained largely from sedimentological (Nehyba) and palaeontological investigations (the molluscan fauna – Hladilová), and that about the terrestrial environment from studies of the palynospectra (Doláková) – Nehyba, Hladilová, Doláková (1997). The most important pollen taxa are shown on Pls 1–3.

RESULTS

The environment in this part of the Carpathian Foredeep at that time was extraordinarily variable and marine facies interchanged with those of lagoons and deltas.

a) The neighbourhood of Znojmo

Around Znojmo, where the Eggenburgian marine transgression first penetrated the seacoast was formed of heavily weathered crystalline rocks, predominantly with highly differentiated relief configurations (ridges, depressions). This is reflected in the raised amounts of Pinaceae pollen in the palynospectra (over 40% in the Unanov borehole), while *Cedrus* pollen was also more abundant (Zdražílková 1992, Nehyba, Hladilová & Zdražílková 1995).

During the Eggenburgian marine transgression, a complex basin system developed in this area. The basins were set in an area of diverse relief and were variably interconnected, as well as being linked to the open sea. With the exception of temperature, practically all the features of the marine environment (water depth and dynamics, light, aeration, salinity) were highly variable and ascillatory in each basin, indicating highly unstable sedimentary conditions in general. The sea was predominantly shallow (up to about 40 m) and warm (subtropical temperatures). The molluscan fauna responded to these changes with a great variability in the number of genera, species diversity and dominance, assemblages of marine and (almost) freshwater environments alternating with those of brackish ones. The two basic mollusc communities, *Congeria* sp. / *Nematurella* sp. (+ *Hydrobia* sp., *Staliopsis* sp. and *Clithon* aff. *pictus*) and *Pirenella moravica* / *Cerastoderma* sp. (+ *Ostrea* sp.) were found. They were generally relatively very species poor and occurred alternately vertically as well as laterally dependending on environmental conditions. In general, evidence of extreme conditions in the marine environment is provided by the fact that only relatively species poor mollusc assemblages occur in this area (Čtyroký 1991, 1993, Hladilová 1988, Hladilová & Hladíková 1993).

The terrestrial flora confirmed the relative·proximity of the shoreline. Due to the oscillations in salinity as well as the inluence of occasional higher evaporation rates, the shores of individual gulfs and lagoons were repeatedly salted, facilitating the growth in places of a relatively rich halophilous vegetation. High numbers of members of the family Chenopodiaceae, which contains many halophytes, sometimes accompanied by increased numbers of *Ephedra* and Buxaceae (e.g. *Monocirculipollis zahnaensis*), were observed in the studied boreholes (Únanov, Čejkovice, Šafov 12, 13). In borehole HV-301 at Čejkovice, which was described in the greatest detail, it was even possible in part to correlate changes in the molluscan assemblages, connected with the salinity fluctuations, with similar changes in some elements of the palynospectra -Chenopodiaceae, Ericaceae (Hladilová 1988, Zdražílková 1992).

Saltmarsh vegetation developed in time and space through to the various growth stages of coal swamp (the sea lagoons gradually became overgrown), and in places, even flora growing directly in fresh water appeared. Higher percentages of Taxodiaceae, Myricaceae, Polypodiaceae, *Osmunda* and *Lygodium* were observed in the boreholes. Even taxa growing in shallow fresh water such as *Sparganium*, *Nelumbo* and Cyperaceae were found (principally in boreholes 12, 13 at Šafov). Šafov borehole 12 (17.5 m) contained a great amount of *Platanus* pollen. Furthermore, frequent pollen of the Poaceae, Ericaceae and *Corsinipollenites* were characteristic for this facies (Doláková-Zdražílková 1996).

Abrupt spatial and temporal changes of the palynospectra reflect the great variability of environmental conditions on the land. The flora generally confirms a warm climate with all the studied palynospectra rich in thermophilous – tropical – subtropical elements. Frequently and abundantly represented were the families Sapotaceae, Palmae, Cyrillaceae, Myricaceae the genera *Engelhardtia*, *Lygodium* and the species *Quercoidites microhenrici*, *Castaneoideapollis pusillus*, *Tricolporopollenites fallax* and *Tricolporopollenites liblarensis*. *Quercoidites henrici*, *Symplocos*, *Reevesia*, *Cornaceaepollis satzveyensis*, *Castaneoideapollis oviformis*, *Tricolporopollenites marcodurensis*, *Tricolporopollenites pseudocingulum* and the families Araliaceae and Rutaceae occurred regularly but in lower quantities and in several samples the genus *Nelumbo* was found. Arctotertiary elements occurred less frequently with the genera *Betula*, *Alnus*, *Fagus*, *Liquidambar*, *Sciadopitys* and *Pterocarya* being found sporadically. *Carya*, *Juglans* and *Celtis* occurred regularly but not in great quantities. Elements depending on the facies (Ulmaceae, Chenopodiaceae, Ericaceae, Poaceae and *Tricolporopollenites retiformis*) were, however observed more frequently. Spores of the lower plants occurred, depending on the facies. Polypodiaceae (*Laevigatosporites haardti*, *Verrucatosporites* div. fsp., *Cingulisporis* div. fsp.), *Selaginella* (*Echinatisporis* div. fsp.), *Lygodium*, *Osmunda*, *Leiotriletes wolffi* and *Toroisporis (Toroisporis) teupitzensis*, were all observed, together with smaller quantities of *Lycopodium* and *Zlivisporis*. Explicit climate changes did not show upin the palynospectra.

b) Miroslav neighbourhood

The marine transgression reached the Miroslav district later than the Znojmo area, because the progradation of the sea basin was generally accompanied by a nothern displacement of the shoreline. In the wider neighbourhood of Miroslav, the coastal strip behind the seashore was flatter than in the Znojmo area. Around Miroslav the marine sedimentation penetrated that of the deltas. Furthermore great accumulations of sediment took place, and the coastline became even less undulating. Consequently, the effects of any sea level changes in this area extended much further inland than they had done around Znojmo. Near Miroslav, the sea was warm and shallow, originally with relatively high dynamics and salinity, although, later on, there was a general decrease in the dynamics and salinity due to the deltaic sedimentation which took place (several pollen grains were found in the pollinia of the Chenopodiaceae, Myricaceae, *Platanus* and *Corsinipollenites* – suggesting low water dynamics in some parts of the profiles – Nehyba, Hladilová, Zdražílková 1994, 1995). The effects of these changes on the mollusc assemblages were similar to those in the Znojmo area. The comparable mollusc assemblages at Miroslav and the shallow-water zones of Znojmo suggest that similar sedimentary conditions occurred in both areas (Čtyroký & Čtyroká 1989, Nehyba, Hladilová & Zdražílková 1994, 1995). The flora evidences a warm climate, oscillations in water salinity and the proximity of a shoreline whose characteristics were undergoing continual change. Different forms of brackish and freshwater plant microplankton are abundant in all the palynospectra (for example much *Botryococcus*, *Ovoidites*, *Sigmopollis* and less *Circulisporites*, *Sculptizygodites* and Tasmanaceae). The relative abundance of particular types varies in the individual samples. Some forms can be regarded as being present en masse – e.g. *Botryococcus* (Trboušany borehole PMK-5A) and *Sigmopollis* (Únanov borehole). Dinoflagellates with branched projections, typical for waters with a good connection to the open sea, were found sporadically. They could have been swept in to the sedimentation areas during storms.

In places, the coastal substrate was – like that of the Znojmo area – considerably saline, promoting the growth of halophilous vegetation (about 37% of the palynospectrum in Miroslav borehole PMK-1, at a depth of 73.65 m – consists of Chenopodiaceae pollen). Later on, the coast changed its character, and moorland and marginal swamp appeared. Water there was essentially stagnant. This is evident, for example, from the palynofacies of the higher parts of the Miroslav and Trboušany boreholes, where, in the latter, there was a great amount of *Lygodium*. Most exstraordinary was the situation observed in the Trboušany borehole at a depth of 49.7 m where a monotonous palynospectrum with dominant triporate pollen of myricoid type occurred, constituting over 40% of the total, together with that of other members of the swamp vegetation such as Taxodiaceae, *Lygodium* and *Osmunda*. The origin of these swamps was of course – unlike the Znojmo area – connected with the delta environment (Nehyba, Hladilová & Zdražílková 1994, 1995).

The changes in the marine environment in this area were primarily connected with changes in the sea (fluctuations in water depth and dynamics, light, aeration and salinity) and with the varying rates and intensities of sediment accumulation. In particular, repeated and appreciable salinity changes must be considered a very important factor.

In the final stage (Ottnangian), deltaic deposition was no longer taking place in the study area, and a reduced supply of sedimentary material as well as completion of the delta progradation process occured. The delta platform was inundated and in the following transgression stage, the sea probably penetrated further north into the area.

ACKNOWLEDGEMENTS

This study was supported by the Grant Agency of the Czech Republic (grant no. 205/95/1211).

REFERENCES

ČTYROKÝ P. 1991. Division and correlation of the Eggenburgian and Ottnangian in the southern Carpathian Foredeep in southern Moravia. Západ. Karpaty, Sér. Geol., 15: 67–109.

ČTYROKÝ P. 1993. Das Tertiär der Böhmischen Masse in Südmähren. Jb. Geol. B.-A., 136(4): 707–713.

ČTYROKÝ P. & ČTYROKÁ J. 1989. Biostratigrafické zhodnocení vrtů PMK v karpatské předhlubni na Moravě. Zpr. Geol. Výzk. v Roce 1986: 35–37. (In Czech).

DOLÁKOVÁ-ZDRAŽÍLKOVÁ N. 1996. Předběžné palynologické zhodnocení vrtů Šafov 12 a 13. Geol. Výzk. Mor. Slez. V r. 1995: 54–55. (In Czech).

HLADILOVÁ Š. 1987. Paleoekologické výzkumy v eggenburgu na lokalitě Znojmo – Dobšice. In: 3. Pracovní seminář z paleoekologie. Sborník konference. Kat. geol. A pal. PF UJEP: 107–123. (In Czech).

HLADILOVÁ Š. 1988. Palaeoecology of the Eggenburgian molluscs (Bivalvia, Gastropoda) from borehole HV-301 at Čejkovice, Moravia. Čas. Mineral. Geol., 33(3): 299–309. (In Czech, English summary).

HLADILOVÁ Š. & HLADÍKOVÁ J. 1993. Palaeoecology and Isotopic Analysis of Eggenburgian Molluscs from the SW Part of the Carpathian Foredeep in Moravia (Czech Republic). Jb. Geol. B.-A., 136(4): 757–768.

NEHYBA S., HLADILOVÁ Š. & ZDRAŽÍLKOVÁ N. 1994. Zpráva o výzkumu spodnomiocenních sedimentů v jz. části karpatské předhlubně na Moravě. Geol. Výzk. Mor. Slez. V r. 1993: 23–26. (In Czech).

NEHYBA S., HLADILOVÁ Š. & ZDRAŽÍLKOVÁ N. 1995. Lower Miocene sediments in the wider surroundings of Miroslav. Knihovnička ZPN, 16: 85–95. (In Czech, English summary).

NEHYBA S., HLADILOVÁ Š. & DOLÁKOVÁ N. 1997. Sedimentary evolution and changes of fossil assemblages in the southwestern Part of the Carpathian Foredeep in Moravia during the Lower Miocene. In: Hladilová Š., (ed.) Dynamika vztahů marinního a kontinentálního prostředí. Sborník příspěvků. Grantový projekt GAČR 205/95/1211. Masarykova Univerzita: 47–58. (In Czech, English summary).

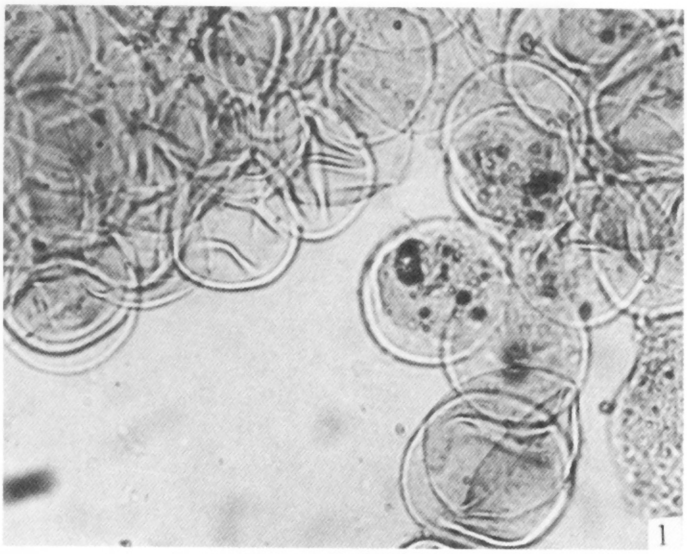
ZDRAŽÍLKOVÁ N. 1992. Palynologické zpracování vrtu Čejkovice HV-301. Knihovnička ZPN, 15: 83–93. (In Czech).

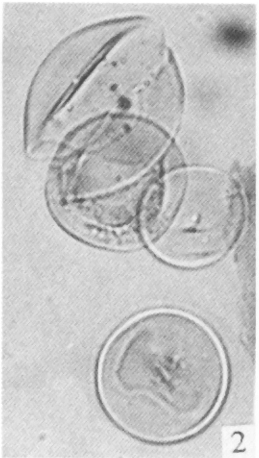
PLATES

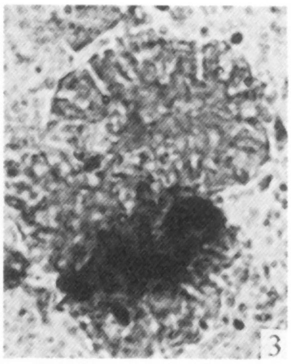
Plate 1

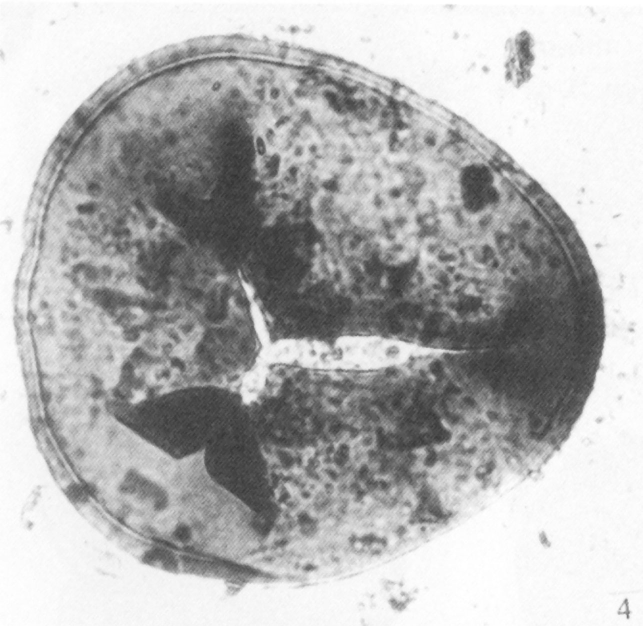
× 1000

1. *Sigmopollis laevigatoides* W. Kr. et Paclt. 1990, Únanov, 6.8 m
2. *Sigmopollis laevigatoides* W. Kr. et Paclt. 1990, Únanov, 6.8 m
3. *Botryococcus braunii* Kützing 1959 – Trboušany, 65.8 m
4. *Leiotriletes maxoides maxoides* W. Kr. 1962 –Trboušany, 17.1 m
5. *Sapotaceoidaepollenites sapotoides* (Th. et Pf. 1953) R. Pot. 1960 – Trboušany, 17.1 m
6. *Sabalpollenites areolatus* (R.Pot. 1934) R. Pot. 1958 – Šafov 13, 20.5 m
7. *Symplocoipollenites latiporis* (Thomson et Pflug 1953) Słodkowska 1994 – Únanov, 6.8 m
8. *Sapotaceoidaepollenites obscurus* (Th. et Pf.1953) Nagy 1969 – Čejkovice, 200.7 m
9. *Reevesiapollis triangulus* (Mamczar 1960) Krutzsch 1970 – Miroslav, 78.4 m
10. *Tricolporopollenites liblarensis* (Potonié 1934) Grabowska 1994 – Šafov 13, 20.5 m
11. *Platycaryapollenites miocaenicus* Nagy 1969 – Trboušany 65.8 m
12. *Engelhardtioidites punctatus* (R. Pot. 1931) Potonié 1951 ex Potonié 1960 – Únanov, 6.8 m
13. *Quercoidites henrici* (Pot.1931) R. Pot., Thoms. et Thierg. 1950 – Miroslav, 78.4 m
14. *Quercoidites microhenrici* (R. Pot. 1931) R. Pot., Thoms. et Thierg. 1950 – Únanov, 6.8 m
15. *Tricolporopollenites pseudocingulum* (R. Pot. 1931) Th et Pf – Čejkovice, 181 m
16. *Tricolporopollenites marcodurensis* Thomson et Pflug 1953 – Trboušany, 69 m
17. *Tricolporopollenites megaexactus* (R. Pot.1931) Th. et Pf. 1953 – Únanov, 6.8 m
18. *Castaneoideaepollis pusillus* (R. Pot. 1934) Grabowska 1994 – Únanov, 6.8 m
19. *Platanus* sp. Pacltová 1966 – Šafov 12, 17.5 m
20. *Platanus* sp. Pacltová 1966 – Šafov 12, 17.5 m
21. *Platanus* sp. Pacltová 1966 – Šafov 12, 17.5 m

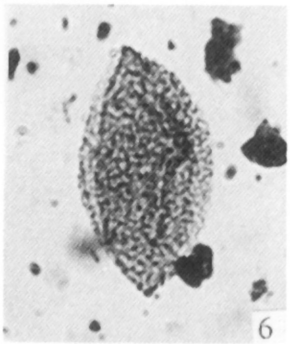

1


2


3

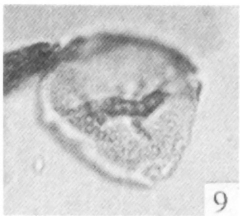

4


5


6

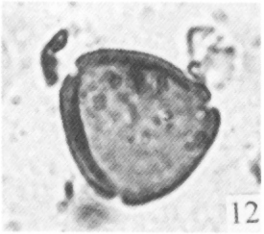

7

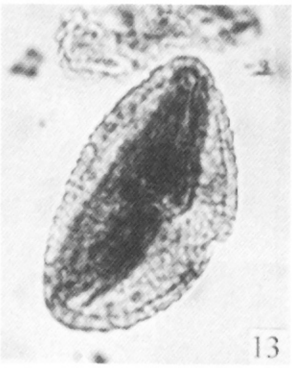

8


9


10

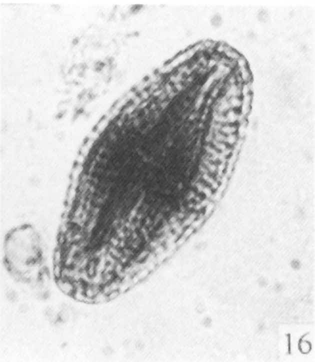

11


12


13


14

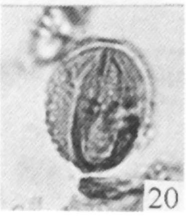

15


16


17


18


19

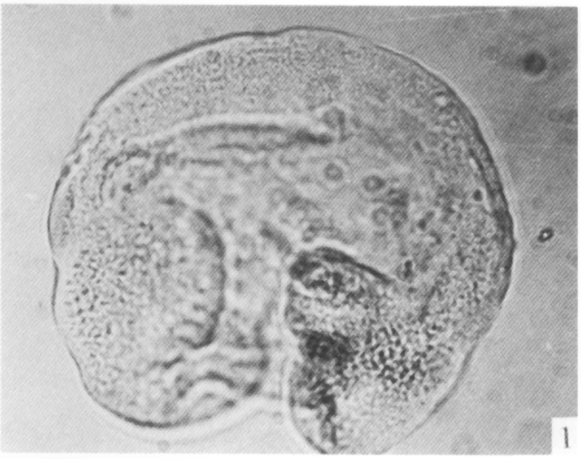

20


21

Plate 2

× 1000

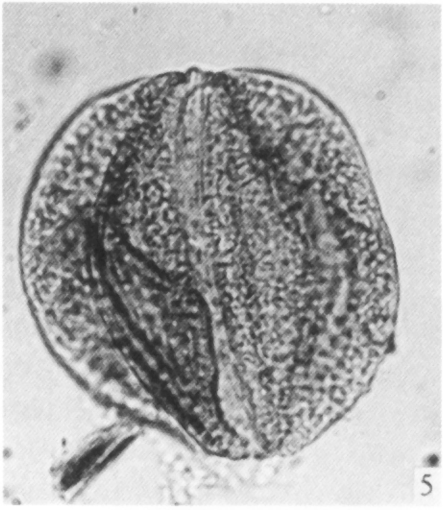
1. *Cedripites miocaenicus* W. Kr. 1971 – Únanov, 6.8 m
2. *Cedripites miocaenicus* W. Kr. 1971 – Únanov, 6.8 m
3. *Corsinipollenites oculusnoctis* (Thierg. 1940) Nakoman 1965 subsp. *oculusnoctis* W. Kr. 1968 – Šafov 12, 17.5 m
4. *Inaperturopollenites hiatus* (R. Pot. 1931b) Th et Pf. 1953 – Trboušany
5. *Pinuspollenites alatus* (R. Pot. 1931) Planderová 1990 – Šafov 13, 6.5 m
6. *Myricaceaepollenites* indet. – pollinium – Trboušany 49.7 m
7. *Myricaceaepollenites* indet. – Trboušany 49.7 m
8. *Myricaceaepollenites* indet. – Trboušany 49.7 m
9. *Sparganiaceaepollenites polygonalis* Th. 1937 – Šafov 12, 17.5 m
10. *Ericipites callidus* (R. Pot. 1931) W. Kr. 1970b – Únanov 6.8 m
11. *Nelumbopollenites europaeus* (Tarasevich 1983) Skawińska 1994 – Šafov 13, 10.5 m
12. *Cyperaceaepollis piriformis* Thiele-Pfeifer 1980 – Šafov 12, 17.5 m

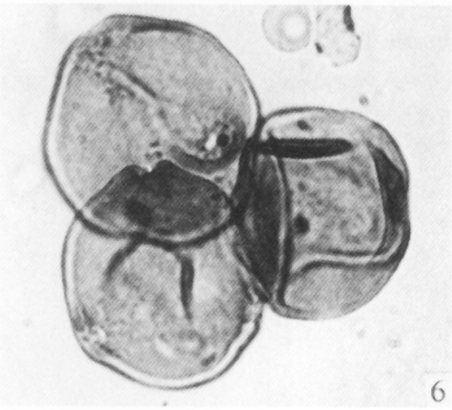

1

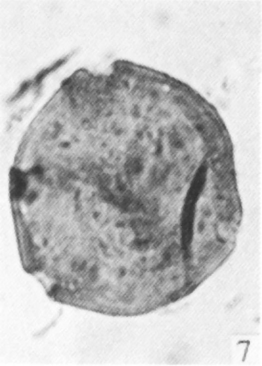

2

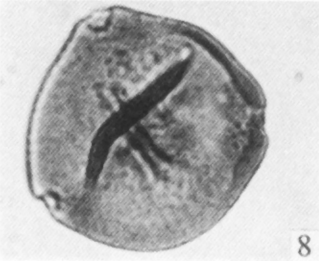

3

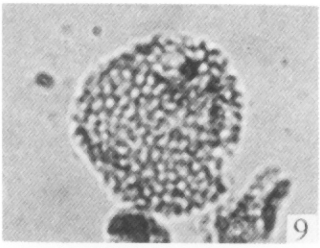

4

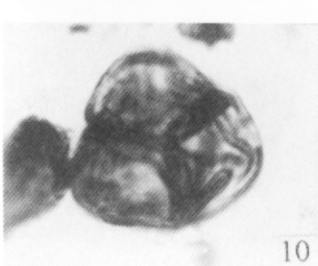

5


6


7


8


9


10


11

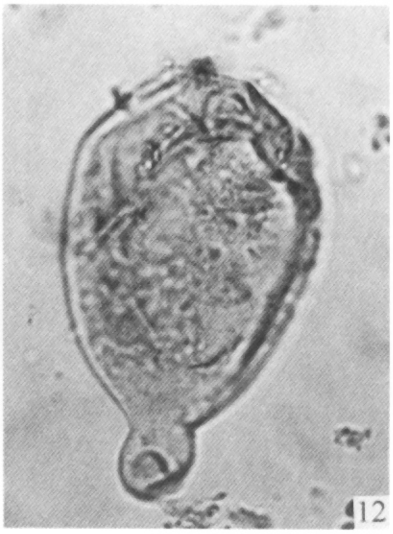
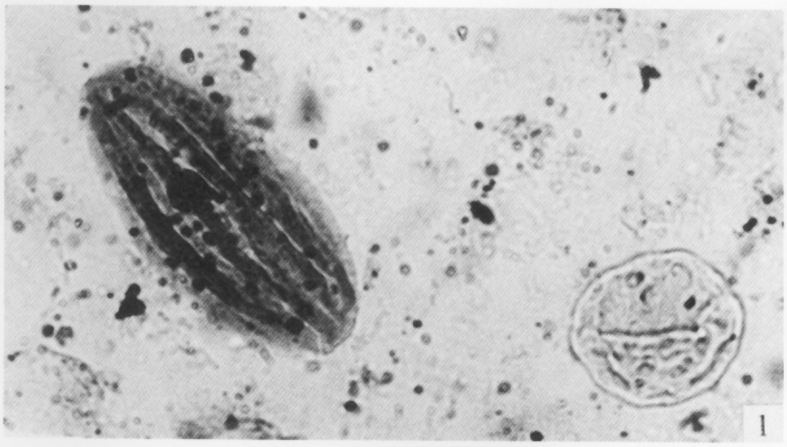
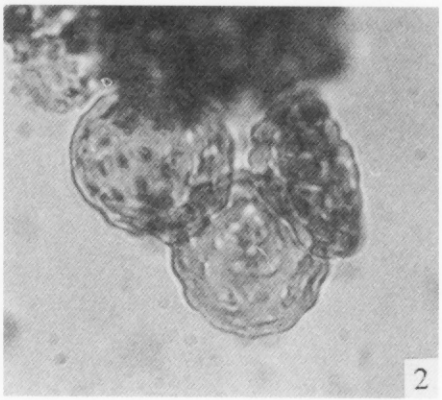

12

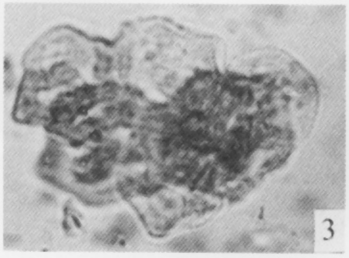
Plate 3

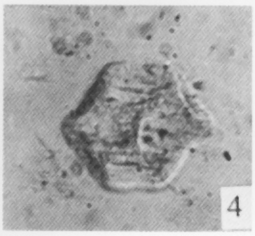
× 1000

1. *Ephedripites (Ephedripites) treplinensis* W. Kr. 1961 and *Chenopodipollis multiplex* (Weyl. et Pf. 1957) W. Kr. 1966 – Miroslav, 73.65 m
2. *Chenopodipollis multiplex* (Weyl. et Pf. 1957) W. Kr. 1966 – pollinium – Miroslav, 78.4 m
3. *Monocirculipollis zahnaensis* W. Kr. 1967 – pollinium – Čejkovice, 176.8 m
4. *Monocirculipollis zahnaensis* W. Kr. 1967 – Únanov, 6.8 m
5. *Monocirculipollis zahnaensis* W. Kr. 1967 – Čejkovice, 176.8 m
6. *Ulmipollenites* div. fsp. – Únanov, 6.8 m
7. *Caryapollenites simplex* (R. Pot. 1931) R. Pot. 1960 – Trboušany, 65.8 m
8. *Pterocaryapollenites stellatus* (R. Pot. 1931) Thiergart 1937 – Trboušany, 69 m
9. *Juglanspollenites verus* Raatz 1937 – Únanov, 6.8 m
10. *Graminidites laevigatus* W. Kr. 1970 – Šafov 12, 17.5 m
11. *Ilexpollenites margaritatus* (R. Pot. 1931) Thierg. 1937 ex R. Pot. 1960 – Trboušany, 49.7 m
12. *Oleaoidearumpollenites* sp. (Th. et Pf 1953) Ziembińska-Tworzydło 1994 – Miroslav, 73.65 m
13. *Selaginellisporis* (*Echinatisporis* W. Kr. 1963) *miocenicus* (Krutzsch et Sontag 1963) Ważyńska 1994 – Trboušany, 65.8 m
14. *Verrucatosporites alienus* (R. Pot. 1931c) Th. et Pf. 1953 – Únanov, 6.8 m
15. *Cingulisporis semiverrucatus* (W. Kr. 1967) – Nagy 1985 – Miroslav, 75.1 m


1

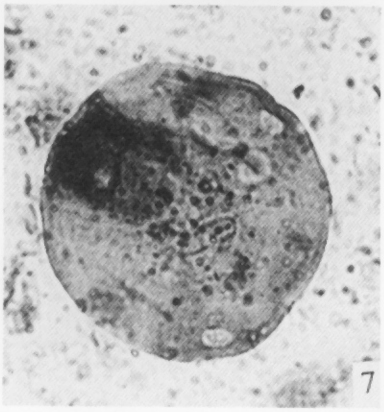

2

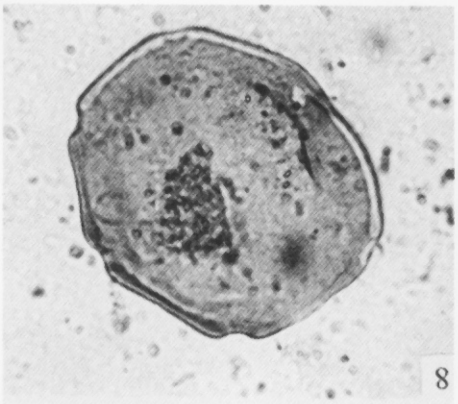

3

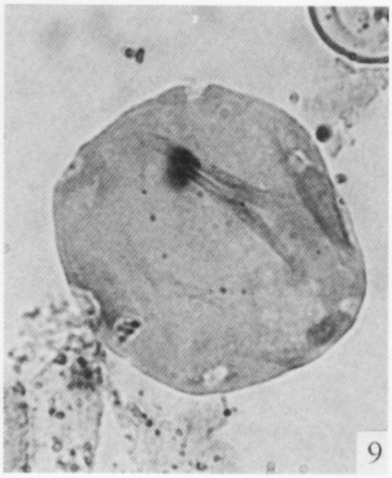

4


5

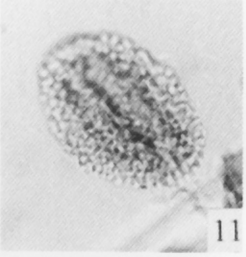

6

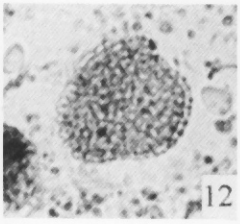

7

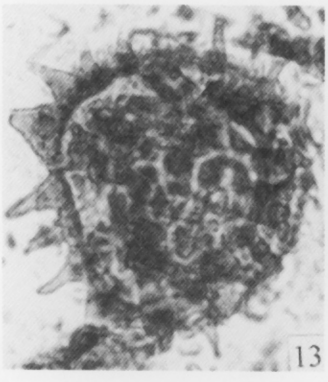

8

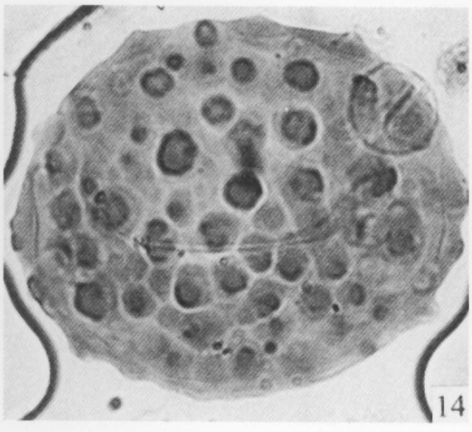

9

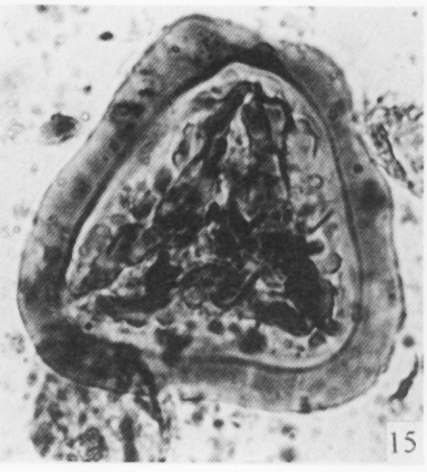

10


11


12


13


14


15

N. Jb. Geol. Paläont. Abh. 271/2 (2014), 169–201
Stuttgart, February 2014

Article

The Badenian parastratotype at Židlochovice from the perspective of the multiproxy study

Nela Doláková, Katarína Holcová, Slavomír Nehyba, Šárka Hladilová, Rostislav Brzobohatý, Kamil Zágoršek, Juraj Hrabovský, Michal Seko, and Torsten Utescher

With 6 figures

Abstract: Two shallow boreholes were drilled in 2010 into the Badenian (Langhian) parastratotype at Židlochovice (Carpathian Foredeep, NN5 Zone, Czech Republic). Their profiles (26 m of sediment) were studied comprehensively (sedimentology, palaeontology – calcareous nannoplankton, red algae, palynology, Foraminifera, Bryozoa, Brachiopoda, Ostracoda, Mollusca, Teleostei and Elasmobranchii). The sedimentary succesion was biostratigraphically correlated with the NN5 Zone (14.9-13.9 Ma), namely with the initial time of the Middle Miocene Climatic Transition. Seven lithofacies representing multiple alternations of mudstone, sandstone and limestone facies were recognised within sedimentary succession. Fossils generally indicated a normal marine, warm to subtropical environment. The generally shallowing trend from the bottom (epibathyal/circalittoral) to the top (shallow infralittoral) of the sedimentary succession with repeated palaeobathymetric changes could be recognized in both boreholes. A mainly subtropical character of terrestrial flora was recorded. Within this framework, either warm wet conditions with seasonal increases, or cooler phases were observed. The abrupt change from mudstone deposited in a calm palaeoenvironment of the upper bathyal/circalittoral to the variegated deposits of shallow water represents the most significant event correlable with the FO of *Orbulina* (approximately 14.5-14.6 Ma). The interval below the FO of *Orbulina* can be characterized by mudstone facies and significantly stable conditions of deposition, high nutrient input and a decrease of oxygen content at the bottom. Seasonal stratification of the water column is probable. Within this interval, cooling and an increase of seasonality were recorded. Above the FO of *Orbulina,* there is evidence of shallowing connected with a higher flow regime and higher sedimentation rate. The alternation of thick redalgal limestone bodies (a stable shallow palaeoenvironment with low terrigenous input and seagrass meadows) and variegated sandstone, mudstone and limestone interbeds (in an unstable deeper environment) possibly reflects orbitally forced climatic cyclicity.

Key words: Badenian, parastratotype, multiproxy quantitative analysis, palaeoecology, climate.

1. Introduction

The locality of Židlochovice – the clay pit of an old brickyard (coordinates: long 16°37‘ 30‘‘; lat. 49°02‘ 34‘‘; Z = 219-240 m a.s.l.) – is located at the southern part of the Carpathian Foredeep in Moravia (Czech Republic), which represents a peripheral system of Central Paratethys basins (Fig. 1A). This site has provoked the interest of many palaeontologists for a very long time due to its rich fossil assemblages of foraminifera, bryozoans, ostracods, microflora (nannoplankton and red algae), molluscs (bivalves, gastropods, cephalopods), sea urchins, corals, and the fish otoliths and teeth (i.e., Procházka 1893; Cicha et. al. 1956; Papp et al. 1978; Říha 1983; Brzobohatý 1997; Doláková et al. 2008; Zágoršek 2010a). Outcropping deposits were assigned as a regional **faciostratotype of the Lower Badenian** by Papp et al. (1978) corresponding to the Langhian in the standard chronostratigraphy (Hohenegger et al., in press).

www.schweizerbart.de
DOI: 10.1127/0077-7749/2014/0383
0077-7749/2014/0383 $ 8.25

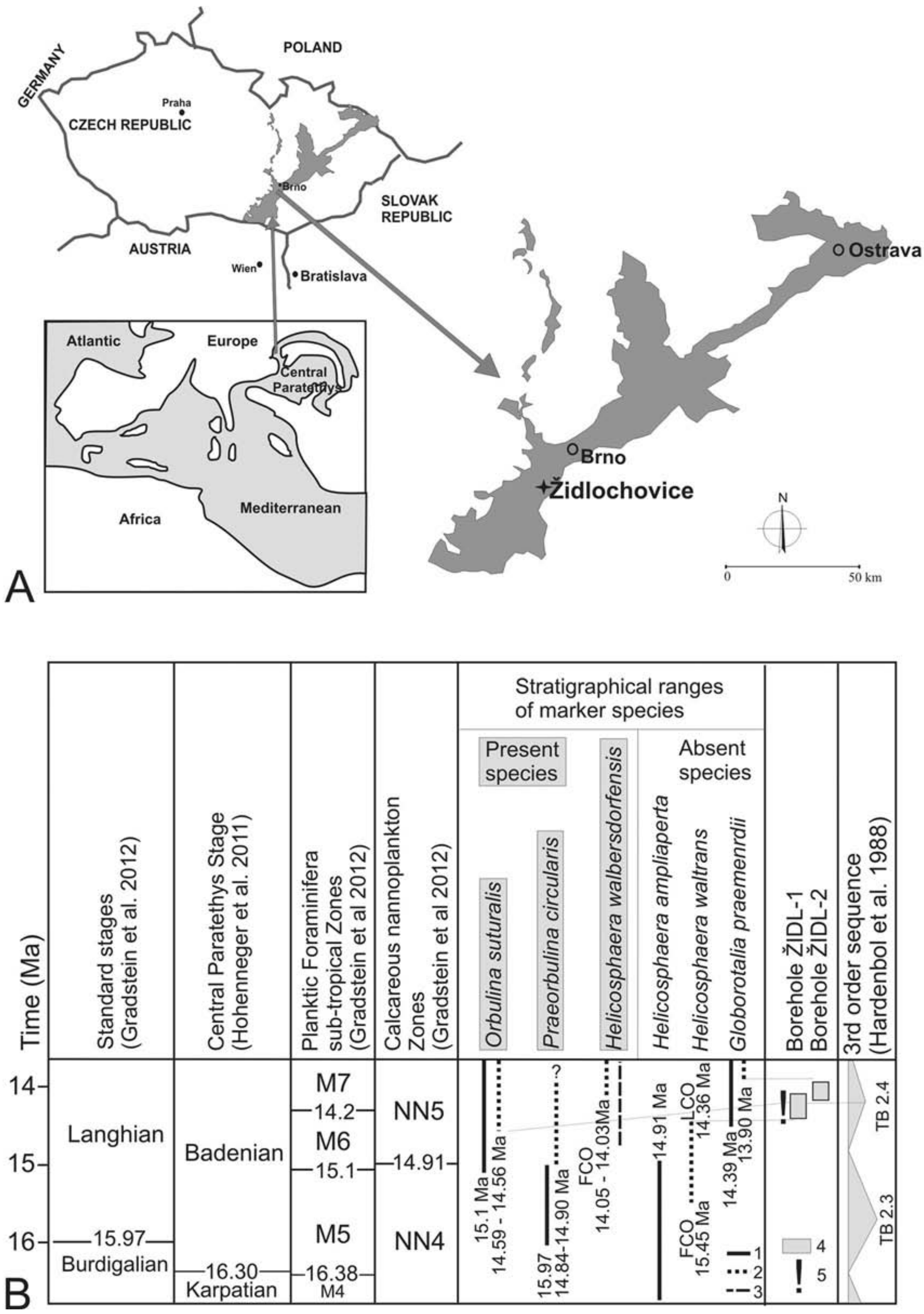


Fig. 1. A – Location of Židlochovice boreholes. **B** – Correlation of Židlochovice boreholes with biostratigraphical events and global sequences 1 ranges from Gradstein et al. (2012); 2 – Mediterranean ranges from DiStefano et al. (2008); Abdul Aziz et al. (2008); Hüsing et al. (2010); 3 – ranges from the Carpathian Foredeep (Švábenická 2002, this work); 4 – stratigraphical range of ŽIDL boreholes; 5 – discrepancy in succession of biostratigraphical events (FO of *Orbulina suturalis* and LO of *Helicosphaera waltrans*) between Mediterranean area and Židlochovice succession.

The outcrop sediments were biostratigraphically correlated with the NN5 nannofossil biozone and *Orbulina suturalis* (foraminiferal zone) (Papp et al. 1978; Fig. 1B).They primarily consist of unlaminated glauconitic calcareous clays – "tegel" – with intercalations of calcareous sands or sandstone and limestone with a dominance of red algae and bryozoans. The environment was interpreted as a shallow circalittoral on the basis of Foraminifera and Mollusca (Papp et al. 1978). However, the study of faciostratotype from the 1970s is insufficient for current detailed interpretation. Therefore, the goal of the revision was to reevaluted biostratigraphy and to reconstruct an ecosystem evolution in the faciostratotype locality using the multiproxy quantitative analysis by trying to achive a high resolution oft he records. In the present day, the claypit is abandoned and covered with slope debris. Therefore, two shallow boreholes representing the original parastratotype section were drilled in 2010: the lower interval was documented as ŽIDL-1 (11.9 m, 230 m a.s.l.) and the upper as ŽIDL-2 (16.9 m, 246 m a.s.l.). The drilled cores were studied in detail from the perspective of their sedimentology, palynology, calcareous nannoplankton, red algae, Foraminifera, Mollusca, Brachiopoda, Ostracoda, Bryozoa and Teleostei – otoliths, teeth, Elasmobranchii (teeth). Some of detailed palaeobiological analyses have been already published (Seko et al. 2012 – Ostracoda; Pavézková et al., in press – Brachiopoda, Tomaštíková & Zágoršek 2012) – Bryozoa).

2. Geological setting

The locality at Židlochovice is located in the Carpathian Foredeep (CF) near the boundary of the eastern slopes of the Bohemian Massif that dip below Neogene sediments and Carpathian flysh nappes (Fig. 1A). The Badenian deposits of the CF in Moravia (Czech Republic) represent the final stage of the depositional history of the outer peripheral basins in the NW of the Central Paratethys (Meulenkamp et al. 1996). At the beginning of the Middle Miocene, extensive erosion took place in the Western Carpathians. The Badenian transgression in the Moravian part of the Carpathian Foredeep could be correlated with global sea level cycle TB 2.4 (Hardenbol et al. 1998, 14.8-13.6 Ma) though local cycles were strongly controlled by tectonics (Kováč et al. 2001) and associated with basin subsidence and continuous mountain chain uplift during the synrift stage of back arc basin development. The basins were filled with clastics transported from uplifted areas (Kvaček et al. 2006).

The studied sedimentation area was profoundly differentiated. In general scheme at the beginning of transgression in the shallow or elevated places, sand, gravel, biostromal and biohermal limestone or calcareous sandstone with a dominance of red algae and bryozoas (Doláková et al. 2008; Zágoršek 2010a) were deposited. By contrast, a hundred meter deep depression was filled with unlaminated calcareous clays – "tegel" (Brzobohatý 1997; Kováč 2000; Kováč et al. 2007).

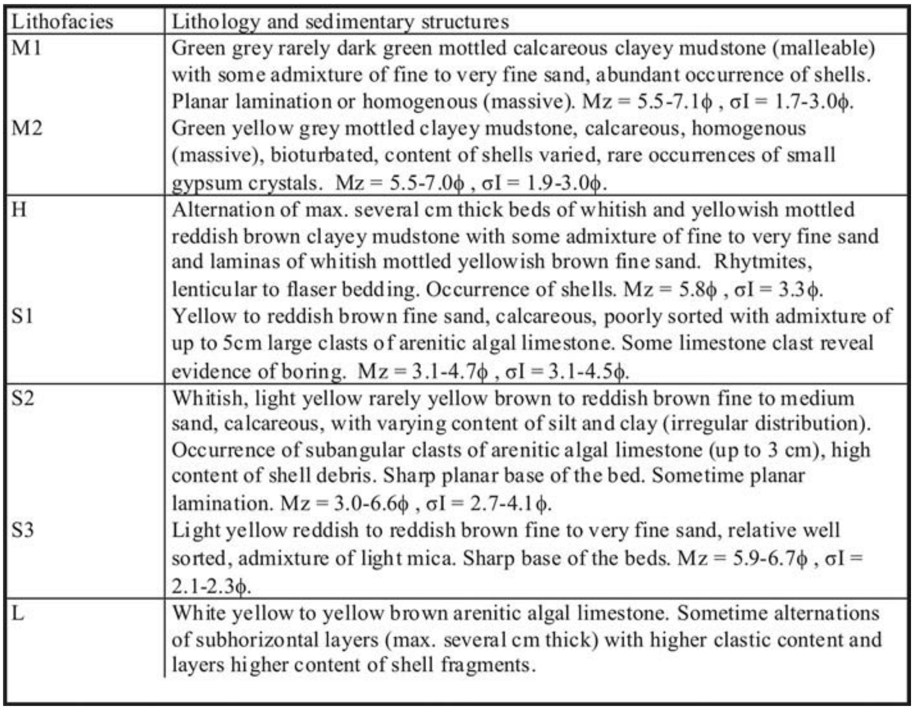
3. Methods

A lithofacies analysis was conducted according to Tucker (1995), Walker & James (1992) and Nemec (2005). The shape and roundness of the coarsest grain fraction (> 4mm – sieve separation, 17 samples) were estimated visually under a microscope using the Powers (1982) method. Combined sieving and laser methods were used for grain size analysis (22 samples). The Retch AS 200 sieving machine analysed the coarser grain fractions (4 mm-0.063 mm, wet sieving); the Cilas 1064 laser diffraction granulometer was used for analyses of the finer fractions (0.0004-0.5 mm). Ultrasonic dispersion, distilled water and washing in sodium polyphosphate were used prior to the analyses in order to avoid flocculation of the analysed particles. Average grain size is expressed as the graphic mean (Mz), uniformity of the grain size distribution/sorting as the standard deviation (σI) (Folk & Ward 1957).

Fossils (with the exception of palynomorphs, red algae and calcareous nannoplankton) were studied from washing residue (fractions 63-2000 µm) – 26 foraminifera samples from the ŽIDL-l borehole and 24 samples from the ŽIDL-2 borehole (Appendices 1, 2), molluscs (13+8) (Appendix 4), ostracods (13+8), brachipods (13+8), bryozoans (13+8), bonefish and sharks (6+7) (Appendix 5), and fragments of coralline algae. Calcareous nannoplankton was studied in slides (26+24) (Appendix 3), coralline red algae in thin sections (3+3) (Appendix 6), and palynomorphs after standard palynological maceration in slides with pure glycerine observation medium (16+16) (Appendix 7).

A KAPPA STM 723 stereomicroscope, Arsenal SZP 1102 ZOOM (bryozoans), WILD Heerbrugg (otoliths, teeths), Nikon SMZ1 (molluscs, brachiopods), and Nikon Alphaphot (red algae, palynomorphs) have been use for taxonomic analyses.

The palynological problematic taxa identification was done using the scanning electron microscope JEOL JSM – 649 OLV (Institute of Geological Sciences, Masaryk University); ostracods – JEOL JSM 6390 (AVSR Banská Bystrica); foraminifera – JEOL JSM 6380 LV (Charles University in Prague); and bryozoan – low-vacuum SEM Hitachi S3700N (Paleontological Department of the National Museum in Prague). About 200300 specimens of foraminifera from each sample were determined and the relative abundance of taxa were calculated (Appendices 1, 2). The taphonomical analysis of foraminiferal assemblages included the study of abrasion and corrosion and the size sorting of tests (Holcová 1996, 1999). The palaeoecological interpretations



Lithofacies	Lithology and sedimentary structures
M1	Green grey rarely dark green mottled calcareous clayey mudstone (malleable) with some admixture of fine to very fine sand, abundant occurrence of shells. Planar lamination or homogenous (massive). $Mz = 5.5\text{-}7.1\phi$, $\sigma I = 1.7\text{-}3.0\phi$.
M2	Green yellow grey mottled clayey mudstone, calcareous, homogenous (massive), bioturbated, content of shells varied, rare occurrences of small gypsum crystals. $Mz = 5.5\text{-}7.0\phi$, $\sigma I = 1.9\text{-}3.0\phi$.
H	Alternation of max. several cm thick beds of whitish and yellowish mottled reddish brown clayey mudstone with some admixture of fine to very fine sand and laminas of whitish mottled yellowish brown fine sand. Rhytmites, lenticular to flaser bedding. Occurrence of shells. $Mz = 5.8\phi$, $\sigma I = 3.3\phi$.
S1	Yellow to reddish brown fine sand, calcareous, poorly sorted with admixture of up to 5cm large clasts of arenitic algal limestone. Some limestone clast reveal evidence of boring. $Mz = 3.1\text{-}4.7\phi$, $\sigma I = 3.1\text{-}4.5\phi$.
S2	Whitish, light yellow rarely yellow brown to reddish brown fine to medium sand, calcareous, with varying content of silt and clay (irregular distribution). Occurrence of subangular clasts of arenitic algal limestone (up to 3 cm), high content of shell debris. Sharp planar base of the bed. Sometime planar lamination. $Mz = 3.0\text{-}6.6\phi$, $\sigma I = 2.7\text{-}4.1\phi$.
S3	Light yellow reddish to reddish brown fine to very fine sand, relative well sorted, admixture of light mica. Sharp base of the beds. $Mz = 5.9\text{-}6.7\phi$, $\sigma I = 2.1\text{-}2.3\phi$.
L	White yellow to yellow brown arenitic algal limestone. Sometime alternations of subhorizontal layers (max. several cm thick) with higher clastic content and layers higher content of shell fragments.

Fig. 2. List of lithofacies recognised in the drill holes Židlochovice 1 and 2 (Mz – mean/average grain size, σIstandart deviation/sorting – counted according to Folk & Ward (1957).

were based on the actuoecological data of Culver & Buzas (1980, 1981), Den Dulk et al. (1998, 2000), Jorissen et al. (1995), Kaiho (1994, 1997), van Hinsbergen et al. (2005), and Murray (2006).

Slides for the study of calcareous nannoplankton were prepared using the following technique: approximately 0.5 cm^3 of rock sample was pulverized and watered with 5 ml of water. One minute after shaking, one drop of suspension from the middle of the water column was dripped on a microscope slide. After this drying, standard microscope slides were prepared and analysed using a light microscope (normal and crossed nicols, 1000 x magnification). The abundance of nannoplankton was expressed semiquantitatively as a number of specimens in the visual field of the microscope. The following categories were distinguished: (i) very rare: 1-2 specimens; (ii) rare: 3-5 specimens; (iii) common: 6-10 specimens; (iv) abundant: 11-20 specimens; (v) very abundant: 21-40 specimens; (vi) mass occurrence: above 40 specimens. The relative abundances of calcareous nannoplankton species in assemblages were evaluated quantitatively based on 200-500 determined specimens from individual samples (Appendix 3).

Calcareous nannoplankton and foraminiferal assemblages were statistically classified using the multivariate techniques of PAST software (Hammer et al. 2001). Euclidean distance was chosen for quantification of object distance. Four tested methods (PCA; cluster analysis: paired group, single linkage, Wards method; nonmetric MDS, CABFAC Factor analysis) gave comparable results. Finally, results of the CABFAC Factor analyses were selected for publication, because its results were the most illustrative.

Molluscs were evaluated semiquantitatively from 100 g dry weight of sediment: less than 5 fragments were classed as rare (1), 615 fragments as common (2), 1635 fragments as abundant (3). Numbers of molluscan fragments reflect the abundances of molluscan clasts among other bioclasts and rock pieces in the washed residuum and do not express the numbers of animals (Appendix 4).

A few samples of bryozoans from more lithified rock were "laboratory weathered" and/or treated with acetic acid as described by Zágoršek et al. (2011). The method might selectively dissolve some part of the skeleton unabling the precise determination. However, without the treatment, the number of determinable specimens considerable decreased.

Ostracod assemblages were analyzed with a focus on taxonomy and palaeoecology, the later based on distribution of the specimens and species along the borehole profiles, the quantification of the valves/carapaces ratio, and the species richness by using Simpson's Reciprocal Index (Seko et al. 2012).

For genera description of Rhodophyta, the methods by Woelkerling (1988) and Braga et al. (1993) were used. Microfacies were described according to Flügel (2004). Planimetric analysis was calculated with JMicrovision software (Roduit 2008).

Standard maceration with HCl (20 %), HF, KOH and

HCl (10 %) and $ZnCl_2$ (density = 2 g/cm^3) was used for the palynological samples. Pure glycerine was most frequently used as the observation medium. The percentage of individual taxa was calculated from the total sum of a minimum of 150 determined pollen grains and spores by using the POLPAL programme (Walanus & Nalepka 1999). The palaeotropical and arctotertiary elements were classified according to Stuchlik et al. (1994). The terminology used for vegetation units and partly for creating the pollen diagrams follows Kvaček et al. (2006) and Kovar-Eder et al. (2008). The pollen diagram was arranged into two parts due to the overrepresentation of conifers: in the left section is the pollen sum (100 %), excluding conifers, thus giving a better visualisation of the basic character of the vegetation changes. The right section shows the proportion of *Pinus* and *Cathaya* and was counted from the sum of all grains.

4. Results

4.1. Sedimentary geology

The lithofacies within the studied core profiles were defined according to their grain size, rare preserved sedimentary structures and petrology. Seven lithofacies were recognised within the drill holes. Their characteristics are presented in Fig. 2 and their distribution can be followed in the presented lithostratigraphic logs in Fig. 6A, B. Mudstone lithofacies (M1 and M2) dominate in both drill holes, with a slightly higher in drill hole ŽIDL-1, forming 69.7 % of the succession, compared to 66.7% in drill hole ŽIDL-2.

The relative proportion of other lithofacies significantly differs between the studied drill holes. The ŽIDL-1 drill hole is characterized by a low content of sandy facies (only 8.3 % of the profile and only S2 facies was recognized), a comparably higher content of limestone facies L (17.9 %), and presence of heterolithic facies (4.1 %). The ŽIDL-2 drill hole shows a comparably higher presence of sandy facies (S1, S2, S3; 22.0 % of the profile), lower content of facies L (11.4 %) and the absence of the heterolithic facies.

Interpretation: The highly abundant mudstone lithofacies reveal dominant deposition from suspension in relatively calm conditions. Variations in the content of sand, bioturbation, preservation of planar bedding and shell debris also reflect periods of a relatively higher input of material transported in traction (possibly by storm currents). Sandy lithofacies and their alternation with mudstone ones can be connected with deposition in the lower shoreface or a transitional zone to a deeper environment. The sharp bases of the beds, occurrence of transported limestone clasts, shell debris and planar lamination all support the role of an increased water energy. The absence of clear wavy structures could point to deposition below the normal wave base; we can speculate about a high energy coast possibly non barred. Heterolitic facies reflects the rapid alternation of clastic input into the depositional environment. The thick beds of limestone facies can be connected with the stable conditions of deposition and also with a severe reduction of clastic input. Thin limestone interbeds could also be connected with the erosion and redeposition of limestone into deeper environments (possibly from the impact of storms). The multiple alternation of relatively thin beds composed of mudstone, sandstone and limestone facies (especially in the ŽIDL-2 drill hole) are interpreted as cyclic changes of depositional conditions (possibly climatically driven). Repeated coarsening upward cycles in the successions with the transition from mudstone facies to sandstone and/or finally limestone can be interpreted as parasequences. The significantly stable conditions of deposition are presumed for the lower parts of the succession in the ŽIDL-1 drill hole.

4.2. Biostratigraphy

Four planktonic foraminiferal and calcareous nanoplankton bioevents were used for biostratigraphical correlation (Fig. 1B)

(1) *Praeorbulina circularis* occurs from the base to the top of both sedimentary successions

(2) The FO (i.e. First Occurrence) of *Orbulina suturalis* was recorded at the level 5.7-5.8 m of the ŽIDL-1 borehole, in the ŽIDL-2 borehole, *Orbulina suturalis* occurs from the base

(3) Neither *Globorotalia preamenardii* nor other younger index species were found.

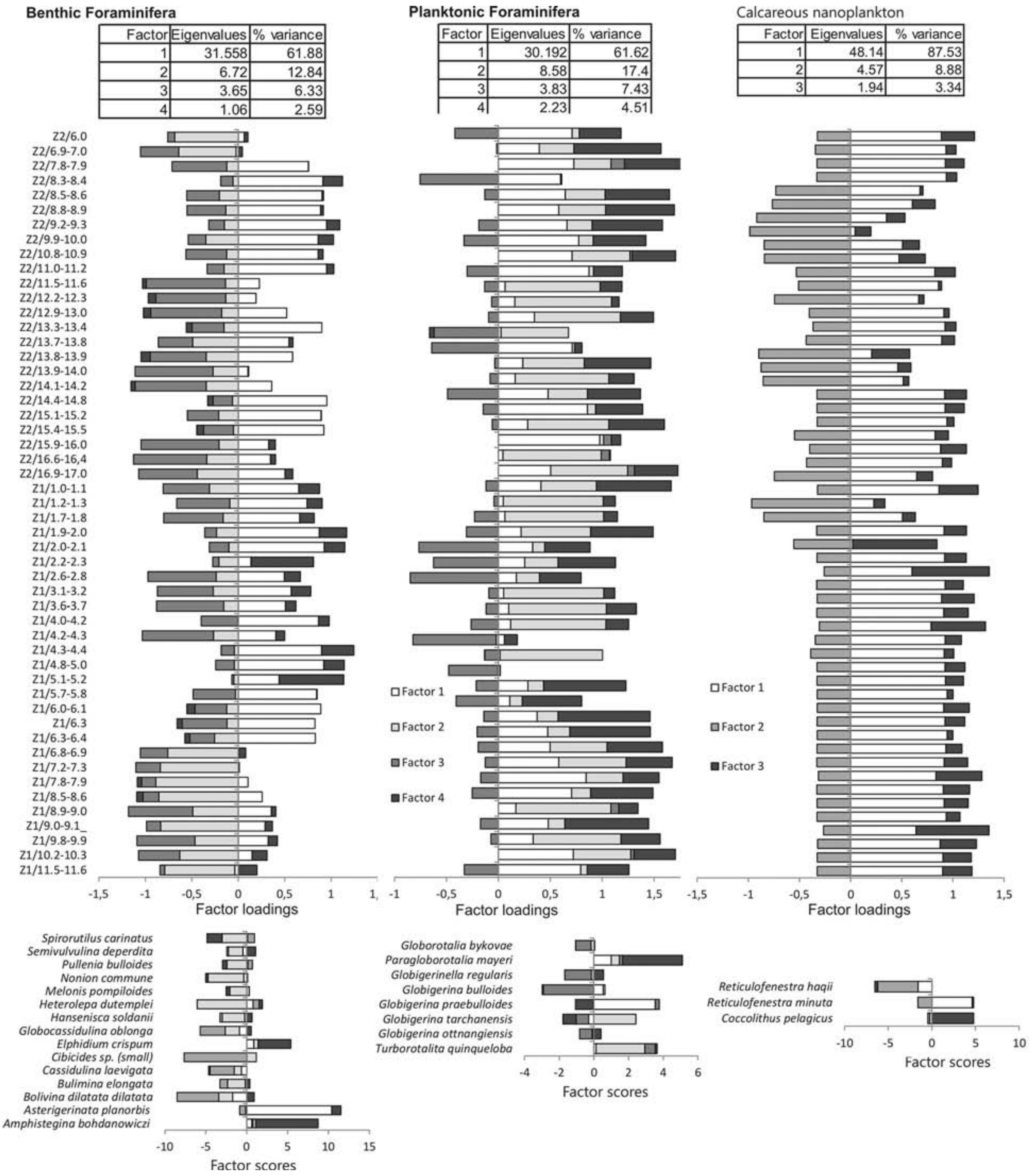
(4) *Sphenolithus heteromorphus* was recorded along the whole sedimentary succession;

(5) *Helicosphaera ampliaperta* as well as *Helicosphaera waltrans*, commonly and continuously occuring in underlying deposits, were not recorded

(6) *Uvigerina macrocarinata*, the marker of the regional Central Paratethyan substage (Moravian, Cicha et al. 1998), occurs from the base to the top of both sedimentary succesion

(7) Among molluscs, a characteristic Badenian taxon is *Costellamussiopecten spinulosus*.

The FO of the species "*Chlamys*" *trilirata* (ŽIDL-2) lies above the base of the Middle Miocene in Paratethys, and this species occurs only in the Lower and ?Middle Badenian (Mandic 2004). Some of the pec-



Benthic Foraminifera

Factor	Eigenvalues	% variance
1	31.558	61.88
2	6.72	12.84
3	3.65	6.33
4	1.06	2.59

Planktonic Foraminifera

Factor	Eigenvalues	% variance
1	30.192	61.62
2	8.58	17.4
3	3.83	7.43
4	2.23	4.51

Calcareous nanoplankton

Factor	Eigenvalues	% variance
1	48.14	87.53
2	4.57	8.88
3	1.94	3.34

Fig. 3. CABFAC Factor analysis (PAST softaware) of assemblages of benthic foraminifera, planktonic foraminifera and calcareous nannoplankton assemblages.

tinid species at Židlochovice also occur in the Grund Formation in the AlpineCarpathian Foredeep in Lower Austria (correlated with the Lower Lagenidae Zone – Mandic 2004). Only *Costellamussiopecten* cf. *spinulosus* – typical exclusively for the upper parts of the Lower Badenian (Upper Lagenidae Zone – Man-

Dic 2004) – is entirely absent in the Grund Formation, which indicates that the sediments at Židlochovice are slightly younger than the sediments of the Grund Formation (the situation is identical in Kralice nad Oslavou – Zágoršek et al. 2009).

Based on events (1) – (5), the ŽIDL-1 and 2 boreholes can be correlated with the upper part of the NN5 Zone of calcareous nannoplankton (Martini 1971) above the LO of *Helicosphaera waltrans* and the upper part of the M5 and lower part of the M6 zones of planktonic foraminifera (Berggren et al. 1995). According to the regional Central Paratethys chronostratigraphy (using also regional bioevents (6) and (7), the age of the sediments at Židlochovice can be interpreted as Badenian, more exactly as upper part of the Early Badenian (sensu Papp et al. 1978; Kováč et al. 2007) or upper part of Mid Badenian according to to the latest subdivision of the Badenian (Hohenegger et al. in press.).

4.3. Palaeobiology

4.3.1. Foraminifera and calcareous nannoplankton

Foraminiferal and calcareous nannoplankton assemblages (Appendices 1, 2) were statistically classified and results of CABFAC Factor analysis are presented in Fig. 3:
Assemblages of benthic foraminifera can be well characterized by four factors which explained 83.64 % of variance; the 5th and next factors explain each only less than 1.5 % of variance.

(B1) The “Epiphytic” Factor 1 dominated by *Asterigerinata planorbis* (4065%) may have alternated with *Elphidium* spp. – *Amphistegina* spp. Factor 4. Epiphytic species, which substantially dominated, allow to interpret a well-aerated environment of seagrass meadows. The assemblages often contain robust corroded and abraded tests of shallow water species (mainly *Elphidium* spp.) as well as foraminifera from different palaeoenvironments (e.g. *Uvigerina* spp., *Lenticulina* spp.) which indicates the postmortal transport of tests by bedload in a higherenergy environment and/or reworking of tests.

(B2) The “Highnutrient” Factor 2 with 30-55 % of *Pullenia bulloides, Nonion commune – Hansenisca soldanii, Melonis pompiloides, Heterolepa dutemplei* and biserial textulariids: these high nutrient markers (deep infauna, detrivore) indicate a high content of nutrients in the sediment.

(B3) The “*Cibicidoides* – lowoxic markers” Factor 3 is dominated by *Bolivina dilatata*, smallsized *Cibicidoides* sp., *Globocassidulina oblonga* and *Cassidulina* spp. (30-50 %). Foraminiferal tests are smallsized and well preserved. The association of lowoxic infaunal species along with opportunistic oxic species may indicate (i) seasonal changes in water circulation – stratification with hypoxic bottom environment change during the year to nonstratified well oxygenated water with a bloom of epifaunal suspension feeder, or (ii) hypoxia only in the sediment (lowoxic infauna: *Bolivina*, *Globocassidulina* and *Cassidulina* marker of phytodetritus supply). At the bottom, there is a well aerated environment with *Cibicidoides* sp. Generally, stress conditions can be expected.

Statistical classification of planktonic foraminifera by CABFAC Factor analysis is presented in Fig. 3. Four factors explained 90-94 % of variance, % of variance for the following factors does not exceed 2 %.

(P1) The smallsized *Globigerina* Factors 1 and 2 (Fourchambered *G. praebulloides* Factor 1 and *G. tarchanensis – Turborotalita quinqueloba* Factor 2) differs from the others in that its smallsized specimens. Relative abundances of fourchambered globigerinas reached values 15-35 % in samples with high factor loading of the Factor 1 while fivechambered globigerinids represent 50-80 % of assemblages with high factor loading of the Factor 2. The relative abundances of groups of five and fourchambered globigerinas negatively correlated (correlation coefficient 0.52). The both groups represent opportunistic, stresstolerant assemblages, isotopic studies (Holcová & Demeny 2012) indicate the bloom of this smallsized specimens to be probable after freshwater input. Fivechambered globigerinids can indicate cold nonstratified water (Rupp & Hohenegger 2008); while DiStefano et al. (2010) described these foraminifers under hypersaline conditions. Summarizing these interpretations, stress condition represented mainly by salinity oscillations can be expected for samples with high factor loadings of these factors. Dominance of fivechambered globigerinids may be accompanied with mixed watercolumn.

(P2) The *Globigerina bulloides* Factor 3 contains common largesized *Globigerina bulloides* and *Globigerinella regularis* (15-30 %) and characterized foraminiferal assemblages generally with low P/Bratio (to 20 %) and higher relative abundances of *Globigerinoides* spp. and orbulinas (5-15 %). The warmwater and oligotrophic species (*Globigerinella regularis*, *Globigerinoides* spp. and orbulinas) (Reynolds & Thunell 1985; Hemleben et al. 1989; Pujol & Vergnaud Grazzini 1995; Spezzaferri 1995; Bicchi et al. 2003; Rupp & Hohenegger 2008) co-occurred with eutrophic marker *Globigerina bulloides* (Reynolds & Thunell 1985; Hemleben et al. 1989) what may indicate the seasonal succession of different groups of plankton.

(P3) In samples with high factor loading of the *Paragloborotalia mayeri* Factor 4, 25-60 % of nominative species were recorded which can be accompanied by small-sized *Globigerina* ex gr. *praebulloides.* The co-occurrence of more eutrophic *Globigerina* spp. with rather oligotrophic and warmer water *Paragloborotalia* may indicate the succession of seasonal populations.

Calcareous nannoplankton assemblages can be excellently classified by 3 factors which represent 99-75 % of variance (Fig. 3):

(N1) *Reticulofenestra minuta* Factor 1 grouped assemblages with more than 80% of small sized *Reticulofenestra minuta* The small reticulofenestras are considered to be stress-tolerant taxa indicating stress characterized by quick changes within that environment, including the oscillation of salinity (Wade & Brown 2006) and nutrient content (Hallock 1987; Beaufort & Aubry 1992; Flores et al. 1997; Wells & Okada 1997; Bollmann et al. 1998; Kameo 2002).

(N2) The *Reticulofenestra haqii – R. minuta* Factor 2 (small to medium-sized *Reticulofenestra*) is characterized besides small *R. minuta* also by 5-15 % of specimens from *R. haqii* group (sensu Holcová 2012).

(N3) The *Coccolithus pelagicus – Reticulofenestra* spp. Factor 3 – is characterized by relative abundances of *Coccolithus pelagicus* over 15 % (15-45 %) The species is a traditional indicator of cold and nutrient-rich water (Okada & McIntyre 1979; Winter et al. 1994), but its common occurrence has also been recorded in waters of up to 18 °C, which can be used as a tracer of the periphery of areas of enhanced productivity (Cachao & Moita 2000).

4.3.2. Mollusca

The systematic and palaeoecological evaluation of molluscs is based on work by Bagdasaryan et al. (1966), Papp et al. (1978), Studencka (1986), Studencka et al. (1998), Schultz (2001), Mandic & Harzhauser (2003), and Mandic (2004).

Molluscs were present in all the studied samples of both boreholes. The mollusc fauna consist predominantly of bivalves; gastropods are less frequent. Small gastropods of the genera *Bittium*, *Alvania*, *Solariorbis*, *Gibbula*, or *Rissoina* were ascertained in some intervals of both boreholes: ŽIDL-1: 2.7-2.8 m, 5.5-5.6 m, 8.4-8.5 m, 10.1-10.2 m; ŽIDL-2: 8.1-8.2 m, 8.7-8.8 m, and 9.7-9.8 m.

The changing numbers of molluscan shells or their fragments in the individual samples generally reflect the changes in molluscan fauna abundance depending on the changing palaeoecological conditions, mostly the changes in water aeration.

In the basal part of ŽIDL-1, a low molluscan abundance was ascertained (up to 7.2-7.3 m). In the upper part, the amount of shells/fragments relatively increased (maximum in 3.7- 3.8 m). In the rest of the profile the amount of material varied. In the lower intervals of the ŽIDL-2 profile, there was a low amount of material (minimum in 15.9-16 m); in the upper part of the profile, a gradual increase (maximum in 10.8-10.9 m) was observed, followed by a subsequent decrease (the minimum at 8.7-8.8m).

Being an efficient active swimmer, *Costellamussiopecten* prefers deeper calm waters without strong currents and rather soft clay substrate (Bagdasaryan et al. 1966). "*Chlamys*" *trilirata* and *Aequipecten macrotis* belong to epibionts usually exhibiting byssal attachment to the substrate and needing primary and secondary hard substrates for shell attachment. They predominantly occur in rocky sublittoral environments (Mandic & Harzhauser 2003), namely in less exposed, deeper infralittoral (shallow subtidal) zones. *Cubitostrea digitalina* is typical for the highly exposed rocky medio/sublittoral (intertidal to shallow subtidal) to depths of 10 m (Mandic & Harzhauser 2003). At Židlochovice, the oysters occurred more or less continuously, but mostly in fragments. *Nuculana* and *Corbula* represent sediment or suspension feeders, shallowly burrowing into muddy bottoms of intertidal/subtidal to bathyal depths. *Nuculana* is adapted to stagnant waters with lower oxygen and higher hydrogen sulphide contents. *Corbula* is generally an opportunistic genus, optimally adapted to unstable conditions. The predominance of thin-shelled indeterminable bivalve fragments and small herbivore gastropods in most samples indicates a calmer sedimentary environment. The general presence of stenohaline bivalves and occasional brachiopods, together with the almost total absence of brackish and estuary elements, confirms a fully marine (~35 ‰) sedimentary environment.

Among the bivalves, suspension feeders dominate, confirming the environment to be rich in organic detritus and planktonic microorganisms. The small gastropods are mostly herbivores living in/on the algal vegetation on the bottom (seagrass meadows). The intervals with their presence can be – more or less – correlated with a general decrease of shells/fragment amounts, which can be interpreted as the consequence of probable temporary lower water aeration (decrease of O_2 /increase of H_2S content – stagnant water, ?greater depth).

4.3.3. Ostracoda

Fiftytwo ostracod taxa were identified from the ŽIDL-1 and ŽIDL-2 boreholes. The occurrence of "Gen. indet." *moravica* (*Heliocythere moravica* – paper in preparation) confirms the early Badenian age of the deposits (Papp et al. 1978; Seko et al. 2012). The sedimentation rate affects the postmortal disintegration of the carapace, and the increase of carapaces (valves/carapace ratio) toward the upper part of both boreholes might reflect an increase of the sedimentation rate (Oertli 1972). In the lower half of the ŽIDL-1 borehole, the amount of valves (33 to 301) is substantially higher than the amount of preserved carapaces (0 to 4). This ratio changes rapidly at a depth of 5.5-5.6 m, at which the carapaces once prevailed over valves (25:49). In the remaining samples (toward the top), an increase is still visible and remains stable with an average value of 35 % of the carapace (valve:carapace ratio) sample. A growing increase of carapaces (toward the top) is also observed in the ŽIDL-2 borehole. The maximum increase (39:104) occurs in the upper part 8-18.2 m (Seko et al. 2012).

Another remarkable change was observed at the depth of 5.5-5.6 m of the ŽIDL-1 borehole. A turnover in the assemblage composition indicates a transition between two marine habitats (Seko et al. 2012). In the lower part of the ŽIDL-1 borehole (12-7.2 m), we observed a higher amount of specimens like *Buntonia subulata subulata*, *Cytherella pestiensis postdenticulata*, *Henryhowella asperrima*, *Bosquetina carinella*, *Parakrithe dactylomorpha* and *Krithe* sp. which according to Gross (2006) are indicative of deeper circalittoral to epibathyal environments. On the contrary, the occurrence of epineritic *Cytheridea acuminata* (12-7.2 m; not only) could indicate a transition to an infraneritic environment, supported by the presence of epineritic to infraneritic *Aurila opaca*, *Cnestocythere lamelicosta*. There was a significant increase in specimens of *Aurila* species, *Cnestocythere lamellicosta*, *Loxocorniculum hastatum*, *Pokornyella deformis*, *Senesia philippi* and *Tenedocythere sulcatopunctata*, which prefer epineritic environments and tolerate a decrease in salinity (Gross 2006). The disappearance of circalittoral to epibathyal ostracods indicates the transition to shallow infrallitoral (5.6-0.9 m). In the assemblage of the ŽIDL-2 borehole, a decrease in the abundance of deeper circalittoral to epibathyal species (*Henryhowella asperrima*) is observed toward the top. Furthermore, indicators of a shallower palaeoenvironment (*Senesia philippi*) and infralittoral and phytal species (*Cnestocythete lamellicosta*) became dominant part of assemblage. In comparison to the ŽIDL-1 borehole, the change in species dominance and composition is not so significant. *Aurila* species dominate in the samples and in this parameter the assemblage of the ŽIDL-2 borehole is similar to the assemblage of the upper part of the ŽIDL-1 borehole (5.6-0.9 m), reflecting shallow infralittoral conditions (Seko et al. 2012).

The ostracod assemblages have been analysed according PSH Platycopids Signal Hypothesis (Whatley et al. 2003). The percentage of Platycopida is not higher then 11.5 %, indicating a well oxygenated palaeoenvironment (oxygen content ›5 ml/l; Whatley et al. 2003). This interpretation does not agree with foraminifera and mollusc assemblages which indicate a poorly oxygenated environment. This contradiction can be explained either by results of modern data, which unsupported PSH (Brandão & Horne 2009) or by seasonal variations of the oxygen content at the seafloor and in the sediment.

4.3.4. Bryozoa

Tomaštíková & Zágoršek (2012) identified 116 bryozoan taxa; 23 of them are mentioned for the first time in this locality. Bryozoans dominate in all the studied samples: cheilostomes represent almost 70 % (81 species), while only 35 species of cyclostomes were found. Among the determined bryozoan species, those from temperate and tropical environments dominate. Very common are *Metrarabdotos maleckii*, *Steginoporella cucullata*, *S. tuberculata* and *Adeonella polystomella*, characteristic for recent tropical seas (Moissette 1988).

Generally, the diverse bryozoan fauna indicate normal marine, temperate to subtropical environments. Based on bryozoan growth form analysis (according to

Hageman et al. 1997 and McKinney & Jackson 1989), shallow water prevails. The most common bryozoan colonial growth forms are erect; encrusting growth forms are less abundant. There were only two reteporiforms and no free living growth forms were found. The absolute number of species of entire growth form depends on the preservation (Zágoršek et al. 2012a). However, the oscillation in the ratio between erect and encrusting forms in the same sedimentary succession may indicate changes in the environment. In the lower part of the ŽIDL-1 borehole, palaeoecological analyses based on the evaluation of the ratio between erect and encrusting bryozoans indicate lower temperatures at the sea bottom because of greater water depth (80-100 m), thus resulting in a large amount of erect bryozoans. In higher parts of the ŽIDL-1 and ŽIDL-2 profiles, minor differences in the ratio of both growth types confirm a relatively stable, rather shallow and warm sea environment with estimated depth about 20-30 m (as similarly interpreted also in Přemyslovice see Zágoršek et al. 2012b).

The lower part of the ŽIDL-2 borehole (a depth of 17-15.7 m) shows a remarkably large proportion of erect bryozoan growth forms, the largest being at a depth of 16 m (19 erect and only 4 encrusting species were identified). The increase in the proportion of erect growth forms may indicate an increase of depth and therefore a decrease of temperature at the sea floor, which is comparable to the interval of the ŽIDL-1 borehole at the depth of 9.3 m.

In the following sequences, the ratio between the erect and encrusting bryozoan growth forms gets closer: at the depth of 12.8 m it is almost the same (26/24), showing what is probably the shallowest environment and therefore the warmest water in the studied sedimentary succesion, comparable to those at the depth of 3.8 m in the ŽIDL-1 borehole.

In samples from depths of 7.3 m in ŽIDL-1 and 10.9 m in ŽIDL-2, the total number of species rapidly decreased. This may indicate an unsuitable environment; probably the increase of water energy also corresponds to a higher amount of reteporiforms bryozoans in these samples. The second event is represented by samples at 3.8 m in ŽIDL-1 and 9.8 m in ŽIDL-2, where the diversity of the bryozoan community is the highest. These samples may be interpreted as bryozoan events comparable with those described by Zágoršek (2010b) from other sections of the Carpathian Foredeep.

Summarizing, the lowest part of the studied sedimentary succesion (the lower part of the ŽIDL-1 borehole culminating at 9.3 m) represents a deeper and therefore cooler environment similar to those described for example from Korytnica (Zágoršek et al. 2012a) than the rest of the profile. Conversely, the younger part (the upper part of the ŽIDL-2 borehole culminating at 12.8 m) indicates the shallowest and warmest environment similar to those reported from Přemyslovice (Zágoršek et al. 2012a) in comparison with the rest of the profile.

4.3.5. Brachiopoda

Brachiopods have been studied for the first time (Pavézková et al., in press) at Židlochovice. There were 4 species identified, all from the family Megathyrididae, namely *Argyrotheca cuneata*, *Argyrotheca* sp., *Joania* sp., and *Megathiris detruncata*. In both boreholes, brachiopods occur in negligible amounts, although *Argyrotheca* cuneata is relatively the most numerous species. All species recognized in Židlochovice are generally common in the Miocene sediments of the Central Paratethys. Extant representatives of Megathyrididae are mostly shallow water species, exhibiting a cryptic mode of life (Logan 1979). The occurrence of brachiopods at Židlochovice – in spite of their scarcity – significantly supplements not only total spectrum of Badenian fauna from this locality, but also mosaic of Badenian brachiopod occurrences in the Carpathian Foredeep on the territory of the Czech Republic.

4.3.6. Ichthyofauna

Ichthyofauna was represented intermittently by otoliths (14 species) and singularly by the isolated teeth (1 species) of teleosts and sharks (1 species) in both boreholes. Due to poor taxonomic representation in the small size of samples from the boreholes, the results are approximate.

The ŽIDL-1 borehole shows the occurrence of otoliths of mesopelagic fishes such as *Valenciennellus tripunctulatus*, *Diaphus acutirostrum*, *D. cahuzaci*, *D. regani* and *Notoscopelus mediterraneus* throughout the section accompanied by teeth of the bathypelagic shark *Deania* sp. at 2.8-3.0 m. Such an assemblage is indicative of the deepest sublittoral with good communication with mesopelagic environments (BrzoBohaty 1997). Picture deviation from this trend only occurs at 10.6-10.8 m, where shallow water taxa such as *Lesueurigobius* ex gr. *vicinalis* and maybe even a juvenile specimen of Acropomatidae indet. are present, possibly indicating an episodic shallowing of the environment. This also seems to be in accordance

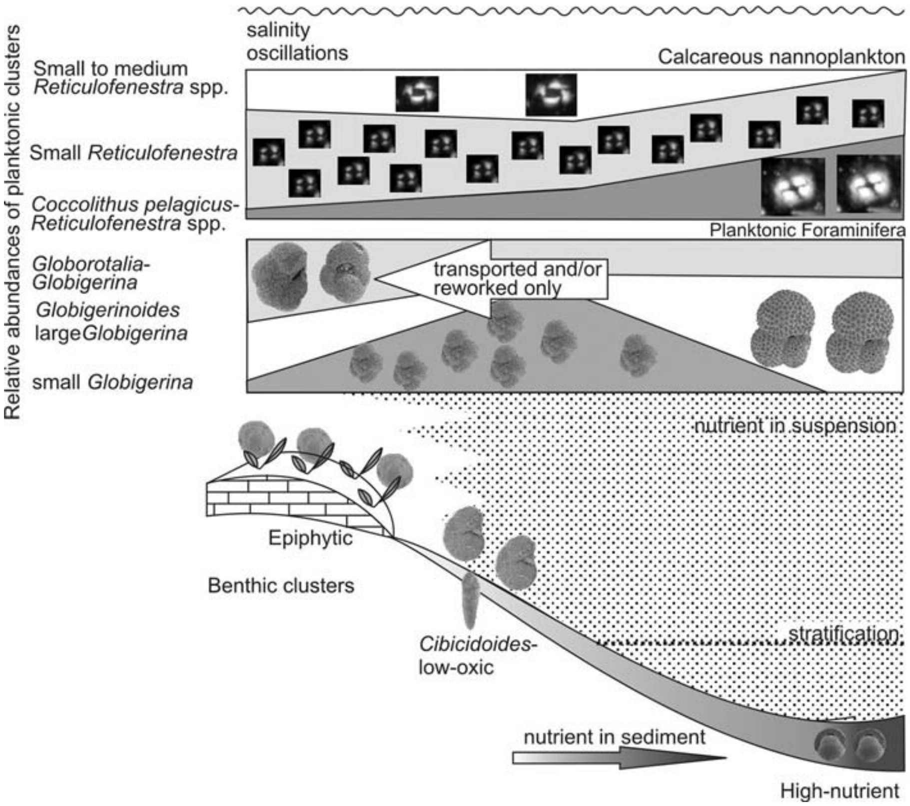


Fig. 4. Co-occurrence of foraminiferal and calcareous nannoplankton clusters (Fig. 3) and their schematized position in the basin.

with the numerous gypsum fragments in the washed residuum from this level.

Mesopelagic fish otoliths persist in the lower part of the ŽIDL-2 borehole, where epimesopelagic *Vinciguerria poweriae*, *Benthosema fitchi* and *Diaphus* div. sp. dominate. At the same time, some sublittoral elements (*Brachydeuterus*, Gobiidae) occur. The upper part is characterised by sublittoral elements – teeth of sparids, otoliths of juvenile gobiids and mere fragments of juvenile mesopelagic diaphids.

Taking into account the original palaeobathymetric analyses based on otoliths from the Židlochovice brickyard, the deepest environment in the bottom part of the original loam pit (150-250 m, Brzobohatý 1997) was clearly indicated by adult otoliths of the nonmigrating bathydemersal macrourid *Trachyrincus scabrus*. To the top of the whole Židlochovice section, the fish fauna reflects a general shallowing from the shallow bathyal/deeper circa-littoral to the shallow sublittoral. The ichthyofauna in the whole section indicates normal salinity.

4.3.7. Red algae and microfacies

Red-algal limestone consists of coralline algae (12.5-57.7 %) and bryozoans (1.9-38.3 %). Other determined components (foraminifers, echinoids, polychaetes, molluscs), if present at all, represent less than 3 %. However, the volume of unrecognized fragments in some samples is 0.5-51 %. Lithoclasts can constitute 0.18-2 %. Micrite is always present in 2.25-3 % and sparite forms in 0.14-8 %. The limestone is of low porosity (0.2-5 %).

Samples can be classified as coralline algal and coralline algal – bryozoans microfacies. Composition of samples with respect to the identified facies is given in Appendix 6. The growth forms of the coralline algae are monospecific protuberant rhodoliths, multispecific rhodoliths with the nucleus of fragments of other frequently protuberant corallines, simple abraded protuberances and the debris of them. Rhodoliths are mostly found in fine biogenic sandy matrices rich in micrite. On the contrary, protuberances are usually

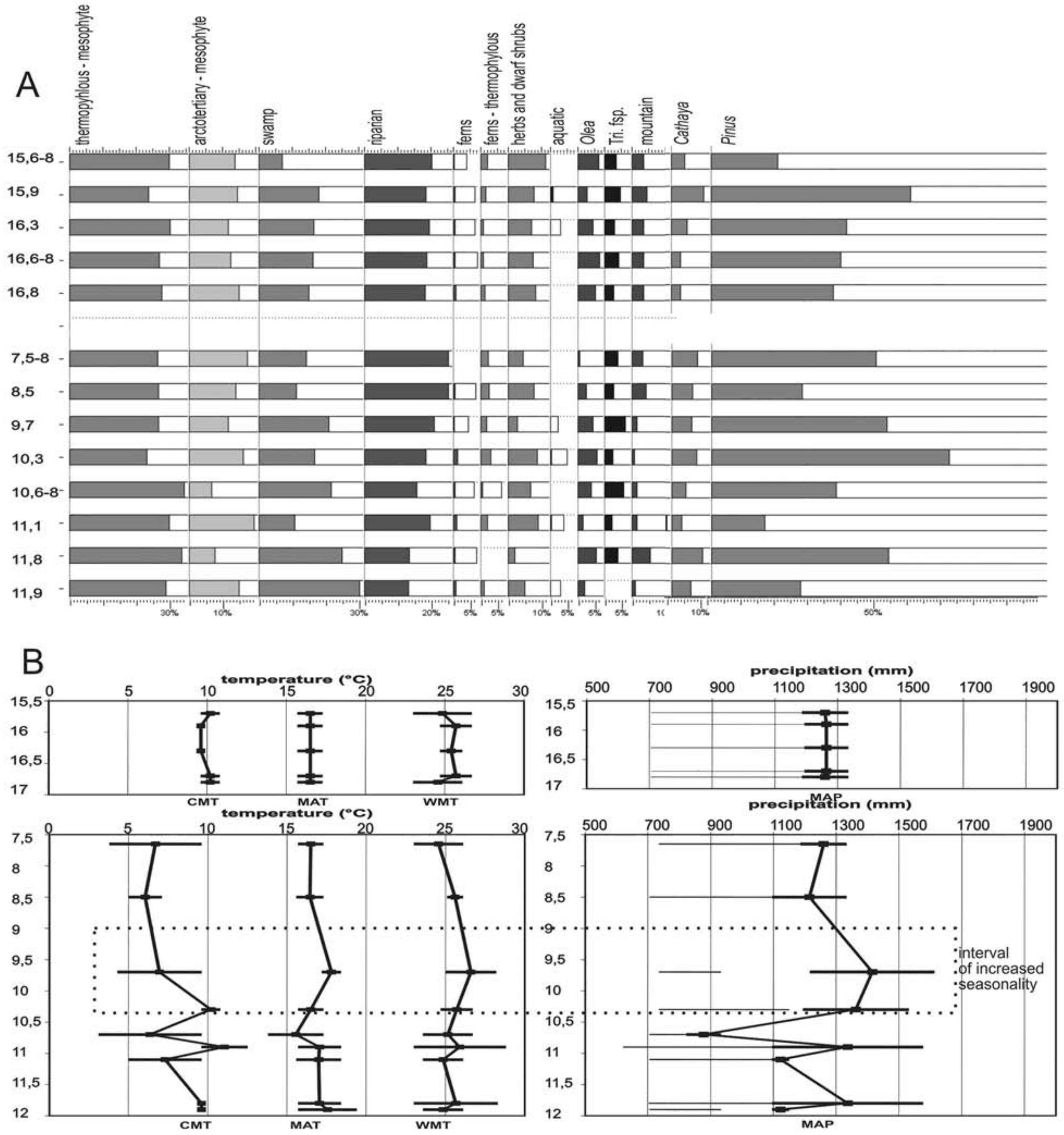


Fig. 5. Pollen diagram (**A**) arranged after paleoecological groups: left side – pollen sum (100%) excluding conifers, the right side proportion of *Pinus* and *Cathaya* (100% all grains).
Zidlochovice CA palaeoclimate data (**B**): Temperatures: MAT- mean annual temperature, CMT- temperature of the coldest month, WMT- temperature of the warmest month. Precipitation: MAP- mean annual precipitation, thick line segments: all taxa, thin line segment: wet taxa excluded.

accompanied by lithoclasts.

Although coralline algal assemblages consist of six genera: *Lithothamnion*, *Mesophyllum*, *Phymatolithon*, *Lithophyllum*, *Spongites* and *Sporolithon*, the first two mentioned dominate in the assemblage. It can be concluded that the algae of the subfamily Melobesioideae predominate over the subfamilies of Lithophylloideae, Mastophoroideae and Sporolithoideae in all samples. This assemblage is frequent in nontropical marine environments (Aguirre et al. 2000). Although coralline algae species descriptions are beyond the scope of this paper, it should be noted that *Phymatolithon calcareum* (Pallas) Adey & McKibbin was observed by as monospecific abraded protuberances as well as crusts in multispecific rhodoliths.

According to the presented data, three limestone facies can be evaluated. First, rhodolith floatstone (RFgm) in a grainstone matrix consists of multispecific and monospecific rhodoliths floating in a fine-grained biogenic sandy matrix (ŽIDL-1, 6.3 m). Lithoclasts are present as low amounts values or are absent. These facies indicate deposition in the outer shelf environment with evidence of storms events (Flügel 2004).

Second, coralline algal detritus limestone (CAdl) consists of abraded protuberances; however, few multispecific rhodoliths are present (ŽIDL-1: 4.5-5 m, ŽIDL-2: 10.6 m and 13.3 m). Facies correspond to coralline algal grainstone and to lithoclastic coralline algal limestone. Other components are lithoclasts, unsorted allochems, sparite, and micrite. The facies indicate an environment of middle to inner shelf, with higher terrigenous input (Flügel 2004). *P. calcareum* indicates a depth of 36-93 m (Basso 1998).

Third, bioclastic breccias (Bbr) consist of angular fragments of rhodoliths and molluscs (ŽIDL-2, 9.6 m). The matrix is mainly micritic, without lithoclasts or mediumsized allochems.

The limestone facies successions thus indicate changes of depositional environment in the drill cores. The transition from rhodolith floatstone to coralline algal detritus limestone from the ŽIDL-1 interval of 6-34.5 m indicates the shallowing of the environment.

4.3.8. Palynology

The most diversified pollen spectra have been found in environments with reduced oxygen content (ŽIDL-1: 11.9-7.5 m and ŽIDL-2: 16.81-5.6 m), also evident as cubic caves where there were pyrite crystals in the pollen grains. The overdominance of conifers and frequent dinoflagellates with a very small amount of other pollen and spores were observed in ŽIDL-1 at 76 m and in ŽIDL-2 at 15.26 m. The remaining samples were sterile or very poor in palynomorphs.

A mainly subtropical character of flora was interpreted (Fig. 5). Three zonal forest formations were spread around the basin. Subtropical Broadleaved forests comprised up to 30 % of the evergreen elements (100 % without *Pinus*, *Cathaya*): including Sapotaceae, *Engelhardia*, *Platycarya*, evergreen Fagaceae – *Castanopsis*, *Trigonobalanopsis*, morphotypes *Tricolporopollenites henrici*, *T. microhenrici*, *Tricolporopollenites liblarensis*, *Reevesia*, *Cornus*/*Mastixia*, Rutaceae and Araliaceae, Pteridaceae (Fig. 5A). Proportions of most thermophilous elements of P1 sensu Stuchlik et al. (1994) were slightly lower in comparison with the Lower Miocene palynospectra of the CF (Doláková et al. 1999, 2011; Doláková & Slamková 2003; Kováčová et al. 2011).The share of deciduous woody elements resulting in warm temperate Mixed Mesophytic and Broadleaved Deciduous forest types (i.e. *Quercus*, *Carya*, *Celtis*, *Juglans*, *Tilia*, *Betula*, *Acer*) was lower in all the studied samples (to a maximum of 17 %). A higher diversity of “oak type” pollen grains (e.g., *Quercus robur*/*pubecscens*) has been recorded in comparison with the Lower Miocene sediments from CF (Doláková et al. 1999; Kováčová et al. 2011).

The fluctuation of coastal swamp (Taxodiaceae, Cyrillaceae, Myricaceae) and riparian elements (*Ulmus*, *Fraxinus*, *Liquidambar*, less generous *Alnus*, *Salix*, Lythraceae) could be as a result of humidity changes (our interpretation). Pollen grains of *Platanus* represent a marked component of the pollen spectra. Herbs and heliophilous elements such as Poaceae, Asteraceae, Caryophyllaceae, Chenopodiaceae and Ericaceae are consistently present. *Urtica*, *Plantago*, *Thalictrum*, *Salvia*, *Lavandula* and *Ephedra* have been recorded locally. The sporadic occurrence of *Botryococcus* and the pollen of the aquatic coastal plants *Sparganium*, *Potamogeton and Nymphaea* indicate freshwater inflow in some facies.

Frequent various Pinaceae (*Pinus*, *Cathaya*) were components of mountain coniferrich forest (with the admixture of *Cedrus*, *Tsuga*, and *Picea* in higher altitudes) and along with *Sciadopitys* they were also a part of the intrazonal lowland formations.

The development of the main climatic characteristic is expressed in the graphs of the Coexistence Approach (Fig. 5B). The general climatic conditions are in accordance with Bruch et al. (2004). Warm wet conditions can be observed in the lowest interval of the studied sequence (ŽIDL-1: 11.9-10.6 m). The seasonality increases in the middle part of ŽIDL-1 (with well expressed seasonality of precipitation – the driest month ~2040 mm; the wettest month 200-250 mm); this is followed by a cooler phase evident from the upper part of ŽIDL-1. A slightly increasing portion of arctotertiary elements is also visible from

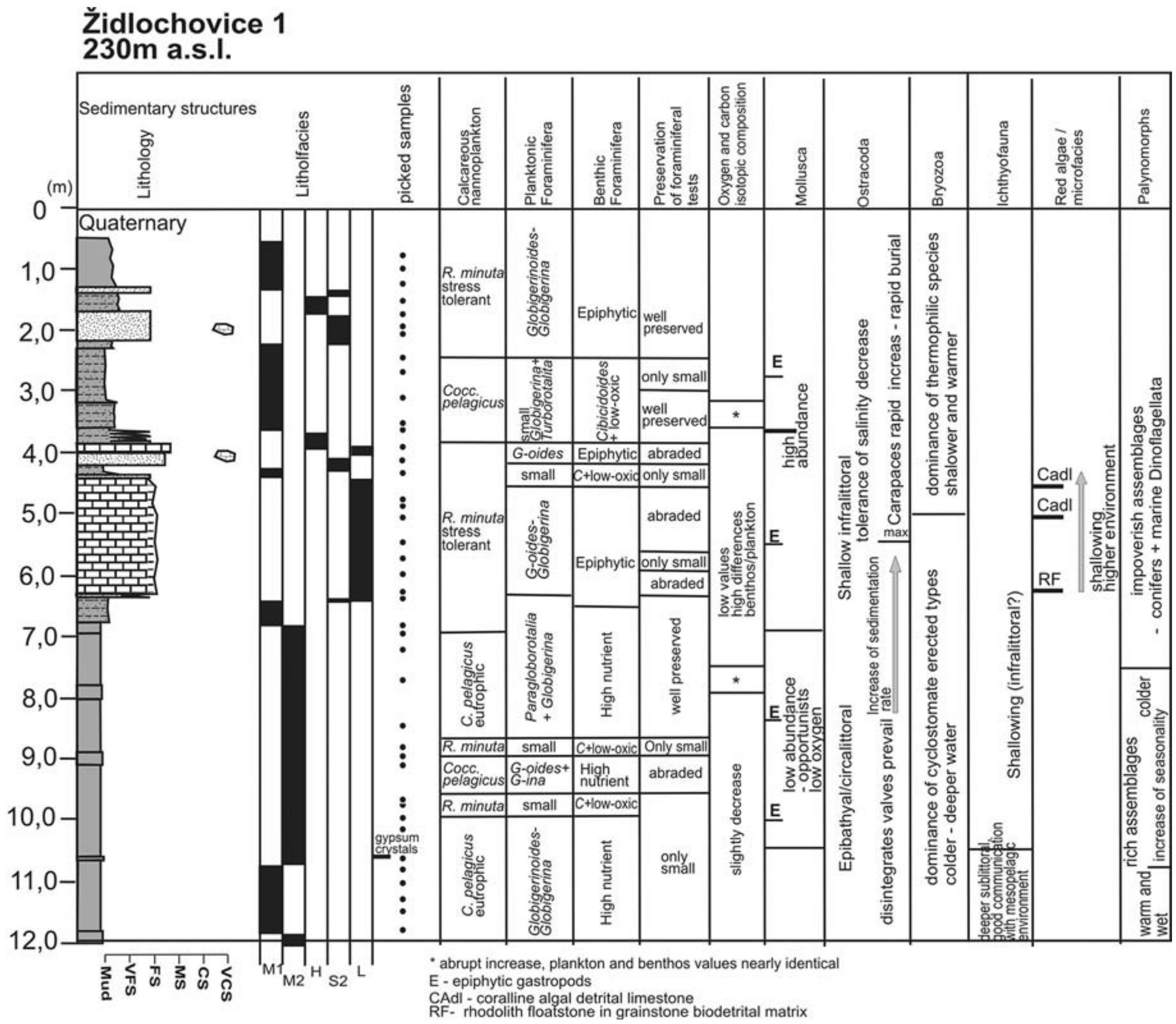


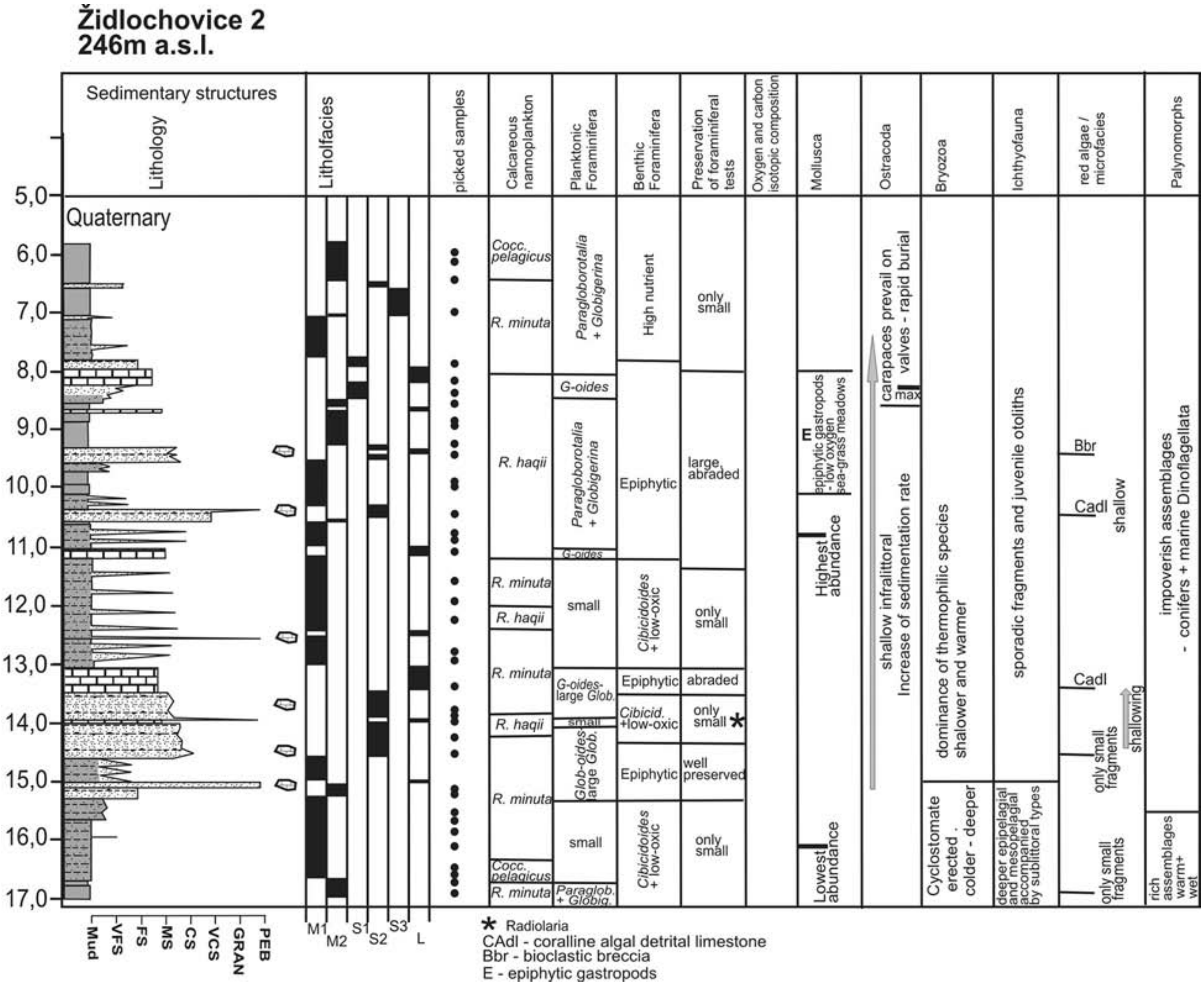
Fig. 6. A, B – Correlation of bioevents an lithology within studied groups of fossils. a) ŽIDL-1. b) ŽIDL 2. Cadl: coralline algal detrital limestone, Carg: coralline algal branch rudstone to floadstone and grainstone, RF: rhodolith floatstone in grainstone biodetrital matrix, E: epiphytic gastropods.

the palynograph (Fig. 5A). The repeating of warm wet conditions is recorded in the lowest part of ŽIDL-2: 16.8-15.7 m.

5. Discussion

5.1. Age

The dating of global biostratigraphical events recorded in the studied succession differs in the world's oceans (Gradstein et al. 2012) from that of the Mediterranean area (Abdul Aziz et al. 2008; Di Stefano et al. 2008; Hüsing et al. 2010). The differences are summarized in Fig. 1B. Due to the communication of the Central Paratethyan Sea with the Mediterranean, the correlation of bioevent timing with the Mediterranean dates is rather probable. The succession of the guide bioevents – the LO of *Helicosphaera ampliaperta* which precedes the FO of *Orbulina suturalis* – agrees with the Mediterranean area. However, co-occurrence of the *Helicosphaera waltrans* and *Orbulina suturalis* described from the Mediterranean was not recorded in the faciostratotype at Židlochovice. This discrepancy caused that lower boundary of studied succession can be dated only approximately: (i) in case of later appearance of *Orbulina suturalis* in the study area, the age of this boundary must be younger than 14.36 Ma (= the LO of *Helicosphaera waltrans*); (ii) more probably age ranges between 14.91 Ma (= the LO of *Heli-*



cosphaera ampliaperta) and c. 14.5-14.6 Ma (= FO of *Orbulina suturalis* in Mediterranean area). The upper boundary is older than the FO of *Globorotalia praemenardii* which is dated in the Mediterranean area to 13.92 Ma (DiStefano et al. 2008).

5.2. Climate

The changing of warm wet conditions, seasonality increases and a cooler phase within the main subtropical character of terrestrial flora could represent the final phase of the Miocene Climatic Optimum Böhme (2003), Utescher et al. (2000), Bruch et al. (2010). Decreasing of the most thermophilous elements in comparison with the Lower Miocene palynospectra of the CF, higher diversity of "oak type" pollen grains and evidence of the NS oriented climatically dependent gradient (Doláková et al. 1999; Doláková et al. 2008; Kováčová et al. 2011; Doláková & Kováčová, in prep.) indicate the beginning of the Middle Miocene Climatic Transition (14.8-12.0 Ma) (Flower & Kennett 1994, see also Harzhauser et al. 2011).

The overdominance of conifers was similarly found in some other pollen spectra from CF from the NN5 zone (e.g. Oslavany, Rebešovice). From palaeoecological point of view, this can be caused for several reasons: the morphology of the land (sandy dunes or mountainous areas), huge pollen production and the great amount of air transport. Accumulation in marine sediments distant from the seashore and greater resistance to oxygenation could also play a role (Heusser 1978, Hopkins & McCarthy 2002). This interpretation is supported by the synchronously plentiful occurrence of dinoflagellates.

5.3. Marine environment

The co-occurrence of calcareous nannoplankton and foraminiferal assemblages distinguished by factor analysis in the samples made it possible to compile the model of marine environment (Fig. 4):

(1) The highnutrient benthic foraminiferal assemblages accompanied by the calcareaous nannoplankton assemblages with higher abundances of *Coccolithus pelagicus* represent the deepest water assemblages recorded only in mudstone. As *Coccolithus pelagicus* is a marker of eutrophic waters, it agrees with the expected high amount of nutrients in the sediment; The "*Cibicidoides* – lowoxic marker" Factor cooccurs mainly with the planktonic assemblages dominated by small fivechambered globigerinids. Both assemblages tolerate unstable, stress conditions (oscillations of salinity and/or nutrient supply). Cooccurrence with *Turborotalita quinqueloba* may indicate mixed water column.

(2) The epiphytic foraminifera represent the shallowest environment with seagrass meadows recorded mainly with the *Reticulofenestra minuta* and with all planktonic foraminifera assemblages. Because epiphytic foraminifers indicate shallow water sea (depth in the first tens of meters, Murray 2006), the postmortem transport of planktonic foraminifera by superficial currents and/or the reworking of plankton is expected, which agrees with the variegated planktonic assemblages. Horizons with smallsized foraminiferal tests within the limestone body (4-6 m of ŽIDL-1 borehole) indicate a sizesorting of tests due to transport in suspensions (i.e. storms) or in flows. The epiphytic foraminifera occur in limestone and sand.

The distribution of fossil assemblages along the studied sedimentary successions (Fig. 6A, B shows the alternation of three main types of palaeoenvironments:
(1) The interval below the FO of *Orbulina* (below 6.8 m of the ŽIDL-1 borehole) can be characterized by mudstone lithofacies deposited from suspension in relatively calm conditions. Rich benthic foraminiferal assemblages with a higher abundance of infauna, a high nutrient marker including elongate biserial textulariids (mainly *Spiroplectinella*) indicate a rich source of nutrients in the sediment; all these species are detrivores; the majority of them can tolerate a decrease of oxygen content in accord with the presence of Mollusca. The higher abundance of *Coccolithus pelagicus* in the calcareous nannoplankton assemblages also indicates a higher nutrient source for primary producers. On the other hand, the oligotrophic planktonic foraminifera indicate episodical stratification. Episodic increase of *Spiroplectinella* abundance (above 5 %) imply that this event depend on specific palaeoecological conditions (? supply of specific nutrients) and cannot be isochronous biostratigraphical zone (*Spiroplectammina* Zone sensu Grill 1941). The predominance of Ostracoda valves indicates a slow sedimentation rate. Ostracoda, Bryozoa, molluscs and fish otoliths and teeth indicate a deeper environment. There is a decrease of oxygen caused by the absence of algae and other organic material creating a suitable surface for encrusting bryozoans. Ichthyofauna proved to have good communication with the mesopelagic environment. Diversified terrestrial vegetation with up to 30 % of broadleaved evergreen and thermophylous elements, a lower proportion of deciduous woody taxa of zonal angiosperms and swamp, and riparian and heliophylous azonal taxons were observed in the pollen spectra. The changing of the warm wet conditions, seasonality increases, and cooler phase were recognized. The deepest environment in the bottom part of the original loam pit of the Židlochovice brickyard (150-250 m, Brzobohatý 1997) was documented.

At the levels of 9.8 m and 8.9 m, the shortterm deviation from a fully marine environment are suggested by elevated levels of stresstolerant foraminifera and rare opportunistic mollusc assemblages. The postmortal transport of foraminiferal tests is very probable, which also confirms the sedimentological record with variations in the content of sand, bioturbation, preservation of planar bedding and shell debris, reflecting periods of higher input of material transported by current in traction (possibly during storms). The seasonality increase followed by beginning of the cooler phase were recorded in pollen spectra.

(2) The upper interval with *Orbulina* is characterized by a variegated palaeoenvironment with rapid alternations of lithofacies. Generally, two horizons can be distinguished:
(2a) Thick beds of limestone can be connected with stable conditions of deposition and with the reduction of clastic input. Epiphytic foraminifera as well as phytal ostracoda and epiphytic gastropods indicate the occurrence of seagrass meadows. Abraded and corroded tests reflect a high-energy environment around the wave base and shallowing. Limestone with red algae is present. Ostracoda, Bryozoa, molluscs and fish otoliths and teeth indicate shallow water conditions. The

increased ratio of Ostracoda valves/carapaces indicates the rapid burial of shells, or the general increase in the depositional rate; this could also be caused by rapid episodic sedimentation after intensive episodic rainfalls.

Palynomorphs, when present, are marked by the dominance of conifers and marine Dinoflagellata. These accumulations (similar to some others of the same age in the CF – Oslavany, Rebešovice) may be caused for palaeoecologic or taphonomic reasons.

(2b) Sandy lithofacies and their alternation with mudstone and thin limestone interbeds were deposited in a higher flow regime. The absence of clear wavy structures points to deposition below the normal wave base. Heterolitic facies support the rapid alternation of clastic input in the depositional environment. Thin limestone interbeds could also be connected with erosion and the redeposition of limestone into a deeper environment (possibly as a result of storms). These lithofacies mainly contain opportunistic small-sized *Cibicidoides* and the lowoxic markers indicate the instability of the environment, the coexistence of oxiphylic taxa at the seafloor, and lowoxic conditions in the sediment, or seasonal changes of oxygen content at the seafloor due to the seasonal stratification of the water column. Common *Globocassidulina* and *Cassidulina* is considered to be a marker of phytodetritus input, which may be seasonal. Palynospectra are mostly impoverished (such as in 2a). Only at the interval of 15.6-16.8 m from ŽIDL-2 there were well diversified pollen and spores indicating warm wet conditions.

6. Conclusions

1) Two shallow boreholes recording 26 m of sediment were drilled in 2010 on the Badenian parastratotype at Židlochovice (Carpathian Foredeep, NN5 Zone, Czech Republic). In comparison with the original definition of the parastratotype:

– The sedimentary succession was studied using sedimentological and palaeontological methods.

– All systematic groups were newly reworked (calcareous nannoplankton, Foraminifera, Ostracoda, Mollusca, Teleostei except Anthozoa and Echinoidea), or extended (red algae, Bryozoa, Brachiopoda, Elasmobranchii, pollen grains); detailed quantitative study was used.

– The environment of sedimentation and its development over time was newly interpreted.

– The stratigraphical position of the parastratotype was stated more precisely.

2) Biostratigraphical dating of the sedimentary succession enabled a correlation with the NN5 Zone 14.9 to 13.9 Ma, namely with the initial time of the Middle Miocene Climatic Transition.

3) Seven lithofacies were recognised within the sedimentary succession representing multiple alternations of mudstone, sandstone and limestone facies. The fauna generally indicated a normal marine, warm to subtropical environment. Individual groups of fauna and flora confirm what appears to be a generally shallowing trend from the bottom (epibathyal/circalittoral) to the top (shallow infralittoral) of the sedimentary succession with repeated palaeobathymetric changes in both boreholes. Though influence of local tectonic movements is expected, the general shallowing may be correlated with regressive phase of the TB 2.4 cycle dated on 14.2-13.6 Ma (Hardenbol et al. 1988).

A mainly subtropical character of terrestrial flora within warm wet conditions, seasonality increases and a cooler phase were observed.

The most significant event correlable with the FO of *Orbulina* (c. 14.5-14.6 Ma) is the abrupt change from mudstone deposited in the calm palaeoenvironment of upper bathyal/circalittoral to the variegated deposits of shallow water.

The lower interval below the FO of *Orbulina* can be characterized by mudstone facies and significantly stable conditions of deposition, high nutrient input and a decrease of oxygen content at the seafloor and/or in sediment. Episodical stratification of the water column is probable. Interval cooling and an increase of seasonality were recorded.

Based on FO of *Orbulina,* shallowing connected with a higher flow regime and a higher sedimentation rate are supported. The alternation of thick redalgal limestone bodies (a stable shallow palaeoenvironment with low terrigenous input and seagrass meadows) and variegated sandstone, mudstone and limestone interbeds of an unstable deeper environment could reflect orbitally-forced climatic cyclicity.

Acknowledgements

The research is supported by the Grant Project 205/09/0103 (Grant Agency of the Czech Republic) and MSM0021620855. We are grateful to the native speaker lector Mrs. Sarka Rousava for correction of the English language. Milos Bartol, Patrick Grunert and Mathias Harzhauser are gratefully acknowledged for valuable remarks and comments in their reviews, and Günter Schweigert for his help with the editorial arrangement.

References

Abdul Aziz, H.A., Di Stefano, L.M., Foresi, F.J., Hilgen, S.M., Iaccarino, K.F., Kuiper, F., Lirer, G., Salvatorini, A. & Turco, E. (2008): Integrated stratigraphy and 40Ar/39Ar chronology of early Middle Miocene sediments from DSDP Leg 42A, Site 372 (Western Mediterranean). – Palaeogeography, Palaeoclimatology, Palaeoecology, **257**: 123-138.

Aguirre, J., Riding, R. & Braga, J.C. (2000): Diversity of coralline red algae: origination and extinction patterns from the Early Cretaceous to the Pleistocene. – Paleobiology, **26**: 651-667.

Bagdasaryan, K.G., Tatishvili, K.G., Kazachashvili, Z.R., Muschelishvili, L.V., Badzoshvili, C.I., Achvelidiani, E.G., Zhgenti, E.M., Taktakishvili, I.G. & Kvalishvili, G.A. (1966): Spravochnik po ekologii morskich dvustvorok. – 353 pp.; Moscow (Nauka).

Basso, D. (1998): Deep rhodolith distribution in the pontian Islands, Italy: A model for the paleoecology of a temperate sea. – Palaeogeography, Palaeoclimatology, Palaeoecology, **137**: 173-187.

Beaufort, L. & Aubry, M.P. (1992): Palaeoceanographic implications of a 17 m.y. long record of highlatitude Miocene calcareous nannoplankton fluctuations. – Proceedings of the Ocean Drilling Program, Scientific Results, **120**: 530-549.

Berggren, W.A., Kent, D.V., Swisher III, C.C. & Aubry, M.P. (1995): A revised cenozoic geochronology and chronostratigraphy. – In: Berggren, W.A., Kent, D.V., Bicchi, E., Ferrero, E. & Gonera, M. (2003): Palaeoclimatic interpretation based on Middle Miocene planktonic Foraminifera: the Silesia Basin (Paratethys) and Monferrato (Tethys) records. – Palaeogeography, Palaeoclimatology, Palaeoecology, **196**: 265-303.

Böhme, M. (2003): Miocene Climatic Optimum: evidence from Lower Vertebrates of Central Europe. – Palaeogeography, Palaeoclimatology, Palaeoecology, **195**: 389-401.

Bollmann, J., Baumann, K.H. & Thierstein, H.R. (1998): Global dominance of *Gephyrocapsa* coccoliths in the late Pleistocene: Selective dissolution, evolution, or global environmental change? – Paleoceanography, **13**: 517-529.

Braga, J.C., Bosence, D.W.J. & Steneck, R.S. (1993): New anatomical characters in fossil coralline algae and their taxonomic implications. – Palaeontology, **36** (3): 535-547.

Brandão, N.S. & Horne, J.D. (2009): The Platycopid Signal of oxygen depletion in the ocean: A critical evaluation of the evidence from modern ostracod biology, ecology and depth distribution. – Palaeogeography, Palaeoclimatology, Palaeoecology, **283**: 126-133.

Bruch, A.A., Utescher, T., Alcade Olivares, C., Dolakova, N., Ivanov, D. & Mosbrugger, V. (2004): Middle and Late Miocene spatial temperature patterns and gradients in Europe – preliminary results based on paleobotanical climate reconstructions. – Courier Forschungsinstitut Senckenberg, **249**: 15-27.

Bruch, A.A., Utescher, T., Mosbrugger, V. & NECLIME Members (2010): Precipitation patterns in the Miocene of Central Europe and the development of continentality. – Palaeogeography, Palaeoclimatology, Palaeoecology, **304**: 202-211.

Brzobohatý, R. (1997): Paleobathymetrie spodního badenu karpatské předhlubně na Moravě z pohledu otolitových faun. – In: Hladilová, Š. (Ed.): Sborník příspěvků: Dynamika vztahů marinního a kontinentálního prostředí, Grantový projekt 205/95/1211, 3745, MU Brno.

Cachao, M. & Moita, M.T. (2000): Coccolithus pelagicus, a productivity proxy related to moderate fronts of Western Iberia. – Marine Micropaleontology, **39**: 131-155.

Cicha, I., Paulík, J. & Tejkal, J. (1956): Stručné shrnutí výsledků geologických a paleontologických prací v miocénu jz. části vněkarpatské pánve na Moravě. – Zprávy o Geologických Výzkumech, **1955**: 13-15.

Cicha, I., Rögl, F., Rupp, C. & Čtyroká, J. (1998): Oligocene-Miocene foraminifera of the Central Paratethys. – Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft, **549**: 13-25.

Culver, S.J. & Buzas, M. (1980): Distribution of recent benthic foraminifera off the North American Atlantic Coast. – Smithsonian Contributions to Marine Sciences, **6**: 1-512.

Culver, S.J. & Buzas, M. (1981): Distribution of recent benthic foraminifera in the Gulf of Mexico. – Smithsonian Contributions to Marine Sciences, **8**: 1-898.

Den Dulk, M., Reichard, G.J., Memon, G.M., Roelofs, E.M.P., Zachariasse, W.J. & Van Der Zwaan, G.J. (1998): Benthic foraminiferal response to variations in surface water productivity and oxygenation in the northern Arabian Sea. – Marine Micropaleontology, **35**: 43-66.

Den Dulk, M., Reichard, G.J., Van Heyst, S., Zachariasse, W.J. & Van Der Zwaan, G.J. (2000): Benthic Foraminifera as proxies of organic matter flux and bottom water oxygenation? A case history from the northern Arabian Sea. – Palaeogeography, Palaeoclimatology, Palaeoecology, **161**: 337-359.

Deuser, W.G. & Ross, E.H. (1989): Seasonally abundant planktonic foraminifera of the Sargasso Sea: Succession, deepwater fluxes, isotopic compositions, and paleoceanographic implications. – Journal of Foraminiferal Research, **19**: 268-293.

Di Stefano, A., Foresi, L.M., Lirer, F., Iaccarino, S.M., Turco, E., Amore, F.O., Morabito, S., Salvatorini, G., Mazzei, R. & Abdul Aziz, H. (2008): Calcareous plankton high resolution biomagnetostratigraphy for the Langhian of the Mediterranean area. – Rivista Italiana di Paleontologia e Stratigrafia, **114**: 51-76.

Doláková, N., Brzobohatý, R., Hladilová, Š. & Nehyba, S. (2008): The redalgal facies of the Lower Badenian limestones of the Carpathian Foredeep in Moravia (Czech Republic). – Geologica Carpathica, **59** (2): 133-146.

Doláková, N., Hladilová, Š. & Nehyba, S. (1999): Development of sedimentation, molluscs and palynospectra in the Lower Miocene of the southwestern part of the Carpathian Foredeep in Moravia (Czech Republic). – Acta Palaeobotanica, Supplements, **2**: 269-278.

Doláková, N., Kováčová, M. & Basistová, P. (2011): Badenian (Langhian – Early Serravallian) palynoflora from the Carpathian Foredeep and Vienna Basin (Czech and

Slovak Republics). – Acta Musei Nationalis Pragae, (B), **67** (1-2): 51-59.

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

Dunbar, R.B. (1983): Stable isotope record of upwelling and climate from Santa Barbara Basin, California. – In: Thiede, J. & Suess, E. (Eds.): Coastal upwelling, its sediment record, Part B. Sedimentary records of ancient coastal upwelling, 217-246; New York (Plenum).

Fairbanks, R.G., Sverdlove, M., Free, R., Wiebe, P.H. & Bé, A.W.H. (1982): Vertical distribution and isotopic fractionation of living planktonic foraminifera from the Panama Basin. – Nature, **298**: 841-844.

Flores, J.A., Sierro, F.S., Francés, G., Vasquez, A. & Zamarreno, I. (1997): The last 100,000 years in the western Mediterranean: Sea surface water and frontal dynamics as revealed by coccolithophores. – Marine Micropaleontology **29**: 351-366.

Flower, B.P. & Kennett, J.P. (1994): The middle Miocene climatic transition: East Antarctic ice sheet development, deep ocean circulation and global carbon cycling. – Palaeogeography, Palaeoclimatology, Palaeoecology, **108** (3-4): 537-555.

Flügel, E. (2004): Microfacies of carbonate rocks. – 976 pp.; Berlin, Heidelberg & New York (Springer).

Folk, R.L. & Ward, W. (1957): Brazos River bar: a study in the significance of grainsize parameters. – Journal of Sedimentary Petrology, **27**: 3-26.

Fontanier, C., Jorissen, F.J., Anschutz, P. & Chaillou, G. (2006): Seasonal variability of foraminiferal faunas at 1000 m depth in the Bay of Biscay. – Journal of Foraminiferal Research, **36**: 61-76.

Gradstein, F.M., Ogg, J.G., Schmitz, M.D. & Ogg, G.M. (2012): The Geologic Time Scale 2012. – 1176 pp.; New York (Elsevier).

Grill, R. (1941): Stratigraphische Untersuchungen mit Hilfe von Mikrofaunen im Wiener Becken und den benachbarten Molasseanteilen. – Oel und Kohle, **37**: 595-602.

Gross, M. (2006): Mittelmiozäne Ostracoden aus dem Wiener Becken (Badenium/Sarmatium, Österreich). – Österreichische Akademie der Wissenschaften, Schriftenreihe der Erdwissenschaftlichen Kommissionen, Sonderbände, **1**: 12-24.

Hageman, S.J., Bone, Y., McGowran, B. & James, N.P. (1997): Bryozoan colonial growth forms as paleoenvironmental indicators: Evaluation of methodology. – Palaios, **12**: 406-419.

Hallock, P. (1987): Fluctuations in the trophic resource continuum: a factor in global diversity cycles? – Paleoceanography, **2**: 457-471.

Hammer, Ø., Harper, D.A.T. & Ryan, P.D. (2001): PAST: Paleontological Statistics Software Package for Education and Data Analysis. – Palaeontologia Electronica, **4**: 19.

Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., De Graciansky, P.C. & Vail, P.R. (1998): Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins. – In: De Graciansky, P.C., Hardenbol, J., Jacquin, T. & Vail, P.R. (Eds.): Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. – SEPM Special Publications, **60**: 313.

Harzhauser, M., Piller, W., Müllegger, S., Grunert, P. & Micheels, A. (2011): Changing seasonality patterns in Central Europe from Miocene Climate Optimum to Miocene Climate Transition deduced from the Crassostrea isotope archive. – Global and Planetary Change, **76**: 77-84.

Hemleben, C., Spindler, M. & Anderson, O.R. (1989): Modern Planktonic Foraminifera. – 363 pp.; New York (Springer).

Heusser, L. (1978): Spores and pollen in the marine realm. – In: Haq, B.U. & Boersma, A. (Eds.): Introduction to marine micropaleontology, 327-339; Amsterdam (Elsevier).

Hohenegger, J., Ćorić, S. & Wagreich, M. (in press): Timing of the regional Badenian Stage (Middle Miocene, Central Paratethys). – Geologica Carpathica.

Hohenegger, J., Ćorić, S., Khatun, M., Pervesler, P., Rögl, F., Rupp, C., Selge, A., Uchman, A. & Wagreich, M. (2009): Cyclostratigraphic dating in the Lower Badenian (Middle Miocene) of the Vienna Basin (Austria): the Baden-Sooss core. – International Journal of Earth Sciences, **98**: 915-930.

Holcová, K. (1996): Determination of transport of foraminiferal tests in the fossil record (South Slovakia Basin Middle Miocene). – Neues Jahrbuch für Geologie und Paläontologie, Monatshefte, **1996**: 193-217.

Holcová, K. (1999): Postmortem transport and resedimentation of foraminiferal tests: relations to cyclical changes of foraminiferal assemblages. – Palaeogeography, Palaeoclimatology, Palaeoecology, **145**: 157-182.

Holcová, K. (2012): Morphological variability of the Paratethyan Oligocene-Miocene small reticulofenestrid coccolites and its paleoecological and paleogeographical implications. – Acta Palaeontologica Polonica, **58**: 651-668.

Holcová, K. & Demeny, A. (2012): The oxygen and carbon isotopic composition of Langhian foraminiferal tests as a paleoecological proxy in a marginal part of the Carpathian Foredeep (Czech Republic). – Geologica Carpathica, **63**: 121-137.

Hopkins, J.A. & McCarthy, F.M.G. (2002): Postdepositional palynomorph degradation in Quaternary shelf sediments a laboratory experiment studying the effects of progressive oxidation. – Palynology, **26**: 167-184.

Hüsing, S.K., Cascella, A., Hilgen, F.J., Krijgsman, W., Kuiper, K.F., Turco, E. & Winson, D. (2010): Astrochronology of the Mediterranean Langhian between 15.29 and 14.17 Ma. – Earth and Planetary Science Letters, **290**: 254-269.

Jorissen, F.J., Destinger, H.C. & Widmark, J.G.V. (1995): A conceptual model explaining benthic foraminifera microhabitat. – Marine Micropaleontology, **26**: 3-15.

Kaiho, K. (1994): Benthic foraminiferal dissolvedoxygen index and dissolved oxygen levels in the modern ocean. – Geology, **22**: 719-722.

Kaiho, K. (1997): Effect of organic carbon flux and dissolved oxygen on the benthic foraminiferal oxygen index (BFOI). – Marine Micropaleontology, **37**: 67-76.

kameo, k. (2002): Late Pliocene Caribbean surface water dynamic and climatic changes basedon calcareous nannofossil records. – Palaeogeography, Palaeoclimatology, Palaeoecology, **179**: 211-226.

kováč, m. (2000): Geodynamical, paleogeografical and structural development of CarpathianPannonian region in Miocene: New perspective on Neogene basins of Slovakia. – 1-176; Bratislava (VEDA) (in Slovak).

kováč, m., anDreyeva-grigorovich, a., BaJraktareviĆ, z., BrzoBohatý, r., filiPescu, s., foDor, l., harzhauser, m., nagymarosy, a., oszczyPko, n., PaveliĆ, D., rögl, f., saftiĆ, B., sliva, l. & stuDencka, B. (2007): Badenian evolution of the Central Paratethys Sea: paleogeography, climate and eustatic sealevel changes. – Geologica Carpathica **58** (6): 579-606.

kováčová, m., Doláková, n. & kováč, m. (2011): Miocene vegetation pattern and climate change in the Northwestern Central Paratethys domain (Czech and Slovak Republic). – Geologica Carpathica, **62** (3): 251-266.

kováč, m., nagymarosy, a., holcová, k., huDáčková, n. & zlinská, a. (2001): Paleogeography, paleoecology and eustacy: Miocene 3rd order cycles of relative sealevel changes in the Western Carpathian – North Pannonian basins. Acta Geologica Hungarica, **44** (1): 1-45.

kovar-eDer, J., Jechorek, h., kvaček, z. & Parashiv, v. (2008): The integrated plant record: An essential tool for reconstructing Neogene zonal vegetation in Europe. – Palaios, **23**: 97-111.

kvaček, z., kováč, m., kovar-eDer, J., Doláková, n., Jechorek, h., Parashiv, v., kováčová, m. & sliva, l. (2006): Miocene evolution of landscape and vegetation in the Central Paratethys. – Geologica Carpathica, **57** (4): 295-310.

logan, a. (1979): The Recent Brachiopoda of the Mediterranean Sea. – Bulletins de l'Institute océanographique de Monaco, **72**: 11-12.

manDic, o. (2004): Pectinid bivalves from the Grund Formation (Lower Badenian, Middle Miocene, Alpine-Carpathian Foredeep) – taxonomic revision and stratigraphic significance. – Geologica Carpathica, **55** (2): 129-146.

manDic, o. & harzhauser, m. (2003): Molluscs from the Badenian (Middle Miocene) of the Gaindorf Formation (Alpine Molasse Basin, NE Austria) – taxonomy, paleoecology and biostratigraphy. – Annales des Naturhistorischen Museums in Wien, (A), **104**: 85-127.

martini, e. (1971): Standard Tertiary and Quaternary calcareous nanoplankton zonation. – In: Proceedings of the 2nd Planktonic Conference, Roma 1970, 739-785; Roma.

mckinney, f.k. & Jackson, J.B.c. (1989): Bryozoan evolution. – 238 pp.; Boston (Unwin Hyman).

meulenkamP, J.e., kováč, m. & cicha, i. (1996): On Late Oligocene to Pliocene depocentre migration and the evolution of the Carpathian Pannonian system. – Tectonophysics, **266**: 301-317.

moissette, P. (1988): Faunes de bryozoaires du Messinien d'Algerie occidentale. – Documents des Laboratoires de Geologie Lyon, **102**: 1-351.

murray, J.W. (2006): Ecology and applications of benthic foraminifera. – 426 pp.; Cambridge (Cambridge University Press).

nemec, W. (2005): Principles of lithostratigraphic logging and facies analyses. Institutt for Geovitenskap, Universitat Bergen, 128 pp.

oertli, h.J. (1971): The aspect of Ostracode faunas a possible new tool in petroleum sedimentology. – In: Oertli, H.J. (Ed.): Paléoécologie des Ostracodes. – Bulletins du Centre de Recherches Pau SNEA, 137-151.

okaDa, h. & mcintyre, A. (1979): Seasonal distribution of modern coccolithophores in the western North Atlantic Ocean. – Marine Biology, **54**: 319-328.

PaPP, a., cicha, i., seneš, J. & steininger, f. (1978): Chronostratigraphie und neostratotypen, Miozän der Zentralen Paratethys, **4**, M4 Badenien (Moravien, Wielicien, Kosovien). Bratislava (VEDA).

Pavézková, J., hlaDilová, š. & Bitner, m.a. (in press): Miocene brachiopods from the Židlochovice locality, Czech Republic. – Geologické výzkumy na Moravě a ve Slezsku.

PoWers, m.c. (1982): Comparison chart for estimating roundness and sphericity. – AGI Data Sheet 18.

Procházka, v.J. (1893): Miocen židlochovický na Moravě a jeho zvířena. – Rozpravy České Akademie věd, 2 Třída II, Praha.

PuJol, c. & vergnauD grazzini, c. (1995): Distribution patterns of live planktic foraminifers as related to regional hydrography and productive systems of the Mediterranean Sea. – Marine Micropaleontology, **25**: 187-217

reynolDs, l. & thunell, r.c. (1985): Seasonal succession of planktonic foraminifera in the subpolar North Pacific. – Journal of Foraminiferal Research, **15**: 282-301.

roDuit, n. (2008): JMicroVision: Image analysis toolbox for measuring and quantifying components of highdefinition images. Version 1.2.7. oftware available for free download at http://www.jmicrovision.com/accessed October, 2008.

ruPP, c. & hohenegger, J. (2008): Paleoecology of planktonic foraminifera from the BadenSooss section (Middle Miocene, Badenian, Vienna Basin, Austria). – Geologica Carpathica, **59**: 425-445.

Říha, J. (1983): Ostrakodi vápnitých jílů (téglů) spodního badenu (Terciér, miocén) okolí Brna. – Acta Musei Moraviae, Scientiae Nature, **68**: 57-83 (in Czech).

seko, m., PiPík, r. & Doláková, n. (2012): Early Badenian ostracod assemblage of the stratotype Židlochovice (Carpathian Foredeep, Czech Republic). – Central European Journal of Geosciences CEJGD1100049R1, London: Springer, **4** (1): 111-125.

schultz, o. (2001): Catalogus Fossilium Austriae. Band 1. Bivalvia neogenica (Nuculacea – Unionacea). – 379 pp.; Wien (Österreichische Akademie der Wissenschaften).

sPezzaferri, s. (1995): Planktonic foraminiferal paleoclimatic implications across the OligoceneMiocene transition in the oceanic record (Atlantic, Indian and south Pacific). – Palaeogeography, Palaeoclimatology, Palaeoecology, **114**: 43-74.

sPötl, c. & vennemann, t.W. (2003): Continuousflow IRMS analysis of carbonate minerals. – Rapid Communications in Mass Spectrometry, **17**: 1004-1006.

stuDencka, B. (1986): Bivalves from the Badenian (Middle Miocene) marine sandy facies of Southern Poland. – Palaeontologia Polonica, **47**: 11-28.

StuDencka, B., gontscharova, i.a. & PoPov, s.v. (1998): The bivalve faunas as a basis for reconstruction of the Middle Miocene history of the Paratethys. – Acta Geologica Polonica, **48** (3): 285-342.

Stuchlik, l. (1994): Neogene Pollen Flora of Central Europe. Part 1. – Acta Palaeobotanica, Supplements, **1**: 1-56.

tomaštíková, t. & Zágoršek, K. (2012): Mechovky z lokality Židlochovice (Bryozoa from the locality Židlochovice). – Geologické Výzkumy na Moravě a ve Slezsku, **2012**: 53-56.

tucker, m. (1988): Techniques in Sedimentology. – 394 pp.; Oxford (Blackwell).

utescher, t., mosBrugger, v. & ashraf, a.r. (2000): Terrestrial climate evolution in northwest Germany over the last 25 Million years. – Palaios, **15** (5): 430-449.

van hinsBergen, D.J.J., kouWengoven, t.J. & van Der zWaan, g.J. (2005): Paleobathymetry in the backstripping procedure: Correction for oxygenation effects on depth estimates. – Palaeogeography, Palaeoclimatology, Palaeoecology, **221**: 245-265.

WaDe, B.s. & BoWn, P.r. (2006): Calcareous nannofossils in extreme environments: the Messinian Salinity Crisis, Polemi Basin, Cyprus. – Palaeogeography, Palaeoclimatology, Palaeoecology, **233**: 271-286.

Walanus, a. & nalePka, D. (1999): POLPAL. Program for counting pollen grains, diagrams plotting and numerical analysis. – Acta Paleobotanica, **2**: 659-661.

Walker, r.g. & James, n.P. (1992) – Facies Models. Response to sea level changes. Geological Association Canada, 13-80.

Wells, P. & okaDa, H. (1997): Response of nannoplankton to major changes in seasurface temperatrure and movements of hydrological fronts over site DSDP 594 (south Chatham Rise, southeastern New Zealand), during the last 130 kyr. – Marine Micropalaeontology, **32**: 341-363.

Whatley, c.r., Pyne, s.r. & Wilkinson, P.i. (2003): Ostracoda and palaeooxygen levels, with particular reference to the Upper Cretaceous of East Anglia. – Palaeogeography, Palaeoclimatology, Palaeoecology, **194**: 355-386.

Winter, a., JorDan, r.W. & roth, P.h. (1994): Biogeography of the living coccolithophores in the oceans. – In: Winter, a. & Siesser, W. (Eds.): Coccolithophores, 161-178; Cambridge (Cambridge University Press).

Woelkerling, W.J. (1988): The coralline red algae: an analysis of the genera and subfamilies of non-geniculate Corallinaceae. – 268 pp.; London & Oxford (Oxford University Press).

Zágoršek, k. (2010a): Bryozoa from the Langhian (Miocene) of the Czech Republic. Part I: Geology of the studied sections, systematic description of the orders Cyclostomata, Ctenostomata and “Anascan” Cheilostomata (Suborders Malacostega levinsen, 1902 and Flustrina Smitt, 1868). – Acta Musei Nationalis Pragae, (B), **66** (12): 31-36.

Zágoršek, k. (2010b): Bryozoa from the Langhian (Miocene) of the Czech Republic. Part II: Systematic description of the suborder Ascophora levinsen, 1909 and paleoecological reconstruction of the studied paleoenvironment. – Acta Musei Nationalis Pragae, (B), **66** (34): 139-255.

Zágoršek, k., holcová, k., nehyBa, s., kroh, a. & hlaDilová, š. (2009): The invertebrate fauna of the Middle Miocene (Lower Badenian) sediments of Kralice nad Oslavou (Central Paratethys, Moravian part of the Carpathian Foredeep). – Bulletins of Geosciences, **84** (3): 465-496.

Zágoršek, k., nehyBa, s., tomanová-Petrová, P., hlaDilová, š., Bitner, m.a., Doláková, n., hraBovský, J. & Jašková, v. (2012b): Local catastrophe caused by tephra input near Přemyslovice (Moravia, Czech Republic) during the Middle Miocene. – Geological Quarterly, **56** (2): 269-284.

Zágoršek, k., Ostrovsky, a.n. & Vávra, n. (2011): The new cheilostome bryozoan Metrarabdotos nehybai from the Middle Miocene of Moravia (Czech Republic): palaeofaunistic, taxonomic and ontogenetic aspects. – Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, **260** (1): 21-31.

Zágoršek, k., raDWańska, u. & raDWański, a. (2012a): Bryozoa from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). – Bulletins of Geosciences, **87** (2): 201-218.

Manuscript received: September 24th, 2013.
Revised version accepted by the Stuttgart editor: December 9th, 2013.

Addresses of the authors:

nela Doláková, Slavomír nehyBa, rostislav BrzoBohatý, JuraJ hraBovský, Institute of Geological Sciences, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic;
e-maisl: nela@sci.muni.cz, slavek@sci.muni.cz

katarína holcová, Institute of Geology and Paleontology, Charles University in Prague, Albertov 6.128 43 Praha 2, Czech Republic;
e-mail: holcova@natur.cuni.cz

Šárka hlaDilová, Department of Biology, Faculty of Education, Palacky University, Purkrabská 2, 771 40 Olomouc, Czech Republic;
e-mail: sarka.hladilova@upol.cz

kamil Zágoršek, Department of Paleontology, National Museum, Václavské nam. 68, CZ 115 79 Prague, Czech Republic;
e-mail: kamil_zagorsek@nm.cz

michal Seko, Geological Institute, Slovak Academy of Sciences, Ďumbierska 1, 974 01 Banská Bystrica, Slovakia;
e-mail: michal.seko47@gmail.com

torsten utescher, Steinmann Institute, University of Bonn, Nussallee 8, Bonn, Germany;
e-mail: utescher@geo.unibonn.de

Appendices

Appendix 1: List and relative abundances of benthic foraminiferal species.

	Z1/11.5-11.6m	Z1/10.2-10.3m	Z1/9.8-9.9m	Z1/9.0-9.1m	Z1/8.9-9.0m	Z1/8.5-8.6m	Z1/7.8-7.9m	Z1/7.2-7.3m	Z1/6.8-6.9m	Z1/6.3-6.4m	Z1/6.3m	Z1/6.0-6.1m	Z1/5.7-5.8m
Ammonia beccarii (linne)	0.38	0	1.16	0	0	0	0	0	0	0.45	0	0	0
Ammonia tepida (Cushman)	0	0.88	0	0	0	0.81	0.4	0	0.45	0	0	0	0.66
Amphicoryna badenensis (D’OrBigny)	0.38	0	0	0	0	0	0.4	0	1.35	5.41	0.76	0	0
Amphistegina bohdanowiczi BieDa	0	0	0	0.39	0	0	0	0	0	0	0	0	0
Amphistegina mammilla (fichtel et moll)	0	0	0	0	0	0	0	0	0	0.9	0	0	0
Angulogerina angulosa (Williamson)	0	0	0	0	0	0	0	0	0	0	0	0	0
Asterigerinata planorbis (D’OrBigny)	0	5.31	12.79	6.25	12.02	4.86	2.82	0.87	1.35	20.27	26.72	31.39	39.07
Baggina sp.	2.26	0	0.78	0.39	0	0.81	2.82	1.74	1.35	0.9	0	0	0
Bolivina antiqua D’OrBigny	0	0	0	1.17	0	0.81	0	0.43	0	0.9	0.38	0.73	0
Bolivina dilatata dilatata reuss	0.75	8.41	17.44	1.56	11.24	0	2.42	1.3	3.59	0	0.38	0	0.66
Bolivina hebes macfaDyen	0	0	0	0	0	0	0	0	0	0	0.38	0	0
Bolivina plicatella Cushman	0.75	3.54	0.78	0.39	1.16	4.45	4.03	3.04	1.79	0	0	0	0
Bolivina pokornyi Cicha et zaPletalova	0	0	0	0	0.39	0	0	0	0	0	0	0	0
Bolivina scalprata retiformis Cushman	0	0	0	0	0	0	0	0	0	0	0	0	0
Buchnerina buchneri (margerel)	0.38	0	2.33	0.39	2.33	0	0.4	0.43	1.79	0	0	0	0
Bulimina elongata D’OrBigny	6.39	4.87	6.98	2.34	5.43	6.88	4.03	0.43	0	2.25	0.38	0.73	3.97
Bulimina striata D’OrBigny	6.02	0	1.55	1.17	0.78	0.81	0.4	4.78	2.69	4.5	1.15	0	1.32
Cancris auriculus (fichtel et moll)	1.13	0	0	0	0.78	0	0.4	0	0	0	0.76	0	0
Cassidulina laevigata D’OrBigny	0.75	6.19	2.71	2.73	2.33	1.62	2.02	3.48	1.35	1.35	0.38	0	4.64
Cibicides sp. (small-sized)	0	5.31	8.53	2.34	13.95	2.02	0.81	3.91	4.93	0.9	13.74	10.95	19.21
Cibicidoides austriacus (D’OrBigny)	0	0	0	0	0	0	0	0	0	0	0	0	0
Cibicidoides ungerianus (D’OrBigny)	0.38	0.88	0.39	0	1.55	0	0	0.87	1.35	6.31	7.25	10.22	3.97
Dentalina sp.	0	0	0	0	0	0.4	1.21	0	0.45	0.45	0	0	0
Elphidium crispum (linne)	0	0	0	0.39	0	0	0	0	0	0.9	0.38	0	0
Elphidium fichtellianum (D’OrBigny)	0	0.88	0.39	0	0	0	0	0.43	0.45	1.8	1.15	0	0.66
Elphidium flexuosum (D’OrBigny)	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium macellum fichtel et moll	0	3.54	1.16	1.95	1.55	3.64	1.61	1.3	0	7.21	8.4	13.14	5.96
Elphidium ortenburgense (egger)	0	0	0	0	0	0	0	0	0	0	0.38	0	0
Elphidium rugosum (D’OrBigny)	0	0	1.16	0	0	0.4	0.81	0	0	0	1.15	3.65	1.99
Elphidium sp. (juvenile)	0	0	0	0	0	0	0	0	0	0	0	0	3.97
Ehrenbergina serrata reuss	0	0	0	0	0	0	0	0	0	0	0	0	0
Fursenkoina acuta (D’OrBigny)	1.13	0.44	0	1.17	0	0.4	0.81	0.87	0	0	0	0	0
Chilostomella ovoidea reuss	0	0	0	0	0	0	0	0	0	0	0	0	0
Globocassidulina oblonga (reuss)	2.26	3.98	5.43	3.52	6.98	3.64	5.24	8.7	4.04	0.9	5.34	0.73	2.65
Globulina gibba D’OrBigny	0	0	0.78	0	0	0	0	0	0.9	0.45	0	0	0
Globulina spinosa D’OrBigny	0	0	0	0.39	0	0	0	0	0	0.45	0	0	0
Grigelis pyrula (D’OrBigny)	0	0	0	0	0	0	0.4	0	0	0	0	0	0
Hansenisca soldanii (D’OrBigny)	3.01	9.29	0.78	5.08	2.33	3.24	4.84	5.22	5.83	1.35	1.15	2.19	0
Hanzawaia boueana (D’OrBigny)	1.13	2.65	0.78	1.56	0.78	0	0.4	1.3	0.45	3.15	1.53	0.73	1.99
Heterolepa dutemplei (D’OrBigny)	11.65	7.08	5.04	15.23	7.75	11.74	8.06	10.43	8.07	4.05	0.76	5.11	0
Heterostegina sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hoeglundina elegans (D’OrBigny)	0.75	0.88	0	0.78	0.78	0.4	3.63	1.74	1.35	1.35	0.76	0.73	0
Karreriella chilostoma (reuss)	0.38	0	0	0	0	0	0	0	0	0.9	0.38	0	0
Laevidentalina elegans (D’OrBigny)	0	0	3.49	0.39	1.16	1.62	0	0	0	0	0	0	0
Lagena striata (D’OrBigny)	0.38	0.44	0	0	0	0	0	0.43	0	0	0	0	0
Lagena hexagona (Williamson)	0	0	0	0	0	0	0	0	0	0	0	0	0
Lenticulina calcar (linne)	0	0	0.39	1.95	0	2.83	0	0.87	3.14	0	0	0.73	0
Lenticulina clypeiformis (D’OrBigny)	0	0	0.39	0	0	0	0	0	0	0	0	0	0
Lenticulina inornata (D’OrBigny)	0.38	0	0.78	0.78	0.78	0	2.02	0.87	0.9	1.35	0	0	0
Lenticulina orbicularis (d´OrBigny)	0	0	0	0	0	0	0	0	0	0	0	0	0
Lenticulina sp. (broken or abraded)	0	0	0	0	0	0	0	0	0	0	0	1.46	0
Lenticulina sp. (juvenile)	0	0	0	0	0	0	0	0.43	0	0	1.91	0	0
Lenticulina vortex (fichtel et moll)	0	0	0	0	0	0	0	0	0	0	0	0	0
Lobatula lobatula (Walker et JacoB)	0.75	1.33	0.39	1.95	1.16	3.64	0.81	0	0	14.41	11.45	10.22	7.28
Marginulina hirsuta D’OrBigny	0	0	0	0	0	0	0	0	0	0	0.38	0	0

Appendix 1: continued

Z1/5.1-5.2m	Z1/4.8-5.0m	Z1/4.3-4.4m	Z1/4.2-4.3m	Z1/4.0-4.2m	Z1/3.6-3.7m	Z1/3.1-3.2m	Z1/2.6-2.8m	Z1/2.2-2.3m	Z1/2.0-2.1m	Z1/1.9-2.0m	Z1/1.7-1.8m	Z1/1.2-1.3m	Z1/1.0-1.1m	Paleoecological characteristic (Jorissen et al. 1992, 1995, 2007, Kaiho 1994, De Stigter et al. 1998; De Dulk et al. 2000, Spezzaferri et al. 2002, van Hinsbergen et al. 2005, Murray 2006, Báldi 2006)
0	0	0.93	0	0	0	0	0	0	0.37	0	0	1.23	0.39	Euryhaline
0	0	0	0	0	0	0	0	0	0	0	1.74	0	0.39	Euryhaline
0	0	0	0	0	0	0	0	0	0	0.63	0	0	0.39	
51.28	5.26	12.09	0	0.49	0	2.14	1.82	36	5.9	7.59	1.74	2.87	4.31	Oxiphylic
0	0	0	0	0	0	0	0	0	0	0	0	0	0	Oxiphylic
0	0	0	0	0	0	2.5	0	0	0	0	0	0	0	
22.22	52.63	46.05	12.39	37.93	14.29	14.64	15	0	40.96	29.75	21.3	23.77	13.73	Epiphytic
0	0	0	0	0	0	0	0	0	0	0	0.43	0	0	
0	0	0	1.71	0	3.67	0.36	0.91	0	1.11	0	0	0	0.39	Hypoxic, infauna
0	0	0	6.84	0	11.02	7.86	11.36	0.5	0.37	0.63	8.26	1.64	1.57	Hypoxic, infauna
0	0	0	0	0	0	1.07	0	0	0	0	0	0.82	0.78	
0	0	0	3.42	0	0	3.57	0.91	0.5	0	0	3.48	2.05	0.39	
0	0	0	0.43	0	0	0.36	0	0	0	0	0	0	0	Hypoxic, infauna
0	0	0	0	0	0	0	5	0	0	0	0	0.41	0	
0	0	0	0.43	0	1.22	1.07	2.27	0	0.37	0.63	2.61	2.46	0.39	
0	0	0.93	0	0.99	3.67	2.5	3.18	0	1.11	0	3.91	2.46	0.78	Hypoxic, infauna, high-nutrient
0	0	0.47	3.42	0	0	6.79	3.64	0	0.74	2.53	1.3	1.64	3.92	
0	0	0	0	0	0	0	0	0	0	0	0	0	0.39	
0	0	0	10.26	0.49	4.49	6.79	4.09	0	0	0	6.09	4.92	4.31	Phytodetritus supply
0.85	9.47	4.19	10.26	12.81	9.8	4.29	10.91	1.5	2.95	0	11.74	15.98	7.45	Oxiphylic, stress-tolerant
0	0	0	0	0	0	0	0	0	0	0	0	0.41	0.39	Oxiphylic
0	5.26	4.19	4.7	6.4	4.9	3.57	6.36	6.5	1.85	6.96	7.83	5.74	2.35	Oxiphylic
0	0	0	0	0	0	0	0	0.5	0	1.27	0	0	0.78	
10.26	11.58	15.35	1.71	10.84	8.57	3.57	1.82	8	7.38	6.33	2.17	4.1	2.75	Euryhaline
0	0	0	0.43	1.97	1.63	0	0.45	0.5	1.85	1.9	1.74	2.87	2.75	Euryhaline
0	0	0	0.43	0	0	0	0	0	0	0	0	0	0	Euryhaline
0	0	0	0	0	0	0	0	0	0	0	0	0	0	Euryhaline
0	0	0	0	0	0	0	0	0	0	0	0	0	0	Euryhaline
0	0	0.47	0	0	0.41	2.86	0	0	0	0.63	0.87	0.41	1.57	Euryhaline
0	0	0	0	0	0	0	0	0	0	0	0	0	0	Euryhaline
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0.43	0	0	0	0	0	0	0	0	0	0	Hypoxic, infauna,
0	0	0	0	0	0	0	0	0	0	0	0	0	0	Hypoxic
0.85	0	0.47	11.97	0	5.71	3.57	4.55	0.5	3.32	1.27	2.61	1.64	2.35	Phytodetritus supply
2.56	0	0	0	0.49	0.41	0.36	0	0	0	0.63	0	0	0.39	
0	1.05	1.86	0.43	0	0	0	0	2	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	1.71	0	1.63	2.14	0.91	1	0.37	0.63	0.43	0.41	3.14	Hypoxic, infauna, high-nutrient
0.85	2.11	0	0.43	0	1.22	2.5	0.45	0	1.48	0	0	1.64	1.57	
5.98	5.26	4.65	2.56	1.48	2.04	0.36	2.27	12.5	4.43	8.23	2.17	2.87	2.75	Oxiphylic
0	0	0	0	0	0	0	0	0	0	0	0	0	0	Oxiphylic
0	0	0	0	0	0	1.07	0	0	0	0	0	0.82	3.53	
0	0	0	0	0	0	0	0	0.5	0	0	0	0	1.18	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0.43	0	0	0	0	0	0	0	0.43	0.41	0.39	
0	0	0	0	0	0	0.36	0	0.5	0	0	0	0	0	
0.85	0	0	0	0	0	0	0	0	0.74	0	0	0	1.18	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0.43	0	0.82	0.36	0.45	1	0.37	0.63	0.43	0	0	
0	0	0.47	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0.43	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4.27	5.26	5.12	7.69	20.69	18.37	8.93	5	8.5	11.81	6.33	5.65	6.56	7.45	Oxiphylic
0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	

Appendix 1: continued

	Z1/11.5-11.6m	Z1/10.2-10.3m	Z1/9.8-9.9m	Z1/9.0-9.1m	Z1/8.9-9.0m	Z1/8.5-8.6m	Z1/7.8-7.9m	Z1/7.2-7.3m	Z1/6.8-6.9m	Z1/6.3-6.4m	Z1/6.3m	Z1/6.0-6.1m	Z1/5.7-5.8m
Martinottiella karreri (Cushman)	0	0	0	0	0	0	0	0	0	0.9	0	0	0
Melonis pompiloides (D’OrBigny)	0.75	1.77	1.55	1.95	0.78	2.83	2.02	4.78	8.07	1.35	3.44	0	0
Nonion commune (D’OrBigny)	10.15	3.1	5.04	3.52	4.65	7.29	7.26	6.52	7.17	1.8	2.29	0	0.66
Nonion sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Nodosaria hispida d´OrBigny	0	0	0	0	0.78	0	0.4	0.43	0	0	0	0	0
Nummoloculina contraria (D’OrBigny)	0	0	0	0	0	0	0	0	0	0	0	0	0
Oridorsalis umbonatus (Reuss)	0	0	0	0	0	0	0	0	0	0.45	0	0	0
Neugeborina longiscata (D’OrBigny)	0	0	0	0	0	0	0	0	0	0	0	0	0
Pappina parkeri (Karrer)	0	1.77	0	0.78	0	0.81	0.4	0.43	0	0	0	0	0
Pararotalia aculeata (D’OrBigny)	0	0	0	0	0	0	0	0	0	0	0	0.73	0
Planularia lanceolata (D’OrBigny)	0	0	0	0	0	0	0	0	0.45	0.45	0	0	0
Plectofrondicularia digitalis (NeugeBoren)	2.26	0.88	0.78	2.73	0.78	1.21	0	0.87	2.24	1.35	0	0	0
Praeglobobulimina pyrula (D’OrBigny)	1.88	1.33	0	0.39	1.55	3.64	1.21	1.74	0.9	0.9	0	0	0
Porosononion granosum (D’OrBigny)	0	0.44	0	0	0.39	0	0.81	0.87	2.24	0	0	0.73	0
Pseudotriloculina consobrina (D’OrBigny)	0	0.44	0	0.39	0	0	1.21	0	0.9	0.45	0.38	0	0.66
Pullenia bulloides (D’OrBigny)	5.64	0.44	2.71	5.86	2.33	2.83	4.03	3.91	1.35	2.25	2.67	0.73	0
Pyramidulina raphanistrum (Linne)	0.75	0	0	0.78	0	0	0	0.43	0	0	0	0	0
Quinqueloculina buchiana d’Orbigny	0	0	0	1.95	0	0	0	0	0.45	0	0	0	0
Quinqueloculina hauerina (d’Orbigny)	1.88	0.44	0	2.34	0.78	4.05	2.42	0.43	1.79	0	0	1.46	0
Reussella spinulosa (Reuss)	0	0	0	0.39	0	0	0	0	0	0	0.38	0	0
Rosalina sp. (cf. *semiporata* (Egger)	0	0	0	0.39	0	0	0	0.43	0	0.45	0.38	1.46	0
Semivulvulina deperdita (D’OrBigny)	11.28	0	0	0	1.94	3.64	6.45	6.09	4.48	0.45	1.15	0	0
Sigmovirgulina tortuosa (BraDy)	0	0	0	0	0	0	0	0	0	0	0	0	0
Siphonina reticulata (CzJzek)	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeroidina bulloides D’OrBigny	0.38	0	0	0	0	0	0.4	0.87	0.45	1.8	0.38	0	0
Spiroloculina sp.	0	0.44	0	0.78	0.39	0.4	1.61	0	0	0.45	0.38	0	0
Spirorutilus carinatus (D’OrBigny)	1.13	2.65	1.16	6.25	1.94	6.88	8.47	8.26	2.24	0	0	0	0
Stilostomella adolphina (D’OrBigny)	2.63	6.19	3.1	4.69	1.94	2.02	2.82	2.61	2.69	0	0.38	0	0
Stilostomella elegans (D’OrBigny)	4.14	0	3.1	1.17	2.71	3.24	3.23	0	2.24	1.35	0	0	0
Textularia gramen D’OrBigny	0	0.44	1.55	1.56	1.16	1.62	4.03	1.74	0	0	0	0	0
Textularia laevigata D’OrBigny	0.38	0.44	0	0	0	0	0	0	0.45	0	0	0	0
Trifarina bradyi Cushman	0.75	0.44	1.55	0	0.39	0	0	0.43	0	1.8	0	0	0
Uvigerina aculeata D’OrBigny	0	0.44	0.78	2.73	1.94	2.02	1.61	3.04	9.42	0.45	0	0	0
Uvigerina bononiensis Fornasini	0	0	0	0	0	0	0	0	0	0	0	0	0
Uvigerina macrocarinata PaPP et Turnovsky	14.29	0	0	3.13	0.39	2.43	0.81	2.17	4.93	0.45	0.76	0.73	0
Uvigerina pygmoides PaPP et Turnovsky	0	0	0	0	0	0	0	0	0	0	0	0.73	0
Uvigerina semiornata d´OrBigny	0	0	0	0	0	0	0	0	0	0	0	0.73	0
Valvulineria complanata (D’OrBigny)	0.38	12.39	2.33	3.91	0	0	0	0	0	0	0	0	0.66
P/B-ratio	13.64	41.6	32.28	20.74	37.38	40.05	29.34	48.2	44.25	43.22	30.13	9.87	11.7
Foraminiferal number (specimens/1 g of rock sample)	308	348.3	571.5	129.2	374.55	529.71	1263.6	799.2	720	156.4	75	15.2	34.2

Appendix 1: continued

Z1/5.1-5.2m	Z1/4.8-5.0m	Z1/4.3-4.4m	Z1/4.2-4.3m	Z1/4.0-4.2m	Z1/3.6-3.7m	Z1/3.1-3.2m	Z1/2.6-2.8m	Z1/2.2-2.3m	Z1/2.0-2.1m	Z1/1.9-2.0m	Z1/1.7-1.8m	Z1/1.2-1.3m	Z1/1.0-1.1m	Paleoecological characteristic (Jorissen et al. 1992, 1995, 2007, Kaiho 1994, De Stigter et al. 1998; De Dulk et al. 2000, Spezzaferri et al. 2002, van Hinsbergen et al. 2005, Murray 2006, Báldi 2006)
0	0	0	0	0	0	0.36	0	2	0	1.9	0	0	0.39	
0	0	0	3.85	0	0.41	1.07	1.82	3.5	0.37	7.59	0	1.23	5.49	Hypoxic, infauna, high-nutrient
0	0	0	0.43	0.49	1.63	0.71	1.36	0	0.37	0.63	0	0	1.57	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	1.18	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	1.57	
0	0	0	0	0	0	0.36	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0.63	0	0	0	
0	0	0	0	0	0	0	0.45	0	1.11	0	0	0	0	
0	0	0	0.43	0	0.41	0.36	0.91	0	1.11	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0.63	0	0	0,39	Hypoxic, infauna, high-nutrient
0	0	0	0	0.99	0.41	1.79	3.64	0.5	0.74	0	1.74	0.41	0	Euryhaline
0	0	0.47	0	0	0	0	0	0.5	0	0	0	0.82	0	
0	0	0	0	0	0.41	1.07	0.45	0	0.74	0.63	0.43	0	0	Hypoxic, infauna, high-nutrient
0	0	0	0	0	0	0	0	0	0	0.63	0	0	0	
0	0	0	0	0	0	0	0	0.5	0.37	1.9	0	0	0,39	Oxiphylic
0	1.05	0	0	0	0	0	0	0	0	0	0	0	0	Oxiphylic
0	0	0	2.56	0	1.22	1.07	2.27	1.5	0.74	0	4.35	3.69	3,53	
0	0	0	0	0	0	0	0	0.5	0.74	0	0	0	0	
0	0	0	0.43	1.97	0	1.43	0	1.5	0.37	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0.82	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	1.82	0.5	0.37	0	0	0.41	0,78	
0	0	0	1.28	0	0	2.14	0.91	0	0.37	0.63	0.43	0.82	0,78	
0	0	0	0	0	0	0.36	0.45	1	0	0	0.87	0	1,18	
0	0	0	4.27	0.49	1.22	4.29	4.55	2	1.85	1.9	3.48	2.87	4,31	
0	0	0	0.43	0	0	0.36	0	1	1.11	1.9	0	0	0	
0	0	0	0	0	0	0	0	0	1.85	2.53	0.43	0.41	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	1,18	
0	0	1.4	2.56	1.48	0.41	0	0	0	0	0	0	0	0,39	
0	0	0	0	0	0	0	0	0	0	0	0	0	1,18	Hypoxic, infauna, high-nutrient
0	0	0	0	0	0	0	0	0	0	0	0	0	0	Hypoxic, infauna, high-nutrient
0	0	0	0.43	0	0	1.07	0	3	0.37	1.9	0.87	0	0,39	Hypoxic, infauna, high-nutrient
0	0	0.93	0	0	0	0	0	0	0	0	0	0	0	Hypoxic, infauna, high-nutrient
0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	Hypoxic, infauna, high-nutrient
0	1.05	0	0.43	0	0	0	0	0.5	0	0	0.43	0.41	1,18	Hypoxic, infauna, high-nutrient
0	1.04	40.27	41.65	1.93	29.55	34.73	48.39	32.43	16.36	37.55	42.29	31.46	34,28	
23.4	9.6	132.6	243.03	41.4	130.95	107.25	263.03	59.2	116.64	25.3	160.8	160.2	279,36	

	Z2/16.9-17.0 m	Z2/16.6-16.4 m	Z2/15.9-16.0 m	Z2/15.4-15.5 m	Z2/15.1-15.2 m	Z2/14.4-14.8 m	Z2/14.1-14.2 m	Z2/13.9-14.0 m	Z2/13.8-13.9 m	Z2/13.7-13.8 m	Z2/13.3-13.4 m	Z2/12.9-13.0 m	Z2/12.2-12.3 m	Z2/11.5-11.6 m	Z2/11.0-11.2 m	Z2/10.8-10.9 m	Z2/9.9-10.0 m	Z2/9.2-9.3 m	Z2/8.8-8.9 m	Z2/8.5-8.6 m	Z2/8.3-8.4 m	Z2/7.8-7.9 m	Z2/6.9-7.0 m	Z2/6.0 m
Ammonia beccarii (Linne)	0	0	0	0	0	0	0	0	0	0.42	0	0	0	0	0	0	0.75	0.82	0	0	0	0	0	0
Ammonia tepida (Cushman)	1.12	2.09	2.87	0	1.51	0	0.41	0	0	0	0.4	0	0.81	1.32	0.98	0	0	0	0	0.8	0	0.42	0	0
Amphicoryna badenensis (D'Orbigny)	0	0.42	0.41	0	0	0.42	0	0	0	0	0	0	0	0	0	0.45	0	0	0	0	0	0.84	0	0.37
Amphistegina bohdanowiczi Bieda	0.37	0	0	0	0	0	0.82	0	1.41	5.02	1.62	1.52	0	0	2.44	3.13	6.02	6.58	3.42	1.2	4.29	0.84	0	0
Amphistegina mammilla (Fichtel et Moll)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.41	0	0	0.48	0	0	0
Angulogerina angulosa (Williamson)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.12
Asterigerinata planorbis (D'Orbigny)	12.3	11.3	13.5	38.9	32.1	47.1	7.76	6.43	14.1	11.3	32.4	14	4.03	4.82	42.4	31.3	22.9	36.2	31.2	29.7	38.6	26.4	1.35	0.75
Baggina sp.	0	0.84	0	0	0	0	0.41	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0.84	0	0
Bolivina antiqua D'Orbigny	2.23	0	0.41	0	0.75	0	0.41	0	0	0	0	1.14	6.85	7.02	0.49	0.45	0.75	0.41	0	0.4	0.48	0.42	0	0
Bolivina dilatata dilatata Reuss	6.69	12.6	17.6	0	2.64	0.42	7.76	22.9	3.76	4.6	0.4	5.3	0	6.14	0.49	2.23	0	0.82	1.71	0.8	0	3.35	14.4	1.5
Bolivina hebes MacFadyen	1.12	0	0	2.29	0	0	0	0	0	0	0	0	0	0.44	0	0	0	0	0	0	0	0	0	0
Bolivina plicatella Cushman	1.86	4.6	1.23	0.76	0.38	0	0.41	0.8	0	0	0	0.38	12.5	3.51	0	2.23	1.13	0.41	0.43	1.2	0	0	3.6	1.87
Bolivina pokornyi Cicha et Zapletalova	0.37	0	1.64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina scalprata retiformis Cushman	0	0	0	0	0	0	0	0	0	0	0	0	0	6.58	0	0	0	0	1.28	0	0	0	0	0
Buchnerina buchneri (Margerel)	1.49	3.77	2.05	1.53	0.75	0	1.22	2.81	0.47	0	0.4	0.38	2.42	3.51	0	0.45	0	0.41	1.71	0.4	0	0	0.45	0.37
Bulimina elongata D'Orbigny	3.35	3.77	2.05	0.38	1.51	1.26	5.31	5.22	4.23	4.18	1.21	4.17	0.4	0	0	0.89	2.63	0.41	0.85	3.61	0	1.67	4.05	2.62
Bulimina striata D'Orbigny	2.23	2.09	0.82	0.38	0.75	0	1.22	1.2	0	0.84	0	1.14	2.02	2.19	0.49	0	4.89	1.65	0	2.41	0	2.93	0.9	2.62
Cancris auriculus (Fichtel et Moll)	0	0	0	0	0	0.42	0	0	0	0	0.4	0	0	0.44	0	0	0.38	0	0	0	0	0	0	0
Cassidulina laevigata D'Orbigny	4.83	2.09	3.28	0	0.75	1.26	9.39	10.8	2.35	3.77	0	9.09	4.84	6.14	0.49	0.89	1.13	0.82	1.71	0.4	0	0.42	2.25	0
Cibicides sp. (small-sized)	4.83	9.62	16	8.78	6.79	2.52	12.7	14.5	16	5.02	10.1	18.9	16.9	13.6	3.9	13.4	0.75	2.06	11.5	7.63	1.9	18.8	0	0.37
Cibicidoides austriacus (D'Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cibicidoides ungerianus (D'Orbigny)	0.74	1.26	2.87	3.05	2.26	2.94	2.86	2.01	3.29	2.09	0	3.79	1.61	3.51	0.49	3.57	1.5	3.29	2.56	2.41	5.24	2.93	2.25	3.37
Dentalina sp.	0	0	0	0.38	0.75	0	0	0	0	0	0	0	0	0.44	0	0.45	0.38	0	0	0	0	0	0	2.25
Elphidium crispum (Linne)	0	0	0	0	0	0	0	0	0	1.67	0.4	0	0	0	4.39	0	0.38	4.12	0.43	1.2	15.2	0	0	0
Elphidium fichtellianum (D'Orbigny)	0	0	0	0.76	0.38	0	0	0.4	0.47	0.84	2.02	0.76	0	0	1.46	0.89	0.75	0.82	0.43	0	0	0	0.45	0
Elphidium flexuosum (D'Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium macellum Fichtel et Moll	2.97	1.67	0	12.6	8.68	14.7	4.9	4.02	9.39	6.28	12.2	7.95	2.02	1.32	7.8	5.36	5.64	8.23	7.69	7.23	3.81	4.18	0.9	0
Elphidium ortenburgense (Egger)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium rugosum (D'Orbigny)	0	1.26	0	0.38	0.38	2.52	0.82	0.8	0.94	0.42	3.24	1.89	0	0.88	0.49	3.13	2.63	0.41	2.56	2.01	1.43	0.42	0	0
Elphidium sp. (juvenile)	0	0	1.64	0	0	0	0	0	0	0	0	0	0	0.44	0	0	0	0	0	0	0	0	0	0
Ehrenbergina serrata Reuss	0	0.42	0	0	0	0	0	0	0	0	0.4	0	0.4	0.88	0.98	0	0.38	0	0.43	0.4	0	0	2.7	3
Fursenkoina acuta (D'Orbigny)	0.37	0	0.41	0	0	0	0	0.8	0	0.42	0	0.38	0	0	0	0	0	0	0	0.4	0	0	0	0
Chilostomella ovoidea Reuss	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.41	0	0	0	0	0	0.37
Globocassidulina oblonga (Reuss)	8.55	12.1	8.2	0	4.91	0	4.08	4.02	2.35	0.84	1.21	2.65	4.03	4.39	0	1.79	0.75	0.41	2.14	2.41	0	5.02	3.15	0.37
Globulina gibba D'Orbigny	0.37	0	0	0	0	0.42	0.82	0	0	0.42	0	0.38	0	0	0	0	0.38	1.23	0.43	0.4	0	0	0	1.87
Globulina spinosa D'Orbigny	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.41	0	0	0	0	0	0
Grigelis pyrula (D'Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0.98	0	0.38	0.41	0	0	0.95	0	2.25	1.5
Hansenisca soldanii (D'Orbigny)	2.97	1.67	2.87	0.76	1.89	0.42	2.04	4.02	1.41	1.67	1.62	1.89	2.02	1.32	1.95	3.57	1.88	0.41	1.28	0.8	0	0.42	3.15	1.87
Hanzawaia boueana (D'Orbigny)	1.12	1.26	0	0	1.51	0.84	0.82	0.4	0.47	0.42	0.81	0.38	0.81	1.32	0	1.34	1.5	0	0.85	1.61	0	2.09	4.5	4.12
Heterolepa dutemplei (D'Orbigny)	4.09	2.93	2.05	1.15	5.66	1.26	7.76	3.21	11.3	15.1	5.67	2.65	1.21	0.44	8.78	1.34	8.27	3.7	4.27	5.22	1.9	2.09	1.8	3.37
Heterostegina sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hoeglundina elegans (D'Orbigny)	0.37	0	0.82	0.38	0	0	0	0	0	0	0	0	0	0	0	0.45	0	0	0	0	0	0.42	2.25	4.49
Karreriella chilostoma (Reuss)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0	1.13	0.82	0.43	0	0	0.42	0.45	5.62
Laevidentalina elegans (D'Orbigny)	0	0	1.64	0	0	0	0	1.61	0.47	0	0	1.52	4.03	0	0	0	0	0	0	0	0	0	0	3.75
Lagena striata (D'Orbigny)	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lagena hexagona (Williamson)	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lenticulina calcar (Linne)	0	0	0	0	0	0	2.45	0	1.88	0	0	0	0.4	0.44	0.49	0	1.5	0	0	0	0	0	0	0.37
Lenticulina clypeiformis (D'Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lenticulina inornata (D'Orbigny)	0.37	0	0	0.38	0.75	0	0	0	0.47	0	0	0.76	0.4	0	0	0	0	2.06	0	2.41	0	1.26	0.45	6.74
Lenticulina orbicularis (d´Orbigny)	0	0	0	0	0	0.42	0	0	0.47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lenticulina sp. (broken or abraded)	0	0	0	0	0	0	0	0	0	7.95	1.62	0	0	0	0	0	0	0	0	0	0	0	1.35	0
Lenticulina sp. (juvenile)	0.74	0.84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lenticulina vortex (Fichtel et Moll)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lobatula lobatula (Walker et Jacob)	7.81	8.79	5.33	19.1	8.3	17.7	15.1	4.82	13.2	11.3	15.4	11	11.7	13.6	10.7	8.48	9.77	8.23	12	12.1	6.67	10.5	3.6	3
Marginulina hirsuta D'Orbigny	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0	0	0	0	0	0

	Z2/16.9-17.0 m	Z2/16.6-16.4 m	Z2/15.9-16.0 m	Z2/15.4-15.5 m	Z2/15.1-15.2 m	Z2/14.4-14.8 m	Z2/14.1-14.2 m	Z2/13.9-14.0 m	Z2/13.8-13.9 m	Z2/13.7-13.8 m	Z2/13.3-13.4 m	Z2/12.9-13.0 m	Z2/12.2-12.3 m	Z2/11.5-11.6 m	Z2/11.0-11.2 m	Z2/10.8-10.9 m	Z2/9.9-10.0 m	Z2/9.2-9.3 m	Z2/8.8-8.9 m	Z2/8.5-8.6 m	Z2/8.3-8.4 m	Z2/7.8-7.9 m	Z2/6.9-7.0 m	Z2/6.0 m
Martinottiella karreri (Cushman)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Melonis pompiloides (d’Orbigny)	1.49	0.84	0.41	0	0.75	0.42	2.45	0.4	0.94	0.42	2.02	0.38	2.02	1.32	1.46	4.02	3.01	1.65	1.71	1.61	2.86	2.93	2.7	3.37
Nonion commune (d’Orbigny)	1.86	3.35	2.46	0.76	1.13	0	2.04	1.2	4.23	3.77	1.62	2.27	2.02	0.88	0.49	1.79	0.75	2.06	0.85	1.2	0.48	2.09	7.66	10.5
Nonion sp.	0	0	2.46	0	0	0	0.82	2.41	0	3.77	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nodosaria hispida d´Orbigny	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	3.6	1.12
Nummoloculina contraria (d’Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.93	0	0	0	0	0	0	0	0	0
Oridorsalis umbonatus (Reuss)	0	0.42	0	0	0	0	0	0	0.47	1.26	0	0	0	0	0	0	0.38	2.06	0	0	6.19	0.42	0	0
Neugeborina longiscata (d’Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0.38	0	0	0	0	0	0	0	0	0	0	0	0
Pappina parkeri (Karrer)	0	0.42	0	0	0	0	0	0	0	0	0	0	0.81	0	0	0	0	0	0	0	0	0	0	0
Pararotalia aculeata (d’Orbigny)	0	0	0	0	0	0	0	0	0.94	0.42	0.81	0	0	0	0.49	0	0	0	0	0	1.43	0	0	0
Planularia lanceolata (d’Orbigny)	0	0	0	0	0	0	0	0	0	0	0	0	0.81	0.44	0	0	0	0	0	0	0	0	0	1.12
Plectofrondicularia digitalis (Neugeboren)	0.74	0.42	0.82	0	0.75	0	0	0.8	0	0.42	0	0.38	0.4	0	0	0.45	0.75	0	0	0.4	0.95	0.42	0.45	0
Praeglobobulimina pyrula (d’Orbigny)	0	0	0	0	0	0	0	0	0	0.42	0	0	0	0	0	0	0.75	0	1.28	0	0	0	1.8	0.37
Porosononion granosum (d’Orbigny)	4.46	3.35	3.69	0	0	1.68	0.82	0	0.47	0	0	0	0.81	0	0	0	0	0	0	0	0	0	1.8	0
Pseudotriloculina consobrina (d’Orbigny)	0	0	0.41	0	1.89	0	0	0	0.47	0	0.4	0	1.21	0	0	0.45	0	0	0	0	0	0	0	0
Pullenia bulloides (d’Orbigny)	0	0	0	0.38	0.38	0	0.82	0.4	1.41	1.67	0.81	1.89	0	0.88	0	0.89	1.5	1.23	1.28	2.01	0.48	0.84	2.7	5.24
Pyramidulina raphanistrum (Linne)	0	0	0	0	0	0	0.41	0	0	0	0	0	0	0	0	0	0	0.41	0	0	0	0.42	0	0.37
Quinqueloculina buchiana d’Orbigny	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.42	0	0
Quinqueloculina hauerina (d’Orbigny)	0	0	0	0	0	0	0	0	0	0.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reussella spinulosa (Reuss)	1.12	0	1.64	3.44	1.89	1.26	0	0	0	0.42	0	0.76	0.4	1.75	0.49	1.79	1.5	0.41	1.28	1.61	0	2.51	0	0
Rosalina sp. (cf. *semiporata* (Egger)	1.12	0	0	1.91	1.89	1.68	0	0	0	0	0	0	1.21	0.88	0	0.45	0	0	0.43	0	0	0	0	0
Semivulvulina deperdita (d’Orbigny)	1.49	2.09	0	0	1.89	0.42	0	0.8	0.94	0.42	1.62	0	0	0	0	0	1.13	0	1.71	0.8	0	0.42	0	0
Sigmovirgulina tortuosa (Brady)	0	0	0	0	0	0	0	0	0	0	0	0	1.21	0.44	0	0	0	0	0	0	0	0	0	0
Siphonina reticulata (Czjzek)	0	0	0	0	0	0	0	0	0	0	0	0	1.21	0	0	0	0	0	0	0	0	0	0	0
Sphaeroidina bulloides d’Orbigny	0	0.42	0.41	0	0.75	0	0	0	0	0	0	0	0.4	1.75	0.49	0.89	1.5	0	0.85	0.4	0	0	0.45	3.75
Spiroloculina sp.	0.37	0.84	0	0	0	0	0	0.8	0	0	0	0	3.23	0	0.49	0.45	0.75	0.41	0.43	0.4	0	0	0.45	0.75
Spirorutilus carinatus (d’Orbigny)	0.74	0	0	0	0	0	0	0	0.47	0.42	0	0.38	0	0	0	0	1.13	0.41	0	0.4	0	0.84	0.45	0.37
Stilostomella adolphina (d’Orbigny)	4.83	1.67	0	0	3.4	0	0	0	0	0.42	0.4	0	0	2.63	0.49	2.68	2.63	0.82	0.85	1.61	0.48	0.42	5.41	3.75
*Stilostomella elegans (*d’Orbigny*)*	1.49	0.84	0	0.38	0	0	0	0	0.47	0.42	0	0	0.4	1.75	1.46	0	1.13	1.23	0	0	0.48	0.42	9.46	4.87
Textularia gramen d’Orbigny	1.49	0	0	0.76	0.38	0	0.41	0	0.94	0.84	0.81	0.38	0	0	0	0	0	2.06	0	0	5.71	0.84	0	0
Textularia laevigata d’Orbigny	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trifarina bradyi Cushman	1.49	0	0	0	1.13	0	0.41	1.2	0	0	0	1.14	3.63	1.75	0	0.45	0	0	0	0.4	0	0	2.7	0.37
Uvigerina aculeata d’Orbigny	0.74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.42	0	0.75
Uvigerina bononiensis Fornasini	1.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75
Uvigerina macrocarinata Papp et Turnovsky	0	0	0	0.38	0.38	0	0	0	0	0	0	0	0.4	0	0.98	0	2.63	1.23	0	0.8	0	0	2.25	0
Uvigerina pygmoides Papp et Turnovsky	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uvigerina semiornata d´Orbigny	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.8	0
Valvulineria complanata (d’Orbigny)	2.23	0	0	0	0	0	2.45	0	0	0	0	0	0	0.44	0	0	1.13	0	0	0.4	0	0	0	4.87
P/B	37.6	35.6	31.8	2.6	31.4	6.3	9.93	41	3.62	4.02	6.44	23.9	34	29.2	8.89	28.4	45.6	41.7	26.9	37.6	11	25.8	41	34.9
Foraminiferal number (specimens/1 g of rock sample)	287	337	358	242	139	408	54.6	141	22.1	33.2	17.6	312	691	587	15	313	176	50.2	320	239	18.9	64.4	96.9	123

Appendix 2: List and relative abundances of planktonic foraminiferal species.

	Z1/11.5-11.6 m	Z1/10.2-10.3 m	Z1/9.8-9.9 m	Z1/9.0-9.1 m	Z1/8.9-9.0 m	Z1/8.5-8.6 m	Z1/7.8-7.9 m	Z1/7.2-7.3 m	Z1/6.8-6.9 m	Z1/6.3-6.4 m	Z1/6.3 m	Z1/6.0-6.1 m	Z1/5.7-5.8 m	Z1/5.1-5.2 m	Z1/4.8-5.0 m	Z1/4.3-4.4 m	Z1/4.2-4.3 m	Z1/4.0-4.2 m	Z1/3.6-3.7 m	Z1/3.1-3.2 m	Z1/2.6-2.8 m	Z1/2.2-2.3 m	Z1/2.0-2.1 m	Z1/1.9-2.0 m	Z1/1.7-1.8 m	Z1/1.2-1.3 m	Z1/1.0-1.1 m	Paleoecological characteristic (Reynolds & Thunell 1985; Hemleben et al. 1989; Keller & Macleod 1992; Pujol & Vergnaud Grazzini 1995; Bicchi et al. 2003; Spezzaferri 1995; Rupp & Hohenegger 2008)
Turborotalita quinqueloba (Natland)	0	21.7	34.2	0	55.2	6.06	14.6	18.2	28.8	7.69	7.08	0	5	0	0	0	38.9	0	34.8	34.2	45.2	2.08	5.66	0	20	31.3	47.4	Mixed wather column, (?)eutrophic, stress, tolerant
Globigerina ottnangiensis Rogl	9.52	3.11	0	0	0	0	4.85	5.61	6.21	15.4	2.65	0	25	0	0	0	0	25	0	3.36	8.1	4.17	0	11.6	8.82	5.36	2.26	
Globigerina tarchanensis Subbotina et Chutzieva	0	11.2	18.7	4.48	19.5	0	3.88	17.8	0	0	0	6.67	0	0	0	0	41.9	0	28.3	29.5	27.6	8.33	11.3	3.16	17.7	35.7	25.6	
Globigerina praebulloides Blow	26.2	28.6	9.76	13.4	5.84	24.9	32	18.7	13	11.8	6.19	0	5	0	0	0	0	0	0	0	0	0	0	5.26	0	0	0	
Globigerina bulloides d'Orbigny	14.3	1.24	4.88	8.96	0.65	21.8	12.6	7.48	14.7	4.73	7.08	0	0	0	0	16.7	6.59	25	17.4	6.04	6.67	27.1	35.9	34.7	16.5	10.7	3.01	Eutrophic, intermediate dweller
Globigerina bulloides d´Orbigny (with bulla)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Globigerinoides bisphericus Todd	9.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.2	0	0	0	0	3.13	3.77	0	1.18	0	0	Oligotrophic, superficial dweller
Globigerinoides quadrilobatus d´Orbigny	2.38	0	0	2.99	0	0	0.97	0	1.69	1.78	0.88	0	0	0	0	0	0	0	0	0	0	1.04	0	0	0.59	0.89	0	Oligotrophic, superficial dweller
Globigerinoides trilobus (Reuss)	0	0	0	0	0	0	0	0	1.13	7.1	4.42	6.67	0	0	0	0	0	25	0	0.67	0	3.13	0	9.47	0	0	3.76	Oligotrophic, superficial dweller
Praeorbulina circularis Blow	7.14	0	0	2.99	0	1.82	0	0.93	0	0.59	1.77	0	0	0	0	16.7	0.6	0	0	0.67	0	3.13	0	0	0	0	1.5	Oligotrophic, superficial dweller
Orbulina suturalis Bronnimann	0	0	0	0	0	0	0	0	0	0	0	13.3	0	0	0	16.7	0	0	0	0	0	5.21	0	0	0	0	0	Oligotrophic, superficial dweller
Globigerinella regularis (d'Orbigny)	7.14	3.73	8.13	13.4	2.6	3.03	4.85	1.87	6.78	12.4	11.5	40	20	0	0	0	1.8	25	2.17	0.67	0.95	19.8	7.55	5.26	1.76	2.68	2.26	Oligotrophic
Paragloborotalia acrostoma (Wezel)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Paragloborotalia mayeri (Cushman et Ellisor)	23.8	30.4	24.4	53.7	16.2	42.4	26.2	29.4	27.7	38.5	55.8	26.7	40	0	0	0	7.78	0	17.4	20.8	10	15.6	32.1	22.1	32.4	13.4	10.5	Superficial dweller
Globorotalia peripherodonda Blow et Banner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Intermediate dweller
Globorotalia bykovae (Aisenstat)	0	0	0	0	0	0	0	0	0	0	2.65	6.67	5	0	0	50	1.2	0	0	4.03	1.43	7.29	3.77	8.42	1.18	0	3.76	Intermediate dweller
Catapsydrax sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Globoquadrina altispira (Cushman et Jarvis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

	Z2/16.9-17.0 m	Z2/16.6-16.4 m	Z2/15.9-16.0 m	Z2/15.4-15.5 m	Z2/15.1-15.2 m	Z2/14.4-14.8 m	Z2/14.1-14.2 m	Z2/13.9-14.0 m	Z2/13.8-13.9 m	Z2/13.7-13.8 m	Z2/13.3-13.4 m	Z2/12.9-13.0 m	Z2/12.2-12.3 m	Z2/11.5-11.6 m	Z2/11.0-11.2 m	Z2/10.8-10.9 m	Z2/9.9-10.0 m	Z2/9.2-9.3 m	Z2/8.8-8.9 m	Z2/8.5-8.6 m	Z2/8.3-8.4 m	Z2/7.8-7.9 m	Z2/6.9-7.0 m	Z2/6.0 m
Turborotalita quinqueloba (Natland)	18.5	30.3	65.8	0	31.4	0	18.5	26	37.5	0	5.88	25.3	28.1	26.6	0	25	3.59	9.2	15.6	19.3	0	21.7	18.2	0
Globigerina ottnangiensis Rogl	3.09	6.06	0	0	0	0	0	0	0	0	0	0	0	1.06	0	0	4.93	5.17	2.46	3.33	11.5	0	0	2.1
Globigerina tarchanensis Subbotina et Chutzieva	11.7	15.9	27.2	0	15.7	0	0	38.7	0	0	41.2	26.5	44.5	43.6	0	8.06	0	0	10.7	0	0	0	0	0
Globigerina praebulloides Blow	8.64	18.2	1.75	71.4	4.96	37.5	11.1	5.2	0	30	0	12.1	7.81	0	40	27.4	27.4	20.1	19.7	20.7	23.1	32.5	7.79	21.7
Globigerina bulloides d'Orbigny	9.26	0	0	0	5.79	12.5	25.9	0	12.5	30	23.5	0	0	4.26	15	4.84	20.2	12.6	3.28	14.7	30.8	0	8.44	18.2
Globigerina bulloides d´Orbigny (with bulla)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Globigerinoides bisphericus Todd	0	0	0	0	0.83	0	0	0	0	0	0	0	0.78	0	0	0	0	0	0.82	0	0	0	0.65	1.4
Globigerinoides quadrilobatus d'Orbigny	1.23	0	0	0	0	0	0	0	12.5	0	0	0	0	0	0	0	0	2.3	0	0	0	0	1.3	8.39
Globigerinoides trilobus (Reuss)	0	0	0	0	1.65	0	0	0	0	0	5.88	0	0	1.06	0	0	2.69	4.02	0	0	11.5	0	1.3	14.7
Praeorbulina circularis Blow	0	0	0	0	0.83	0	0	0	0	0	0	0	0	0	0	0.81	0.45	1.72	0	0	0	0	0	0.7
Orbulina suturalis Bronnimann	0	0	0	0	4.13	0	0	0	0	0	5.88	0	0	1.06	0	0	0.45	0	0	0	3.85	0	0	0.7
Globigerinella regularis (d'Orbigny)	3.09	0	0	0	3.31	6.25	14.8	3.47	0	20	5.88	12.1	0	1.06	20	1.61	6.73	4.6	2.46	2	15.4	0	0	1.4
Paragloborotalia acrostoma (Wezel)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paragloborotalia mayeri (Cushman et Ellisor)	43.2	29.6	5.26	28.6	31.4	37.5	25.9	22.5	37.5	10	5.88	22.9	15.6	21.3	25	31.5	33.6	39.7	45.1	39.3	3.85	45.8	59.7	23.8
Globorotalia peripherodonda Blow et Banner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Globorotalia bykovae (Aisenstat)	1.23	0	0	0	0	0	3.7	4.05	0	10	5.88	1.2	3.13	0	0	0.81	0	0	0	0.67	0	0	1.95	4.9
Catapsydrax sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Globoquadrina altispira (Cushman et Jarvis)	0	0	0	0	0	6.25	0	0	0	0	0	0	0	0	0	0	0	0.57	0	0	0	0	0.65	2.1

Appendix 3: List and relative abundances of calcareous nannoplankton species.

	Z1/0.7-0.8 m	Z1/1.0-1.1 m	Z1/1.2-1.3 m	Z1/1.7-1.8 m	Z1/1.9-2.0 m	Z1/2.0-2.1 m	Z1/2.6-2.8 m	Z1/3.1-3.2 m	Z1/3.6-3.7 m	Z1/4.0-4.2 m	Z1/4.3-4.4 m	Z1/4.8-5.0 m	Z1/5.1-5.2 m	Z1/5.7-5.8 m	Z1/6.0-6.1 m	Z1/6.3-6.3 m	Z1/6.3-6.4 m	Z1/6.8-6.9 m	Z1/7.2-7.3 m	Z1/7.8-7.9 m	Z1/8.5-8.6 m	Z1/8.9-9.0 m	Z1/9.0-9.1 m	Z1/9.8-9.9 m	Z1/10.2-10.3 m	Z1/10.3 m	Z1/10.9 m	Z1/11.1 m	Z1/11.5-11.6 m	Z1/11.8m	Remarks (paleoecological characteristics according Beaufort & Aubry 1992; Wells & Okada 1997; Flores et al. 1997; Bollmann et al. 1998; Kameo 2002; Wade & Brown 2006)
Coccolithus pelagicus (Wallich) Schiller	19.7	19.6	24.2	45.6	8.68	17.1	15.5	29.2	14.3	10.9	2.56	14.3	18.4	2.56	11.6	13.1	5.94	9.58	32.6	14.4	19.8	10.5	41.8	14	39.7	12.1	7.28	7.44	22.4	9.68	High-nutrient
Reticulofenestra minuta Roth	73.9	76.5	69.7	46.5	86.8	81.1	70.8	62.8	73.7	85.3	97.4	85.7	80.2	95.7	80.4	81.5	86.8	79.2	56	72.1	67.6	77.3	39	78.6	11	69.5	44.1	31	61.8	53	Stress-tolerant, euryhaline
Reticulofenestra haqii Backman	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.94	1.25	0	0	0	0	0	0	22.4	0	36.4	48.4	0	30	
Reticulofenestra pseudoumbilica Gartner	0	0.71	0.41	1.77	0.91	0	5.31	3.59	2.76	0	0	0	0	0.85	1.79	1.36	0	2.08	4.85	3.15	3.15	3.64	4.78	0.44	10.1	6.73	2.3	4.55	4.82	0	
Cyclicargolithus abisectus (Müller) Wise	0.38	0	0.41	0	0.46	0	0.44	0	0	0	0	0	0	0	0	0	0	0	0	1.35	0	0	0.8	0	0.46	0	0	0	0	0	Reworked - Oligocene
Reticulofenestra bisecta (Hay, Mohler & Wade) Roth	0	0	0.41	0.88	0	0	0	0	0	0	0	0	0	0	1.79	1.36	0	0	0.44	0	0	0	1.99	0	0.91	0.45	0	0	0	0.92	Reworked - Oligocene
Reticulofenestra daviesi (Haq) Haq	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	Reworked - Oligocene
Cyclicargolithus floridanus (Roth & Hay) Bukry	0.38	0	0.82	0	0	0	0.44	0	0.92	0.78	0	0	0.94	0	2.68	0	0	0	2.64	0	0.9	0	2.79	0	0	0.45	0	1.24	1.32	0	
Helicosphaera carteri (Wallich) Kamptner	1.89	0	0.82	1.33	0	0	0.44	0.9	0.92	0	0	0	0	0	0.89	0	0.91	1.25	0	0	2.25	0.45	2.39	1.31	1.37	3.14	0.77	1.24	2.63	0.92	
Helicosphaera walbersdorfensis Müller	2.27	1.42	1.64	1.33	2.74	0.9	4.87	0.9	4.15	2.33	0	0	0.47	0	0.89	2.71	0.46	4.58	1.76	7.21	3.6	6.36	4.38	4.37	9.59	4.04	7.66	4.55	5.7	2.76	
Syracosphaera pulchra Lohmann	1.14	1.42	0	0.44	0	0.9	0.88	0.9	1.84	0	0	0	0	0	0	0	0	1.25	0	0	0.45	0.45	0	0.44	0.91	1.79	1.53	1.24	0	0.46	
Sphenolithus heteromorphus Deflandre	0	0	0.41	0	0.46	0	0	0.9	0	0	0	0	0	0	0	0	0	0.42	0	0	0.45	0	0.4	0	0.91	0	0	0	0	0.46	
Sphenolithus moriformis (Bronnimann & Stradner) Bramlette & Wilcoxon	0	0	0.82	0	0	0	0	0.45	0.46	0.78	0	0	0	0	0	0	0	0	0.44	0.9	0.45	0.91	0.4	0.44	0	0	0	0	0	0	
Pontosphaera multipora (Kamptner) Roth	0.38	0.36	0.41	1.77	0	0	1.33	0	0.92	0	0	0	0	0	0	0	0	0.42	0.88	0.9	0	0	0.8	0.44	0.91	0	0	0	1.32	0	
Discoaster variabilis Martini & Bramlette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0	0	0	0	0	0	0	0.41	0	0	
Discolithina latelliptica Báldi-Beke & Báldi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.46	0.9	0	0	0	0.46	Reworked - Oligocene
Braarudosphaera bigelowii (Gran & Braarud) Deflandre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.46	Euryhaline
Thoracosphaera spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0.85	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0.46	Oligotrophic, stratified
Eifelithus spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Reworked -Cretaceous, Eocene
Watzenauria spp.	0	0	0	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.35	0.45	0	0	1.37	0	0	0	0	0.46	Reworked - Cretaceous
Nannoplankton abundance (semiquantitative, for explanantion see Method)	vi	vi	v	v	v	iv	iv	iii	iv	iii	i	i	iv	ii	i	vi	vi	vi	ii	iv	iv	iii	iii	v	ii	v	v	iv	iv	vi	

	Z2/16.9-17.0 m	Z2/16.6-16.4 m	Z2/15.9-16.0 m	Z2/15.4-15.5 m	Z2/15.1-15.2 m	Z2/14.4-14.8 m	Z2/14.1-14.2 m	Z2/13.9-14.0 m	Z2/13.8-13.9 m	Z2/13.7-13.8 m	Z2/13.3-13.4 m	Z2/12.9-13.0 m	Z2/12.2-12.3 m	Z2/11.5-11.6 m	Z2/11.0-11.2 m	Z2/10.8-10.9 m	Z2/9.9-10.0 m	Z2/9.2-9.3 m	Z2/8.8-8.9 m	Z2/8.5-8.6 m	Z2/8.3-8.4 m	Z2/7.8-7.9 m	Z2/6.9-7.0 m	Z2/6.5 m	Z2/6.0 m	Remarks (paleoecological characteristics according Beaufort & Aubry 1992; Wells & Okada 1997; Flores et al. 1997; Bollmann et al. 1998; Kameo 2002, Wade & Brown 2006; stratigraphical range Gradstein et al. 2012)
Coccolithus pelagicus (Wallich) Schiller	4.85	15.1	7.41	3.3	12.6	15.16	4.62	9.83	23.1	7.96	6.43	1.77	3.57	0.93	12.7	14.43	10.3	12.06	11.79	12.96	1.36	4.65	12.15	5.09	21.21	High-nutrient
Reticulofenestra minuta Roth	79.3	67.3	66.67	94.34	81.4	81.97	50.4	46.15	28.0	79.65	85.7	84.07	60.2	79.44	67.4	40.21	45.4	23.05	36.59	48.61	59.09	82.95	80.97	85.65	0	Stress-tolerant, euryhaline
Reticulofenestra haqii Backman	8.81	5.31	16.67	0	0	0	42.0	42.74	42.6	9.29	3.57	7.08	33.4	16.36	15.5	34.36	37.1	56.74	42.68	30.09	31.36	0	0	1.39	69.26	
Reticulofenestra pseudoumbilica Gartner	2.64	4.49	3.7	0.94	0	0.82	0.42	0	0	1.77	0.71	2.21	0.45	0.47	3.3	4.47	4.13	6.38	1.22	3.7	5.91	6.2	2.02	2.78	0	
Cyclicargolithus abisectus (Müller) Wise	0	0	0	0	0	0	0	0	1.22	0	0	0	0	0	0	0	0.83	0	0	0	0	0	0	0	0.43	
Reticulofenestra bisecta (Hay, Mohler & Wade) Roth	0	0	0	0	0	0	0	0	1.22	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	Reworked - Oligocene
Reticulofenestra daviesi (Haq) Haq	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.78	0	0	0.43	Reworked - Oligocene
Cyclicargolithus floridanus (Roth & Hay) Bukry	1.32	0.41	0.37	0	0	0	0	0.43	1.22	0	0	0.88	0	0	0	0	0	0	1.22	0	0	0.78	0	0	0	Reworked - Oligocene
Helicosphaera carteri (Wallich) Kamptner	0	1.63	1.48	0	0.9	0	0	0	1.22	0	0	0.44	0	0	0	2.41	0	1.42	1.63	0	0	0.78	1.62	1.85	0	
Helicosphaera walbersdorfensis Müller	1.32	2.04	2.22	0.94	2.71	1.64	1.68	0	0	0.44	2.14	0.44	2.23	0.93	0.94	2.75	1.24	0	2.85	2.31	0.45	3.1	1.21	2.31	3.46	
Syracosphaera pulchra Lohmann	0	2.45	1.11	0.47	2.26	0.41	0.84	0.43	0	0.44	0	0	0	0.93	0	0.69	0.83	0	0.81	0.46	0.45	0	0.81	0.46	3.03	
Sphenolithus heteromorphus Deflandre	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.81	0	0.43	
Sphenolithus moriformis (Bronnimann & Stradner) Bramlette & Wilcoxon	0	0.41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.78	0	0	0.43	
Pontosphaera multipora (Kamptner) Roth	0.44	0.82	0.37	0	0	0	0	0	1.22	0.44	0	0	0	0	0	0.34	0	0.35	0.41	0.93	0	0	0	0.46	0	
Discoaster variabilis Martini & Bramlette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.43	
Discolithina latelliptica Báldi-Beke & Báldi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.34	0	0	0	0	0	0	0	0	0	Reworked - Oligocene
Braarudosphaera bigelowii (Gran & Braarud) Deflandre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Euryhaline
Thoracosphaera spp.	0	0	0	0	0	0	0	0	0	0	1.43	1.33	0	0.93	0	0	0	0	0	0.93	0.91	0	0	0	0	Oligotrophic, stratified
Eifelithus spp.	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0	0	0	0	0	0.41	0	0	0	0	0	0	Reworked - Cretaceous, Eocene
Watzenauria spp.	0.88	0	0	0	0	0	0	0.43	0	0	0	1.33	0	0	0	0	0	0	0.41	0	0.45	0	0	0	0.43	Reworked - Cretaceous
Nannoplankton abundance (semiquantitative, for explanantion see Method)	iii	v	v	iv	iv	v	iv	iv	i	ii	i	iii	vi	v	ii	v	vi	v	v	iv	iii	ii	v	v	v	

Appendix 4: List and relative abundances of mollusca.

ŽIDL- 1	**0.9-1**	**1.4-1.5**	**2.3-2.4**	**2.7-2.8**	**3.7-3.8**	**4.2-4.3**	**5.5-5.6**	**7.2-7.3**	**7.8-7.9**	**8.4-8.5**	**9.2-9.3**	**10.1-10.2**	**11.9-12**
BIVALVIA													
Cubitostrea digitalina (DuBois, 1831)	1	2	1				1			1			
Ostreidae indet.		2		1	1	1	2		1	2			
?*Pododesmus striatus* (Brocchi, 1814).			1				1						
Crassadoma multistriata (Poli, 1795)	2	2	2	1	1		2				2		
?*Aequipecten* sp.	2	2	1		1	1							
Costellamussiopecten cf. *spinulosus* (Münster, 1833)	2	2	1	1		1							
Aequipecten cf. *scabrellus* (Lamarck, 1819)								1		1			
Pectinidae indet.							2	1	1	2	2		
Cardiidae indet.				1									
Carditidae indet.										1			
Veneridae indet.					1								
Nuculana cf. *fragilis* (Chemnitz, 1784)								1		1	1	1	
Nuculana sp.									1				
Nucula sp.										1			
Bivalvia indet.	2				2		2	1	1	2	2	1	1
GASTROPODA													
Bittium sp.				2			1						
Alvania sp.				1								1	
Solariorbis sp. (cf. *woodi* (Hörnes, 1856)												1	
Gastropoda indet.										2			
Cirripedia indet.	1						1						

ŽIDL- 2	**8.1-8.2**	**8.7-8.8**	**9.7-9.8**	**10.8-10.9**	**12.7-12.8**	**14.3-14.4**	**15.9-16**	**16.9-17**					
BIVALVIA													
Cubitostrea digitalina (DuBois, 1831)		1	1	2	1	1							
Ostreidae indet.	2	2	2	2	2	1	1	1					
Ostrea sp.		1											
?*Pododesmus striatus* (Brocchi, 1814)						1	1	1					
Crassadoma multistriata (Poli, 1795)	2	2	2	2	2	2	2	2					
Aequipecten cf. *macrotis* (SoWerBy in Smith, 1847)		1	2	2	2	1	1						
Aequipecten cf. *scabrellus* (Lamarck, 1819)		1											
?*Aequipecten* sp.			1					1					
Costellamussiopecten cf. *spinulosus* (Münster, 1833)				2		1		1					
Flexopecten cf. *scissus* (Favre, 1869)		1				1		1					
?*"Chlamys" trilirata* (Almera et Bofill, 1897)						1	1	1					
?*Macrochlamis* sp.					1								
Pectinidae indet	2	2	2	3	2	2	1	1					
Cardiidae indet.		1											
Veneridae indet.							1						
Nuculana cf. *fragilis* (Chemnitz, 1784)							1						
?*Spondylus* sp.								1					
?*Corbula* sp.								1					
Bivalvia indet		2		3		2	1	2					
GASTROPODA													
Bittium sp.	3	1	1										
Alvania sp.	3												
?*Gibbula* sp.	1												
Rissoina sp.	1												
Solariorbis sp. cf. *woodi* (Hörnes, 1856)	1												
Gastropoda indet.	3	2											
Cirripedia indet.	1	1											

semiquatitative abundance (number of fragments): 1 - rare (1-5 fragments); 2 - common (6-15 fragments); 3 - abundant (over 15 fragments)

Appendix 5: List and relative abundances of ichthyofauna.

	Deania sp. (tooth)	„g. *Etrumeus*" *weileri*	*Vinciguerria poweriae*	*Valenciennellus tripunctulatus*	*Benthosema fitchi*	*Diaphus acutirostrum*	*Diaphus cahuzaci*	*Diaphus haereticus*	*Diaphus kokeni*	*Diaphus regani*	*Diaphus taaningi*	*Diaphus* sp. juv. corroded	*Lampichthys schwarzhansi*	*Notoscopelus mediterraneus*	*Grammonus* sp.	*Physiculus* aff. *huloti*	*Gadiculus argenteus*	*Gadomus tejkali*	*Coelorinchus* sp.	*Trachyrincus scabrus*	*Merluccius* aff. *merluccius*	Sparidae indet. (tooth)	*Brachydeuterus speronatus*	Acropomatidae indet.	*Trachurus* aff. *picturatus*	*Lesueurigobius* ex. gr. *vicinalis*	*Deltentosteus telleri*	Gobiidae indet. juv. corroded
ŽIDL-2:																												
6.6-6.7 m												+																
7.6-7.8 m												+																
10.6-10.8 m												+																
11.6-11.8 m												+																+
14.6-14.8 m																						+						
15.6-15.8 m			+		+	+				+	+	+																
16.6-16.8 m					+	+	+		+		+												?					+
ŽIDL-1:																												
2.8-3.0 m	+											+																
6.6-6.8 m				+							+	+		+														+
7.5-7.8 m						+						+																
8.6-8.8 m						+	+					+																
9.6-9.8 m				+		+	+					+														+		+
10.6-10.8 m												+												+		+		
clay pit	+	?	+	+	+	+	+	+	+	?		+	+		+	+	+	+	+	+	+		+		+	+	+	+

Appendix 6: Composition of studied limestone samples with identified facies.

Thin-section/components	Corallines	Bryozoa	Molluska	Foraminifera	Echinoids	Serpulids	Unsorted	Micrite	Sparite	Litoclasts	Pores	Facies
42139-11151 ŽIDL-2 13.3 m	27.31	3.41	1.46	2.44	0.98	0	41.95	11.22	5.37	5.85	0	CAdl
42139-11251, ŽIDL-2 13.3 m	20.3	15.35	0	0.99	0	0	36.14	25.25	0.5	1.49	0	CAdl
42139-111051, ŽIDL-210.6 m	35.61	1.95	0.98	0	0	0	27.32	1.95	14.15	18.5	0	CAdl
42139-11351, ŽIDL-2 9.6 m	48.81	13.27	1.42	0	1.42	0.47	12.32	19.43	0	2.84	0	Bbr
42139-11551, ŽIDL-1 6.3 m	18.36	13.53	0	0.97	1.45	2.42	42.51	13.4	7.25	0	0.48	RFgm
42139-11751, ŽIDL-1 6.3 m	45.06	30.2	0	0	0	0	15.35	7.43	1.49	0	0.5	RFgm
42139-11851, ŽIDL-1 6.3 m	49.76	14.43	0	0	0.5	0.5	17.41	15.92	1	0.5	0	RFgm
42139-11951, ŽIDL-1 6.3 m	45.55	13.37	0	0	0.99	1.49	22.77	12.38	0	3.47	0	RFgm
42139-111151, ŽIDL-1 6.3 m	57.71	38.31	0	0	0	0	0.5	3.48	0	0	0	RFgm
42139-11651, ŽIDL-1 4.7-4.8 m	13.8	17.24	0	0.49	0	0.49	28.8	4.43	14.78	18.23	2.46	CAdl
42139-11451, ŽIDL-1 4.5-5 m	12.5	1.92	0	2.4	1.44	0	50.96	12.2	8.17	10.58	0	CAdl

Appendix 7: List and relative abundances of palynomorphs.

			ŽIDL-2 - 246 m a s.l.						ŽIDL 1 - 230m a s.l.									
		Taxon/m	15.6-8	16	16	16.6-8	16.8		7	7.5-8	8.5	9.7	10	10.6-8	10.9	11.1	11.8	11.9
marine Dinophyta	several types	Types with branched projections	x	x		xx	xx		xx	x	xx	xx	x	x	x	x	x	x
other Dinophyta	*Ovoidites…*	several types		x					x			xx					.	
Cyanophyta	gen. indet.	*Sigmopollis laevigatoides* Krutzsch & Pacltová 1990								x					x			x
Chlorophyta	Tasmanaceae	*Pterospermella* Eisenack 1972, *Pleurozonaria* Wetzel 1933	x	x	x	x	x		x	x		x				x		
	Botryococcus	*Botryococcus braunii* Kützing 1969	.	x	x		.		x	x			.		.	x	x	
	kubic caves		x			x	x				x			x	x		x	x
Sporophyta																		
- „ -	gen. indet.	*Toroisporis* sp.														1		
?Polypodiaceae	gen. indet.	*Laevigatosporites haardti* (Potonié & Venitz 1934) Thomson & Pflug 1953	1	1	1	2	3				2	1	2	1		2		2
Davaliaceae	*Davalia*	*Verrucatosporites alienus* (Potonié 1931) Thomson & Pflug 1953			1				1									
Dennstaedtiaceae	*Paesia*	*Verrucatosporites favus* (Potonié 1931) Thomson & Pflug 1953		1			1			1	1	1	1		x			
Gleicheniaceae	gen. indet.	*Neogenisporis neogenicus* Krutzsch 1962																1
Lycopodiaceae	*Lycopodium*	*Retitriletes* sp.		1	1													
Lygodiaceae	*Lygodium*	*Leiotriletes wolffi* Krutzsch Krutzsch 1962	1			1				1		1						1
		Corrugatosporites multivallatus (Thomson & Pflug 1953) Planderová 1990/*microvallatus* (Krutsch 1967) Nagy 1985										1						
	- „ -	*Leiotriletes maxoides* Krutzsch 1962					1										1	1
Lygodiaceae	gen. indet.	*Leiotriletes* sp., *Triplanosporites sinuosus* Pflug 1952 ex Thomson & Pflug 1953	1	1	1					1				1				
Osmundaceae	*Osmunda*	*Baculatisporites primarius* (Wolff 1934) Thomson & Pflug 1953										1	1	1	x	1	1	1
Pteridaceae	gen. indet.	*Undulozonosporites semiverrucatus* (Krutzsch 1967) Stuchlik 2001										1						
Pteridaceae	*Pteris*	*Polypodiaceoisporites muricinguliformis* Nagy 1959/*corrutoratus* Nagy 1985	3	3	1	2	2			3	7	5	5	1		5		1
Selaginellaceae	*Selaginella*	*Echinatisporis miocenicus* Krutzsch & Sontag in Krutzsch 1963										1						
Gymnosperms																		
Pinaceae	*Pinus*	haploxylon and sylvestris types	63	600	228	182	168		348	278	120	540	650	198	260	46	200	123
	Cathaya	*Cathayapollenites krutzschi* (Sivak 1976) Planderová 1990	13	100	28	14	14		27	44	28	63	70	23	31	9	35	27
	Keteleeria	*Keteleeriapollenites dubius* (Chlonova 1960) Slodkowska 1994	1	1		1			2	1					1			1
	Picea	*Piceapollis* sp.	4	9	3	4	4		2	3	4	3		5	1	2	3	2
	Abies	*Abiespollenites* sp.		1					1	2	2				1			1
	Cedrus	*Cedripites miocaenicus* Krutzsch 1971	2	2	2	5	5		4	2	5	3	1		4	2	4	
	Tsuga	*Zonalapollenites maximus* (Raatz 1937) Krutzsch 1971	2	1	6		1		2		2	1	1		5		1	
Sciadopitaceae	*Sciadopitys*	*Sciadopityspollenites serratus* (Potonié & Venitz 1934) Raatz 1937	2	7	7	2	2			3	4	5	4	1	5	2	3	2
Taxodiaceae	*Taxodium, Glyptostrobus* type	*Inaperturopollenites hiatus* (Potonié) Thomson & Pflug; *I. concepidites* (Wodehouse) Krutzsch	1	21	21	23	20			12	7	46	8	32	3	14	14	50
	Sequoia	*Sequoiapollenites polyformosus* Thierg.											2			1		3
Ephedraceae	*Ephedra*	*Ephedripites* div. fsp.										1		1				1
Angiosperms																		
Aceraceae	*Acer* sp.	*Aceripollenites striatus* (Pflug 1959) Thiele-Pfeifer 1980		1							1	1	1					2
Aquifoliaceae	*Ilex*	*Ilexpollenites margaritatus* (Potonié 1931) Raatz 1937 ex Potonié 1960	2	1	1				1								1	2
	- „ -	*Ilexpollenites propinquus* (Potonié 1931) Thiergart 1937 ex Potonié 1960		2		3	3			2		2	3	3			3	
Araliaceae	*Aralia*	*Araliaceoipollenites edmundi* (Potonié 1931) Potonié 151 ex Potonié 1960		1	1	1	1						2					
	Hedera	*Araliaceoipollenites reticuloides* Thiele-Pfeifer 1980	1	1														
Asteraceae	gen. indet.	*Tubulifloridites macroechinatus* (Trevisan 1967) Nagy 1985		1			1		1		1							1
	gen. indet.	*Cichorieacidites gracilis* Nagy 1969 (Nagy 1985)																
	Artemisia	*Artemisiapollenites sellularis* Nagy 1969												2				
Betulaceae	*Alnus*	*Alnipollenites verus* (Potonié 1931 ex Potonié 1960)	2	4	8	2	2		2	6	3	7	2	4	1	2	1	4
	Betula	*Betulaepollenites betuloides* (Pflug 1953) Nagy 1969	3	4	4	2	3			2	1	4	4			2		4
	Carpinus	*Carpinidites carpinoides* (Pflug 1953) Nagy 1985								1		2	2					
	Ostrya	*Ostryapollenites rhenanus* (Thomson 1950) Nagy 1969		1									1					
Buxaceae	*Buxus*	*Buxapollis buxoides* Krutzsch 1966	2	1	1	1	2			1	2		2	1				
?Caryophyllaceae	gen. indet.	*Caryophyllidites microreticulatus* Nagy 1969																
Caryophyllaceae, Alismataceae	*Stellaria, Alisma*	*Minutipollis granulatus* Krutzsch 1966																
Caryophyllaceae	gen. indet.		17	8	15	12	12		1	6	8	8	10	3	5	8	1	2
Cercidiphyllaceae	*Cercidiphyllum*	*Cercidiphyllites minimireticulatus* (Trevisan 1967) Ziembińska-Tworzydło 1994			1					1		6		1	1	2	1	
Cornaceae	Cornoideae, Mastixioideae	*Cornaceaepollis satzveyensis* (Pflug 1953) Ziembińska-Tworzydło 1994	1	1	1	1	2						2		2		1	2
Corylaceae	*Corylus*	*Triporopollenites coryloides* Pflug		1									1					
Cyrillaceae, Clethraceae	gen. indet.	*Tricolporopollenites megaexactus* (Potonié 1931) Thomson & Pflug 1953	2	6	3	2	2			4	4	13	5	12	3	4	4	8
	- „ -	*Tricolporopollenites exactus* (Potonié 1931) Grabowska 1994	3	2	2	4	3				1	1	2	2	1		4	4
	Calluna	*Ericipites callidus* (Potonié 1931) Krutzsch 1970		1		1	2										2	
Eucommiaceae	*Eucommia*	*Eucommioipollis parmularius* (Potonié 1934) Ziembińska-Tworzydło 1994		2	1					1		2		2		1	1	1
Fagaceae	*Fagoideae*	*Tricolporopollenites pseudocingulum* (Potonié 1931) Thomson & Pflug 1953	2			1	2				2	3	1	4		2		1
	Trigonobalanus	*Fususpollenites fusus* (Potonié 1931) Kedves 1978										2						

			ŽIDL-2 - 246 m a s.l.						ŽIDL 1 - 230m a s.l.									
		Taxon/m	15.6-8	16	16	16.6-8	16.8		7	7.5-8	8.5	9.7	10	10.6-8	10.9	11.1	11.8	11.9
	Castaneoideae, *Trigonobalanopsis*	*Tricolporopollenites cingulum* (Potonié 1931) *oviformis* Thomson & Pflug 1953	6	4	3	4	4			5	8	16	9	21	3	6	6	10
	?Castaneoideae X Lythraceae (*Decodon*)	*Tricolporopollenites cingulum* (Potonié 1931) *pusillus* Thomson & Pflug 1953	4	3	2	4	3			1	3	4	2	3	3	1	2	4
	gen. indet.	*Quercoidites henrici* (Potonié 1931) Potonié, Thomson, Thiergart. 1950	4		1	3	3			1		2		2	1	2		3
	gen.indet.	*Quercoidites microhenrici* (Potonié 1931) Potonié, Thomson, Thiergart. 1950	7	20	14	8	12			14	14	31	7	21	1	8	7	25
	- „ -	*Quercoidites* sp., *Q. granulatus* (Nagy 1969) Slodkowska 1994, *Q. asper* (Pflug &Thomson 1953) Slodkowska 1994	3	5	5	5	8			9	3	8	5	6		2	1	5
		Quercus ilex type			3		1			8	7					4		9
	Fagus	*Faguspollenites verus* Raatz 1937	3	2		3	3			2		1	4	3			1	3
	gen. indet.	*Tricolporopollenites liblarensis* (Thomson 1950) Grabowska 1994	18	13	26	31	28		10	16	20	15	5	15	1	17	7	15
	gen. indet.	*Tricolporopollenites quisqualis* (Potonié 1934) Krutzsch 1954	11	2	7					3	8	4	1	3		2		3
Hamamelidaceae	*Liquidambar*	*Liquidambarpollenites stigmosus* (Potonié 1934) Krutzsch 1954	1	1		1	1		1	1	2	3	3				1	3
		Periporopollenites orientalis (Nagy 1969) Kohlan-Admska & Ziembińska-Tworzydło 2009									3		2		1	1		
	Parrotia-Distylium type	*Tricolporopollenites indeterminatus* (Romanovicz) Ziembińska-Tworzydło 1994									1							
	Parrotia-Distylium type	*Tricolporopollenites starosedloensis* Krutsch & Pacltová 1969																
Chenopodiaceae	gen. indet.	*Chenopodipollis multiplex* (Weyland & Pflug 1957) Krutzsch 1966	3			2	2			1			1	2		1		
Juglandaceae	*Carya*	*Caryapollenites simplex* (Potonié 1931) Raatz 1937	3	6	5	3	3		1	7	8	12	4	3	7	21	4	5
	Pterocarya	*Pterocaryapollenites stellatus* (Potonié 1931) Thiergart 1937	1	1	2	1	2			3		2	1	1	2	1		1
	Juglans	*Juglanspollenites verus* Raatz 1937	4	9	5	4	4			5	1	4	4	1	1	4		2
	Engelhardia	*Engelhardtioidites punctatus* (Potonié 1931) Potonié 1951 ex Potonié 1960, *E. quietus* (Potonié 1931) Potonié 1951	12	21	25	15	12			20	14	29	8	33	1	25	16	18
	Platycarya	*Platycaryapollenites miocaenicus* Nagy 1969	6	3	8	6	7			4	8	7	3	5	2	4	5	7
Lamiaceae	gen. indet.										1			4				1
	Lavandula t.													2				
	Salvia t.										2					2		
Lythraceae	gen. indet.	*Lythraceaepollenites* sp.		1	4		1		3				2	1		6		
?Magnoliaceae	gen. indet.	*Magnoliapollis neogenicus* Krutzsch 1970					1						1					
Myricaceae	*Myrica*	*Myricipites bituitus* (Potonié 1931) Nagy 1969 / *coryphaeus* (Potonié 1931) Potonié 1960	7	15	14	9	11			13	17	21	8	17		4	6	26
Nyssaceae	*Nyssa*	*Nyssapollenites kruschi* (Potonié 1931) Nagy 1969											1			1		1
Nymphaeaceae	*Nymphaea*	*Nymphaeaepollenites* Nagy 1969											1					1
Oleaceae	*Olea* t.	*Oleaidearumpollenites* sp.	15	9	14	18	15			2	8	20	11	13		4	8	7
	Sambucus, Fraxinus	*Oleaidearumpollenites microreticulatus* Thomson & Pflug																
	Fraxinus	*Fraxinoipollenites* sp.	5	3	6	5	5			8	11	7	4	15		5		4
Plantaginaceae	*Plantago*	*Plantaginacearumpollenites miocaenicus* Nagy								1			1		1			
Platanaceae	*Platanus*	*Platanipollis ipelensis* (Pacltová) Grabowska	13	6	9	16	16			6	17	19	8	14	3	1	3	6
Polygonaceae	*Rumex*	*Rumex* t.	1	1		2	2					2		2				1
Ranunculaceae	*Thalictrum*	*Thalictrum* t.	1			1				1	4		2			3		
Rosaceae	*? Sorbus*	*Sorbus* t.																
	cf. *Rubus* type	*Rubus* t.	1			1	1							1				1
Rubiaceae	*Galium*	*Galium* t		3	2					1	5		1	2		4		2
Rutaceae	gen. indet	*Rutacearumpollenites* sp.	1	2	3	1	2						2				3	1
Salicaceae	*Salix*	*Salixipollenites* sp.		7	1	1	1			3	4	3		1		2	1	3
Sapotaceae	gen. indet. - several types	*Sapotaceoidaepollenites* div. sp.										2	2	1		1		1
Staphyleaceae	*Staphylea*	*Staphylea* t.									1							
Sterculiaceae	*Reevesia*	*Reevesiapollis triangulus* (Mamczar 1960) Krutzsch 1970	1				1			1								
Symplocaceae	*Symplocos*	*Symplocoidites vestibulum* (Potonié 1931) Potonié 1960									1	1				1		
?Tamaricaceae	*?Tamarix*	*Tamarixpollenites* sp.											1	1		4		1
Tiliaceae	*Craigia*	*Intratriporopollenites insculptus* Mai 1961		1	2	1							1					
	Tilia	*Intratriporopollenites instructus* (Potonié 1931) Thomson & Pflug 1953	1	2	1	1	1			1	1	2	1					
Tricolporopollenites indet.	gen. indet. - several types	*Tricolporopollenites* indet.	9	15	10	12	8			10	9	27	5	18		6	6	
Ulmaceae	*Ulmus*	*Ulmipollenites undulosus* Wolff 1934	19	23	23	18	17			29	30	35	7	8	8	18	10	14
	Zelkova	*Zelkovaepollenites potoniei* Nagy 1969	2	1	2		1			1		1		2	4	2	2	
	gen. indet.														1			
	Celtis	*Celtipollenites* sp.	17	18	13	19	19		2	7	20	15	5	4		11	2	13
Urticaceae	gen. indet.	*Urtica* t.		3								1						
Verbenaceae	gen. indet.	*Tricolporopollenites wackersdorfensis* Thiele-Pfeifer 1980									1							1
	Clerodendrum type	*Clerodendrumpollenites minimireticulatus* Skawinska 1994													1			
Vitaceae	*Parthenocissus*	*Tricolporopollenites marcodurensis* Thomson & Pflug 1953		1														
Liliopsida																		
Arecaceae	gen. indet.	*Arecipites* sp.									1		1	1				
	Calamus	*Dicolpopollis kockeli* Pflanzl 1956	1	2	1	2	1				1					1	2	2
Butomaceae	*Butomus*	*Butomuspolenites* sp.																
Poaceae	gen. indet.	*Graminides* sp.	2	6	4	1	1			1		1		1		3		7
Potamogetaceae	*Potamogeton*	*Potamogeton* sp.		2	1							1						
Sparganiaceae	*Sparganium*	*Sparganiaceaepollenites* sp.		1												1		

SBORNÍK NÁRODNÍHO MUZEA V PRAZE
Řada B – Přírodní vědy • sv. 64 • 2008 • čís. 2–4 • s. 165–173

ACTA MUSEI NATIONALIS PRAGAE
Series B – Historia Naturalis • vol. 64 • 2008 • no. 2–4 • pp. 165–173

PANNONIAN VEGETATION FROM THE NORTHERN PART OF VIENNA BASIN

NELA DOLÁKOVÁ
Institute of Geological Sciences, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic, e-mail: nela@sci.muni.cz

MARIANNA KOVÁČOVÁ
Comenius University, Faculty of Sciences, Department of Geology and Palaeontology, Mlynská dolina,
SK – 842 15 Bratislava, Slovak Republic, e-mail: kovacova@fns.uniba.sk

Doláková, N., Kováčová, M. (2008): Pannonian vegetation from the northern part of Vienna Basin. – Acta Mus. Nat. Pragae, Ser. B, Hist. Nat., 64(2–4): 165–173. Praha. ISSN 0036-5343.

Abstract. The studied pollen assemblages come from the Pannonian (Tortonian and Early Messinian) sediments in the Moravian and Slovak part of the Vienna Basin. Vienna Basin represents a pull-apart basin situated between the Eastern Alps and Western Carpathian mountain ranges. Due to the paleogeographic changes and climatic oscillations during the Late Miocene, the number of thermophilous taxa decreased, and some of them disappeared completely. The variable heights and forms of the uplifted mountain chains created ideal conditions for mixed mesophytic forests and extrazonal vegetation (*Cedrus, Tsuga, Picea*). The swamp, riparian, often hydrophilous (*Azolla*, *Nymphaea*, *Potamogeton*) and halophyte (Chenopodiaceae) plants represent coastal swamps, local lagoons, and marshlands. Occasional occurrences of dinoflagellates indicate slightly higher salinities, whereas green algae of the genus *Pediastrum* represent freshwater environments. The amount of herbaceous plants (*Artemisia*, Asteraceae, Lamiaceae, *Polygonum*, Daucaceae, Caryophyllaceae, *Plantago)* increased.

■ Late Miocene, Palynology, Vienna Basin, Paleoclimate

Received August 8, 2008
Issued December 2008

Geology

Important changes in the paleogeography of the Western Carpathians can be documented during the Late Miocene. The basins represent grabens or half grabens; partly „pull apart" basins along strike slipe zones, but mostly flexural type basins without apparent brittle tectonics, except for normal faults at the basins´ margins (Kováč 2000).

The Vienna Basin is situated within the Alpine-Carpathian mountain chain, between the Eastern Alps and the Western Carpathians. It represents a polyhistoric basin with Neogene to Quaternary sedimentary fill, deposited in various types of basins in relation to the paleotectonic development of the orogen. During the Late Miocene, due to paleogeographic changes, the connection with the Pannonian basin became gradually closed. Lake Pannon retreated southwards, and the northern coast of the back-arc basin was slightly elevated due to progradation of deltaic and alluvial facies, especially in the lowlands. Lake Pannon was continuously filled by sediments transported by rivers from uplifting mountain chains. The sedimentary environments changed from deep to shallow lake and deltaic environment, followed by development of alluvial plains. Due to Paratethys isolation, the salinity decrease led to the development of a totally fresh-water environment by the end of this period. (Kováč et al. 1998).

Material and methods

All the studied samples were pelitic, partly calcareous sediments. The lignite layers have not been used in these studies.

The pollen data come from the well-preserved and well-determined plant macrofossil samples of the E. Knobloch collection deposited in the Moravian Museum Brno, ~~(Postorna, Dubnany, Moravske Nova Ves~~ surface localities – 13 samples), claypit Gbely, deep boreholes (Suchohrad 32, Suchohrad 38, Jakubov 54 – 30 samples), and six shallow boreholes (28 samples) made by the interdisciplinary research programme (archeology, natural environment) of the Masaryk University Brno at the Slavic (Great Moravian) settlement Pohansko near Břeclav.

For maceration of the samples, HCl, HF and heavy liquid $ZnCl_2$ were used. Pure glycerine or glycerine gels were used mostly as the observation media.

The coexistence approach is an efficient and reliable method for quantitative terrestrial palaeoclimate reconstructions in the Tertiary. It is based on the assumption that Tertiary plant taxa have similar climatic requirements to their nearest living relatives. The aim of the coexistence approach is to find for a given fossil flora, the climatic interval in which all the nearest living relatives of the fossil flora can coexist (Mosbrugger and Utescher 1997).

Vegetation and climate

Detailed palaeontological study of the Late Miocene sediments of the Vienna Basin were realized by Bůžek (1962) at the locality of Poštorná. At different localities, systematic macrofloristic studies were carried out by Knobloch (1962, 1963, 1968, 1969, 1972, 1981, 1985). In these studies Knobloch categorised the Pannonian and Pontian vegetation of this area into the four different mutually associated floristic biotopes – 1.vegetation of the open water level (*Azolla*, *Nymphaea*, *Trapa*, *Potamogeton, Ceratophyllum*) 2. coastal and coastal rim plants (*Carex*, *Scirpus*, *Phragmites*, *Sparganium*) 3. plants associated with brown coal swamp forest (*Glyptostrobus*, *Nyssa*, *Alnus*, *Byttneriophyllum*, *Myrica*, *Acer*), and 4. vegetation growing on the moist inner land stands (*Carpinus*, *Betula*, *Fagus, Liquidambar*, *Ulmus*, *Platanus*)

At the Poštorná locality, Gabrielová (1966) interpreted a marshy environment during the Pannonian based on the pollen data from the coal seam. Kalvoda (1979), Lázničková (2006) and Doláková et al. (2006) identified many herbaceous taxa. Konzalová (2005) carried out a detailed palynological study of the Pannonian palynospectra. She documented an aquatic environment with a mix of freshwater and brackish plankton, coastal herbaceous plants, swamp and riparian forest, mixed mesophytic forest, and extrazonal vegetation. In the studied samples she found an absence of *Myrica* compensated for by water plants frequently showing higher inundation.

Based on the previously published research and our new pollen data, it was possible to characterize vegetation assemblages and climate during the Pannonian.

Due to paleogeographical changes and climatic oscillations, the number of thermophilous taxa decreased during this time span, and some of them disappeared completely from this area (e. g. Sapotaceae, Palmae). Mostly broadleaved deciduous elements of warm – temperate mixed mesophytic forests such as *Quercus*, *Celtis*, *Carya*, *Tilia*, *Zelkova*, *Ostrya*, *Liquidambar*, *Carpinus, Betula, Juglans* dominate generally (Pl.1, figs 2, 10-14). Thermophilous elements and mixtures of *Engelhardia*, evergreen Fagaceae morphospecies *Quercoidites microhenrici,* and less frequently *Quercoidites henrici*, *Trigonobalanopsis*, *Symplocos, Cornaceaepollis satzveyensis*, T*ricolpopollenites liblarensis* up to a maximum of 25 % were present (Pl I., figs 5-9).

The various heights and forms of the uplifted mountain chains created ideal conditions for a higher presence of extrazonal vegetation (*Cedrus, Tsuga, Picea, Cathaya*) (Pl.1, figs 15,16) in the investigated area. Nevertheless, according to Ferguson et al. (1998) *Cathaya* which grows nowadays at high altitudes, was adapted in the Miocene to the lower ground conditions with enough air humidity. The sharply demarcated facies changing both in time and space in their individual pollen spectra were created by intrazonal types of vegetation or by high amounts of herbaceous plants. They included marshes and coastal swamps with Taxodiaceae, *Nyssa,* and bush woods with *Myrica. Ilex* and *Sciadopitys* replenished the plant spectra in the floodplain lowlands. The prevailing vegetation types were often riparian forests with *Alnus* (up to 20%, often 4-porate pollen grains), *Salix*, *Pterocarya*, *Liquidambar*, *Betula* (up to 14%), *Fraxinus, Platanus* (Pl.1, figs 1-3). Polypodiaceae, *Osmunda,* and some thermophile ferns (Lygodiaceae) occured in the moist and shady places. Shrubs and lianas such as *Buxus*, *Ephedra*, Ericaceae, Vitaceae, *Lonicera*, Rosaceae type *Rubus* (Pl. 3, figs 15,16) occurred on drier substrates in the associated riparian forests. Accumulations of Chenopodiaceae in the interfluvial areas probably indicate local saline swampy environments during falls in sea level. The increased amounts of herbs (up to 30% in pollen spectra) indicate the existence of local open places such as wet meadows (*Thalictrum*, *Rumex*, *Valeriana*, Dipsacaceae, Lamiaceae, *Galium*) or areas which were never inundated (*Artemisia* – up to 17%, Asteraceae, *Campanula*, Fabaceae, Daucaceae, Caryophyllaceae, *Plantago* – Pl. 3). Poaceae could even have been components of the associations forming the undergrowth of the forest margin.

Aquatic plants created belts in shallow waters (*Nelumbo*, *Nymphaea*, *Myriophyllum*, *Sparganium*, *Potamogeton* – Pl. 2.), and along the water/land boundaries (*Decodon*, *Polygonum persicaria*, *Caltha*, *Valeriana* – Pl. 3). Very interesting findings are represented by microsporangia – massulae (within small circled microspores) with very characteristic glochidia of the freshwater fern *Azolla bohemica* (Pl. 2) described by Pacltová (1958). Isolated glochidia, found separately, were also frequent. According to Knobloch (1981) this genus occurs in eutrophic waters today. Due to the absence of glochidia, part of microsporangia is indistinguishable from the genus *Salvinia.* Similar results were published by Konzalová (2005) from the locality of Poštorná near Pohansko. Knobloch (1981) identified seeds and fruits of both mentioned taxa at Pannonian – Pontian localities within this area (*Azolla* – Dubňany, Čáry, and *Salvinia* – Ořechov-Mistřín).

Occasional occurences of dinoflagellates and green algae Tasmanaceae indicate a slightly higher salinity, *Botryococcus* can thrive in both brackish or freshwater environments, whereas green algae *Pediastrum*, *Mougeotia,* aquatic ferns *Azolla,* and aquatic and coastal plants (*Nelumbo*, *Nymphaea*, *Myriophyllum*, *Sparganium*, *Potamogeton* etc.) represent freshwater environments.

The noticeable *Pediastrum* cenobia belong predominantly to the species *P. simplex* and *P. boryanum* which are typical for open waters of eu- to mesotrophic conditions (Komárek and Jankovská 2001, Miola et al. 2006, Zetter 1987). The non-pollen palynomorph *Sigmopollis* occurred commonly. This morphotype is very similar to the Quaternary type 128 after Van Geel et al. (1983). In our samples it was often accompanied by type 74 as referred to by the same authors. Both these types possibly pertain to algal palynomorphs according to Van Geel et al. (1983), and Miola et al. (2006), indicating open water environments in eu-/mesotrophic conditions. Observations under the fluorescent microscope also support their determination as algal spores. Due to the chemical differences in sporopollenin of lower and higher plants, and also to different rates of corrosion, the algal bodies show very high fluorescence intensities, whereas other palynomorphs show much lower, and fungal remains are completely invisible (Van Gijzel 1971, Yeloff and Hunt 2005, Doláková and Burešová 2007).

The fact that the sea level fell at the beginning of the Late Miocene and led to large-scale erosion of older sediments in the area of the back-arc basin system is documented in the Early Pannonian pollen spectra, where a lot of redeposited sporomorphs of subtropical and tropical ferns appeared (Slamková 2004). A higher percentage of nonarboreal pollen (10-14%) indicates local marshes and partly open woodland vegetation. The increase in halophyte taxa documents the presence of coastal swamps, local lagoons and marshlands during the lowstand of the brackish sea (Kvaček et al. 2006).

During the Late Pannonian, the Western Carpathian paleogeography started to change. Lake Pannon retreated southwards and the northern coast of the back-arc basin was slightly elevated due to progradation of deltaic and alluvial facies, especially in the lowlands.

Swamp vegetation with straight growth in the swamp substratum is mainly characterized by Taxodiaceae trees. They are often present in association with Myricaceae, less often with Nyssaceae. The riparian forest elements subdominantly occurred with *Alnus* and *Ulmus,* mixed mesophytic forests with *Carya, Quercus, Craigia, Carpinus, Fagus* and herbs were represented by Chenopodiaceae, Asteraceae, Ericaceae, Poaceae and *Artemisia.* Extrazonal vegetation of the mountain areas with *Picea, Tsuga, Abies, Cedrus* is common in the pollen spectra.

Paleoclimatic data quantified by the Coexistence approach method (Mosbrugger and Utescher 1997) characterized a climate in several categories. Using primary pollen data from the Pannonian sediments of the Slovak part of the Vienna Basin, the mean annual temperature (MAT) was between 15.6–21.7°C, the coldest month temperature (CMT) between 5.0 13.6°C, the warmest month temperature (WMT) between 13.8–27.9 °C, mean annual precipitation (MAP) between 373.0– 520.0 mm, the wettest month precipitation (WtMP) between 73.0– 45.0 mm, the driest month precipitation (DMP) between 5.0– 9.0 mm, and the warmest month precipitation (WMP) between 27.0–227.0 mm (Kováč et al. 2006).

Discussion

A temperate climate with broad-leaved deciduous and warm – temperate mixed mesophytic forests, was interpreted for all the areas adjacent to the Vienna Basin. Increasing amounts of herbaceous plant pollen were also observed. It was presumed by Utescher et al. (2000), that the gradual cooling started from the 14 Ma untill the Late Pliocene and seasonality increased from the beginning of the Late Miocene Planderová et al. (1993a,b) noticed a clear floristic differentiation in representation of paleotropical and arctotertiary elements between the southern and northern part of Central and Eastern Europe during the Pannonian.

The Danube Basin situated at the Alpine-Carpathian-Pannonian junction represents a region of the Central Paratethys, strongly influenced by the orogen building processes and climatic changes (Kováč 2000). In the reference section of the Tajná 1 borehole, in the Lower Pannonian sequence, dominant vegetation was formed by the swamp representatives Taxodiaceae – Myricaceae with subdominant presence of *Nyssa, Alnus, Carya, Quercus* deciduous, *Engelhardia*, Chenopodiaceae and Poaceae. In the Middle Pannonian sequence, changes in proportion of the dominant elements are apparently related to the mild cooling of climate and beech has been partly supplanted by fir and deciduous oak. Taxa ratio in the predominant association changed. The proportion of beech in *Abies-Quercus* (deciduous) – *Fagus* association decreased. Oleaceae*, Myrica, Carya, Pterocarya, Alnus, Nyssa, Picea, Tsuga* and *Cedrus* occurred subdominantly (Kováč et al. 2006). Presence of an increasing number of coniferous taxa *Picea, Tsuga* and *Abies* also observed in earlier studies of the Pannonian sequences (Nagy and Planderová 1985), can be interpreted as a consequence of two factors: higher relief in the hinterland of the basin or transition to seasonality. From the Danube Basin, Planderová (1972, 1984, 1990) described reduced marshes, isolated lakes with floras surrounded by steppe meadows with scarce woody plants. In comparison with Hungary, the climate was cooler and drier with a dominance of *Artemisia* over other herbaceous pollen (Nagy 1985, Nagy and Planderová 1985, Planderová 1990) during the Late Miocene.

Erdei et al. (2007) confirmed the significant role of paleogeography – subsidence of the Pannonian basin – in the appearance of Pannonian floras and vegetation types with extremely low diversities. The authors characterised most of the Pannonian localities by monotonous azonal swamp associations with *Byttneriophyllum* predominating which indicates warmer climatic conditions.

In Poland, Wazynska (1998), Sadowska et al. (1993) and others presumed a temperate and relatively arid climate, thus not stimulating the development of swamp forest with *Nyssa* and *Taxodium*. They were replaced by moist riparian forests with *Alnus*, *Celtis* and *Pterocarya*. More arid terrains were occupied by mixed forests with large amounts of conifers, especially pines, and with only scarce paleotropical relics. The amount of herbaceous plant pollen increased during this time span (Poaceae, *Artemisia*, the family Asteraceae, Daucaceae etc.).

Pannonian (Meotian) pollen data from the Ukraine indicate the development of steppe or forest-steppe areas with Poaceae and *Artemisia* (Syabraj 2000, Syabraj et al. 2007).

Kovar-Eder (1987) analyzed Pannonian vegetation and climate in the Central Paratethys region. She has established that the percentage of evergreen species increased towards the southeastern part of the investigated area, and arguments for either xeromorphic mediterranean-like vegetation or for steppe-like conditions are invalid.

Very rich pollen assemblages were determined from the Late Pannonian sediments of the Styrian Basin (Hoffmann and Zetter 2005). Six associated paleo-plant habitats were distinguished by the authors in the ancient wetland system, namely, belts of aquatic plants, freshwater marsh habitat, clastic swamp habitat, natural levee or crevasse-splay habitat, organic swamp and wet-prairie habitat. They identified 40 herbaceous taxa, which documented not only closed forest, but also the herbaceous vegetation of more xeric layers.

Conclusion

Due to paleogeographical changes and climatic oscillations, thermophilous taxa numbers decreased during the studied time span, and some of them disappeared completely from the northern part of the Vienna Basin. Based on the macropalaeobotanical and pollen data, a temperate climate with broad-leaved deciduous and warm-temperate mixed mesophytic forests was interpreted. The marked facies mutually changing in time and space in their individual pollen spectra were created by intrazonal types of vegetation (marshes, riparian, coastal and aquatic) or by high amounts of herbaceous plants (existence of local open places such as drier substrata in the associated riparian forests, and wet meadows). Variable height and form of the uplifted mountain chains created ideal conditions for a higher presence of extrazonal vegetation.

Based on pollen data from the Pannonian sediments of the Slovak part of the Vienna Basin quantified climatic data (mean annual temperature, mean annual precipitation...) were calculated.

Comparison with the adjacent areas confirms the existence of a climatically dependent gradient between the southern and northern part of Central and Eastern Europe during the Pannonian as documented by floristic differentiation in representation of paleotropical and arctotertiary elements. Increasing amounts of the herbaceous plants pollen were also observed.

Acknowledgements

The study has been sponsored by the Research Project MSM0021622427 (Czech Republic), projects of the Slovak Research and Development Support Agency APVV-51-011305, APVV-0280-07 and European Science Foundation EUROCORES programme TopoEurope project ESF-EC-009-07.

References

Bůžek, Č. (1962): Contribution to knowledge of Pannonian Flora in Poštorná u Břeclavi. – Čas. mineral. geol., 7 (3): 257-259. (in Czech, German summary)

Doláková, N., Burešová, A. (2007): Use of fluorescent microscopy in the study of redeposited palynomorphs in the cave and marine sediments of Moravia (Czech Republic). – Acta Palaeobotanica, 47 (1): 275-279.

Doláková, N., Kováčová, M., Beláčková, K., Lázničková, J. (2006): Development of the open land areas during the Miocene in the Czech and Slovak parts of the Central Paratethys. Scripta Fac. Sci. Nat. Univ. Masaryk. Brun., Geology, 33-34 (2003-2004): 24-25.

Erdei, B., Habbly, L., Kázmér, M., Utescher, T., Bruch, A. (2007): Neogene flora and vegetation development of the Pannonian domain in relation to paleoclimate and paleogeography. – Palaeogeogr., Palaeoclimatol., Palaeoecol., 253: 115-140.

Ferguson, D.K., Pingen, M., Zetter, R., Hofmann, Ch. Ch. (1998): Advances in our knowledge of the Miocene palnt assemblage from Kreuzau, Germany. – Rev. Paleobot. Palynol., 101: 147-177.

Gabrielová, N. (1966): Preliminary report about palynological research at the locality Poštorná. – Zpr. geol. výzk. 1966, pp.285-286. (in Czech)

Hofmann, Ch.Ch., Zetter R. (2005): Reconstruction of Different Wetland plant Habitats of the Pannonian Basin Systém (Neogene, Eastern Austria). – Palaios, 20: 266-279.

Kalvoda, J. (1979): Microflora of the Upper Miocene at the locality Poštorná. – MS, Rigorous thesis, PřF MU, pp. 100 Brno (in Czech).

Knobloch, E. (1962): Preliminary report about paleobotanical researches in moravian Teritiary. – Zpr. geol. výzk. 1961, pp. 215-217. (in Czech).

Knobloch, E. (1963): Die Floren des südmährischen Neogens. – N. Jb. Geol. Paläont. Mh., 1: 1-11.

Knobloch, E. (1968): The plant association in Czechoslovakian Teritary. – Čas. mineral. geol., 13 (1): 109-118 (in Czech, German summary)

Knobloch, E. (1969): Tertiäre Floren von Mähren. – Moravské muzeum a Muz. spol. Brno., 1-201, pp. 309, Brno.

Knobloch, E. (1972): Die gegenseitigen Beziehungen der tschechoslowakischen und ungarischen Teritiärfloren. – Földt. Közlöny, Bull. Of the Hungarian Geol.soc., 102: 246-259.

Knobloch, E. (1981): Micropaleobotanical research of Pannonian and Pontian in Moravia and Slovakia. – Zem. Plyn Nafta, XXVI (4): 741-757 (in Czech, German summary).

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

Komárek, J., Jankovská, V. (2001): Review of the Green Algal Genus Pediastrum; Implication for Pollenanalytical Research. – Gebrüder Borntraeger, Berlin, 127pp.

Konzalová, M. (2005): Upper Miocene (Pannonian, Pontian) palynomorphs from the south Moravian extension of the Vienna Basin (Czech Republic). – Documenta Naturae, 155 (5): 1-51. München.

Kováč, M. (2000): Geodynamický, paleogeografický a štruktúrny vývoj karpatsko-panónskeho regiónu v miocéne: nový pohlad na neogénne panvy Slovenska. Veda, Bratislava, pp. 5-203 (in Slovak).

Kováč, M., Baráth, I., Fordinál, K., Grigorovich, A.S., Halásová, E., Hudáčková, N., Joniak, P., Sabol, M., Slamková, M., Sliva, Ľ., Töröková, I., Vojtko, R. (2006): Late Miocene to Early Pliocene sedimentary environments and climatic changes in the Alpine-Carpathian-Pannonian junction area: a case study from the Danube Basin northern margin (Slovakia). – Palaeogeogr., Palaeoclimatol., Palaeoecol., 238 (1-4): 32-52.

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

Kovar-Eder, J. (1987): Pannonian (Upper Miocene) Vegetational Character and Climatic Inferences in the Central Paratethys Area. – Ann. Naturhist. Mus., 88, A, Wien: 1987, 117-129.

Lázničková, J. (2006): Palynological study of selected localities in Upper Miocene of theMoravian part of the Vienna Basin. – MS, diploma thesis, MU Brno: 77 pp. (in Czech, with English summary).

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

Miolla, A., Bondesan, A., Corain, L., Favaretto, S., Mozzi, P., Piovan, S., Sostizzo, I. (2006): Wetkabds in the Venetian Po Plain (northeastern Italy) during the Last Glacial Maximum: Interplay between vegetation, hydrology and sedimentary inivronment. – Rev. Paleobot. Palynol., 141 (1-2): 53-81.

Mosbrugger, V., Utescher, T. (1997): The coexistence approach – a method for quantitative reconstructions of Tertiary terrestrial palaeoclimate data using plant fossils. – Palaeogeogr., Palaeoclimatol., Palaeoecol., 134: 61-86.

Nagy, E. (1985): Sporomorphs of the Neogene in Hungary. – Geologica Hungarica, ser. Palaeont., 47: 1-470.

Nagy, E., Planderová, E. (1985): Palynologische Auswertung der Floren des Pannonien. – In: Papp et al. (eds): Chronostratigraphie und Neostratotypen. Miocaen M6 Pannonien. – Jugosl. Serb. Akad. Wiss. Künste, Zagreb/ /Beograd., 586-615pp.

Pacltová, B. (1958): The plant microfossils (mainly sporomorphae) of the lignite deposits near Mydlovary in the České Budějovice basin. – Sbor. Ústř. Úst. geol. Paleont., XXV: 109-176 (in Czech, English summary).

Planderová, E. (1984): Palynological evolution of Pannonian sediments from the West Carpathians. – Záp. Karpaty, sér. Paleont., 9: 131-134.

Planderová, E. (1972): Pliocene Sporomorphs from the West Carpathians Mountains and their Stratigraphisc interpretation. – Geol. Práce. Zprávy, 59: 209-284.

Planderová, E. (1990): Miocene Microflora of Slovak Central Paratethys and its Biostratigraphical Significance, Geol. Inst. D. Štúra, Bratislava, 144pp.

Planderová, E., Ziembińska-Tworzydło, M., Grabowska, I., Kohlman-Adamska, A., Konzalová, M., Nagy, E., Pantić, N., Ryłova, T., Sadowska, A., Słodkowska, B., Stuchlik, L., Syabraj, S., Zdražílková, N., (1993a): On paleofloristic and paleoclimatic changes during the Neogene of Eastern and Central Europe on the basis of palynological research. – Proceedings of the International Symposium: Paleofloristic and paleoclimatic changes during Cretaceus and Tertiary, Dionýz Štúr Institute of Geology in Bratislava, pp. 119-129.

Planderová, E., Ziembińska-Tworzydło, M., Grabowska, I., Kohlman-Adamska, A., Sadowska, A., Słodkowska, B., Stuchlik, L., Ważyńska H. (1993b): Wahania klimatyczne w Neogenie Europy Środkowej na podstawie zmiennego udziału w palinoflorze składników paleotropikalnych i arktycznotreciorzędowych. – Przeglad Geologićny.Państw. Inst. Geol., 41(12): 829-834.

Slamková, M. (2004): Paleovegetácia a klimatické trendy počas stredného a vrchného miocénu vo Viedenskej panve; Dizertačná práca. – MS, Archív Katedry geológie a paleontológie, 87 pp.(in Slovak, English summary).

Syabraj, S. (2000): Tertiary Flora, Vegetation and Climate of Ukraine. – Chin. Bull. of Bot., 17: 95-101.

Syabraj, S., Utescher, T., Molchanoff, S., Bruch, A. A. (2007): Vegetation and paleoclimate in the miocene of Ukraine. – Palaeogeogr., Palaeoclimatol., Palaeoecol. 253 (1-2), 169-184.

Stuchlik, L., ed. (1994). Neogene Pollen Flora of Central Europe. Part 1. – Acta Palaeobotanica, Suppl. 1: 1-56.

Ważyńska, H. ed. (1998): Palynology and Paleogeography of the Neogene in the Polish Lowlands. – Prace Panstw. Inst. Geol., CLX, 45pp.

Utescher, T., Mosbrugger, V., Ashraf, A. R. (2000): Terrestrial Climate Evolution in Northwest Germany Over the last 25 Million Years. – Palaios, 15 (5): 430-449.

Van Geel, B., Hallewas, D.P., Pals, J.P. (1983): A Late Holocene deposit under Wetfiese Zeedijk near Enkhuizen (prov. of N-Holland, The netherlands): paleoecological and archaeological aspects. – Rev. Paleobot. Palynol., 38: 269-335.

Van Gijzel, P. (1971): Review of the UV-fluorescence microphotometry of fresh and fossil exines and exosporia. – In Brooks, J., Grant, P. R., Muir, M., Van Gijzel, P., Shaw, G. (eds.).: Sporopollenin: Academic Press, London–New York, pp.659-685.

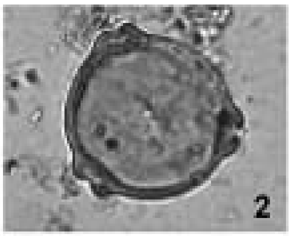
Ważyńska, H. (1998): Palynology and Paleogeography of the Neogene in the Polish Lowlands. – Prace Panstw. Inst. Geol. CLX: 45p.

Yeloff, D. E., Hunt, C. O. (2005): Fluorescence microscopy of pollen and spores: a tool for investigating environmental change. – Rev. Paleobot. Palynol., 133: 203-219.

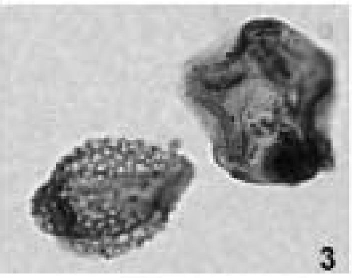
Zetter, R. (1987): Untersuchungen and Pediastrum – Arten aus dem Ober Miocän des Burgenlandes (Österreich). – Beiträge zur Paläontologie von Osterreich., 13: 69-87.

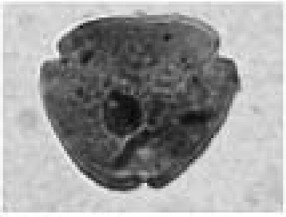
PLATE 1


1

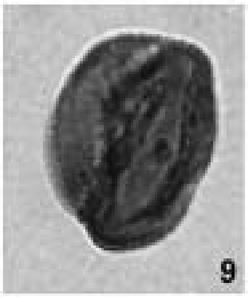

2

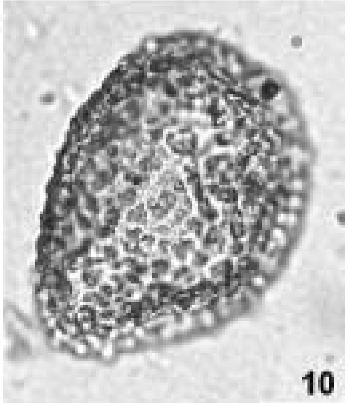

4

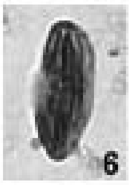

3

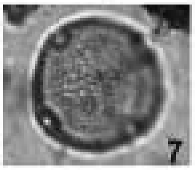


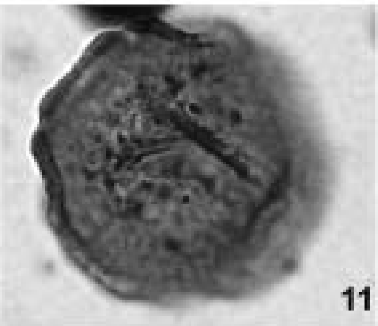

8


9


10

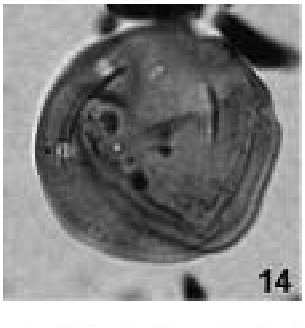

6

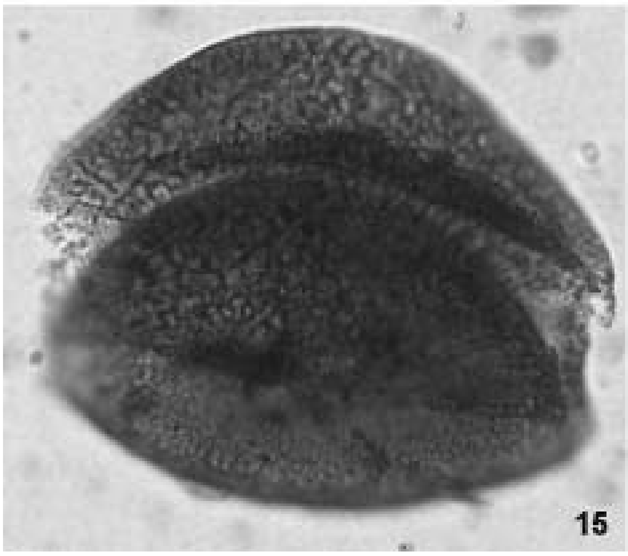

7


11


12


13


14


15

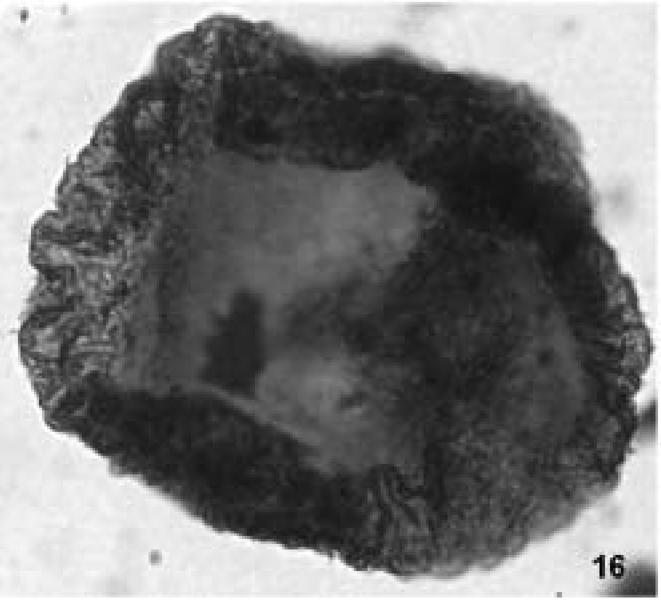
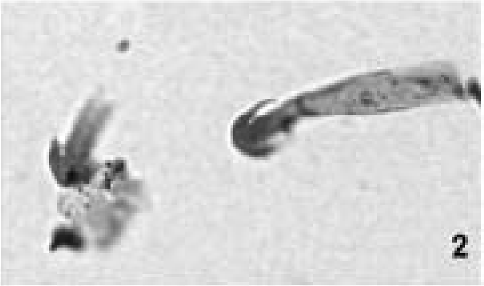
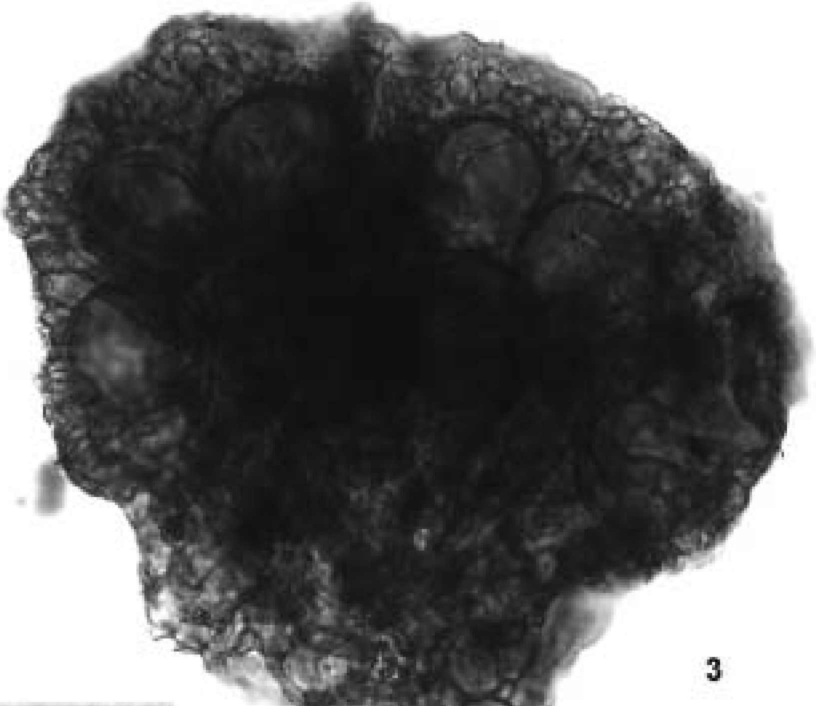
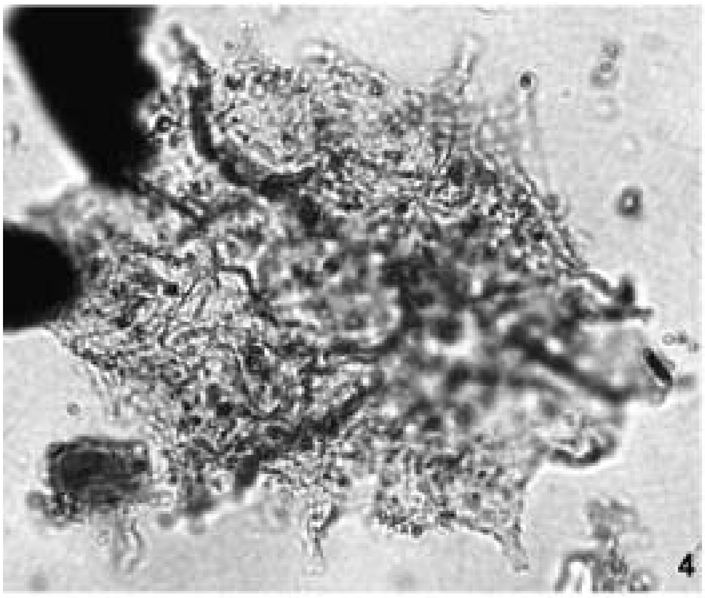

16

PLATE 2

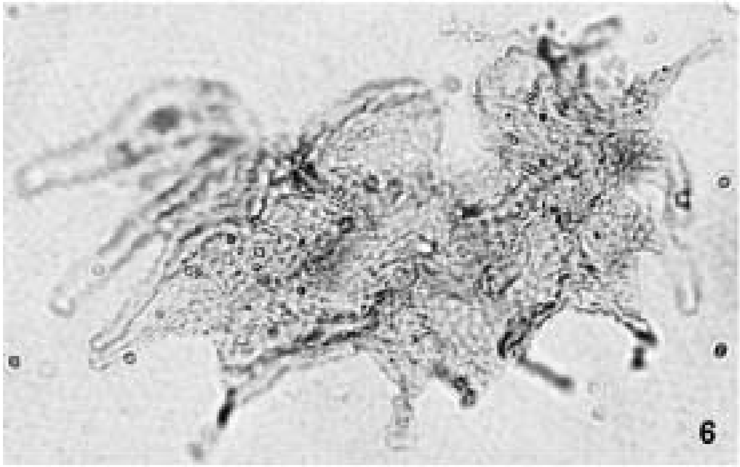

1


2


3


4


5


6

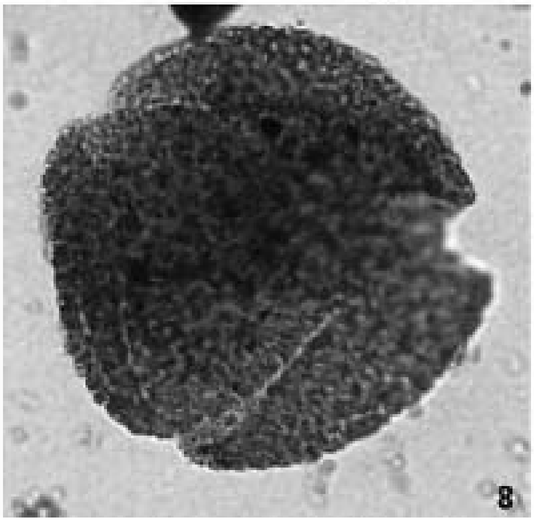
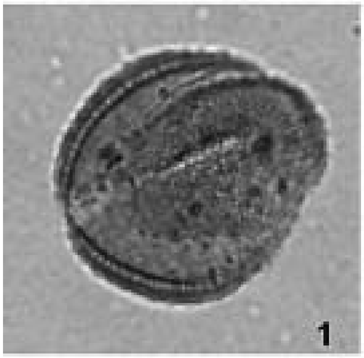
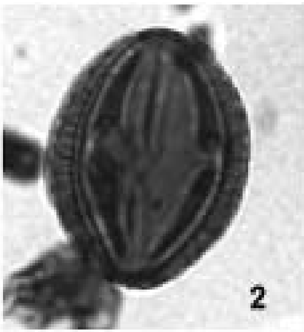
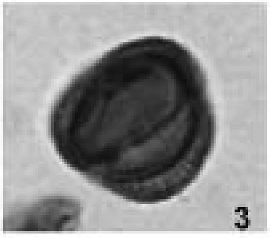
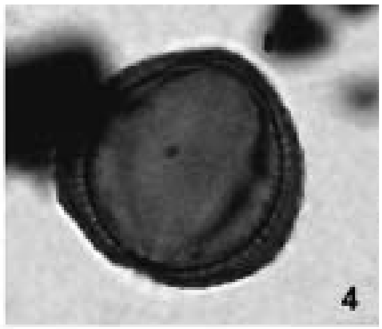

8

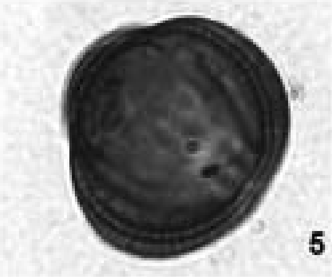
PLATE 3

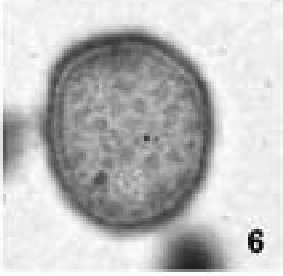

1


2

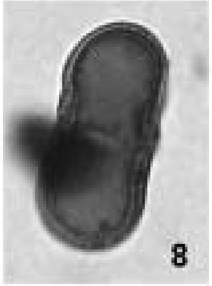

3


4

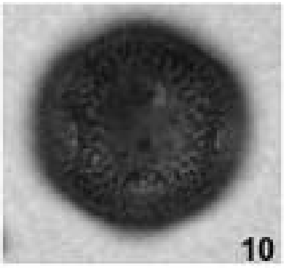

5

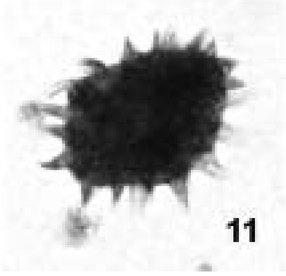

6

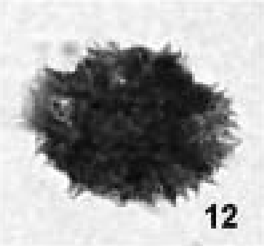

7

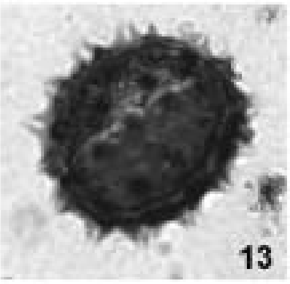

8


9

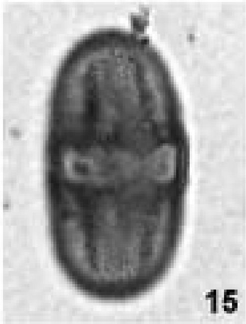

10

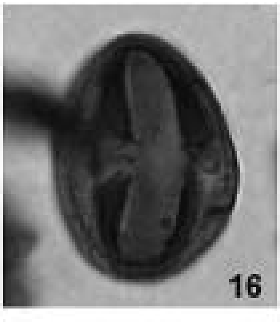

11

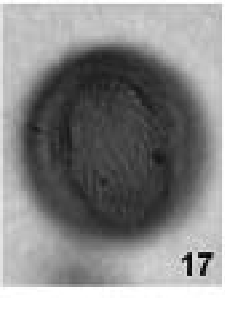

12


13

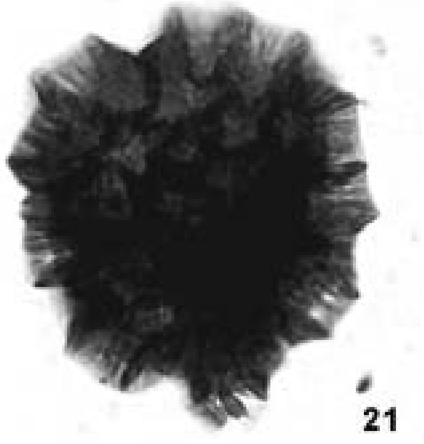

14

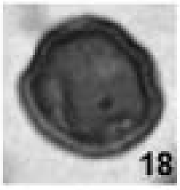

15

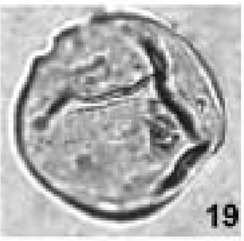

16


17


20


21


18


19

Explanation to the plates

PLATE 1

1. four-porate *Alnus – Alnipollenites verus* Potonié; Poštorná 3.
2. *Betulaepollenites betuloides* (Pflug) Nagy; Pohansko V9, 6 m.
3. *Salixipollenites* sp. + *Alnipollenites* sp.; Pohansko V9, 6 m.
4. *Nyssapollenites rodderensis* (Thiergart) Kedves; Pohansko V9, 4.2 m.
5. *Engelhardia* sp. – *Engelhardtioidites quietus* (Potonié) Potonié; Pohansko V9, 3 m.
6. *Tricolporopollenites liblarensis* (Thomson) Grabowska; Pohansko V7, 4.2 m.
7. *Reevesiapollis triangulus* (Mamczar) Krutzsch; Moravská Nová Ves 7.
8. *Quercoidites henrici* (Potonié) Potonié,Thomson etThiergart; Pohansko V9, 3 m.
9. *Platanus* sp. – *Platanipollis ipelensis* (Pacltová) Grabowska; Pohansko V9, 3 m.
10. *Sciadopitys* sp. – *Sciadopityspollenites serratus* (Potonié et Venitz) Raatz; Pohansko V9, 6 m.
11. *Zelkova* sp. – *Zelkovaepollenites potoniei* Nagy; Pohansko V9, 6 m.
12. *Quercus* sp. *Quercoidites* sp.; Pohansko V9, 6 m.
13. *Quercus robur* type; Pohansko V9, 3 m.
14. Juglans sp. *Juglanspollenites verus* Raatz; Pohansko V9, 3 m.
15. Picea sp – *Piceapollis* sp; Poštorná 3
16. *Tsuga* sp. – *Zonalapollenites maximus* (Raatz) Krutzsch; Pohansko V9, 6 m.

PLATE 2

1. Microsporangium *Azolla bohemica* Pacltová; Pohansko V9, 6 m.
2. Isolated glochidia of *Azolla bohemica* Pacltová; Pohansko V9, 6 m.
3. Micosporangium cf. *Salvinia* x cf. *Azolla*; Pohansko V9, 6 m.
4. *Pediastrum boryanum* (Turp) Menegh; Pohansko V9, 4.2 m
5. *Pediastrum simplex* Meyen; Pohansko V3, 8 m.
6. *Pediastrum boryanum* (Turp) Menegh var. boryanum; Pohansko V3, 8 m.
7. *Nelumbo* sp. – *Nelumbopollenites europaeus* (Tarasewich) Skawińska; Pohansko V9, 4.2 m.

PLATE 3

1–5. *Artemisia* sp. several types cf. *Artemisiapollenites sellularis* Nagy; Pohansko V9, 3 m.

6. *Plantago* sp. – *Plantaginacearumpollenites miocaenicus* Nagy; Pohansko V9, 3 m.
7. *Centaurea jacea* type – Pohansko V9, 3 m.

8.,9. Daucaceae gen. indet. several types; Pohansko V9, 3 m.

10. Caryophyllaceae gen. indet.; Pohansko V9, 3 m.
11. Asteroideae – *Senecio* type.; Pohansko V9, 3 m.
12. Asteroideae – *Cichoreacidites gracilis* Nagy; Pohansko V9, 3 m.
13. Asteroideae – *Tubulifloridites macroechinatus* (Trevisan) Nagy; Pohansko V9, 4.2 m.
14. cf. *Echinops* type; Pohansko V9, 3 m.
15. Fabaceae gen. Indet; Pohansko V9, 3 m.
16. Rosaceae gen. indet.; Pohansko V9, 3 m.
17. Rosaceae – *Prunus* type; Pohansko V9, 3 m.
18. *Thalictrum* sp.; Pohansko V9, 3 m.
19. *Humulus/Cannabis* type; Moravská Nová Ves
20. *Ranunculus* type; Pohansko V9, 6 m.
21. *Polygonum persicaria – Persicarioipollis persicarioidites* Krutsch; Pohansko V9, 6 m.

Journal of Archaeological Science 37 (2010) 2538–2550

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Palynology and natural environment in the Pannonian to Holocene sediments of the Early Medieval centre Pohansko near Břeclav (Czech Republic)

N. Doláková*, A. Roszková, A. Přichystal

Institute of Geological Sciences, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic

ARTICLE INFO

Article history:
Received 29 June 2009
Received in revised form
4 May 2010
Accepted 22 May 2010

Keywords:
Early Middle Ages
Great Moravia
Pohansko
Palynology
Non-pollen objects
Carpinus

ABSTRACT

Pohansko (Czech Republic) is an important Early Medieval centre of the Great Moravian Empire (9th century AD). The locality has a settlement with archaeological findings from Mesolithic to the modern times.

The studied sediments belong to the stream and flood deposits of the Dyje river, aeolian sands and buried soils. The lower parts of some boreholes penetrated into the Upper Miocene sediments. 172 samples were palynologically analysed. The original forest with relative small human impact was observed on the base of Holocene layers. Even sporadic Cerealia pollen were found here. A deforestation was visible in the cultural layer; it is linked with existence of the Great Moravian agglomeration and its fortification. Later, a partial forest reconstruction probably took place in the surroundings. Very abundant pollen of human-exploited plants (cereals, herbs) were discovered in the filling of archeological feature O1. The possible practical potential of rampart also as the flooding protection was indicated by the existence of marshy plants palynomorphs. The existence of oxbow was proved in the excavated probe S3. The lowermost sample was dated by 14C as 7830 ± 60 BP. The findings of *Carpinus* pollen in the layer dated as Early Atlantic support the earlier spreading of this genus in the Czech Republic (i.e. South Moravia).

1. Introduction

The archaeological locality Pohansko near Břeclav lies approximately 2 km from the town of Břeclav (South Moravia, eastern part of the Czech Republic) (Fig. 1). It was a significant Early Medieval centre in the core area of the Great Moravian Empire, 9th century AD, interpreted as a munitio, emporium and palatium of the Moravian Early Medieval rulers (Macháček, 2005). The site lies at an altitude of about 155–157 m a. s. l. and is situated about 12 km from the confluence of the Dyje and Morava rivers. Today the surrounding area is woody and boggy with meadows and floodplain forests.

One of the key problems of this Early Medieval fortified site (as with other Early Medieval sites in South Moravia) that must be solved in co-operation with geologists and palaeobotanists is determining a conclusion about its decline. It is believed that at the end of the 9th century AD, such environmental events occurred that caused extensive flooding and the covering of the Early Medieval sites by flood sediments.

Palynological studies have been carried out within a framework of broad interdisciplinary (archaeological, geological, environmental) research between the Faculty of Science and the Faculty of Arts, Masaryk University.

2. Description of the studied area

2.1. Archaeology

Fifty-year-long ongoing archaeological research studies have led to the discovery of settlement traces from prehistoric times (Mesolithic) to the Middle Ages. Findings of microlithic stone artefacts are typical for the Mesolithic age (Kalousek, 1966). The Neolithic settlement in the above-mentioned locality was represented by Linear Pottery culture. According to Podborský (1993), the beginning of Linear Pottery culture in the Moravia area is dated between 7650 and 7450 BP. More frequent are Eneolithic artefacts: a fragment of greenschist axe (Dostál, 1975) and finds connected with the Funnel Beaker culture and Channelled Ware. Even some artefacts from the Bronze Age have been found here (Dresler, 2008). According to a non-verified information, one burial-ground from the Hallstatt period was found before systematic excavation. Plentiful decorations from the La Téne Age are known to be

---

* Corresponding author.
E-mail address: nela@sci.muni.cz (N. Doláková).

0305-4403/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jas.2010.05.014

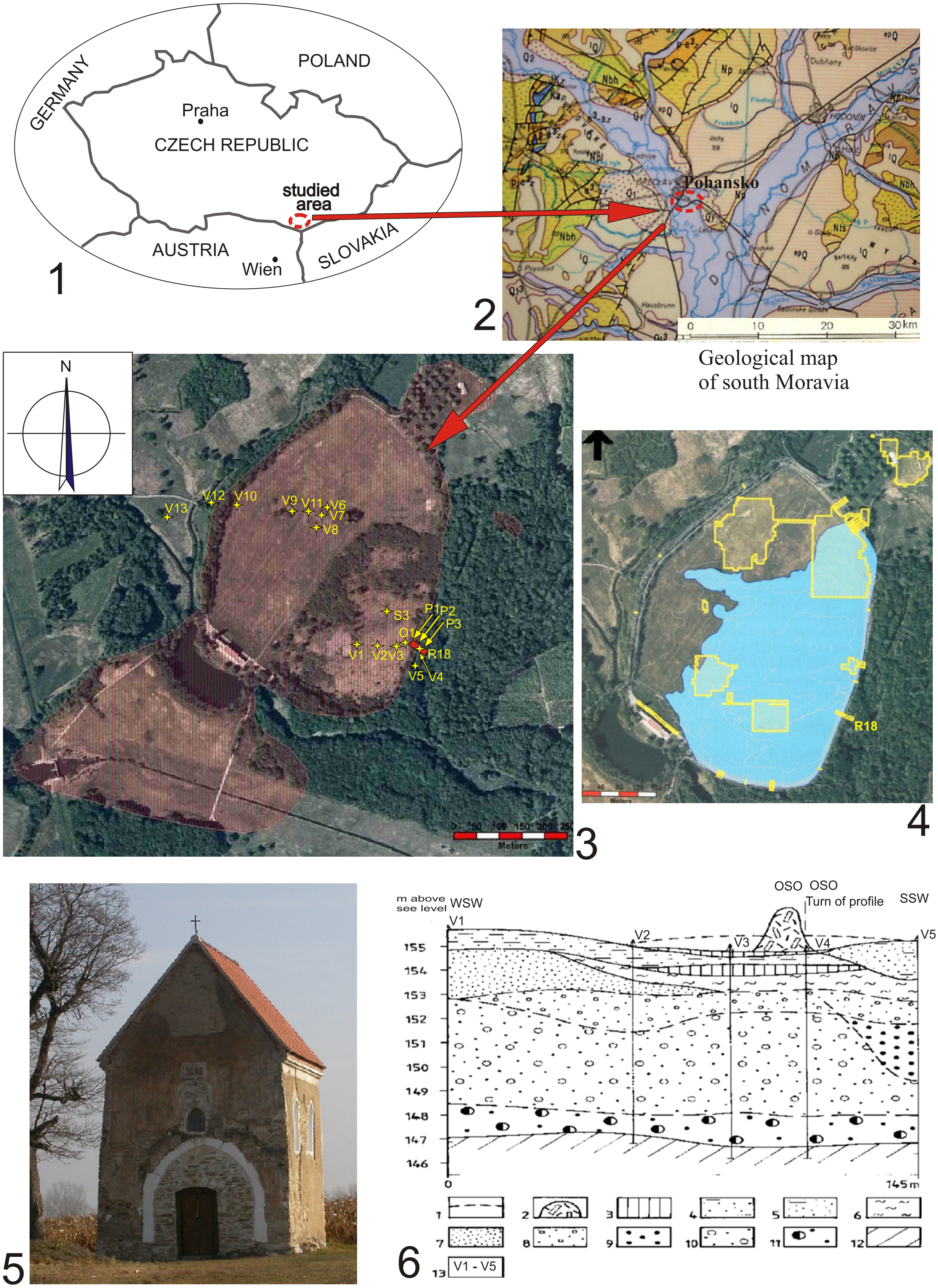


Fig. 1. 1. Localisation of the studied area. 2. Part of the geological map. 3. Aerial photo (after www.mapy.cz) of fortification with mark of the boreholes and profiles. 4. Extreme flooding (2006) through the opening in the fortification – according to Macháček et al., 2007. 5. Kopčany – only the one preserved church from the Great Moravia Empire (9th century). 6. Geological profile – according to Macháček et al., 2007. 1 – original surface 2 – Great Moravian rampart 3 – buried semiterrestric gleysols 4–6 – sandy-clay flood loams 7 – wind-blown sands (sand dune) 8 – grey fluvial fine sands and/or sandy clays 9 – weakly clay sands and sandy gravels 10 – coarse or middle-grained Upper Pleistocene fluvial sands and gravels 11 – coarse-grained fluvial gravels 12 – blue-grey sandy clays and clays – Neogene 13 – boreholes.

connected to this area. Relics of the Roman age have also been left here (Dostál, 1975). The youngest pre-Slavonic artefacts are examples of pottery from the Migration Period. The time of the greatest expansion is embodied by Pohansko from the period 900–1000 AD within the Great Moravian Empire (Macháček, 2005). After its destruction (Fig. 2), or since 1500 AD, there have no longer been any settlements here.

2.2. Geological background of the locality

From a geological point of view, the Early Medieval Centre of Pohansko lies within an extended flood plain near the confluence of the Morava and Dyje rivers (Fig. 1). The flat valley around the ring wall reaches a width of about 4 km and is filled with Holocene flood loams. Towards the confluence, the width reaches up to 10 km. The

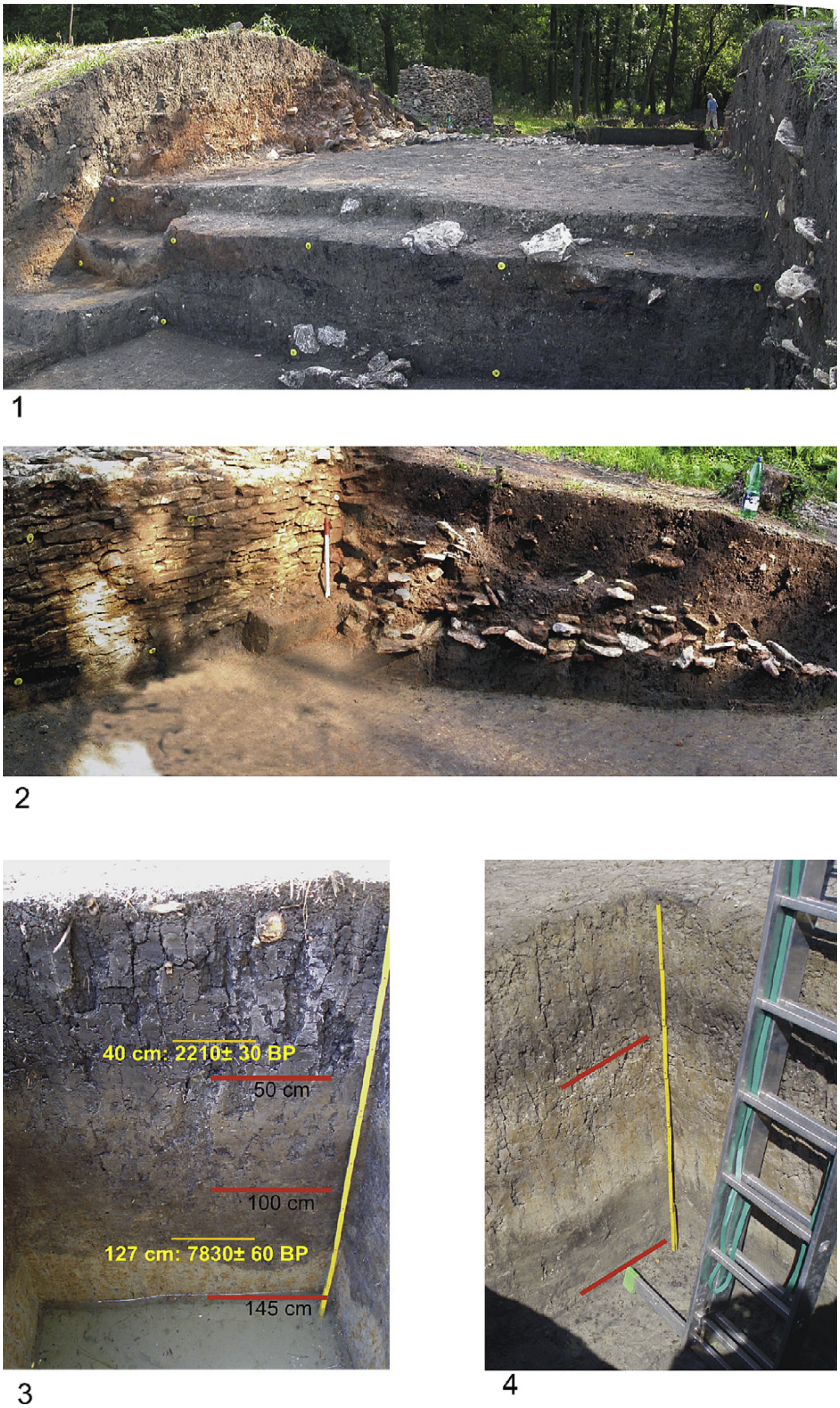


Fig. 2. 1. The inner part of the fortification. 2. The outer part of the fortification – destruction. 3. Excavated test trench S3 – sediments of oxbow, with ^{14}C dating. 4. Archaeological feature O1 – Flood loams and clays intercalated with buried terrestric gleysols.

marginal slopes of the valley protrude some 5 m above the flood plain and are composed of Middle Pleistocene (Riss) fluvial sandy gravels with Late Würmian dunes of wind-blown sands. In some places these dunes also protrude from under Holocene flood loams in the flood plain; one of them was used to build the Early Medieval fortified site. The dune could have originated in the Dryas III (Late Würm), i.e. 1210–1700 BP (Havlíček, 2004). The sand dunes were also partly resedimented in the Holocene, as is evidenced by some buried Mesolithic chipped artefacts. The fine to medium grained blown sands have a yellowish to brownish colour and, especially at the dune base, alternate with coarser grained layers of what were probably of fluvial genesis. These Quaternary fluvial–eolian rocks form the uppermost part of the Cenozoic filling of the Vienna basin, a large geological unit of the Outer Carpathians. The bedrock of the Quaternary deposits in the area of Pohansko was obtained through boreholes at various depths from 4.4 to 8.1 m and is represented by grey clays of the Pannonian Age.

Originally the sand dunes had a height of between 6 and 8 m, but recently because of younger flood loam deposits, they are only 1–2 m above the flood plain. Some lower dunes were even buried under the flood loams. The beginning of flood loam sedimentation is estimated to be about 3000–4000 BP at the initial phase of the Subboreal period (Břízová and Havlíček, 2002; Havlíček, 2004; Havlíček and Smolíková, 1994; Opravil, 1983b).

From the 10th and especially 12th century AD (Opravil, 1983b), the more intensive sedimentation of flood loams precipitated (or substantially contributed to) early medieval settlement at Pohansko and other similar sites in the flood plain near the Morava and Dyje confluence (Macháček et al., 2007).

The deposition of flood loams was not continuous and a few hiatuses occurred. Pelíšek (1942) describes two soil horizons within the flood loam sequence in the area of the Lower Morava depression. Opravil (1999) estimates their origin to be the end of the Subboreal (i.e. about 2900 BP) and the end of the older Subatlantic (around 1000 AD).

Flood loams and clays intercalated with buried terrestric gleysols in the construction of the Great Moravian fortification are recorded in Pohansko (Fig. 2) even before this time.

As both semiterrestric soils underlie the whole fortification area, we can safely say that they pre-date the Great Moravian times. The deposition of the youngest flood sediments, which covered the ruins of the fortification from the outer side, took place after a short break in deposition marked by the formation of humic horizon “A” of the upper buried soil in the flood plain. The surface of this soil was active during both the construction and destruction of the Great Moravian rampart. After this intermezzo, the deposition of flood loams has continued, with some interruptions, to the present. This is evidenced by the layer of the youngest flood clays, which covered the ruins of the rampart from the outer side (Macháček et al., 2007).

2.3. Paleovegetation reconstructions based on previous paleobotanical studies

Several authors such as Břízová and Havlíček (2002), Jankovská et al. (2003), Opravil (1962, 1978, 1983b), Rybníček and Rybníčková (2001) and Svobodová (1990) have attempted to create reconstructions of the vegetation composition of the South Moravian regions near the confluence of the Morava and Dyje rivers that were acquired on the basis of macroflora and palynology.

Rybníček and Rybníčková (2001) presume the development of grassy subxerophyle oak woods in the bottom lands of the Early Atlantic (Neolithic) and the development of mixed linden-oak woods with elms in the medially wet areas. There was a striking human influence registered there. Due to progressive deforestation, intensive agriculture and herding in pastures, humans changed the mesoclimate during the Bronze and Older Iron Ages. They caused the secondary development of stands of xerothermic vegetation and, similarly, the development of peat in the valleys. Several authors (i.e. Firbas, 1949; Ložek, 2007; Opravil, 1999) suppose that there were transient climatic (primarily humidity) oscillations during the whole younger Atlantic to Subboreal. The intensification of precipitation in the Lower Subatlantic caused an increase in erosion and the first levelling of the lower niches of the bottom land, according to Ložek (2007) and Opravil (1999). Since then the modern-day cultural landscape has gradually developed.

Opravil (1978, 1983a, 1999) made reconstructions of plant assemblages in the surroundings of the Early Medieval Centre (Great Moravia) Mikulčice on the basis of fossil macroflora. In the more variegated morphology here, he noticed greater diversity and other quantitative proportions in the fossil plants compared to today’s. The surface of the bottom land was formed by fluvial sandy gravel overgrown with sporadic vegetation before the main deposition of the flood sediments. Moor vegetation, alders and the edges of shrubby willows developed in the depressions along the water streams and erosive trenches. Forest formations, primarily hard flood-forest, grew in the elevated benches.

Svobodová (1990) conducted the first palynological analyses of sediments from the Pohansko and Mikulčice localities. She documented increased human impact in the profile: deforestation, synanthropic elements (such as *Artemisia*, *Plantago lanceolata*, *Convolvulus arvensis*, *Centaurea cyanus*, Viciaceae) and cultural plants (Cerealia). She proved that the environment of Mikulčice had the character of a town with a great agricultural foundation, whereas Pohansko was surrounded by mixed oak wood (unfortunately without any chronological or archeological support).

Findings of anthropogenic elements were documented by Břízová and Havlíček (2002) from the underlying sediments of the cultural layer of the Mikulčice fortification.

3. Methods

Overall, 172 samples were palynologically analysed. They came from 3 profiles in the archaeological section R18 across the rampart and its ruins, the sedimentary filling of archaeological feature (a pit) O1, excavated test trench S3, separate samples from the sedimentary filling of the rampart structure and 13 boreholes V1–V13 (to a depth of 8 m) (Fig. 1). The studied Holocene sediments belong to the stream and flood loams of the Dyje river, aeolian sands and buried soils. The lower parts of the boreholes penetrated into Pleistocene fluvial sandy gravels and the underlying clay sediments of the Upper Miocene (Pannonian) age (Macháček et al., 2007).

The sediments contained a varied amount of organic matter. Primarily soils and flooding loams had typically low proportions of palynomorphs. During soil-forming processes, the oxidation and intensive activities of Bacteria and Fungi can cause partial or total decomposition of the organic walls of pollen grains and spores. More resistant palynomorphs (*Alnus*, *Tilia*, Pinaceae) could be overestimated in the pollen diagrams (Havinga, 1967). The flooding sediments are deposited very quickly in a large capacity (mostly in early spring), which means that the palynomorphs are very dispersed in the mass of inorganic material.

The sediments were macerated using the HCl, HF, KOH and acetolysis (Erdtman, 1960).

The application of heavy liquid ($ZnCl_2$) was used to increase the number of palynomorphs.

For the identification of palynomorphs, the following publications were consulted: Beug (2004), Erdtmann (1957), Erdtmann et al. (1961), Komárek and Jankovská (2001), Moore et al. (1991), Reille (1995), Rybníčková (1974), Van Geel et al. (1983), Zetter (1987).

The pollen diagrams were created using the POLPAL programme (authors Walanus and Nalepka, 1999). Five samples were dated by ^{14}C dating in the Poznań Radiocarbon Laboratory (T. Goslar).

Some profiles and boreholes contained time-comparable lithological (geologic–pedologically defined) horizons (Figs. 1 and 2) related to the development of the Dyje river bottom (see above). Due to these facts, the vegetation history could be interpreted from the most plentiful pollen spectra of different spots in the equivalent layers. On this basis, two combined pollen diagrams were constructed – one from the inner parts of the fortification (Figs. 1 and 5), another from outside of the rampart (Figs. 2 and 6).

We usually did not make pollen diagrams for each individual plant, but instead plotted several plants into "ecological floral units" to give a basic idea of the vegetation relationships. We realize that there is some simplification: e.g *Quercus* (Opravil, 1978, 1983b) could be a member of either mesophyte oak-lime-hornbeam or flood-plain forest vegetation, depending on the species.

1. The unit "oak-lime-hornbeam forest" contains *Quercus* + *Loranthus*, *Carpinus*, *Tilia*, *Acer* (Fig. 3);
2. The group "Flood-plain forest" contains *Alnus* and *Ulmus*, *Fraxinus*, *Salix* and *Populus*;
3. "Marshy and aquatic herbs" contains *Potamogeton*, *Sparganium*, *Filipendula*, *Myriophyllum*, *Nymphaea*, *Nuphar*, *Typha*, Cyperaceae, *Caltha* (Fig. 3);
4. Some primary as well as secondary anthropogenic indicators are marked in yellow (Fig. 4);
5. All other herbs were included in the unit called "Other herbs".

4. Results

4.1. The oldest sediments

The bottom sediments (6–8 m) were sedimentologically dated as Upper Neogene-Pannonian (Macháček et al., 2007) (Fig. 1). The pollen spectra with only Miocene palynomorphs (i.e. *Engelhardia*, *Symplocos*, *Glyptostrobus*, *Tsuga*, *Cedrus*) (V9 – 6 m, V2 and V3 – 8 m) testified to these ages (Doláková and Kováčová, 2008). Redeposited Miocene palynomorphs were also occasionally found in some Holocene sediments (from a base of up to 1.5 m deep). The preservation states of individual palynomorphs known both from the Quaternary and Tertiary (e.g. *Pinus*, *Ulmus*, *Alnus*, *Quercus*, *Juglans*) may be different or not under a light microscope. Observation under a fluorescent microscope can help to determine the reworked palynomorphs (Van Gijzel, 1971; Yeloff and Hunt, 2005; Doláková and Burešová, 2007).

Particular coarse-grained Upper Pleistocene fluvial sands and gravels, in positions similar to the boreholes (about 3,8–8.5 m) (Fig. 1), represent the basal Quaternary layers (Macháček et al., 2007) here and were palynologically sterile (due to their mechanical properties).

4.2. The basal Holocene fluvial sands

Pollen spectra from fluvial fine sands and/or sandy clays correspond to the former research of flood-plain vegetation near the confluence of the Morava and Dyje rivers (see above).

The pre-domination of oak-lime-hornbeam forest (*Quercus* was most frequent) alternating with flood-plain forest (dominant *Alnus*, and less *Ulmus*, *Fraxinus*, *Salix* and *Populus*) was visible in the pollen diagrams (Figs. 5 and 6), V5, V13 – outside of the ramparts (Fig. 6), V1 (Fig. 7), P1, S3 (Figs. 2 and 8). This phenomenon could have been caused by primeval human activity or climatic reasons. There was regular occurrence of the pollen of *Betula*. *Pinus sylvestris* is frequent; *Picea* was found in low quantities. The infrequent pollen grains of *Abies* were transported here from the more distant higher areas. The occurrence of *Juglans* pollen is very interesting and disputatious. This genus had no natural occurrence in Central Europe in the Holocene. Its cultivation by humans or re-deposition from the underlying Miocene sediments should not be ruled out (see discussion).

In addition, there is a minor proportion of shrubs (sporadically Rosaceae – *Prunus* and *Rubus*); only *Corylus* was commonly found.

Trees dominated over herbs, but the landscape was not completely forested. Associations of open locally moist areas were represented mainly by the following herbs: grasses – Poaceae, Asteraceae, Cyperaceae, Ranunculaceae, fewer *Euphrasia*, *Chrysosplenium* and *Symphytum*. There were also plants growing at the edges of bodies of water: *Typha*, *Potamogeton*, *Nymphaea*. Nevertheless, there were some anthropogenic indicators in these layers – archaeophytes such as Cerealia (Figs. 3 and 4) and field weed such as *Polygonum aviculare*, *C. cyanus* (profile P1 – 2 m) (Fig. 3). There were also secondary anthropogenic elements, original to this landscape, but spreading thanks to human activity, which created suitable places for them due to deforestation, ruderalisation, pasturage and agriculture. They are as follows: *P. lanceolata*, *Rumex acetosella*, *R. acetosa*, *Artemisia* (Fig. 3), and Chenopodiaceae.

These facts indicated that there was agriculture in the period preceding Slavonic settlement, even in the time before the sedimentation of the flooding loam in the bottom land.

A charcoal particle from a depth of about 5 m in borehole V13 was dated by ^{14}C as the 7350 ± 50 cal BP (6370–6070 cal BC). The ^{14}C dating of overlaying sediment: 3 m: 8240 cal BP (7470–7070 cal BC) proved the big sedimentological dynamics of the bottom land. The Cerealia-type pollen (Cerealia X *Glyceria* species) from these layers should be considered (see discussion).

4.3. The lower flooding sediments

A marked decrease in pollen grains of woody genera already in the overlying lower flooding sediments and the lower buried soil inside of them was documented. Their palynomorph content is generally very low (see chapter 3.). Only a few samples yielded more palynomorphs capable of creating an image of the vegetation. Oaks (*Quercus*), hornbeams (*Carpinus*) and elms (*Ulmus*) almost disappeared. Alders (*Alnus*) decreased and only poplars (*Populus*) and pines (*Pinus*) remained. In contrast to the decrease of trees, herbs (primarily grasses and ferns) increased (Fig. 5). It is presumed that the great amount of deforestation allowed more flooding.

The regular occurrence of spores of *Sphagnum*, the increased percentage of sedges (Cyperaceae) and the finding of aquatic plants *Myriophyllum spicatum* (Fig. 7), *Utricularia* and green algae of *Botryococcus* in the layers directly beneath and outside of the fortification all provide evidence for the existence of marshes here. The fortification must have been partially built on a swamp. It may have also played a role in protecting against flooding. Practical evidence of this was shown in 2006, a year of extreme flooding (Fig. 1). The opening in the fortification for archaeological investigation caused the inundation of a large part of the locality.

4.4. Sand dune

Borehole V1 (Fig. 7) was located on the sandy dune and contained slightly loamy aeolian sands. Within the whole borehole, the predominance of herbs over trees was noticeable (mainly Poaceae and Asteraceae). *P. sylvestris* is the richest arboreal element. It is the typical tree of sand dunes and also a significant pioneer tree, penetrating open spaces such as fallow land first. It is often overvalued in pollen spectra due to its strong resistance during deposition (Havinga, 1967) or high pollen production and large dispersion range. *Tilia* was more frequent here than in other boreholes. This could be related to its better resistance in sandy sediments. The number of elements of flood-plain forest was lower.

The alternating predominance of flood-plain forest over oak-lime-hornbeam forest – similar to other boreholes and profiles – is conspicuous. The pollen spectra indicated vegetation of drier places with bad ground.

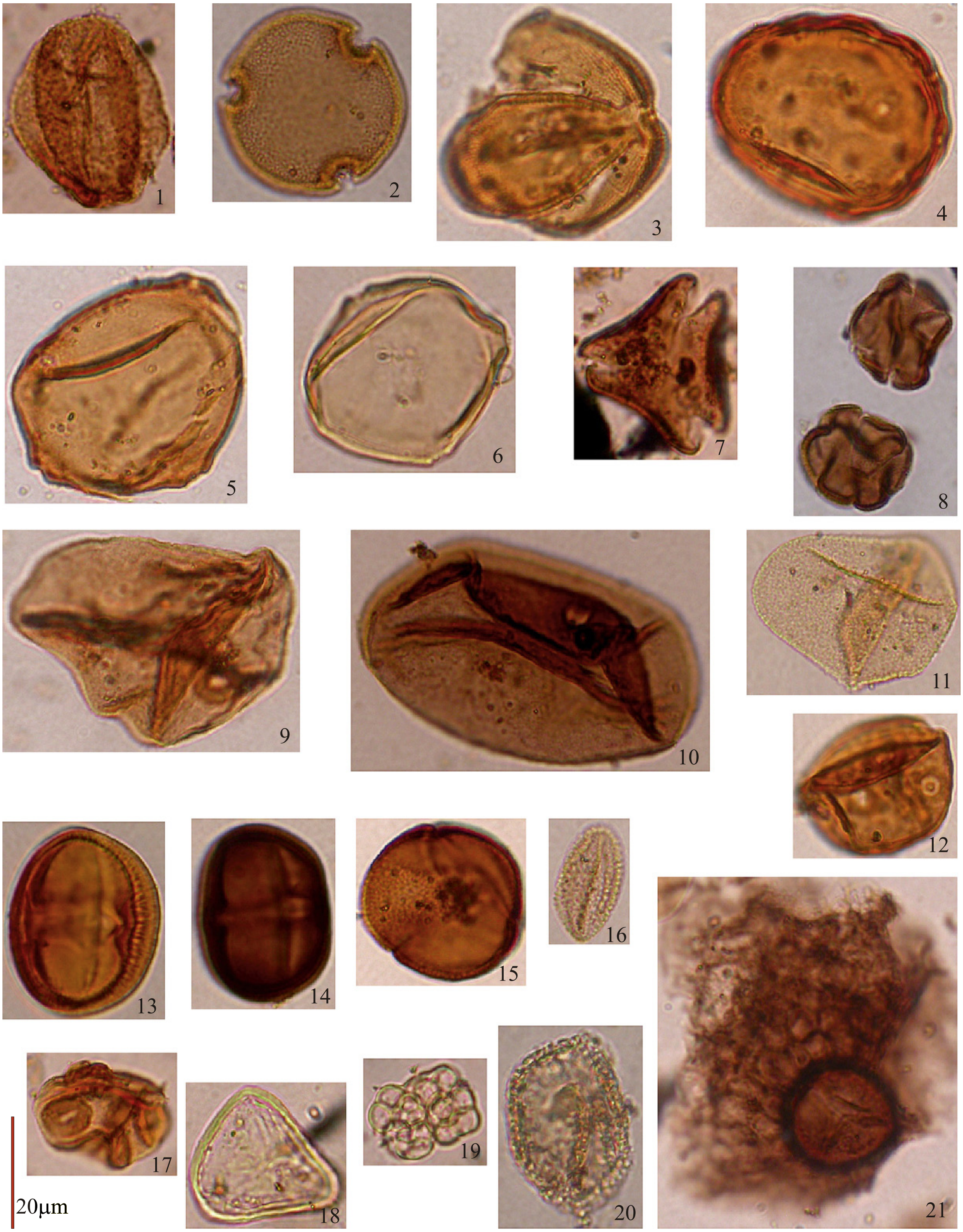


Fig. 3. Main pollen types, LM magnification 1000×. 1. *Quercus* sp. – O1, 150 cm. 2. *Tilia* sp. – P1, 160 cm. 3. *Acer* sp. – V5, 320 cm. 4. *Juglans* sp. – V5, 320 cm. 5. *Carpinus* sp. – V5, 320 cm. 6. *Carpinus* sp.– S3, 135 cm. 7. *Loranthus* sp.– O1, 150 cm. 8. *Galium* sp. – O1, 154 cm. 9. Cerealia – *Triticum* type – V5, 320 cm. 10. Cerealia – *Secale* type – O1, 154 cm. 11. Cyperaceae – P1, 200 cm. 12. *Plantago lanceolata* – V5, 250 cm. 13. *Centaurea cyanus* – P1, 200 cm. 14. *Polygonum aviculare* – V1, 230 cm. 15. *Rumex* sp. – V5, 250 cm. 16. *Salix* sp. – P1, 200 cm. 17. *Myriophyllum* sp. – O1, 150 cm. 18. *Sphagnum* sp. – P3, 15 cm. 19. *Botryococcus* sp. – S3, 110 cm. 20. Probably aquatic moss, type 340 – S3, 110 cm. 21. *Salvinia* sp. – S3, 90 cm.

4.5. Excavated test trench S3

Most of the sediments were dark humic flooding loams (Fig. 2). Palynology confirmed the sedimentological results regarding the existence of an oxbow inside of the locality. Freshwater green algae *Pediastrum boryanum*, frequent *Botryococcus* (Fig. 8) as well as zygospores of Zygnemataceous algae, including *Spirogyra* and *Mougeotia*, occurred in these sediments. There were plenty of non-pollen types 128A and 74 (Van Geel et al., 1983), as well as some possible algal palynomorphs. *Sphagnum* was sporadic, however, there was an abundance of spores of type 340 found belonging to the aquatic mosses, according to Miola et al. (2007) (Fig. 3).

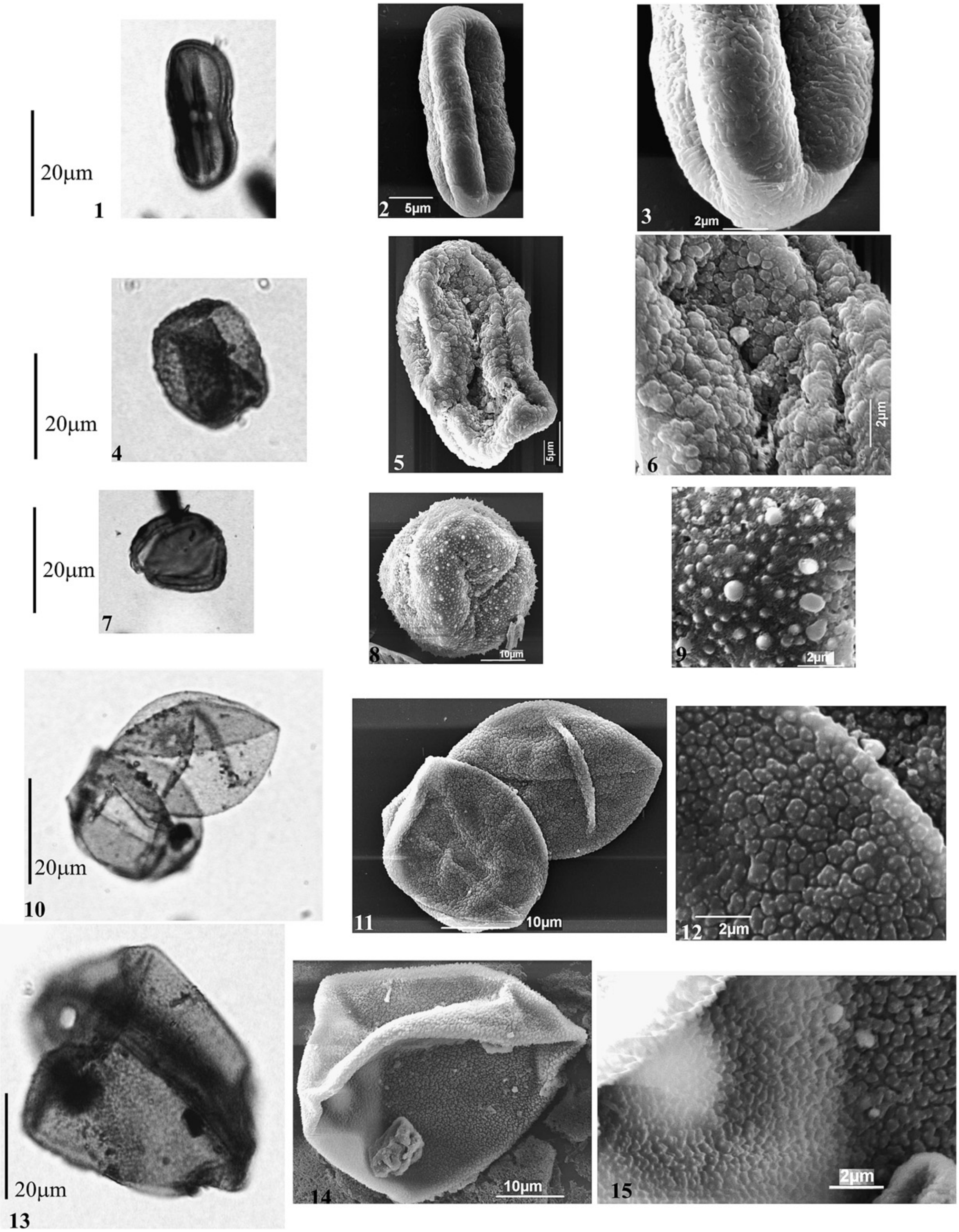


Fig. 4. Author of SEM photos – J. Štelcl. 1–3. Daucaceae – *Peucedanum* sp. – O1, 150 cm 1. LM 1000× magn. 2–3 SEM. 4–6. *Quercus* sp. – O1, 150 cm 4. LM magn. 1000×, 5–6 SEM 7–9. *Artemisia* sp. – O1, 154 cm. 7. LM 1000× magn. 8–9 SEM. 10–12. Poaceae – wild grasses – O1, 150 cm. 10. magn. 1000×, 11–12 SEM. 13–15. Cerealia *Triticum* type – O1, 150 cm. 13. LM magn. 1000×, 14–15 SEM.

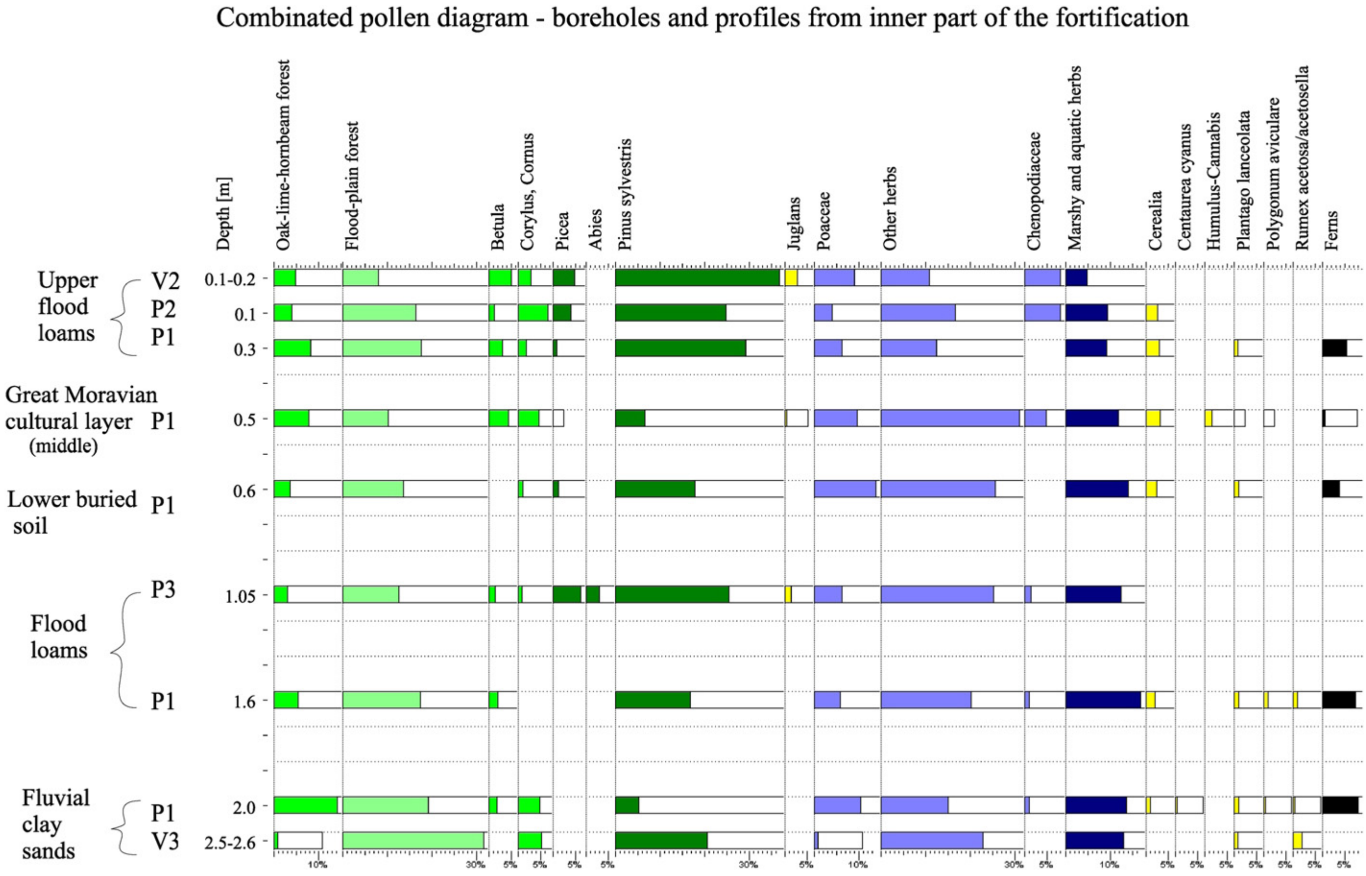


Fig. 5. Combinated pollen diagram – boreholes and profiles from inner part of fortification.

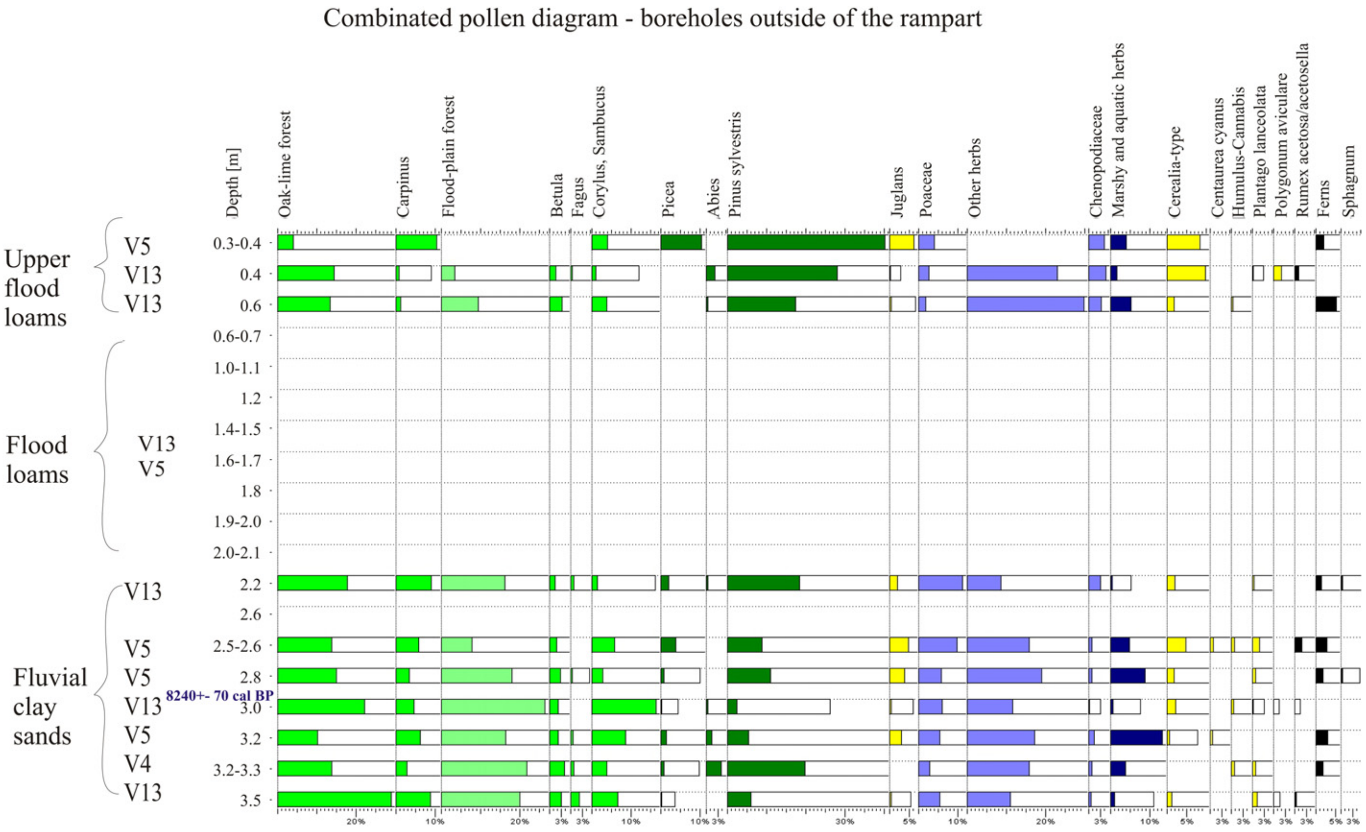


Fig. 6. Combinated pollen diagram – boreholes outside of fortification.

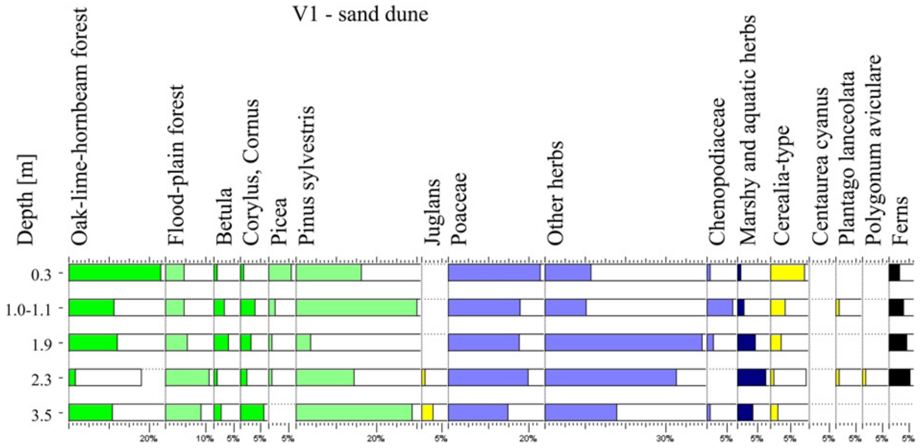


Fig. 7. Pollen diagram of borehole V1 – through the sandy dune.

Common sporangia with microspores of the water fern *Salvinia natans* (Fig. 3) were found at some depths. There was also a regular occurrence of water rim genera of *Potamogeton*, *Typha*, *Sparganium* and the family Cyperaceae, sporadic *M. spicatum* and several objects resembling Charophytes gyrogonia. These fossil types indicate an open water environment in eu- to mesotrophic conditions. From the uppermost part of the sediments, the water indicators decreased.

The ^{14}C dating manifested surprisingly high ages of the dated sediments (Fig. 2):

S3 1.27 m: 7830 ± 60 BP (7050–6450 cal BC) as Lower Atlantic–Neolithic;
S3 0.4 m: 2210 ± 30 BP (380–190 cal BC) as Lower Subatlantic-Hallstatt; La Téne.

The pollen diagram can be divided into two parts (Fig. 8). The boundary is created by the practically sterile samples from the middle part of the profile.

A pre-domination of trees over herbs was observed in the lower part. In addition to *Pinus*, elements of oak-lime-hornbeam forest also occurred. The pollen of *Carpinus* occurred sporadically, but it was found at almost all depths from the lower part of the test trench (even below the sample dated as Early Atlantic). These findings are significant as they confirm the earlier spreading of *Carpinus* (Figs. 3 and 6) in the Czech Republic and refute the traditional assumption of their Subboreal penetration (see discussion). *Corylus* reached 8% in some samples. Elements of flood-plain forest prevailed in the lowermost part, where anthropogenic indicators *Cerealia* and *Juglans* were found, although to a lesser extent than in the upper part.

There were a visibly decreasing number of trees, increasing number of herbs and more frequent primary and secondary indicators of human activity (Cerealia, *C. cyanus*, *P. lanceolata*, *P. aviculare*, *Rumex acetosa*, Chenopodiaceae) in the upper part of the studied layers. The prevailing presence of flood-plain forest is visible at the samples dated as Hallstatt, which correspond to the abundant occurrence of *Salvinia* (see above in this chapter). A markedly

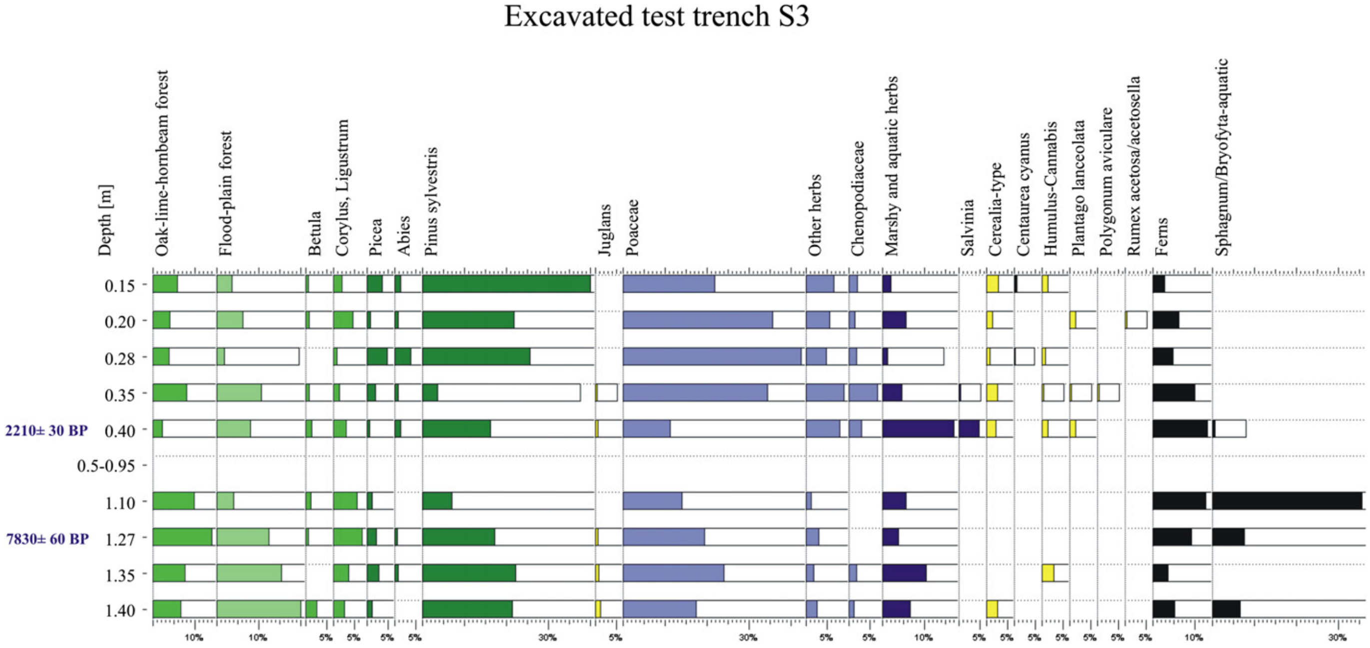


Fig. 8. Pollen diagram – excavated test trench S3.

increasing amount of *Pinus* is noticeable in the uppermost sample, compared to other boreholes and profiles (see below).

4.6. The cultural layer

A cultural layer of about 0.30 m was uncovered at a depth of about 0.5 m from the surface in section R18 (Fig. 2). It represents the homogenized upper buried soil with artefacts from the Great Moravia age. Generally, herbs prevailed over trees (Fig. 9). The base of the cultural layer probably occludes the natural flood-plain surface from the beginning of Early Medieval times. The initial deforestation (mainly oak-lime-hornbeam forest group) was connected with the existence of the Great Moravian agglomeration and its fortification. High quality timber was already consumed from the immediate vicinity of Pohansko (as a building material for houses and fortification and as fuel). Opravil (2000) analysed the coalified tree remains from the construction of a protective wall. He concluded the following composition: 75% *Quercus*, 5% *Ulmus* and 3% *Fraxinus*. *Corylus* also had an increasing tendency. *Juglans* could have been cultivated by the inhabitants of Pohansko. Herbs were evidently also abundant (e.g. Asteraceae, Poaceae, Cyperaceae, Ranunculaceae, Rosaceae, Rubiaceae).

Cereals were found in the whole cultural layer with the maximum amount of 5%. Pollen grains of other cultural and synantropic plants (e.g. *Humulus-Cannabis*, *P. lanceolata*, *P. major/media*, *Urtica*) were found. Chenopodiaceae increased mostly in the upper part of the cultural layer, which was related to ruderalisation caused by human activity. The surroundings of the fortification could have been used as pastures or fields.

4.7. Archaeological feature O1

Samples from the wall of archaeological feature (a pit) O1 were almost sterile. Another two samples came from the anthropogenic filling of this object. The lower samples were dated by ^{14}C as 2560 ± 50 years BP (820–520 cal BC) as Lower Subatlantic – Hallstatt.

The samples contained about 24% trees and 76% herbs (Fig. 9). Elements of flood-plain forest slightly prevail over the oak-lime-hornbeam forest. *Pinus* was the most abundant tree in both samples. *Abies* was also more highly represented. We can assume that it was carried by the wind from more distant regions. *Abies* was used as a revetment of a grave in the nearby Great Moravia locality Mikulčice (Opravil, 1962). It could have been that this precious tree was imported on special occasions from more distant places.

In both samples *Sambucus*, which prefers moist nitrogenous soil, was found. *Juglans* and *Corylus* may have been cultivated for nuts.

Herbaceous pollen was very abundant (Fig. 9). Meadow herbs include *Centaurea* sp., *Centaurea jacea*, Euphorbiaceae, *Euphrasia*, Fabaceae (*Lotus*, *Trifolium*), Rosaceae and *Veronica*. Plants such as Daucaceae (Fig. 4), Fabaceae, *Galium*, Polygonaceae and Ranunculaceae could belong to a category of herbs which grew near the edges of woods or in damp places. There was a frequent occurrence

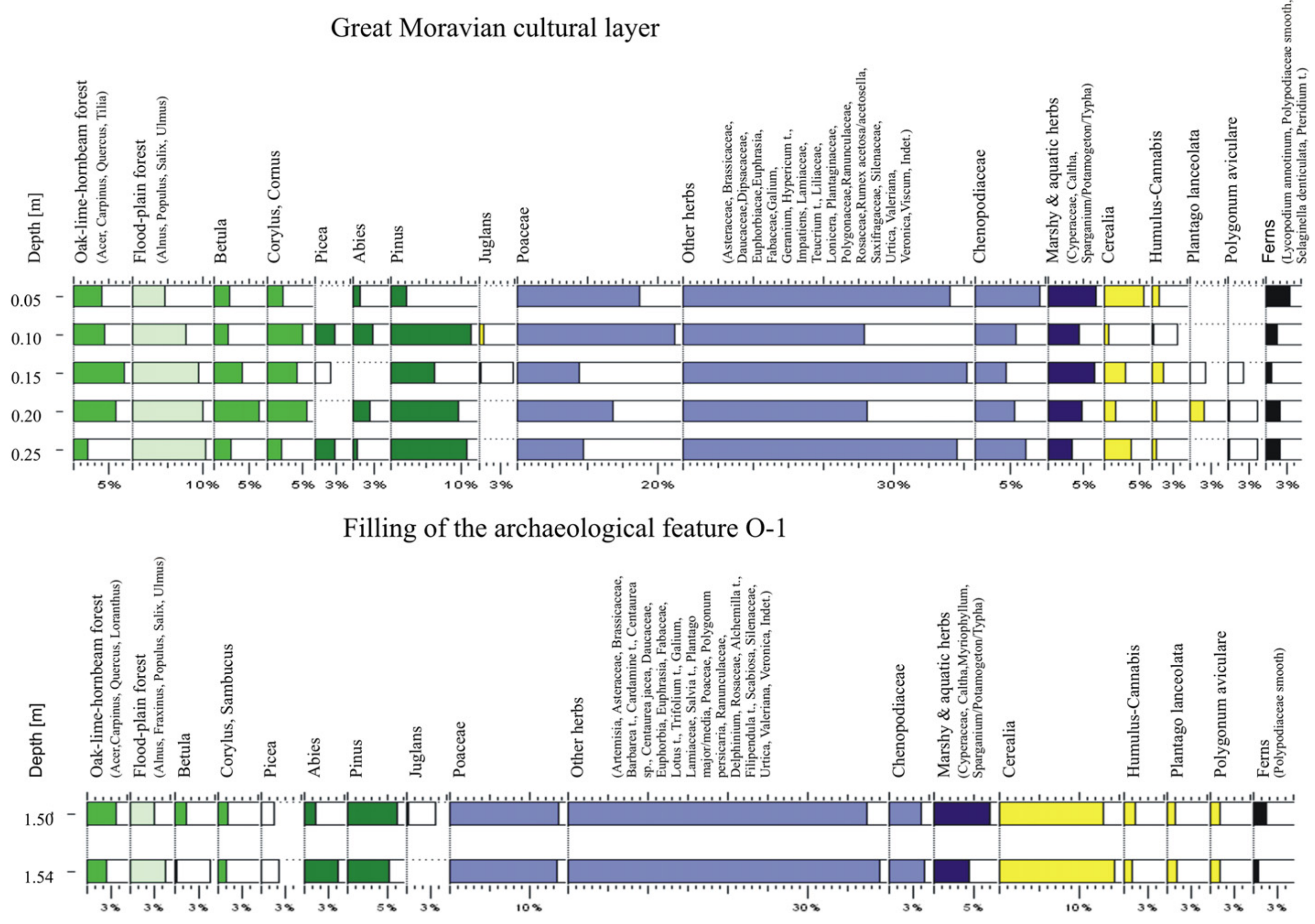


Fig. 9. Pollen diagram from the Great Moravian cultural layer and filling of the archaeological feature O1.

of marshy and aquatic herbs (Cyperaceae, *Chrysosplenium*, *Myriophyllum*, *Potamogeton/Sparganium*).

In both samples, a prominently high amount (over 13%) of Cereal (*Triticum* and *Secale*) types (Figs. 3 and 4) were found (Fig. 9). This is evidence of the probable manipulation or processing of cereals in human settlement. The following plants were connected to the presence of human and agricultural activities: weeds such as *Polygonum persicaria* and Silenaceae and other synantropic herbs such as *Urtica*, *Humulus/Cannabis*, *P. lanceolata*, *Plantago major/media* and *P. aviculare*.

We suppose that some plants could have been collected or cultivated and used as medicinal plants (e.g. *Sambucus*, *Euphrasia*, *Salvia*, *Plantago*, *Alchemilla*, *Urtica*, *Valeriana*, *Artemisia*). Some plants could have been used for dyeing textiles (e.g. the fruits of *Sambucus* and some Rosaceae, leaves of *Urtica*, *Juglans* and *Betula*). It is necessary to support this hypothesis with further research and evidence.

Both samples are different from the other samples from Pohansko. The higher accumulation of normally scarce pollen could be connected to human activity within the location of the fort.

4.8. *Samples of sediments from the stone rampart*

The pollen spectra were very poor. They contained almost all the trees known from the other samples in this locality. Asteraceae were the abundant herbs. There were many charcoal particles and non-pollen objects. Most of them were spores of terrestrial algae and spores and conidia of Fungi often living on decomposed wood (some of them on oak). Sporadic cysts of marine algae originated from the Neogene under-layer. They could have been redeposited or people could have used the Neogene sediments as filling for the stone ramparts.

4.9. *Overlays of the cultural layer*

Above the cultural layer, humic loam was noticed in the inner part of the rampart and youngest flood clays, which covered the destroyed part of the rampart from the outer side. These youngest flood sediments levelled the flood-plain surface (Opravil, 1983b; Havlíček, 2001). In these samples there was evidence of the partial regeneration of woodland. The large quantity of *Pinus* pollen that is manifest indicates that the process of succession is still continuing. The same phenomenon is visible in all the uppermost parts of the profiles and boreholes. This landscape regeneration seems to be the result of a decrease in the intensity of human activity.

5. Discussion and interpretations

The occurrence of *Carpinus* in the sediments dated as Early Atlantic is noteworthy. Its spreading into the Czech Republic (Bohemia and Moravia) during the Subboreal is assumed to be based on a traditional idea (i.e. Firbas, 1949). In addition, Kalis et al. (2003) does not assume its penetration in the Early Atlantic forests in Central Europe. Magyari (2002) noted the first appearance of *Carpinus* in the SE Carpathians and in the North Hungarian Middle mountains around 8500 cal BP and their role as an important element of the woodlands from about 7500 cal BP. Glacial refugia for C*arpinus* are referred to in the Balkan Peninsula (Huntley, 1988; Willis, 1994; Bozilova and Tonkov, 2000) and in restricted areas of the Hungarian plains (Magyari, 2002; Feurdean, 2005). According to Ralska-Jasiewiczova et al. (2002), an isopollen map of the spreading of *Carpinus* from Italy and Romania shows that it reached the SE of Poland in 7000 BP. Several authors (Gardner, 2002; Ralska-Jasiewiczova et al., 2002) presume the expansion of *Carpinus* to be an anthropogenic activity (from 6800 cal. BP).

Rybníčková (1985) supposed the much earlier spreading of *Carpinus* in the area of the confluence of the Dyje and Morava rivers than in other regions of the Czech Republic. The scarce findings of *Carpinus* in the Mesolithic age and the increased occurrence of settlements where Linear Pottery was used (Lower Neolithic) confirm, according to Opravil (1983a), the early arrival of *Carpinus* in South Moravia. From the time of the climatic-optimum Atlantic, macro remains such as wood and nutlets have been found (Opravil, 1983a, 1984). Our findings of *Carpinus* (6%) (Fig. 6) in the layer dated as Mesolithic (V 13 – 8240 cal BP), and also below it, also confirm the earlier spreading of *Carpinus* in the Czech Republic (i.e. South Moravia).

The occurrence of pollen grains of *Juglans* is very interesting and disputatious in the area studied. It occurred in nearly all types of sediment at almost all the depths of this locality (e.g. S3 1.27 m: 7830 ± 60 cal BP) (Fig. 8). The present area of the natural extent of *Juglans* is in the mesophyte forest of the Balkans, northern Turkey, the Caucasus and Central Asia. The occurrence of *Juglans* is traditionally interpreted as an import from southern Europe during Roman times (Hajnalová, 2001). From several investigations, it is presumed that there is an older occurrence of it in the northern Alps. Another example is the coalified *Juglans* wood that was found in the Slovakian Neolithic locality Šarišské Michaľany (Hajnalová, 2001). Cyprien et al. (2004) presents pollen diagrams from France (lower Loire) with grains of Cerealia, *Fagopyrum* and *Juglans* occuring at about 6300 cal B.C.; nevertheless, Behre (2007) recommends a thorough reinvestigation of the site. Griffiths et al. (2004) assumes Juglans in the pre-Holocene refugias of the Balkans (Slovenia and Greece). The survival of *Juglans* during the last glacial stage is assumed by Carrión and Sánches-Gómez (1992) in southern Spain. Pollen grains of *Juglans* were found by Jankovská et al. (2003) in some handmade boreholes in the neighbouring Slavonic fort of Mikulčice (flooding sediments of 2.20–2.30 m) and also by Svobodová (1990) in Pohansko at a depth of 1.60 m. Due to the presence of redeposited Neogene pollen grains in some Holocene samples, the eventual redeposition of *Juglans* pollen could not be excluded. Long-distance transport by strong winds from southern areas could be considered.

The findings of Cereal-type pollen in the pre-Neolithic (V 13–8240 cal BP) sediments are disputable. Secondary anthropogenic indicators *P. aviculare*, *P. lanceolata*, *R. acetosella*, *Humulus-Cannabis* (which could, however, be original to this landscape) were found. Cereal-type pollen was found in parts of Central Europe sporadically and known from the pre-Neolithic period, according to Lang (1994). The first cereal pollen found in the Neolithic (7600 cal BP) was in south-west Germany (Rösch, 2000). The possibility of the pre-Neolithic origin of Cereals in Central Europe is discussed by Behre (2007) and Kalis et al. (2003). According to Zolitschka et al. (2003), there is a strong influence of human activity on the natural landscape in the late Neolithic, indicating that agriculture was expanding over most of Central Europe. These changes coincide with the start of colder and moister climatic conditions following the “Holocene climatic optimum” (Davis et al., 2003). According to Behre (2007) and Beug (2004), apart from cultivated cereals, several species could belong to the Cerealia-type pollen. Particularly the *Glyceria* species, growing in wet habitats, could be expected in Central European pollen diagrams, according to Behre (2007). Similar vegetation types are typical for the basal Holocene pollen spectra in our area of study (Figs. 1, 2 and 4). Long distance transport of cereal pollen must also be considered (Behre, 2007). Roszková (2007) found the *Triticum*-type pollen in the locality at the Giant Mountains at an altitude of 1471 m a. s. l., which could have been transported by wind currents from the lowland.

6. Conclusions

Palynological studies were done in the boreholes and profiles from the inside and outside space of the settlement. The investigated material was composed of mineral sediment with mostly a small admixture of organic particles.

The lowermost parts of some boreholes penetrated into the Upper Miocene sediments of the Vienna basin. The age of the studied Holocene sediments were dated from the Mesolithic (^{14}C in 8240 cal BP) up to the 12th century or even more recent times (the youngest flood loam).

Variations in the proportions of individual plant types of the studied Holocene layers were probably controlled by the character of deposition caused by changing humidity as well as by human activity (clearance, agriculture, pasture). The predominance of flood-plain forest against the mesophyte oak-lime-hornbeam forest, which is visible (several times) in the pollen spectra, indicates increased aerial and edaphic humidity. The first significant decrease of arboreal pollen was detected in the level preceding the lower flood loams and lower soil horizon. There is evidence of human impact in these layers (the occurrence of Cerealia, field weed such as *P. aviculare*, *C. cyanus*, as well as secondary anthropogenic elements *P. lanceolata*, *R. acetosella*, *Humulus – Cannabis* and Chenopodiaceae).

These facts indicate that there was agriculture in the Neolithic period – in the time before the sedimentation of the flooding loam in the bottom land. There may have been human activity at the first accumulation of these flooding sediments.

A striking human influence was also registered in the layers dated as Hallstatt.

The partial rejuvenation of forest was visible in the overlaying horizons. This rejuvenation was followed by the greatest deforestation in the Great Moravian cultural horizon.

The findings of pre-Neolithic Cereal-type pollen such as *Juglans* are disputable.

The palynomorphs demonstrate that the stone ramparts served not only as protection against invasions by Hungarians, but additionally as a flood prevention barrier.

The occurrence of *Carpinus* pollen in the layer dated as Early Atlantic, and also beneath it, confirms the earlier spreading of *Carpinus* in the Czech Republic (i.e. South Moravia). This concurs with earlier findings of macro remains from the old settlement regions of the Czech Republic.

Acknowledgements

The study was supported by Research project MSM0021622427 (Czech Republic) Inter-disciplinary Centre for Research into Prehistoric to High Medieval Social Structures.

We are grateful to Sarka Rousava for correction of the English language and to anonymous reviewers for constructive comments.

References

Behre, K.E., 2007. Evidence for Mesolithic agriculture in and around central Europe? Veg. Hist. Archaeobot. 16, 203–219.

Beug, H.J., 2004. Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. Verlag Dr. Friedrich Pfeil, München.

Bozilova, E.D., Tonkov, S.E., 2000. Pollen from Lake Sedmo Rilsko reveals southeast European Postglacial vegetation in the highest mountain area of the Balkans. New Phytol. 148, 315–325.

Břízová, E., Havlíček, P., 2002. Několik poznámek k pylové analýze kvartérních sedimentů z Mikulčic na jižní Moravě. Zpr. Geol. Výzk. v r 2001, 124–126.

Carrión, J.S., Sánches-Gómez, P., 1992. Palynological data in support of the survival of walnut (*Juglans regia* L.) in the western Mediterranean area during Last Glacial times. J. Biogeogr. 19, 623–630.

Cyprien, A.L., Visset, L., Carcaud, N., 2004. Evolution of vegetation landscapes during the Holocene in the central and downstream Loire basin (Western France). Veg. Hist. Archaeobot. 13, 181–196.

Davis, B.A.S., Brewer, S., Stevenson, A.C., Guiot, J., 2003. The temperature of Europe during the Holocene reconstructed from pollen data. Quat. Sci. Rev. 22, 1701–1716.

Doláková, N., Kováčová, M., 2008. Pannonian vegetation from the northern part of Vienna basin. Sborník Národního muzea v Praze (Acta Musei Nationalis Pragae), Řada B, Přírodní vědy 64 (2–4), 163–171.

Doláková, N., Burešová, A., 2007. Use of fluorescent microscopy in the study of redeposited palynomorphs in the cave and marine sediments of Moravia (Czech Republic). Acta Palaeobot. 47 (1), 275–279.

Dostál, B., 1975. Břeclav – Pohansko. Velkomoravský velmožský dvorec, UJEP Brno.

Dresler, P., 2008. Opevnění Pohanska u Břeclavi. MS PhD. Ústav archeologie a muzeologie FF MU, Brno.

Erdtman, G., 1960. The acetolysis method, a revised description. Svensk Bot. Tidskr. 54, 561–564.

Erdtmann, G., 1957. Pollen and Spore Morphology. Plant Taxonomy. Gymnospermae, Pteridophyta, Bryophyta. Almquist and Wiksell, Stockholm.

Erdtmann, G., Berlund, B., Praglovski, J., 1961. An Introduction to a Scandinavian Pollen Flora. Almqvist & Wiksell, Stockholm.

Feurdean, A., 2005. Holocene forest dynamics in northwestern Romania. Holocene 15 (3), 435–446.

Firbas, F., 1949. Spät- und nachzeitliche Waldgeschichte Mitteleuropas nördlich der Alpen. I. Allgemeine Waldgeschichte. Jena.

Gardner, A.R., 2002. Neolithic to Copper Age woodland impacts in the northeast Hungary? Evidence from the pollen and sediment chemistry records. Holocene 12 (5), 541–553.

Griffiths, H.I., Kryštufek, B., Reed, J.M., 2004. Balkan biodiversity: pattern and process in the European hotspots. Kluwer Academic Publishers, Dordrecht.

Hajnalová, E., 2001. Ovocie a ovocinárstvo v archeobotanických nálezoch na Slovensku. Nitra.

Havinga, A.J., 1967. Palynology and pollen preservation. Rev. Paleobot. Palynol. 2, 81–98.

Havlíček, P., 2001. Geologická stavba velkomoravského mocenského centra Břeclav-Pohansko a jeho okolí. Zpr. geol. Výzk. v r. 2000, 71–73.

Havlíček, P., 2004. Geologie soutokové oblasti Dyje s Moravou. Břeclav. In: Hrib, M., Kordiovský, E. (Eds.), Lužní les v Dyjsko-moravské nivě, pp. 11–19.

Havlíček, P., Smolíková, L., 1994. Vývoj jihomoravských niv. Věst. Čes. geol. Úst. 69 (1), 23–40 (Bull. Czech Geol. Surv.).

http//www.mapy.cz (accessed 30.1.2007).

Huntley, B., 1988. Glacial and Holocene vegetation history: Europe. In: Huntley, B., Webb, T. (Eds.), Vegetation History. Kluwer, Dordrecht, pp. 341–383.

Jankovská, V., Kaplan, M., Poláček, L., 2003. Pollenanalytische Forschung in Mikulčice. In: Poláček, L. (Ed.), Studien zum Burgwall von Mikulčice. Spisy Archeologického ústavu AV ČR, Brno, pp. 39–74.

Kalis, A.J., Merkt, J., Wunderlich, J., 2003. Environmental changes during the Holocene climatic optimum in central Europe – human impact and natural causes. Quat. Sci. Rev. 22, 33–79.

Kalousek, F., 1966. Habitat mésolithique à Pohansko près de Břeclav (Moravie). Investigations archéologiques en Thécoslovaquie, Prague.

Komárek, J., Jankovská, V., 2001. Review of the Green Algal Genus *Pediastrum*. Implication for Pollenanalytical Research. Gebrüder Borntraeger, Berlin.

Lang, G., 1994. Quärtare Vegetationsgeschichte Europas. Gustav Fischer Verlag, Jena–Stuttgart-New York.

Ložek, V., 2007. Zrcadlo minulosti. Česká krajina v kvartéru. Dokořán, Praha.

Macháček, J., Doláková, N., Dresler, P., Havlíček, P., Hladilová, Š., Přichystal, A., Roszková, A., Smolíková, L., 2007. Early Medieval centre at Pohansko near Břeclav and its natural environment. Arch. rozhledy LIX (2), 278–314.

Macháček, J., 2005. Raně středověké Pohansko u Břeclavi – munitio, palatium nebo emporium moravských panovníků? (Early Medieval centre in Pohansko near Břeclav/Lundenburg: munitio, emporium or palatium of the rulers of Moravia?). Arch. rozhledy. LVII, 100–138.

Magyari, E., 2002. Holocene biogeography of *Fagus sylvatica* L. and *Carpinus betulus* L. in the Carpathian-Alpine region. Folia Historico-Naturalia Musei Matraensis 26, 15–35.

Miola, A., Bondesan, A., Corain, L., Favaretto, S., Mozzi, P., Piovan, S., Sostizzo, I., 2007. Wetlands in the Venetian Po plain (northeastern Italy) during the last glacial maximum: interplay between vegetation, hydrology and sedimentary environment. Rev. Paleobot. Palynol. 141 (1–2), 53–81.

Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen Analysis, second ed. Blackwell, London.

Opravil, E., 1962. Paleobotanický výzkum slovanského hradiska Na valech u Mikulčic. Arch. rozhledy. 24, 475–482.

Opravil, E., 1978. Rostlinná společenstva v okolí Mikulčic v období předvelkomoravském a velkomoravském. Arch. rozhledy. 30, 67–75.

Opravil, E., 1983a. Habr obecný (*Carpinus betulus* L.) v československém kvartéru. Čas. Slez. Muz. Opava (A) 32, 67–82.

Opravil, E., 1983b. Údolní niva v době hradištní. (ČSSR – povodí Moravy a Poodří). Academia, Praha.

Opravil, E., 1984. Poznámky k rekonstrukci přírodního prostředí v neolitu ČSSR. Studia Minora Facultatis Philosophicae Universitatis Brunnensis. E 29, 167–178. Brno.

Opravil, E., 1999. Umweltentwicklung in der Talaue der March (Ober- und Untermarch). Brno. In: Poláček, L., Dvorská, J. (Eds.), Probleme der mitteleuropäischen Dendrochronologie und naturwissenschaftliche Beiträge zur Talaue der March. Internationale Tagungen in Mikulčice V, pp. 165–180.

Opravil, E., 2000. Archäobotanische Funde aus dem Burgwall Pohansko bei Břeclav. Brno. In: Poláček, L. (Ed.), Studien zum Burgwall von Mikulčice IV, pp. 165–169.

Pelíšek, J., 1942. Pohřbené půdy v aluviích dolní Moravy. Příroda 35, 148–150.

Podborský, V., 1993. Pravěké dějiny Moravy. Muzejní a vlastivědná společnost v Brně.

Ralska-Jasiewiczova, M., Latalowa, M., Wasylikowa, K., Tobolski, K., Madeyska, E., Wright, H.E., Tuner, Ch, 2002. Late Glacial and Holocene History of Vegetation in Poland Based on Isopollen Maps. Polish Academy of Sciences, Krakow.

Reille, M., 1995. Pollen et Spores d'Europe et d'Afrique du nord. Laboratoire de Botanique Historique et Palynologie, Marseille.

Rösch, M., 2000. Long term human impact as registered in an upland pollen profile from the southern Black Forest, south-western Germany. Veget. Hist. Archaeobot. 9, 205–218.

Roszková, A., 2007. Pylové analýzy vybraných kvartérních lokalit (Stříbrná bystřina, Rýchory) Krkonošského národního parku. Acta Mus. Moraviae. Sci. Geol. 92, 157–168.

Rybníček, K., Rybníčková, E., 2001. Vegetace a přírodní prostředí jako pozadí archeologických kultur ČR, 28 000 – 1 000 BP. In: Podborský, V. (Ed.), 50 let archeologických výzkumů Masarykovy Univerzity na Znojemsku. MU, Brno, pp. 301–310.

Rybníčková, E., 1974. Vegetace ČSSR A7. Die Entwicklung der Vegetation und Flora im südlichen Feil der Böhmisch - Mährischen Höhe während des Spätglazials und Holozäns. Academia, Praha.

Rybníčková, E., 1985. Dřeviny a vegetace Československa v nejmladším kvartéru (paleobotanická studie). MS Ústav experimentální fytotechniky ČSAV, Brno.

Svobodová, H., 1990. Vegetace jižní Moravy mezi 500–1000 A.D. Arch. Rozhledy. 42, 170–205.

Van Geel, B., Hallewas, D.P., Pals, J.P., 1983. A Late Holocene deposit under Wetfiese Zeedijk near Enkhuizen (prov. of N-Holland, The Netherlands): paleoecological and archaeological aspects. Rev. Paleobot. Palynol. 38, 269–335.

Van Gijzel, P., 1971. Review of the UV-fluorescence Microphotometry of Fresh and Fossil Exines and Exosporia. In: Brooks, J., Grant, P.R., Muir, M., van Gijzel, P., Shaw, G. (Eds.), Sporopollenin. Academic Press, London-New York, pp. 659–685.

Walanus, A., Nalepka, D., 1999. POLPAL. Program for counting pollen grains, diagrams plotting and numerical analysis. Acta Paleobot. 2, 659–661.

Willis, K.J., 1994. The vegetational history of the Balkans. Quat. Sci. Rev. 13, 769–788.

Yeloff, D.E., Hunt, C.O., 2005. Fluorescence microscopy of pollen and spores: a tool for investigating environmental change. Rev. Palaeobot. Palynol. 133, 203–219.

Zetter, R., 1987. Untersuchungen and *Pediastrum* –Arten aus dem Ober Miocän des Burgenlandes (Österreich). Beiträge zur Paläontologie von Osterreich 13, 87–89.

Zolitschka, B., Behre, K.E., Schneider, J., 2003. Human and climatic impact on the environment as derived from colluvial, fluvial and lacustrine archives – examples from the Bronz Age to the Migration period, Germany. Quat. Sci. Rev. 22, 81–100.

SBORNÍK NÁRODNÍHO MUZEA V PRAZE
Řada B – Přírodní vědy • sv. 67 • 2011 • čís. 1–2 • s. 63–71

ACTA MUSEI NATIONALIS PRAGAE
Series B – Historia Naturalis • vol. 67 • 2011 • no. 1–2 • pp. 63–71

BADENIAN (LANGHIAN – EARLY SERRAVALLIAN) PALYNOFLORA FROM THE CARPATHIAN FOREDEEP AND VIENNA BASIN (CZECH AND SLOVAK REPUBLICS)

NELA DOLÁKOVÁ
Masaryk University, Faculty of Sciences, Institute of Geological Sciences, Kotlářská 2, 611 37, Brno, Czech Republic, e-mail: nela@sci.muni.cz

MARIANNA KOVÁČOVÁ
Comenius Universtity, Faculty of Sciences, Department of Geology and Palaeontology, Mlynská dolina G, SK-84215 Bratislava, Slovak Republic, e-mail: kovacova@fns.uniba.sk

PETRA BASISTOVÁ
Masaryk University, Faculty of Sciences, Institute of Geological Sciences, Kotlářská 2, 611 37, Brno, Czech Republic, e-mail: 162649@sci.muni.cz

Doláková, N., Kováčová, M., Basistová, P. (2011): Badenian (Langhian – Early Serravallian) palynoflora from the Carpathian Foredeep and Vienna Basin (Czech and Slovak Republics). – Acta. Mus. Nat. Pragae, Ser. B, Hist. Nat., 67(1-2): 63-71, Praha.

Abstract. The Badenian (Langhian - Early Serravallian) marine sediments from the adjacent areas within the Central Paratethys and NE part of the Vienna Basin, were studied from a palynological perspective. The pollen data document a subtropical climate during the Miocene Climatic Optimum with dominant representation of zonal vegetation being evergreen broadleaved forests. Higher differentiation of oak type pollen, increasing number of *Platanus* pollen and different types of herb were observed.
Some thermophilous elements (especially Sapotaceae, Palmae, Mastixiaceae and Lygodiaceae) decreased and there was an increase of the warm to cold temperate zone taxa which were first registered during the Late Badenian. These findings together with a higher proportion of extrazonal vegetation (*Tsuga*, *Picea* and *Abies*) in the Late Badenian pollen spectra document changes due to the uplift of the Carpathian Mountain chain.

■ Palynology, Badenian, Langhian, Early Serravallian, Carpathian Foredeep, Vienna Basin

Received December 10, 2010
Issued August 2011

Introduction

The adjacent areas within the Central Paratethys in the Czech and Slovak republics, the Carpathian Foredeep and Vienna Basin, were studied from a palynological perspective. The Lower Badenian (early Langhian) transgressions from the Mediterranean toward the Central Paratethys realm flooded the Pannonian Basin and continued along straits in the Carpathian Chain into the Carpathian Foredeep. During the Lower Badenian, in addition to the shallow partial basins, depressions of unstratified calcareaous clay developed which were more than a hundred metres deep – "tegels" (Brzobohatý 1982, 1997; Chlupáč et al. 2002). The isolation of eastern parts of the Central Paratethys at the end of this period (Late Langhian) resulted in the “Middle Badenian” salinity crisis. Thick evaporite sediments were deposited in the Carpathian Foredeep. During the Upper Badenian (Early Serravallian), the most recent total marine flooding covered the whole back-arc basin and a great part of the foredeep (Kováč et al. 2007). The globally observed Middle Miocene Climatic Optimum is, according to Böhme (2003) and Utescher et al. (2000), clearly reflected in the studied Badenian material. Mountain chain uplift and strong relief development is documented by the origin of river drainage feeding into the huge deltaic systems of the back arc basin (Kováč 2000; Konečný et al. 2002).

The lowermost Badenian strata, which can be recognized almost everywhere in the Central Paratethys realm, contain planktonic foraminiferal assemblages in which the genus *Praeorbulina* is associated with the genus *Orbulina* in the calcareous nannoplankton Sphenolithus heteromorphus Zone NN5 (Berggren et al. 1995; Fornaciari, Rio 1996). The time span of the Late Badenian is approximately coeval to the upper part of the MN7 Globorotalia peripheroacuta Lineage Zone of Berggren et al. (1995) and the lower part of the Discoaster exilis Zone NN6 (Martini 1971).

Material and methods

In total 64 Lower Badenian and 39 Upper Badenian samples of marine clays were studied palynologically.

The Lower Badenian samples came from the boreholes Ivaň, Rebešovice, Chrlice, Opatovice, Otmarov, Přemyslovice and outcrops Brno-Královo Pole, Moravské Knínice and Sivice, situated in the southern part of the Carpathian Foredeep and from the three regional stratotype localities Oslavany (OV-1), Židlochovice (Ž–1) and (Ž–2). The Late Badenian sediments came from the boreholes Gajary 23, Sekule 1, Jakubov 54, Zohor 1, Lozorno and outcrop at the faciostratotype locality Devínska Nová Ves situated in the Vienna Basin.

Standard maceration with HCl (20%), HF, KOH and HCl (10%) was carried out. Due to the increasing number of palynomorphs, heavy liquid ($ZnCl_2$) with a density of $2g/cm^3$ was utilised. Pure glycerine or glycerine gelatine were most frequently used as the observation media.

The percentage of the individual taxa were calculated from the total sum of a minimum 150 determined pollen grains and spores.

The palaeotropical and arctotertiary elements are classified based on the Neogene pollen flora of Central Europe (Stuchlik et al.1994). The vegetation units terminology was used according to Kvaček et al. (2006) and Kovar-Eder et al. (2008).

To resolve the situation with problematic taxa identification, *Quercus*, *Platanus,* selected herbs, *Castanea* x *Castanopsis,* a recent *Castanea* pollen material has been studied under SEM. These observations and photos were done using Scanning Electron Microscope JEOL JSM – 649 OLV at the Institute of Geological Sciences, Masaryk University in Brno.

Vegetation

The Lower Badenian palynospectra were rich in Dinoflagellata and foraminiferal linings (Pl. 1, figs 1-3). Sporadic occurrences of *Botryococcus* (Pl. 1, fig. 4) and pollen of aquatic coastal plants *Sparganium*, *Potamogeton* and *Utricularia* (Pl. 2, fig. 25) indicated a fresh water influence on some facies.

The proportion of zonal vegetation with evergreen broad-leaved forests (Sapotaceae, *Engelhardia*, *Platycarya*, evergreen Fagaceae – *Castanopsis, Trigonobalanopsis*, morphotypes *Tricolporopollenites henrici*, *T. microhenrici*, *T. liblarensis*, *Reevesia*, *Cornus-Mastixia*, Rutaceae and Araliaceae and Pteridaceae) represents up to 30% of the pollen spectra (Pl. 2). In the Miocene time interval, the thermophilous morphotaxa *Gothanipollenites gothani* and *Clerodendrumpollenites microechinatus* were first found in Lower Badenian sediments of the studied area.

The broad-leaved deciduous elements of warm – temperate mixed mesophytic forests such as *Quercus*, *Castanea*, *Carya*, *Celtis*, *Juglans, Tilia*, *Zelkova*, *Ostrya*, *Carpinus, Betula* and *Cercidiphyllum* generally did not exceed 10%. A higher diversity of "oak type" pollen grains, e.g. *Quercus robur-pubecscens,* were recorded in the pollen spectra (Pl. 2, figs 6-10, Pl. 4, figs 7-12). *Cercidiphyllum* and *Castanea/Castanopsis* were identified from the Lower Badenian pollen spectra (Pl. 2, fig. 15; Pl. 3, figs 1-15).

The azonal vegetation was represented by riparian forests with *Ulmus*, *Alnus*, *Fraxinus, Liquidambar*, *Salix* and Lythraceae and the coastal swamps by *Nyssa, Sciadopitys,* Taxodiaceae, Cyrillaceae and Myricaceae. Pollen grains of *Platanus ipelensis* sensu Pacltová (1984) were abundantly present for the first time in the Lower Badenian taphocenoses (Pl. 2, figs 11-14, Pl. 4, figs 10-12). In the pollen spectra herbs and heliophilous elements Poaceae, Asteraceae, Caryophyllaceae, Chenopodiaceae, Ericaceae and *Ephedra* were regularly present, less frequent were *Urtica, Plantago, Salvinia* and *Lavandula* (Pl. 2). There were noticeable polyporate pollen grains with microechinate perforate sculptures visible under SEM, they were determined as Caryophyllaceae cf. *Saponaria* (Pl. 4, figs 1-3), or without perforations – *Thalictrum* type (Pl. 4, figs 4-6).

An extremely high proportion (more than 60%) of Pinaceae pollen was present in some samples (Pl. 1). From the borehole Oslavany and the uppermost parts of boreholes Židlochovice 1, practically only Pinaceae and dinoflagellates were found. This could be due to taphonomical and ecological reasons (long air-transport range and therefore accumulation in marine sediments distant from the seashore).

In comparison with the Lower Miocene spectra, portion of the thermophilous elements P1 sensu Stuchlik et al. (1994), *Symplocos*, Sapotaceae, Palmae, Mastixiaceae and Lygodiaceae started to decrease since the Badenian (Doláková, Slamková 2003; Doláková et al. 1999). An increased proportion of the arctotertiary taxa (*Quercus, Ulmus* and *Carya*) were noted in the Upper Badenian palynospectra from the Vienna Basin. Thermophilous elements (*Platycarya, Engelhardia, Myrica, Distylium* and thermophilous Fagaceae) were still present, but Sapotaceae had disappeared. Herbs were represented predominantly by the halophytic taxa – mainly Chenopodiaceae. The higher proportions (up to 30%) of extrazonal (mountain) vegetation in the pollen spectra (*Picea, Abies, Tsuga, Cedrus*) were first recorded from the Upper Badenian. The main reason of this phenomenon is the uplift of the Carpathian Mountain chain and subsidence of adjacent lowlands.

Discussion

Lower Badenian macrofloristic remains from the Carpathian Foredeep are rare. Only in the Lower Badenian marine sandstones at Smolín near Pohořelice, Knobloch (1963, 1968) and Knobloch et al. (1975), described poorly preserved Lauraceae leaves *Daphnogene bilinica*, and Betulaceae leaves. The macrofloristic taphocenoses from the vicinity of Česká Třebová were described by Knobloch (1968); Knobloch et al. (1975) as an association totally dominated by arctotertiary elements (prevailing being *Myrica lignitum*, *Alnus* cf. *feroniae*, *Pinus, Salix, Populus, Fagus, Pterocarya, Parrotia, Ulmus* and *Fraxinus*).

Equally previously published palynological results from the Lower Badenian sediments of the Carpathian Foredeep (Basistová, 2009; Bruch et al. 2004; Hladilová et al. 1999, 2001) our results indicate a more thermophilous – subtropical character of the climate.

Macrofloristic findings from the Upper Badenian were described at the localities Opava – Kateřinky, and borehole Smolkov near Opava (Knobloch 1968). An absence of laurophylous leaves was observed and a generally warm – temperate character of the paleoclimate equaly to sediments with Lower Badenian floras.

In the Upper Badenian pollen spectra from boreholes OS-1 Kravaře and OS-2 Hať in the vicinity of Opava, the arctotertiary elements (with a high proportion of Pinaceae, partly mountain vegetation) dominated and thermophilous taxa were represented only by *Engelhardia* and Lygodiaceae (Cicha et al. 1985).

Planderová and Gabrielová (1975) noticed a decrease in the most thermophilous elements (Sapotaceae, *Symplocos*, Palmae, Mastixiaceae and Lygodiaceae) in the Lower Badenian pollen spectra in comparison with Early Miocene spectra. Based on this data they interpreted a subtropical climate with humidity oscillations during the Badenian time interval. Based on the Upper Badenian pollen spectra Planderová (1990) interpreted a drier and colder climate in comparison with the Lower Badenian time span. In comparison with the Karpatian pollen spectra, the proportion of herbs and heliophillous elements in Badenian material is higher (Doláková and Slamková 2003).

Holcová et al. (1996) observed up to 30% thermophilous taxa in the Lower Badenian pollen spectra from the borehole N-95 in Strháry-Trenč graben from the South Slovakia basin.

Based on many palynological studies, Oszast and Stuchlik (1977), Łancucka-Srodoniowa (1966) and Dyjor and Sadowska (1984) observed some differences between Badenian floras from the Lowlands in Southern Poland (more subtropical and warm – temperate) and from the mountain regions (2-3 altitudinal zones with warm-temperate mixed forests and with coniferous forests in the upper parts).

Planderová et al. (1993a,b) noted a lack of paleotropical elements of the P1 group in the Lower Badenian in the northern part of the Paratethys area. In the Upper Badenian they observed these elements only in the southern Paratethys area (Hungary and former Yugoslavia). Based on the flora of Parschlung (Karpatian/Early Badenian) Kovar-Eder et al. (2004) indicated a drier warm-temperate climate with relatively rare subtropical humid elements, while subhumid sclerophyllous woody taxa were well represented.

Kováč et al. (2008) and Kvaček et al. (2006) previously published palynological studies of Badenian sediments. In comparison with these data it is evident that even though the Badenian climate was generally subtropical, the proportion of key termophilous taxa rapidly decreased in the Upper Badenian.

Conclusions

Pollen flora from the Lower Badenian sediments indicated the presence of evergreen broadleaved forests, constituting up to 30% of the pollen spectra. In comparison with the Lower Miocene time span the proportion of thermophilous elements, Sapotaceae, *Symplocos*, Palmae, Mastixiaceae and Lygodiaceae, decreased in the Badenian pollen spectra. A greater differentiation of "oak type" pollen and a higher amount of *Platanus* pollen were recorded in the studied samples which corresponds with the results of Knobloch and Kvaček (1996).

Herbs and heliophilous vegetation started to be more frequent than in Lower Miocene floras.

In comparison with macrofloristic findings, the pollen grains indicate that the Lower Badenian floras had a more thermophilous character. Due to the need for more detailed analyses and correlation, this study will continue on a larger scale and Badenian sediments from Hungary, Slovenia, and Austria will be analysed in the future.

Initiation of altitudinal zonation (Kováč et al. 1998, Kováčová et al. in press) is documented by an increase of mountain elements and arctotertiary taxa (*Quercus, Ulmus* and *Carya*), a decrease of thermophilous elements (*Platycarya, Engelhardia, Myrica, Distylium* and thermophilous Fagaceae), and the disappearance of Sapotaceae in the palynospectra during the Upper Badenian.

Acknowledgements

The study was supported by the Projects 205/09/0103 (Grant Agency of the Czech Republic), APVV-0280-07, VEGA 2/0060/09, ESF-EC-009-07, VEGA 1/0483/10.

References

Basistová, P. (2009): Palynospektra ze sedimentů badenu karpatské předhlubně; Diplomová práce. – MS, MU: 63 pp. Brno.

Böhme, M. (2003): Miocene Climatic Optimum: evidence from Lower Vertebrates of Central Europe. – Palaeogeogr., Palaeoclimatol., Palaeoecol., 195: 389-401.

Bruch, A., Utescher, T., Alcade Olivares C., Dolakova, N., Ivanov, D., Mosbrugger, V. (2004): Middle and Late Miocene spatial temperature patterns and gradients in Europe – preliminary results based on paleobotanical climate reconstructions. – Cour. Forsch. Inst. Senckenberg, 249: 15-27.

Berggren, W.A., Kent, D.V., Swisher, III. C.C., Aubry, M.P.A (1995): Revised Cenozoic geochronology and chronostratigraphy. – In: Berggren, W.A., Kent, D.V., Hardenbol, J. (eds.): Geochronology, time scale and global stratigraphic correlations: a unified temporal framework for a historical geology. – Soc. Econ. Paleontol. Mineral. Spec. Publ., 54: 129-212.

Brzobohatý, R. (1982): Rybí fauna spodnobadenských vápnitých jílů v Brně – Králově Poli a její paleogeografický význam. – Čas. Mor. muz., Vědy přír., 67: 57-64.

Brzobohatý, R. (1997): Paleobathymetrie spodního badenu karpatské předhlubně na Moravě z pohledu otolitových faun. – In: Hladilová, Š. (ed.): Sborník příspěvků – Dynamika vztahů marinního a kontinentálního prostředí, MU Brno, pp. 37-45.

Cicha, I., Brzobohatý, R., Čtyroká, J., Gabrielová, N., Krejčí, O., Krystek, I., Mátl, V., Molčíková, V., Novotná, E., Řeháková, Z., Soták, J., Staňková, J., Knobloch, E., Váca, F. (1985): Neogén v opěrných vrtech OS-1 Kravaře a OS-2 Hať v opavské pánvi. – Sbor. Geol.Věd., Geologie 40: 183-229.

Doláková, N., Hladilová, Š. Nehyba, S. (1999): Development of Sedimentation, molluscs and palynospectra in the Lower Miocene of the south-western Part of the Carpathian Foredeep in Moravia (Czech Republic). – Acta Palaeobot., 2: 269-278.

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

Dyjor, S., Sadowska, A. (1984): Problem granicy między utworami badenu I sarmatu w regione Starej Kuźni Koło Kedzięrzynaw świetle badań palynologicznych. – Acta Palaeobot., 24: 27-51.

Fornaciari, E., Rio, D. (1996): Latest Oligocene to early Middle Miocene quantitative alcareous nannofossil biostratigraphy in the Mediterranean region. – Micropaleontology 42(1): 1-36.

Hladilová, Š., Nehyba, S., Doláková, N., Hladíková, J. (1999): Comparison of some relics of Miocene sediments on the eastern margin of the Bohemian Massif. – Geol. Carpathica, 50: 31-33.

Hladilová, Š., Doláková, N., Nehyba, S., Hladíková, J. (2001): Nové výsledky studia spodnobadenských sedimentů a fosilií z některých vrtů v karpatské předhlubni jižně od Brna. – Geol. výzk. Mor. Slez. v r. 2000: 31-34. Brno.

Holcová, K., Doláková, N., Vass, D., Zagoršek, K., Zelenka, J. (1996): Morský vývoj v spodnom badene v strhársko-trenčskej prepadline z pohľadu foraminiferových, machovkových a ostrakódových spoločenstiev a palynológie. – Mineralia Slovaca, 28: 99-119.

Chlupáč, I., Brzobohatý, R., Kovanda, J., Stráník, Z. (2002): Geologická minulost České republiky. – Academia, Praha, 436 pp.

Knobloch, E. (1963): Die Floren des südmährischen Neogens. – N. Jb. Geol. Paläont. Mh., 1: 1-11.

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

Knobloch, E., Bůžek, Č, Holý, F., Kvaček, Z., Němejc, F. (1975): Signifikant megafloral assemblages in Neogene of Central Europe. – In: Cicha I. (ed.): Biozonal division of the Upper Tertiary Basins of the Eastern Alps and Western Carpathians, Czech Geol. Survey, Prague, pp. 87-100.

Knobloch, E., Kvaček, Z. (1996): Miozäne floren der südbohemischen Becken. – Sbor. Geol. věd., Paleontologie 33: 39-77.

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

Kováč, M. (2000): Geodynamický, paleogeografický a štruktúrny vývoj karpatsko – panónskeho regiónu v miocéne: nový pohlad na neogénne panvy Slovenska (Geodynamic, paleogeographic and structural evolution of the Carpathian – Pannonian region in the Miocene: New view on the Neogene basins of Slovakia). – VEDA: 1-202. Bratislava. [in Slovak]

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

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

Kováč, M., Hudáčková, N., Hlavatá, J., Sopková, B., Andrejeva-Grigorovič, A., Halásová, E., Kováčová, M., Kováčová, P., Sliva, Ľ., Baráth, I. (2008): Miocénne usadeniny vo vrtoch z regiónu Záhorská nížina: sedimentológia, biostratigrafické zaradenie a prostredie depozície. – Geol. práce, Správy 114: 7-49.

Kováčová, M., Doláková, N., Kováč, M.: Miocene Vegetation Pattern and Climate Change in the Northwestern Central Paratethys Domain (Czech and Slovak Republic). – Geol. Carpathica, 2011, 62, 3, 251—266..

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

Kovar-Eder, J., Kvaček, Z., Strobitzer-Hermann M. (2004): The Miocene Flora of Parschlung (Styria, Austria) – Revision and Synthesis. – Ann. Naturhist. Mus. Wien., 105A: 45-459.

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

Łancucka-Srodoniowa, M. (1966): Tortonian flora from „Gdów Bay“ in the south of Poland. Acta. Paleobot., 7: 1-135. [in Polish]

Martini, E. (1971): Standard Tertiary and Quaternary calcareous nannoplankton zonation. – Proc. of 2nd Planctonic conference, Roma 1970, pp. 739-785.

Pacltová, B. (1984): Some Pollen of Recent and Fossil Species of the Genus *Platanus* L. Methodological Study. – Acta Univ. Carol., Geol., 4: 367-391.

Planderová, E. (1990): Miocene Microflora of Slovak Central Paratethys and its Biostratigraphical Significance. – Geol. Inst. D. Štúra, Bratislava, 144 pp.

Planderová, E., Gabrielová, N. (1975): Biozones of Neogene stages from viewpoint of micropaleobotany. – In: Cicha, I. (ed).: Biozonal division of the Upper Tertiary basins of the Eastern Alps and West Carpathians, Geol. Survey Prague, pp. 101-109.

Planderová, E., Ziembińska-Tworzydło, M., Grabowska, I., Kohlman-Adamska, A., Konzalová, M., Nagy, E., Pantić, N., Ryłova, T., Sadowska, A., Słodkowska, B., Stuchlik, L., Syabraj, S, Zdražílková, N. (1993a): On palaeofloristic and palaeoclimatic changes during the Neogene of Eastern and Central Europe on the basis of palynological research. – Proceedings of the International Symposium: Palaeofloristic and palaeoclimatic changes during Cretaceous and Tertiary. Dionýz Štúr Institute of Geology, Bratislava, pp. 119-129.

Planderová, E., Ziembińska-Tworzydło, M., Grabowska, I., Kohlman-Adamska, A., Sadowska, A., Słodkowska, B., Stuchlik, L., Ważynska H. (1993b): Wahania klimatyczne w Neogenie Europy Środkowej na podstawie zmiennego udziału w palinoflorze składników paleotropikalnych i arktycznotreciorzędowych. – Przegled Geologićny Państw. Inst. Geol., 41(12): 829-834.

Stuchlik, L. (1992): Correlation of the Neogene floras of Transcaucasia, Ukrainian Carpathians, South Poland and Czechoslovakia. – Paleontologia i Evolució, 24-25: 483-488.

Stuchlik, L. ed. (1994): Neogene Pollen Flora of Central Europe. Part 1. – Acta Palaeobot., Suppl.1: 1-56.

Utescher, T., Mosbrugger, V., Ashraf, A. R. (2000): Terrestrial Climate Evolution in Northwest Germany Over the last 25 Million Years. – Palaios, 15(5): 430-449.

Explanation of the plates

PLATE 1

1. Foraminiferal tapetum, Židlochovice 1 (2.3 m).
2. Marine dinoflagellates, Židlochovice 2 (8.9 m).
3. Marine dinoflagellates: a – LM, b – SEM, Židlochovice 1 (11.1 m).
4. *Botryococcus* sp., Židlochovice 1 (7 m).
5. *Cathayapollis potoniei* (Sivak) Ziembińska-Tworzydło, Židlochovice 1 (7 m).
6. *Cedripites miocaenicus* Krutzsch, Židlochovice 1 (8,5 m).
7. *Cathayapollis* sp., SEM, a – whole pollen grain, b – detail, Židlochovice 1 (11.1 m).

PLATE 2

1. Sapotaceae: *Sapotaceoipollenites sapotoides* (Pflug et Thomson) Potonié; Moravské Knínice.
2. Mastixioideae: *Cornaceaepollis satzvayensis* (Pflug) Ziembińska-Tworzydło, Židlochovice 1 (10.9 m).
3. *Quercoidites henrici* (Potonié) Potonié, Thomson et Thiergart, Ivaň (43.75 m).
4. *Platycaryapollenites miocaenicus* Nagy, Židlochovice 1 (10.9 m).
5. *Hedera* type: *Araliaceoipollenites reticuloides* Thiele-Pfeifer; Židlochovice 1 (9.7 m).

6.–10. *Quercus robur-pubescens* type: *Quercoidites granulatus* (Nagy) Slodkowska; 6,7 – Židlochovice (excavation); 8 – Židlochovice 1 (10.3 m); 9,10 – Moravské Knínice.

11.–14. *Platanus* sp.: *Platanipollis ipelensis* (Pacltová) Grabowska; 11,12 – Židlochovice 1 (10.3 m); 13 – Židlochovice 1 (11.1 m).

15. *Cercidiphyllum* sp.: *Cercidiphyllites minimireticulatus* (Trevisan) Ziembińska-Tworzydło, Židlochovice 1 (10.9 m).
16. *Urtica* sp.: *Triporopollenites urticoides* Nagy, Židlochovice 2 (16 m).
17. *Plantago* sp.: *Plantaginacearumpollenites miocaenicus* Nagy, Židlochovice 1 (10.3 m).
18. *Lavandula* sp.: a,b, Židlochovice 1 (0.9 m).
19. *Salvia verticillata* type; Židlochovice 1 (9.7 m).

20.–23. Caryophyllaceae gen. indet.: *Caryophyllidites microreticulatus* Nagy, 20 – Židlochovice 1 (10.9 m); 21, 22 – Židlochovice 1 (7 m); 23 – Židlochovice 1 (10.3 m).

24. *Galium* type, Židlochovice 1 (9.7 m).
25. *Utricularia* sp.; Židlochovice 1 (9.7 m).
26. Asteraceae: *Tubulifloridites macroechinatus* (Trevisan) Nagy, Ivaň (16.2 m).
27. Asteraceae: *Cichoreacidites gracilis* Nagy, Ivaň 43.7 m).

PLATE 3

1.–9. *Castanea* sp. – recent pollen, 1–6 LM; 7–9 SEM.

10.–12. *Castanea* sp.: *Tricolporopollenites cingulum* (Potonié) *oviformis* Thomson et Pflug – form A, Židlochovice1 (11.1 m), 10 – LM; 11–12 – SEM.

13.–15. *Castanopsis* sp.: *Tricolporopollenites cingulu*m (Potonié) *oviformis* Thomson et Pflug – form B, Židlochovice 1 (11.1 m), 13 LM; 14–15 SEM.

16.–18. ?Fagaceae: *Tricolporopollenites liblarensis* (Thomson) Grabowska, Židlochovice 1 (11.1 m), 16 – LM; 17–18 – SEM.

PLATE 4

1.–3. Caryophyllaceae: cf. *Saponaria* sp., Židlochovice 1 (11.1 m), 1 – LM; 2–3 – SEM.

4. –6. cf. *Thalictrum* sp., Židlochovice 1 (11.1 m), 4 – LM; 5–6 SEM.

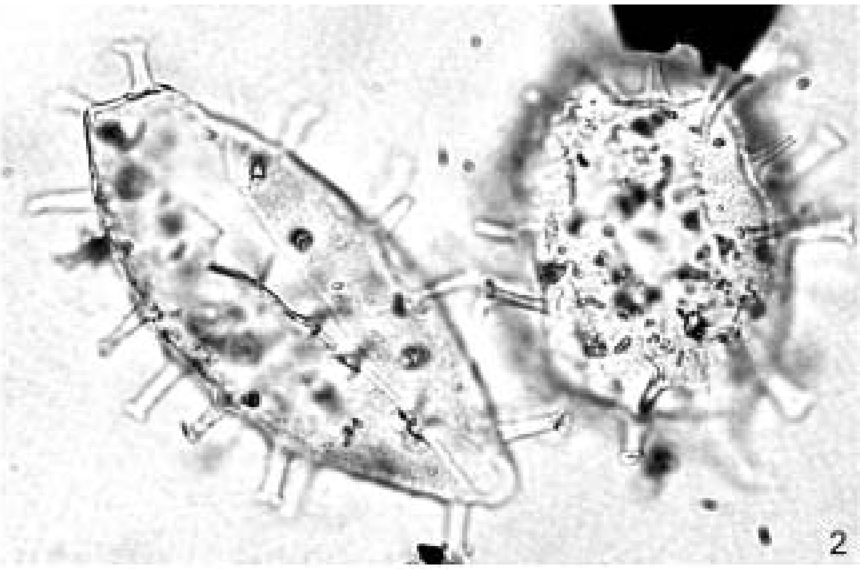
7. –9. *Quercus* sp., Židlochovice 1 (11.1 m), 7 – LM; 8–9 SEM.

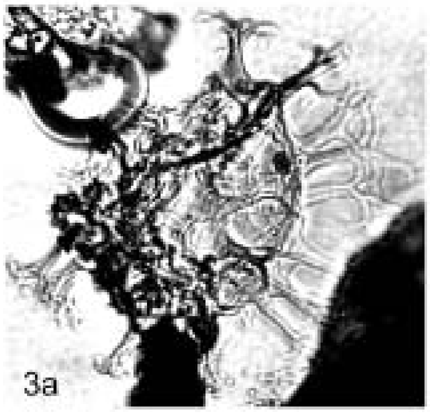
10.–12. *Quercus* sp., Židlochovice 1 (11.1 m), 10 – LM; 11–12 SEM.

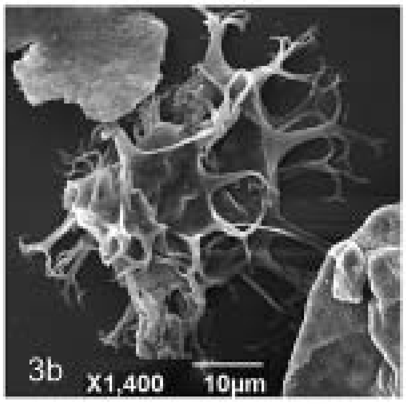
13.–15. *Platanus* sp.: *Platanipollis ipelensis* (Pacltová) Grabowska, Židlochovice (11.1 m), 13 – LM; 14–15 – SEM.

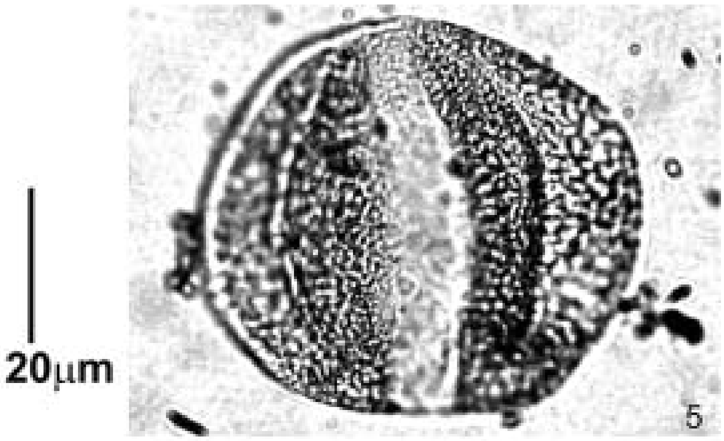
LM – light microscope
SEM – scanning electron microscope
Magnification of all photographs is indicated directly in figures.

PLATE 1









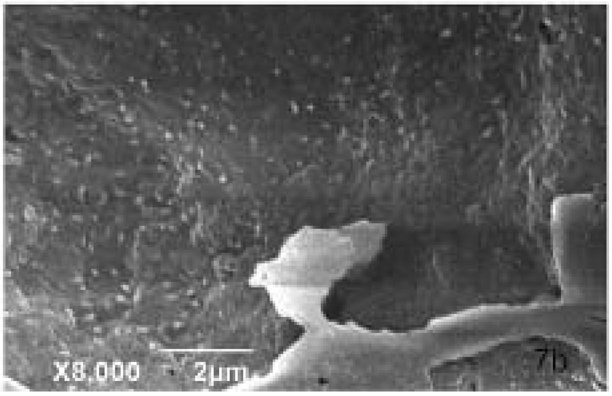


PLATE 2

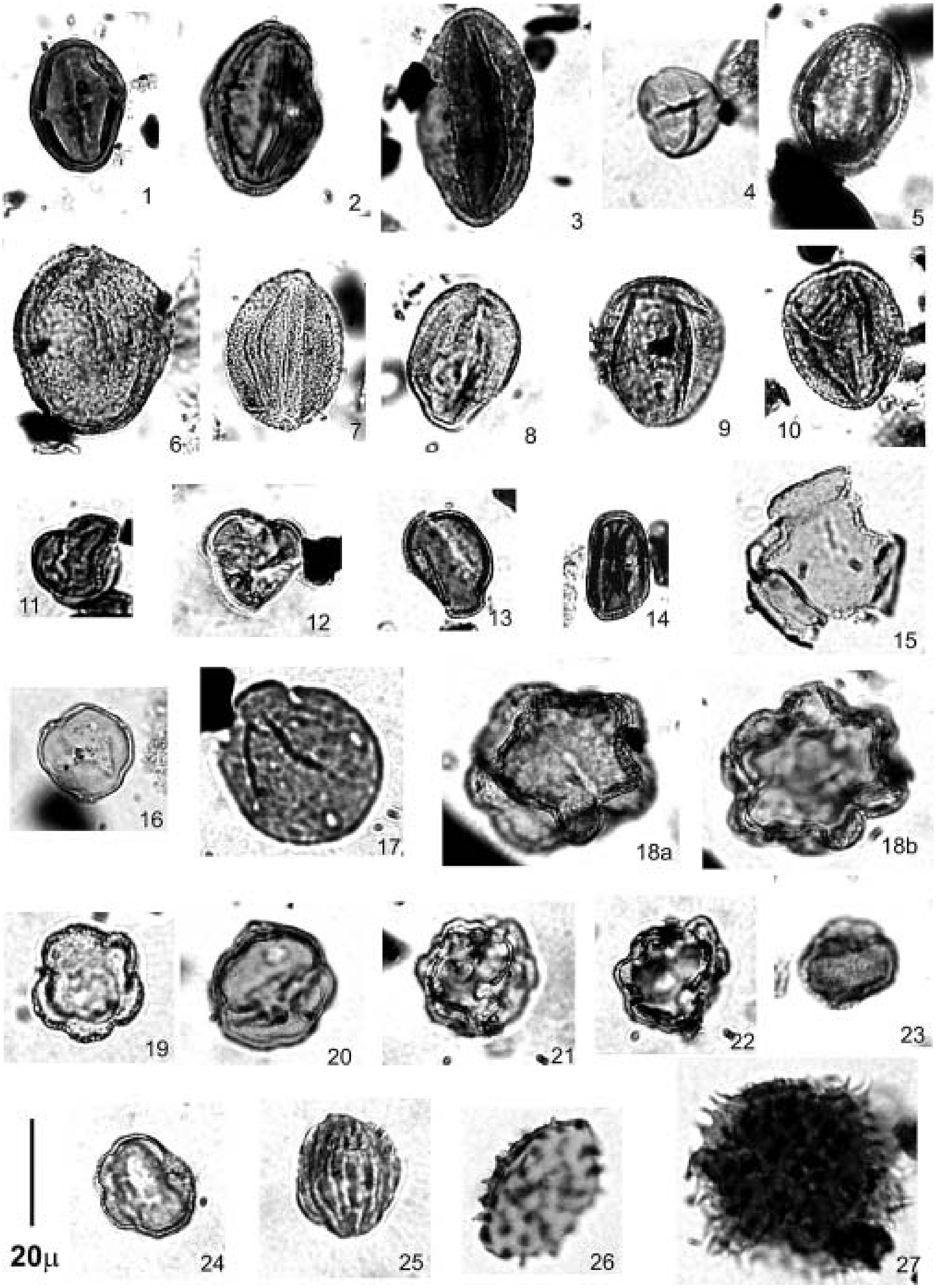

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18a
18b
19
20
21
22
23
20µ
24
25
26
27

PLATE 3

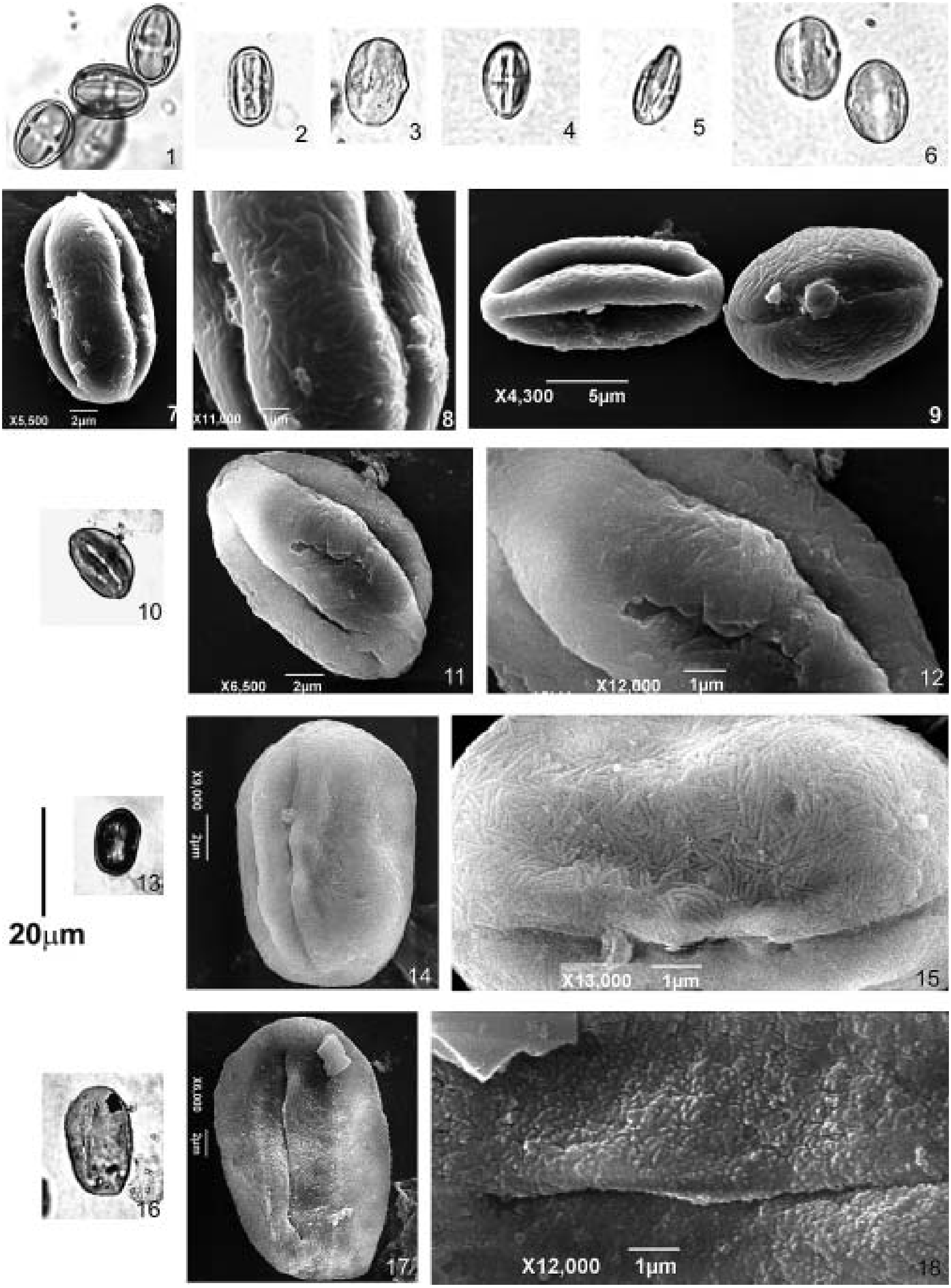
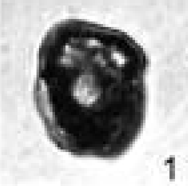
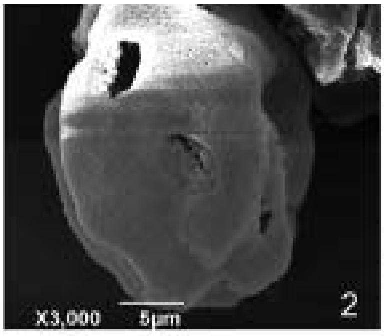
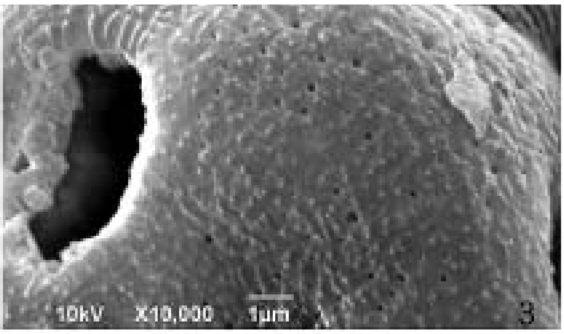

1
2
3
4
5
6
X5,500 2µm
7
X11,000 1µm
8
X4,300 5µm
9
10
X6,500 2µm
11
X12,000 1µm
12
13
20µm
X9,000 4µm
14
X13,000 1µm
15
16
X8,000 4µm
17
X12,000 1µm
18

PLATE 4

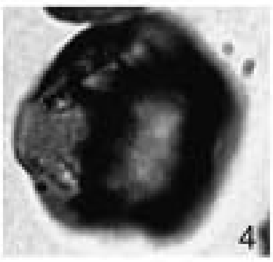

1

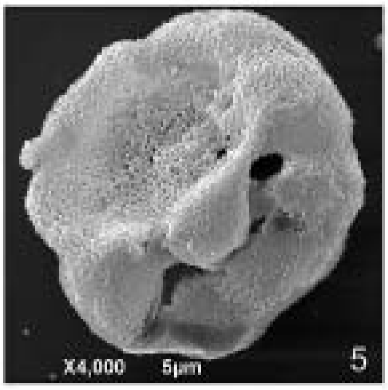


2

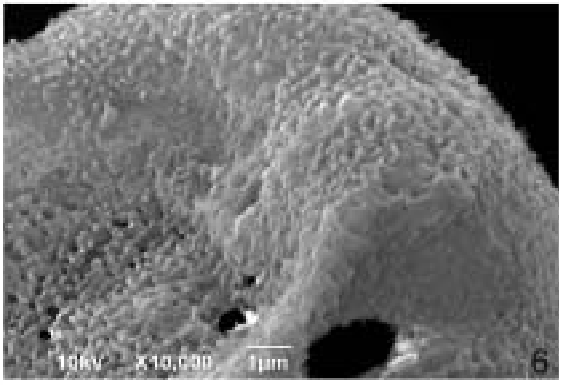


3

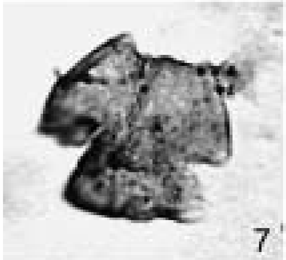

4

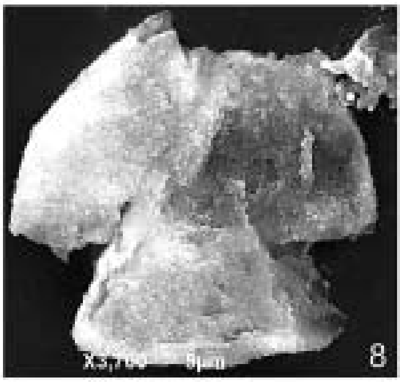


5

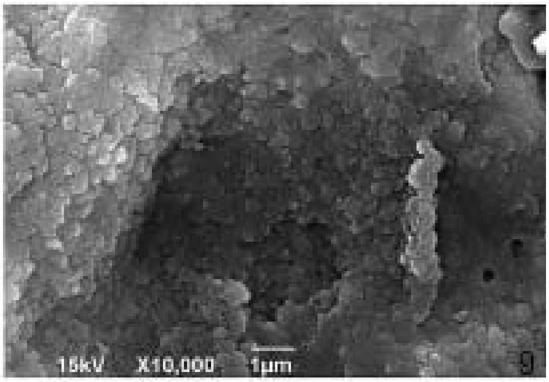


6


7



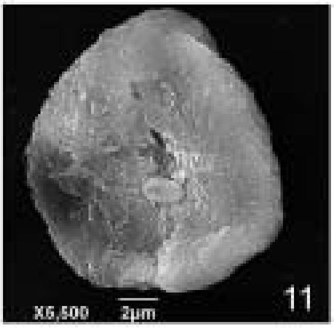
8



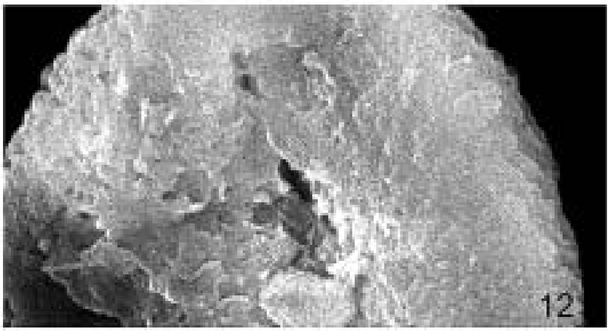
9


10

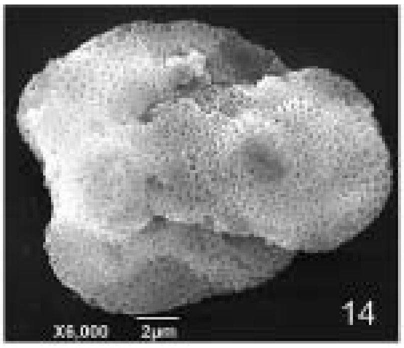
20µm



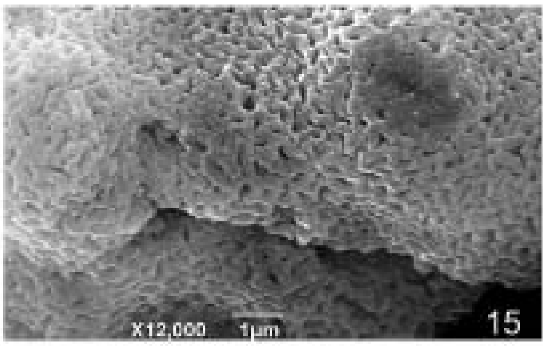
11


12


13



14



15

Palynological Characteristics of Karpatian Sediments

Nela Doláková[1] *& Marianna Slamková*[2]

[1] *Department of Geological Sciences, Masaryk University Brno, Kotlářská 2, 611 37 Brno, Czech Republic; e-mail: nela@sci.muni.cz*

[2] *Department of Geology and Paleontology, Comenius University Bratislava, Mlynská dolina G-2, 842 15 Bratislava, Slovak Republic; e-mail: kovacova@fns.uniba.sk*

Abstract. Palynological studies of the sediments from the Carpathian Foredeep in Moravia were not included in the original Karpatian volume (Planderová 1967). The stratotype localities Slup, Hevlín and Dolní Dunajovice as well as other sites, including Medlov and the Nosislav-3, Ždánice 67 and 68 boreholes (Carpathian Foredeep, Moravia) are evaluated in this publication. Palynological studies from the Vienna Basin (the Zohor 1 and Gbely 139 boreholes) are also included. A brief summary of the palynological studies of the Karpatian in other Central Paratethys areas are presented.

Palynological studies in Karpatian sediments of the Carpathian Foredeep in South Moravia, Czech Republic

(*Nela Doláková*)

Introduction

Pollen spectra were studied from the southern part of the Carpathian Foredeep in Moravia. Sediments of Karpatian age were evaluated from several localities (Slup, Hevlín, Dolní Dunajovice—the stratotype localities in Cicha *et al.* 1967—and Medlov) and boreholes (Nosislav-3, Ždánice 67, 68). The Karpatian sediments from these sections are of marine or brackish origin. Palynological studies were done in the pelitic sediments and also on coal lamines from the Ždánice boreholes (Tab. 1).

Planderová (1967) studied the Karpatian palynospectra from the southern and eastern Slovak Neogene basins. Palynological studies of the sediments from the Carpathian Foredeep are missing in this publication.

Palynomorphs from the Carpathian Foredeep were observed mostly under a light microscope. An SEM study was unsuccessful because the surfaces of the grains were heavily damaged during marine sedimentation.

Results

Pollen and spores from the Karpatian sediments confirm a warm (sub-tropical) to warm-temperate climate over the whole of the studied interval. The following paleotropical elements occurred: abundant—*Engelhardia*, *Platycarya*, Myricaceae, thermophile Fagaceae and Fabaceae, and thermophile ferns; stable levels—Sapotaceae, Palmae, *Lygodium*, *Rhuspollenites*, *Ilex*, less frequently *Symplocos*, *Platanus*, *Reevesia*, Rutaceae, Araliaceae, *Cornaceaepollis satzveyensis*, *Parthenocissus*, and sporadic occurrences of *Alangium*. Arctotertiary members are represented by frequent Oleaceae, *Alnus*, Ulmaceae, Polypodiaceae, *Carya*, and stabile levels of *Pterocarya*, *Juglans*, *Celtis*, *Quercus*, Poaceae, rare *Betula*, *Fagus*, *Liquidambar*, *Sciadopitys*, and sporadic *Tsuga* (Fig. 1; Pl. 1, Pl. 2).

Oscillations in salinity and occasional higher evaporation rates were ascertained in the marginal basins in the Eggenburgian-Ottnangian sediments (Nehyba *et al.* 1997). The vegetation of the salt marshes (Chenopodiaceae, *Tamarix*) and insolation places (Caryophyllaceae, Poaceae, Ericaceae) changed very quickly with the various growth stages of the swamp (Taxodiaceae, Myricaceae). Even freshwater flora appeared: *Sparganium*, *Potamogeton*, *Nelumbo*, Cyperaceae (Doláková *et al.* 1999).

In contrast with the Eggenburgian-Ottnangian time span, the marsh and riparian facies were generally common in the Karpatian palynospectra. Practically all the palynospectra are strongly facially influenced. This fact is reflected in the proportional changes between the paleotropic and arctotertiary members and it is very difficult to specify any explicit climatic changes. A higher percentage of the arctotertiary elements locally occurred (Fig.1): for example *Alnus*, Tiliaceae-*Craigia*, Polypodiaceae, Lythraceae, *Sparganium*.

Some regular trends are visible in the group of taxons represented in the mixed mesophilous forest (Sapotaceae, *Symplocos*, Araliaceae, Juglandaceae, Fagaceae). The amount and diversity of the arctotertiary elements slightly increased in the Ottnangian and Karpatian sediments over in comparison with the Eggenburgian. Markedly colder associations known from the Upper Ottnangian and Lower Karpatian sediments from the adjacent areas—for example Slovakia, and Poland (Planderová 1990, Planderová *et al.* 1993a, Planderová *et al.* 1993b, Stuchlik 1980, Ważyńska *et al.* 1998)—have not been found in the studied area. In comparison to the Lower Badenian palynospectra the markedly higher amount of *Engelhardia*, *Platycarya* and Oleaceae, as well as a generally lower representation of Taxodiaceae-Myricaceae is visible in the Karpatian "Schlier" sediments (both developed in the marine conditions).

The gradual transgression on the flat relief of the coast, which was connected with anoxic conditions, was interpreted in the lower part of the Karpatian from the sedimentological and paleontological points of view. The frequent alteration of palynomorphs caused by the crystallization of pyrite in the anoxic conditions was observed. The massive existence of Prasinophyta and probably green algae similar to the genus *Botryococcus* representing the bloom was also ascertained (Ždánice 67, 68, Nosislav-3). Findings of pollen in conglomerations indicating short transport and low water dynamics were found in some samples from the lower and marginal facies (Myricaeae, *Alnus*, Lythraceae, Gleicheniaceae-Pteridaceae, Polypodiaceae –Ždánice, Slup; Pl. 4).

In the lower and marginal developments of the Karpatian marked azonal associations, predominantly marshes and riparian forest, were primarily visible (Pl. 3): the marsh palm forest with Sparganiaceae, *Potamogeton* and Poaceae and Onagraceae (Ždánice 67), facies with predominant Tiliaceae-*Intratriporopollenites insculptus* (*Craigia*), Taxodiaceae, Pteridaceae, Polypodiaceae (Ždánice 68), Myricaceae, Lythraceae, *Alnus* (Ždánice 67), *Carya*, Myricaceae, *Selaginella* (Nosislav-3), riparian forest with *Alnus*, Myricaceae, Ulmaceae, or *Celtis* (Hevlín, Dolní Dunajovice, Slup). Palynospectra with the predominance of Taxodiaceae over Pinaceae were found only in the coal lamines, which occurred in the boreholes of Ždánice 67, 68 (Fig. 1). The boreholes of Ždánice 67, 68 have a specific position, because the Karpatian sediments are situated under the base of the flysh nappes. The area was situated in the marginal part of the foredeep at the time of sedimentation.

In the "Schlier" facies a lower proportion of palynomorphs related to the marginal swamp and riparian forest is visible. These facies were connected with an increase in Pinaceae and marine microplankton (Dinoflagellates and or Prasinophyta) (Pl. 4). This fact is in the relation to the development of the real marine conditions and a greater distance to the shore. Pollen of Pinaceae may become concentrated in the marine sediments because of their easy transport by the wind (Medlov, Slup, Dolní Dunajovice, upper part of the Nosislav-3 Borehole).

The most complex investigation of the Karpatian sediments was made in the Nosislav-3 Borehole (Pálenský *et al.* 1991). The sediments were processed by paleontological, geological, geophysical (logging, magnetometry), geochemical and technical methods. The predominance of the species *Uvigerina graciliformis*, which is present in the upper part of the profile (270–67.6 m), is typical for Karpatian "Schlier" facies microfauna. The general character of the palynoassociations reflects the predomination of the thermophile over arctotertiary members (Fig.1). Thanatocenoses of the marginal marsh communities (particularly with the frequent families of Myricaceae and ferns: Schizeaceae, Cyatheaceae, Pteridaceae, *Selaginella*) are strongly represented in the lower part of the borehole (340–280.8 m). The ingression of the sea water was supposed at the depth 281.5–280.5 m. The palynospectra contain an increased number of Dinoflagellata and the highest amount of Prasinophyta. In the upper part of the Nosislav-3 Borehole (Nový Přerov Member, Adámek *et al.* 2003) the amount of the marsh vegetation generally decreased and members of the mesophyte mixed forest such as Fagacee, Fabaceae, *Carya* increased. Oleaceae and Chenopodiaceae appeared more frequently.

The palynospectra of the localities Slup, Dolní Dunajovice and Hevlín are also strongly facially influenced. The predomination of marshes and riparian forest with Myricaceae, *Alnus*, Ulmaceae was quite striking. Sapotaceae were found only sporadically. *Celtis* is quite frequent (Fig.1). Pollen in conglomerations (Myricaeae, *Alnus*) indicated short transport and low water dynamics (Pl. 4). This fact indicates that the sedimentation area was very close to the seashore. Macrofloral remains were studied from the sediments of the localities Slup and Dolní Dunajovice. According to Knobloch (1967) the dominance of the members of the family Lauraceae documents the subtropical humid climate. The character of the macroflora supports the assumption, that the high proportion of the arctotertiary elements in the palynospectra (as the *Alnus* and Ulmaceae) was probably not connected with the deterioration of the climate.

Figure 1: The percentage distribution of the main types of pollen and spores and number of plant microplankton in the localities of the Carpathian Foredeep in Moravia (Karpatian).

List of pollen and spores:		**Localities:**	**Slup**	**Hevlín**	**Dolní Dunajovice**	**Nosislav 3**		**Ždánice**		**Medlov**
						340-283.5m	280.8-68.5m	**67**	**68**	
marine Dinophyta	several types	Types with branched projections	x	x	x	x	x	x	x	x
other Dinophyta	*Ovoidites* …	several types	x	x	x	x	x	x	x	x
Cyanophyta	gen. indet.	*Sigmopollis laevigatoides* Krutzsch & Pacltová 1990	x	x		x	x		x	
Chlorophyta	Tasmanaceae	*Pterospermella* Eisenack 1972, Pleurozonaria Wetzel 1933			x	x	x	x	x	x
	Botryococcus	*Botryococcus braunii* Kützing 1969			x			x		x
	unknown							x	x	
Ferns and fern allies										
Bryophyta	*Riccia*	*Ricciaesporites* sp.			x					
	Sphagnum	*Stereisporites stereoides* (Potonié & Venitz 1934) Thomson & Pflug 1953				x			x	
Unknown	gen. indet.	*Triplanosporites sinuosus* Pflug 1952 ex Thomson & Pflug 1953.			x	x	x	x	x	x
- " -	gen. indet.	*Toroisporis* sp.		x		x	x		x	x
?Polypodiaceae	gen. indet.	*Laevigatosporites haardti* (Potonié & Venitz 1934) Thomson & Pflug 1953			x	x	x	x	x	x
Davaliaceae	*Davalia*	*Verrucatosporites alienus* (Potonié 1931) Thomson & Pflug 1953				x	x		x	
Davaliaceae, Dryopteridaceae	gen. indet.	*Verrucatosporites clatriformis* (Murringer & Pflug ex Thomson & Pflug 1953)			x	x	x	x		
Dennstaedtiaceae	*Paesia*	*Verrucatosporites favus* (Potonié 1931) Thomson & Pflug 1953	x	x	x	x	x	x	x	x
Gleicheniaceae	gen. indet.	*Neogenisporis neogenicus* Krutzsch 1962	x			x	x	x		
Lycopodiaceae	*Lycopodium*	*Retitriletes* sp.					x			x
Lygodiaceae	*Lygodium*	*Leiotriletes wolffi* Krutzsch 1962	x		x	x			x	x
	- " -	*Leiotriletes maxoides* Krutzsch 1962				x	x	x	x	x
	- " -	*Leiotriletes neddenoides* Krutzsch 1962		x		x	x			
	- " -	*Corrugatosporites multivallatus* (Thomson & Pflug 1953) Planderová 1990		x	x	x	x			x
Lygodiaceae	gen. indet.	*Leiotriletes* sp.		x	x	x	x		x	
Osmundaceae	*Osmunda*	*Baculatisporites primarius* (Wolff 1934) Thomson & Pflug 1953		x	x	x	x	x	x	x
	- " -	*Baculatisporites nanus* (Wolff 1934) Krutzsch 1959					x	x		
Pteridaceae	gen. indet.	*Segmentizonosporites paucirugosus* (Nagy 1985) Stuchlik 2001			x	x	x	x	x	
	gen. indet.	*Undulozonosporites semiverrucatus* (Krutzsch 1967) Stuchlik 2001	x			x	x	x	x	x
Pteridaceae	*Pteris*	*Polypodiaceoisporites muricinguliformis* Nagy 1959	x	x	x	x	x	x	x	x
	- " -	*Polypodiaceoisporites corrutoratus* Nagy 1985			x	x	x	x	x	x
Selaginellaceae	*Selaginella*	*Echinatisporis miocenicus* Krutzsch & Sontag in Krutzsch 1963			x	x	x			x
	- " -	*Echinatisporis echinoides* Krutzsch & Pacltová in Krutzsch 1963			x	x				
	- "-	*Muerrigerisporis monstrans* Krutzsch 1963				x				
	- "-	*Muerrigerisporis* sp.				x	x			
Schizaeaceae, Dicksoniaceae	gen. indet.	*Polypodiaceoisporites marxheimensis* (Mürringer & Pflug 1952 ex Thomson & Pflug 1953) Krutzsch 1959			x	x			x	
Gymnosperms										
Pinaceae	*Pinus*	haploxylon and sylvestris types	x	x	x	x	x	x	x	x
	Cathaya	*Cathayapollenites krutzschi* (Sivak 1976) Planderová 1990	x	x	x	x	x	x	x	x
	Keteleeria	*Keteleeriapollenites dubius* (Chlonova 1960) Slodkowska 1994					x			x
	Picea	*Piceapollis* sp.	x	x	x	x	x	x	x	x
	Abies	*Abiespollenites* sp.	x	x	x	x	x	x	x	x

Table 1: List of palynomorphs in the localities of the Carpathian Foredeep in Moravia. The assignation of palynomorphs (Karpatian) to the recent botanical system after: Krutzsch *et al.* 2002, Nagy 1985, Planderová 1990, Stuchlik *et al.* 1994, Stuchlik *et al.* 2001, Zetter & Keri 1987.

Tab. 1
Continued.

	Cedrus	*Cedripites miocaenicus* Krutzsch 1971	x		x	x	x	x		x
	Tsuga	*Zonalapollenites maximus* (Raatz 1937) Krutzsch 1971			x	x	x	x		x
Sciadopitaceae	*Sciadopitys*	*Sciadopityspollenites serratus* (Potonié & Venitz 1934) Raatz 1937	x	x	x	x	x	x	x	x
Taxodiaceae	*Taxodium*, *Glyptostrobus* type	*Inaperturopollenites hiatus* (Potonié 1931) Thomson & Pflug 1953	x	x	x	x	x	x		x
	Sequoia	*Sequoiapollenites polyformosus* Thierg. 1937	x					x		x
Ephedraceae	*Ephedra*	*Ephedripites* div. fsp.			x	x	x	x	x	x
Angiosperms										
Aceraceae	*Acer* sp.	*Aceripollenites striatus* (Pflug 1959) Thiele-Pfeifer 1980			x		x	x		
Alangiaceae	*Alangium*	*Alangiopollis barghoornianum* (Traverse 1955) Krutzsch 1962				x				
Amaranthaceae	aff. *Gomphrena*	*Vaclavipollis soiana* Nagy 1973								
Anacardiaceae	*Rhus* type	*Tricolporopollenites pseudocingulum* (Potonié 1931) Thomson & Pflug 1953		x	x	x	x	x	x	x
Aquifoliaceae	*Ilex*	*Ilexpollenites iliacus* (Potonié 1931) Thiergart 1937 ex Potonié 1960	x		x	x	x	x		
	- " -	*Ilexpollenites margaritatus* (Potonié 1931) Raatz 1937 ex Potonié 1960		x		x	x	x	x	x
	- " -	*Ilexpollenites propinquus* (Potonié 1934) Potonié 1960	x	x	x	x	x			
Araliaceae	*Aralia*	*Araliaceoipollenites edmundi* (Potonié 1931) Potonié 151 ex Potonié 1960		x	x	x	x	x	x	x
	Hedera	*Araliaceoipollenites reticuloides* Thiele-Pfeifer 1980				x		x		
Asteraceae	*gen. indet.*	*Tricolporopollenites macroechinatus* Trevisan 1967					x	x		x
Betulaceae	*Alnus*	*Alnipollenites verus* (Potonié 1931 ex Potonié 1960)	x	x	x	x	x	x	x	x
	Betula	*Betulaepollenites betuloides* (Pflug 1953) Nagy 1969	x		x	x	x	x	x	x
	Carpinus	*Carpinidites carpinoides* (Pflug 1953) Nagy 1985			x	x	x	x		x
Buxaceae	*Buxus*	*Buxapollis buxoides* Krutzsch 1966		x			x			
Chenopodiaceae	gen. indet.	*Chenopodipollis multiplex* (Weyland & Pflug 1957) Krutzsch 1966		x	x	x	x	x	x	x
Cornaceae	Cornoideae, Mastixioideae	*Cornaceaepollis satzveyensis* (Pflug 1953) Ziembinska-Tworzydlo 1994					x	x		x
Cyrillaceae, Clethraceae	gen. indet.	*Tricolporopollenites megaexactus* (Potonié 1931) Thomson & Pflug 1953	x	x	x	x	x	x	x	x
	- " -	*Tricolporopollenites exactus* (Potonié 1931) Grabowska 1994	x	x	x		x			
Ericaceae	*Erica*	*Ericipites ericius* (Potonié 1931) Potonié 1960				x		x		
	Calluna	*Ericipites callidus* (Potonié 1931) Krutzsch 1970	x			x	x	x	x	x
Eucommiaceae	*Eucommia*	*Eucommioipollis parmularius* (Potonié 1934) Ziembińska-Tworzydło 1994			x	x	x			x
Fagaceae	?Castaneoideae gen. indet.	*Castaneoideaepollis oviformis* (Potonié 1934) Grabowska 1994	x	x	x	x	x	x	x	x
	?Castaneoideae gen. indet.	*Castaneoideaepollis pusillus* (Potonié1934) Grabowska 1994		x	x	x	x	x	x	x
	Quercoideae gen. indet.	*Quercoidites henrici* (Potonié 1931) Potonié, Thomson, Thiergart. 1950	x	x	x	x	x	x	x	x
	Quercoideae gen. indet.	*Quercoidites microhenrici* (Potonié 1931) Potonié, Thomson, Thiergart 1950	x	x	x	x	x	x	x	x
	Quercus	*Quercoidites granulatus* (Nagy 1969) Slodkowska 1994			x					
	- " -	*Ouercoidites asper* (Pflug &Thomson 1953) Slodkowska 1994		x		x	x	x	x	x
	- " -	*Quercoidites* sp.	x	x	x	x	x	x	x	x
	Fagus	*Faguspollenites verus* Raatz 1937		x	x	x	x	x	x	x
Fabaceae, Fagaceae, Combretaceae	gen. indet.	*Tricolporopollenites falax* (Potonié 1934) Krutzsch 1960	x	x	x	x	x	x	x	x
	gen. indet.	*Tricolporopollenites liblarensis* (Thomson 1950) Grabowska 1994	x	x	x	x	x	x	x	x
	gen. indet.	*Tricolporopollenites quisqualis* (Potonié 1934) Krutzsch 1954			x		x			
	Lonicera	*Lonicerapollis* sp.						x		
Hamamelidaceae	*Liquidambar*	*Liquidambarpollenites stigmosus* (Potonié 1931) Raatz ex Potonié 1960	x	x	x	x	x	x		x
	Parrotia-Distylium type	*Tricolporopollenites starosedloensis* Krutsch & Pacltová 1969	x	x						

Tab. 1
Continued.

Juglandaceae	*Carya*	*Caryapollenites simplex* (Potonié 1931) Raatz 1937	x	x	x	x	x	x	x	x
	Pterocarya	*Pterocaryapollenites stellatus* (Potonié 1931) Thiergart 1937	x	x	x	x	x	x	x	x
	Juglans	*Juglanspollenites verus* Raatz 1937	x	x	x	x	x	x		x
	Engelhardia	*Engelhardtioidites punctatus* (Potonié 1931) Potonié 1951 ex Potonié 1960	x	x	x	x	x	x	x	x
	- " -	*Engelhardtioidites quietus* (Potonié 1931) Potonié 1951	x	x	x	x	x	x	x	x
	Platycarya	*Platycaryapollenites miocaenicus* Nagy 1969	x	x	x	x	x	x	x	x
Lythraceae	gen. indet.	*Lythraceaepollenites* sp.		x				x	x	
?Magnoliaceae	gen. indet.	*Magnoliapollis neogenicus* Krutzsch 1970				x	x	x	x	x
Myricaceae	*Myrica*	*Myricipites myricoides* (Kremp 1949) Nagy 1969	x	x	x	x	x	x	x	x
	- " -	*Myricipites rurensis* (Thomson & Pflug 1953) Nagy 1969			x	x	x	x	x	
	- " -	*Myricipites bituitus* (Potonié 1931) Nagy 1969	x	x	x	x	x	x	x	x
Nyssaceae	*Nyssa*	*Nyssapollenites kruschi* (Potonié 1931) Nagy 1969	x		x	x	x	x	x	x
Oleaceae	gen. indet.	*Oleaidearumpollenites* sp.	x	x	x	x	x	x	x	x
Onagraceae	*Ludwigia, Epilobium, Circea*	*Corsinipollenites oculusnoctis* (Thierg. 1940) Nakoman 1965 subsp. *oculusnoctis* Krutzsch 1968						x	x	
Plantaginaceae	*Plantago*	*Plantaginacearumpollenites miocaenicus* Nagy 1963	x		x					x
	Platanus	*Platanipollis ipelensis* (Pacltová 1966) Grabowska 1994	x		x					x
	-" -	*Platanipollis sp.*	x	x	x	x			x	x
Potamogetonaceae	*Potamogeton*	*Potamogetonpolenites* sp.		x	x			x		
Rutaceae	gen. indet	*Rutacearumpollenites komloensis* Nagy 1969		x						
	gen. indet	*Rutacearumpollenites* sp.	x		x	x	x		x	
Salicaceae	*Salix*	*Salixipollenites* sp.		x		x	x		x	x
Sapotaceae	gen. indet	*Sapotaceoidaepollenites sapotoides* (Thomson & Pflug 1953) Potonié 1960			x	x	x	x		
	gen. indet. - several types	*Sapotaceoidaepollenites* div. sp.		x	x	x	x	x	x	x
Sterculiaceae	*Reevesia*	*Reevesiapollis triangulus* (Mamczar 1960) Krutzsch 1970		x		x	x	x		x
Symplocaceae	*Symplocos*	*Symplocoidites latiporis* (Thomson & Pflug 1953) Slodkowska 1994				x				
	- " -	*Symplocoidites vestibulum* (Potonié 1931) Potonié 1960	x		x	x	x	x	x	x
Tamaricaceae	*Tamarix*	*Tamarixpollenites* sp.								x
Tiliaceae	cf. *Craigia*	*Intratriporopollenites insculptus* Mai 1961		x	x	x	x	x	x	x
	Tilia	*Intratriporopollenites instructus* (Potonié 1931) Thomson & Pflug 1953	x		x	x	x	x		x
Tricolporopollenites indet.	gen. indet. - several types	*Tricolporopollenites* indet.	x	x	x	x	x	x	x	x
Ulmaceae	*Ulmus*	*Ulmipollenites undulosus* Wolff 1934	x	x	x	x	x	x	x	x
	Zelkova	*Zelkovaepollenites potoniei* Nagy 1969	x	x	x	x	x	x	x	x
	Celtis	*Celtipollenites* sp.	x	x	x	x	x	x		x
Umbeliferae	gen. indet.	*Umbelliferoipollenites* sp.		x						
Verbenaceae	gen. indet.	*Tricolporopollenites wackersdorfensis* Thiele-Pfeifer	x						x	
Vitaceae	*Parthenocissus*	*Tricolporopollenites marcodurensis* Thomson & Pflug 1953	x			x		x	x	x
Poaceae	gen. indet	*Graminidites* sp.	x	x	x	x	x	x	x	x
Arecaceae	gen. indet.	*Arecipites* sp.	x	x	x	x	x	x	x	x
	Calamus	*Dicolpopollis kockeli* Pflanzl 1956	x	x	x	x	x	x	x	x
Arecaceae, Musaceae	gen. indet	*Monocolpopollenites tranquillus* (Potonié) Thomson				x		x		
Sparganiaceae	*Sparganium*	*Sparganiaceaepollenites* sp.	x		x		x	x	x	x

Discussion and comparison with the adjacent areas

The palynospectra similar to the ones from the Carpathian Foredeep are described from the "Coal Seam Formation" and the "Cypris Claystone" from northern Bohemia (Konzalová 1976, Konzalová & Stuchlik 1983). Konzalová (1976) mentioned a very similar horizon with Palmae, Sparganiaceae from this region. Another similar horizon contains an amount of *Intraporopollenites insculptus* and it seems to be suitable for correlation. In the Carpathian Foredeep, this horizon has so far been observed in the lower part of the Karpatian sediments—under the typical "Schlier" sediments (Nosislav-3, Ždánice 68, Dolní Dunajovice). After the most recent investigations (Kvaček *et al.* 2002) this type of pollen (Pl. 3) is assigned to the genus *Craigia*, which in recent times thrives in wetland habitats such as the Inden vegetation. In our material, these pollen were accompanied by Taxodiaceae, Polypodiaceae, Pteridaceae, Lythraceae, Myricaceae.

A similar development of palynospectra to the ones from the Moravian Carpathian Foredeep was described by Planderová (1984) from the locality of Dežerice. She established the progression from a lagoonal or coastal environment gradually into a deep-sea environment or distal from the coast. The amount of planktonic organisms (Prasinophyta, Dinnoflagellata) increased and pollen and spores decreased towards the upper part of the profile. She ascertained a warm subtropical climate with Taxodiaceae-Nyssaceae-Mastixiaceae and also plenty of *Engelhardia-Platycarya*. In contrast with the material from the Carpathian Foredeep, she has not found palms, *Tricoloporopollenites henrici* or smooth trilete spores (*Leiotriletes maxoides*, *L. maximus* and *L. wolffi*) belonging to the genus *Lygodium*. Sapotaceae were described only sporadically. The author described the same facts in the stratotype localities and boreholes in the original Karpatian volume (Planderová 1967). The decrease in the paleotropic elements was classified by Planderová (1967, 1990) as the MF-3 Zone (palynoassociations of the Lower Ottnangian-Lower Karpatian time span) characteristic for a climate equivalent to the stratotype locality Schanze bei Ottnang (Hochuli 1978). The genus *Pentapollenites* KRUTZSCH occurred in the Karpatian sediments of the Novohrad Basin (Modrý Kameň: core N-91, and Lučenec: core LKŠ-1) in southern Slovakia (Holcová & Doláková in prep.). This pollen type was described also by Planderová (1990) and Nagy (1985). Planderová (1967) mentioned similar pollen such as *Tricolporopollenites* sp. The author regarded them as typical elements of the Slovak Lower Miocene coal facies. These pollen did have not yet been found in the Carpathian Foredeep. Hofmann & Zetter (2001) described similar pollen from the Paleocene/Eocene of Austria and considered a part of them as the family Simarubaceae. In the comparison with the literature on recent taxons (Reille 1995) part of our material is close to the genus *Haplophyllum* (Rutaceae).

A number of paleotropical elements lower than in the central part of the Central Paratethys were observed by Oszast & Stuchlik (1977), Stuchlik (1980), Sadowska (1989, 1993) from the Polish part of the Carpathian Foredeep.

Nagy (1999) established a good concordance among the Karpatian palynospectra from the Mecsek Mountains and from a part of the sediments in the Carpathian Foredeep in Moravia (Zdražílková [Doláková] 1993) and with Slovak areas (Planderová 1990).

In the Moravian part of the Carpathian Foredeep ecological conditions quite similar to the Korneuburg Basin, but probably not so warm, are supposed. The amount of different types of palms (including the *Calamus*) did not usually exceed 3 % (only in the Ždánice 67 Borehole do facies of marsh palm forest with 12–13 % of palms exists) whereas in Korneuburg it ranges from 9–14 %, with a maximum of 29 % (Hofmann *et al.* 2002). The pollen of *Avicenia* has still not been found in the Carpathian Foredeep. In accordance with the study of foraminifers, the authors suppose the existence of the locally limited Korneuburg area in which the warm currents from the southeast penetrated.

From the study of the marine fauna, several authors conclude that there was relatively cold water in the Karpatian basin of the Carpathian Foredeep. Spezzaferri & Coric (2001) suggest (using sediments drilled at Laa an der Thaya) a near shore environment with high nutrient availlability possibly related to the presence of river mouths or alternatively a coastal wind-related upwelling of cool water. This cooling probably did not have to influence on terrestrial vegetation. The climatic optimum of the upper Early to Middle Miocene (ca.14–18 Ma) was recorded also by Utesher *et al.* (2000) from the Northwest Germany.

Conclusion

The following paleotropical elements occurred: abundant—*Engelhardia*, *Platycarya*, Myricaceae, thermophile Fagaceae and Fabaceae, and thermophile ferns, stabile levels—Sapotaceae, Palmae, *Lygodium*, *Rhuspollenites*, *Ilex*, less *Symplocos*, *Platanus*, *Reevesia*, Rutaceae, Araliaceae, *Cornaceaepollis satzveyensis*, *Partheno-*

cissus, and sporadic *Alangium*. Arctotertiary members are represented by frequent Oleaceae, *Alnus*, Ulmaceae, Polypodiaceae, *Carya*, constantly *Pterocarya*, *Juglans*, *Celtis*, *Quercus*, Poaceae, rarely *Betula*, *Fagus*, *Liquidambar*, *Sciadopitys*, and sporadically *Tsuga*.

In the basal and marginal part of the Karpatian sedimentation frequent occurrences of alteration in palynomorphs caused by the crystallization of pyrite in anoxic conditions were observed. The locally mass existence of Prasinophyta (the bloom) was also ascertained. Marsh and riparian facies with frequent Myricaceae, Cyrillaceae, locally with *Alnus*, *Selaginella*, Lythraceae, are typical. The azonal association as the marsh palm forest or of the Tiliaceae-*Craigia* facies is interesting. A great amount of pollen in the conglomerations (*Alnus*, Myricaceae, Lythraceae) indicates short transport and the low water dynamics at the sedimentation site. The higher amount of Taxodiaceae exceeding Pinaceae was found only in the coal layers.

A large amount of Pinaceae, increasing percentages of Oleaceae and sporadic occurrences of the marsh facies are observed in the marine sediments of the Nový Přerov Member. The marine environment is characterised by marine dinoflagellates and locally large amounts of Prasinophyta.

In the Moravian part of the Carpathian Foredep there is no evidence in the palynospectra of strong climate changes during the Karpatian. In the percentage graphs of similar pollen types, only a small increase of arctotertiary mesophyte elements in comparison with the Eggenburgian is visible.

In comparison with Badenian palynospectra, the Karpatian "Schlier" sediments (both developed in the marine conditions) contain a markedly larger amount of *Engelhardia*, *Platycarya* and Oleaceae and a lower amount of Taxodiaceae.

Palynological studies in Slovak Neogene basins

(*Marianna Slamková*)

The evolution of flora in Slovakia during the Karpatian is affected by paleogeographic changes controlling the character of vegetation. The Karpatian has been mostly investigated in southern Slovakia, in the basins Hornonitrianska kotlina and Bánovská kotlina. Paleogeographical investigations (Gašparík 1979) revealed Upper Karpatian greyish-green sandy calcareous clays with a typical splintering indicative of a new Badenian transgression. In eastern Slovakia, the Upper Karpatian consists of salt deposits.

The Late Ottnangian-Karpatian transgression (Steininger & Nevesskaya 1975, Vass *et al*. 1987, Vass 1989) in southern Slovakia caused the inundation of swamp plant assemblages. The assemblages of plants growing in higher places—although devoid of tropical-subtropical woody plants—were preserved. Information about climate cooling at that time is in accordance with paleoclimatic data (18 Ma) of neighbouring regions. On the basis of a comparison between microflora from the stratotype locality Schanze bei Ottnang (Hochuli 1978) and from southern Slovakia (Plachtince Beds) both floras can be regarded as equivalent (Planderová 1990).

The Late Ottnangian (in the sense of Seneš 1973, Vass 1989)-Karpatian (MF-4 Zone) periods are characterized by decreasing subtropical flora in our region and by increasing percentage of arctotertiary elements (*Carpinus*, *Ulmus*, *Betula*, *Picea*, *Tsuga*) and plentiful intermediary elements (*Carya*, *Alnus*, *Pterocarya*). Planderová (1990) has recorded the swamp vegetation decreasing in the MF-4 Zone (overlying clays of the Plachtince Beds). In southern Slovakia, a sea transgression proceeded. The sea water inflow to fresh water swamps might have caused the decrease of swamp vegetation and the pollen spectra were poor in sporomorphs representing the main component of freshwater swamps and lakes of the Pôtor Beds (MF-3 Zone sensu Planderová 1990).

Among Poaceae, imprints of grass ears, described by Sitár (2001) as *Palaeotriticum mockii* SITAR and *Palaeotriticum carpathicum* SITAR, which do not have analogies in paleontology, have been found in the Vienna Basin at the locality Cerová Lieskové.

In the pollen spectra from the Vienna Basin (boreholes Zohor 1 and Gbely 139, Tab. 2) *Cedripites miocaenicus*, *Piceapollis tobolicus* and *Pinuspollenites* sp. were dominant. Of secondary importance were the taxa *Zonalapollenites*, *Inaperturopollenites* sp., *Cathayapollis* sp., *Graminidites* sp., *Myricipites rurensis*, *Quercoidites* sp., *Caryapollenites simplex*, *Pterocaryapollenites stellatus*, *Alnipollenites verus* and trilete spores of *Leiotriletes* sp. A subtropical climate was documented by the abundant presence of *Engelhardioipollenites* sp., *Platycaryapollenites miocaenicus*, *Tricolporopollenites exactus* (Cyrillaceae), *Castaneoideaepollis pusillus*, *Magnolipollis neogenicus*, and *Rhoipites pseudocingulum* (Slamková *in* Kováč *et al*. 1995, 1996).

Zohor 1			
Taxon/depth (m)	**1495.8**	**1497.2**	**1497.5**
Abiespollenites latisaccatus (Trevisan 1967) Krutzsch 1971 ex Ziembińska-Tworzydło 1974	2	3	1
Alnipollenites verus Potonié 1934	3	0	2
Betulaepollenites betuloides (Pflug 1953) Nagy 1969	0	0	1
Carpinites carpinoides (Pflug 1953) Nagy 1985	2	0	0
Caryapollenites simplex (Potonié 1931b) Raatz 1937 ex Potonié 1960	2	0	0
Cedripites miocaenicus Krutzsch 1971	1	5	0
Engelhardtioipollenites Potonié 1951 ex Potonié 1960	2	0	4
Ericipites callidus (Potonié 1931b) Krutzsch 1970	1	3	0
Graminidites Cookson 1947 ex Potonié 1960	3	0	0
Inaperturopollenites Pflug & Thomson 1953	6	1	0
Juglandipollis juglandoides Kohlman-Adamska 1994	6	4	1
Leiotriletes Naumova 1937 ex Potonié & Kremp 1954	2	2	0
Magnolipollis neogenicus Krutzsch 1970	1	0	1
Myricipites rurensis (Pflug et Thomson 1953) Nagy 1969	8	2	0
Nyssapollenites analepticus (Potonié 1934) Planderová 1990	0	0	1
Osmundacidites nanus (Wolff 1934) Nagy 1985 cf. *baculatus* (Krutzsch 1967) Planderová 1990	2	0	2
Piceapollis tobolicus (Panova 1966) Krutzsch 1971	3	1	0
Pinuspollenites Raatz 1937 ex Potonié 1958	8	12	4
Platycaryapollenites miocaenicus Nagy 1969	2	0	0
Pterocaryapollenites stellatus (Potonié 1931b) Thiergart 1937	5	2	0
Quercoidites asper (Pflug & Thomson 1953) Slodkowska 1994	1	0	0
Quercoidites microhenrici (Potonié 1931) Potonié, Thomson, Thiergart 1950	1	0	0
Salixipollenites Srivastava 1966	2	0	0
Sciadopytispollenites tuberculatus (Zaklinskaja 1957) Krutzsch 1971	2	1	1
Selaginellisporis (*Echinatisporites* Krutzsch 1959) *miocenicus* (Krutzsch & Sontag 1963) Wazyñska 1994	0	2	0
Ulmipollenites undulosus Wolff 1934	6	2	0

Gbely 139			
Taxon/depth (m)	**650.0**	**655.0**	**657.0**
Abiespollenites latisaccatus (Trevisan 1967) Krutzsch 1971 ex Ziembińska-Tworzydło 1974	2	2	0
Alnipollenites verus Potonié 1934	2	0	4
Betulaepollenites betuloides (Pflug 1953) Nagy 1969	1	0	0
Carpinites carpinoides (Pflug 1953) Nagy 1985	1	0	0
Caryapollenites simplex (Potonié 1931b) Raatz 1937 ex Potonié 1960	4	3	0
Castaneoideaepollis pusillus (Potonié 1934) Grabowska 1994	2	3	4
Cathayapollis Ziembińska-Tworzydlo 2002	12	5	1
Cedripites miocaenicus Krutzsch 1971	34	12	1
Engelhardtioipollenites Potonié 1951 ex Potonié 1960	2	6	5
Faguspollenites crassus Nagy 1969	1	1	0
Graminidites Cookson 1947 ex Potonié 1960	8	2	0
Chenopodipollis multiplex (Weyland et Pflug 1957) Krutzsch 1966	1	2	1
Inaperturopollenites Pflug & Thomson 1953	5	3	4
Intratriporopollenites instructus (Potonié 1931b) Thomson et Pflug 1953	2	0	0
Juglandipollis juglandoides Kohlman-Adamska 1994	0	1	1
Laevigatosporites haardti (Potonié et Venitz 1934) Thoms. et Pflug 1953 ssp. *haardtioides* Krutzsch 1967	0	23	0
Leiotriletes Naumova 1937 ex Potonié & Kremp 1954	2	0	2
Liquidambarpollenites stigmosus (Potonié 1931) Raatz 1937 ex Potonié 1960	0	1	0
Magnolipollis neogenicus Krutzsch 1970	1	1	0
Myricipites rurensis (Pflug et Thomson 1953) Nagy 1969	7	3	0
Osmundacidites nanus (Wolff 1934) Nagy 1985 cf. *baculatus* (Krutzsch 1967) Planderová 1990	0	0	3
Piceapollis tobolicus (Panova 1966) Krutzsch 1971	22	4	0
Pinuspollenites Raatz 1937 ex Potonié 1958	43	32	1
Platycaryapollenites miocaenicus Nagy 1969	2	1	2
Pterocaryapollenites stellatus (Potonié 1931b) Thiergart 1937	0	1	0
Quercoidites asper (Pflug & Thomson 1953) Slodkowska 1994	3	2	0
Quercoidites granulatus (Nagy 1969) Slodkowska 1994	1	2	0
Quercoidites microhenrici (Potonié 1931) Potonié, Thomson & Thiergart 1959	4	5	0

Table 2: Distribution of palynomorphs in the Karpatian of the boreholes Zohor 1, Gbely 139 (Vienna Basin).

The Late Karpatian-Early Badenian time span (MF-5 Zone) is characterized by a warming climate and more abundant subtropical microflora represented by spores of the family Schizaceae, pollen of the family Sapotaceae, the genus *Sabal*, less abundant Symplocaceae, and plentiful *Quercoidites henrici* and *Tricolpopollenites liblarensis*. Species of the genera *Engelhardia*, *Platycarya* are also frequent. Microfloral investigation of the Upper Karpatian-Lower Badenian shows that a warm subtropical climate allowed the return of subtropical vegetation after the colder Upper Ottnangian-Lower Karpatian. Microflora is abundant and well preserved despite the marine character of sedimentation—perhaps because the dry land was close to the depositional area in the Danube Lowlands. There is microfloral evidence of an arid phase by the end of the Karpatian and in the Lower Badenian (*Leguminosae*, *Ilex*, *Engelhardia*, *Quercus*). The relatively drier climate favoured the formation of salt deposits in eastern Slovakia. In terms of microfloral correlations, the zone as a warm phase of the Miocene may correspond to the NG-VIII Zone according to Krutzsch & Majewski (1967).

A brief summary of palynological studies in the Central Paratethys Karpatian

(*Nela Doláková*)

Karpatian sediments from the Central Paratethys area were studied from the palynological point of view in an area covered by the Czech Republic, Slovakia, Poland, Hungary, Austria, Ukraine, and Croatia. The palynological correlation of the whole Neogene of the Central Paratethys was summarized by Nagy (1999).

Many studies of Karpatian palynoflora have been carried out for the territory of Poland. Karpatian sediments are present here in two areas—the freshwater Polish Lowlands and the Silesian part of the Carpathian Foredeep. Paleofloristic and paleoclimatic changes during the whole Neogene in the Polish Lowlands were described by Ważyńska *et al.* (1998).

Palynological research from the Paratethys region was published by Oszast & Stuchlik (1977), Stuchlik (1980) for the Nowy Sącz Basin. These authors concluded that climate was warm-temperate to subtropical. The floristic character in the northern part of the Central Paratethys (north of the Carpathian arc) was more temperate than in the central section (Slovakia). The Karpatian is characterized by a large proportion of Taxodiaceae and other Tertiary genera such as *Castanopsis-Castanea*, *Celtis*, *Nyssa*. *Engelhardia*, *Platycarya*, and also *Alnus* and Ulmaceae were present in some samples in large amounts. Paleotropical elements such as Gleicheniaceae, Sapotaceae, Symplocaceae occurred only sporadically. Sadowska (1986, 1989, 1993) studied the Karpatian Kłodnica Beds. The author presumed a Mediterranean-type climate with the typical deciduous and mixed forest growing on the coasts of Paratethys and on the neighbouring uplands. The role of the swampy communities was not as important as in the Polish Lowlands. The paleotropical elements (Palmae, Araliaceae, *Quercoidites henrici*, *Platycarya*, Sapotaceae, *Symplocos*) occurred, but in smaller amounts than in the central part of the Central Paratethys.

The palynocomplexes from the "Burdigalian" of the Ukraine were described by Syabryai (2000). She placed the first Miocene optimum (a warm and humid climate) in the middle part of the Lower Miocene section. It was characterised by forest vegetation in which the number of subtropical plants increased and *Taxodium* and ferns were abundant.

In Belarus, sediments (16.55–17.2 Ma) were palynologically described from the part of the Brinev Floristic Complex. Several authors considered the Miocene climatic optimum with the subtropical, variable humid conditions as existing here (e.g., Jakubovskaya 1993).

Karpatian palynoassociations from Hungary were described by Nagy (1969, 1985, 1992) from the clay marl with fish scales and "Schlier" from the Mecsek and Bakony Mountains and from the Nógrád area. She considered a warm subtropical climate for the Karpatian, but in some cases with a larger amount of temperate elements. She referred a rich coastal swamp and limnic environment and in the mountainous region a large number of Coniferae and rich warm-temperate piedmont forest in southern Hungary. In the northern areas of the country, the poorer pollen spectra pointing to a transgression of the sea could be indentified. Nagy (1999) correlated Karpatian palynospectra from the Mecsek Mountains with the ones from the sediments in the Carpathian Foredeep in Moravia (Zdražílková [Doláková] 1993) as well as with Slovak areas (Planderová 1990) and established a good concordance. The high degree of similarity was observed by the author even to palynoassociations from the "Coal Seam Formation" and "Cypris Claystone" from northern Bohemia (Konzalová 1976, Konzalová & Stuchlik 1983), which is outside of Paratethys area.

In Austria, the Karpatian sediments of the Korneuburg Basin (Hofmann *et al.* 2002) were closely studied. From the palynospectra and as well as diaspores and leaves, two depositional areas were distinguished: 1. A brackish influenced site with algae, algal cysts, dinoflagellate cysts, foraminifera linings and abundant pyritized palynomorphs as well as a palynospectrum including the pollen of the black mangrove (*Avicennia*) and a Chenopodiaceae, presumably a halophyte. 2. A terrestrial swampy area with numerous woody components, fungal spores and hyphae as well as pollen of *Glyptostrobus*, *Acer*, *Alnus*, Fagaceae, Juglandaceae etc., which are typical for the Karpatian. The amount *Calamus* pollen (9–14 %, max. 29 %) together with *Avicenia* is taken as evidence for a warm climate during the Karpatian sedimentation in this area. In contrast with the study of foraminifers, the authors supposed the existence of the locally limited Korneuburg area in which the warm currents from the southeast penetrated.

From Croatia, Krizmanić (1995) derived palynospectra from Miocene bentonite from Gornja Jelenska. Their age was determined as Upper Karpatian to Lower Badenian according to the palynology. The climate was warm to subtropical. Sedimentation took place in a swamp (with algae, Taxodiaceae water plants—*Nelumbo*, *Nymphea*, and mosses), which was surrounded by meadows and hill-side forest.

Planderová with her co-authors summarized paleoclimatic changes during the Neogene of Eastern and Central Europe on the basis of palynological research (Planderová *et al.* 1993a, Planderová *et al.* 1993b). They stated that a long-lasting cooling occurred from the Upper Ottnangian throughout the Lower Karpatian in the Paratethys area. In the Polish Lowlands, this cooling begins later—in the lowermost Karpatian. This deterioration of the climate was established among others by an absence of *Leiotriletes maxoides* and the Sapotaceae. In the Upper Karpatian the amount of paleotropical elements (primarily palms and thermophile ferns) increased distinctly in the both areas—the Paratethys and the Polish Lowlands. These most favourable climatic conditions were responsible for the formation of the widest-spread brown coal layers, the so called II Lusathia layer and its equivalents in Poland and Belarus. In the Paratethys the Upper Karpatian warming up was lower, but it lasted longer—till the middle of Badenian.

References

Adámek, J., Brzobohatý, R., Pálenský, P. & Šikula, J. (2003): The Karpatian in the Carpathian Foredeep (Moravia). — *In:* Brzobohatý, R., Cicha, I., Kováč, M. & Rögl, F. (*eds*): The Karpatian—a Lower Miocene Stage of the Central Paratethys, *75–92*. Brno.

Cicha, I., Seneš, J. & Tejkal, J., *eds* (1967): M3 (Karpatien), Die Karpatische Serie und ihr Stratotypus. — Chronostratigr. Neostratotyp., **1**: *1–312*. Bratislava.

Doláková, N., Hladilová, Š., Nehyba, S. (1999): Development of Sedimentation, molluscs and palynospectra in the Lower Miocene of the south-western Part of the Carpathian Foredeep in Moravia (Czech Republic). — Acta Palaeobotanica, Suppl. **2**: *269–278*. Kraków.

Gašparík, J. (1979): Paleogeographical maps of Slovakia (Neogene). — Geol. Úst. D. Štúra, *34 pp.* Bratislava.

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

Hofmann, Ch.Ch. & Zetter, R. (2001): Palynological investigation of the Krappfeld area, Paleocene/Eocene, Carinthia (Austria). — Paleontographica B, (**Lfg. 1-6**): *47–64*. Stuttgart.

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

Jakubovskaya, T. (1993): Evolution of Flora and Climate in the Miocene of Belarus. — Proceedings of the International Symposium: Paleofloristic and paleoclimatic changes during Cretaceous and Tertiary, September 14–20, 1992, *153–158*. Geol. Úst. D. Štúra. Bratislava.

Knobloch, E. (1967): Pflanzenfunde aus der karpatischen Serie in der Vortiefe in Mähren. — Chronostratigr. Neotratotyp. **1**: *244–256*. Bratislava.

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

Konzalová, M. & Stuchlik, L. (1983): Micropaleontological research of the sediments overlaying the Main brown-coal seam in the Cheb Basin (Miocene, West Bohemia). — Čas. Miner. Geol., **28** (4): *363–376*. Praha.

Kováč, M., Aubrecht, R., Baráth, I., Halásová, E., Hudáčková, N., Kováčová, M., Marko, F., Mašurová, S. & Zágoršek, K. (1995): Sedimentologické, biostratigrafické a štruktúrne vyhodnotenie jadra vrtu Gbely 139. — MS, Comenius University, *64 pp.* Bratislava.

Kováč, M., Aubrecht, R., Baráth, I., Halásová, E., Hudáčková, N., Kováčová, M., Marko, F., Mišík, M., Pipík, R., Sýkora, M. & Zágoršek, K. (1996):

Sedimentologické, biostratigrafické a štruktúrne vyhodnotenie jadra vrtu Zohor 1. — MS, Comenius University, *81 pp.* Bratislava.

Krizmanić, K. (1995): Palynology of the Miocene bentonite from Gornja Jelenska (Mt. Moravačka Gora, Croatia). — Geol. Croatica, **48** (2): *107–190.* Zagreb.

Krutzsch, W. & Majewski, J. (1967): Methodik der Pollen stratigraphischen Zonengliederung im Jungtertiär Mitteleuropas. — Abh. Zentr. Geol. Inst., **10**: *83–98* . Berlin.

Krutzsch, W. & Pacltová, B. (1990): Die Phytoplankton-Mikroflora aus den Pliozänen Süsswasserablagerungen des Cheb-Beckens (Westböhmen, ČSFR). — Acta Univ. Carol., Geologica, **4**: *345–420.* Praha.

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

Nagy, E. (1969): Palynological elaborations the Miocene layers of the Mecsek Mountains. — A Magyar Áll. Földt. Int. Évk. II, **2**: *237–537.* Budapest.

Nagy, E. (1985): Sporomorphs of the Neogene in Hungary. — Geol. Hungarica, Paleont., **47**: *1–235.* Budapest.

Nagy, E. (1992): A comprehensive Study of Neogene Sporomorphs in Hungary. — Geol. Hungarica, Paleont., **53**: *1–379.* Budapest.

Nagy, E. (1999): Palynological Correlation of the Neogene of the Central Paratethys. — Geol. Inst. of Hungary Budapest, *126 pp.* Budapest.

Nehyba, S., Hladilová, Š. & Doláková, N. (1997): Sedimentary evolution and changes of fossil assemblages in the sw. part of the Carpathian Foredeep in Moravia during the Lower Miocene. — *In:* Hladilová, Š. (*ed.*): Dynamika vztahů marinního a kontinentálního prostředí, *47–58.* Masarykova univerzita. Brno (in Czech with English summary).

Oszast, J., Stuchlik, L. (1977): Roślinność Podhala w Neogenie. — Acta paleobotanica, **18** (1): *45–86.* Kraków.

Pálenský, P., Adamová, M., Brzobohatý, R., Bucha, V., Cicha, I., Čtyroká, J., Čtyroký, P., Eliáš, M., Franců, J., Hamršmíd, B., Hladilová, Š., Hladíková, J., Horáček, J., Horák, J., Krejčí, O., Kropáček, V., Malkovský, M., Michalíček, M., Müller, P., Nehyba, S., Novák, Z., Pazderková, A., Pírková, D., Procházková, V., Řeháková, Z., Říha, B., Šmíd, B., Svrčinová, M., Čížek, R., Urdihová, O., Zdražílková, N. & Zelenka, J. (1991): Závěrečná zpráva o vrtu Nosislav-3. — MS, Czech Geological Survey Prague. Praha.

Planderová, E. (1967): Palynologische Charakteristik der Karpatischen Serie. — Chronostratigr. Neostratotyp., **1**: *269–290.* Bratislava.

Planderová, E. (1984): Sporomorphs and Plankton of the Karpatian from Locality Dežerice. — Západné Karpaty, Paleont., **9**: *111–130.* Bratislava.

Planderová, E. (1990): Miocene Microflora of Slovak Central Paratethys and its Biostratigraphical Significance. — Geol. Úst. D. Štúra, *144 pp.* Bratislava.

Planderová, E., Ziembińska-Tworzydło, A., Grabowska I., Kohlman-Adamska, A., Konzalová M., Nagy, E., Pantić, N., Ryłova, T., Sadowska, A., Słodkowska, B., Stuchlik, L., Syabryai, S., Ważyńska, H. & Zdražílková, N. (1993a): On paleofloristic and paleoclimatic changes during the Neogene of Eastern and Central Europe on the basis of palynological research. — Proceedings of the International Symposium: Paleofloristic and paleoclimatic changes during Cretaceus and Tertiary, September 14–20, 1992: *119–129.* Geol. Úst. D. Štúra. Bratislava.

Planderová, E., Ziembińska-Tworzydło, A., Grabowska, I., Kohlman-Adamska, A., Sadowska, A., Słodkowska, B., Stuchlik, L. & Ważyńska, H. (1993b): Wahania klimatyczne w Neogenie Europy Środkowej na podstawie zmiennego udziału w palinoflorze składników paleotropikalnych i arktycznotreciorzędowych. — Przegl. Geol., **41** (12): *829–834.* Warszawa.

Reille, M. (1995): Pollen et Spores d' Europe et d' Afrique du Nord, (I,II). Laboratoire de Bot. Histor. et Palynol. Marseille.

Sadowska, A. (1986): Palynological Investigations of the Kłodnica Beds in the Silesian Part of the Carpathian Foredeep. — Geologia, Kwartalnik AGH, **12** (3): *37–44.* Kraków.

Sadowska, A. (1989): Miocene palynostratigraphy of the Silesian part of the Paratethys Basin. — Cour. Forsch.-Inst. Senckenberg **109**: *229–235.* Frankfurt a. M.

Sadowska, A. (1993): The stratigraphical table of the Neogene floras from Poland. — Proceedings of the International Symposium: Paleofloristic and paleoclimatic changes during Cretaceus and Tertiary, September 14-20, 1992: *119–129.* Geol. Úst. D. Štúra. Bratislava.

Seneš, J. (1973): Die Schichtengruppen und Formationen des Ottnangien. — Chronostratigr. Neostratotyp. **3**: *43–45.* Bratislava.

Sitár, V. (2001): The impressions of cereal ears in geological sediments of Karpatian stage (Nález obilného klasu v sedimentoch karpatského veku). — Scripta Fac. Sci. Nat. Univ. Masaryk. Brun., Geol., **30 (2000)**: *115–118.* Brno. (In Slovak.)

Spezzaferi, S. & Coric S. (2001): Ecology of Karpatian (Early Miocene) foraminifers and calcareous nannoplankton from Laa an der Thaya, Lower Austria: A statistical approach. — Geol. Carpathica, **52** (6): *361–374.* Bratislava.

Steininger, F.F. & Nevesskaya, L.A., *eds* (1975): Stratotypes of Mediterranean Neogene stages, **2**: *1–366.* VEDA, Bratislava.

Stuchlik, L. (1980): Chronostratygrafia neogenu Polski poludniowej (polnoczna czesc Paratetydy centralnej) na podstawie badan paleobotanicznych. — Przegl. Geol. **8**: *443–448.* Warszawa.

Stuchlik L. (1994): Neogene Pollen Flora of Central Europe. Part 1. — Acta Paleobotanica **1**: *1–56*. Kraków.

Stuchlik, L., Ziembińska-Tworzydło, M., Kohlman-Adamska, A., Grabowska, I., Ważyńska, H., Słodkowska, B., Sadowska, A. (2001): Atlas of Pollen and Spores of the Polish Neogene, Volume 1, Spores. — W. Szafer Inst. Bot., Pol. Acad. Sci. Kraków.

Syabryai, S. (2000): Tertiary Flora, Vegetation and Climate of Ukraine. — Chines Bulletin of Botany, **17**: *95–101*. Beijing.

Utescher, T., Mosbrugger, V. & Ashraf, A.R. (2000): Terrestrial Climate Evolution in Northwest Germany Over the last 25 Million Years. — Palaios, **15** (5): *430–449*. Tulsa.

Vass, D. (1989): Litologicko-stratigrafická schéma Rimavskej, Lučenskej a Ipeľskej kotliny — MS, Geol. Úst. D. Štúra. Bratislava.

Vass, D., Elečko, M., Kantorová, V., Lehotayová, R. & Klubert, J. (1987): Prvý nález morského otnangu v juhoslovenskej panve. — Mineralia Slovaca, **19** (5): *417–422*. Bratislava.

Ważyńska H., Grabowska I., Kohlman-Adamska, A., Pivocki, M., Słodkowska, B., Stuchlik, L., Ziembińska-Tworzydło, M. (1998): Palynology and Paleogeography of the Neogene in the Polish Lowlands. — Prace Panstw. Inst. Geol., **70**: *1–45*. Warszawa.

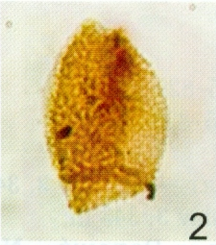
Zdražílková (Doláková), N. (1993): Paleopalynology of the lower Miocene of the Carpathian Foredeep in Moravia. — Proceedings of the International Symposium: Paleofloristic and paleoclimatic changes during Cretaceus and Tertiary, September 14–20, 1992: *145–147*. Geol. Úst. D. Štúra. Bratislava.

Zetter, R. & Keri, Ch. (1987): New details on the morphology of fossil onagraceous pollen grains. — Pl. Syst. Evol., **157**: *1–7*. Berlin.

Plate 1:
Paleotropical elements—×1000

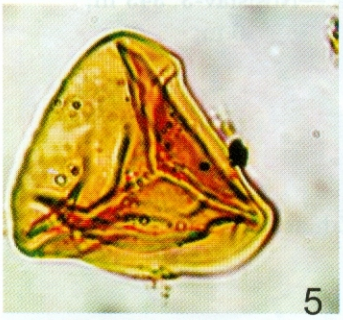
1: *Sapotaceoidaepollenites* sp.—Ždánice 67, 780–785 m;
2: *Arecipites sp.*—Ždánice 67, 795–800 m;
3: *Cornaceaepollis satzveyensis* (PFLUG) ZIEMBINSKA-TWORZYDLO.—Ždánice 67, 780–785 m;
4: *Vaclavipollis soiana* NAGY.—Nosislav 3, 343 m;
5: *Leiotriletes wolffi* KRUTZSCH.—Nosislav 3, 323 m;
6, 7: *Engelhardtioidites punctatus* (POTONIÉ) POTONIÉ.—Ždánice 68, 815–820 m;
8: *Platycaryapollenites miocaenicus* NAGY.—Ždánice 68, 815–820 m;
9: *Platycaryapollenites miocaenicus* NAGY.—Hevlín;
10: *Tricolporopollenites megaexactus* (POTONIÉ) THOMSON & PFLUG.—Hevlín;
11: *Castaneoideaepollis oviformis* (POTONIÉ) GRABOWSKA.—Nosislav-3, 343 m;
12: *Reevesiapollis triangulus* (MAMCZAR) KRUTZSCH.—Hevlín;
13: *Ilexpollenites margaritatus* (POTONIÉ) RAATZ.—Nosislav 3, 343 m;
14: *Myricipites bituitus* (POTONIÉ) NAGY.—Ždánice 68, 790–795 m;
15: *Tricolporopollenites falax* (POTONIÉ) KRUTZSCH.—Hevlín;
16: *Tricolporopollenites liblarensis* (THOMSON) GRABOWSKA—Ždánice 67, 795–800 m;
17: *Symplocoidites vestibulum* (POTONIÉ) POTONIÉ.—Nosislav-3, 343 m;
18: *Quercoidites henrici* (POTONIÉ) POTONIÉ, THOMSON, THIERGART.—Ždánice 68, 815–820 m;
19: *Quercoidites microhenrici* (POTONIÉ) POTONIÉ, THOMSON, THIERGART.—Ždánice 68, 815–820 m;
20: *Rutacearumpollenites* sp.—Ždánice 68, 815–820 m;
21: *Leiotriletes maxoides* KRUTZSCH.—Ždánice 67, 780–785 m.


1


2


3


4


5


6


7


8


10


9


11


12


13


14


15


16


17


18


19


20

20µm

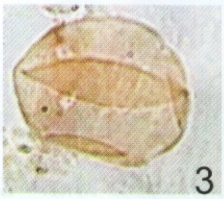

21

Plate 2:
Arctotertiary elements—×1 000

1: *Zelkovaepollenites potoniei* Nagy.—Ždánice 68, 815–820 m;
2: *Ulmipollenites undulosus* Wolff.— Ždánice 68, 815–820 m;
3: *Celtipollenites* sp.—Hevlín;
4: *Pterocaryapollenites stellatus* (Potonié) Thiergart.—Nosislav 3, 343 m;
5: *Caryapollenites simplex* (Potonié) Raatz.—Nosislav 3, 343 m;
6: *Liquidambarpollenites stigmosus* (Potonié) Raatz ex Potonié.—Nosislav-3, 343 m;
7: *Aceripollenites striatus* (Pflug) Thiele-Pfeifer.—Ždánice 68, 815–820 m;
8: *Oleoidearumpollenites* sp.—Hevlín;
9: *Alnipollenites verus* Potonié.—Dolní Dunajovice;
10: *Plantaginacearumpollenites miocaenicus* Nagy.—Hevlín;
11: *Quercoidites* sp.—Nosislav-3, 323 m;
12: *Graminidites* sp.—Ždánice 67, 795–800 m;
13: *Sciadopityspollenites serratus* (Potonié & Venitz) Raatz.—Ždánice 67, 795–800 m;
14: *Cathayapollenites krutzschi* (Sivak 1976) Planderová.—Slup;
15: *Zonalapollenites maximus* (Raatz 1937) Krutzsch.—Medlov.

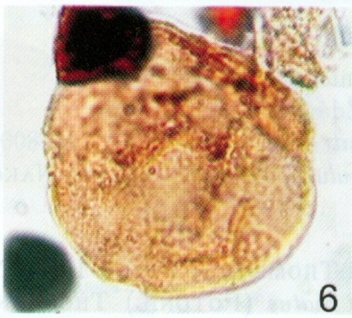

1


2


3


4

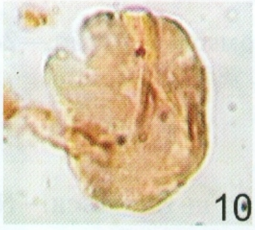

5


6


7


8


9


10


11


12


13


14

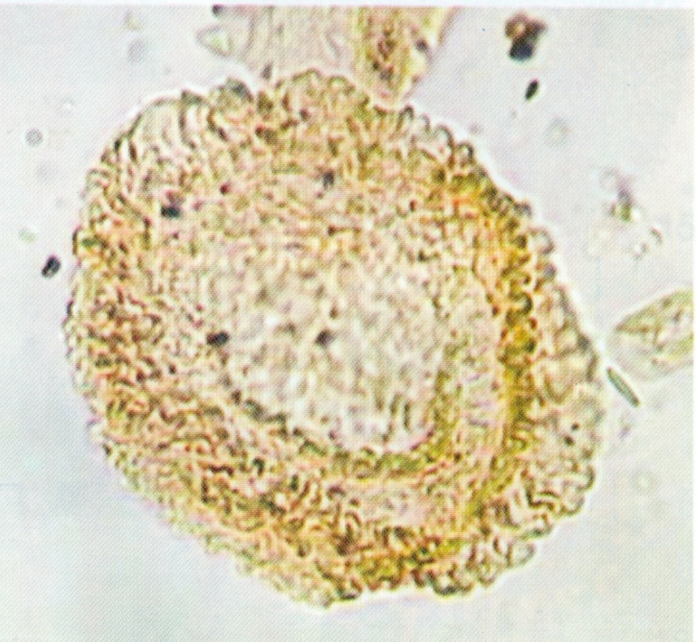

15

Plate 3:
Characteristic facies—×1000

Facies 1:

1: *Inaperturopollenites hiatus* (POTONIÉ) THOMSON & PFLUG—*Glyptostrobus* type.—Ždánice 68, 815–820 m;
2, 3: *Intratriporopollenites insculptus* MAI.—Ždánice 68, 815–820 m;
4: *Polypodiaceoisporites muricinguliformis* NAGY.—Ždánice 68, 815–820 m;

Facies 2:

5: *Arecipites* sp.—Ždánice 67, 795–800 m;
6: *Graminidites* sp.—Ždánice 67, 795–800 m;
7: *Sparganiaceaepollenites* sp.—Ždánice 67, 795–800 m;
8: *Corsinipollenites oculusnoctis* (THIERGART) NAKOMAN.—Ždánice 67, 795–800 m;

Facies 3:

9: *Myricipites rurensis* THOMSON & PFLUG 1953) NAGY.—Ždánice 67, 780–785 m;
10: *Inaperturopollenites hiatus* (POTONIÉ) THOMSON & PFLUG—*Glyptostrobus* type.—Ždánice 67, 780–785 m;
11, 12: *Lythraceaepollenites* sp.—Ždánice 67, 780–785 m;

Facies 4:

13: *Alnipollenites verus* POTONIÉ.—Ždánice 67, 785–790 m;
14: *Laevigatosporites haardti* (POTONIÉ & VENITZ 1934) THOMSON & PFLUG.—Ždánice 67, 785–790 m;
15: *Baculatisporites primarius* (WOLFF 1934) THOMSON & PFLUG.—Ždánice 67, 785–790 m;
16: *Leiotriletes maxoides* KRUTZSCH.—Ždánice 67, 785–790 m;
17: *Myricipites* sp.—Ždánice 67, 785–790 m;

Facies 5:

18: *Echinatisporis miocenicus* KRUTZSCH & SONTAG IN KRUTZSCH.—Nosislav-3, 343 m.


1


2


3


4


5


6


7


8


9

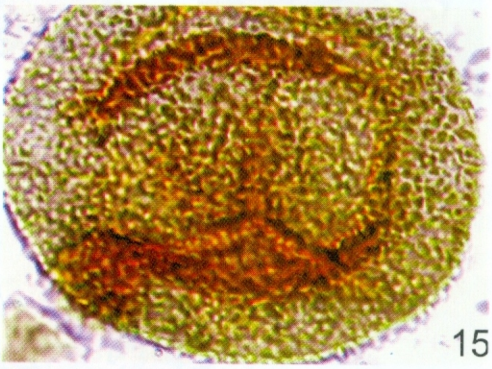

10


11


12


13


14


15


16


17

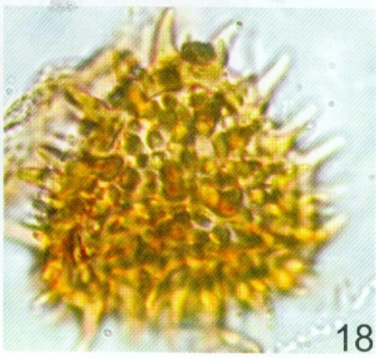

18

Plate 4:
Characteristic facies—×1 000, Algae—×500

Facies 6 – "Schlier":

1: *Castaneoideaepollis oviformis* (POTONIÉ) GRABOWSKA.—Nosislav-3, 280.8 m;
2: *Quercoidites microhenrici* (POTONIÉ) POTONIÉ, THOMSON, THIERGART.—Nosislav-3, 280.8 m;
3: *Oleoidearumpollenites* sp. ZIEMBINSKA-TWORZYDLO.—Nosislav 3, 68.58 m;
4: *Pinuspollenites* sp.—sylvestris type.—Medlov;

Facies 7 – drier and salty stations:

5: *Ephedripites* sp. KRUTZSCH.—Hevlín;
6: *Chenopodipollis multiplex* (WEYLAND & PFLUG 1957) KRUTZSCH.—Dolní Dunajovice;

Pollen in conglomerations:

7: *Alnipollenites verus* POTONIÉ.—Hevlín;
8: *Potamogetonpollenites* sp.—Ždánice 67, 795–800 m;
9: *Myricipites* sp.—Ždánice 67, 785–790 m;

Cavities after pyrite crystals:

10: *Engelhardtioidites quietus* (POTONIÉ) POTONIÉ.—Ždánice 68, 815–820 m;
11: *Pentapollenites* sp.—LKŠ-1, 224 m (Novohrad Basin);

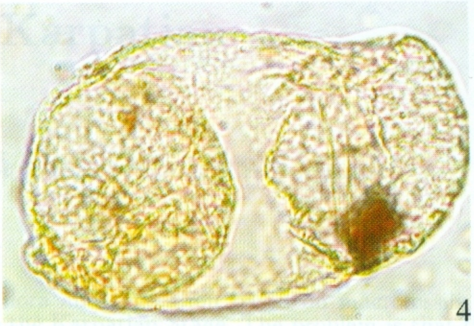
Algae:

12: marine Dinophyta—Hevlín;
13: *Botryococcus* sp.—Medlov;
14: cf. Chlorophyta—Ždánice 67, 785–790 m;
15: *Crassosphaera* sp.—Ždánice 68, 725–730 m;
16: *Pterospermella* sp.—Medlov.


1


2


3

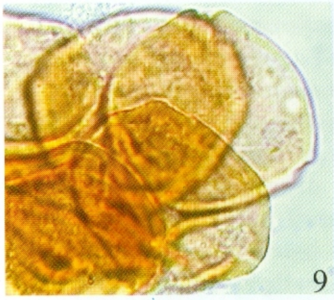

4


5

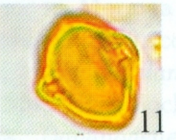

6


7

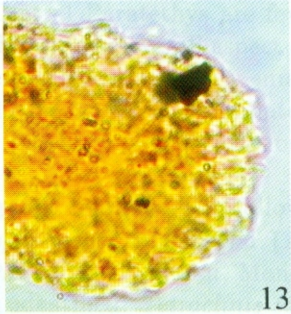

8


9


10

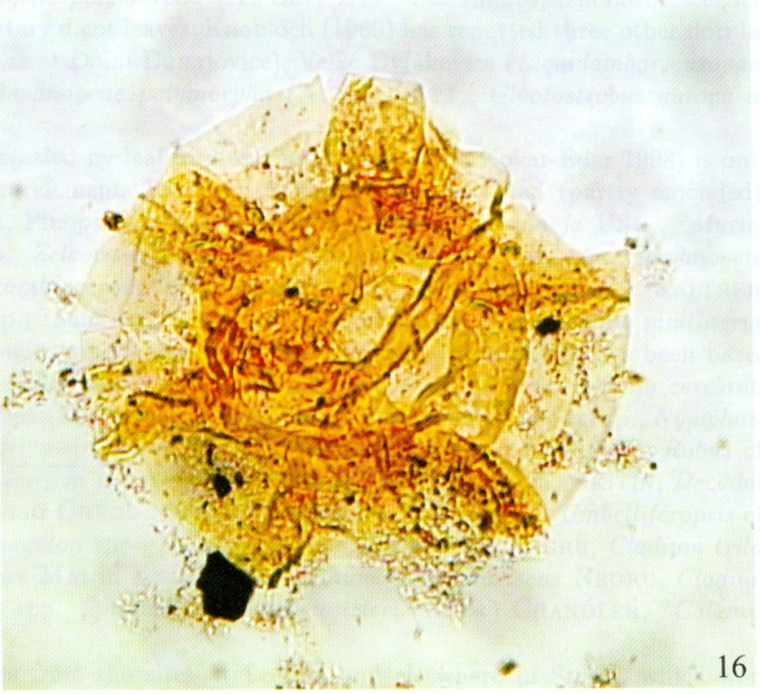

11


12


13


14


15


16

Facies (2014) 61:419
DOI 10.1007/s10347-014-0419-z

ORIGINAL ARTICLE

The Langhian (Middle Badenian) carbonate production event in the Moravian part of the Carpathian Foredeep (Central Paratethys): a multiproxy record

Katarína Holcová · Juraj Hrabovský · Slavomír Nehyba · Šárka Hladilová · Nela Doláková · Atilla Demény

Received: 30 January 2014 / Accepted: 1 September 2014

Abstract The carbonate production event in the Moravian part of the Carpathian Foredeep is known as a deposition of a carbonate–siliciclastic complex in the marginal part of the basin, correlating with the time period from the last occurrence of *Helicosphaera waltrans* (14.36 Ma) to the last occurrence of *Sphenolithus heteromorphus* (13.34 Ma). Sedimentological and microfacial data, analysis of foraminifera, calcareous nannoplankton, red algae, mollusks, palynology, as well as oxygen and carbon stable isotopes from foraminiferal tests, were used to interpret the specific paleoenvironment of the carbonate production event. The event was accelerated by a decrease of terrigenous input due to a large transgression and, primarily, an increasingly arid climate. Production of carbonate was related to oligotrophic conditions, expansion of sea-grass meadows, summer downwelling circulations and winter stratification of the water column. Autochthonous and semi-autochthonous carbonates were deposited in shallow-water near the fair-weather wave-base; allochthonous carbonates were transported to the outer shelf by gravity flows. Climatic instability and relative sea-level changes, induced mainly by substantial tectonic activity, caused the carbonate bodies to be small with a high ratio of siliciclastic components, indicating only a short-term and spatially restricted environment suitable for carbonate production. Exceptionally, carbonate production persisted longer during the whole sea-level cycle ("Rousínov Ridge"). Siliciclastic intercalations in these larger limestone bodies represent catastrophic rain events that transported a higher amount of terrigenous material into the basin. The specific climatic conditions of the carbonate production event, namely climatic instability and aridification with episodic intensive rain, were associated with the Middle Miocene climatic transition in the study area.

Keywords Carbonate–siliciclastic complex · Paleoecology · Middle Miocene climatic transition · Langhian · Carpathian Foredeep

Introduction

The study area, the Central Paratethys, represents a chain of Oligocene and Miocene epeiric seas in Central and Eastern Europe with marked oscillations of paleoecological parameters and episodic communication with the oceanic realms (Rögl 1999). Siliciclastic sedimentation strongly prevailed in the basin. Rare occurrences of carbonates were recorded from the Early Miocene (Nebelsick 1989), but only carbonates from the Middle Miocene have been described from many places. In addition to the studied Moravian part of the Carpathian Foredeep (Doláková et al. 2008), they were also recorded in the Eastern Alpine Foredeep (Mandic 2004), the Vienna and Styrian basins (Schaleková 1973; Baráth

---

K. Holcová (✉)
Institute of Geology and Paleontology, Charles University in Prague, Albertov 6, 12843 Prague 2, Czech Republic
e-mail: holcova@natur.cuni.cz

J. Hrabovský · S. Nehyba · N. Doláková
Departure of Geology and Paleontology, Masaryk University, Kotlářská 2, 600 00 Brno, Czech Republic

Š. Hladilová
Department of Biology, Faculty of Education, Palacký University, Purkrabská 2, 771 40 Olomouc, Czech Republic

A. Demény
Institute for Geological and Geochemical Research, RCAES, Hungarian Academy of Sciences, Budaorsi ut 45, Budapest 1112, Hungary

et al. 1994; Kysela 1988; Riegl and Piller 2000; Wiedl et al. 2012), the Pannonian Basin in Hungary (Randazzo et al. 1999; Moissette et al. 2007) and Slovakia (Vass et al. 2007), the Zrin-Dvor Basin in Croatia (Basso et al. 2008; Martinuš et al. 2012) and Bosnia–Herzegovina (Pezelj et al. 2013), the Carpathian Foredeep in Poland (Pouyet and Tarkowski 1998) and Ukraine (Radwański et al. 2006) and the Transylvanian Basin in Romania (Filipescu and Gîrbacea 1997).

The aim of this study is to evaluate the influence of global and local paleoclimatic, paleogeographic and tectonic factors on carbonate production in the Moravian part of the Carpathian Foredeep based on a multiproxy analysis.

Geological setting

The Early–Middle Miocene Carpathian Foredeep is a peripheral foreland basin that developed from subsurface loading of the Alpine-Carpathian orogenic belt on the passive margin of the Bohemian Massif. The Carpathian Foredeep exhibits striking lateral variations in basin width, depth and stratigraphy of deposits, along with variations in the pre-Neogene basement composition and tectonic subsidence. The basin continued to the south (the Alpine Foredeep/Alpine Molasse Zone) and to the northeast (the Polish part of the Carpathian Foredeep) (Oszczypko 1998; Nehyba et al. 2008a).

The distinctive geometry of the Early Badenian deposits reflects the important reconstruction of the basin. The location of the basin and the distribution and character of the deposits could be explained by the tectonic development of the Carpathian orogenic wedge. Both eustasy and tectonics governed the depositional architecture of the basin during the Early–Middle Badenian (Nehyba and Šikula 2007; Nehyba et al. 2008a).

Pelitic sediments (“Tegel”) with sandstone intercalations and biohermal bodies strongly dominate volumetrically within the basin with a maximum thickness of about 600 m. These mudstones vary in silt and clay content, amount of shell debris, intensity of bioturbation and sedimentary structures. They were interpreted as predominantly outer shelf deposits or hemipelagites (Papp et al. 1978; Cicha 2001; Nehyba et al. 2008a). Limestone bodies are represented by lenses in siliciclastic complexes. Their thickness varies by a few meters, occassionally reaching a few tens of meters (maximum 40 m). Limestone bodies (called “Leitha-limestones” or “Lithothamnian-limestones; Papp et al. 1978) are concentrated in three areas and their positions in the succession are not necessarily isochronous. Their occurrences are connected with the prograding coast line in the western and north-western margins of the preserved Carpathian Foredeep in Moravia. At the eastern margin, redeposition of the red-algal limestones into more internal parts of the basin apparently played an important role (Doláková et al. 2008). Biohermal bodies, restricted both areally and in thickness, are represented mainly by red algal limestones and, more rarely, by bryozoan bioherms. The rich fossil content of the bioherms has attracted the attention of paleontologists since the nineteenth century; many works describing individual fossil groups originate from the 2nd half of the 20th century. These works are summarized by Hladilová and Zdražílková (1989) and Doláková et al. (2008). Most recent contributions were focused on the bryozoan limestones from Podbřežice (Zágoršek and Holcová 2005: Bryozoa and Foraminifera; Nehyba et al. 2008b: oxygen and carbon isotopes from bryozoan fragments; Hrabovský et al. 2015). However, a detailed multiproxy analysis of the ecosystem evolution is missing.

Material and methods

This work is focused on a detailed analysis of two limestone bodies north of the town of Rousínov in the middle part of the Carpathian Foredeep in Moravia (Czech Republic): the sections of Kroužek (molluscan and bryozoan biodetritic and biomicritic limestone) and Podbřežice (bryozoan biodetritic limestone/bryozoan bank) (Hladilová and Zdražílková 1989; Fig. 1). These sections, situated on the western margin of the Foredeep basin, were compared with limestone bodies from boreholes in Židlochovice situated at the eastern margin of this marine basin (Doláková et al. 2014) and with denudation relicts in Middle Badenian deposits (including carbonates) from Kralice (Zágoršek et al. 2007, 2009).

Microfacies and red algae were studied in thin-sections. The ratio of microfacial components was evaluated using JMicrovision software and the point-counting method. They were evaluated according to a 250–400 points/thin-section scale. Quantitative data were collected from 24 thin-sections. Twelve components were distinguished in the samples (Table 1). Components were recognized and classified according to Flügel (2004). We classified mixed siliciclastic limestones with more than 10 % of lithoclasts according to Mount (1985). Limestones with less than 10 % of lithoclasts were classified according to Dunham (1962) and Wright (1992). Woelkerling (1988) and Braga et al. (1993) were followed in generic description of coralline algae (Sporolithalles, Corallinales, and Rhodophyta).

Foraminifera and molluscs were studied from 63–2,000 µm fractions. Molluscs were studied from 38 samples (Kralice nad Oslavou: 12 samples; Židlochovice boreholes: ŽIDL1—13 samples, ŽIDL2—8 samples) and foraminifera from 106 samples (Podbřežice: 21 samples; Kroužek: 24 samples; Kralice nad Oslavou: 12 samples; Židlochovice boreholes: ŽIDL1—26 samples and ŽIDL2—23 samples). Ultrasonic treatment was used for further cleaning of

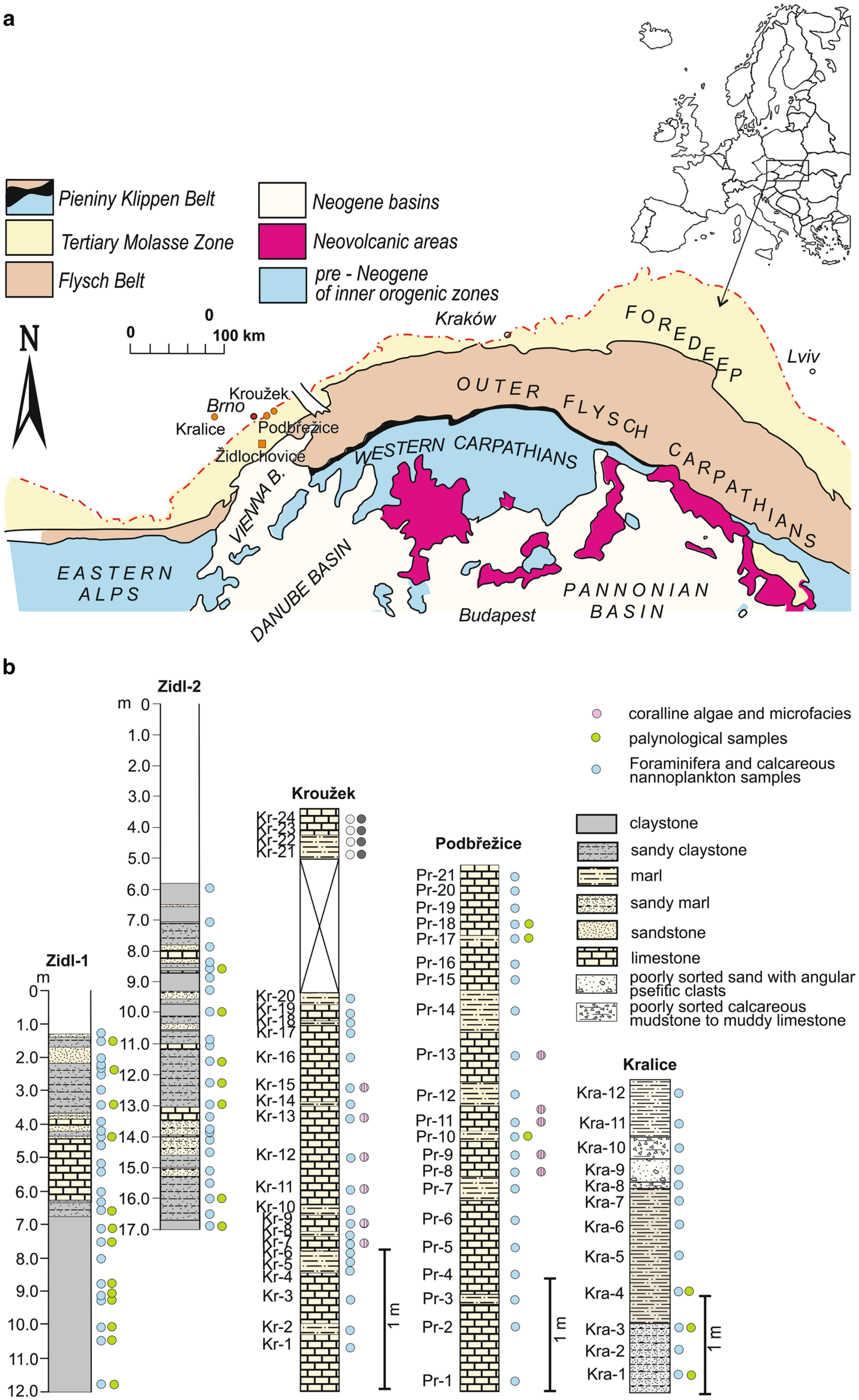


Fig. 1 Locations of sections studied (**a**) and their lithology (**b**)

Table 1 Volume of identified components in the study samples, counted using JMicrovision

	CRA	BRY	MOLL	FRM	ECHN	SRP	BRC	UNA	PRS	LIT	MIC	SPR	MicF
27611151	17.4	17.2	2.7	0.3	0.3	1.2	2	14.3	4.9	4.9	34.2	0.3	3
27611251	10.7	32.5	3.5	0.2	0.2	2.1	1.4	2.3	10.7	1.9	28.3	6.3	3
27611351	1.5	41.6	0.5	1	0.3	0.8	0	2.3	14.8	2.5	26.6	8.3	3
276111251	10.7	59.9	2.7	0	0.3	0	0	0.3	7.7	1	16.2	1.3	3
27611551	52.5	16.2	0.3	0.8	0	0.3	0	3.7	6.7	2	16.2	1.5	3
27611451	27.3	35.3	1	2.3	0.5	0	0	3.3	2.8	3.3	18.8	6.3	3
27611651	20	31.3	1	1.5	0.3	0.3	0	1.5	1.3	4.3	32.5	6.3	3
27611751	7	43	0.7	1.7	0.2	0.2	0	2.9	0.5	1.2	40.5	1.9	3
27611851	4.2	43.8	1	2	0.3	0.8	0.8	6.2	0.5	2.5	33.1	5	3
276111351	5.2	41.3	0.3	1	0	5.2	0	5.2	5.5	2.2	28.9	5.2	3
27611951	6.2	44.6	1.8	0.8	0	0.3	0	5	0.5	3	22.4	15.5	3
276111051	6.7	35.7	12.2	1.5	0	0	0	5.5	1.5	1	25.7	10.2	3
276111151	3.7	37.9	2.2	1	0.5	0	0	6	1.8	4	37.7	5.2	3
17311351	26.5	16.8	17.3	2.2	0	0.7	0	1.5	4.5	8.2	4.5	17.8	1
17311451	17.9	24.6	5.5	2.7	0	0.3	0	5.2	4	10	5.5	24.4	1
17311751	53.9	11	3.7	1.3	0	1	0	2.7	1	4	4.5	18	1
17311951	40.3	15.3	8	0	0	1.8	0	4	7.5	3.5	6.5	13.3	1
173111051	25.2	18	10.7	0.74	0.3	0.5	0	3.2	8.2	7.9	1	24	1
173111151	16.2	15.5	*92*	1.25	2.5	0	0	4	5.5	16.5	1.5	31.4	1
17311251	6.2	40.1	3.2	2.5	0.8	0.3	0	6.7	3.2	12.4	14.4	10.2	2
173111251	6.5	33.9	2.5	2.7	0	2.5	0	5	6.7	13.2	14.5	12.5	2
173111351	10.7	23.6	7.5	1.5	0	0	0	4.5	17.2	9.2	6.2	19.7	2
17311551	4.5	18.9	2	5.5	0	0.8	0	16.7	1.7	15.9	12.2	21.9	2
17311651	4.3	24	3	2.3	0	1	0	13	1.8	16.8	16.8	17.3	2

The code of each thin-section is in the left column and identified microfacies (MicF) are in far right column

CRA coralline red algae, *BRY* bryozoans, *Mol* mollusks, *FRM* foraminifera, *serpulids, SRP* polychaetes, *BRC* brachiopods, *UNS* unidentified allochems, *PRS* pores, *LIT* lithoclasts, *MIC* micrite, *SPR* sparite

molluscs. For the molluscan fauna from Kroužek, the material of Šob (1940), kept in the collections of the Moravian Museum in Brno (Hladilová 1984), was studied. About 200–300 specimens of foraminifera from each sample were determined and relative abundances of taxa, as well as plankton/benthos ratios (P/B ratio), were calculated.

Benthic foraminiferal assemblages and calcareous nannoplankton were statistically classified using the multivariate techniques of PAST software (Hammer et al. 2001).

Calcareous nannoplankton was studied from the same 106 samples as the foraminifera. The abundance of nannoplankton was expressed semi-quantitatively as the number of specimens in the visual field of the microscope (Zágoršek et al. 2007). About 200–500 specimens of calcareous nannoplankton were determined from individual samples and the relative abundances of taxa were calculated.

For palynological studies, two samples from sandy siltstones, one limestone sample of the Podbřežice section and four samples from sandy siltstones of the Kralice section were studied (Fig. 1). The samples were treated with cold HCl (35 %) and HF (70 %), removing carbonates and silica. Separation of the palynomorphs from the rest of the residue was carried out using $ZnCl_2$ (density = 2 g/cm^3). No Tertiary palynomorphs were observed in the limestone, the only samples containing contemporary pollen contamination. Palynomorphs were recorded only in siliciclastic intercalations in carbonates from the Židlochovice boreholes (Doláková et al. 2014).

Oxygen and carbon isotopic composition tests of the foraminiferal can be evaluated only for well-preserved samples from the Židlochovice and Kralice sections. The methods used were described by Holcová and Demeny (2012). Groups of small-sized, four-chambered *Globigerina* sp. and *Cibicidoides* spp. were chosen for isotopic analysis. Planktonic foraminifera for isotopic analysis were picked from a size fraction of 63–200 µm, in which no specimens with reproductive chambers were observed. *Cibicidoides* spp. were picked from the 63–300 µm fraction. The carbon and oxygen isotope compositions of calcite were determined at the Institute for Geological and Geochemical Research, RCAES, Hungarian Academy of Sciences (Budapest, Hungary).

Results

Biostratigraphy

Biostratigraphic correlation of the carbonate production event was based on the occurrence/absence of planktonic

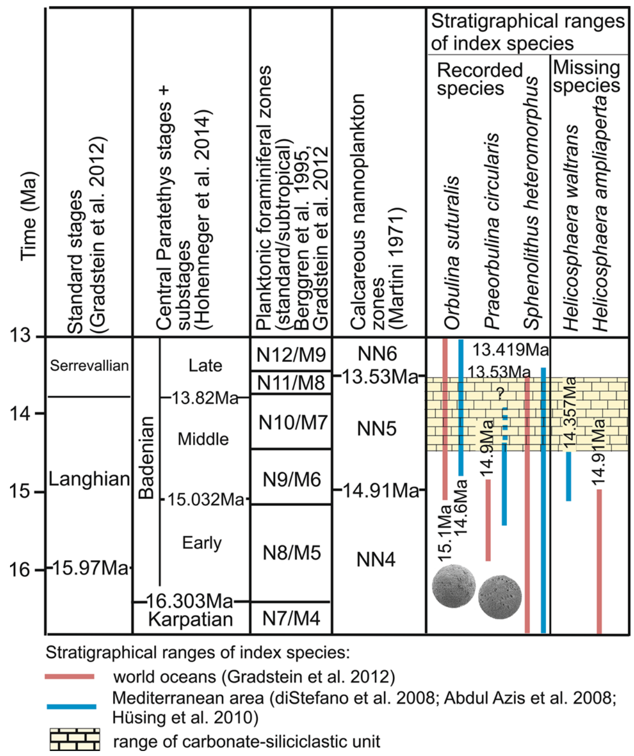


Fig. 2 Biostratigraphic correlation of the sections studied

foraminifera and calcareous nannoplankton index species. The dating of the first and last occurrences (FO, LO) of index species differs in the world's oceans (Gradstein et al. 2012) and in the Mediterranean area (Di Stefano et al. 2008; Abdul Azis et al. 2008; Hüsing et al. 2010). The differences are summarized in Fig. 2. Due to the connection of the Central Paratethyan Sea with the Mediterranean, the correlations of bioevents with the Mediterranean dating are more probable. Our succession of bioevents follows well the successions in the Mediterranean area (Di Stefano et al. 2008; Abdul Azis et al. 2008; Hüsing et al. 2010), where the LO of *Praeorbulina* spp. is an indefinable event that may be observed above/before the LO of *Helicosphaera waltrans*. The same succession of bioevents was described in the Carpathian Foredeep by Švábenická (2002).

Of the index species, *Praeorbulina* (LO: 14.9 Ma; Gradstein et al. 2012; Mediterranean area: Abdul Azis et al. 2008), *Orbulina* (FO: 15.1 Ma; Gradstein et al. 2012; Mediterranean: 14.6 Ma; Abdul Azis et al. 2008; Hüsing et al. 2010) and *Sphenolithus heteromorphus* (LO: 13.53 Ma; Gradstein et al. 2012; Mediterranean area: 13.419 Ma; Abdul Azis et al. 2008; Hüsing et al. 2010) were recorded in all rocks included in the carbonate production event. *Helicosphaera ampliaperta* (LO: 14.91 Ma; Gradstein et al. 2012) and *H. waltrans* [last common occurrence (LCO) in the Mediterranean area 14.357 Ma; Abdul Aziz et al. 2008] are missing.

According to the above-mentioned data, the carbonate production event can be correlated with the upper part of the NN5 Zone of calcareous nannoplankton and the M6 Zone of planktonic foraminifera (Berggren et al. 1995); numerically, the range from 14.36 Ma (LO of *H. waltrans*) to 13.34 Ma (LO of *S. heteromorphus*) can be estimated based on the Mediterranean dating of bioevents. In the local Central Paratethys stratigraphy, this interval represents the Middle Badenian (Hohenegger et al. 2014).

Lithology

The mixed siliciclastic-carbonate complex can be lithologically characterized by alternations of the following: (1) Mudstone lithofacies revealing dominant deposition from suspension in relatively calm conditions. Variations in the sand content, bioturbation, preservation of planar bedding and shell debris also reflect periods of a relatively higher input of material transported by currents in traction (storms?); (2) Sandy lithofacies and their alternations with mudstone lithofacies can be connected with deposition in the lower shoreface or transition zone to a deeper environment. The sharp bases of the beds, occurrence of transported limestone clasts, shell debris and planar lamination suggest a higher flow regime. The absence of clear wavy structures points to deposition below the fair-weather wave-base; (3) Heterolithic facies support rapid fluctuation of siliciclastic input into the environment. Limestone beds, 10–110 cm in thickness, indicate stable conditions of deposition and severe reduction of siliciclastic input. Multiple alternations of relatively thin beds composed of mudstone, sandstone and limestone are interpreted as cyclic changes of depositional conditions (climatically driven?). Repeated coarsening-upward successions with a transition from mudstone to sandstone and/or finally limestone can be interpreted as parasequences (Fig. 1).

In the Kralice area (Zágoršek et al. 2007, 2009; Fig. 1), a carbonate production event is manifested by deposition of calcareous mudstones to muddy limestones. The sediment can be interpreted as having been deposited in a shallow marine setting. The absence of sedimentary structures induced by waves or tidal activity may point to offshore conditions. Shells were eroded in coastal environments, transported offshore by gravity currents or storm-induced flows (tempestites), and rapidly deposited. Horizontal lamination in mudstone points to the pulsed nature of sedimentation. Intercalations of poorly sorted sand with angular psefitic clasts, intraclasts of sandy clay or clayey sand originating from the underlying bed, and shell debris with abundant Rhodophyta reveal a typical textural inversion that can be explained by highly disparate sediment deposition/transport environments. Transport of outsized isolated angular clasts can be explained by rock falls (Nemec 1990),

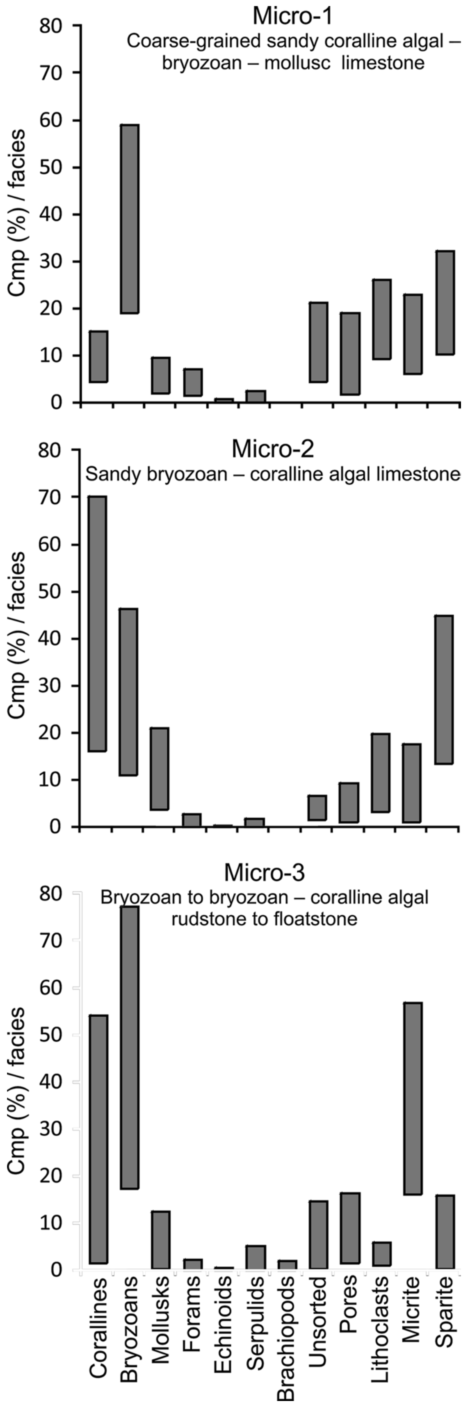


Fig. 3 Composition of microfacies in the Podbřežice and Kroužek sections. Ranges of component percentages in individual microfacies are summarized. **a** Coarse-grained coralline algal–bryozoan–mollusc sandy limestone; **b** Sandy bryozoan–coralline algal limestone; **c** Bryozoan to bryozoan–coralline algal rudstone to floatstone with grainstone matrix

a relatively dramatic relief of the basin floor and redeposition of large clasts into shallow marine environments by density currents.

Fig. 4 Microfacies (**a**–**d**) and coralline algae (**e**–**h**). **a** Coarse-grained coralline algal–bryozoan–mollusc sandy limestone, Kroužek. Limestone composed of protuberances and debris of coralline algae (appearing as *black*) and elongated mollusk shells; **b** Sandy bryozoan–coralline algal limestone, Kroužek. Sample consists mostly of bryozoan debris with fewer coralline algae; **c**–**d** Bryozoan to bryozoans–coralline algal rudstone to floatstone, Podbřežice. Bryozoan colonies float in a grainstone to micritic matrix and are encrusted with coralline algae; **e** *Sporolithon lvovicum* (Maslov) Bassi, Braga, Zakrevskaya and Petrovna-Radionova; **f** *Lithothamnion roveretoi* Airoldi; **g** *Lithophyllum* sp. 1; **h** *Spongites fruticulosa* Kützing

▶

In the large limestone bodies (Kroužek and Podbřežice, Fig. 1), three lithofacies were macroscopically identified. The first is detrital limestone with reworked lithoclasts and bioclasts (biodetrital grainstone). The amount of detrital material varies both in volume and in grain size. The second lithofacies reveals a very limited siliciclastic admixture; bioclasts are separated by a sparitic or micritic groundmass (rudstone-floatstone). Ripple cross-stratification and grading were the most common sedimentary structures and were identified especially within grainstones. The third lithofacies is calcareous marl to sandstones. These "clastic intercalations" are only thin interbeds within the dominant limestones. The lithology and sedimentary structures indicate dynamic changes in depositional conditions. Alternations of relatively calm periods and predominant deposition from suspension with periods characterised by either tractional or gravity currents can be supposed.

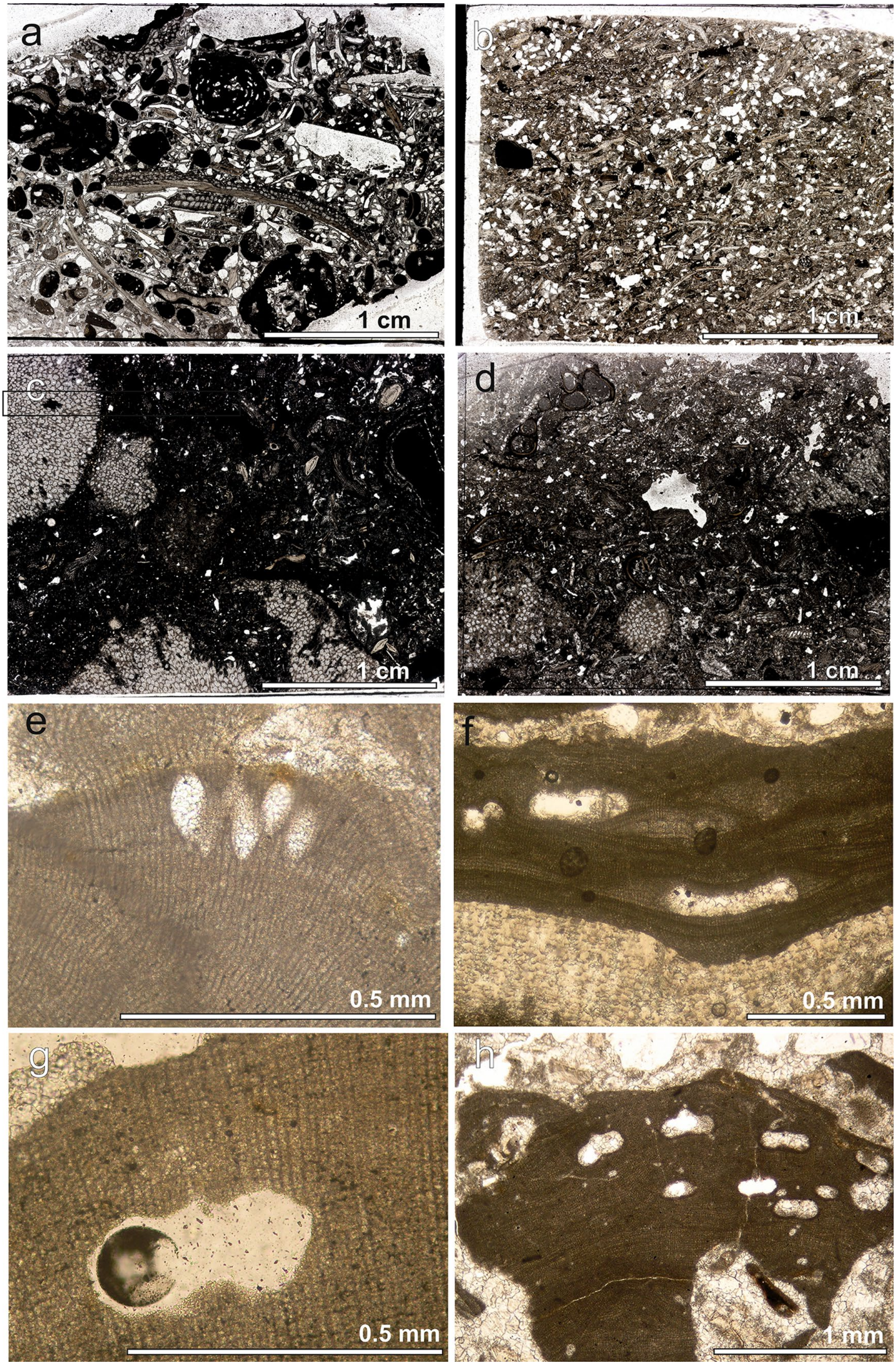
Biofacies

The main allochems in the samples are bryozoan colonies, coralline algae, unsorted allochems, lithoclasts and mollusks with minor foraminifera and serpulids; the groundmass consists of micrite and sparite (Fig. 3; Table 1). The skeletal assemblage can be classified as heterozoan (James 1997) or as rhodalgal (Carannante et al. 1988).

Three microfacies were identified based on skeletal components, the volume of lithoclasts and the mean grain size. Compositions of each microfacies are summarized in Fig. 3 and Table 1. The microfacies are: (1) sandy coarse-grained coralline algal–bryozoan–mollusc limestone (Fig. 4a); (2) sandy bryozoan–coralline algal limestone (Fig. 4b); and (3) bryozoan to bryozoan–coralline algal rudstone to floatstone with grainstone matrix (Fig. 4c–d).

Differences in the fossil content of siliciclastic and mixed siliciclastic-carbonate units

Based on the occurrence of *Helicosphaera waltrans*, the Mid Badenian sediments (sensu Hohenegger et al. 2014) of the Carpathian Foredeep in Moravia can be divided into two intervals (Švábenická 2002). In the older interval containing *H. waltrans*, carbonates were not recorded; in the


a
1 cm
b
1 cm
c
1 cm
d
1 cm
e
0.5 mm
f
0.5 mm
g
0.5 mm
h
1 mm

younger interval without *H. waltrans*, carbonates occurred. To define the specific paleoceanographic situation during a carbonate production event, firstly, the general differences between the intervals with and without the deposition of carbonates were tested using a Kruskal-Wallis test (Fig. 5). The test showed that the units differ in relative abundances of textulariids, epiphytic and oxyphilic benthic foraminifera, *Globigerina praebulloides* and reworked calcareous nannoplankton (higher in the siliciclastic-carbonate unit), an abundance of calcareous nannoplankton and a relative abundances of infauna, high-nutrient benthic foraminiferal markers and *Helicosphaera* spp. (lower in the siliciclastic-carbonate unit). Visual estimation (Fig. 5) showed higher variances in abundances of *Turborotalita quinqueloba, Paragloborotalia mayeri, Reticulofenestra minuta* and high-nutrient markers in the siliciclastic-carbonate unit.

Planktonic assemblages in the siliciclastic-carbonate unit

In the siliciclastic-carbonate unit, planktonic organisms are generally rare and only calcareous plankton was recorded. However, siliceous plankton (diatoms and radiolaria) was mentioned from isochronous siliciclastics of the Carpathian Foredeep (Řeháková in Papp et al. 1978; Sláma 1983); in the sections studied, they were recorded only below the first limestone bodies in the Židlochovice boreholes.

Calcareous nannoplankton The Kruskal–Wallis test documented statistically significant differences in nannoplankton abundance between the limestones and siliciclastics in the siliciclastic-carbonate complex (Fig. 6; Table 2): abundances are approximately two times lower in the limestone bodies than in the siliciclastics. In the former, peaks of calcareous nannoplankton abundance can be correlated with siliciclastic intercalations (Fig. 6).

Calcareous nannoplankton assemblages contain a total of 15 Miocene species, of which *Reticulofenestra minuta, R. haqii*, *Coccolithus pelagicus* and *Thoracosphaera* spp. are common to abundant. The Kruskal–Wallis tests showed statistically significant differences in the abundance of *Thoracosphera* spp., which is higher in the limestone bodies and of *Reticulofenestra minuta* which are higher in siliciclastic intercalations within the limestones (Fig. 6; Table 2). Though the assemblages look generally very similar, dominated by *Reticulofenestra minuta,* nonmetric multdimensional scaling (n-MMDS) showed the differences between assemblages from a larger limestone body (Kroužek and Podbřežice) and from an area dominated by siliciclastics (Židlochovice and Kralice). Comparison of multivariate statistical classification of samples with relative abundances of the most common taxa showed that variable but generally higher abundance of *Thoracosphaera* spp. characterize assemblages from the larger limestone body. Assemblages from the Židlochovice and Kralice areas are less diverse with abundant *Reticulofenestra minuta* and variable abundance of *Coccolithus pelagicus.* A higher abundance of *Reticulofenestra haqii* is recorded in the Židlochovice area; *Braarudosphaera bigelowi* appears in the Kralice area (Fig. 7).

Fig. 5 Differences in the relative abundance of groups of microfossils between the siliciclastic and siliciclastic-carbonate units. Statistically significant differences (tested by Kruskal–Wallis test) are marked by *light yellow arrows* (*p* value from 0.05–0.0001) or *dark yellow arrows* (*p* value <0.0001). *SC* siliciclastic unit with *H. waltrans*; *S-CC* siliciclastic-carbonate unit above the LO of *H. waltrans*; *p- p*-values for tested parameters

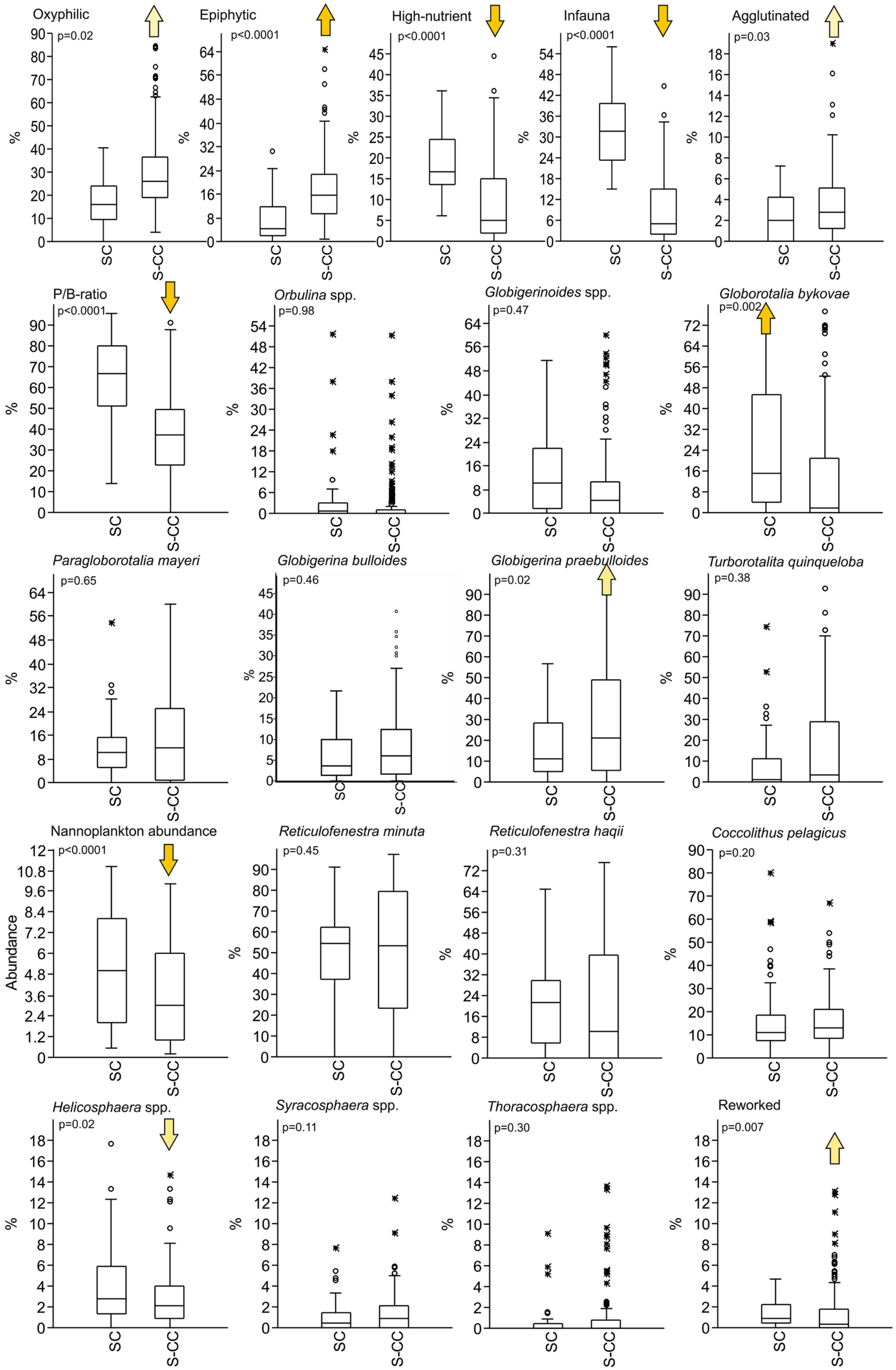
Planktonic foraminifera (Fig. 8z, ab) The Kruskal–Wallis test showed the differences between planktonic foraminiferal assemblages in the limestone bodies, siliciclastics and siliciclastic intercalations to be statistically significant. These differences concern the P/B-ratio and the abundance of cool-water/high nutrient plankton (*Globigerina* spp. and *Turborotalita quinqueloba*), *Globorotalia* spp. and *Turborotalita quinqueloba* (higher in siliciclastics, lower in limestone bodies; Fig. 6). Of note, the P/B-ratio in limestones exceeds 10 % mainly in the siliciclastic intercalations. nMMDS as well as relative abundances of the most common taxa showed variable compositions of assemblages. Assemblages from the Podbřežice section substantially differ by a high abundance of *Globigerinoides* spp. and *Orbulina suturalis* and a low abundance of 5-chambered *Turborotalita quinqueloba* and *Globigerina ottnangiensis*. Assemblages from the Židlochovice and Kralice boreholes are characterized by a higher abundance of globorotaliids; a scarcity of four-chambered *Globigerina* spp. was recorded in the Židlochovice area (Fig. 9).

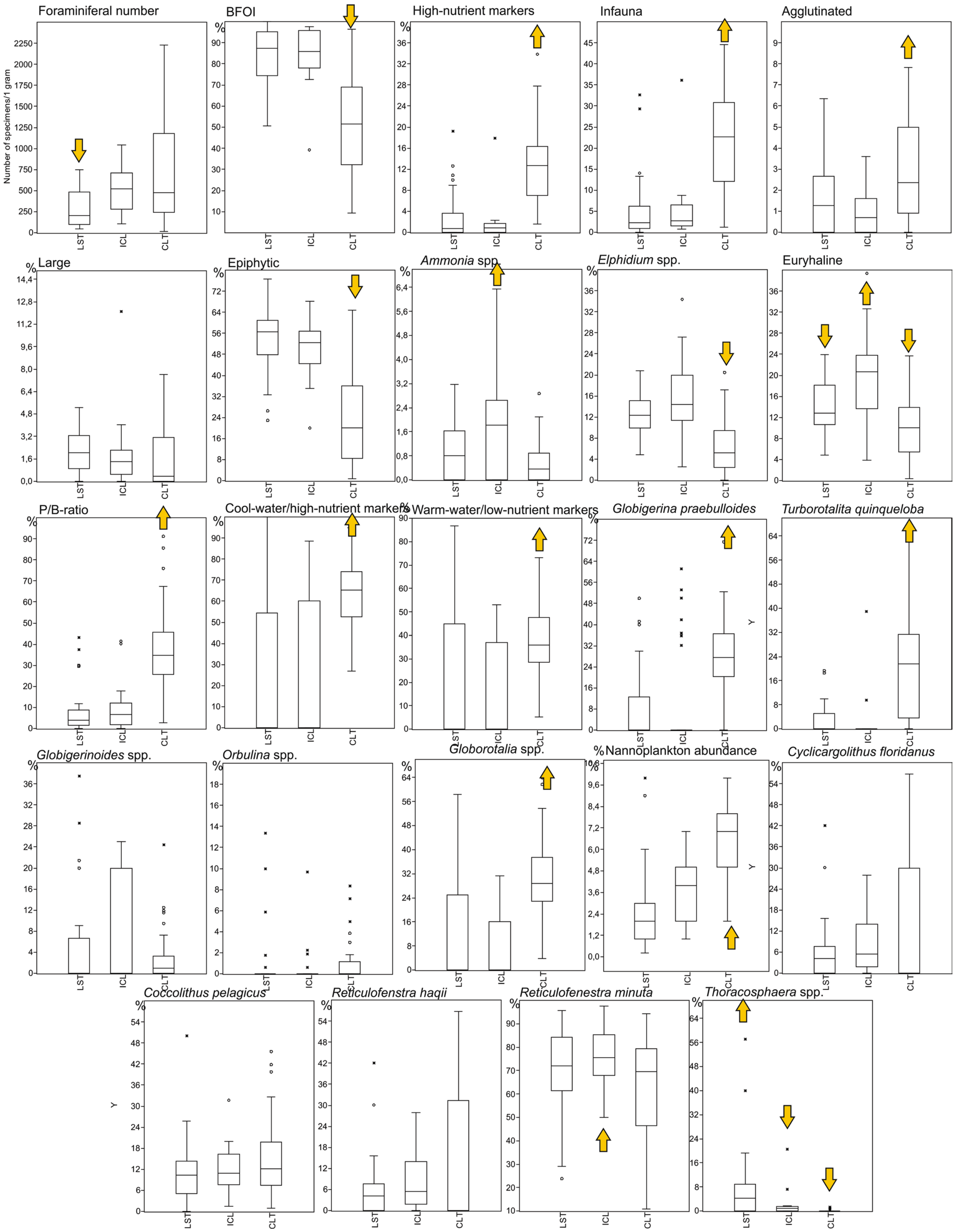
Benthic biota in the siliciclastic-carbonate units

Coralline algae (Fig. 4e–h) *Lithothamnion roveretoi* Airoldi, *Lithothamnion* sp. 1, *Mesophyllum* cf. *printzianum* Woelkerling & Harvey Adey, *Lithophyllum* sp. 1, and *Spongites fruticulosa* Kützing were identified in the Podbřežice section (Hrabovský et al. submitted). *Sporolithon lvovicum* (Maslov) Bassi, Braga, Zakrevskaya & Petrovna-Radionova, *Lithothamnion* sp. 2, *Mesophyllum curtum* Lemoine, *M.* cf. *printzianum* Woelkerling & Harvey, *Phymatolithon* sp., *Lithophyllum* sp. 1, *L.* sp. 2, *Hydrolithon lemoinei* (Miranda) Aguirre, Braga & Bassi, and *Spongites fruticulosa* Kützing were identified in the Kroužek section (Hrabovský et al. submitted). According to these authors *Mesophyllum* cf. *printzianum* and *Spongites fruticulosa* inhabit present-day inner shelf environments with normal salinity.

A diverse assemblage comparable to that at Kroužek was documented in Židlochovice (Hrabovský et al. submitted).

Benthic foraminifera (Fig. 8a–y, ac–ad). The abundances of benthic foraminifera in limestones vary from 50 to 700


Oxyphilic
p=0.02
Epiphytic
p<0.0001
High-nutrient
p<0.0001
Infauna
p<0.0001
Agglutinated
p=0.03
P/B-ratio
p<0.0001
Orbulina spp.
p=0.98
Globigerinoides spp.
p=0.47
Globorotalia bykovae
p=0.002
Paragloborotalia mayeri
p=0.65
Globigerina bulloides
p=0.46
Globigerina praebulloides
p=0.02
Turborotalita quinqueloba
p=0.38
Nannoplankton abundance
p<0.0001
Abundance
Reticulofenestra minuta
p=0.45
Reticulofenestra haqii
p=0.31
Coccolithus pelagicus
p=0.20
Helicosphaera spp.
p=0.02
Syracosphaera spp.
p=0.11
Thoracosphaera spp.
p=0.30
Reworked
p=0.007
%
SC
S-CC


Foraminiferal number
Number of specimens/1 gram
BFOI
High-nutrient markers
Infauna
Agglutinated
Large
Epiphytic
Ammonia spp.
Elphidium spp.
Euryhaline
P/B-ratio
Cool-water/high-nutrient markers
Warm-water/low-nutrient markers
Globigerina praebulloides
Turborotalita quinqueloba
Globigerinoides spp.
Orbulina spp.
Globorotalia spp.
Nannoplankton abundance
Cyclicargolithus floridanus
Coccolithus pelagicus
Reticulofenestra haqii
Reticulofenestra minuta
Thoracosphaera spp.
%
LST
ICL
CLT

◀ **Fig. 6** Differences in quantitative parameters of microfossil assemblages among siliciclastics (CLT), carbonates (LST) and siliciclastic intercalations in limestones (ICL) in the siliciclastic-carbonate unit. Statistically significant differences (tested by Kruskal–Wallis test) are marked by *yellow arrows*. *P* values are summarized in Table 2. *BFOI* the benthic foraminiferal oxygenation index; ratio between oxyphilic and hypoxic benthic foraminifera

specimens/g of rock; values of 700–1,000 specimens/g were reached in the siliciclastic intercalations in the Podbřežice section. In the siliciclastics, there abundances may reach more than 1,000 specimens/g. Kruskal–Wallis tests showed statistically significant differences in the composition of benthic foraminiferal assemblages (Fig. 6; Table 2): siliciclastics differ from limestones in higher abundances of infauna, high-nutrient markers and textulariids, in the lower values of BFOI (=the Benthic Foraminiferal Oxygenation Index, Kaiho 1994), and in lower abundances of epiphytic foraminifers and *Elphidium* spp. Siliciclastic intercalations in limestones are characterized by higher abundances of *Ammonia* spp.

Generally, the high abundances of *Asterigerinata planorbis* (40–60 %) are very characteristic for all samples from the limestones bodies. In limestones, three groups of benthic foraminifera species with statistically significant differences of relative abundances based on Spearman correlation coefficients can be distinguished (Fig. 10): (1) *Bulimina* spp., *Bolivina* spp., *Hansenisca soldanii, Melonis pompiloides, Cassidulina* spp., *Globocassidulina* spp., lagenids and textulariids; (2) *Ammonia* spp., *Elphidium* spp., and *Nonion commune*; (3) *Cibicidoides* spp. and *Lobatula lobatula*. The nMMDS (Fig. 11) clearly separated assemblages from the Kralice sections due to the higher abundances of taxa from group (1), mainly *Cassidulina* spp. Assemblages from the limestones of the Židlochovice section can be characterized by dominance of taxa from groups (2) and (3), *Asterigerinata planorbis* (common) and at some levels higher abundances of *Bolivina dilatata, Globocassidulina* spp., and *Cassidulina* spp. from group (1). Assemblages from the Podbřežice and Kroužek sections are very similar and differ from the assemblages of

Table 2 Kruskal–Wallis test *p* values: evaluated differences in quantitative parameters of microfossil assemblages among siliciclastics, carbonates and siliciclastic intercalations in limestones of the siliciclastic-carbonate unit

Characteristics	Limestones/ intercalations	Limestones/ elastics	Clastics/ intercalations
Benthic forminifera			
Foraminiferal number	0.00945	0.01822	0.5916
Agglutinated	0.3894	0.0037	0.000704
BFOI	0.9545	2.8E−9	2.29E−7
Infauna	0.785	2.63E−8	1.06E−6
High-nutrient	0.765	1.02E−8	4.41 E−8
Epiphytic	0.2009	3.66E−9	4.03E−6
Euryhaline	0.008256	0.00119	5.14E−5
Elphidium spp.	0.1666	2.78E−6	1.40E−5
Ammonia spp.	0.2015	0.0635	0.01594
Large	0.2455	0.08701	0.2553
Planktonic forminifera			
P/B-ratio	0.403	1.33E−8	7.39E−5
Turborotalita quinqueloba	0.2875	5.96E−7	1.73E−8
Small *Globigerina* spp.	0.8907	4.05E−8	0.00015
Globigerina praebulloides	0.1306	1.65E−6	3.41 E−5
Cool-water/high-nutrient	0.8137	7.48E−7	0.000139
Warm-water/low-nutrient	0.7173	0.001562	0.000501
Globigerinoides spp.	0.3765	0.197	0.8912
Orbulina spp.	0.9011	0.142	0.2554
Globorotalia spp.	0.6837	2.96E−6	4.37E−7
Calcareous nannoplankton			
Calcareous nannoplankton abundance	0.01537	1.26E−6	5.31 E−5
Coccolithus pelagicus	0.5828	0.1381	0.5193
Reticulofenestra minuta	0.4382	0.1391	0.04827
Reticulofenestra haqii	0.229	0.9195	0.3475
Thoracosphaera spp.	0.03226	1.51E−9	4.13E−6
Cyclicargolithus floridanus	0.2261	0.8105	0.2788

the Židlochovice and Kralice areas by abundant *Asterigerinata planorbis* and the absence of taxa from group (1). The assemblages of Kroužek section and of the middle part of Podbřežice section differ from the other ones at Podbřežice only in slightly higher abundances of small-sized cibicidoids and *Lobatula lobatula*.

Molluscs The molluscan association at Kroužek is relatively rich; it includes species of *Corbula, Ostrea, Turritella, Conus, Nassarius*, *Petaloconchus, Lemintina, Genota, Bittium*, etc. At Židlochovice, the molluscan fauna consists predominantly of bivalves; gastropods are less common. Small gastropods of the genera *Bittium, Alvania, Solariorbis, Gibbula,* and *Rissoina* were identified in some

Fig. 8 Foraminifera. **a–e** *Asterigerinata planorbis* (d'Orbigny), Kr 21, Pr 21, Kr 21, Pr 9, Kr 9; **f–l** *Small-sized Cibicidoides* spp., Kr 21 Kr 17, Kr 7, Kr 12, Kr 12, Kr 9, Kr 22; **m** *Lobatula lobatula* Walker and Jacob, Kr 23; **n** *Cibicidoides austriacus* (d'Orbigny), Kr 23; **o** *Quinqueloculina akneriana* d'Orbigny, Kr 23; **p** *Elphidium flexuosum* (d'Orbigny), Kr10; **q** *Elphidium subtypicum* Papp, Kr 22; **r** *Elphidium fichtelianum* (d'Orbigny), Kr 2; **s** *Elphidium macellum* (d'Orbigny), Kr 7; **t** *Nonion* sp., Pr 21 undeterminable corroded and broken test; **u** *Uvigerina acuminata* Hosius, Pr 14; **v** *Bolivina plicatella* Cushmann, abraded test, Pr 10; **w** *Pullenia bulloides* (d'Orbigny), Pr 14; **x** *Melonis pompiloides* (Fichtel and Moll), Kr 17; **y** *Ammonia viennensis* (d'Orbigny), abraded test, Pr 20; **z–aa** *Globigerinoides bisphericus* Todd, 26-Kr 7, 27, Kr 22; **ab** *Globorotalia peripheroronda* Blow and Banner, Kr22; **ac** *Pararotalia aculeata* (d'Orbigny), Kr 10; **ad** *Amphistegina bohdanowiczi* Bieda, Kr 10. Lenght of *scale bars* 100 μm ▶

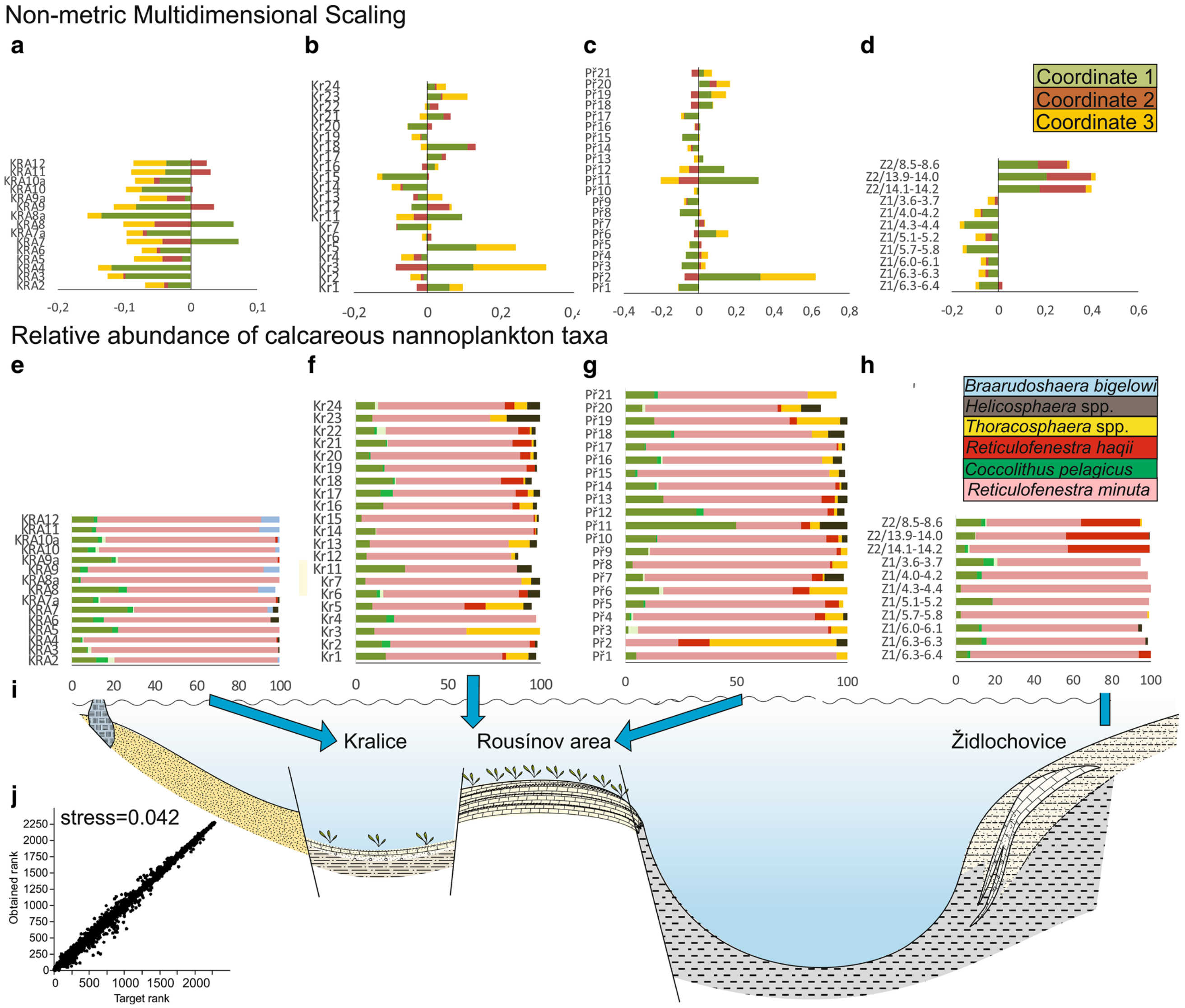
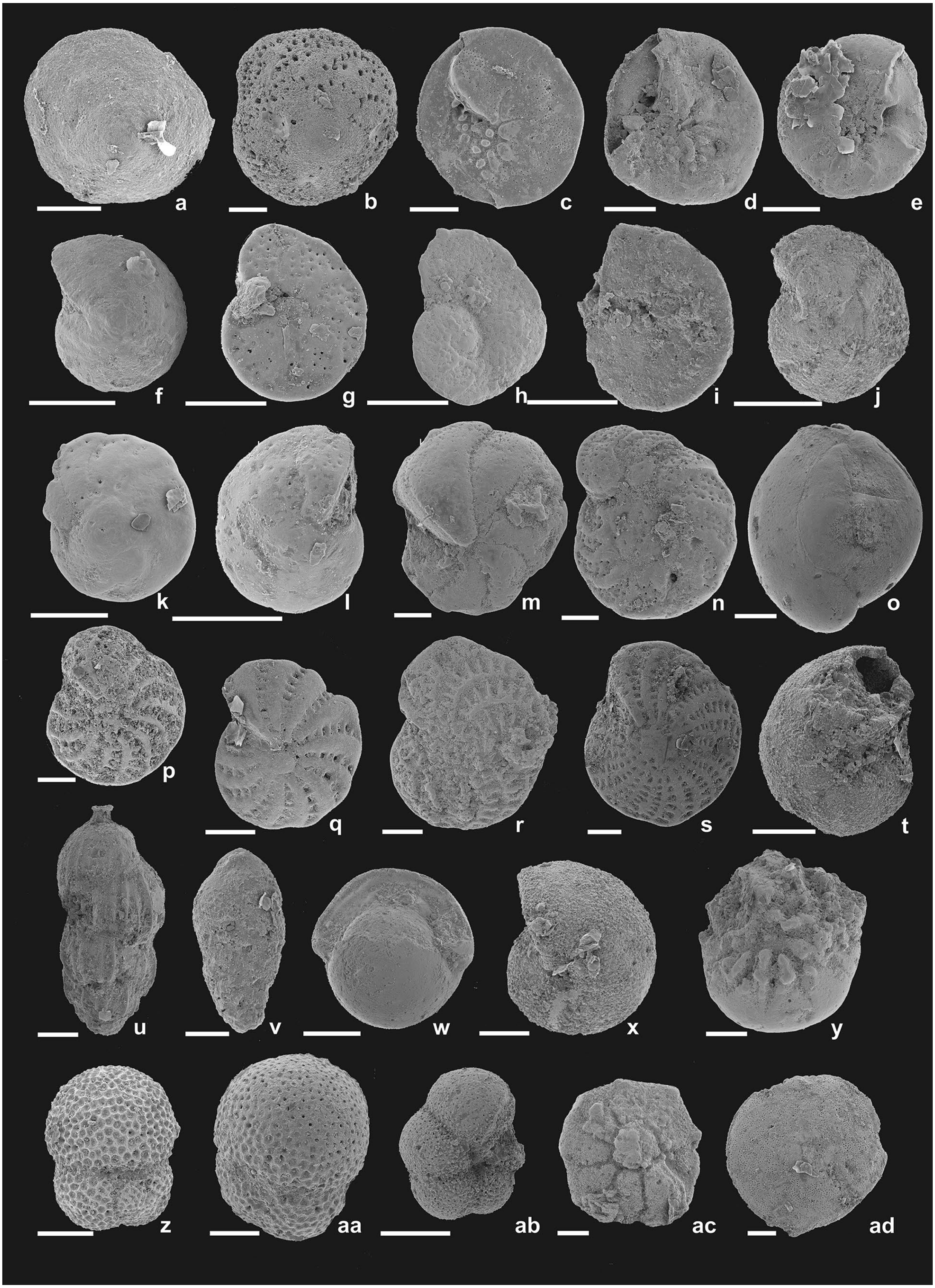


Fig. 7 **a–d** Differences in the calcareous nannoplankton assemblages using non-metric multdimensional scaling (nMMDS); **e–h** Comparison of relative abundances of common taxa; **i** Location of sections studied in basin; **j** Shepard plot of nMMDS


a
b
c
d
e
f
g
h
i
j
k
l
m
n
o
p
q
r
s
t
u
v
w
x
y
z
aa
ab
ac
ad

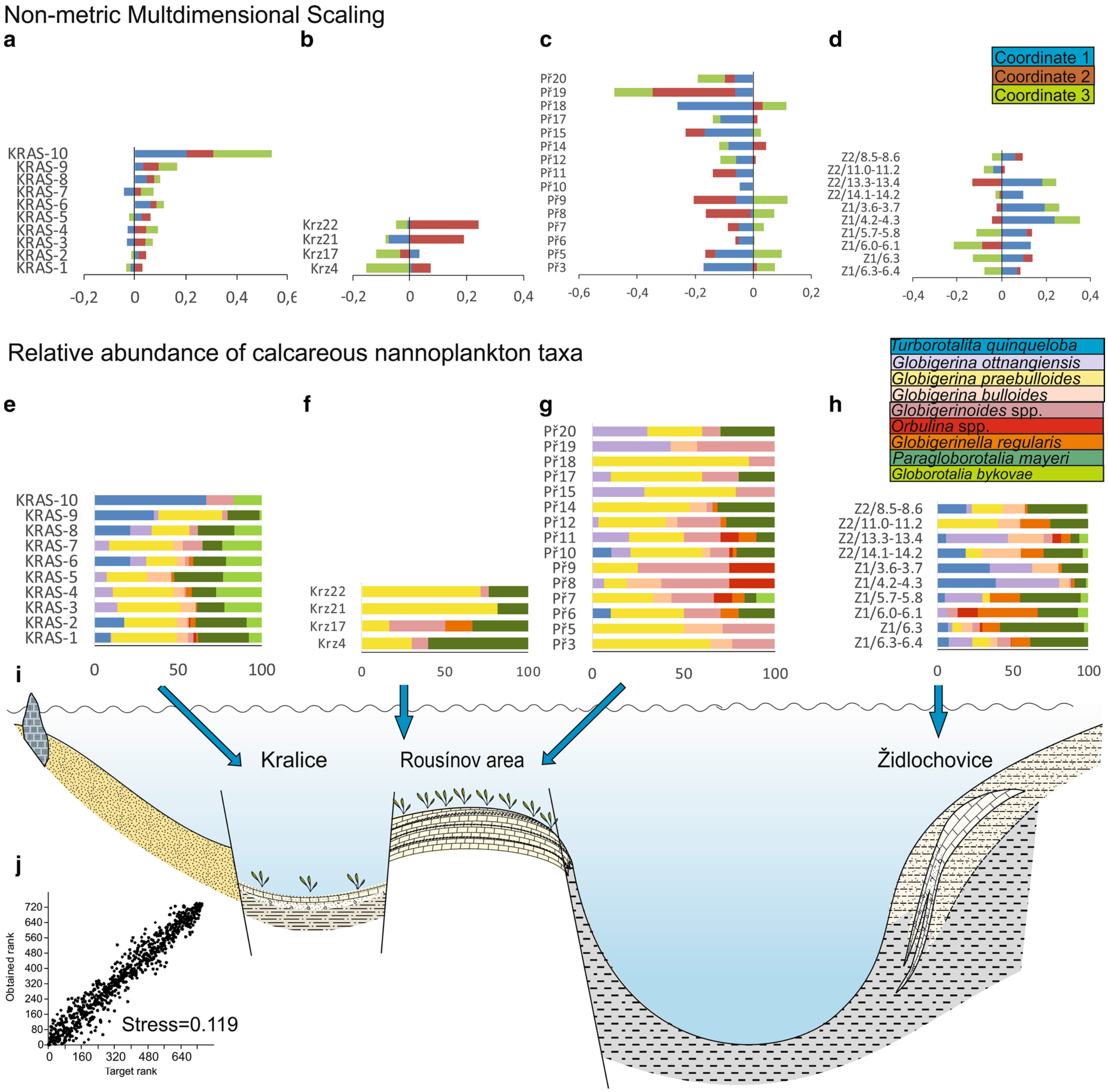


Fig. 9 **a**–**d** Differences in the planktonic foraminifera assemblages using non-metric multdimensional scaling (nMMDS); **e**–**h** Comparison of relative abundances of common taxa; **i** Locations of sections studied in the basin; **j** Shepard plot of nMMDS

intervals. At Kralice, the mollusc fauna is composed predominantly of bivalves; fragments of pectinids dominate, chitons are rare, and gastropods are completely absent.

Palynomorphs

From a palynological point of view, all samples from limestone bodies (with sand intercalations) were sterile. These sediments were not suitable for the preservation of palynomorphs due to their large grain size (without clay admixture) and chemical conditions during sedimentation. Pollen grains were probably washed out from these sediments and destroyed by oxidation. The absence of pollen grains in ancient carbonate environments was also described by Heusser (1978).

The palynomorph content seemed to be also dependent on the redox potential in the siliciclastics (Heusser 1978; Doláková et al. 2014). Large segments of the age-equivalent sediments from the boreholes in Židlochovice, Rebešovice, Chrlice, Opatovice and Oslavany were

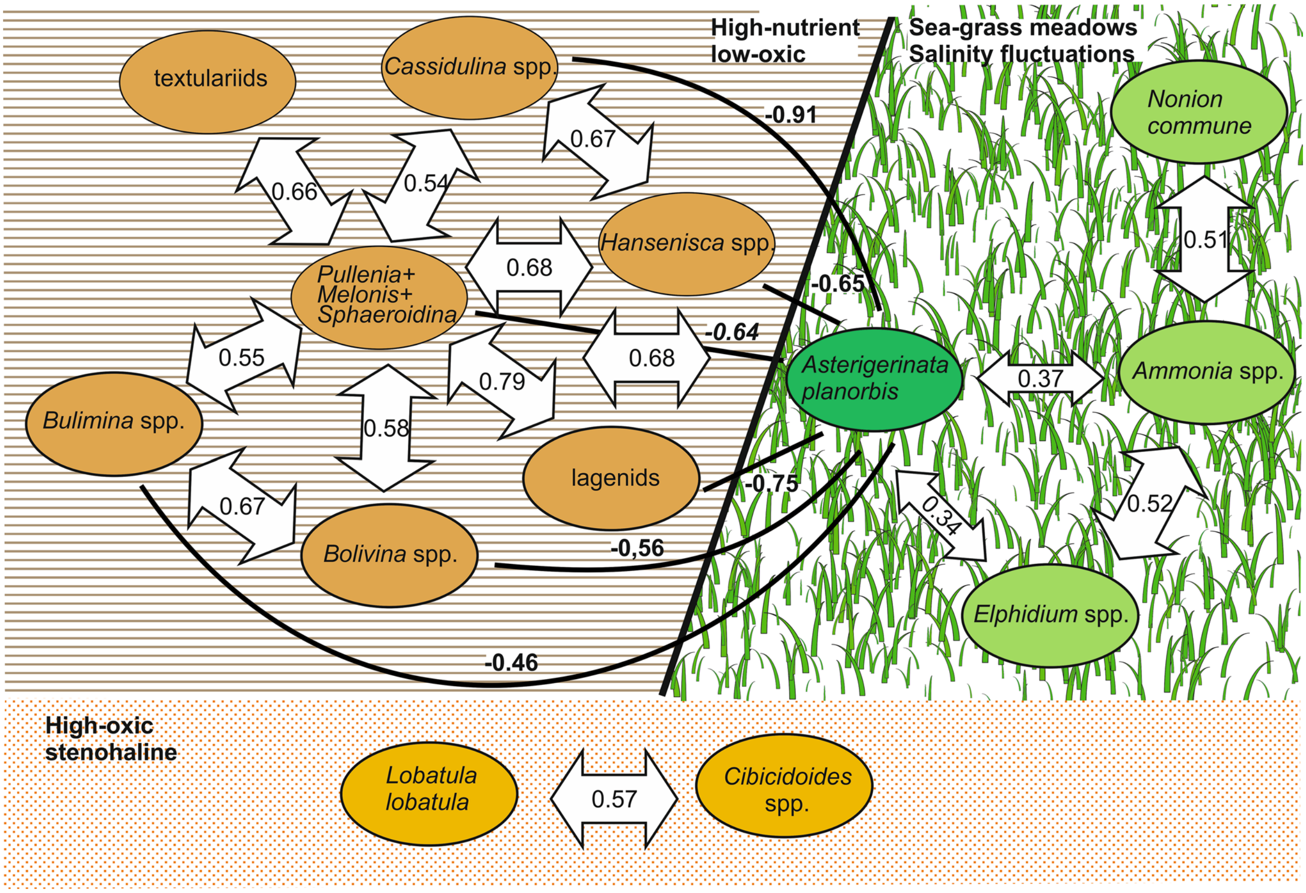


Fig. 10 Statistically significant correlations (p values < 0.05) among relative abundances of benthic foraminifera in limestones: three groups of species are distinguished by *different colors* of circles. Positive values of Spearman coefficient are given in wide arrows, negative values next to *slender arrows*

studied (Hladilová et al. 1999; Doláková et al. 2011; Doláková et al. 2014). They revealed periodic changes of oryctocoenoses with diversified pollen spectra followed by a strong dominance of conifers together with marine dinoflagellates and, afterward, the disappearance of all pollen and spores. Above that succession, limestone layers were recorded.

Flora with up to 30 % of evergreen, broad-leaved forest elements (*Engelhardia*, *Platycarya*, evergreen Fagaceae: *Castanopsis, Trigonobalanopsis*) is thought to have a mainly subtropical character. The share of warm-temperate mixed-mesophytic and broad-leaved deciduous forest members (i.e., *Quercus*, *Carya*, *Celtis*, *Juglans*) was lower. A higher diversity of "oak type" pollen grains (e.g., *Quercus robur-pubescscens*) and the general occurrence of *Platanus* pollen were typical. The proportions of most thermophilous elements of P1 sensu Mai (1981, 1991) and Stuchlik (1994) slightly decreased in comparison with the Lower Miocene palynospectra of the Carpathian Foredeep (Doláková et al. 2011; Kováčová et al. 2011). The abundant and diverse Pinaceae (with an admixture of *Cedrus*, *Abies*, *Picea*, *Cathaya* and *Tsuga*) were components of mountain conifer-rich forests.

Fluctuation of coastal swamp and riparian elements could be a result of humidity changes. Herbs and heliophilous elements such as Poaceae, Asteraceae, Caryophyllaceae, Chenopodiaceae, *Olea*, *Buxus* and *Ephedra* indicate the existence of more open areas and floral elements growing on drier places at this time. Warm-wet conditions, an increase in seasonality and cooler phases were observed within the subtropical character of the terrestrial flora (Doláková et al. 2014).

Oxygen and carbon isotopes

Stable oxygen and carbon isotopic values from bulk samples of limestones and siliciclastic intercalations from a large limestone body ("Rousínov ridge") were compared (data from Nehyba et al. 2008b). The Kruskal-Wallis test showed a statistically significant difference between δ^{18}O and δ^{13}C values in the siliciclastic intercalations of the Kroužek section (Fig. 12a). Kroužek limestones are more δ^{13}C-enriched than those from Podbřežice. In the Židlochovice boreholes (Fig. 12b), the planktonic foraminifers have lower δ^{13}C and δ^{18}O values relative to their benthic counterparts. This difference in δ^{13}C values is enhanced for the limestone-hosted tests relative to those collected from siliciclastic layers. At some levels (ZIDL1/3.1 m; ZIDL2/12.9 m), the isotopic differences between planktonic and benthic foraminifera are minimal. Contrary to the Židlochovice data, in the siliciclastics from the Kralice section (Fig. 12c), carbon isotope compositions of foraminifers are significantly lower in planktonic tests than in benthic ones, while the isotopic oxygen difference between plankton and benthos is only slightly lower. In these limestones, the isotopic carbon compositions of these foraminifer types overlap, while δ^{18}O values are higher for plankton, opposite to samples from the Židlochovice boreholes.

Fig. 12 **a** Differences in isotopic oxygen and carbon values of bulk sediment between the Kroužek and Podbřežice sections; **b** Isotopic oxygen and carbon values of foraminifera tests in the ZIDL-1 borehole; **c** Isotopic oxygen and carbon values of foraminifera tests in the Kralice section ▶

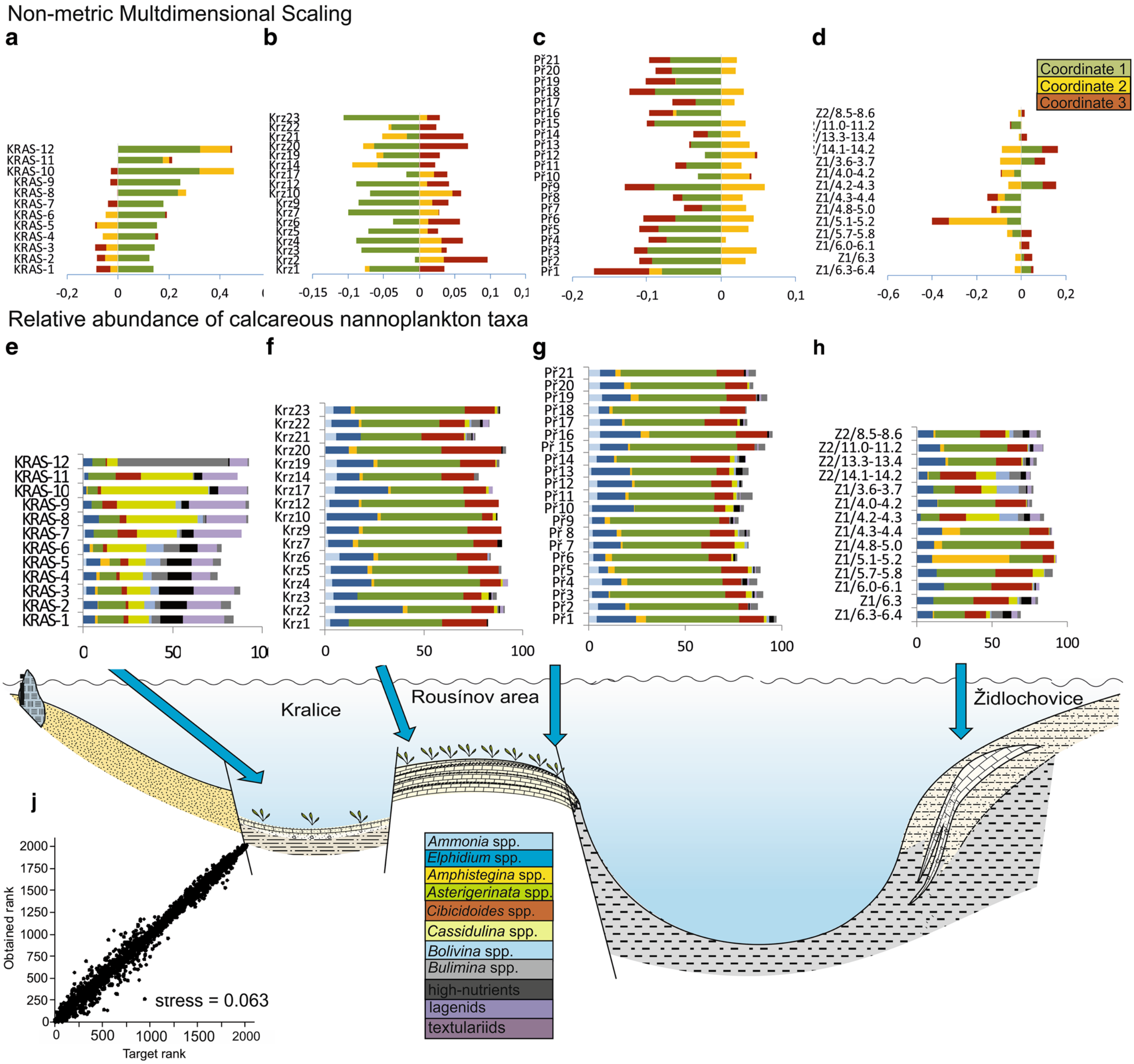
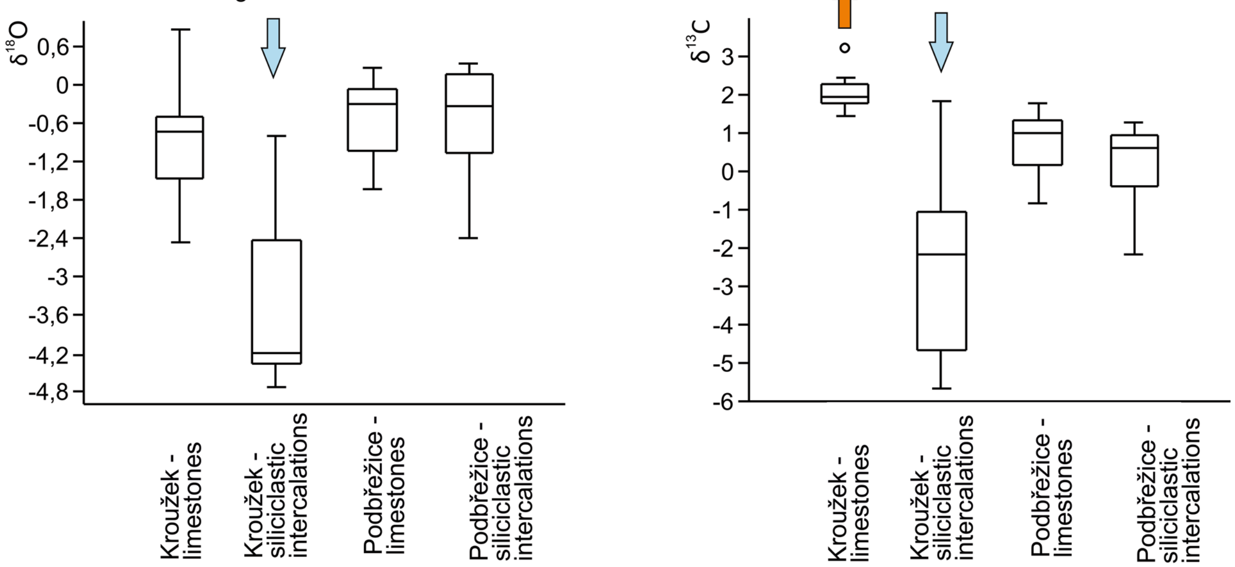
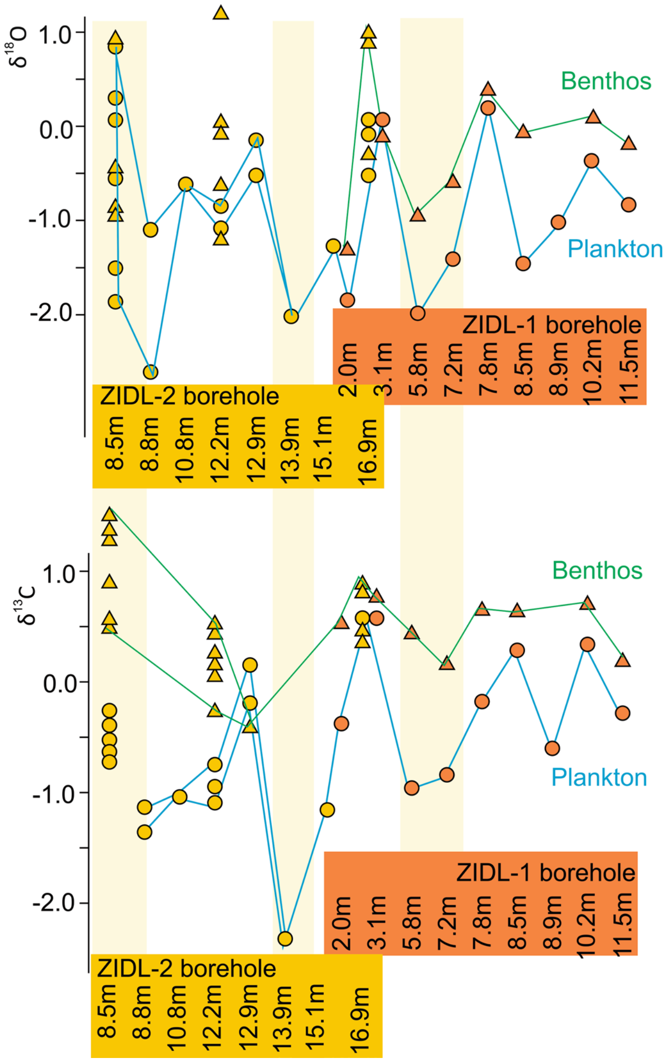


Fig. 11 **a**–**d** Differences in benthic foraminifera assemblages using non-metric multidimensional scaling (nMMDS). **e**–**h** Comparison of relative abundances of common taxa. **i** Location of studied sections in basin. **j** Shepard plot of nMMDS

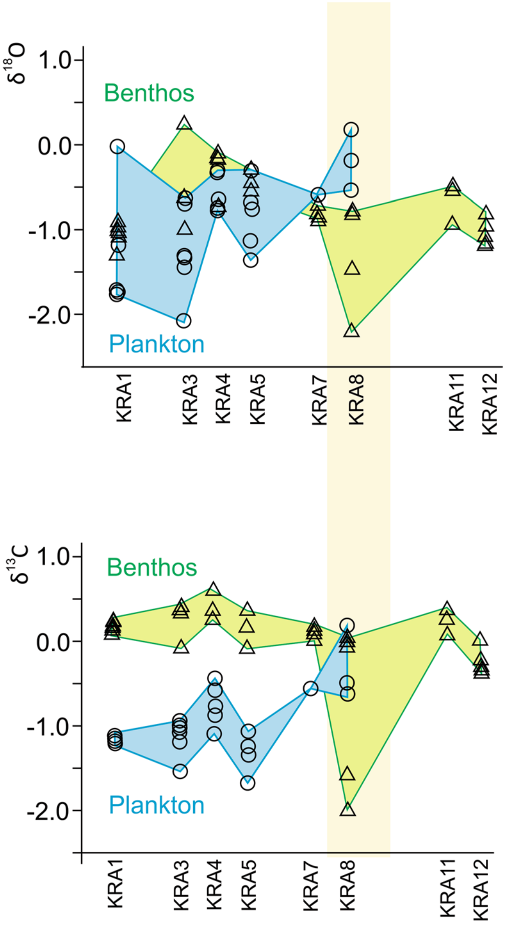
a Bulk sediment - large limestone bodies



b Foraminifera - ZIDL boreholes



c Foraminifera - Kralice



Discussion

Correlation of the Middle Miocene carbonate production event across the Central Paratethys

A carbonate production event, manifested by the deposition of a mixed carbonate–siliciclastic unit in the Moravian part of the Carpathian Foredeep is dated by the co-occurrence of *Praeorbulina, Orbulina* and *Sphenolithus heteromorphus*, and the absence of *H. waltrans*. A similar biostratigraphic position of the siliciclastic-carbonate unit was also recorded in the Ugljevic section (Pezelj et al. 2013). In the Transylvanian Basin, the studied limestones contain only *Orbulina* sp. (Filipescu and Gîrbacea 1997; Zágoršek et al. 2010); nevertheless, nannoplankton assemblages enable correlation with the upper part of the NN5 Zone without *H. waltrans* (Holcová, unpublished data). Croatian limestones from the Zrin Basin (Martinuš et al. 2012) can be correlated with the NN5 Zone; *H. waltrans* was not recorded. The co-occurrence of *Praeorbulina* and *Orbulina* is characteristic for the appearance of limestones in the Mailberg Formation of the Eastern Alpine Foredeep in Austria (Mandic 2004). The formation correlates with chron C5Bn.r, based on paleomagnetic data from Ćorić et al. (2004). The age of the limestone bodies in Hungary, Poland and Ukraine (Pisera and Studencki 1989; Randazzo et al. 1999; Radwański et al. 2006) cannot be determined so strictly; nevertheless, the same age is very probable. However, other younger intervals involving carbonate production in the Badenian were described from Ukraine (Gorka et al. 2012).

Despite these uncertainties, the carbonate production event in the Central Paratethys can be correlated with the NN5 Zone. While magnetostratigraphic dating in the Eastern Alpine Foredeep (chron C5Bn.r, based on paleomagnetic data; Ćorić et al. 2004) enumerated the age at 15.034–14.888 Ma, the biostratigraphic events dated the carbonate production in the Moravian part of the Carpathian Foredeep, in the Transylvanian Basin, and in the Zrin Basin to the upper part of the NN5 Zone, above the LO of *H. waltrans* at approximately 14.4–14.3 Ma (the LO of *H. waltrans*) to 13.42 Ma (the LO of *S. heteromorphus*).

Factors triggering the Middle Miocene carbonate production event

The start of the mixed siliciclastic-carbonate sedimentation was connected with the following paleoenvironmental changes: (1) Decrease of siliciclastic input in the basin; the decrease can be indirectly interpreted from the disappearance of siliceous plankton, which may be caused by the lack of a silica source. The silica in the Early-Middle Badenian deposits of the Carpathian Foredeep could originate from distal Badenian acidic air fall tephra or from the weathered crystalline basement along the passive, i.e., western, margin of the basin. The strongly restricted occurrence of volcaniclastic beds in the successions studied points to the dominant role of a decreased input of reworked and weathered siliciclastics.

The reduction of siliciclastic input can be connected either to transgressive and early highstand conditions, aridification of climate, or to both. The beginning of the Middle Miocene was characterized in the Carpathian Foredeep by a large marine transgression affecting the entire circum-Mediterranean area (Rögl 1999; Popov et al. 2004; Kováč et al. 2007; Piller et al. 2007). The carbonate production event is connected to the culmination of this transgression, which is documented by the occurrence of the denudation relicts of siliciclastic-carbonate deposits far on the Bohemian Massif (Hladilová and Zdražílková 1989). Thus, deposition of the carbonate–siliciclastic complex corresponds to the maximum flooding zone.

The Langhian aridification events were described from the Mediterranean area (Hüsing et al. 2010). The first discrete paleoenvironmental step, at 15.074 Ma, might be linked to reduced riverine discharge and climatic cooling (Hüsing et al. 2010). The dating of this step agrees with the appearance of carbonate bodies in the Alpine Foredeep (Mandic 2004). The second discrete step occurred at 14.489 Ma. This age corresponds to the onset of carbonate sedimentation in the Carpathian Foredeep. Findings of pollen grains of herbs and heliophilous plants such as Poaceae, Asteraceae, Caryophyllaceae, Chenopodiaceae, *Olea*, *Buxus* and *Ephedra* indicate the existence of more open and dryer areas at that time; (2) The appearance of sea-grass meadows and a well-aerated sea-floor can be interpreted from the statistically significant increase in the abundance of epiphytic as well as oxyphilic taxa. Pyrite infillings of foraminiferal tests, described from the older siliciclastic interval (Tomanová-Petrová and Švábenická 2007), disappeared, which also indicates an increase of oxygenation. This may be correlated with the establishment of downwelling (anti-estuarine) circulation (Brzobohatý 1987; Báldi 2006) and the culmination of the third order transgression, connected with the appearance of a shallow marginal part of the basin suitable for the expansion of sea-grass meadows. Seagrasses are, indirectly, important producers of biogenic $CaCO_3$ because their epibionts, invertebrate shells and coralline algae occur often in high density (Brasier 1975). Sea-grass respiration and photosynthesis cause variations in the O_2 and CO_2 content of seawater, which influences the rate of $CaCO_3$ fixation by marine organisms (Davies 1970). (3) Environmental instability and an increase in seasonality can be interpreted from the variable abundances of the opportunistic *Reticulofenestra minuta*. It indicates environmental stress in the upper part of the water column, characterized by fast changes within that environment, including fluctuations of salinity from brackish to hypersaline (Wade and Brown 2006), and oscillations of the nutrient content between oligotrophic and eutrophic (Wells and Okada 1997; Flores et al. 1997; Kameo 2002). Instability can also be interpreted from the large variation in the abundance of *Turborotalita quinqueloba,* a marker of cold, non-stratified water masses (Hohenegger et al. 2008), and *Globorotalia mayeri*. The large abundance variability of high-nutrient markers in the benthic assemblages shows the instability of environmental conditions at the sea floor. The bimodal abundance distributions of all these groups may indicate short-term (maybe seasonal) changes of non-stratified, mixed eutrophic waters with small *Turborotalita quinqueloba* and high nutrient markers at the bottom; the stratified water column is marked by oligotrophic warmer water with *Globorotalia mayeri* in the upper part. Salinity fluctuations in the upper part of water column cannot be excluded (Kendl, pers. comm., determined dinoflagellate markers of hypersaline conditions). The alternation of stratified and mixed water columns is also confirmed by the oxygen and carbon isotope data (Fig. 12).

The instability (probably connected with increased seasonality) can be connected with environmental and climatic changes preceding the Middle Miocene Climate Transition (MMCT) at 13.82 Ma (Holbourn et al. 2005). In terrestrial climates, the MMCO/MMCT transition is characterized by an increase in the mean annual range of temperature, mainly due to decreasing cold month temperatures (Bruch et al. 2010); increased seasonality is principally expressed in the seasonality of precipitation (Doláková et al. 2014). While the decrease of terrigenous input and oxic conditions with seagrass meadows accelerated the production of carbonates, the instability of the environment was a rather unfavorable factor. It could have caused the reduced thickness of limestone bodies and high amount of siliciclastic components in the carbonates, indicating only short-term and spatially-restricted intervals suitable for carbonate deposition.

Cyclicity in the mixed limestone-siliciclastic complex

Orbital forcing climatic cyclicity strongly influenced the evolution of the Middle Miocene ecosystems in the Central Paratethys (Hohenegger et al. 2009) and affected the paleobiological, as well as the geochemical and sedimentological, characteristics of sediments. Cyclical changes in the mixed siliciclastic-carbonate units are manifested by the alternation of paleoenvironments suitable for the deposition of limestones and siliciclastics. The direct relation between orbital forcing climate changes (wet-dry climatic cycles) and pelagic limestone-marl alternation was documented in the Langhian succession of the Conero Riviera by Mader et al. (2004). According to these authors, limestones represent dry/colder-water periods and marls represent wet/warmer-water periods with limited productivity and increased terrigenous supply.

To test the character of cyclical changes in the study area and compare the local model with the Mediterranean one, the paleoenvironments represented by the limestones and siliciclastics in the mixed limestone-siliciclastic unit were interpreted separately.

Paleoenvironment during deposition of limestones

Generally, the limestones in the Central Paratethys are interpreted as warm-water (Filipescu and Gîrbacea 1997; Pouyet and Tarkowski 1998; Riegl and Piller 2000; Radwański et al. 2006; Basso et al. 2008; Doláková et al. 2008; Martinuš et al. 2012; Pezelj et al. 2013). However, Randazzo et al. (1999) considered the limestones from the Pannonian Basin as being cool-water. This interpretation does not agree with other paleoclimatological data from the Central Paratethys (Kvaček et al. 2006; Doláková et al. 2014). The estimated paleotemperatures agree with a subtropical climate, which is expected from the biofacies analysis of red algal limestones (Kroeger et al. 2006).

In agreement with results from the other Central Paratethys basins, rhodalgal or bryorhodalgal facies dominate within the Early–Middle Badenian limestones (Pisera and Studencki 1989; Randazzo et al. 1999; Studencki 1999; Radwański et al. 2006; Doláková et al. 2008; Martinuš et al. 2012; Wiedl et al. 2012). Using recent analogues from the Mediterranean (Martinuš et al. 2012), subtropical, low- to moderate-energy clean waters with a depth of 10–80 m (mainly 20–40 m) are expected during deposition of these types of carbonates.

Mollusc assemblages from Kroužek correspond well to this microfacies interpretation. A simple paleoecological analysis (Hladilová 1984) generally indicated a shallow (littoral to sublittoral, with a maximum depth of up to 80 m) warm-water environment of marine salinity (above 30 ‰), good aeration, sufficient light and a prevailing soft bottom. Variations in water energy can be observed.

Recorded mollusc and foraminifera species are suspension-feeders, detritivores, predators and herbivores. The ratio between these trophic groups in assemblages varies but suspension-feeders, herbivores or predators always predominate over detritivores and deposit-feeders. This indicates a deficiency of organic detritus in the sediment as a nutrient source during deposition of the limestones.

During the deposition of limestones in the Podbřežice area the upper water column was characterized by a low abundance of plankton. The presence of *Globigerinoides* spp. indicates oligotrophic and well-stratified waters (Reynolds and Thunell 1985; Hemleben et al. 1989), and the characteristic nannoplankton genus, *Thoracosphaera* spp., is a general proxy for oligotrophy or stratification (Höll et al.

1998; Vink et al. 2002). Thus, a stratified water column with oligotrophic conditions in the upper layer can be expected during the deposition of limestones, also confirmed by the absence of *Turborotalita quinqueloba*. The latter occurs in siliciclastics and is a marker of a cold, non-stratified water body. However, autochthony of the planktonic foraminifera in the limestone bodies is questionable. Transport of plankton is confirmed by the assumed depth for *Asterigerinata* assemblages (up to 100 m; Holcová and Zágoršek 2008), in which live planktonic foraminifera are extremely rare. The transport mechanism of planktonic foraminifera from central to marginal parts of the basin may have been expected downwelling circulation (Brzobohatý 1987; Báldi 2006). The discrepancy between downwelling circulation leading to mixed water masses and presence of markers of a stratified water column may be explained by seasonal changes of the circulation pattern, with downwelling in summer and a stratified water body in winter, which is in agreement with the data of Hohenegger et al. (1999) and others. Seasonality is supported by the variable oxygen isotope composition of benthic foraminifera which may indicate mixing of seasonal populations (Holcová and Demeny 2012).

The increase in oxygen values in the Kralice section at the transition from siliciclastics to limestones and the oxygen isotope composition of bulk sediment from the limestone bodies in the “Rousínov Ridge”, stratigraphically higher than that of isochronous data from the Mediterranean (Mader et al. 2004; Fig. 12a), may indicate higher evaporation in the marginal part of the Central Paratethys basin and a decrease of temperature. Higher evaporation is supported by assemblages composed only of miliolids in the upper part of the Kroužek section. The absence of coral patch reefs in the Moravian part of the Carpathian Foredeep, which are known from isochronous rocks in Austria, Hungary, Ukraine and Poland (Pisera and Studencki 1989; Randazzo et al. 1999; Radwański et al. 2006; Martinuš et al. 2012; Wiedl et al. 2012), may be also due to both fluctuations in salinity and lower temperatures. Salinity fluctuations are more likely because the Polish and partly Ukrainian basins were located at a higher latitude than Moravia (Popov et al. 2004). Although it is not possible to exclude the influence of lower temperatures on the oxygen isotope values and on the absence of coral patch reefs during deposition of limestones in the Carpathian Foredeep, increasing salinity appears to have been the decisive factor.

Paleoenvironment during deposition of siliciclastics in the limestone-siliciclastic unit

During deposition of siliciclastics, both planktonic and benthic assemblages showed enhanced productivity. In the upper layer of the water column, the abundance of calcareous nannoplankton and planktonic foraminifera increased. The increase of small, 5-chambered *Turborotalita quinqueloba* indicates a non-stratified water column characterized by intensive vertical mixing or upwelling (Reynolds and Thunell 1985; Hemleben et al. 1989). Globorotaliids, as is the case with other abundant groups of planktonic foraminifera, are classified as cold-temperate taxa (Bicchi et al. 2003) and indicate surface water stratification (Pérez-Folgado et al. 2003). Alternation of assemblages dominated by *T. quinqueloba* and by *Globorotalia* indicates that the alternation of stratified and mixed water bodies persisted from the period of carbonate production. The increase in nutrient content at the bottom, indicated by a higher abundance of high-nutrient markers and detritivores (textulariids and deeper infauna), is connected with the appearance of organic detritus in the sediment. The lower Benthic Foraminiferal Oxygenation Index, as well as the disappearance of oxyphilic epiphytic taxa, showed a decrease of oxygen content at the bottom.

There are two possible ways to explain the nutrient sources: terrigenous input or seasonal upwelling. The decrease in carbon isotope values of planktonic foraminifers from the siliciclastics in the marginal area of the basin (Kralice section) in comparison with the values from the central part of the Carpathian Foredeep (which are near to the values from the Mediterranean Sea and Atlantic Ocean) favours terrestrial input. Furthermore, the occurrence of *Cassidulina* as a marker of phytodetritus supply and its decrease from marginal (Kralice) to more central parts of the basin suggests input of nutrients from the continent. Thus, deposition of siliciclastics corresponded with a more humid climate with higher rainfall.

In the Zrin Basin (Pezelj et al. 2013), high-nutrient markers (*Bulimina, Globocassidulina* and *Valvulineria*) occur also in siliciclastics. The alternation of siliciclastic and carbonate sediments can be explained by sea-level fluctuations (Mandic 2004) in the Eastern Carpathian Foredeep: the marly layers are characterized by an enhanced richness and heterogeneity of benthic foraminifera and by abundant planktonic foraminifera. These indicate open-marine conditions of the upper middle shelf, while carbonate production might be linked with shallowing. To summarize, the genesis of the mixed limestone-siliciclastics unit can be explained by alternating wet and dry phases: during the wet phase, siliciclastics were deposited due to higher terrigenous input. Carbonates were deposited during the dry intervals, connected with low nutrient input and at least occasional increases in salinity. For both intervals, short-term (probably seasonal) changes between mixed and stratified water masses are assumed.

Spatial paleoenvironmental variations during times of carbonate deposition

Though generally limestones were deposited in a uniform environment, some differences among individual areas existed:

1. In the Kralice Bay (Zágoršek et al. 2009; Holcová and Demeny 2012), sedimentation of carbonates is connected with the regressive phase of fourth or lower orders of sea-level changes. Carbonates contain a high admixture of siliciclastics and indicate rather unfavourable conditions for carbonate production. A facies study shows the pulsed nature of sedimentation, a relatively dramatic relief of the basin floor and redeposition of clasts to shallow marine environments by density currents. Molluscs represent a mixture of different environments, which also indicates higher water energy. Bivalves, as well as benthic foraminiferal assemblages, differ from other sections by higher abundances of detritivores and suspension feeders, confirming the environment to be rich in organic detritus and suspended organic particles. Holcová and Demeny (2012) interpreted the bay to be influenced by seasonal phytodetritus supply connected with the bloom of opportunistic taxa. However, the almost total absence of brackish and estuarine elements, and the presence of occasional brachiopods, confirm that the terrigenous input did not decrease salinity, because brackish-water biota have not been recorded either by autochthonous or allochthonous taxa. The situation in the upper part of the water column is very well comparable with that of the "Rousínov Ridge": planktonic foraminifera are rare and very likely have been transported by superficial currents from the central part of the basin. More abundant and probably autochthonous planktonic foraminifera were recorded in sample KRA8 with its higher oxygen isotope values; this may indicate a decrease of temperature and/or increase in salinity. Since a lower temperature in the upper part of the water column is less likely, a higher rate of evaporation in the marginal part of the basin is preferred. Higher variations in benthic isotope values may have been caused be greater seasonal differences. The occurrence of *Thoracospharea* spp. indicates oligotrophic waters and, together with different oxygen isotope values for plankton and benthos, also indicates at least a seasonal termohaline stratification of the water column.
2. Limestones from the Židlochovice site were deposited, as at Kralice, during a sea-level lowstand (of fourth or lower order; Doláková et al. 2014). Similar to Kralice, the mixing of elements of the deeper infralittoral and shallow sublittoral, or on rare occasions, even with elements of an exposed rocky coastline, indicates relatively high water energy; the almost total absence of brackish and estuarine elements confirms that even at the eastern coast of the Carpathian Foredeep brackish biota did not exist or were rare.

   Foraminiferal assemblages from Židlochovice differ in their higher abundance of detritivores: infaunal *Bolivina dilatata* and markers of terrigenous input, *Globocassidulina* spp. and *Cassidulina* spp. The appearance of *Turborotalita quinqueloba* indicates non-stratified and the most eutrophic waters in comparison with other areas of limestone deposition studied.

   Variable isotope values may be explained by the allochthony of some limestones. The isotope values from thin limestone bodies correspond to values from siliciclastic intercalations in the "Rousínov Ridge"; therefore, an allochtonous origin of material is expected. Deposition of allochthonous limestones may be connected with comparable catastrophic climatic events, as assumed for deposition of the siliciclastic intercalations.
3. The "Rousínov Ridge" limestones were deposited during the whole fourth or lower order transgressive-regressive cycle (Zágoršek and Holcová 2005). Various environments at the "Rousínov Ridge" can be interpreted mainly from microfacial differences that show the decisive role of hydrodynamic conditions in the differentiation of the limestone bodies. The Kroužek section is characterized by more lithoclasts, molluscs, a diverse assemblage of coralline algae and sparite, suggesting a more dynamic and shallower paleoenvironment with a higher input of lithoclasts in comparison with Podbřežice, where a deeper and sheltered environment existed. Also, a higher abundance of the opportunist *Cibicidoides* sp. and of euryhaline foraminiferal species indicate more stress and an unstable near-shore environment with salinity fluctuations in the Kroužek section in comparison with Podbřežice. Molluscs from Kroužek differ from other sections in that bivalves are dominant and gastropods occur only sporadically. This dissimilarity can be explained both by primary differences in the molluscan assemblages, and probably also by a certain degree of sorting of shells. The primary differences are probably related to water energy, depth and substrate types. Specific conditions of the Podbřežice sections indicate a facies with pedunculate bryozoans and a high amount of micrite, recorded for the first time from the Central Paratethys. Hageman et al. (2000) interpreted the paleoecological differences between rhodolith and rhodolith–bryozoan accumulations and assumed that bryozoans and a higher abundance of micrite indicate a deeper and colder environment, which is supported by microfacies and foraminiferal data. The statistically significant (Kruskal–Wallis test) increase in the carbon isotope composition in Kroužek may also have been caused by higher evaporation.

To summarize the individual interpretations, the paleobiological, microfacies and sedimentological differences in the individual carbonate bodies reflect variations in the intensity of terrigenous input (higher in

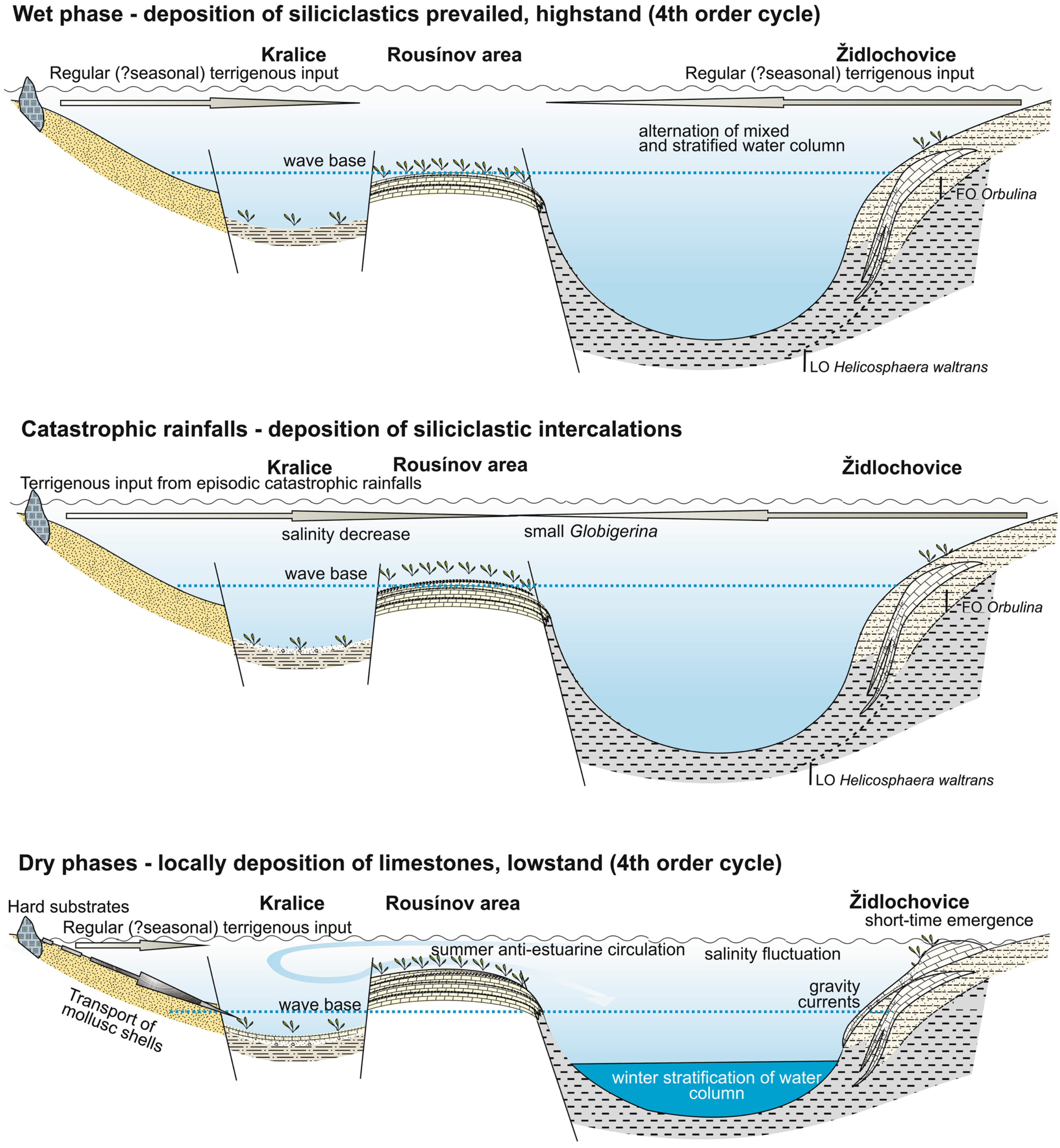


Fig. 13 Paleoenvironmental model of the carbonate production event

Kralice and Židlochovice; lower on the “Rousínov Ridge”), the environmental dynamics, depth (above and below wave base) and morphology of the sea floor, which was predisposed to gravity flows. These flows are thought to occur mainly in the Židlochovice area, where the majority of limestones most likely consist of allochthonous components.

Genesis of siliciclastic intercalations within the limestones

Thin (cm-thick) siliciclastic intercalations were recorded in the limestones bodies of the “Rousínov Ridge.” They occur at irregular distances, from tens of centimetres to two metres. The temporal frequency of these intercalations is hard to estimate due to the unknown depositional rate.

Generally, the sedimentation rate of comparable types of carbonates is high, but diagenetic compaction may substantially decrease the thickness. However, an occurrence every few hundred years is likely.

A high abundance of *Ammonia* sp. in these intercalations (Fig. 6) accompanied by a low abundance of infauna suggest a decrease in salinity during their deposition. A higher abundance of *Reticulofenestra minuta* and higher BFOI indicate stress conditions. In Podbřežice, an increase in the abundance of the suspension-feeder *Lobatula lobatula* (Murray 2006) and detritivorous infaunal species, as well as of plankton, both primary producers (nannoplakton) and consumers (planktonic foraminifera) and, particularly of small-sized *Globigerina* spp. (Zágoršek and Holcová 2005), indicate a high level of nutrients in suspension. In the Kroužek section situated nearer to the coastline, siliciclastic intercalations are more numerous and of a greater thickness. Both oxygen and carbon isotope values are statistically significantly lower in the intercalations in this section (Fig. 12a). All these observations could indicate that siliciclastic intercalations were deposited during high episodic input of terrigenous material with nutrients connected to the input of freshwater. This may correspond with "extreme climate events" deduced from the strongly negative excursions in δ^{18}O and δ^{13}C in the *Ostrea* isotope archive (Harzhauser et al. 2011). The expected frequency of siliciclastic intercalations of about several hundreds of years corresponds with the assumed frequency of catastrophic storm and rainfall events. As mentioned above, deposition of the thin allochthonous limestone bodies at the western coastline near Židlochovice may be related to comparable catastrophic climatic events as the deposition of siliciclastic intercalations.

Comparable intercalations have been described in the Eastern Alpian Foredeep (Mandic 2004). Similar to our interpretations, the disappearance of plankton, the decrease of benthic foraminifera diversity and the dominance of opportunistic *Cibicidoides* and euryhaline *Elphidium* in these intercalations may have been caused by a salinity decrease due to freshwater input.

Based on the paleoenvironmental interpretation presented above, a paleoenvironmental model of a carbonate production event has been compiled in Fig. 13.

Conclusions

1. A carbonate production event in the Central Paratethys, connected with deposition of a siliciclastic-carbonate unit in the marginal part of the basin, can be correlated with the culmination of transgression in the NN5 Zone. The event was caused by a decrease of terrigenous input due to the high-stand conditions and, above all, aridification. Aridification preceded the Middle Miocene Climate Transition. The event can also be correlated with the increase of seasonality that emphasized the cyclical character of the siliciclastic-carbonate unit. An increase of environmental instability led to small carbonate bodies with a high percentage of siliciclastic components, indicating only short-term and spatially restricted conditions conducive to carbonate production.
2. Orbitally-forced cyclicity caused the alternating deposition of carbonates and siliciclastics. The production of carbonates was connected with dry periods that caused a decrease of nutrient input from the continent, oligotrophic conditions and the expansion of seagrass meadows. The postulated seasonality probably led to downwelling circulations with mixed warm oligotrophic water masses in summer and a well-stratified water column in winter. In the upper layer of the water column, salinity fluctuations occurred. Siliciclastics were deposited during a wet period with a concomitant increase of nutrient input from the continent.
3. Carbonate bodies were deposited in various positions within a paleodepth of the first tens of metres, whereby accumulation of allochthonous carbonate material cannot be excluded. They correlate with lowstand conditions. Exceptionally, larger limestone bodies were deposited under transgressive, highstand and lowstand conditions. Differences in the individual carbonate bodies reflect variations in the intensity of terrigenous input, the dynamics of the environment, the depth (above and below the fair-weather wave-base) and the morphology of the sea-floor.
4. Siliciclastic intercalations in the limestone bodies represent catastrophic rainfall events that transported a higher amount of terrigenous material to the basin, including phytodetritus, which represents a food source for suspension-feeders. The input of freshwater is responsible for a decrease in salinity.

Acknowledgments This research was supported by grant nos. PRVOUK P44 and GAČR 205/09/0103. We are grateful to Mrs. Sarka Rousava for correction of the English language. The constructive reviews of Natália Hudáčková (Comenius University in Bratislava, Slovakia) and of an anonymous reviewer substantially improved the manuscript.

References

Abdul Aziz HA, Di Stefano LM, Foresi FJ, Hilgen SM, Iaccarino KF, Kuiper F, Lirer G, Salvatorini A, Turco E (2008) Integrated stratigraphy and 40Ar/39Ar chronology of early Middle Miocene sediments from DSDP Leg 42A, Site 372 (Western Mediterranean). Palaeogeogr Palaeoclimatol Palaeoecol 257:123–138

Báldi K (2006) Paleoceanography and climate of the Badenian (Middle Miocene, 16.4–13.0 Ma) in the Central Paratethys based on foraminifera and stable isotope (δ^{18}O and δ^{13}C) evidence. Int J Earth Sci (Geol Rund) 95:119–142

Baráth I, Nagy A, Kováč M (1994) Sandberské vrstvy-vrchnobádenské marginálne sedimenty východného okraja Viedenskej panvy. Geol Práce Spr 99:59–66

Basso D, Vrsaljko D, Grgasovic T (2008) The coralline flora of Miocene maërl: the Croatian „Litavac". Geol Croat 61:333–340

Berggren WA, Kent DV, Swisher III.CC, Aubry M-P (1995) A revised Cenozoic geochronology and chronostratigraphy. In: Berggren WA, Kent DV, Hardenbol J (eds) Geochronology, time scale and global stratigraphic correlations: A unified temporal framework for an historical geology. Soc Econ Paleont Miner Spec Publ 54:129–212

Bicchi E, Ferrero E, Gonera M (2003) Palaeoclimatic interpretation based on Middle Miocene planktonic Foraminifera: the Silesia Basin (Paratethys) and Monferrato (Tethys) records. Palaeogeogr Palaeoclimatol Palaeoecol 196:265–303

Braga JC, Bosence DWJ, Steneck RS (1993) New anatomical characters in fossil coralline algae and their taxonomic implications. Palaeontology 36:535–547

Brasier MD (1975) An outline history of seagrass communities. Palaeontology 18:681–702

Bruch AA, Utescher T, Mosbrugger V, NECLIME members (2010) Precipitation patterns in the Miocene of Central Europe and the development of continentality. Palaeogeogr Palaeoclimatol Palaeoecol 304:202–211

Brzobohatý R (1987) Contribution to paleogeography of the Miocene basins of the Central Paratethys from otolith fauna. Miscell Micropalaeont II/2, Knihovn zem plyn nafta 6b:101–111

Carannante G, Estban M, Milliman JD, Simone L (1988) Carbonate lithofacies as paleolatitude indicators: problems and interpretations. In: Nelson CS (ed) Non-tropical shelf carbonates—modern and ancient. Sediment Geol 60:333–346

Cicha I (2001) Náčrt stratigrafie středního miocénu v alpsko-karpatské předhlubni (Dolní Rakousko, Morava). Scripta Fac Sci Natur Univ Masaryk Brunen 30:23–26

Ćorić S, Harzhauser M, Hohenegger J, Mandic O, Pervesler P, Roetzel R, Rögl F, Scholger R, Spezzaferri S, Stingl K, Švábenická L, Zorn I, Zuschin M (2004) Stratigraphy and correlation of the Grund Formation in the Molasse Basin, northeastern Austria (Middle Miocene, Lower Badenian). Geol Carpath 55:207–215

Davies GR (1970) Carbonate bank sedimentation, Eastern Shark Bay, Western Australia. Am Assoc Petrol Geol Mem 13:85–16

Di Stefano A, Foresi LM, Lirer F, Iaccarino SM, Turco E, Amore FO, Morabito S, Salvatorini G, Mazzei R, Abdul Aziz H (2008) Calcareous plankton high resolution bio-magnetostratigraphy for the Langhian of the Mediterranean area. Riv Ital Paleont Stratigr 114:51–76

Doláková N, Brzobohatý R, Hladilová Š, Nehyba S (2008) The red-algal facies of the Lower Badenian limestones of the Carpathian Foredeep in Moravia (Czech Republic). Geol Carpath 59:133–146

Doláková N, Kováčová M, Basistová P (2011) Badenian (Langhian–Early Serravallian) palynoflora from the Carpathian Foredeep and Vienna Basin (Czech and Slovak Republics). Acta Mus Natur Pragae, Ser B: Hist Nat 67:51–59

Doláková N, Holcová K, Nehyba S, Hladilová Š, Brzobohatý R, Zágoršek K, Hrabovský J, Seko M, Utescher T (2014) The Badenian parastratotype at Židlochovice from the perspective of high resolution stratigraphy. N Jb Geol Paläont 271:169–201

Dunham RJ (1962) Classification of carbonate rocks according to depositional texture. In: Hamm WE (ed) Classification of carbonate rocks, a symposium. Amer Ass Petrol Geol, Tulsa, OK, pp 108–171

Filipescu S, Gîrbacea R (1997) Lower Badenian sea-level drop on the western border of the Transylvanian Basin: foraminiferal palaeobathymetry and stratigraphy. Geol Carpath 48:325–334

Flores JA, Sierro FS, Francés G, Vasquez A, Zamarreno I (1997) The last 100,000 years in the western Mediterranean: Sea surface water and frontal dynamics as revealed by coccolithophores. Mar Micropaleont 29:351–366

Flügel E (2004) Microfacies of carbonate rocks. Analysis, interpretation and application. Springer, Berlin, Heidelberg, New York

Gorka M, Studencka B, Jasionowski M, Hara U, Wysoka A, Poberzhskyy A (2012) The Medobory Hills (Ukraine): Middle Miocene reef systems in the Paratethys, their biological diversity and lithofacies. Biul Panstwow Inst Geol 449:147–174

Gradstein FM, Ogg JG, Schmitz MD, Ogg GM (2012) The geologic time scale 2012. vol 2, Elsevier, New York

Hageman SJ, James NP, Bone Y (2000) Cool-water carbonate production from epizoic bryozoans on ephemeral substrates. Palaios 15:33–48

Hammer Ø, Harper DAT, Ryan PD (2001) PAST: Paleontological statistics software package for education and data analysis. Palaeont Electron 4(1):1–9

Harzhauser M, Piller WE, Müllegger S, Grunert P, Michels A (2011) Changing seasonality patterns in central Europe from Miocene Climate Optimum to Miocene Climate Transition deduced from the *Crassostrea* isotope archive. Glob Planet Change 76:77–84

Hemleben C, Spindler M, Anderson OR (1989) Modern planktonic foraminifera. Springer, New York

Heusser LE (1978) Spores and pollen in the marine realm. In: Haq BU, Boersma A (eds) Introduction to marine micropaleontology, 1st edn. Elsevier, New York, pp 327–339

Hladilová Š (1984) A contribution to the knowledge of the variability of the species *Ancilla (Baryspira) glandiformis* (Lamarck, 1810) (Mollusca: Gastropoda). Scr Fac Sci Natur Univ Masaryk Brunen 14:239–260

Hladilová Š, Zdražílková N (1989) Paleontologické lokality karpatské předhlubně na Moravě. Přírodovědecká fakulta Jana Evangelisty Purkyně, Brno

Hladilová Š, Nehyba S, Doláková N, Hladíková J (1999) Comparison of some relics of Miocene sediments on the eastern margin of the Bohemian Massif. Geol Carpath 50:31–33

Hohenegger J, Yordanova E, Nakano Y, Tatzreiter F (1999) Habitats of larger foraminifera on the upper reef slope of Sesoko Island, Okinawa, Japan. Mar Micropaleont 36:109–168

Hohenegger J, Andersen N, Báldi K, Ćorić S, Pervesler P, Rupp C, Wagreich M (2008) Paleoenvironment of the Early Badenian (Middle Miocene) in the southern Vienna Basin (Austria)—multivariate analysis of the Baden-Sooss section. Geol Carpath 59:461–487

Hohenegger J, Ćorić S, Khatun M, Pervesler P, Rögl F, Rupp C, Selge A, Uchman A, Wagreich M (2009) Cyclostratigraphic dating in the Lower Badenian (Middle Miocene) of the Vienna Basin (Austria)—the Baden-Sooss core. Int J Earth Sci 98:915–930

Hohenegger J, Ćorić S, Wagreich M (2014) Timing of the regional Badenian Stage (Middle Miocene, Central Paratethys). Geol Carpath 65:55–66

Holbourn AE, Kuhnt W, Schulz M, Erlenkeuser H (2005) Impacts of orbital forcing and atmospheric CO_2 on Miocene ice-sheet expansion. Nature 438:483–487

Holcová K, Demeny A (2012) The oxygen and carbon isotopic composition of foramiferal tests like paleoecological proxy in the marginal part of the epicontinental sea (example from the early Badenian (=Langhian) of the Central Paratethys). Geol Carpath 63:121–137

Holcová K, Zágoršek K (2008) Bryozoa, foraminifera and calcareous nannoplankton as environmental proxies of the "bryozoan event" in the Middle Miocene of the Central Paratethys (Czech Republic). Palaeogeogr Palaeoclimatol Palaeoecol 267:216–234

Höll C, Zonneveld KAF, Willems H (1998) On the ecology of calcareous dinoflagellates: the Quaternary eastern equatorial Atlantic. Mar Micropaleont 33:1–25

Hrabovský J, Basso D, Doláková N (2015) Diagnostic characters in fossil coralline red algae (Corallinales, Sporolithales, Rhodophyta) from the Lower Badenian (Early Langhian) of Židlochovice, Podbřežice and Kroužek (Carpathian Foredeep, Czech Republic). J System Palaeont (in press)

Hüsing SK, Cascella A, Hilgen FJ, Krijgsman W, Kuiper KF, Turco E, Winson D (2010) Astrochronology of the Mediterranean Langhian between 15.29 and 14.17 Ma. Earth Planet Sci Lett 290:254–269

James NP (1997) The cool-water carbonate depositional realm. In: James NP, Clarke AD (eds) Cool-water carbonates. SEPM SpecPubl 56:1–20

Kaiho K (1994) Benthic foraminiferal dissolved-oxygen index and dissolved oxygen levels in the modern ocean. Geology 22:719–722

Kameo K (2002) Late Pliocene Caribbean surface water dynamics and climatic changes based on calcareous nannofossil records. Palaeogeogr Palaeoclimatol Palaeoecol 179:211–226

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

Kováčová M, Doláková N, Kováč M (2011) Miocene vegetation pattern and climate change in the northwestern central Paratethys domain (Czech and Slovak Republic). Geol Carpath 62:251–266

Kroeger KF, Reuter M, Brachert TC (2006) Palaeoenvironmental reconstruction based on non-geniculate coralline red algal assemblages in Miocene limestone of central Crete. Facies 52:381–409

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

Kysela J (1988) Mikrofácie, typy porozity litavských vápencov a vrchnotriasových dolomitov podložia viedenskej pánvy. Záp Karpaty sér Geol 13:9–142

Mader D, Cleaveland L, Bice D, Montanari A, Koeberl C (2004) High-resolution cyclostratigraphic analysis of multiple climate proxies from a short Langhian pelagic succession in the Conero Riviera, Ancona (Italy). Palaeogeogr Palaeoclimatol Palaeoecol 211:325–344

Mai HD (1981) Entwicklung und klimatische Differenzierung der Laubwaldflora Mitteleuropas im Tertiär. Flora 171:525–582

Mai HD (1991) Palaeofloristic changes in Europe and the confirmation of the Arctotertiary-Palaeotropical concept. Rev Palaeobot Palynol 68:29–36

Mandic O (2004) Foraminiferal paleoecology of a submarine swell—the Lower Badenian (Middle Miocene) of the Mailberg Formation at the Buchberg in the Eastern Alpine Foredeep: initial report. Ann Naturhist Mus Wien 105A:161–174

Martinuš M, Fio K, Pikelj K, Aščic Š (2012) Middle Miocene warm-temperate carbonates of Central Paratethys (Mt. Zrinska Gora, Croatia): paleoenvironmental reconstruction based on bryozoans, coralline red algae, foraminifera, and calcareous nannoplankton. Facies 59:481–504

Moissette P, Dulai A, Escarguel G, Kázmér M, Müller P, Saint Martin JP (2007) Mosaic of environments recorded by bryozoan faunas from the Middle Miocene of Hungary. Palaeogeogr Palaeoclimatol Palaeoecol 252:530–556

Mount J (1985) Mixed siliciclastic and carbonate sediments: a proposed first-order textural and compositional classification. Sedimentology 32:435–442

Murray JW (2006) Ecology and applications of benthic Foraminifera. Cambridge University Press, Cambridge

Nebelsick JH (1989) Temperate water carbonate facies of the Early Miocene Paratethys (Zogelsdorf Formation, Lower Austria). Facies 21:11–40

Nehyba S, Šikula J (2007) Depositional architecture, sequence stratigraphy and geodynamic development of the Carpathian Foredeep (Czech Republic). Geol Carpath 58:53–69

Nehyba S, Doláková N, Hladilová Š, Petrová P (2008a) Carpathian Foredeep – western part (Czech Republic). In: McCann T (ed) The geology of central Europe, vol 2. Paleogene and Neogene, 1st edn. The Geological Society, London, pp 1081–1083

Nehyba S, Zágoršek K, Holcová K (2008b) Stable isotope composition of bryozoan skeletons from Podbřežice (Middle Miocene, Central Paratethys, South Moravia, Czech Republic). In: Hageman SJ, Key M, Winston JE (eds) Bryozoan studies 2007. Proceedings of the 14th International Bryozoology Association Conference, Boon, North Carolina. Virginia Mus Nat Hist Spec Publ 15:163–175

Nemec W (1990) Aspects of sediment movement on steep delta slopes. In: Colella A, Prior DB (eds) Coarse-grained deltas. Int Assoc Sediment Spec Publ 10:29–73

Oszczypko N (1998) The Western Carpathian Foredeep—Development of the foreland basin in front of the accretionary wedge and its burial history (Poland). Geol Carpath 49:415–431

Papp A, Cicha I, Seneš J, Steininger F (1978) M-4 Badenien (Moravien, Wielicien, Kosovien). Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys VI, VEDA, Bratislava

Pérez-Folgado M, Sierro FJ, Flores JA, Cacho I, Grimalt JO, Zahn R, Shackleton NJ (2003) Western Mediterranean planktonic foraminifera events and millennial climatic variability during the last 70 kyr. Mar Micropaleont 48:49–70

Pezelj Đ, Mandic O, Ćoric S (2013) Paleoenvironmental dynamics in the southern Pannonian Basin during initial Middle Miocene marine flooding. Geol Carpath 64:81–100

Piller WE, Harzhauser M, Mandic O (2007) Miocene Central Paratethys stratigraphy—current status and future directions. Stratigraphy 4:151–168

Pisera A, Studencki W (1989) Middle Miocene rhodoliths from the Korytnica Basin (Southern Poland): environmental significance and paleontology. Acta Palaeont Polon 34:179–209

Popov SV, Rögl F, Rozanov AY, Steininger FF, Shcherba IG, Kováč M (2004) Lithological-paleogeographic maps of Paratethys. 10 Maps Late Eocene to Pliocene. Cour Forsch-Inst Senckenberg 250:1–46

Pouyet S, Tarkowski R (1998) Les bryozoaires Cheilostomes du Miocene d'Olimpow (Pologne, Paratéthys Centrale). Geobios 31:39–45

Radwański A, Górka M, Wysocka A (2006) Middle Miocene coralgal facies at Maksymivka near Ternopil (Ukraine): A preliminary account. Acta Geol Polon 56:89–103

Randazzo AF, Müller P, Lelkes G, Juhász E, Hámor T (1999) Cool-water limestones of the Pannonian basinal system, Middle Miocene, Hungary. J Sediment Res 69:283–293

Reynolds L, Thunell RC (1985) Seasonal succession of planktonic foraminifera in the subpolar North Pacific. J Foram Res 15:282–301

Riegl B, Piller WE (2000) Biostromal coral facies—a Miocene example from the Leitha Limestone (Austria) and its actualistic interpretation. Palaios 15:399–413

Rögl F (1999) Mediterranean and Paratethys. Facts and hypotheses of an Oligocene to Miocene paleogeography (short overview). Geol Carpath 50:339–349

Schaleková A (1973) Vrchnobádenské Corallinaceae z lomu Rohožník-Vajar na západním úpatí Malých Karpát. Acta geol geogr Univ Comeniae 26:211–221

Sláma P (1983) Lower Badenian Radiolaria in the Moravian part of the Carpathian foredeep. Knihovn Zem Plyn Nafta 4:145–170

Stuchlik L (1994) Neogene Pollen Flora of Central Europe. Part 1. Acta Palaeobot, Suppl 1:1–56

Studencki W (1999) Red-algal limestones in the Middle Miocene of the Carpathian Foredeep in Poland: facies variability and palaeoclimatic implications. Geol Quart 43:395–404

Šob A (1940) Geologické poměry v jihozápadní části Vyškovského úvalu. Zpr Geol Úst Čechy Moravu 16:73–95

Švábenická L (2002) Calcareous nannofossils of the Upper Karpatian and Lower Badenian deposits in the Carpathian Foredeep, Moravia (Czech Republic). Geol Carpath 53:197–210

Tomanová Petrová P, Švábenická L (2007) Biostratigraphy and paleoecology of the Middle Miocene sediments in the Carpathian Foredeep, Czech Republic. Geol Carpath 58:333–352

Vass D, Elečko M, Konečný V (2007) Geology of Lučenská kotlina depression and Cerová vrchovina upland. Štát Geol Úst Dion Štúra, Bratislava

Vink A, Brune A, Höll Ch, Zonneveld KAF, Willems H (2002) On the response of calcareous dinoflagellates to oligotrophy and stratification of the upper water column in the equatorial Atlantic Ocean. Palaeogeogr Palaeoclimatol Palaeoecol 178:53–66

Wade BS, Bown PR (2006) Calcareous nannofossils in extreme environments: The Messinian Salinity Crisis, Polemi Basin, Cyprus. Palaeogeogr Palaeoclimatol Palaeoecol 233:271–286

Wells P, Okada H (1997) Response of nannoplankton to major changes in seasurface temperature and movements of hydrological fronts over site DSDP 594 (south Chatham Rise, southeastern New Zealand), during the last 130 kyr. Mar Micropalaeont 32:341–363

Wiedl T, Harzhauser M, Piller WE (2012) Facies and synsedimentary tectonics on a Badenian carbonate platform in the southern Vienna Basin (Austria, Central Paratethys). Facies 58:523–548

Woelkerling WJ (1988) The coralline red algae: An analysis of the genera and subfamilies of nongeniculate Corallinaceae. Oxford University Press, London, Oxford

Wright VP (1992) A revised classification of limestones. Sediment Geol 76:177–186

Zágoršek K, Holcová K (2005) A bryozoan and foraminifera association from the Miocene of Podbřežice, south Moravia (Czech Republic): an environmental history. In: Moyano HG, Cancino JM, Wyse Jackons PN (eds) Bryozoan studies 2004, Taylor & Francis, London, pp 383–396

Zágoršek K, Holcová K, Nehyba S, Kroh A, Hladilová Š (2009) The invertebrate fauna of the Middle Miocene (Lower Badenian) sediments of Kralice nad Oslavou (Central Paratethys, Moravian part of the Carpathian Foredeep). Bull Geosci 84:465–496

Zágoršek K, Holcová K, Třasoň T (2007) Bryozoan event from Middle Miocene (Early Badenian) lower neritic sediments from the locality Kralice nad Oslavou (Central Paratethys, Moravian part of the Carpathian Foredeep. Int J Earth Sci (Geol Rundsch) 97:835–850

Zágoršek K, Filipescu S, Holcová K (2010) New Middle Miocene Bryozoa from Garbova de Sus (Romania) and their relationship to the sedimentary environment. Geol Carpath 61:495–512

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

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

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

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

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

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

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

Introduction

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

Paleogeography

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

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

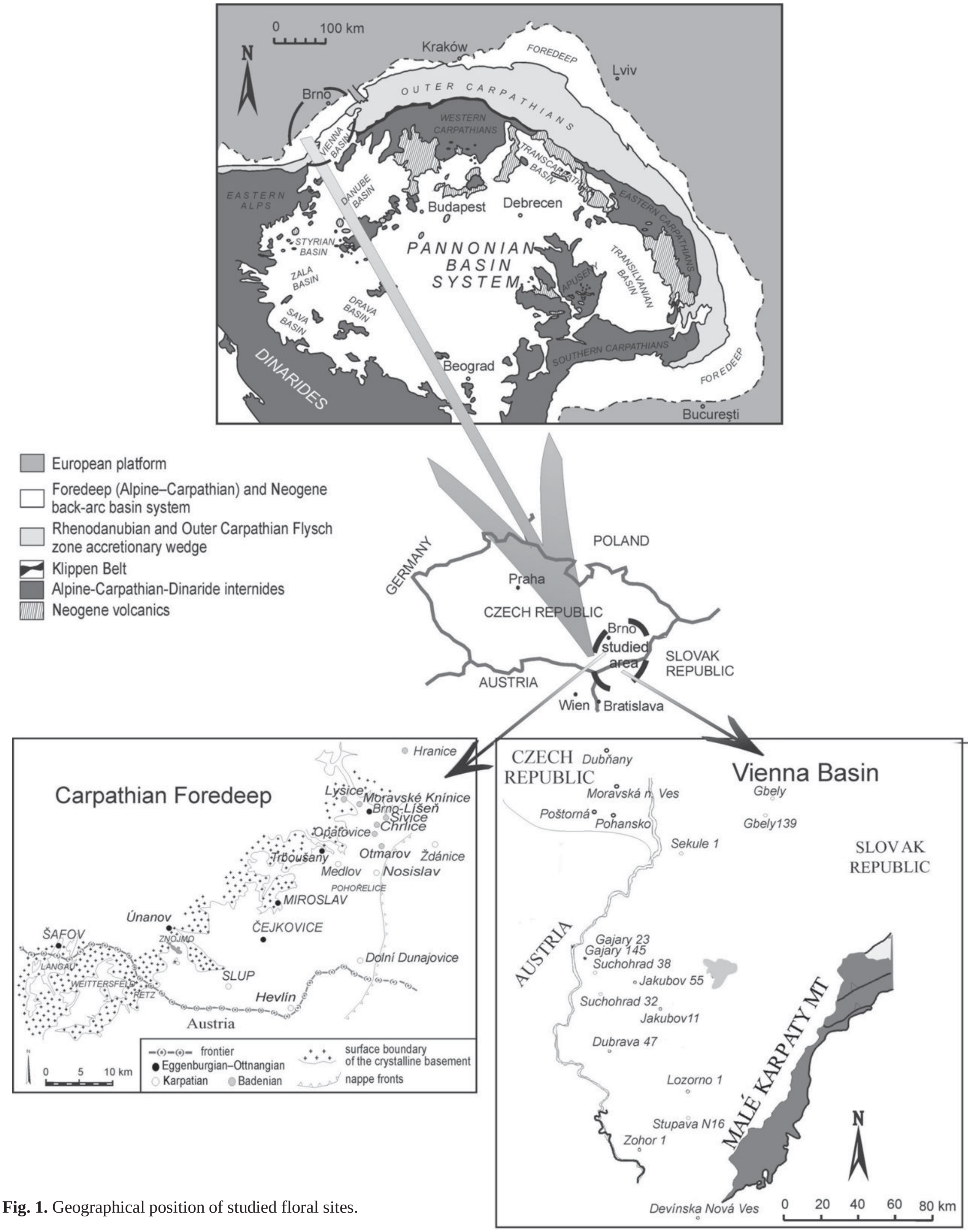


Fig. 1. Geographical position of studied floral sites.

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

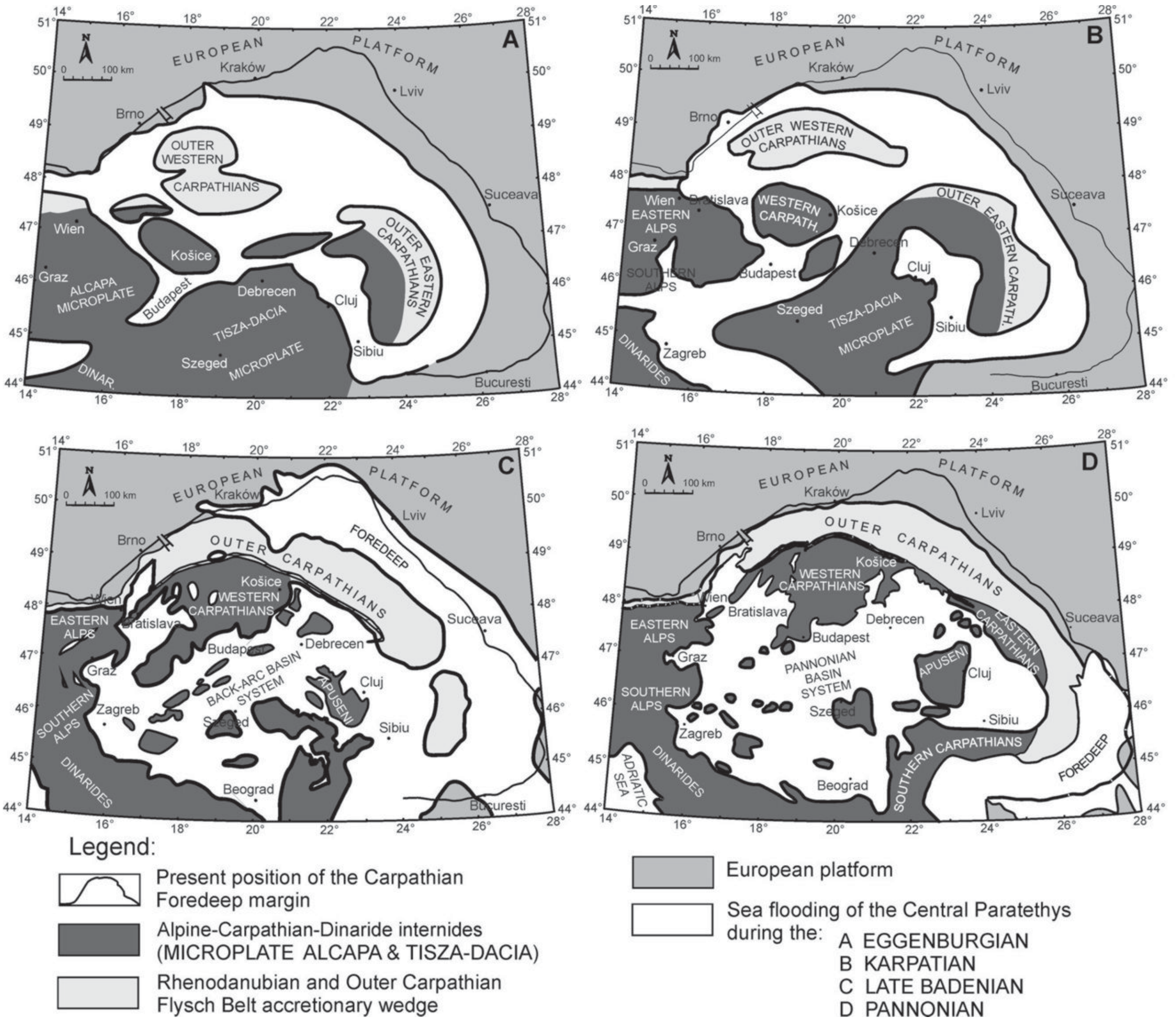


Fig. 2. Paleogeography of the Central Paratethys (according to Kováč 2000).

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

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

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

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

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

Material and methods

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

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

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

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

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

Results and discussion

Early Miocene

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

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

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

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

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

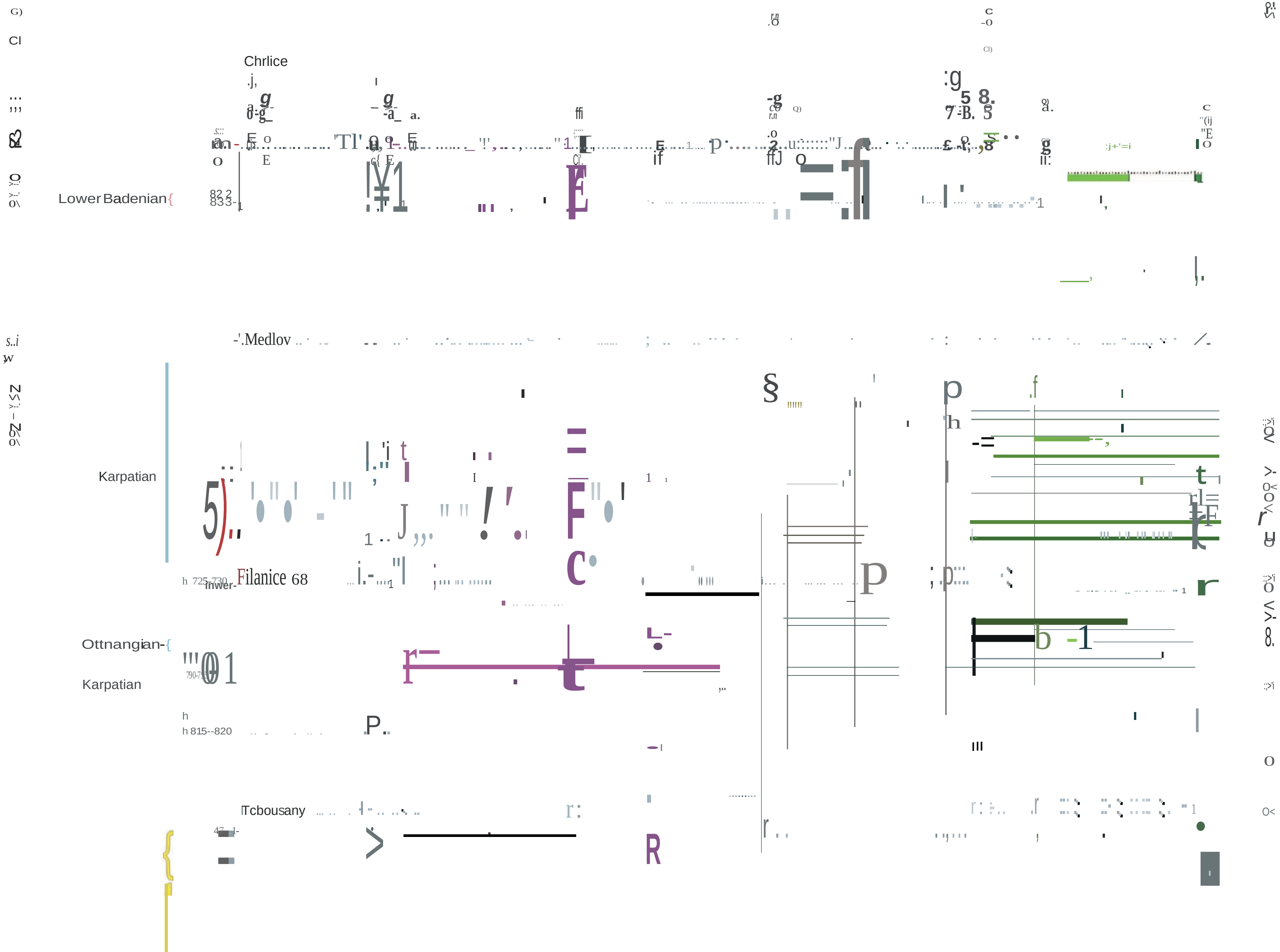
Marshy-palm forest with *Calamus*, Poaceae, *Lygodium*, *Sparganium*, *Potamogeton* and riparian forest with *Alnus*, *Ulmus*, Myricaceae, Lythraceae or *Selaginella* are frequent (Figs. 4, 8). The associations with Taxodiaceae, *Craigia* and Pteridaceae (up to 10 %) and Polypodiaceae document a well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

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

Middle Miocene

Badenian—Sarmatian (Langhian—Serravallian)

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


Chrlice
Lower Badenian
82 2
833-
-'.Medlov
Karpatian
h 725-730
lnwer-
Filanice 68
Ottnangian-
Karpatian
790-795
h
h 815--820
Tcbousany
47

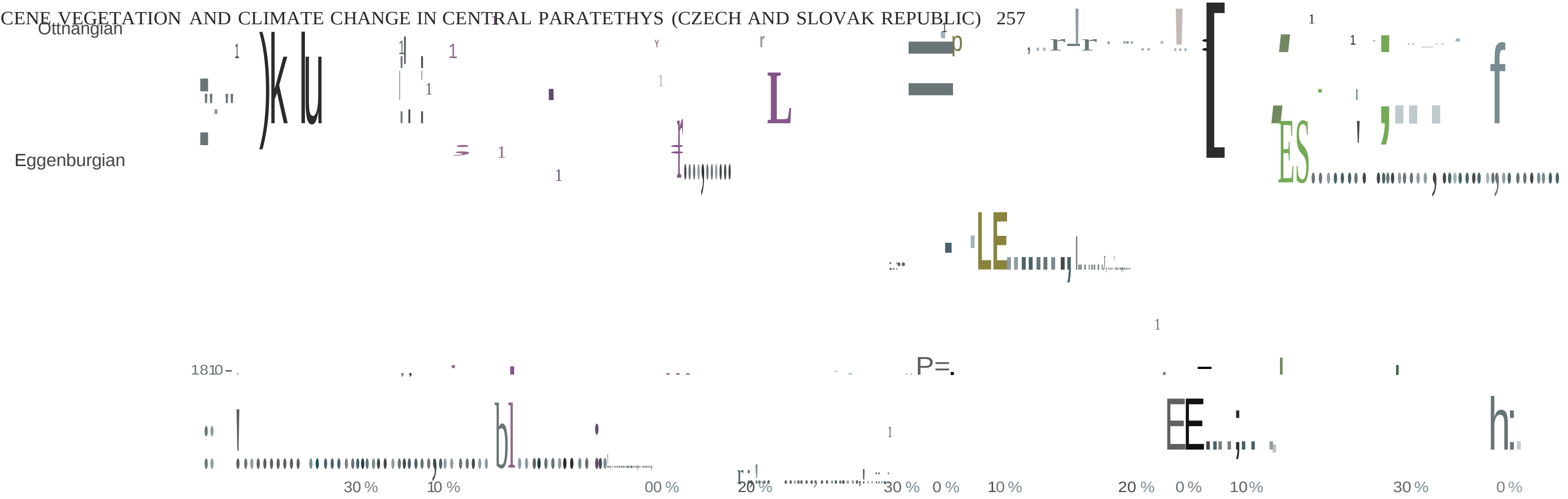


Fig. 3. Vegetation assemblage distribution during the Eggenburgian-Early Badenian time intervals.

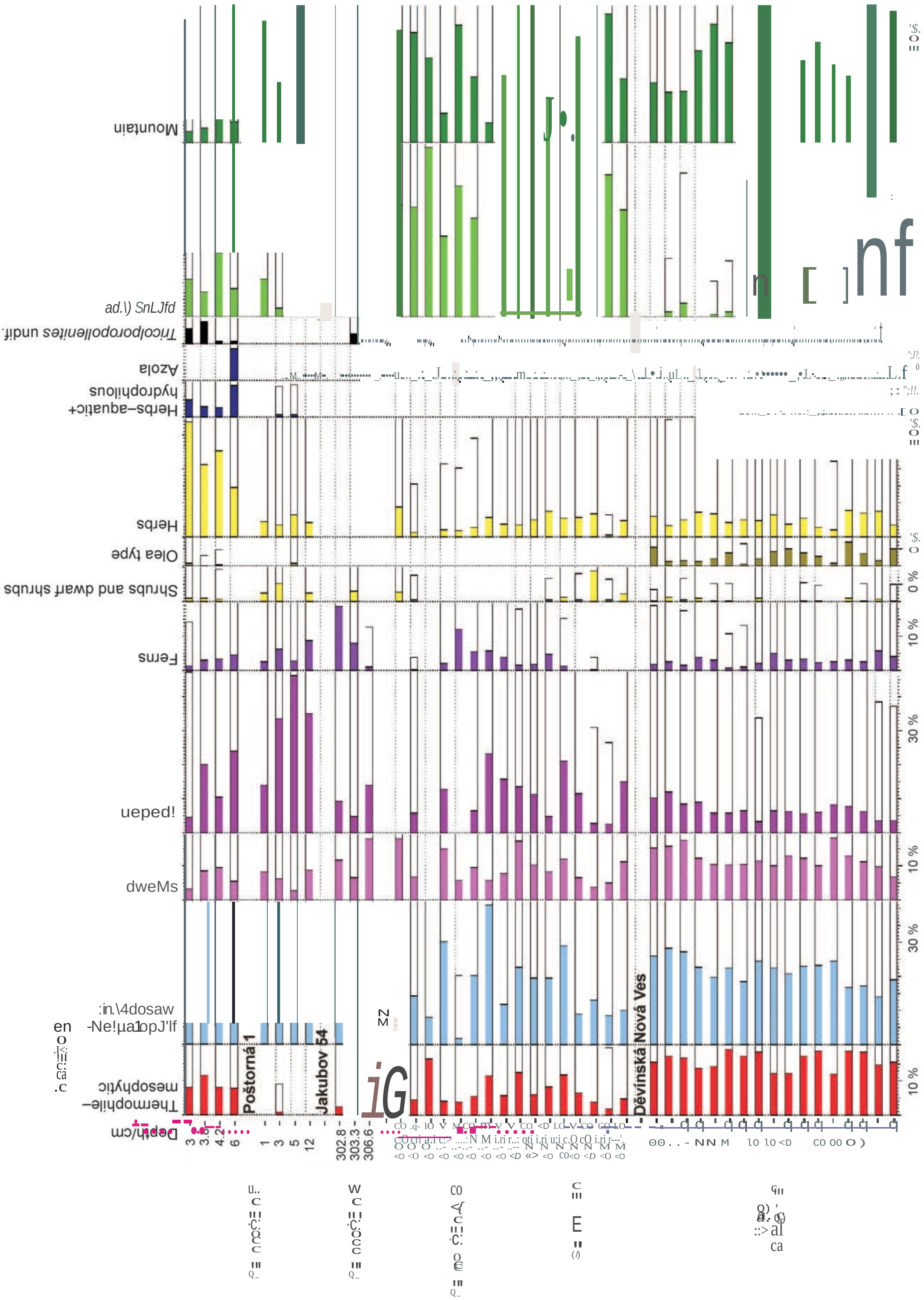


Fig. 4. Vegetation assemblage distribution during the Late Badenian–Pannonian time intervals.

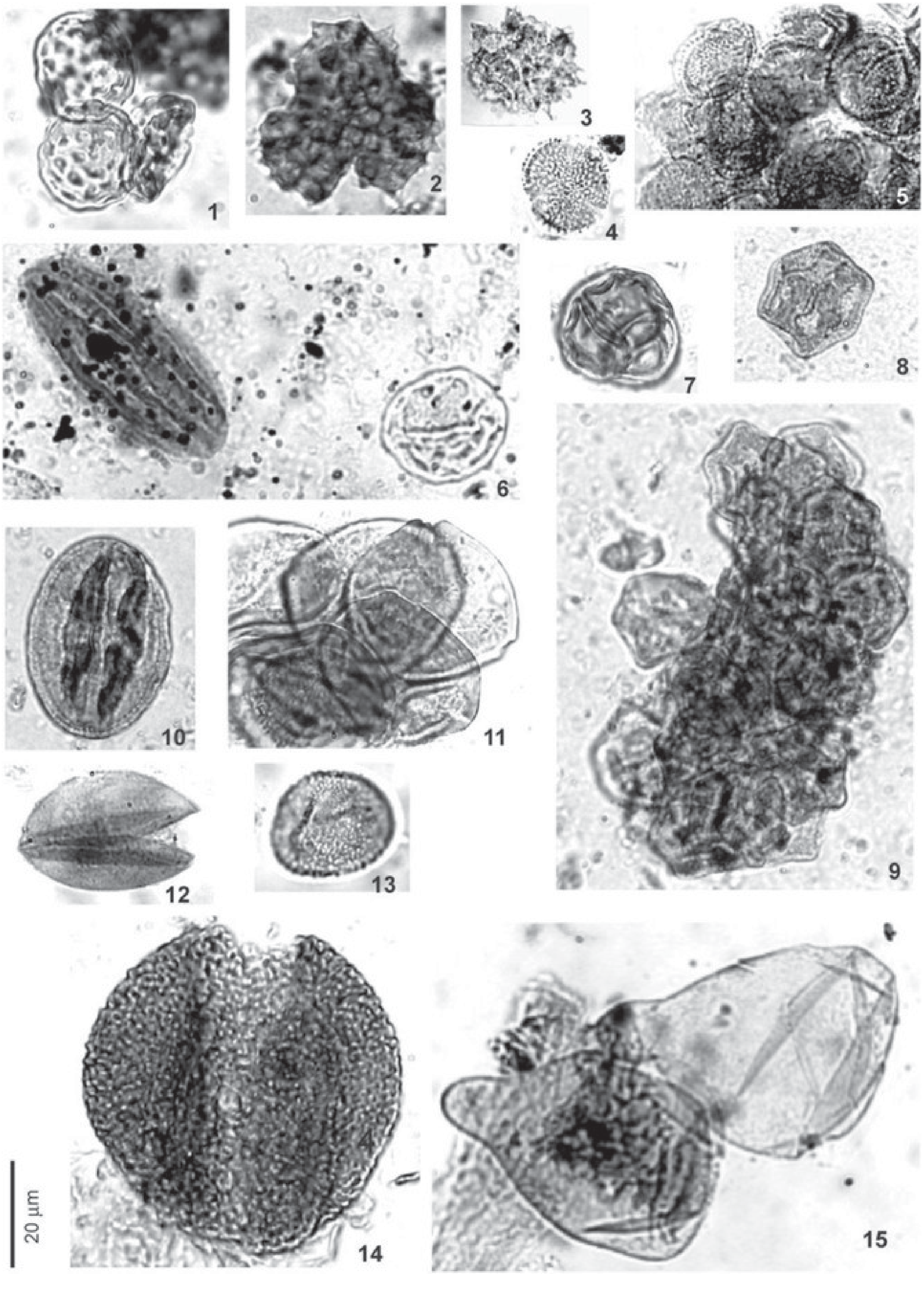


Fig. 5. Early Miocene sporomorphs from the studied area. **1** — Chenopodiaceae accumulation, **2** — Asteraceae—Asteroideae — *Tricolporopollenites grandis* Nagy, **3** — Asteraceae—Cichorioideae — *Cichoreacidites gracilis* Nagy, **4** — Oleaceae — (*Oleoidearumpollenites* sp.), **5** — Oleaceae accumulation,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

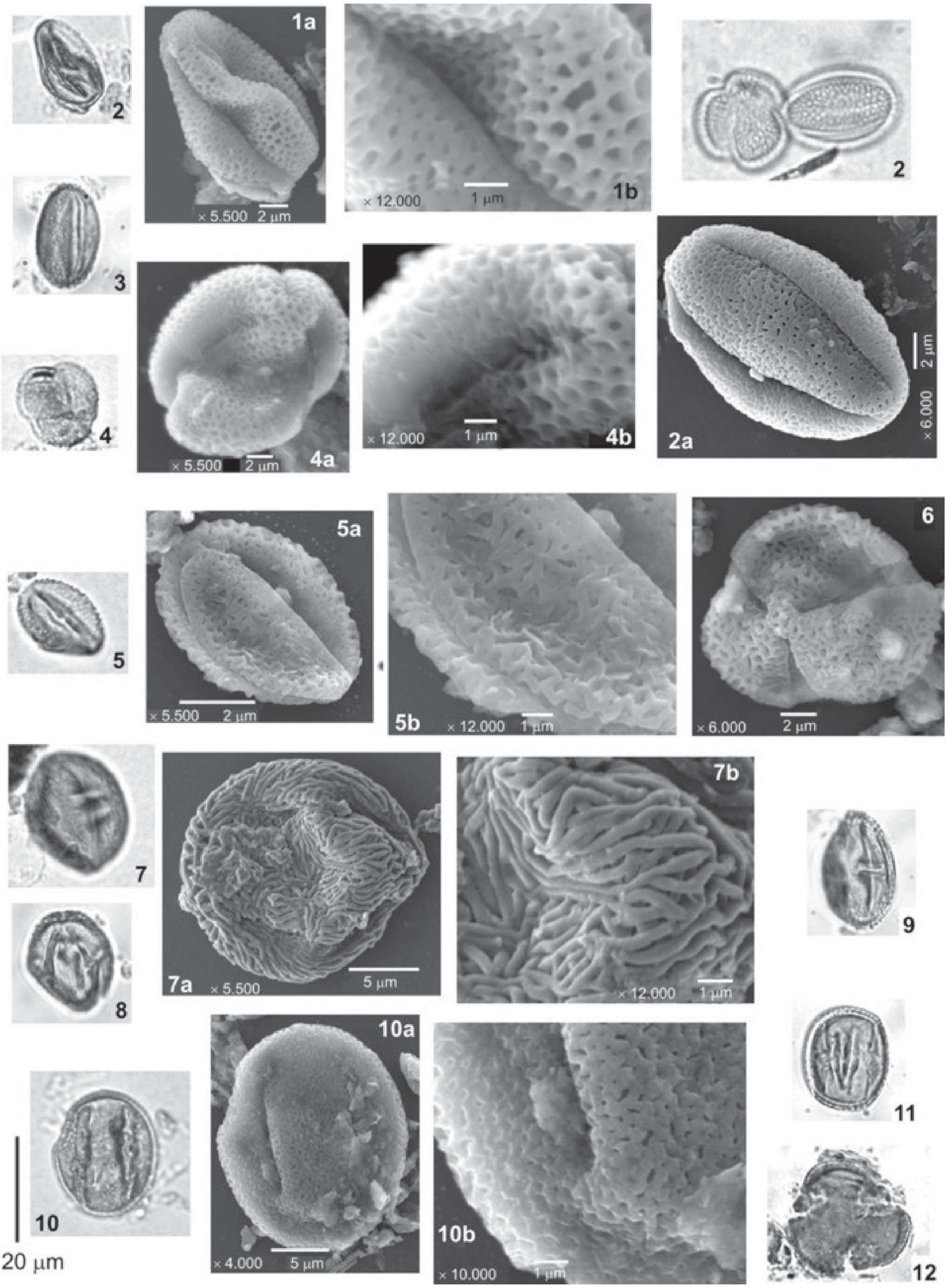


Fig. 6. Eggenburgian palynomorphs. **1a,b, 3, 4a,b** — *Tamarix* sp.; 1, 3, 4 — LM 1000ξ; 1a — SEM 5500ξ; 1b — SEM 12,000ξ; 4a — SEM 5500ξ; 4b — SEM 12,000ξ. **2** — *Tamarix gallica* — recent — LM 1000ξ; 2a — SEM 6000ξ. **5a,b, 6** — *Salix* sp.; 5 — LM 1000ξ; 5a — SEM 5000ξ; 5b — SEM 12,000ξ. **6**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

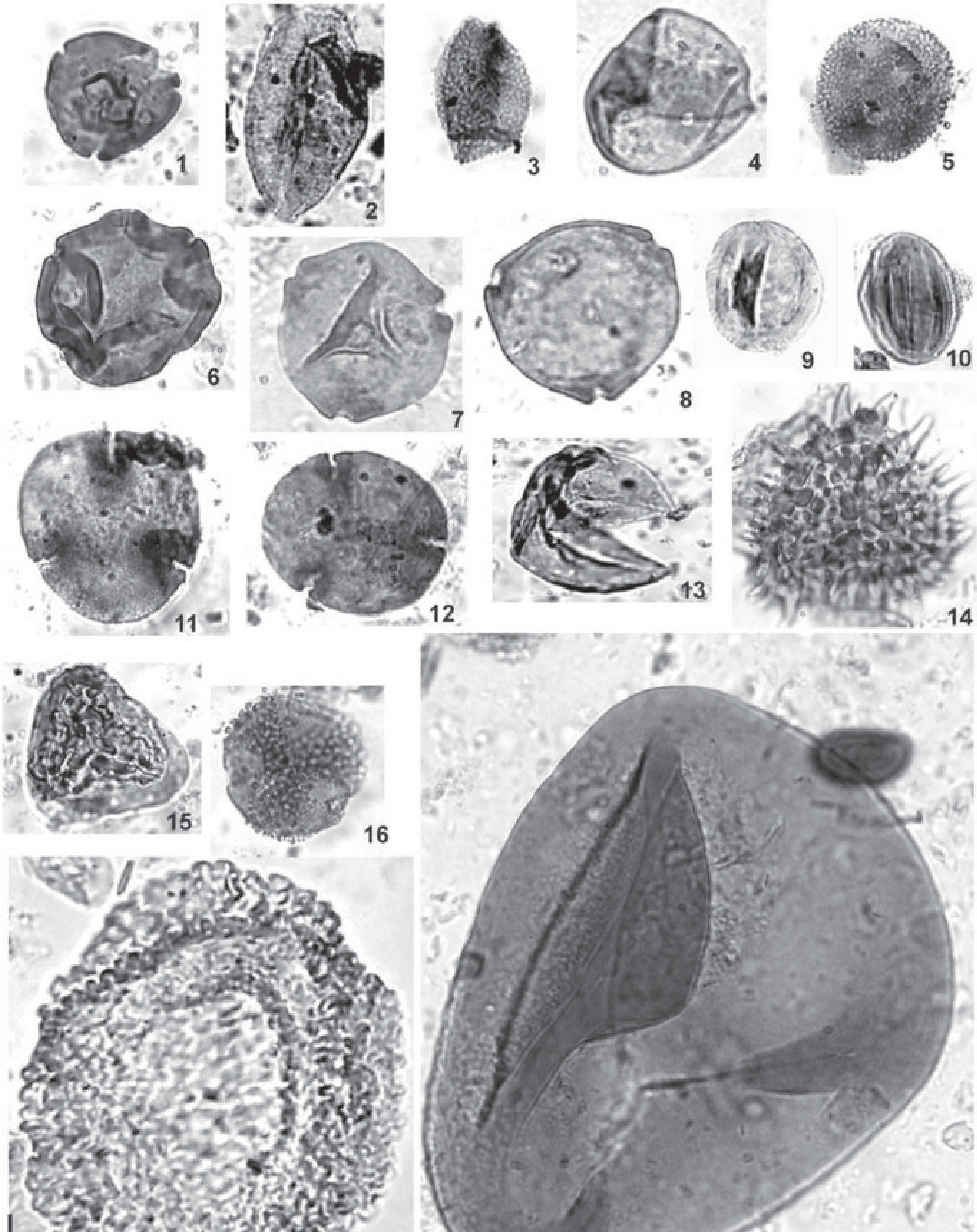


Fig. 7. Karpatian sporomorphs from the studied area. **1**—*Engelhardia* sp. with cavities after pyrite crystals; **2**—Palmae—*Monocolpopollenites tranquillus* (Potonié) Thomson & Pflug; **3**—Palmae—*Arecipites* sp.; **4**—Poaceae—*Graminidites* sp.; **5**—*Sparganium* sp.—(*Sparganiaceaepollenites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

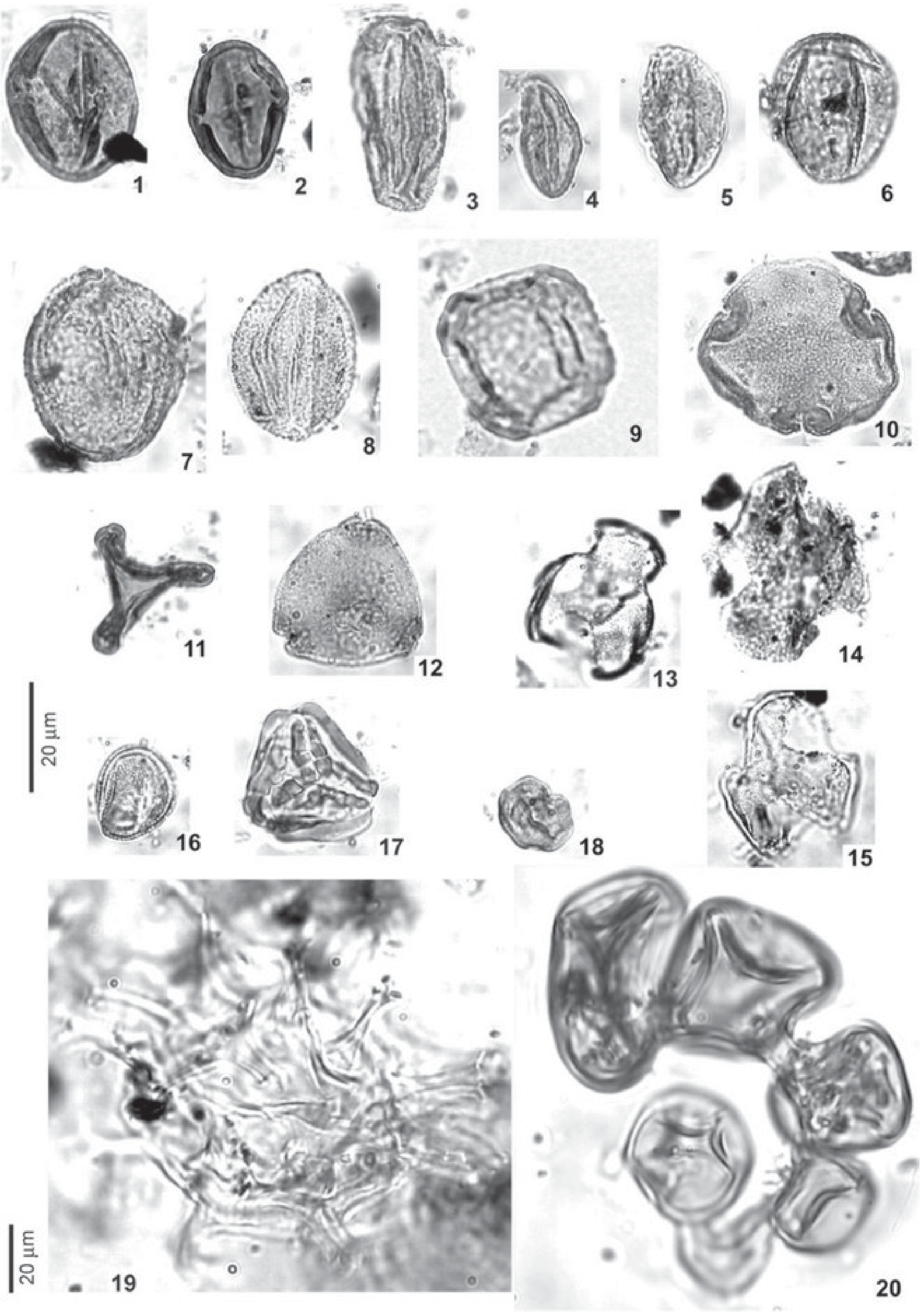


Fig. 8. Badenian sporomorphs from the studied area. **1**—*Mastixia* sp.—(*Tricolporopollenites satzvayensis* Pflug); **2**—Sapotaceae—(*Sapotaceoipollenites sapotoides* (Pflug & Thomson) Potonié); **3** – *Quercoidites henrici* (Potonié) Potonié, Thomson & Thiergart; **4, 5** – *Quercoidites microhenrici*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

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

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

Late Miocene

Pannonian—Pontian (Tortonian—Messinian)

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

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

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

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

Conclusions

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

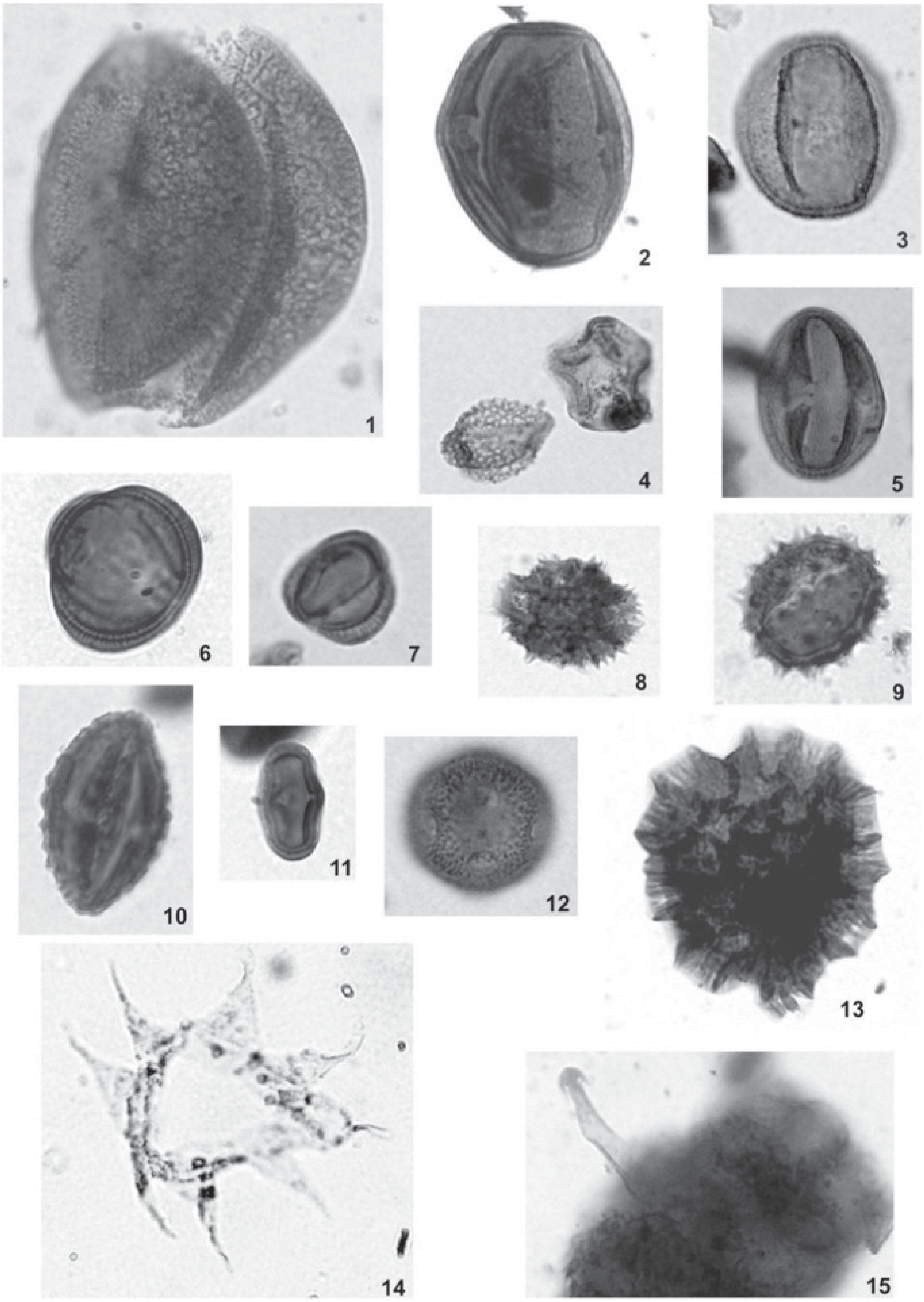


Fig. 9. Pannonian palynomorphs from the studied area. **1** — *Picea* sp. — (*Piceapollis* sp.); **2** — *Nyssa* sp. — (*Nyssapollenites rodderensis* (Thiergart) Kedves); **3** — *Quercus robur* type; **4** — *Salixipollenites* sp. + *Alnipollenites* sp.; **5** — Rosaceae gen. indet.; **6, 7** — *Artemisia*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

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

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

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

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

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

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

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

References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Pliocene depocentre migration and the evolution of the Carpathian-Pannonian system. *Tectonophysics* 266, 301—317.

Nagy E. 1985: Sporomorphs of the Neogene in Hungary. *Geol. Hung., Ser. Palaeont.* 47, 1—470.

Nagy E. 1999: Palynological correlation of the Neogene of the Central Paratethys. *Geol. Inst. Hung.*, Budapest, 1—126.

Nagy E. 2005: Palynological evidence for Neogene climatic change in Hungary. *Occass. Pap. Geol. Inst. Hung.*, Budapest, Vol. 205, 120.

Nagy E. & Planderová E. 1985: Palynologische Auswertung der Floren des Pannonien. In: Papp A., Jámbor Á. & Steininger F.F. (Eds.): Chronostratigraphie und Neostratotypen: Miozän der Zentralen Paratethys, Band VII. M6, Pannonien. *Akadémiai Kiadó*, Budapest, 586—615.

Nehyba S., Hladilová Š. & Doláková N. 1997: Sedimentation and fossil assemblages development during the Early Miocene in Southwest part of Carpathian Foredeep in Moravia. In: Hladilová Š. (Ed.): Dynamics of marine and continental environment relationships. *Grant Project report GAČR 205/95/1211*, Brno, 47—58 (in Czech).

Oszast J. & Stuchlik L. 1977: Vegetation in Podhala during the Neogene. *Acta Paleobot.* XVIII, 1, 45—86 (in Polish).

Pacltová B. 1982: Organically preserved microfossils as indicators of the paleoenvironment. In: Novák V.J.A. & Mlíkovský J. (Eds.): Evolution and environment. *ČSAV*, Praha, 757—773.

Pavelić D. 2001: Tectonostratigraphic model for the North Croatian and North Bosnian sector of the Miocene Pannonian Basin System. *Basin Research* 13, 359—376.

Planderová E. 1972: Pliocene sporomorphs from the Western Carpathians Mountains and their stratigraphic interpretation. *Geol. Práce, Spr.* 59, 209—283.

Planderová E. 1990: Miocene microflora of Slovak Central Paratethys and its biostratigraphical significance. *Geol. Inst. D. Štúra*, Bratislava, 1—144.

Planderová E., Ziembińska-Tworzydło M., Grabowska I., Kohlman-Adamska A., Konzalová M., Nagy E., Pantić N., Ryłova T., Sadowska A., Słodkowska B., Stuchlik L., Syabraj S. & Zdražílková N. 1993a: On palaeofloristic and palaeoclimatic changes during the Neogene of Eastern and Central Europe on the basis of palynological research. Proceedings of the International Symposium: Palaeofloristic and palaeoclimatic changes during Cretaceous and Tertiary. *Dionýz Štúr Inst. Geol.*, 119—129.

Planderová E., Ziembińska-Tworzydło M., Grabowska I., Kohlman-Adamska A., Sadowska A., Słodkowska B., Stuchlik L. & Ważyńska H. 1993b: Climate in Central Europe during the Neogene based on presence palaeotropical and arctotertiary sporomorphs. *Przegl. Geol.*, 41, 12, *Państw. Inst. Geol.*, Bratislava, 829—834 (in Polish).

Ratschbacher L., Merle O., Davy P. & Cobbols P. 1991a: Lateral extrusion in the Eastenn Alps. Part 1. Boundary conditions and experiments scaled for gravity. *Tectonics* 10, 245—256.

Ratschbacher L., Frisch W., Linze H.G. & Merle O. 1991b: Lateral extrusion in the Eastern Alps. Part 2. Structural analysis. *Tectonics* 10, 257—271.

Roetzel R., Ćorić S., Galović I. & Rögl F. 2006: Early Miocene (Ottnangian) coastal upwelling conditions along the southeastern scarp of the Bohemian Massif (Parisdorf, Lower Austria, Central Paratethys). *Beitr. Paläont.* 30, 387—413.

Royden L.H. 1985: The Vienna basin: a thin skinned pull apart basin. In: Biddle K.T. & Christie-Blick N. (Eds.): Strike-slip deformation, basin formation and sedimentation. *Soc. Econ. Paleont. Mineralogists, Spec. Publ.*, Tulsa 37, 319—339.

Royden L.H. 1988: Late Cenozoic tectonics of the Pannonian basin system. In: Royden L. & Horváth F. (Eds.): The Pannonian Basin: A study in basin evolution. *AAPG Memoir* 45, 27—48.

Rögl F. 1998: Paleogeographic considerations for Mediterranean and Paratethys Seaways (Oligocene to Miocene). *Ann. Naturhist. Mus. Wien* 99A, 279—310.

Rögl F., Brzobohatý R., Cicha I., Ćorić S., Daxner-Höck G., Doláková N., Harzhauser M., Hladilová Š., Kroh A., Kvaček Z., Mandic O., Olshtynska A., Pisera A., Reichenbacher B., Schultz O., Švábenická L., Tempfer P., Vávra N. & Zorn I. 2003: Paleobiological characterization of the Karpatian Stage. In: Brzobohatý R., Cicha I., Kováč M. & Rögl F. (Eds.): The Karpatian a lower Miocene stage of the Central Paratethys. *Masaryk University Brno*, 357—360.

Sadowska A. 1989: Miocene palynostratigraphy of the Silesian part of the Paratethys Basin. *Cour.-Forsch. Inst. Senckenberg* 109, 229—235.

Sadowska A. 1993: The stratigraphical table of the Neogene floras from Poland. Proceedings of the International Symposium: Palaeofloristic and palaeoclimatic changes during Cretaceous and Tertiary. *Dionýz Štúr Inst. Geol.*, Bratislava, 133—139.

Sitár V., Knobloch E., Roman S. & Ticleanu N. 1978: Die Makroflora des Badenian (Rumänien und Tschechoslowakei). In: Papp A., Cicha I., Seneš J. & Steininger F.F. (Eds.): Chronostratigraphie und Neostratotypen. Miozän der Zentralen Paratethys. M_4 Badenien. (Moravien, Wielicien, Kosovien). *Veda*, Bratislava, 555—563.

Stuchlik L. 1980: Chronostratigraphy of Neogene in the South of Poland (North part of Paratethys) based on palaeobotanical research. *Przegl. Geol.* 8, 443—448 (in Polish).

Syabryaj S.V. & Vodoryan N.S. 1975: Vegetation and paleogeographical conditon of Middle Sarmatian in the Carpathian area from the data of diatom, spore and pollen analysis. *Ukraine Bot. Zsurnal* 33, 1, 71—77.

Tomek Č. & Hall J. 1993: Subducted continental margin imaged in the Carpathians of Czechoslovakia. *Geology* 21, 535—538.

Walanus A. & Nalepka D. 1999: POLPAL. Program for counting pollen grains, diagrams plotting and numerical analysis. *Acta Paleobot.*, Suppl. 2, 659—661.

Ważyńska H. (Ed.) 1998: Palynology and paleogeography of the Neogene in the Polish Lowlands. *Pr. Panstw. Inst. Geol.*, 1—160.

Vail P.R., Mitchum R.M.J., Todd R.G., Widmier J.M., Thompson S., Sangree J.B., Bubb J.N. & Hatlelid W.G. 1977: Seismic stratigraphy and global changes of sea level. In: Clayton C.E. (Ed.): Seismic stratigraphy — application to hydrocarbon exploration. *Amer. Assoc. Petrol. Geol. Mem.* 26, 49—212.

GEOLOGICA CARPATHICA, AUGUST 2006, 57, 4, 295–310

Miocene evolution of landscape and vegetation in the Central Paratethys

ZLATKO KVAČEK[1], MICHAL KOVÁČ[2], JOHANNA KOVAR-EDER[3], NELA DOLÁKOVÁ[4], HENRIETTE JECHOREK[5], VALENTIN PARASHIV[6], MARIANNA KOVÁČOVÁ[2] and ĽUBOMÍR SLIVA[2]

[1]Charles University, Faculty of Science, Albertov 6, CZ-128 43 Praha 2, Czech Republic; kvacek@natur.cuni.cz
[2]Department of Geology and Paleontology, Faculty of Sciences, Comenius University, Mlynská dolina, SK-842 15 Bratislava, Slovak Republic; kovacm@fns.uniba.sk; kovacova@ fns.uniba.sk
[3]Staatliches Museum für Naturkunde Stuttgart, Rosenstein 1, D-07191 Stuttgart, Germany; eder.smns@naturkundemuseum-bw.de
[4]Department of Geology and Paleontology, Faculty of Sciences, Masaryk University, Kotlářská 2, CZ-611 37 Brno, Czech Republic; nela@sci.muni.cz
[5]Carl-von-Ossietzky-Straße 5, D-02826 Görlitz, Germany; hjechorekgr@surfeu.de
[6]Faculté de Géologie, Université de Bucharest, Str. N. Balcescu, Bucharest, Romania; paleovaly@yahoo.com

(Manuscript received June 27, 2006; accepted in revised form December 8, 2005)

Abstract: The digital elevation model (DEM) helps to express Neogene landscapes and vegetation on palinspastic maps with reconstructed orography. To reconstruct ancient vegetation cover, basic zonal vegetation formations and their characteristics have been defined based on diversity and proportions of zonal woody evergreen, deciduous, sclerophyllous and legume-type elements, besides intrazonal (azonal, e.g. coal-forming, aquatic and riparian) and extrazonal (montane conifer-rich) vegetation. Three time intervals have been analysed — Karpatian to Early Badenian, Late Badenian to earliest Sarmatian and Early to Middle Pannonian. After evaluating respective local sites of leaf, fruit/seed and spore/pollen assemblages, paleogeobotanical maps have been constructed for the area of the Central Paratethys and its periphery.

Key words: Miocene, Central Paratethys, paleogeography, palinspastic maps, digital elevation models, vegetation mapping.

Introduction

It is a common task of geobotany today to express interpreted vegetation over larger areas on maps, because the extent of various types of plant communities is an important factor, for example, in tracing human influence or migrations of terrestrial animals. However, several aspects of such studies are different considering Neogene vegetation (Kovar-Eder et al. submitted). The paleogeographic configuration of land and sea was different from the present situation. The regional relief changed in connection with orogeny processes. The floristic spectra included elements mostly extinct or no longer living in Europe. The time slices for the respective maps are many million years distant from the Recent. Global climate, atmospheric circulations and the world ocean varied depending on the time interval studied. To overcome these problems a team of specialists is needed. The paleogeographic background with an approximate demarcation of sea, basins and approximate relief is the first premise to attempt such a paleogeobotanical mapping.

Complex and well determined spectra of plant elements from the reference sites with both megafossil and spore/pollen records are most relevant. The megafossil record usually reflects the situation near the site and is differentiated according to the lithofacies. It also reflects the presence of plants producing poorly preservable pollen (e.g. Lauraceae) and indicates more strongly floristic changes than the spore/pollen spectra. Leaves may convey information on the vegetation physiognomy. Fruits and seeds are better indicators of systematic affinities. Pollen and spores may undergo long distance transport by wind and their spectra thus include information on the composition and changes of upland vegetation, which usually consists of mountain conifer-rich forests. It is problematic to transfer frequencies of any kind of plant organs in the fossil spectra into true abundances of plants in a community or landscape, because the fossil record is biased either by overproduction of fossil organs (e.g. pollen, diaspores) and taphonomic processes (e.g. deciduous vs. evergreen foliage, more rapid decay of delicate leaves). In our analyses, we relied mostly on qualitative proportions of elements, that is the floral diversity, within the given assemblage.

A synthetic view over a large area that includes several countries should be obtained based both on own experiences including authentic knowledge of plant fossil sites and the review of the published data. In the latter cases, it is often a difficult task to critically re-evaluate older taxonomical interpretations, both in the megafossil and pollen spectra. Particularly the interpretations of various pollen types within the natural system look very different today from the traditional morphological or semi-natural systems used previously (or even at present). Particularly by efforts of large-scale comparisons with living plants (Stuchlik 1994) and electron scanning microscopy (Walther & Zetter 1993; Ferguson et al. 1998; Zetter 1998; Liu et al. 2001), surprising solutions for several sporomorphs have been suggested and important natural affinities have been recognized (e.g. *Mastixia*, i.e. *Cornaceaepollis satzveynsis*, *Trigonobalanopsis*, i.e. *Castaneoipollenites pusillus*, etc.). Studies of pollen *in situ* and co-occurrence with megafossils are also important. Thus it has recently become obvious that the tilioid pollen does not belong in most cases to *Tilia*, a deciduous zonal element, but to *Craigia* & *Dombeyopsis lobata* or *Banisteriaecarpum* & *Byttneriophyllum tiliaefolium* (alias "*Alangium*") plants both intrazonal, frequent constituents of the *Glyptostrobus* swamp forests (e.g. Kvaček et al. 2002).

This paper introduces a new methodology of the Neogene paleogeobotanical mapping presenting it on three time slices of the Neogene in the Central Paratethys.

Methodology

Digital Elevation Models (DEMs) of the Central Paratethys (Fig. 1) in individual time intervals of the Miocene, which help us to express landscapes with expected orography, were constructed on the basis of present knowledge of geodynamic evolution of the Alpine-Carpathian-Pannonian region (Csontos et al. 1992; Kováč et al. 1993, 1997, 2001, 2002; Meulenkamp et al. 1996; Baráth et al. 1997; Plašienka et al. 1997; Plašienka & Kováč 1999; Bezák et al. 2002; Konečný et al. 2002; Soták & Kováč 2002; Bielik et al. 2004), existing palinspastic maps (Kováč et al. 1989, 1998, 2003; Magyar et al. 1999; Kováč 2000; Popov et al. 2004), as well as burial and uplift history of sedimentary or other rock complexes (Horváth et al. 1988; Dunkl 1992; Kováč et al. 1994; Hurai et al. 1995; Dunkl & Demény 1997; Danišík et al. 2004, etc.).

Models of the Central Paratethys vegetation (Figs. 2–4) use a simplified system of vegetation units (formations), which are usually sufficient to get tentative pictures of paleovegetation in space. Our attention has been paid to distinguish zonal, intrazonal (azonal) and extrazonal formations on the basis of autecology and leaf physiognomy of elements, whose grouping has been attempted in this respect (Kovar-Eder & Kvaček 2003; Kovar-Eder et al. submitted). The characteristics of the elements have been mostly derived from autecologies of their nearest living relatives or analogues. Reference fossil localities/plant assemblages often included taxa of different vegetation formations, of which zonal elements are relevant for the maps of the reconstructed fossil vegetation. However, it is apparent from the sedimentary settings that assemblages dominated by intrazonal elements prevailed in the record of megafossils, mainly from the basin deposits. Extrazonal conifer-rich mountain vegetation was represented in pollen spectra, exceptionally in megafossil records from the intra-montane basins. Not only altitude, but also the direction of exposure of mountain slopes and substrate may have influenced the composition of the conifer stands. Volcanic settings are the best environments to bring information on zonal vegetation of mesic habitats. Percentages of zonal herbs as well as Non Arboreal Pollen (NAP) as a whole in pollen spectra may refer to close canopy forests versus open woodland to steppe vegetation. Even intrazonal elements can bring information on the character of climate (e.g. the presence of palms), although the intrazonal assemblages usually bear "cool" aspects due to higher proportion of deciduous arboreal elements.

For the purpose of the presented paleovegetation maps several formations have been distinguished and characterized mostly based on the proportion of broad-leaved deciduous, broad-leaved evergreen, sclerophyllous and legume-type components of zonal woody angiosperms (Kovar-Eder et al. submitted).

Zonal formations

1. (Warm-) temperate Broad-leaved Deciduous Forest with very low proportion of evergreen woody elements (vegetation unit 1) includes more than 80 % of zonal deciduous woody elements of angiosperms, such as *Parrotia*, *Zelkova*, *Ostrya*, *Acer angustilobum* etc.
2. Warm-temperate Mixed-Mesophytic Forest (vegetation unit 2) includes less than 80 % deciduous woody elements of zonal angiosperms, less than 30 % evergreen broad-leaved woody taxa of zonal angiosperms and less than 20 % sclerophyllous and legume type elements, regular admixture of *Tetraclinis salicornioides* and other thermophilous elements, less than 30 % of zonal herbs of zonal angiosperms.
3. Subtropical Broad-leaved Evergreen Forests including the "Younger Mastixioid Floras" *sensu* Mai (1964) (vegetation unit 3) includes equal or more than 30 % broad-leaved evergreen and thermophilous elements, represented mainly by Lauraceae, Theaceae, Mastixiaceae, Symplocaceae, Sapotaceae, *Engelhardia*, and evergreen Fagaceae (represented in pollen spectra by morpho-species *Castaneoideoipollenites pusillus*, *Quercoidites henrici*, *Quercoidites microhenrici* — types) and less than 25 % of zonal herbs among zonal angiosperms.
4. Subtropical Sub-humid Sclerophyllous Forest (vegetation unit 4) includes more than 20 % sclerophyllous taxa (*Quercus mediterranea*, *Quercus drymeja*) and legume-type microphyllous woody elements of zonal angiosperms.

Intrazonal formations

5. Swamp forest and coal-forming mire (not expressed by patterns on maps, vegetation unit 7) is dominated by coal-forming woody and herbaceous elements (e.g. *Glyptostrobus* and other Taxodiaceae, *Byttneriophyllum*, *Nyssa*, *Myrica*, *Calamus*, *Spirematospermum*, etc.).
6. Marsh and aquatic vegetation (not expressed by patterns on maps, vegetation unit 8) is dominated by aquatic herbs and helophytes (Cyperaceae, *Typha*, *Potamogeton*, *Stratiotes*, etc.).
7. Deciduous riparian forest (not expressed by patterns on maps, vegetation unit 9) is dominated by woody elements of moist substrates (*Taxodium*, *Alnus*, *Salix*, *Populus*, *Fraxinus*, *Acer tricuspidatum*, etc.).

Extrazonal formations

8. Mountain conifer-rich forest is dominated (mostly in pollen records, vegetation unit 10) by Pinaceae (including *Cedrus*, *Tsuga*, *Picea*, *Cathaya*, etc.).

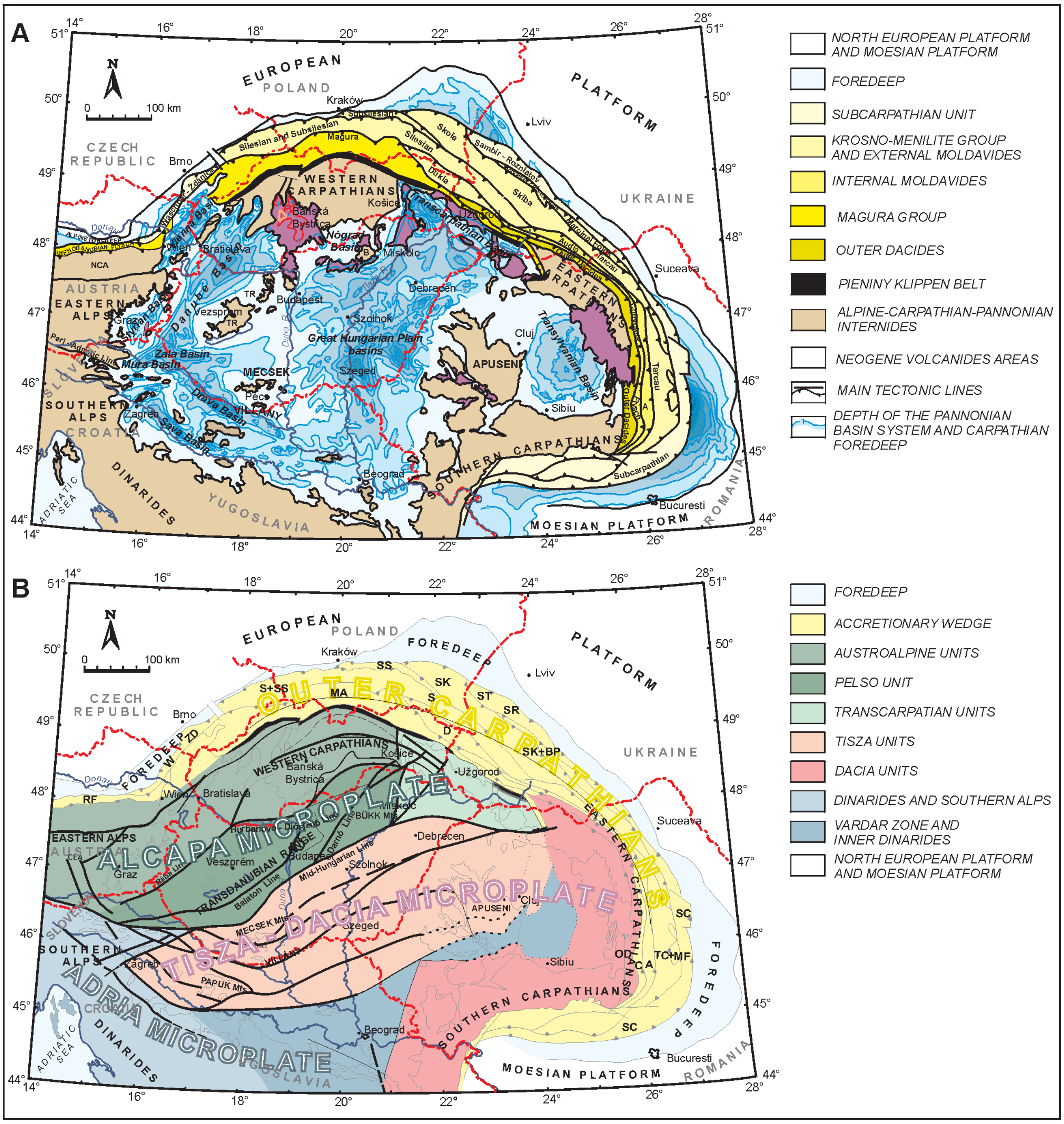


Fig. 1. Geological maps: **A** — Alpine-Carpathian-Pannonian region, **B** — Position of the ALCAPA and Tiszia Dacia microplates.

The network of localities is quite loose and does not sufficiently cover the study area. Thus the gaps between them have been only tentatively extrapolated according to the reconstructed relief. The construction of the maps proceeded in two steps. First, circles of reference sites have been placed on palinspastic maps that include reconstructed sea depths and orography. The sites received name abbreviations (e.g. MA for Mataschen.), which are included in the explanations of the figures and in the review of the sites (available in the digital form on request). Different colours of circles have been used to designate the vegetation formations. The presence of extrazonal mountain conifers in the palynospectra has been marked as a blue-green rim, all kinds of intrazonal vegetation as the brown centre or brown full circle. Colours of zonal vegetation have been divided as follows: light green for the Deciduous Broad-leaved Forest (unit 1), green for the Mixed Mesophytic Forest (unit 2), dark green for mostly evergreen forests (unit 3), and orange for sub-humid, partly sclerophyllous forest types (unit 4).

In the next step, we used various raster patterns (as specified in the explanations of the maps) to depict probable vegetation formations between and around the reference sites. The intrazonal vegetation was omitted because of its limited extent compared with the scale of the maps. The approximate position of extrazonal conifer belts has been placed according to the nearby palynodata and orography.

Early Miocene — model of the Karpatian landscape and vegetation of the Central Paratethys

During Early Miocene, the Central Paratethys was situated at least 200–300 km to the south of its present position. The sea, located along the southern slopes of the European platform, covered the southwestward dipping subduction zone in front of the developing Alpine-Carpathian orogene. The accretion wedge, build up by external Alpine and Carpathian Flysch Belt units, was marked in that time only with islands, forming an archipelago along the platform margin. The uplifted islands, composed of units of the Outer Carpathian nappe pile, were surrounded by residual flysch troughs with turbidite deposition. Toward the south, the epicontinental sea stretched over a large part of the internal zones of the Alpine and Carpathian mountain chains, included the northern lithosphere fragment of ALCAPA and the southern fragment of Tisza-Dacia (Csontos et al. 1992; Csontos 1995). The lithospheric fragments (or microplates) moved towards the subduction zone separately, their amalgamation set at first since the Middle Miocene. The southern boundary of the Central Paratethys Sea was represented by the Dinaride mountain chain, dividing it from the Mediterranean Sea.

In late Early Miocene, the subduction gradually converted to a collision from the west to the east. The weight of the overriding Carpathian orogene front and deep subsurface load of the submerging plate led to development of a flexure on the platform margin. The foredeep basin developed along the whole front of the Outer Carpathian accretion wedge. The evolution of the accretion wedge was associated with compression, controlling folding and thrusting of the Flysch Belt nappe piles (Kováč et al. 1998).

The internal units of the Carpathians, belonging to the ALCAPA and Tisza-Dacia microplates, started to collapse due to stretching in consequence of the subduction pull (Royden 1993a,b), as well as due to asthenospheric mantle upheaval in the western part of the back-arc region. The extension led to initial rifting of the Pannonian basin system (Horváth 1993). By basin opening, besides normal and low angle faults, strike slip faults also played an important role (Vass et al. 1988, 1993; Tari et al. 1992; Fodor 1995; Kováč et al. 1998; Konečný et al. 2002). In the west a sinistral shear dividing the Alpine and Carpathian orogenes opened the Vienna Basin, in the east a dextral shear along the external and internal Carpathians boundary (Pieniny Klippen Belt) opened the Transcarpathian Basin towards the northern part of the East Slovak Basin. Extension in the western part of the back-arc region led to beginning of the formation of the Danube Basin, associated with structural unroofing of the deepest Alpine-Carpathian structural units.

During the Karpatian, a new marine connection opened between the Central Paratethys and the Mediterranean Sea. This connection is supposed through the trans-Dinaride corridor situated in the area of Slovenia and northern Croatia (Rögl 1998). Apart from tectonics, the global sea-level rise during the late Burdigalian had an important role in the development of this seaway (TB 2.2 cycle, *sensu* Haq et al. 1988; Hardenbol et al. 1998; Kováč et al. 2001). The sea transgression, with new elements of marine fauna and flora, flooded the present territory of the Drava and Sava Basins (Pavelić 2001), from where the sea penetrated into the Mura, Zala and Styrian Basins. The NE oriented flooding then followed the way between the northern margin of the Mecsek Mts and the southern margin of the Transdanubian Range reaching the North Hungarian–South Slovak sedimentary area. Northwards, the sea spread to the Bánovská kotlina Depression, the Vienna Basin, the Váh river valley and the East Slovak Basin (Kováč et al. 1993). The Karpatian sea covered especially the western part of the Carpathian Foredeep, in the east the sea extended especially over the area of the present Outer Carpathian units of accretionary wedge with wide marine connections into the East Slovak Basin (Rudinec 1989, 1990; Kováč et al. 1995).

The DEM paleogeographical model of the Central Paratethys during the Karpatian (Fig. 2) documents the beginning of the Carpathian orogene uplift. The ratio between continental and marine environments (ratio of land and surface covered by the sea) can be very roughly interpreted due to the enormous erosion of the Early Miocene sediments at the begin of the Middle Miocene (Kováč et al. 2003). The erosion is documented by a total absence of marginal facies particularly in northern areas of the Central Western Carpathians and by very sporadic findings of the Karpatian sediments in the Outer Carpathians, folded together with the Flysch Belt deposits (Cieszkowski 1992; Oszczypko 2003). The results of study of fluid inclusions also confirm erosion of 2 to 5 km thick pile of deposits (Hurai et al. 2002), as well as an important angular unconformity between the Karpatian and Badenian strata at many places in the Pannonian basin system.

The Carpathian paleo-relief was probably low at this time. In many places, the pre-Tertiary basement units were covered by Paleogene and Early Miocene sediments, much larger in extent than those preserved today in the Paleogene and Neogene basins. In the Western Carpathians, for example, a continuous sedimentary area covering the territory from the Bánovská kotlina Depression to the Vienna Basin has been recorded (Kováč et al. 1993), without indication of an uplift of the Považský Inovec core mountain (Kováč et al. 1994, 1997).

The paleo-river net started to develop in areas with higher relief. The Eastern Alps belonged to such places, where rivers fed deltas in the Alpine Foredeep and the southern part of the Vienna Basin (Aderklaa Formation), and later in the uplifted parts of both the Central Western Carpathians and the Outer Carpathians in the western segment of the Carpathian collision zone (Kováč 2000).

Considerations about prevailing low paleo-relief are also supported by the paleobotanical study, which docu-

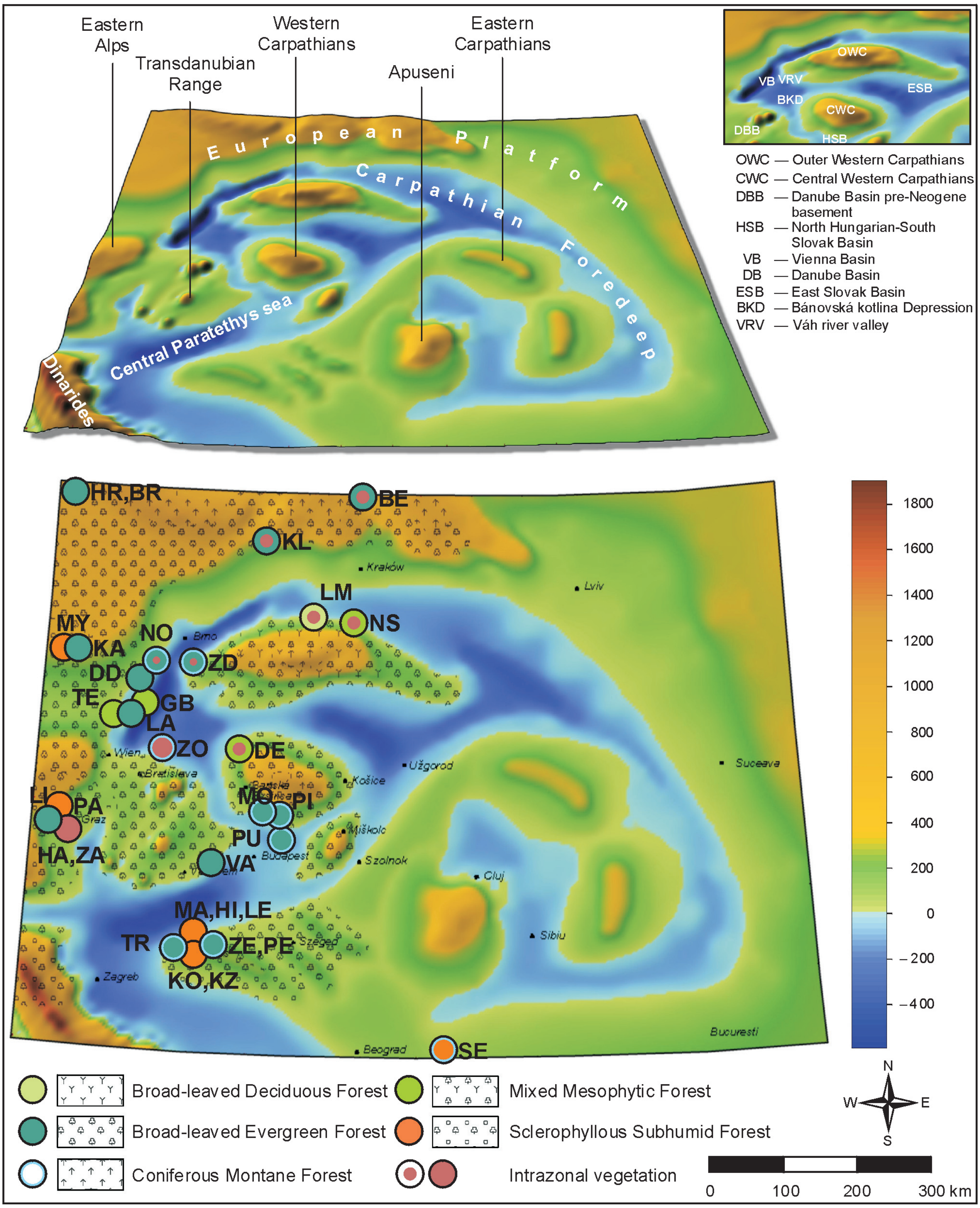


Fig. 2. DEM of the Central Paratethys: landscape & vegetation cover during the Karpatian. Abbreviations of the localities with numbers of vegetation units: **BE** — (3, 8) Bełchatów, KRAM-P 211/214; **BR** — (3, 9) Berzdorf; **DD** — (3) Dolní Dunajovice, Slup, Hevlín; **DE** — (3, 7) Dežerice; **GB** — (3, 10) Core Gbely 139, depth 650–660 m; **HA** — (9) Haiden; **HI** — (3, 9) Core Hidas 53, 1071.0–763.3 m; **HR** — (3, 7) Hrádek/N., Kristina Mine, Turów; **KA** — (3) Kamenný Újezd, Olešník, Hluboká; **KL** — (3, 10) Kłodnica area, Biała and Twardawa cores; **KO** — (4, 9, 10) Core Komló 120; **KZ** — (3, 9, 10) Komló-Zobák puszta; **LA** — (3) Laa/Thaya; **LE** — (3, 10) Leánykö; **LI** — (3, 9) Lintsching; **LM** — (1, 7, 8) Lipnica Mała; **MA** — (4) Magyaregregy; **MO** — (3, 7, 8, 10) Modrý Kameň, Stredné Plachtince, Ďurkovce, Dolné Príbelce; **MY** — (4) Mydlovary; **NO** — (3, 7, 9) Core Nosislav 3, 368–345 m; **NS** — (2, 7, 8) Nowy Sącz; **PA** — (4, 9) Parschlug; **PE** — (9) Core Pécsvárád 44; **PI** — (3, 8, 9) Core Piliny 8; **PU** — (3, 8, 10) Core Püspäkhatran 4; **TE** — (3, 9) Core Tekeres 1; **TR** — (2, 8, 9) Teiritzberg; **VA** — (3, 9, 10) Core Várpalota 133; **ZA** — (7) Zangtal near Voitsberg; **ZD** — (3, 9, 10) Cores Ždánice 67, depth 765–858 m, Ždánice 68, depth 700–820 m; **ZE** — (3, 9, 10) Core Zengővárkony 59; **ZO** — (9, 10) Core Zohor 1, depth 1495–1500 m.

ments an altitudinally not much differentiated character of vegetation in the whole Carpathian-Pannonian region during the Karpatian. Similarly, no obvious latitudinal and longitudinal changes were observed there. Some zonation marks, indicated by the diferentiation of the paleovegetation cover, are visible in the lowlands and margins of the marine sedimentary area.

Karpatian vegetation (Fig. 2) is documented by reference sites, of which only some have been dated by marine fauna. The age of the others is indicated by the mammalian MN5 Zone and thus may overlap with the Early Badenian. In other cases the boundary to the Ottnangian may also be uncertain (MN4 Zone).

Three zonal forest formations were spread over the Central Paratethys region during the Karpatian. Subtropical broad-leaved forests with high to medium proportion of evergreen elements were spread in the western part and continued into the Boreal Province westwards in the form of the typical Younger Mastixioid Floras *sensu* Mai (1964). The corresponding phytostratigraphic unit of the Boreal Province has been called the Floral Assemblage ("Florenkomplex") Františkovy Lázně — Kleinleipisch (Mai 1995, 2001; Czaja 2003), but direct dating to the lower part of the MN5 Zone is available only for Františkovy Lázně in the Cheb Basin outside the Central Paratethys. Domination of thermophilous elements (*Engelhardia*, *Platycarya*, Sapotaceae, Symplocaceae, evergreen Fagaceae, such as *Trigonobalanopsis*, in pollen records expressed by *Castaneoideaepolis pusillus*-, *Castaneoideaepolis oviformis*-, *Tricolporopollenites liblarensis*-, *Quercoidites henrici*- types, etc.) is apparent for the Karpatian–Early Badenian time span (Planderová 1990, Zone MF5; Doláková & Slamková 2003). Only in the central and northern parts near mountains (e.g. Lipnica Mała, Nowy Sącz), the proportion of the broad-leaved deciduous elements increased resulting in the warm-temperate Mixed Mesophytic and Broad-leaved Deciduous Forest types. Some sites (Mydlovary — Knobloch & Kvaček 1996; Parschlug — Kovar et al. 2004; Magyaregregy — Hably 2002) have a sub-humid character (subtropical forests with high proportion of sub-humid and sclerophyllous elements). This may indicate some heterochronity, which we are unable to resolve from the paleobotanical record and short-time fluctuation of perhumid and seasonal climate, as proposed by exothermic vertebrates (Böhme 2003). A distinct East-West gradient is apparent, when broader parts of Europe are compared (Kovar-Eder et al. submitted).

Extrazonal mountain zones with conifers were probably as high as 1500–2000 m a.s.l. and more. The upland forests were dominated by *Pinus*, *Abies*, *Cathaya* and only at still higher altitudes with the admixture of *Cedrus*, *Tsuga*, and *Picea*, as demonstrated in the pollen spectra (Nagy 1992; Doláková & Slamková 2003). Various Pinaceae (*Pinus*, *Cathaya*) and *Sciadopitys* entered also intrazonal lowland formations.

Intrazonal coal-forming forests appeared mainly in the inter-Alpine basins (Leoben-Bruck Basin, Parschlug, Fohnsdorf, and Mecsek Mts — Hably 2002, p. 92). Besides *Glyptostrobus* these thermophilous communities occasionally included palms, e.g. *Calamus*-type at Teiritzberg, evergreen oaks, *Nyssa*, *Myrica*, *Cyrilla* (Zittau Basin), and not yet clarified enigmatic *Rhoipites pseudocingulum* (= *Rhus*-type). Among other mostly intrazonal elements, ferns of Gleicheniaceae, Schizaeaceae (*Lygodium*), *Osmunda* and Polypodiaceae *sensu lato* (including, e.g. *Pronephrium*) were well represented. Pollen of *Avicennia* (Korneuburg Basin) suggests the presence of impoverished mangrove shrubs in the NW part of the Central Paratethys.

Paleobotanical data are lacking for this time interval from the eastern part of the studied region because of unfavourable conditions for the preservation of fossil plants there (Syabryaj 2003). Assemblages from the upper part of the Smoliarka Horizon (Rylova et al. 1999) and Rozhok (zone IV FC *sensu* Yakubovskaya 1993) in Belarus give evidence that the subtropical vegetation of the mastixioid type may have extended north-eastwards from the Central Paratethys.

Middle Miocene — model of the Late Badenian landscape and vegetation of the Central Paratethys

During the Middle Miocene, the active collision/subduction in front of the Carpathians shifted eastwards due to gradual break-down of the submerging slab (Tomek & Hall 1993). In the west, this process led to the termination of collision between the orogene and the European platform, followed by gradual uplift of the Outer Carpathian accretionary wedge and by the migration of foredeep depocentres from the Western Carpathian foreland towards the Eastern Carpathians (Jiříček 1979). The sea flooding in the front of the Carpathian orogene gradually schifted from west to east. At the end of the Early Badenian, the sea abandoned the western part of the foredeep (Czech Republic), marine sedimentary areas extended only in the northern front of the Western Carpathians and in the front of the Eastern Carpathians. The foredeep at the edge of the Western and Eastern Carpathians reached its maximum extent during Late Badenian–Early Sarmatian time, when 2500 m of sediments were deposited (Meulenkamp et al. 1996). The Sarmatian compression associated with uplift of the Outer Western Carpathians draw the sea away from the northern part of the Carpathian Foredeep for ever (Kováč et al. 1998). A connection between the Carpathian Foredeep and the Pannonian basin system remained preserved only in the Eastern Carpathian region (Kováč 2000; Kováč et al. 1998).

The Middle Miocene development of the back-arc basin region was controlled by two geodynamic factors: in the western and central parts of the Pannonian basin system it was upheaval of asthenosphere mantle masses, in the eastern part it was stretching of an overriding plate induced by subduction pull in front of the Eastern Carpathians. In the western part of the back-arc basin, subsidence of the Vienna and Danube Basins caused depocentres above the thinned crust and lithosphere associated with volcanic activity in the hinterland of the Central Western Carpathians (Wernike 1985; Nemčok & Lexa 1990; Tari et al. 1992; Konečný et al. 2002). In the east, orogene that was parallel to the back-arc basin depocentres opened in the area of the Transcarpathian and Transylvanian Basins. Mighty acid and later also "island arc" type volcanic activity appeared in a belt along the eastern border of the back-arc region in the hinterland of the Eastern Carpathians (Konečný et al. 2002).

Synrift subsidence of the back-arc basin in the Pannonian basin system was associated with mighty acid and calc-alkaline volcanic activity (Kováč 2000; Konečný et al. 2002). Individual depocentres formed in the extensional tectonic regime. The main types were grabens and half-grabens associated with normal and low angle faults, although some pull apart basins opened along active strike-slip faults (Vass et al. 1988, 1993; Tari et al. 1992; Fodor 1995; Kováč et al. 1998; Konečný et al. 2002; Kováč 2000).

The Badenian marine conection of the Central Paratethys with the Mediterranean Sea is supposed through a trans-Dinaride corridor (Rögl 1998), at a similar place as during the Karpatian. The Early Badenian sea-level rise, which can be correlated with the early Langhian global sea-level change (TB 2.3 cycle *sensu* Haq et al. 1988; Hardenbol et al. 1998), is documented only in the SW part of the Pannonian basin system — from the Styrian Basin (Rögl et al. 2002). In the northern parts of the back-arc region wide-ranging erosion of Early Miocene deposits is observed. In depressions (future basin depocentres), fan deltas or terrestrial red coloured sediments were deposited during this time.

The Early Badenian tectonically-controlled transgression, followed by rapid subsidence (deep sedimentary environment), started about 15 Ma. The basins were filled by clastics transported by rivers running from uplifted areas of the Eastern Alps and the Western Carpathians. After sea-level fall (documented by erosion of the Early Badenian carbonate platforms in the SW part of back-arc basin — Vienna and Styrian Basins), the "Middle Badenian" transgression, which can be correlated with the global sea-level change in late Langhian (TB 2.4 cycle *sensu* Haq et al. 1988; Hardenbol et al. 1998), took place. The Central Paratethys sea reached the present extent in the intra-Carpathian Neogene basins, except the uplifted North Hungarian–South Slovak sedimentary area. Since that time, a gradual filling up of the Pannonian basin system by deltas has been observed, leading to shallowing of sedimentary environment and development of isolated depocentres. Basins situated in the north and east suffered from isolation. A salinity crisis took place in the Carpathian Foredeep as well as in the Transcarpathian and Transylvanian Basins.

The Late Badenian transgression, which can be correlated with the global sea-level change at the Langhian/Serravalian boundary (TB 2.5 cycle, *sensu* Haq et al. 1988; Hardenbol et al. 1998; 13.65 Ma.) represents the last full marine flood of the Central Paratethys. Since the end of the Late Badenian (12.7 Ma), an isolation of epicontinental sea in the Intra-Carpathian region can be documented and a direct connection of the Central Paratehtys with the Mediterranean is not expected. The Sarmatian flood, from the Eastern Paratethys region, can be correlated with the late Serravalian global sea-level change (TB 2.6 cycle *sensu* Haq et al. 1988; Hardenbol et al. 1998). The sedimentary environment was dominantly shallow marine with decreased salinity.

The DEM model of the Central Paratethys during the Late Badenian (Fig. 3) documents uplift of the Western Carpathians, including accretionary wedge in front of the orogene and broad marine flood in the back-arc basin region. The intra-Carpathian region gained the characteristic features of an archipelago sea, with many small islands surrounded by shallow epicontinental sea. The paleogeography was still strongly influenced by tectonic processes (Styrian phase), as it is well marked by rapid changes of subsiding depocentres (sea bays, small basins) and position of the coastal line.

The paleo-relief of the Carpathians significantly changed during the Middle Miocene, due to strong tectonic influence. The belt of the Outer Carpathians, bordered by internal parts of the orogene, started to be uplifted. The land surface was also strongly differentiated by volcanic activity, some stratovolcanoes reached heights of 2000 to 3000 m a.s.l. The river net transporting eroded clastic material headed mostly towards the back-arc area.

Fair-sized altitudinal differences between lowlands and mountains are documented by paleobotanical studies. Mixed pollen spectra with mountain and lowland vegetation taxa indicate only seemingly the decrease of thermophilous taxa and the increase of more dominant temperate taxa (Sitár & Kováčová-Slamková 1999; Slamková 2004). The Badenian vegetation in the Central Paratethys can generally be characterized as thermophilous without dominance of typical boreal plant elements. Hence, we cannot document sufficiently a gradual cooling of climate indicated in the literature (Böhme 2003) that influenced the European flora from the Late Badenian onwards.

Late Badenian vegetation (Fig. 3) has been documented from sites more often dated by marine fauna (due to an extensive marine transgression), but also from some others that are dated by mammals to Zone MN6 or by regional correlation. The differentiation of the levels within the Badenian has not always been accomplished and such sites are exceptionally included into the map. Some sites overlap with the lowermost Sarmatian, which is floristically hardly distinguishable (see Syabryaj & Stuchlik 2004; merged into a single "Florenkomplex" Stare Gliwice-Unterwohlbach by Mai 1995).

The southernmost sites in Romania, Serbia and Hungary differ from the remaining ones by thermophilous, partly sub-humid aspects under subtropical climatic conditions, which continued from previous times. A general cooling trend appears in other sites by an increasing role of deciduous elements, while thermophilous plants withdrew stepwise southwards and only a part survived, mainly *Tetraclinis*, *Amentotaxus*, *Magnolia*, Lauraceae, *Engelhardia* and others. This is in the contrast to the preceding "Wieliczien" thermophilous humid mastixioid assemblage even in the Polish part of the Carpathian Foredeep (Łancucka-Środoniowa & Zastawniak 1997). From the differentiation of vegetation in the Late Badenian it is obvious that the climatic gradient between the southern and northern parts of the Central Paratethys increased at that time, partly due to altitudinal differenciation, as noted above. A noteworthy forest-forming tree was *Fagus* accompa-

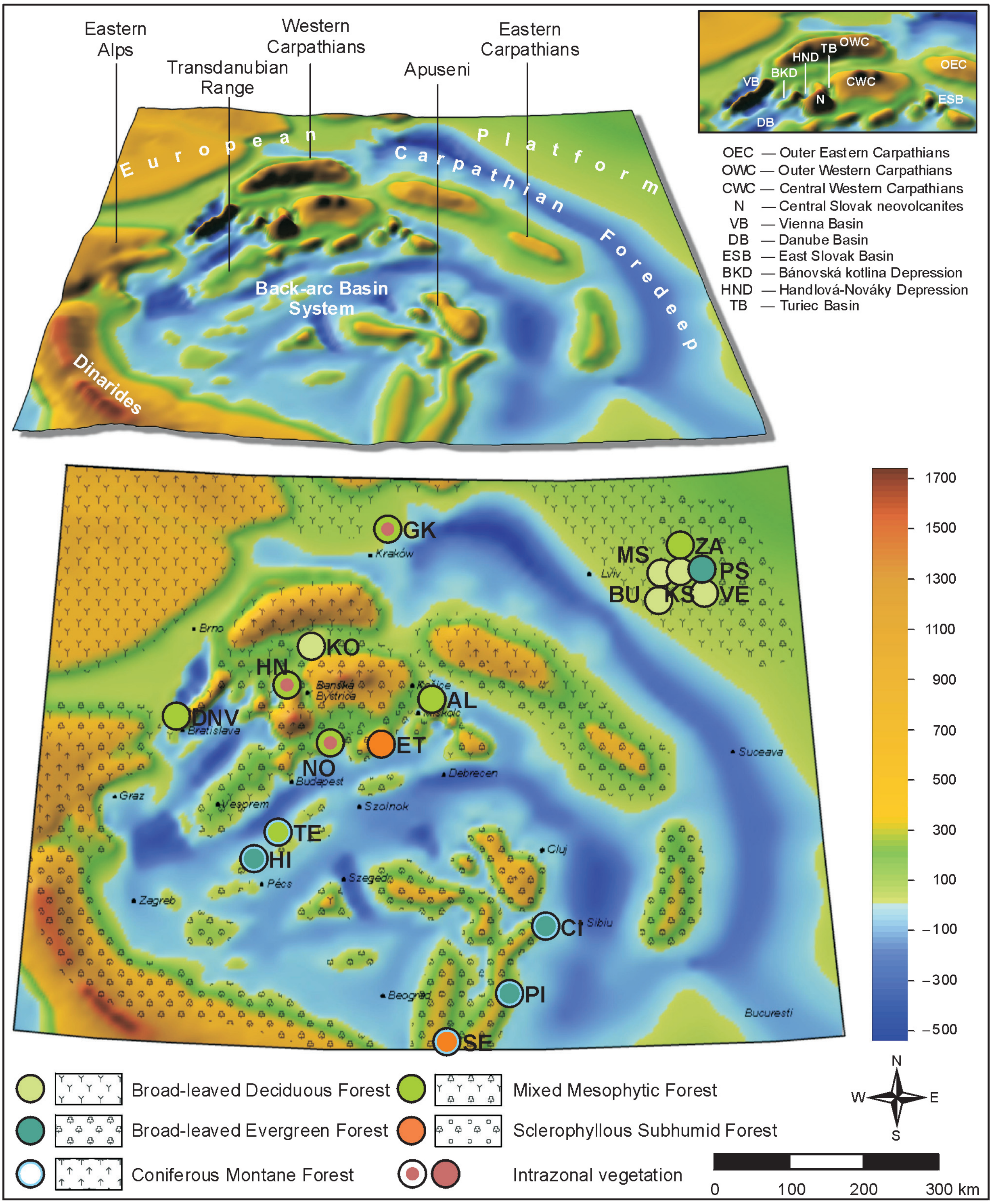


Fig. 3. DEM of the Central Paratethys: landscape & vegetation cover during the Late Badenian. Abbreviations of the localities and numbers of vegetation units: **AL** — (2) Core Alsóvadász 1; **BU** — (1, 9) Burkalo; **CI** — (3) Ciocadia; **DNV** — (2, 7, 10) Devínska Nová Ves — brickkiln; **ET** — (4) Eger-Tihamér; **GK** — (2, 8, 9, 10) Gdów area, core Kłaj 1, depth 30–405 m; **HI** — (2, 10) Core Hidas 53; **HN** — (2, 7, 9) Handlová-Nováky; **KO** — (1, 9) Kolisky; **KS** — (1, 9) Kosov; **MS** — (1, 7) Myshin; **NO** — (2, 9) Nográdszakál, Páris valley; **PI** — (3) Pirlage; **PS** — (3) Pistynka; **SE** — (4) Selishte; **TE** — (2, 10) Core Tengelic 2; **VE** — (1, 9) Verbovets; **ZA** — (2, 9) Zalescy.

nied by other deciduous Fagaceae. *Acer* was diversified in several species, among which *Acer aegopodifolium* (syn. *A. quercifolium* — see Ströbitzer-Hermann 2002; Walther & Zastawniak 2005) appears for the first time in the Central Paratethys (Kovar-Eder et al. 1994), together with *Ginkgo*, *Eucommia* both arriving from Asia via the Turgay migration route. Over most of the Central Paratethys, warm-temperate Mixed Mesophytic Forest thrived, only in the Western Carpathians and the Transcarpathian Ukraine some sites already acquired the character of Broad-leaved Deciduous Forest, probably due to influence of mountains or due to cooling effect of intensive volcanic activity (Navrotskaja et al. 1991; Syabryaj 1992). The proportion of herbs was generally low, not indicating lowland open vegetation (Syabryaj & Stuchlik 2004).

Extrazonal mountain forests are well discernible in pollen assemblages, as at Devinská Nová Ves (Sitár & Kováčová-Slamková 1999), where the coniferous belt reflected by the dominant pollen of *Pinus* includes additional high-mountain elements, such as *Cedrus* and *Tsuga*. Its lower boundary may have decreased towards 1200 m a.s.l. However, this guess is only inferred from the analogous Recent situation in the Colchis area (Stuchlik & Kvavadze 1987; Klotz 1990).

In the intrazonal *Glyptostrobus* peat-forming forests, *Byttneriophyllum* and *Alnus* constituted a basic community, which became wide spread later in the Neogene. Among riparian elements, *Platanus leucophylla* is occasionally present. Lignite-forming communities are typically developed in intra-montane depressions (e.g. Handlová and Nováky) and they are also common in the lowlands outside the Paratethys area in Poland and Germany (Lusatia seam 1). The corresponding phytostratigraphical level in the Boreal Province is probably represented by the Floral Assemblage Schipkau-Konin *sensu* Mai (2001), but this correlation is opposed by Krutzsch (2000.) The paleofloristic differentiation around the Late Badenian and Early Sarmatian boundary has been discussed with little success to give clear-cut differences based on plant megafossils (Němejc 1951, 1967; Shvareva 1965; Sitár 1967, 1982). It is still uncertain, which Early Miocene elements did not enter the Sarmatian flora, where broad-leaved deciduous trees predominate. In her pollen assemblages, Planderová (1990) created a transitional Zone MF7 for this type of flora in the Slovak Neogene. Its pollen spectra include a very low proportion of or no thermophilous Symplocaceae, Sapotaceae and Cyrillaceae.

Late Miocene — model of the Middle Pannonian landscape and vegetation of the Central Paratethys

During the Late Miocene, the area of the Central Paratethys gained paleogeographical features similar to the present situation in the Carpathian-Pannonian region. The main difference was represented by flooding of the intra-Carpathian region and the foredeep depocentres, which were restricted to the southeastern foreland of the Eastern Carpathians in that time (Jiříček 1979; Meulenkamp et al. 1996). Thus a connection of the brackish Eastern Paratethys with the Lake Pannon originated (Magyar et al. 1999).

The Late Miocene geodynamic development of the Carpathians can be characterized by termination of collision between the Western Carpathian and the European platform and reinforced collision connected with subduction in front of the Eastern Carpathians. This process was followed not only by the uplift of the accretionary wedge loop, but also by the uplift of the whole Carpathian orogene mountain chain.

Pull of the active subduction in front of the Eastern Carpathians southern edge led to the "second" rifting phase in the back-arc basin at the begining of the Pannonian, followed by thermal post-rift subsidence (Lankreijer et al. 1995; Kováč 2000; Konečný et al. 2002). Among the Late Miocene basins of the intra-Carpathian domain formed in an extensional regime, flexural basins without important fault activity prevailed, although in the Early Pannonian normal and strike slip faults allowed development of small pull-apart basins (Vass et al. 1988, 1993; Tari et al. 1992; Fodor 1995; Kováč et al. 1998; Kováč 2000; Konečný et al. 2002). The Lake Pannon — the Pannonian basin system was gradually filled up by deltaic deposits, generally from the northwest toward the southeast. The sedimentary environment gradually changed from a brackish deepwater to a shallow water — lake environment due to isolation from the Mediterranean and Eastern Paratethys (Magyar et al. 1999). At the northern margin of the Lake Pannon, marshes, swamps and deltaic systems spread in an ever-larger extent. Due to the retreat of the coastal line the lacustrine environment changed generally into alluvial also in the Late Pannonian. Later, in the Pliocene a broad area of lowlads appeared in the hinterland of the Carpathian chain. Scattered mountains (e.g. the Transdanubian Range Mts, Bükk Mts, Apuseni Mts) and basalt volcanoes formed higher morphological elevations.

At the end of the Late Miocene, tectonic inversion of the basin system (Horváth 1993, 1995; Horváth & Cloetingh 1996) led to the retreat of the aquatic sedimentary environment in the whole intra-Carpathian area, exept the central and southeastern regions. Uplift of the Eastern Alps, the Western and Eastern Carpathians was associated with angular unconformity between the Middle and Late Miocene (or younger) strata.

The architecture of the Late Miocene fill of the Pannonian basin system was distinctly influenced by paleogeographical changes. From the sequence stratigraphy and depositional systems point of view, the succession of the Late Miocene sediments can be characterized at first by a dominant portion of proximal deltaic deposits (A–C zones, *sensu* Papp 1951), which pass upward into distal deltaic to basinal fine-grained clay–silt–sandy facies (D, E zones). Fluvio-lacustrine sediments with coal seams (F–H zone) formed the terminal part of the Pannonian. The overlying Pliocene strata were deposited mostly in an alluvial sedimentary environment. The Pannonian cyclicity can be correlated by global changes Tor-1 cycle (11.6–9.3 Ma, *sensu* Hardenbol et al. 1998) and Tor-2 cycle (9.3–7.2 Ma, *sensu* Hardenbol et al. 1998).

The DEM model of the Central Paratethys during the Middle Pannonian (Fig. 4) documents the extinction of the sedimentary area of the Carpathian Foredeep, except its southeastern part and uplift of the Carpathian mountain chain. At that time, a maximum extent of brackish seawaters covered the intra-Carpathian domain.

The expected paleo-relief of the Carpathian orogenic chain in the Late Miocene began to match the present-day situation, characterized by the presence of both mountains and lowland areas. A difference can be seen in the more elevated belt of the Outer Carpathian accretionary wedge, which formed a natural barrier between flat territories of the European platform and the ever-subsiding Pannonian basin system covered by the Lake Pannon. During the Pannonian and Pliocene, basalt volcanic activity also participated in paleo-orography of the back-arc region (Kováč et al. 1998; Kováč 2000).

The Middle Pannonian vegetation (Fig. 4) corresponds to the warm temperate climatic zone with evidence of sporadically present termophilous and evergreen taxa. A higher percentual proportion of non-arboreal pollen (10 to 14 %) indicates local vegetation of partly open woodland (i.e. woods with open canopy). An increase of halophytic taxa documents the presence of coastal lagoons and marshlands during the lowstand of the brackish sea. Swamp vegetation, which grew directly on swamp substrates, is characterized mainly by noteworthy Taxodiaceae trees. They are often present in the association with Myricaceae and subordinary Nyssaceae. The riparian forest elements subdominantly occurred with *Alnus* and *Ulmus*. The extrazonal vegetation of the mountain areas with *Picea*, *Tsuga*, *Abies*, *Cedrus* is well represented in the pollen spectra.

During the Late Pannonian, the Western Carpathian paleogeography started to change. The Lake Pannon withdrew southwards, the nothern margin of the back-arc basin was slightly uplifted with the progradation of deltaic and alluvial facies, especially in lowlands. These areas were often covered by hygrophilous plants: *Myrica*, *Salix*, *Ulmus*, *Alnus*. Herbs were represented by Chenopodiaceae, Asteraceae, Ericaceae, Poaceae and *Artemisia*. Unevenly high moutain relief of the uplifted mountain chains created ideal conditions for the mixed mesophytic forests with *Carya*, *Quercus*, *Craigia*, *Carpinus*, *Fagus*, *Picea*, *Abies*, *Tsuga* and *Pinus*.

The reference sites considered on the map have been assigned to the Pannonian zones C–E *sensu* Papp 1951, namely the time slice before the major spreading of the lignite facies over the Pannonian Basin (zone F). The dating is based mostly on molluscs or regional correlation, rarely on mammals (MN9 Zone). Additional sites of Early Pannonian age (zones A–B) are shown in brackets on the map. They indicate the previous vegetation type at the Sarmatian/Pannonian boundary. Most leaf assemblages of Pannonian age are at least partly intrazonal and it is difficult to obtain a true picture of zonal vegetation from them. Most spore/pollen assemblages, mainly from the Hungarian Pannonian, have not been revised and the stratigraphic position of pollen samples remains partly uncertain.

At the very beginning of the Pannonian, subtropical conditions returned to some parts of the Central Paratethys. The thermophilous vegetation from southern Austria (Mataschen, Styrian Basin, Pannonian B — Kovar-Eder 2004) can also be found to the north-western periphery outside the Paratethys (Gozdnica) and may correspond to the Floral Assemblage ("Florenkomplex") Düren *sensu* Mai (1995) in western Europe with the latest occurrences of mastixioid plants. However, the dating of Gozdnica is still under dispute (see Dyjor et al. 1992, 1998; Mai, personal communication).

Later in the Pannonian, thermophilous evergreen, partly sub-humid vegetation remained in the south and south-eastern parts (Serbia, southern Hungary, the Borod Basin in Romania). In the Middle Pannonian, broad-leaved deciduous and Mixed Mesophytic warm-temperate to temperate forests with a low proportion of evergreen elements generally became widespread over the Central Paratethys (Styrian Basin, Molasse Zone, Vienna Basin). Characteristic elements in these communities included *Fagus haidingeri–pliocenica* complex, *Quercus* (*?Castanea*) *kubinyii*, *Quercus pseudocastanea–pseudorobur* complex, *Carpinus* sp. div., *Betula*, *Acer integrilobum*, *Acer vindobonense* and *Acer subcampestre* (syn. *Acer jurenakyi*) (Kovar-Eder 1988; Ströbitzer-Hermann 2002; Ströbitzer-Hermann & Kovar-Eder 2003). Cooling trends can be traced in spore/pollen spectra from the cores in the Pannonian Basin (Nagy & Planderová 1985; Nagy 1992). At some sites (Alsóvadász, Suchohrad) somewhat higher frequencies of Chenopodiaceae and *Artemisia* (max. 15 %) may indicate patches of herbaceous vegetation on marshes within broad-leaved deciduous forests. However, high mean annual precipitation (Bernor et al. 2003) prevented the development in this aera of open woodland and grassland vegetation like that suggested for south-eastern to southern Ukraine outside the Central Paratethys (Syabryaj 1999, 2003). Temperate purely deciduous broad-leaved forests were also spread during the Middle Pannonian in the Western Carpathians (e.g. sites at Nové Ustie in the Orava Basin and Martin in the Turiec Basin). In most cases these assemblages include a considerable proportion of intrazonal elements, both woody and aquatic (*Trapa*). Characteristic riparian woody elements were Salicaceae, *Platanus leucophylla*, *Alnus ducalis*, *Alnus cecropiifolia*, and partly intrazonal *Quercus gigas* and *Pterocarya paradisiaca*. The dominant peat-forming community during the whole Pannonian consisted mostly of the *Glyptostrobus-Byttneriophyllum-Alnus* swamp forest. This swampy coal-forming vegetation reached its widest distribution over the Pannonian Basin during the Late Pannonian, as the large extension of the lignite facies in Hungary, southern Moravia, Slovakia and Serbia corroborates (Knobloch 1969; Givulescu 1992; Pantić & Dulić 1993; Hably 2003).

Extrazonal montane conifers of all kinds (including *Tsuga*, *Cedrus*, *Picea*, *Abies*, *Keteleeria*) were found in pollen spectra throughout the Pannonian Basin as regular accessories. In the intra-montane basins macrofossils of these conifers were also formed (Nove Ustie, Martin). Therefore we may expect high mountain conifer belts reaching over 1500 m a.s.l. on the Carpathian and Alpine ridges and descending to medium altitudes, mixed with deciduous broad-leaved elements.

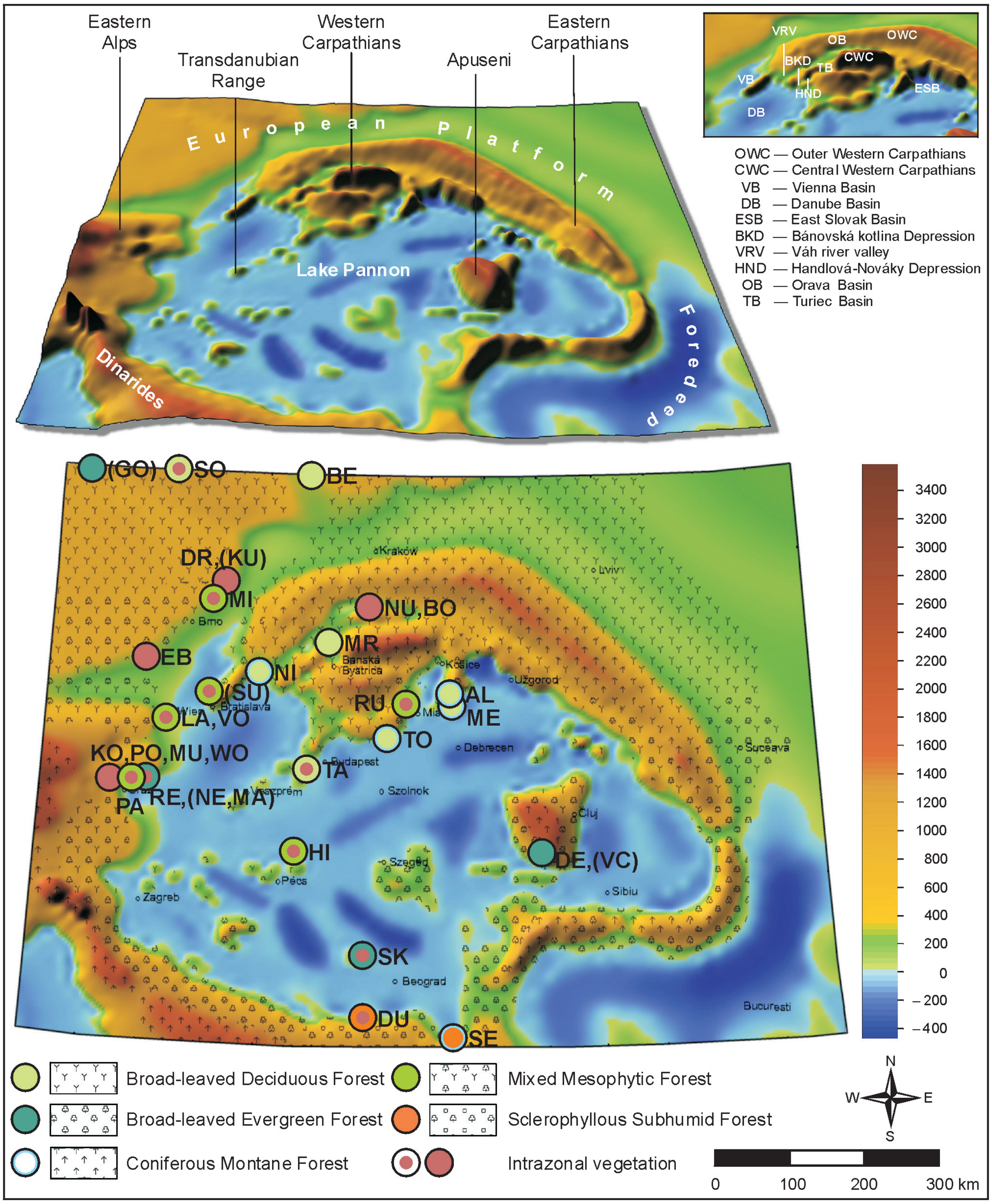


Fig. 4. DEM of the Central Paratethys: landscape & vegetation cover during the Middle Pannonian. Abbreviations of the localities (in brackets earliest Pannonian, not considered for raster pattern) and numbers of vegetation units: **AL** — (1, 10) Core Alsóvadász 1, depth 155.8–240 m, Cszerehát environment; **BE** — (1, 8, 9, 10) Belchatow, upper level (section VI.1, KRAM-P 17, Stawek-1A); **BO** — (9, 10) Bobrov, core V 6; **DE** — (3) Delureni; **DU** — (4, 9) Dubona I; **EB** — (9) Ebersbrunn; **(GO)** — (3, 8, 9, 10) Gozdnica; **HI** — (2, 8, 9, 10) Core Hidas 53, depth 298–367 m; **(HO)** — (8, 9) Höllgraben; **KO** — (9) Kogelwald, core KO 4; **(KU)** — (7, 8) Kunovice, cores KU 1, depth 42-46 m, KU 2, depth 109–174 m; **LA** — (2, 9) Laaerberg; **(MA)** — (3, 8) Mataschen near Fehring; **ME** — (1-2, 9, 10) Core Megyaszó 1, depth 52–206 m; **MI** — (2, 8) Mistřín, DV 4 Mine; **MR** — (1, 8, 9) Martin, Turiec Basin; **MU** — (7, 9) Münzengraben, core MÜ 21; **(NE)** — (3) Neuhaus/Klausenbach; **NI** — (1, 8, 10) Nitra environs, Vozokany, core N-7, Rohoznica, core N-8, Mechenice, core B-23, Pohranice, core B-25; **NU** — (8, 9) Nové Ustie, Orava Basin; **OR** — (7, 8) Ořechov, Polešovice, cores UH 18, depth 11.3 m, UH 19, depth 14.1–29.4 m; **(PA)** — (2, 8, 9) Paldau; **PO** — (7, 9) Pöllau, core PÖ 2; **RE** — (3, 8, 9) Reith near Unterstorcha; **RU** — (2, 7, 9) Rudabánya; **SK** — (3, 9) Sremska Kamenica; **SO** — (1, 8, 9) Sośnica; **(SU)** — (2, 9, 10) Core Suchohrad 32, depth 625–638 m; **TA** — (1, 9, 10) Tata, Core TVG 26 depth 7–39m; **TO** — (1, 9, 10) Core Tököl 1, depth 688.5–730 m; **(VC)** — (3, 4) Valea Crisului; **VO** — (2, 8, 9) Vösendorf; **WO** — (8, 9) Wörth near Kirchberg/Raab.

Paleoclimatic trends

Palaeoclimatic proxies are available for many sites considered in the presented maps (see Mai 1995). Most of them have been derived from "intuitive" comparisons with extant vegetation, while the objective co-existence and leaf physiognomical (CLAMP) methodologies have not been largely applied so far.

Broad-leaved evergreen forests, including the "Late Mastixioid Floras", were usually compared with similar forests in monsoon East Asia. In general, the climate corresponding to this type of vegetation was humid to per-humid (annual sum of precipitation about 1000 to 3000 mm), with heavy rains prevailing in the summer, but without any month with a humidity deficit. The temperature of the coldest month varied between 4–10 °C and absolute minima rarely reached under zero. The Mean Annual Temperature (MAT), according to various estimates (e.g. Mai 1995) varied in larger spans, according to the percentage of evergreen taxa, from 13 to almost 20 °C. The climate must have been quite equable, with a range of temperature less than 25 °C. This is a prevailing condition in the Karpatian to Lower Badenian stages over the Central Paratethys. Only in some parts, high summer mean temperatures over 20 °C and also dry substrate caused a relative humidity deficit and local expansions of sub-humid sclerophyllous (microphyllous) evergreen forests. This type of forest has nothing to do with the etesian (Mediterranean-type) climate and was probably more similar to the microphyllous montane forests in drier parts of the Himalayas today.

The cooling trends expressed by the decline of MAT in the Late Badenian over northern and eastern parts of the Central Paratethys caused changes in the forests. Evergreen elements mostly withdrew southwards and only less frost-sensitive trees remained forming the Mixed Mesophytic Forest with high representation of deciduous taxa. MAT, under which this type of vegetation optimally thrives, is variously estimated, depending on what type of forests is brought for comparison — East Asiatic or North American (Wolfe 1979). While in the former, the Coldest Month Mean Temperature (CMMT) is usually quite low (up to –2 °C), the latter thrives in warmer, subtropical conditions (northern Florida — mean annual temperature ca. 20 °C, January mean up to 10 °C). In general, the following estimation of the decline in temperature can be expected for the Central Paratethys from the published data (e.g. Mai 1995) — MAT 16(–?10) °C, that is lowering by about 3 °C in comparison with the Karpatian, and adequate lowering of the January mean, which may have been even stronger, because of decrease of climatic equability. The sum of Mean Annual Precipitation (MAP) remained high enough for humid conditions in any case, also thanks to the colder climate. Such warm temperate conditions predominated during the Late Badenian and the Middle Pannonian. In the Pannonian in northern and easterly parts of the area studied, particularly near the mountains, the Deciduous Broad-leaved Forests indicate still more severe deterioration of climatic conditions. These temperate forests dominated by deciduous oaks and beech and intermixed with various Pinaceae withstood decrease of CMMT up to –10 °C, particularly on higher altitudinal habitats. The impact of such severe winters was certainly milder due to heavy snows, as is the case today in East Asia, particularly in Japan. Equally high precipitation throughout the year also prevented expansion of herbaceous steppe vegetation, although patches of it can be noticed in the pollen record within deciduous broad-leaved forests in the Middle Pannonian. Due to high humidity of climate, extensive lignite deposits originated over most of the Paratethys area and its north and west periphery.

Conclusions

After having compiled the presented Miocene geobotanical maps according to the methodology applied above, the following conclusions can be drawn for the future research in other areas and time slices of the Cenozoic.

Contrary to various models of ancient Cenozoic vegetation that rely on the physiognomy and composition (diversity) as well as abundance of elements (e.g. Wolfe 1979; Mai 1995), the presented system of vegetation units is much more simplified. It surely suffers from various deficiencies. It neglects abundance. But this parameter is, in our opinion, not objectively derivable from frequencies of fossils in a given site or core level. Another weak point of the system employed above is that individual elements with a broader ecological span can enter more units or they are transitional and their foliar physiognomy (evergreen vs. deciduous) cannot be precisely identified (e.g. *Symplocos*, *Engelhardia*). The defined vegetation formations were certainly not profoundly clear-cut in ancient landscapes and transitions between them existed. Still the diversity percentages are most objective characteristics for a given assemblage and can be verified any time, the assignment into the system of the defined vegetation formations as characterized above (see also Kovar-Eder et al. submitted) is easy and mostly unequivocal.

According to our experience, it is advisable to use paleogeographical and geobotanical maps of narrow time slices, because they reveal better consistent patterns of vegetation and its dynamics in spite of fewer reference localities. When a longer time interval has been considered, local differences between the sites sometimes expressed trends in time rather than climatic gradients in space (see Fig. 3 for the Early-Middle Pannonian).

Megafossil and spore/pollen plant records were combined, whenever feasible, to gain better understanding of taxonomy and ecology of elements composing assemblages. Of course, great problems exist, concerning how to transfer spore/pollen diagrams with various enigmatic plant elements into a formation with known physiognomy. In the fututre, it would be desirable to unify views on the taxonomy of those elements of uncertain affinities both in megafossil and spore/pollen records.

Older data of paleobotanical and palynological research have not been neglected but revised and transferred to a common nomenclature, when the documentation (illustrations, preparations) was available and re-studied. In many cases, such assemblages and their elements were wrongly interpreted, or wrongly assigned to the natural system. Yet the current progress in knowledge of whole fossil plants is improving these inconsistencies. Actuopalynological studies of Recent vegetation (e.g. Stuchlik & Kvavadze 1987; Kvavadze & Stuchlik 1990, 1993) offered important clues for converting spore/pollen spectra into various types of real vegetation. It would be worth attempting to apply for the same sets of fossil data the new methodology presented in this account, which is based on proportions of components and diversity, along with that currently employed by palynologists, which uses abundance percentages of elements.

Acknowledgments: We appreciate discussion, data and exchange of views with our colleagues L. Stuchlik, Kraków, V. Mosbrugger and A. Bruch, Frankfurt am Main and I. Magyar, Budapest. L. Stuchlik, L. Hably and D. Ivanov as the reviewers and P. Bosák as the editor who suggested useful improvements to the first version of the text. This research has been sponsored by the European Science Foundation (Project EEDEN), by the Czech Grant Agency GAČR (Project No. 205/04/0099), Slovak Grant Agency VEGA (Projects No. 2/5016/05, 1/2035/05, 1/0080/03), project of the Slovak Research and Development Support Agency APVV-51-011305 and the Slovak Ministry of Education (Project No. AV/808/2002).

References

Baráth I., Kováč M., Soták J. & Lankreijer A. 1997: Tertiary collision, metamorphism and basin forming processes in the Eastern Slovakia (central Western Carpathians). In: Grecula et al. (Eds.): Geological evolution of the Western Carpathians. *Mineralia Slovaca — Monograph,* Bratislava, 65–79.

Bernor R.L., Kordos L., Rook L., Agusti J., Andrews P., Armour-Chelu M., Begun D., Cameron W.D., Damuth J., Daxner-Höck G., de Bonis L., Fejfar O., Fessaha N., Fortelius M., Franzen J., Gasparik M., Gentry L., Heissig K., Hernyak G., Kaiser T., Koufos G., Krolopp E., Janossy D., Llenas M., Meszaros L., Müller P., Renne P., Roček Z., Sen S., Scott R., Szyndlar Z., Topal Gy., Ungar P.S., Utescher T., van Dam J.A., Werdelin L. & Ziegler R. 2003: Recent advances on multidisciplinary research at Rudabánya, Late Miocene (MN9), Hungary: a compendium. *Palaeontogr. Italica* 89, 3–36.

Bezák V., Kováč M., Lexa J. & Plašienka D. 2002: Polystage tectonic evolution of the Western Carpathian crust. *Krystalinikum* 28, 189–196.

Bielik M., Šefara J., Kováč M., Bezák V. & Plašienka D. 2004: The Western Carpathians — interaction of Hercynian and Alpine processes. *Tectonophysics* 393, 63–86.

Böhme M. 2003: The Miocene climatic optimum: evidence from exothermic vertebrates of Central Europe. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 31, 1–13.

Cieszkowski M. 1992: Marine Miocene deposits near Nowy Targ, Magura nappe, Flysch Carpathians (South Poland). *Geol. Carpathica* 43, 339–346.

Cicha I., Seneš J. & Tejkal J. 1967: Chronostratigraphie und Neostratotypen. Miozän der Zentralen Paratethys I. M_3 Karpatian. *Vydavateľstvo SAV*, Bratislava, 1–312.

Csontos L. 1995: Tertiary tectonic evolution of the intra-Carpathian area: a review. *Acta Vulcanol.* 7, 1–13.

Csontos L., Nagymarosy A., Horváth F. & Kováč M. 1992: Tertiary tectonic evolution of the Intra Carpathian area — a model. *Tectonophysics* 208, 1, 3, 221–241.

Czaja A. 2003: Paläokarpologische Untersuchungen von Taphozönosen des Unter- und Mittelmiozäns aus dem Braunkohlentagebau Berzdorf/Oberlausitz (Sachsen). *Palaeontographica, Abt. B* 265, 1–148.

Danišík M., Dunkl I., Putiš M., Frisch W. & Kráľ J. 2004: Tertiary burial and exhumation history of basement highs along the NW margin of the Pannonian Basin — an apatite fission track study. *Aust. J. Earth Sci.* 95, 96, 60–70.

Doláková N. & Slamková M. 2003: Palynological characteristics of the Karpatian sediments. In: Brzobohatý R., Cicha I., Kováč M. & Rögl F. (Eds.): The Karpatian — an Early Miocene stage of the Central Paratethys. *Masaryk University,* Brno, 325–345.

Dunkl I. 1992: Final episodes of the cooling history of eastern termination of the Alps. In: Neubauer F. (Ed.): ALCAPA field guide — The Eastern Central Alps of Austria. Graz, 137–140.

Dunkl I. & Demény A. 1997: Exhumation of the Rechnitz Window at the border of the Eastern Alps and Pannonian Basin during neogene extension. *Tectonophysics* 272, 197–211.

Dyjor S., Kvaček Z., Łancucka-Środoniowa M., Zastawniak E., Pyszyński W. & Sadowska A. 1992: The younger Tertiary deposits in the Gozdnica region (SW Poland) in the light of recent palaeobotanical research. *Polish Bot. Stud.* 3, 1–129.

Dyjor S., Sadowska A., Hummel A., Baranowska-Zarzycka Z. & Zastawniak E. 1998: Geological position and flora of the younger neogene deposits in Lower Silesia In: Sadowska A. & Szynkiewicz A. (Eds.): Tertiary-Quaternary (Pleistocene) floras of Belchatów (Middle Poland) and several localtities in south-western Poland, Field Guide. *The 5th European Palaeobotanical and Palynological Conference, Cracow. W. Szafer Institute of Botany*, Cracow, 37–54.

Ferguson D.K., Pingen M., Zetter R. & Hofmann C.-C. 1998: Advances in our knowledge of the Miocene plant assemblage from Kreuzau, Germany. *Rev. Palaeobot. Palynol.* 101, 147–177.

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

Givulescu R. 1992: Les forets marécageuses du Miocene supérieur de Roumanie: unpaléobiotope d'exception et sa végétation dans le Miocene supérieur de l'ouest de la Roumanie. In: Kovar-Eder J. (Ed.): Paleovegetational development in Europe and regions relevant to its paleofloristic evolution. *Natur. Hist. Mus.*, Vienna, 147–151.

Hably L. 2002: The Middle Miocene flora of Magyaregregy — as shown by a study of recent collections. *Abstracts, 6th European Paleobotany-Palynology Conference*, Athens, 91–92.

Hably L. 2003: Late Neogene vegetation and climate reconstruction in Hungary. *Acta Univ. Carol. Geol.* 46, 4, 85–90.

Haq B.U., Hardenbol J. & Vail P.R. 1988: Mesozoic and Cenozoic chronostratigraphy and cycles of sea level changes. In: Wilgus C.K. et al. (Eds.): Sea-level changes — an integrated approach. *SEPM Spec. Publ.* 42, 71–108.

Hardenbol J., Thierry J., Farley M.B., Jacquin T., Graciansky P.C. & Vail P.R. 1998: Mesozoic and Cenozoic sequence chronostratigraphic framework of European Basins. In: Graciansky P.Ch., Hardenbol J., Jacquin T. & Vail P. (Eds.): Mesozoic and Cenozoic sequence stratigraphy of European Basins. *SEPM Spec. Publ.* 60, 1–786.

Horváth F. 1993: Towards a mechanical model for the formation of the Pannonian basin. *Tectonophysics* 226, 333–357.

Horváth F. 1995: Phases of compression during the evolution of the Pannonian basin and its bearing on hydrocarbon exploration. *Mar. Petrol. Geol.* 12, 837–844.

Horváth F. & Cloetingh S. 1996: Stress-induced late-state subsidence anomalies in the Pannonian Basin. *Tectonophysics* 266, 287–300.

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

Hurai V., Kihle J., Kotulová J., Marko F. & Świerrczewska A. 2002: Origin of methane in quartz crystals from the Tertiary accetionary wedge and fore-arc basin of the Western Carpathians. *Appl. Geochem.* 17, 1259–2171.

Hurai V., Širáňová V., Marko F. & Soták J. 1995: Hydrocarbons in fluid inclusions from quartz-calcite veins hosted in Paleogene flysch sediments of the Central Western Carpathians. *Miner. Slovaca* 27, 383–396.

Jiříček R. 1979: Tectogenetic development of the Carpathian arc in the Oligocene and Neogene. In: Maheľ M. (Ed.): Tectonic profiles of the West Carpathians. *Konf. Symp. Sem., GÚDŠ*, Bratislava, 205–214.

Jiříček R. 1983: Redefinition of the Oligocene and Neogene Ostracod Zonation of the Paratethys. *Knihovnička ZPN* 4, 195–236.

Klotz G. 1990: Hochgebirge der Erde und ihre Pflanzen- und Tierwelt. *Urania-Verlag*, Leipzig, Jena, Berlin, 1–355.

Knobloch E. 1969: Tertiäre Floren von Mähren. *Mor. Muz.*, Brno, 1–201.

Knobloch E. & Kvaček Z. 1996: Miozäne Floren der südböhmischen Becken. *Sbor. Geol. Věd, Paleont.* 33, 39–77.

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

Kováč M. 2000: Geodynamic, paleogeographical and structural development of the Carpatho-Pannonian region during Miocene: New view on the Neogene basins in Slovakia. *VEDA,* Bratislava, 5–203.

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

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

Kováč M., Cicha I., Krystek I., Slaczka A., Stráník Z., Oszczypko N. & Vass D. 1989: Palinspastic maps of the Western Carpathian Neogene. Scale 1:1,000,000 maps. *Ústř. Úst. Geol.,* Praha, 6 1–31.

Kováč M., Kováč P., Marko M., Károli S. & Janočko J. 1995: The East Slovakian Basin — A complex back-arc basin. *Tectonophysics* 252, 453–466.

Kováč M., Král J., Márton E., Plašienka D. & Uher P. 1994: Alpine uplift history of the central Western Carpathians: geochronological, paleomagnetic, sedimentary and structural data. *Geol. Carpathica* 45, 2, 83–97.

Kováč M., Lexa J., Konečný V. & Šefara J. 2002: Geodynamic evolution of the Carpathian Pannonian region during the Neogene. *Geol. Carpathica, Spec. Issue* 53, 1–2.

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

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

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

Kovar-Eder J. 2004: Die obermiozäne Flora von Mataschen bei Fehring, Steiermark–Blattvergesellschaftungen. *Joannea Geol. Paläont.* 5, 163–175.

Kovar-Eder J. & Kvaček Z. 2003: Towards vegetation mapping on the fossil plant record. *Acta Univ. Carol., Geol.* 46, 4, 7–13.

Kovar-Eder J., Kvaček Z. & Ströbitzer-Hermann M. 2004: The Miocene flora of Parschlug (Styria, Austria) — Revision and synthesis. *Ann. Naturhist. Mus. Wien* 105A, 45–159.

Kovar-Eder J., Jechorek H., Kvaček Z. & Parashiv V. submitted: The integrated plant record to reconstruct Neogene zonal vegetation in Europe. *Palaios.*

Kovar-Eder J., Givulescu R., Hably L., Kvaček Z., Mihajlović D., Teslenko Y., Walther H. & Zastawniak E. 1994: Floristic changes in the areas surrounding the Paratethys during Neogene time. In: Boulter M.C. & Fisher H.C. (Eds.): Cenozoic plants and climates of the arctic, NATO-ASI Ser. I: Global environmental change. *Springer,* Heidelberg, 27, 347–369.

Krenn H. 1998: Die obermiozäne (pannone) Flora von Paldau, Steiermark. *Österr. Mitt. Geol. Paläont. Landesmus. Joanneum* 56, 165–271.

Krutzsch W. 2000: Stratigraphische Tabelle Oberoligozän und Neogen (marin–kontinental). *Berliner Geowiss. Abh., E* 34, 153–165.

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

Kvavadze E.V. & Stuchlik L. 1990: Subrecent spore-pollen spectra and their relation to Recent vegetation belts in Abkhazia (northwestern Georgia, USSR). *Acta Palaeobot.* 30, 227–257.

Kvavadze E.V. & Stuchlik L. 1993: Subfossil pollen spectra of the steppe regions of east Georgia. *Acta Palaeobot.* 33, 365–376.

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

Łancucka-Środoniowa M. & Zastawniak E. 1997: The Middle-Miocene flora of Wieliczka, revision of Jan Zabłocki's collection. *Acta Palaeobot.* 37, 17–49.

Liu Yu-Sheng, Zetter R., Mohr B.A.R. & Ferguson D.K. 2001: The flowers of an extinct legume from the Miocene of southern Germany. *Palaeontographica Abt. B,* 256, 159–174.

Magyar I., Geary D.H. & Müller P. 1999: Paleogeographic evolution of the Late Miocene Lake Pannon in Central Europe. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 47, 151–167.

Mai D.H. 1964: Die Mastixioideen-Floren im Tertiär der Oberlausitz. *Paläont. Abh. B (Berlin),* 2, 1, 1–192.

Mai D.H. 1995: Tertiäre Vegetationsgeschichte Europas. *Gustav Fischer Verlag,* Jena, Stuttgart, New York, 1–691.

Mai D.H. 2001: Die mittelmiozänen und obermiozänen Floren aus der Meuroer und Raunoer Folge in der Lausitz. III. Fundstellen und Paläobiologie. *Palaeontographica Abt. B* 258, 1–85.

Meulenkamp J.E., Kováč M. & Cicha I. 1996: On Late Oligocene to Pliocene depocenter migrations and the evolution of the Carpathian-Pannonian system. *Tectonophysics* 266, 301–317.

Nagy E. 1992: A comprehensive study of Neogene sporomorphs in

Hungary. *Geol. Hung., Ser. Palaeont.* 53, 1–379.

Nagy A. & Planderová E. 1985: Palynologische Auswertung der Floren des Pannoniens. In: Papp A., Jámbor A. & Steiniger F.F. (Eds.): Chronostratigraphie und Neostratotypen Miozän der Zentralen Paratethys. *Akadémiai Kiadó,* Budapest, 7, 586–615.

Navrotskaya I.L., Syabryaj S.V., Bezusko L.G., Stuchlik L. & Tasenkevich L.A. 1991: The Ugolsky massif — a refuge of thermophilic flora in the Ukrainian Carpathians. *Acta Palaeobot*. 31, 261–272.

Nemčok M. & Lexa J. 1990: Evolution of the basin and range structure around Žiar mountain range. *Geol. Zborn. Geol. Carpath.* 41, 229–258. In: Brzobohatý R., Cicha I., Kováč M. & Rögl F. (Eds.): 2003: Karpatian — a Lower Miocene Stage of the Central Paratethys. *Masaryk University,* Brno, 93–96.

Němejc F. 1951: On the mutual relations of the fossil floras of the coal basin of Handlová and of several sediments of the ryolithic mountain region S of Kremnica (Slovakia). *Sbor. Ústř. Úst. Geol., Odd. Paleont*. 18, 197–207 (in Czech).

Němejc F. 1967: Palaefloristical studies in the Neogene of Slovakia. *Acta Mus. Nat. Pragae B* 23, 1–32 (in Czech).

Oszczypko N. 2003: The Polish Outer Carpathians and their Foredeep in the Karpatian. In: Brzobohatý R., Cicha I., Kováč M. & Rögl F. (Eds.): Karpatian — a Lower Miocene Stage of the Central Paratethys. *Masaryk University*, Brno, 49–72.

Pantić N. & Dulić I. 1993: Pontian palynomorphs in Serbia. In: Planderová E. et al. (Eds.): Paleoflor. Paleoclim. Chang. Cret. Tert. *Geol. Úst. D. Štúra*, Bratislava, 181–186.

Papp A. 1951: Das Pannon des Wiener Beckens. *Mitt. Geol. Gesell. Wien* (1946–1948), 39–41, 99–193.

Pavelić D. 2001: Tectonostratigraphic model for the North Croatian and North Bosnian sector of the Miocene Pannonian Basin System. *Basin Res.* 13, 359–376.

Planderová E. 1990: Miocene microflora of Slovak Central Paratethys and its biostratigraphical significance. *Dionýz Štúr Inst. Geol.,* Bratislava, 1–144.

Plašienka D. & Kováč M. 1999: How to loop Carpathians — an attempt to reconstruct Meso-Cenozoic palinspastic history of the carpathian orocline. *Geol. Carpath., Spec. Issue* 50, 63–165.

Plašienka D., Grecula M., Putiš M., Kováč M. & Hovorka D. 1997: Evolution and structure of the Western Carpathians: an overview. In: Grecula et al. (Eds.): Geological evolution of the Western Carpathians. *Mineralia Slovaca — Monograph,* Bratislava, 1–25.

Popov S.V., Rögl F., Rozanov A.Y., Steininger F.F., Shcherba I.G. & Kováč M. 2004: Lithological-paleogeographic maps of Paratethys. *Cour. Forsch.-Inst. Senckenberg* 250, 1–46, 10 maps (Late Eocene to Pliocene).

Royden L.H. 1993a: The tectonic expression of slab pull at continental convergent boundaries. *Tectonics* 12, 2, 303–325.

Royden L.H. 1993b: Evolution of retreating subduction boundaries formed during continental collision. *Tectonics* 12, 629–638.

Rögl F. 1998: Paleogeographic consideration for Mediterranean and Paratethys Seaways (Oligocene to Miocene). *Ann. Naturhist. Mus. Wien* 99A, 279–310.

Rögl F., Spezzaferri S. & Corić S. 2002: Micropaleontology and biostratigraphy of the Karpatian-Badenian transition (Early-Middle Miocene transition) in Austria (Central Paratethys). *Cour. Forsch.-Inst. Senckenberg* 237, 47–67.

Rudinec R. 1989: New view on the paleogeographic development of the Transcarpathian depression during the Neogene. *Miner. Slovaca* 21, 27–42.

Rudinec R. 1990: Vertical distribution of Neogene sediments in the Transcarpathian depression. *Miner. Slovaca* 22, 393–398.

Rylova T., Yakubovskaya T. & Khursevich G. 1999: Palaeobotanical evidence for correlating the stratigraphy of the Neogene deposits of Belarus. *Acta Palaeobot. Suppl.* 2, 359–363.

Shvareva N.Ya. 1965: Correlation of the Lower Sarmatian and Upper Tortonian fossil flora from the Lvov and Fore-Carpathian areas. *Dokl. AN SSSR*, 163, 4, 952–955 (in Russian).

Sitár V. 1967: Tertiärflora aus der Umgebung von Levice. *Acta Geol. Geogr. Univ. Comen., Geol.* 12, 155–162.

Sitár V. 1982: Tertiäre Flora des SW-Teiles des Turiec-Beckens (Westkarpaten*). Acta Geol. Geogr. Univ. Comen., Geol.* 38, 191–206.

Sitár V. & Kováčová-Slamková M. 1999: Palaeobotanical and palynological study of the Upper Badenian sediments from the NE part of the Vienna Basin (locality Devínska Nová Ves). *Acta Palaeobot. Suppl.* 2, 373–389.

Slamková M. 2004: Paleovegetion and climatic trends during the Middle and Upper Miocene in Vienna Basin. Manuscript. *Dissertation*, *Dept. of Geology and Paleontology — Comenius University,* Bratislava, 1–87 (in Slovak).

Soták J. & Kováč M. 2002: Paleogeographic changes of the West Carpathian Paleogene basins in time of Paratethys separation. *Geol. Carpathica, Spec. Issue* 53, 7–8.

Ströbitzer-Hermann M. 2002: Systematik, Variabilität, regionale und stratigraphische Verbreitung sowie Ökologie der Gattung *Acer* L. in Mitteleruopa vom Oligozän bis ins Pliozän. *Manuscript, Diss. Thesis, Formal. Naturwiss. Fakultät, Universtiät,* Wien, 1–253.

Ströbitzer-Hermann M. & Kovar-Eder J. 2003: *Acer* L.: Some stratigraphically relevant species and their importance as potential indicators of vegetation conditions. *Acta Univ. Carol., Geol.* 46, 4, 101–106.

Stuchlik L. 1994: Neogene pollen flora of Central Europe. Part 1. *Acta Palaeobot. Suppl.* 1, 3–56.

Stuchlik L. & Kvavadze E.V. 1987: Subrecent sporo-pollen spectra and their relation to Recent forest vegetation of Colchis (western Georgia, USSR). *Palaeontographica*, *Abt. B* 207, 133–151.

Syabryaj S.V. 1992: Vegetation and volcanism in the Neogene of the Transcarpathians. In: Kovar-Eder J. (Ed*.)*: Palaeovegetational development in Europe and regions relevant to its palaeofloristic evolution. *Natur. Hist. Mus.*, Vienna, 231–234.

Syabryaj S.V. 1999: Palaeolandscapes of the Late Sarmatian *Hipparion* Fauna Stage of the Ukraine (using palynological data). *Acta Palaeobot. Suppl.* 2, 399–401.

Syabryaj S.V. 2003: Vegetation and climate of the Ukraine in the Neogene. *Acta Univ. Carol. Geol.* 46, 4, 49–55.

Syabryaj S.V. & Stuchlik L. 1994: Development of flora and vegetation of the Ukrainian Estern Carpathians and Polish Western Carpathians. *Acta Palaeobot*. 34, 165–194.

Syabryaj S.V. & Stuchlik L. 2004: Palaeofloristic and palaeoclimatic reconstruction on the territories of Ukraine and Poland during the Badenian-Sarmatian. *Acta Palaeobot.* 44, 55–68.

Tari G., Horváth F. & Rumpler J. 1992: Styles of extension in the Pannonian Basin. *Tectonophysics* 208, 203–219.

Ticleanu N. 1984: Contributions to the study of the Upper Badenian flora from Romania. *D. S. Inst. Geol. Geofiz. Paleont*. 68, 135–150.

Tomek Č. & Hall J. 1993: Subducted continental margin imaged in the Carpathians of Czechoslovakia. *Geology* 21, 535–538.

Yakubovskaya (Jakubovskaya) Z. 1993: Evolution of flora and climate in the Miocene of Belarus. In: Planderová E. et al. (Eds.): Paleoflor. Paleoclim. Chang. Cret. Tert. *Geol. Úst. D. Štúra,* Bratislava, 153–158.

Vass D., Hók J., Kováč P. & Elečko M. 1993: The Paleogene and Neogene tectonic events of the Southern Slovakia depressions in the light of the stress-field analyses. *Miner. Slovaca* 25, 2, 79–92.

Vass D., Kováč M., Konečný V. & Lexa J. 1988: Molasse basins and volcanic activity in Western Carpathian Neogene — its evolution and geodynamic chracter. *Geol. Zbor. Geol. Carpath.* 39, 5, 539–561.

Walther H. & Zastawniak E. 2005: Sapindaceae (Aceroideae) from the late Miocene flora of Sośnica near Wrocław, a revision of Goeppert's original materials and a study of more recent collections. *Acta Palaeobot*. 45, 85–106.

Walther H. & Zetter R. 1993: Zur Entwicklung der paläogenen Fagaceae Mitteleuropas. *Palaeontographica*, *Abt. B* 230, 183–194.

Wernike G. 1985: Uniform sense simple shear of continental lithosphere. *Canad. J. Earth Sci*. 22, 108–125.

Wolfe J.A. 1979: Temperature parameters of humid and mesic forests of Eastern Asia and relation to forests of other regions of the Northern Hemisphere and Australasia. *U. S. Geol. Surv. Prof. Pap*. 1106, 1–37.

Zetter R. 1998: Palynological investigation in the opencast mine Oberdorf, N Voitsberg, Styria, Austria. *Jb. Geol. Bundesanst*. 140, 4, 461–468.

N. Jb. Geol. Paläont. Abh. 279/2 (2016), 209–238
Stuttgart, February 2016

Article

The Lower Badenian transgressive-regressive cycles – a case study from Oslavany (Carpathian Foredeep, Czech Republic)

Slavomír Nehyba, Katarína Holcová, Przemysław Gedl, Nela Doláková

With 13 figures and 2 tables

Abstract: Two newly drilled boreholes (OSL-1 and OSL-2) at Oslavany (Carpathian Foredeep, Czech Republic, a holostratotype of the Moravian/Lower Badenian) provide data documenting the processes of the Lower Badenian marine transgression and regression along the passive margin of the peripheral foreland basin (south-eastern margin of the Bohemian Massif). Three facies associations show the evolution of the deposition and distinct basin margin paleogeography. Deposits of marine transgression (transgressive lag) are followed by open-marine (outer to inner shelf) deposits interpreted as transgressive and highstand systems tract. They reflect a cratonward shift of the coastline. The topmost foreshore and upper shoreface deposits (falling stage systems tract) recorded forced regression and basinward shift of the shoreline. The recorded transgressive-regressive cycle was induced by the coincidence of global TB 2.4. sea-level cycle and forebulge subsidence. The identified higher-frequency cycles were interpreted as climatically controlled.

Key words: Facies analyses, provenance, foraminifera, calcareous nannoplankton, dinoflagellate cysts, shoreline position.

1. Introduction

The majority of siliciclastic shallow marine systems and their associated hydrocarbon reservoirs are regressive and regressive units typically form most of the sediment volume within any given T-R cycle (Reynolds 1999). Such regressive deposits within a high frequency relative sea level cycle are typically characterized by a shallowing-upward shoreline succession, or parasequence (Van Wagoner et al. 1988). On the other hand, it is the flooding surface or corresponding transgressive deposits that most strongly affect the correlation of marginal marine deposits. While transgressive and regressive units can appear to be stratigraphically correlative, they in reality formed at different times. Transgressions and regression within high-resolution stratigraphical records are commonly rapid events and their time difference is commonly disregarded, being beyond biostratigraphic resolution. However, the correlation and interpretation of T-R cycles is crucial in peripheral foreland basins because the formation of accommodation space in distal and proximal parts of such basins is governed by different factors and commonly resulted in stratigraphically reciprocal stacking pattern (Heller et al. 1988; Catuneanu et al. 1997, 1999). For that reason, a detailed study of regional T-R events can provide unique insights into the role of tectonics, eustasy and sediment supply (i.e. into the detailed evolution of basin paleogeography and evolution).

Shallow marine deposits that were preserved along the outer cratonward margin of the Carpathian Foredeep are traditionally interpreted as transgressive ones (Čtyroký 1991; Brzobohatý & Cicha 1993). More recent studies (Nehyba 2000; Zagoršek et al. 2012;

DOI: 10.1127/njgpa/2016/0548
www.schweizerbart.de
0077-7749/2016/0548 $ 7.50

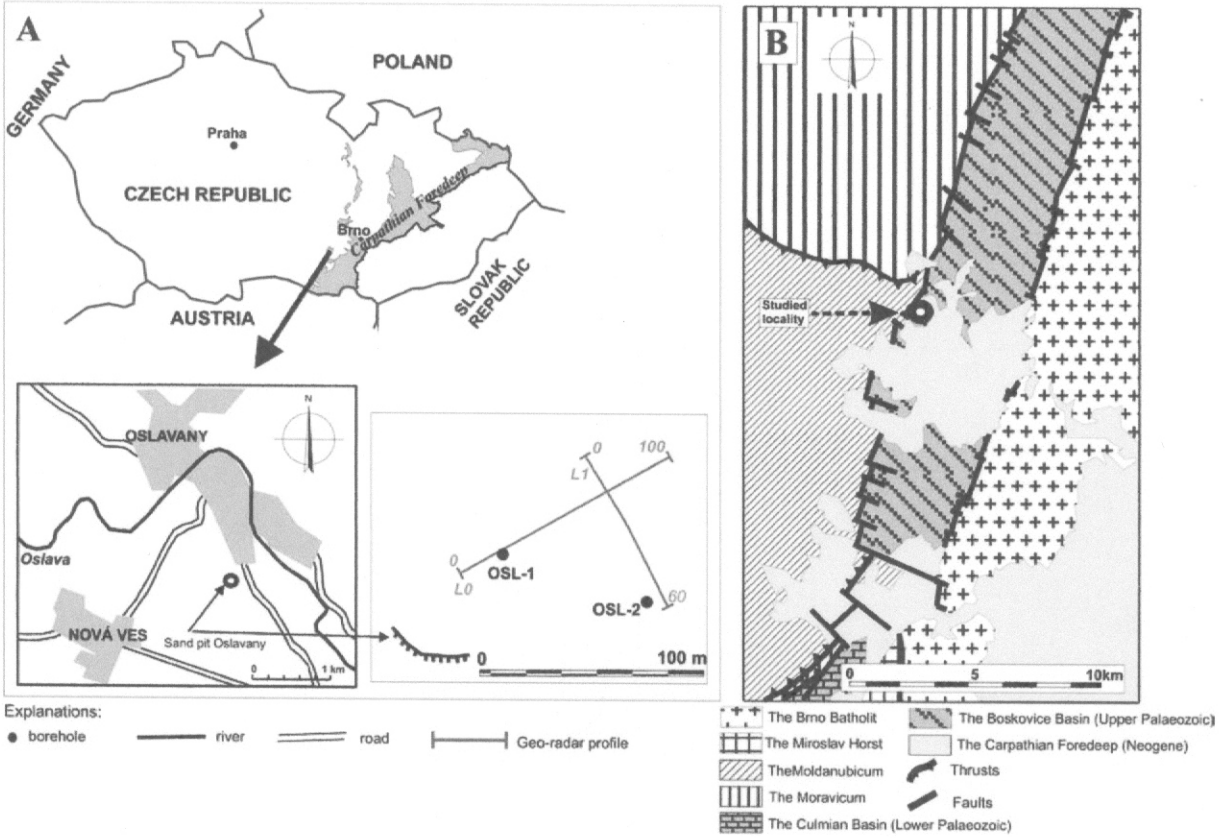


Fig. 1. (A) Geographic location of the Neogene Carpathian Foredeep in the area of Czech Republic and the Oslavany boreholes (OSL-1 and OSL-2) and georadar profiles. (B) Simplified geological map of the broader surroundings of the locality.

Hladilová et al. 2014; Holcová et al. 2015a) reveal that a significant portion of these deposits is in reality regressive. The Oslavany sand pit is connected with the Lower Badenian transgression as a holostratotype of the Moravian (Lower Badenian) deposits of the Carpathian Foredeep (Papp et al. 1978). The revision of the deposits at Oslavany presented in this paper demonstrates that the deposits provide more complex data about the evolution of the basin during the Lower Badenian T-R cycle TB 2.4. (Haq et al. 1988; Hohenegger et al. 2014).

2. Geological setting

The studied Neogene deposits represent the sedimentary infill of the Carpathian Foredeep, which formed as a peripheral foreland basin due to the tectonic emplacement and crustal loading of the Carpathian orogen onto the flexed western margin of the Bohemian Massif. Sedimentation in this sector of the basin started in the Egerian/Early Eggenburgian and continued into the Late Badenian (Brzobohatý & Cicha 1993). The early Middle Miocene (Badenian) forms a distinct stage in the evolution of the basin when the basin geometry was reorganised by the northward (NW- to NNW-oriented) structural contraction of the Carpathian orogenic wedge (Kováč 2000; Nehyba & Šikula 2007).

The sand pit at Oslavany (GPS location 49°06.820 N and 016°20.237 E) represents an important outcrop of the Carpathian Foredeep deposits in southern Moravia. The sand pit was formerly established as a type locality of Oncophora (Rzehakia) Beds (Rzehak in Papp et al. 1978), although Cicha & Tejkal (1958) already demonstrated the Early Badenian age of the deposits and recognised the redeposition of the older Ottnangian deposits. The outcrop was evaluated as holostratotype of the Moravian (Lower Badenian) deposits of the Carpathian Foredeep (Cicha in Papp et al. 1978), reflecting the Lower Badenian transgression represented by the local lithostratigraphic unit of Brno sands. Because the sand pit is no longer active, the original extent of the profile (cf. Cicha in Papp et al. 1978) has been severely reduced and represents only the upper-most part of the former outcrop. These deposits were interpreted as a product of deposition in foreshore and shoreface zones (Nehyba et al. 2009); however, the Brno sands are a product of coarse-grain delta deposition. The occurrence of soft-sediment deformations were recognised and evaluated as "seismites" in the succession of the Oslavany sand pit (Nehyba 2014). Two new drilled boreholes have been produced in the close vicinity of the sand pit, marked as OSL-1 and OSL-2, to obtain data about the complete sedimentary succession. The results of the complex investigation of the cores of these boreholes are presented in this paper. The positions of the boreholes, sand pit and georadar profiles, are presented in Fig. 1, where a simplified geological map of the locality is also available.

3. Methods

Lithofacies analysis, according to Tucker (1995), Walker & James (1992) and Nemec (2005), is based on sedimentary structures and textures. Because the deposits are mostly unlithified, the preservation of sedimentary structures was partly affected by the drilling. Combined sieving and laser methods were used for grain size analysis (26 analyses). The Retch AS 200 sieving machine analysed the coarser grain fraction (4-0.063 mm, wet sieving); the Cilas 1064 laser diffraction granulometer was used for the analyses of the finer fraction (0.0004-0.5 mm). Ultrasonic dispersion, distillate water and washing in sodium polyphosphate were used prior to analyses in order to avoid flocculation of the analysed particles. The average grain size is demonstrated by the graphic mean (Mz) and the uniformity of the grain size distribution/sorting by the standard deviation (σI) (Folk & Ward 1957). The shape and roundness of the coarsest grain fraction (>4 mm – sieve separation) were estimated visually using the Powers (1982) method. Heavy minerals were quantified through a counting method under a polarizing microscope in the grain-size fraction 0.063-0.125 mm (11 analyses). The opaque minerals were not considered in the calculation. The mineral compositions of selected heavy minerals were determined using a Cameca SX 100 electron microprobe at the Joint Laboratory of Electron Microscopy and Microanalyses of Masaryk University and the Czech Geological Survey Brno. Data from 110 analysed garnet grains and 32 analysed rutiles were available. The gamma-ray spectra (GRS) were measured by a GR-320 enviSPEC laboratory spectrometer with a 3x3 in. NaI(Tl) scintillation detector (Exploranium, Canada). Counts per second in selected energy windows were directly converted to concentrations of K (%), U (ppm) and Th (ppm). One measurement of 30-minutes was performed for each measured sample (34 samples – min. 300 g).

Ground penetrating radar (GPR) scanning was done with Pulse Ekko Pro radar (manufactured by the Canadian company Sensor & Software), at a frequency of 50 MHz with an antenna distance of 3 m. The measurement interval was 0.5 m.

Foraminifera were studied from 63-2000 μm fraction and about 200-300 specimens from each sample were determined. Standard microscope slides were prepared for calcareous nannoplankton study using a light microscope (normal and crossed nicols, 1000x magnification). About 200-500 specimens of calcareous nannoplankton were determined from individual samples. The abundance of nannoplankton was expressed semiquantitatively based on the number of specimens in the visual field of the microscope (Zágoršek et al. 2009).

Foraminiferal as well as calcareous nannoplankton assemblages were statistically classified using the Non-metric Multidimensional Scaling technique of PAST software (Hammer et al. 2001). Correlations among the relative abundances of species in the samples were enumerated using the Spearman correlation coefficient. Calcareous nanoplankton and foraminiferal samples are stored at the Institute of Geology and Paleontology, Charles University, Prague.

Pollen and spores were studied in 20 samples, which were treated with cold HCl (35%) and HF (70%) to remove carbonates and silica. Separation of the palynomorphs and other organic particles from the rest of the residue was carried out using $ZnCl_2$ (density = 2g/cm^3). Due to the increasing amount of palynomorphs, part of the samples was sieved (10 μm). Pure glycerine was used as the observation medium. Part of the samples was observed under fluorescence microscopy to detect reworked palynomorphs (Van Gijzel 1971; Dolakova & Buresova 2007). Samples are stored at the Department of Geological Sciences MU, Brno.

Seven samples for dinoflagellate studies were processed following a palynological procedure including 38% hydrochloric acid (HCl) treatment, 40% hydrofluoric acid (HF) treatment, heavy liquid ($ZnCl_2$+HCl; density 2.0 g/cm^3) separation, ultrasound for 10-15 s and sieving at 15 μm on a nylon mesh. No fuming nitric acid (HNO_3) treatment was applied. The quantity of rock processed equalled 20 g for each sample. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

4. Results

4.1. Biostratigraphy

4.2.1. Foraminifera and calcareous nannoplankton

The biostratigraphical correlation of the section is based on the first and last occurrences of planktonic foraminifera and calcareous nannoplankton index species (Fig. 2). Planktonic foraminiferal biostratigraphical correlation might be based on the co-occurrence of *Orbulina suturalis* and *Praeorbulina circularis* that corresponds within the time span of 15.1-14.9 Ma in the world's ocean (Gradstein et al. 2012). However, in the Mediterranean the base of the interval is dated

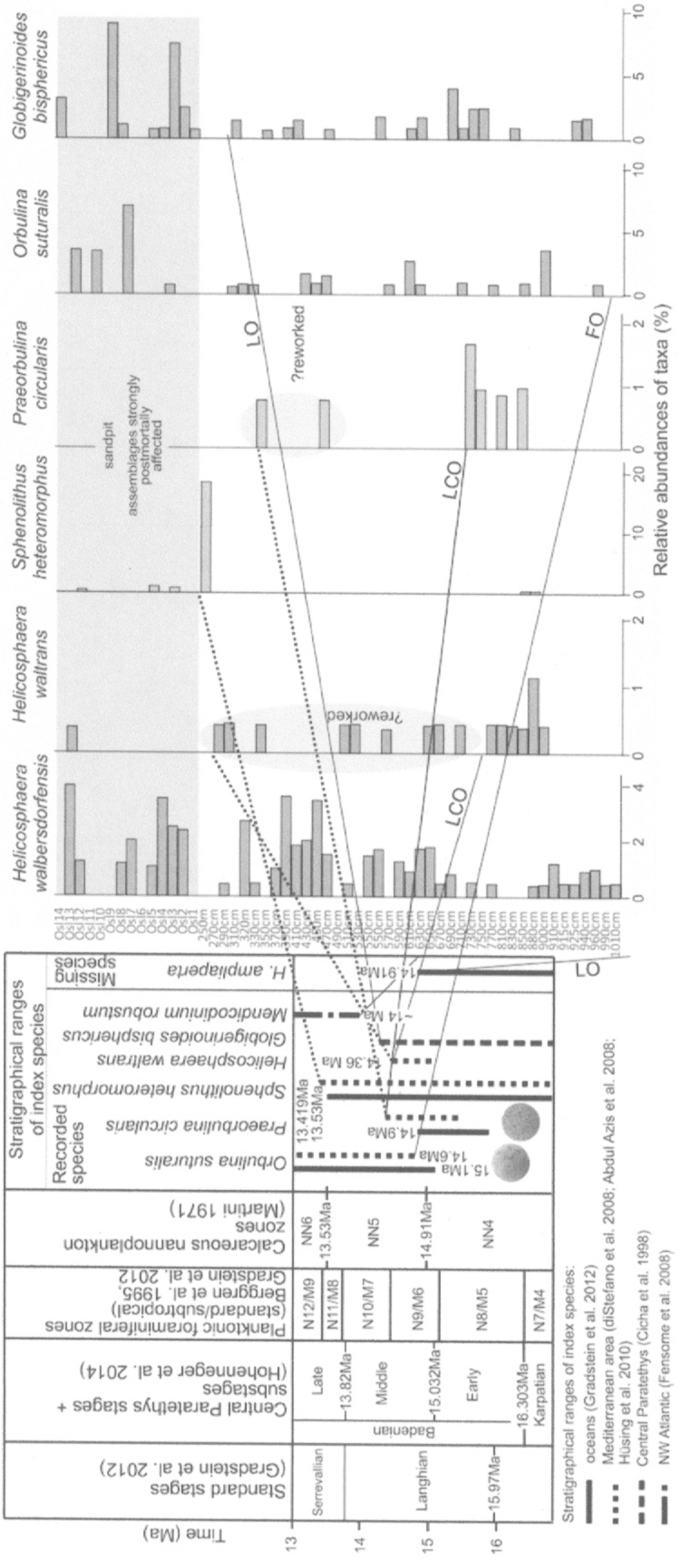


Fig. 2. Biostratigraphical correlations of OSL-1 borehole and sand pit Oslavany. FO = the first occurrence of species, LO = the last occurrence of species, LCO = the last common occurrence of species

at 14.6 Ma (= the FO of *Orbulina suturalis*), while the upper boundary is unclear (Abdul Azis et al. 2008; Hüsing et al. 2010). Calcareous nannoplankton assemblages enable correlation with the NN5 Zone due to the occurrence of *Sphenolithus heteromorphus* and the absence of *Helicosphaera ampliaperta* (14.91-13.53 Ma; Gradstein et al. 2012). The significant biostratigraphical marker *Helicosphaera waltrans* is present to a level of 270 cm, but the continue occurrence finished at a level of 770 cm above which the abundances of *Helicosphaera walbersdorfensis* increased. From the Mediterranean, the LCO (Last Common Occurrence) of the species is given at 14.357 Ma (Abdul Aziz et al. 2008). In the study area, the event is related to an increase of *H. walbersdorfensis* abundances (Holcová et al. 2015b). As such, the LCO of *Helicosphaera waltrans* can be correlated with the peak of its continual occurrence at a level of about 770 cm. For the local Central Paratethys biostratigraphy, the occurrence of *Globigerinoides bisphericus* is significant and indicates the Karpatian-Moravian interval (Cicha et al. 1998).

The biostratigraphical correlation of the Oslavany sand pit is not very clear, because the relative abundances of reworked calcareous nannoplankton are the highest in the Early Badenian of the Carpathian Foredeep (8-22%). The Oligocene (*Cyclicargolithus abisectus, Reticulofenestra bisecta*) as well as Cretaceous taxa (*Watzenaueria* sp., *Archangeskiella* sp., *Micula* sp.) are the most common; occasionally also Eocene *Chiasmolithus* sp. was recorded. Among planktonic foraminifera, Createaceous *Globotruncana* sp. and the Early Miocene *Cassigerinella* occur rarely. Therefore, a marker of the NN5 Zone *Sphenolithus heteromorphus* may be considered to be reworked and the section might be younger than the NN5 Zone. However, a younger species has not been identified as such in foraminifera even in calcareous nannoplankton assemblages; therefore, the correlation with the NN5 Zone is also assumed for the section in Oslavany.

Summarizing this data, foraminiferal and calcareous nannoplankton assemblages enable the correlation of the drill and the section with an interval from 14.6 Ma (the FO of *Orbulina suturalis*) to 13.53 Ma (the LO of *Sphenolithus heteromorphus*). It agrees well with the Central Paratethys substage Moravian (Papp et al. 1978), traditionally Early Badenian, recently redefined as Mid Badenian (Hohenegger et al. 2014).

4.1.2. Dinoflagellate cysts

The studied dinoflagellate cysts represent forms with relatively long stratigraphic ranges (cf. e.g., Powell 1992; de Verteuil & Norris 1996; Williams et al. 2004). Most of them are known from the Badenian strata of the central part of the Carpathian Foredeep, both from pre- and post-evaporitic series (Gedl 1996, 1997, 2005; Peryt & Gedl 2010; Gedl & Peryt 2011; Peryt et al. 2014). However, most typical species for the pre-evaporitic series (*Unipontidinium aquaeductum, Labyrinthodinium truncatum, Palaeocystodinium striatogranulosum*) are missing in the material studied. Their absence suggests that the Oslavany succession is older or younger than the NN5-NN6 zones. *Unipontidinium aquaeductum* – a typical species for this time interval, appeared for the first time during early Middle Miocene that correlated with the NN5 Zone (de Verteuil & Norris 1996). According to Williams et al. (2004), this species appeared in Northern Hemisphere mid-latitudes close to the Langhian-Serravalian boundary (i.e. mid part of the NN5 Zone; Berggren et al. 1995). *Labyrinthodinium truncatum* appeared earlier, at the Burdigalian-Langhian boundary that correlated with the mid part of the NN4 Zone (Berggren et al. 1995).

Cribroperidinium tenuitabulatum is another species that has been described from the pre-evaporitic deposits of the Carpathian Foredeep (Gedl 1996, 1997) that correlated with the upper part of NN5 and lower part of NN6. No record of this species in post-evaporitic series of the Carpathian Foredeep has been documented so far (Gedl & Peryt 2011; Andreychouk et al. 2014; Peryt et al. 2014). This suggests that the dinoflagellate cysts studied are older than the main transgressive event in the central sector of the Carpathian Foredeep that took place during the Badenian.

Dinoflagellate cyst-based age interpretation is being disputed with the one based on foraminifera and calcareous nannoplankton, which correlate the drillhole and the section with the interval from 14.6 Ma (the FO of *Orbulina suturalis*) to 13.53 Ma (the LO of *Sphenolithus heteromorphus*). This suggests that the older age proposed from dinoflagellate cyst data, that is Burdigalian (correlated with at least the lower part of NN4) is improbable, and that the absence of *Labyrinthodinium truncatum* may be caused by environmental factors.

Interestingly, the species *Mendicodinium robustum* occurs (Tab. D1) in a sample from the depth of 6.3 m. This species was described by Zevenboom and Santarelli (in Zevenboom 1995) from the Upper Miocene strata of Italy. According to these authors, its stratigraphic range includes the latest Middle Miocene to early Late Miocene. Williams et al. (2004) date the earliest appearance of this species at 13.25 Ma, that

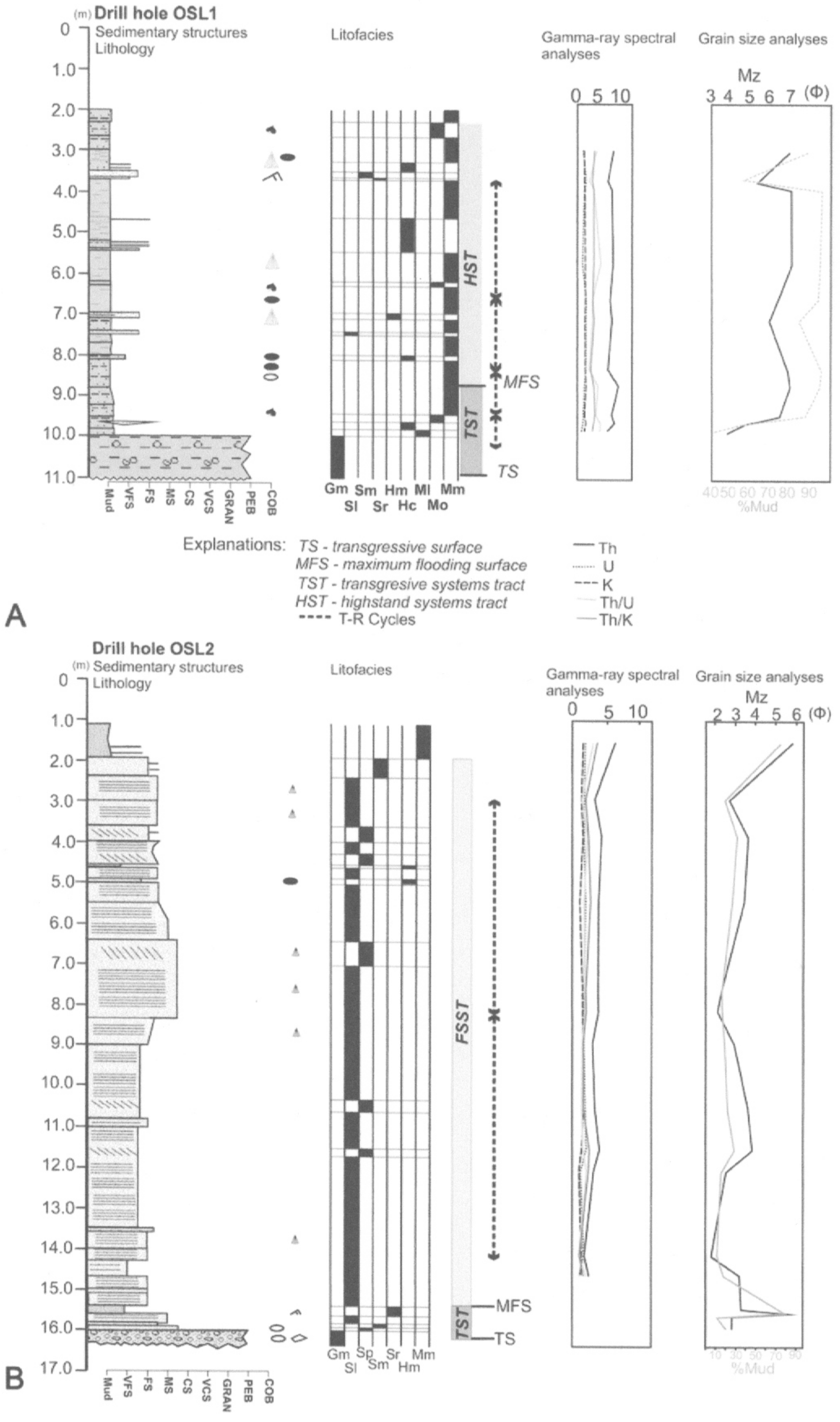

Drill hole OSL1
(m)
Sedimentary structures
Lithology
Litofacies
Gamma-ray spectral analyses
Grain size analyses
Mz
3 4 5 6 7 (Φ)
0 5 10
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
Mud
VFS
FS
MS
CS
VCS
GRAN
PEB
COB
Gm
Sl
Sm
Sr
Hm
Hc
Ml
Mo
Mm
HST
MFS
TST
TS
40 50 60 70 80 90
%Mud
Explanations:
TS - transgressive surface
MFS - maximum flooding surface
TST - transgresive systems tract
HST - highstand systems tract
T-R Cycles
Th
U
K
Th/U
Th/K
A
Drill hole OSL2
2 3 4 5 6 (Φ)
12.0
13.0
14.0
15.0
16.0
17.0
Sp
FSST
10 30 50 70 90
B

Fig. 3.

Table 1. Descriptive summary list of early Badenian lithofacies distinguished in the Oslavany OSL-1 and OSL-2. Mz is the mean grain size and σI is grain-size sorting.

Facies symbol	Description
Gm	Light yellow to yellowish brown, whittish grey to whitish brown gravel, matrix supported (matrix of light yellow fine sand or muddy sand), poorly sorted. Subangular to subrounded pebbles, max. clast up to 6 cm in diameter. Milky quartz, arkoses and gneisses are most common in pebbles. Facies represents 12.1% of the succession of the drill hole OSL1 and 2.1% of the OSL2.
Sp	Grey, brown mottled, medium to coarse grained sand, cross stratified, poorly sorted due to admixture of granules and small pebbles up to 2 cm in diameter. Admixture of light mica. Mz = 3.6-3.8ϕ, σI = 1.7-2.2 ϕ. Facies represents 12.4% of the succession of OSL2.
Sm	Light grey to whittish grey, brown mottled, fine to medium massive/structureless sand, common occurrence of light mica, calcareous. Mz = 2.8ϕ, σI = 2.2 ϕ. Facies represents 1.8% of the succession of the drill hole OSL1 and 3.8% of OSL2.
Sl	Light grey, yellow green, light brown mostly fine to very fine sand, rarely medium grained, well sorted, planar lamination, horizontal or slightly inclined, calcareous. Common occurrence of light mica, locally shell debris. Mz = 1.8-3.4ϕ, σI = 1.1-2.0ϕ. Facies represents 1.2% of the succession of the drill hole OSL1 and 73.6% of OSL2.
Sr	Light yellow very fine sand, silty sand, well sorted, ripple-cross stratification. Mz = 2.8-5.6ϕ, σI = 1.1-2.7ϕ. Facies represents 0.6% of the succession of the drill hole OSL1 and 1.4% of OSL2.
Hm	Reddish brown, light brown-grey very fine to fine sand with laminas of brown and brown-green silt. Well sorted. Mz = 6.0ϕ, σI = 1.1 ϕ. Facies represents 1.2% of the succession of the drill hole OSL1 and 1.0% of OSL2.
Hc	Olive green to green-yellow clayey mud with laminas and small lenses of yellow-green fine sand. Calcareous. Mz = 3.9-5.4ϕ, σI = 2.0-3.2 ϕ. Facies represents 14.5% of the succession of the drill hole OSL1.
Mm	Light green-grey, yellow-green, grey-green mud or sandy, sometime reddish or whitish mottled. Large variations in the proportion of fine sand. Massive, calcareous, occurrence of calcareous concretions.. Mz = 5.8-7.1ϕ, σI = 1.5-2.3ϕ. Facies represents 59.0% of the succession of the drill hole OSL1 and 5.8% of OSL2.
Ml	Grey-brown, dark mottled, muddy sand to sandy mud, calcareous, planar laminated. Occurrence of shell debris. Mz = 6.5-7.0ϕ, σI = 1.5-2.4 ϕ. Facies represents 2.4% of the succession of the drill hole OSL1.
Mo	Grey to dark grey sometime black mottled clayey mud with admixture of plant fragments. Facies represents 8.4% of the succession of drill hole OSL1.

is the upper part of the NN6 Zone (upper part of Serravalian; Berggren et al. 1995). Thus, its presence in the material studied may indicate a younger age of the Oslavany succession, or that the stratigraphic range of *M. robustum* is wider than it was previously believed. This agrees with the observations of Fensome et al. (2008), who recorded the FCO of species at a level of about 14.0 Ma below the LO of *Sphenolithus heteromorphus* in the NN5 Zone.

4.2. Sedimentary geology

4.2.1. Facies analyses, sedimentary petrography, gamma-ray spectral analyses

Ten lithofacies were recognised according to grain size and the rarely preserved sedimentary structures in both boreholes. The description of lithofacies is presented in Table 1. The lithofacies have been combined, based on their spatial grouping and depositional architecture, into three facies associations (cf. Reading 1996). The distribution of both lithofacies and facies associations significantly differ within the studied boreholes, which

---

Fig. 3. Sedimentological core logs of the Oslavany boreholes OSL-1 (A) and OSL-2 (B) with an explanatory legend (C). The logs include palaeontological data and show the stratigraphic distribution of sedimentary facies (letter code as in Table 1), plot of mean grain size and sequence-stratigraphic interpretation (letter symbols explained in legend).

is marked in the lithostratigraphic logs (Fig. 3 a, b). A depositional stacking pattern can be seen to some extent in the ground penetrating radar profiles (Fig. 4 a, b).

The first facies association (FA 1) is formed by the only Gm lithofacies and was recognised in both boreholes in the lowermost part of the successions. The recognised thickness of FA 1 varies between 0.2 to 1 m, but the actual one is larger because the base of the bed was not reached. The gravels are poorly sorted and structureless, sandy matrix supported. Subangular to subrounded pebbles (max. clast up to 6 cm in diameter) of milky quartz, arkoses and gneisses are distributed within a fine sand or muddy sand matrix. The heavy mineral assemblages of FA 1 differ from the results obtained for FA 2 and FA 3. Garnet is the most common heavy mineral forming 33.0% of the spectra; there are also zoisit-epidote (27.5%), amphibole (13.8%) and disthene (24.3%) are present in significant amounts. Zircon, apatite, sillimanite, tourmaline, monazite, rutil and titanite are accessories. The value of ZTR index (zircon+tourmaline+rutil) content – a criterion for the mineralogical "maturity" of heavy mineral assemblages (cf. HUBERT 1962; MORTON & HALLSWORTH 1994) is relatively low (1.1%).

The second facies association (FA 2) is formed by 8 lithofacies (Sl, Sm, Sr, Hm, Hc, Ml, Mo and Mm); however, mudstone facies (Ml, Mo, Mm) strongly dominate (forming 67.5%). FA 2 was recognized only in the OSL1 borehole and these deposits were previously not known from the locality in such thickness and position. The occurrence of a gravelly fraction was rarely recognised within the FA 2 and its petrography is relative monotonous. Pebbles of milky quartz (predominantly spherical, rarely bladed or discoidal in shape) usually dominate (forming 34.8-78.9%). They are mostly subrounded or subangular; less common are rounded and only rarely are there ones that reach 1 cm in diameter. Pebbles of various types of gneisses (bladed, discoidal and elongated in shape, mostly subangular or subrounded) represent 10.6-38.9%. The gneisses commonly represent the largest pebble within the sample, with a diameter of up to 2 cm being noted. Subangular to subrounded pebbles of quartz+feldspar aggregates were also recognised (forming 10.5%-25.8%). Their shapes vary highly. Small pebbles of mica schists, phyllites, and amphibolites were exceptional, forming only up to a few percent of the pebble spectra. The intensity of weathering of the pebbles of metamorphic rocks varies considerably.

The heavy mineral assemblages of the FA2 are characterised by the significant prevalence of garnet, its content ranging between 47.1% and 58.3% (average, AVG 52.9%); there are higher contents of zoisit-epidote (3.4-12.2%, AVG 9.1%) and amphibole (7.3-12.7%, AVG 9.8%). The contents of disthene, zircon, apatite, sillimanite, tourmaline, staurolite, monazite, rutil and andalusite are usually only a few percent. Titanite, spinel, anatas and pyroxene were recognised only exceptionally. The value of the ZTR index is relatively low, ranging between 4.9 and 7.4% (AVG 6.0%).

Deposits of the FA 2 have relatively lower concentrations of K (Ø 2.1%), with average concentrations of U (Ø 1.9 ppm) and Th (Ø 8.6 ppm), as compared with the concentrations of the average Earth's crust. Deposits of the FA 2 often show relatively low variations for K (standard deviation, SD 0.2), U (SD 0.3) and Th/K (SD 0.3), whereas slightly higher variations were observed for Th (SD 0.8) and Th/U (SD 1.0). The K and Th concentrations show high correlation (linear regression coefficient; R = 0.64). On the other hand, negative or no correlation were recognised for concentrations of Th and U (R = -0.25) and for K and U (R = -0.09). Thus we can presume a similar source of signal for Th and K, but a different one for U. Low positive correlations between K (R = 0.20), Th (R = 0.40), U (R = 0.30) and clay content, and negative correlations between K (R = -0.20), Th (R = -0.34), U (R = -0.45) and sand fraction both reflect that the dominant hosting minerals of these radio elements are contained in clay fraction. The gamma ray spectra distribution shows a considerable degree of vertical organisation (Fig. 3A). Several "narrow funnel shaped" cycles can be recognised, connected with an upward increase mainly in the content of Th and value of Th/U, and partly also in the content of K and the value of Th/K. The thickness of these cycles varies between 0.5 to 1.8 m. The "absolutely" highest concentrations of Th and K were recognised in the sample from a depth of 8.7 m; the highest concentrations of U were recognised in the directly adjacent sample at a depth of 8.3 m. The cycles of gradual increase/decrease in gamma can be compared with these results of grain size analyses, that is in the distribution of mean grain size Mz and in the content of mud fraction (Fig. 3A).

The third facies association (FA 3) is formed by five lithofacies (Sp, Sm, Sl, Sr and Hm) with an absolute predominance of sandy lithofacies (forming 98.6% of the FA). FA 3 was recognised only in the OSL 2 borehole (Fig. 3B) and these deposits can be well compared to the situation in the sand pit.

The petrography of clastic pebbles reveals the wide spectra of rocks from surrounding geological units and

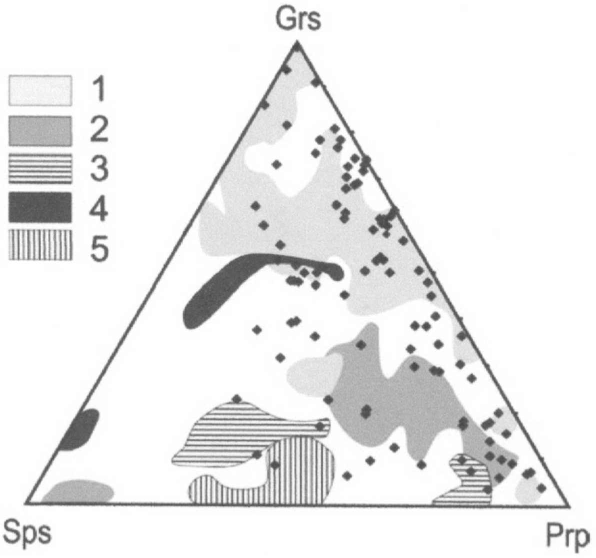


Fig. 4. Ternary diagram of the chemistry of detrital garnets (GRS: grossular, PRP: pyrope, SPS: spessartine) in comparison with possible source areas (1 Moravicum, 2) Moldanubicum, 3) Svratka Crystalline Complex, 4) granites of Brno Massif, 5) migmatites of Brno Massif). Data from crystalline rocks according to Buriánek et al. (2012).

Table 2. Garnet types of the studied deposits (OSL) compared with the data from the Boskovice Basin (BB) (ALM – almandine, GRS – grossular, PRP – pyrope, SPS – spessartine, AND – andradite).

Garnet type	OSL %	BB %
ALM(82-90)	9.1	5.3
ALM(49-83)-PRP(11-48)	29.3	50.4
ALM(69-70)-PRP(14-18)-SPS(11-12)	1	0.8
ALM(50-64)-PRP(18-27)-GRS(10-22)	5.1	2.3
ALM(58)-GRS(22)-SPS(16).	-	0.8
ALM(48-76)-GRS(12-37)	29.3	16.7
ALM(54-728)-GRS(12-28)-PRP(10-17)	17.2	11.3
ALM(50-83)-SPS(12-42)	3	4.5
ALM(71-72)-SPS(13-15)-PRP(10-11)	-	2.3
ALM(42-56)-SPS(21-27)-GRS(15-21)-PRP(13-15)	-	1.6
ALM(44-56)-SPS(25-29)-GRS(18-23)	3	-
GRS(66-89)-AND(11-31)	-	1.5
GRS(74)-PRP(13)-AND(12)	-	0.8
GRS(50-53)-ALM(37-41)	2	0.8
GRS(69)-ALM(14)-SPS(12)	1	-
PRP(40)-AND(36)-ALM(20)	-	0.8

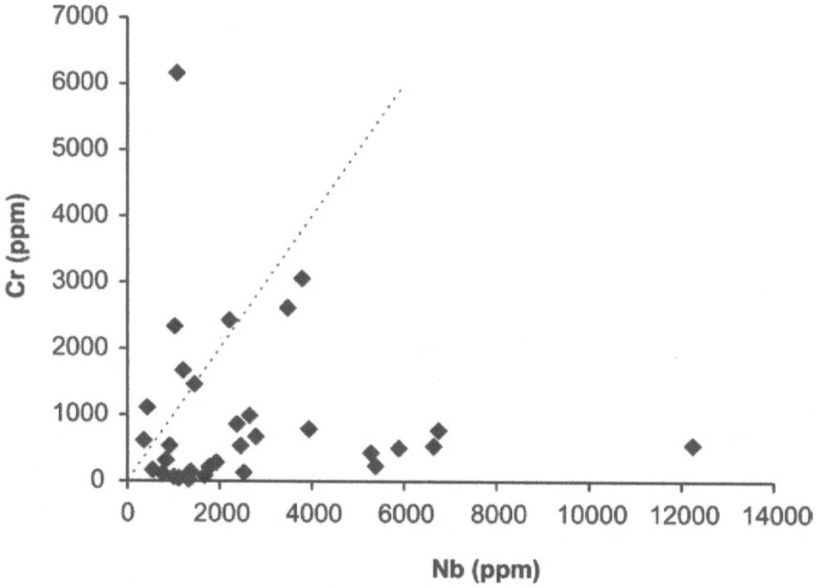


Fig. 5. Discrimination plot Cr vs. Nb of investigated rutiles.

varies highly within individual samples. Three different groups of samples were recognised based on the pebble composition. The dominance of pebbles (typically spherical, or bladed, rarely discoidal of elongated in shape, mostly subrounded, and less commonly rounded and subangular) of Permo-Carboniferous arkoses and shales is typical for the first group, which was usually identified in the lower part of the succession of FA 3. The predominance of subangular or subrounded pebbles of milky quartz with mainly spherical or discoidal shape, less commonly bladed shape, is typical for the second group of samples. Some lower occurrence of mostly subrounded or subangular pebbles of mica schists, gneisses, phyllites, quartz+feldspar aggregates and quartzites was identified in both group 1 and 2. Finally, the third group is typical with a dominance of subrounded to rounded, commonly discoidal or spherical pebbles of phyllites and mica shists. Gneisses, quartzites, orthoquartzite ("sun-stone") and milky quartz are less commonly present in this group. Pebbles are generally relatively small (mostly less than 1 cm in diameter).

The heavy mineral assemblages of the FA 3 are typical in their high dominance of garnet, where its content ranges between 50.3% and 67.5% (AVG 61.5%). Higher contents of amphibole (max. 15.8%, AVG 8.4%) and disthene (max. 11.0%, AVG 6.4%) were also observed. The contents of zircon, apatite, sillimanite, tourmaline, staurolite, monazite, rutil and andalusite are a few percent only. Titanite, spinel, anatas and pyroxene were recognised exceptionally. The value of the ZTR index is relatively low, ranging between 4.4 and 6.6% (AVG 5.3%).

Deposits of the FA 3 have relatively low concentrations of K (Ø 1.7%) and Th (Ø 4.5 ppm); the average concentrations of U (Ø 2.1 ppm) are lower than the average of the Earth´s crust. They often show a relatively low variation for K (SD 0.2); higher for U (SD 0.6) and Th/U (SD 0.3), whereas high variations were observed for Th (SD 2.0) and for Th/K (SD 1.0). The U and Th concentrations show high correlation (R = 0.78); positive correlations were also recognised for concentrations of Th and K (R = 0.5) and for K and U (R = 0.53). Positive correlations between Th (R = 0.74), U (R = 0.51), K (R = 0.22) and clay content were observed. These observations point to a similar source of signal for all radioelements (i.e. dominantly in the clay fraction). The negative correlation between K (R = -0.33), Th (R = -0.90), U (R = -0.73) and sand support this interpretation. The gamma ray spectral logs are relatively flat and only a poorly developed general increase of Th content towards the top of FA 3 can be followed (Fig. 3B).

Significant vertical organisation can be recognised in the distribution of mean grain size Mz and in the content of mud fraction. Two "bow shaped" cycles with gradual increase followed by a gradual decrease of both Mz and mud content can be identified. These cycles can be partly compared with variations in the Th content and Th/K or Th/U ratios.

Garnet, as the most common heavy mineral in all the studied samples, was further evaluated by analyses of its chemistry. The results are presented in Table 2 and Fig. 4. The garnet composition is relatively wide. Although almandine garnets predominate, ten types of garnets were determined. Pyrope-almandines and grossular-almandines predominate, each comprising 29.3% of the spectra. Pyrop-grossular almandines make 17.2%, almandines represent 9.1%, grossular-pyrope-almandines comprise 5.1%, spessartine-almandines and grossular-spessartine almandines also each similarly form 3.0% of the studied grains. Almandine-grossulars, spessartine-almandine grossulars and spessartine-pyrope almandines were only exceptional. The spectra of garnets can be compared with data from the Permo-Carboniferous deposits of the Boskovice Basin (Nehyba et al. 2012; see Table 2) and results from possible crystalline source rocks (Buriánek et al. 2012) in Fig.4.

Rutile represents one of the most stable heavy minerals and so is attractive for provenance analysis (Force 1980; Zack et al. 2004; Triebold et al. 2005; Stendal et al. 2006; Meinhold et al. 2008). The concentration of the main diagnostic elements (Fe, Nb, Cr, and Zr) varies significantly in the rutiles from Early Badenian deposits. The majority (87.5%) of rutiles reveal concentrations of Fe above 1000 ppm. The concentration of Nb varies between 360 and 12250 ppm (AVG 2728 ppm); those of Cr vary between 20 and 6160 ppm (AVG 949 ppm); those of Zr between 10 and 2080 ppm (AVG 515 ppm), and the value of logCr/Nb is mostly negative (90.3 %). The discriminate plot Cr vs. Nb is presented in Fig. 5. The Zr-in-rutile thermometry was applied for metapelitic zircons only (cf. Zack et al. 2004a, b; Meinhold et al. 2008) and the results indicate that 47.1% belong to the amphibolite/eclogite facies; 35.3% of metapelitic rutiles originate from granulite metamorphic facies; and 17.6% belong to the greenschist/blueschist facies. The rutile data can be compared with similar data for the Permo-Carboniferous deposits of the Boskovice Basin (Nehyba et al. 2012). These possible source rocks reveal a higher portion of rutile from magmatic rocks (12.5%) and metamafic rocks (38.8%), thus showing significantly lower provenance from metapelites (50.8%) than the studied Early Badenian rutiles.

4.2.2. Ground penetrating radar

Two geo-radar profiles (GPR) were measured in the locality with the aim to determine the relief of the un-

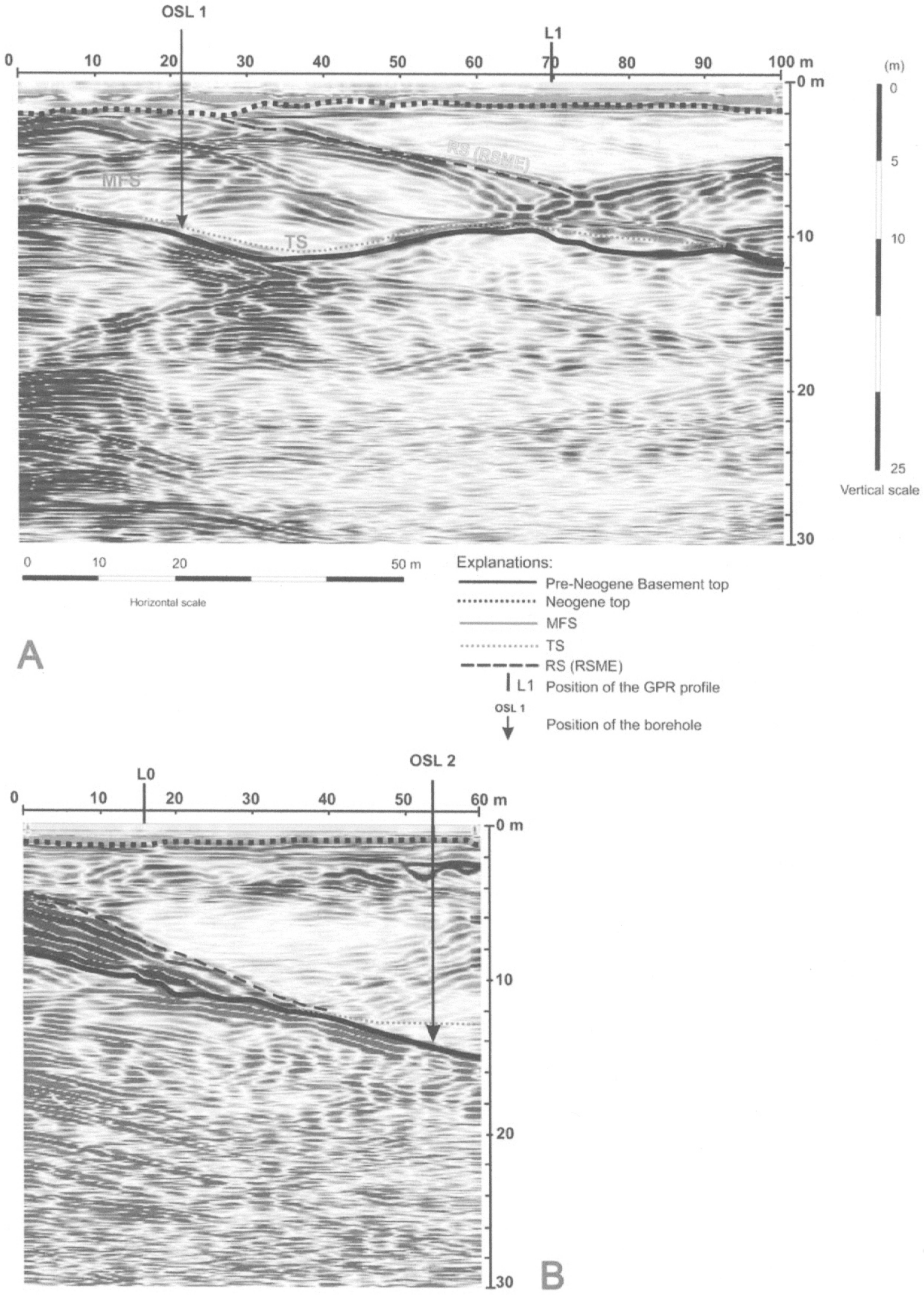


Fig. 6. Ground penetration radar profiles (A) Profile L0, (B) Profile L1.

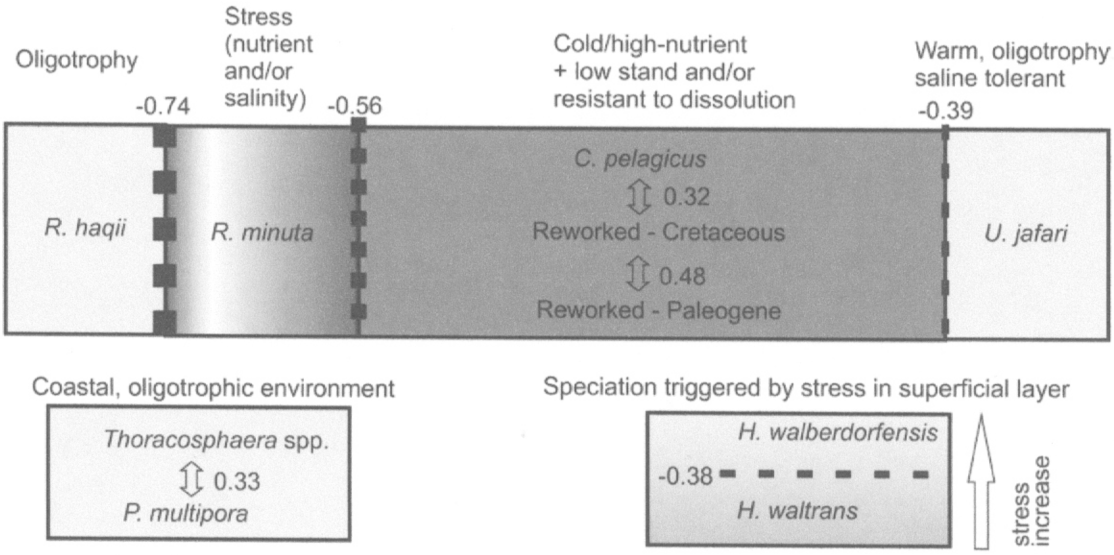


Fig. 7. Ecological interpretations of the most abundant calcareous nannoplankton taxa as a source of paleoenvironment interpretation of OSL-1 borehole and sand pit Oslavany

derlying pre-Neogene bedrock and to better understand the depositional architecture of the studied deposits after calibration by OSL 1 and 2 boreholes.

The interpretation of the GPR indicates (Fig. 6 A, B) that the Lower Badenian sediments rest on the highly irregular surface of pre-Neogene bedrock formed by the Permo-Carboniferous deposits of the Boskovice Basin. The top part (about 10 m) of the bedrock is deeply weathered with the upper surface inclined SE or E. The thickness of the Lower Badenian deposits ranges from 9 to about 16 m. The deposits of FA 1 were recognised along the contact with the pre-Neogene basement. They are typified by relatively high amplitude reflectors mostly aligned along the irregular base (i.e. "mantle geometry"). The thickness of the FA 1 is mostly about a few dm, but can be enriched in depressions of the basement. The surface of FA1 is broadly undulated and generally follows the undulations of the pre-Neogene basement. The deposits of FA 2 reveal in the majority a generally planar (i.e. "aggradational") to slightly convex upward arrangement; reflectors are more continuous with higher frequency than in FA 1. The onlap onto the undulated base is poorly developed. The aggradational arrangement transforms into more progradational/accretional one in the upper part of the FA 2. A prograding stacking pattern with generally continuous reflectors (inclined E-SE) and a downlap onto the undulated or sub-horizontal top of deposits of FA 1 or possibly pre-Neogene basement can be followed. Inclined broadly tabular to slightly wedge-shaped geometry is connected with the deposits of the lower part of FA 3. The upper part of the deposits of FA3 can be connected with sub-horizontal to slightly inclined, less continuous reflectors. The top surface of Neogene deposits is sub-horizontal, irregular and generally follows the surface morphology.

4.3. Palaeobiology

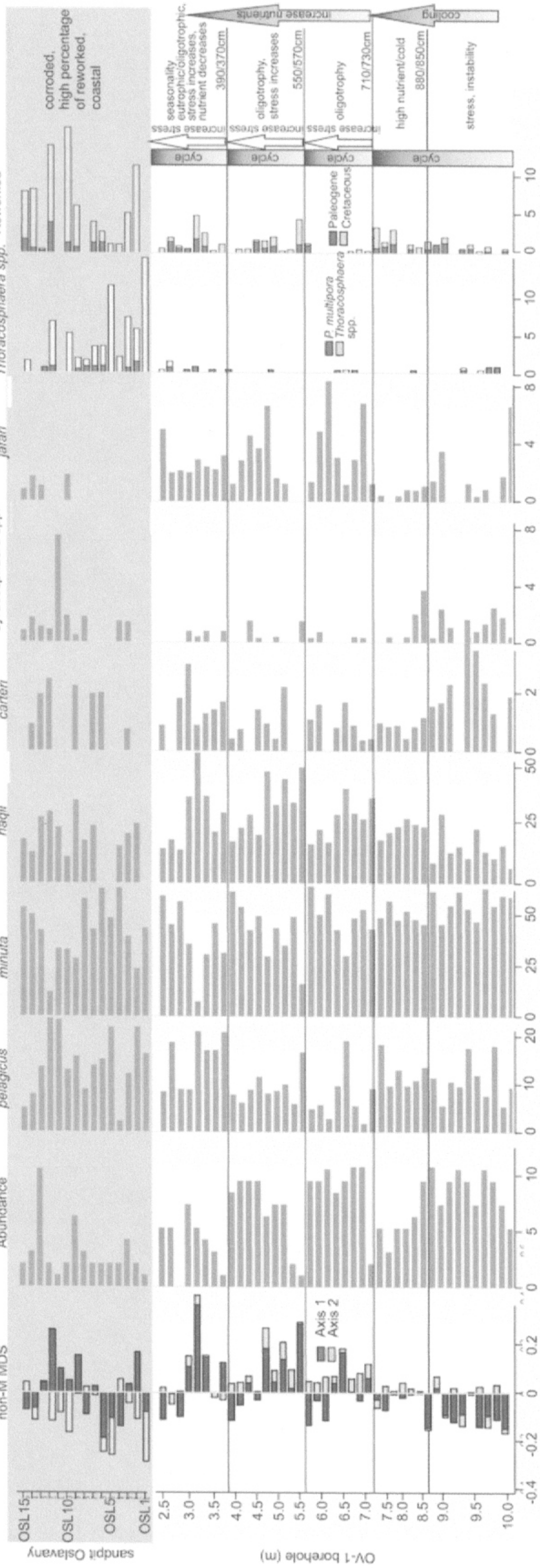
The cores from OSL 2 were not available for the paleobiological studies so samples from the walls of the sand pit were taken to partly substitute them. The conditions in the sand pit are well comparable with the upper part of the FA 3 succession (i.e. datum 0 to 8 m).

4.3.1. Foraminiferal and calcareous nannoplankton assemblages

4.3.1.1. Calcareous nannoplankton

The actuoecological data as well as relations among species abundances in individual samples (expressed by the Spearman correlation coefficient) were used for paleoecological interpretation (Fig. 7):

Reticulofenestra minuta negatively correlated with *R. haqii* and *Coccolithus pelagicus* and indicates stress conditions in the upper layer, including oscillations of salinity and/or nutrient content (Wells & Okada 1997; Flores et al. 1997; Wade & Bown 2006).



Reticulofenestra haqii negatively correlated with *R. minuta* and according to previous interpretations (Holcová et al. 2015a) indicate rather oligotrophic but full marine conditions.

Umbilicosphaera jafari negatively correlated with *Coccolithus pelagicus* and *Thoracosphaera* spp. and show affinities to warmer rather oligotrophic water (Ziveri et al. 2004). Böckel et al. (2006) described its tolerance to saline water.

Coccolithus pelagicus negatively correlated with *R. minuta* and *Umbilicosphaera jafari*. This agrees with its traditional interpretation as an indicator of cold, but mainly nutrient-rich water (Okada & McIntyre 1979; Winter et al. 1994; Cachao & Moita 2000). Its positive correlation with reworked taxa may indicate relations of colder interval with low stand with more reworked taxa, or more probably with a higher resistance of *Coccolithus pelagicus* as well as *Watzenauria* spp. and large *Cyclicargolithus abisectus* and *Reticulofenestra bisecta* to dissolution.

Thoracosphaera spp. positively correlated with *Pontosphaera multipora*. *Thoracosphaera* spp. is a general proxy for oligotrophy or a stratified water column (Höll et al. 1998; Vink et al. 2002). *Pontosphaera* spp. represent a coastal environment of open shallow to deep subtidal shelf (Amarasi et al. 2014).

The negative correlation between *H. waltrans* and *H. walbersdorfensis* reflects the gradual replacements of large *H. waltrans* by smaller *H. walbersdorfensis*, which can be caused by a stress increase in the superficial water during this stratigraphically significant event.

Using results of non-metric MDS and variability of relative abundances of the most common taxa as well as an abundance of calcareous nannoplankton, five intervals were recognized in the OSL1 borehole; one significantly different interval characterizes the Oslavany section. The variegated abundances of taxa discussed in (i) to (vi) were followed in individual intervals to interpret paleoenvironmental changes within the studied interval (Fig. 8).

The calcareous nannoplankton assemblages from the sand pit can be interpreted like postmortally transported and/or reworked according to the following indicators: (i) They have the highest recorded abundances

Fig. 8. Results of the Non-metric Multidimensional Scaling, abundance of calcareous nannoplankton and relative abundances of the most common calcareous nannoplankton taxa in the OSL-1 borehole and sand pit Oslavany.

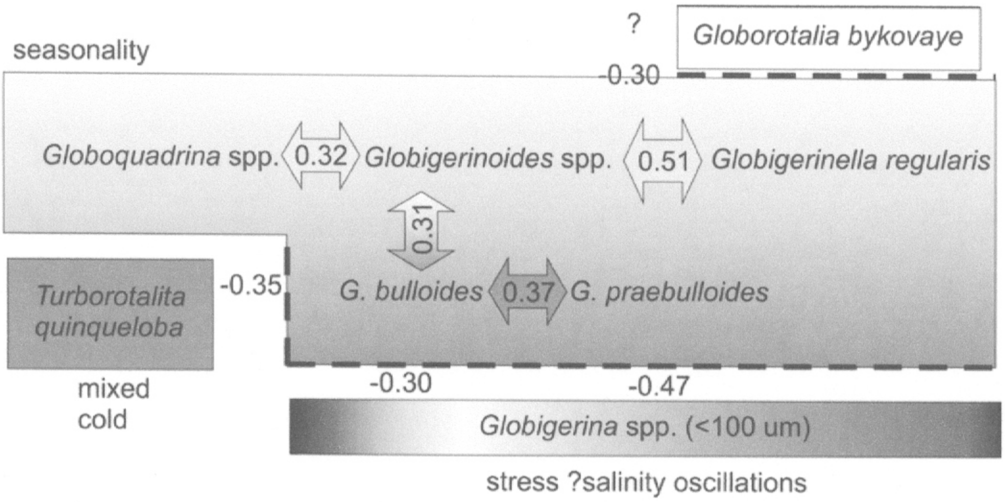


Fig. 9. Ecological interpretations of the most abundant planktonic foraminifera taxa as a source of paleoenvironment interpretation of OSL-1 borehole and sand pit Oslavany.

of reworked nannoplankton in the Carpathian Foredeep (also including nannoplankton from the shallow-water limestones; Holcová et al. 2015a); (ii) there is unusually strongly damaged nannoplankton especially in the upper part of the section; (iii) nannoplankton is nearly absent in the sample in which the most indigenous foraminifera have been recorded.

4.3.1.2. Planktonic foraminifera

The Spearman coefficient enables us to define four characteristic taxa or groups of taxa (Fig. 9) which can be paleoecologically interpreted:

Turborotalita quinqueloba negatively correlated with the 4-chambered *Globigerina bulloides-praebulloides* group and represents a marker of cold non-stratified water (Rohling et al. 1993).

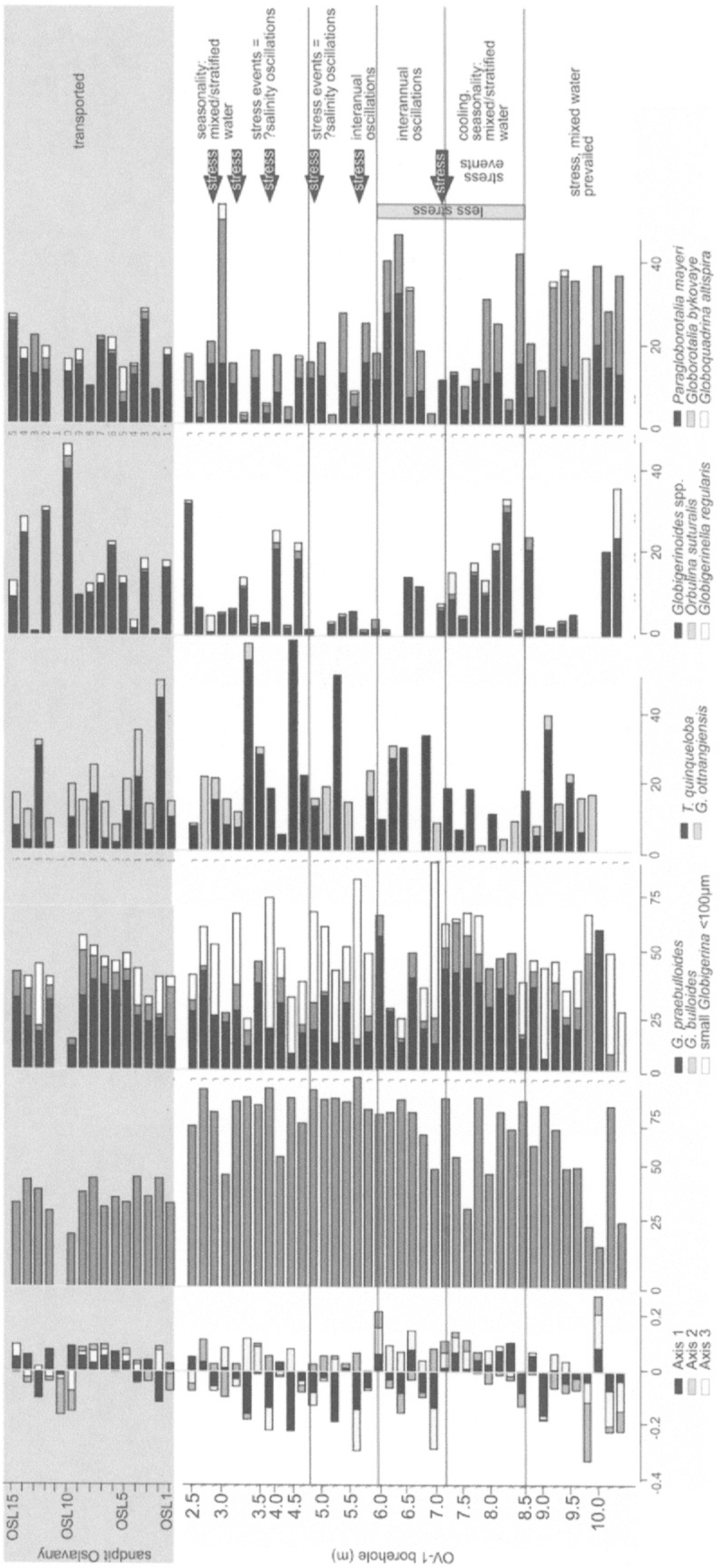
Small 4-chambered *Globigerina* spp. (<100 µm) negatively correlated with larger *Globigerina praebulloides* and *bulloides*. Generally, the size oscillations of *Globigerina* reflect a variegated environment: the largest tests occur in the optimum environmental conditions for this species (Malmgren & Kennett 1978). Then, the extremely small tests indicate environmental stress, including e.g. oscillation of nutrient content and/or salinity.

The *Globigerina bulloides* and similar but smaller *G. praebulloides* represent opportunistic species that bloomed in a high-productivity regimen (Schiebel et al. 1997). They co-occur with markers of warm, oligotrophic and stratified-water such as *Globigerinoides* spp., *Globigerinella regularis* and *Globoquadrina* spp. (Bé 1977; Reynolds & Thunell 1985; Hemleben et al. 1989; Schiebel & Hemleben 2005). The co-occurrence of *Globigerinoides* spp. and *Globigerinella* spp. with *Globigerina* spp. suggests seasonal succession of assemblages (e.g. Reynold & Thunell 1985; Rigual-Hernandez et al. 2012; Kuhnt et al. 2013; Salmon et al. 2014).

The ecological preferences of *Globorotalia bykovaye* are not known; it was probably a deep-dweller that agrede with its dominance in the deepest central part of the basin (borehole Ry-1; Kopecká 2012). The isotopic composition (unpublished data) showed a wide range of oxygen isotopic values and greater variability of carbon isotopic values between the values of the oligotrophic *Globigerinoides-Orbulina* group and the eutrophic *Globigerina bulloides-praebulloides* group.

Based on non-metric MDS and variance in relative abundances of the most common planktonic foraminiferal taxa, five intervals were recognized in the OSL-1 borehole (Fig. 10). The paleoenvironmental interpretations of these intervals are based on the above given paleoecological interpretations of the most common taxa.

The paleodepth estimated from sedimentological data (first meters) indicates that whole of the planktonic foraminiferal assemblages from the Oslavany sand pit could not be autochtonous and must have been postmortally transported from a deeper part of the basin or reworked from older sediments.



sandpit Oslavany
OSL15
OSL10
OSL5
OSL1
OV-1 borehole (m)
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
non-MMDS
Axis 1
Axis 2
Axis 3
-0.4
-0.2
0
0.2
P/B-ratio
Four-chambered Globigerina spp.
G. praebulloides
G. bulloides
small Globigerina <100µm
Five-chambered Globigerina + Turborotalita
T. quinqueloba
G. ottnangiensis
Relative abundances (%)
Warm-water/oligotrophic taxa
Globigerinoides spp.
Orbulina suturalis
Globigerinella regularis
Globorotaliids
Paragloborotalia mayeri
Globorotalia bykovaye
Globoquadrina altispira
transported
seasonality; mixed/stratified water
stress events = ?salinity oscillations
stress events = ?salinity oscillations
interanual oscillations
interannual oscillations
cooling, seasonality; mixed/stratified water
stress, mixed water prevailed
stress
less stress
stress events

Fig. 10.

4.3.1.3. Benthic foraminifera

Non-metric MDS classified benthic foraminifera into four groups (Fig. 11).

(i) The taxa included in this group can be clearly paleoecologically interpreted. The core group is represented by shallow-water, stenohaline, oxiphylic taxa associated with sea-grass meadows (*Asterigerinata planorbis, Elphidium* spp., large *Cibicidoides* spp., *Amphistegina* spp. and miliolids; Murray 2006). Broken and abraded thick-walled tests of *Lenticulina* spp. are reworked and/or bedload transported tests and indicate a dynamic environment. "Outliers" of this group represent specific inner shelf environments: small *Cibicidoides* spp. are opportunists connected with seasonal nutrient influx; *Ammonia* spp. tolerate salinity oscillations. Very near to this group is group of three taxa with poor and inconsistent ecological data: *Gyroidina* spp. (epifaunal, detrivore genera occurring on the mud substrate (Murray 2006), *Valvulineria akneriana* (unclear preference to sand or mud substrate; high-nutrient marker tolerating dysoxia; Fontanier et al. 2002; Pezejl et al. 2013); and epifaunal to shallow infaunal *Hoeglundina elegans* (Rathburn & Corliss 1994; Jorissen et al. 1998; Fontanier et al. 2002). Although the latter is often regarded as a deep water species (e.g. Cita & Zacchi 1978), muddy substrate may be crucial to its occurrence (Murray 2006). The species was recorded in both oligotrophic (De Rijk et al. 1999) as well as high-flux conditions (Gooday 2003). These contradictory data could be explained by the opportunistic life strategy of these taxa, similar to small *Cibicidoides* spp. and *Ammonia* spp.

Dividing "typical" high-nutrient and low-oxic markers (such as *Bolivina, Bulimina, Uvigerina, Fursenkoina, Melonis, Pullenia, Chilostomella, Globobulimina*) into groups (ii) to (iv) evokes the hypothesis of different ecological preferences of these genera. Instead of indicators of changes in bottom water oxygen level, they may reflect the organic carbon contents of the sediments (Caralp 1989; Hermelin 1992; Sjoerdsma & Van Der Zwaan 1992; Sen Gupta & Machain-Castillo 1993; Miao & Thunell 1993; Rathburn & Corliss 1994). Schönfeld (2001) recorded maximum abundances of *Melonis* under oxic conditions near the sediment surface; nevertheless, *Melonis* may indicate a high-nutrient but more oxic environment. However, Jorissen et al. (1995) and Fontanier et al. (2002) questioned the high-nutrient preference of *Melonis* when they recorded that with a decreasing organic input, the oxygenated layer expands, and under such oligotrophic conditions, intermediate infaunal taxa (such as *Melonis*) may become very successful. The second possibility may be the variegated quality of organic matter (Caralp 1989; Mojtahid et al. 2010), although actuoecological studies have provided partly contradictory data. Caulle et al. (2014) observed that *Melonis* species prefer organic matter in a more altered form (terrigenous origin) and *Bulimina* is indicative of high organic matter quality and quantity (marine origin), whereas Abu-Zied et al. (2008) recorded that *Bolivina, Bulimina and Uvigerina* are dependent on a rather continuous abundance of organic matter, possibly of lower quality. Nevertheless, the distribution of *Bolivina, Bulimina, Uvigerina, Fursenkoina, Melonis* and *Pullenia* reflects variation in oxygen content and in the quantity and quality of nutrients.

(ii) The group of *Fursenkoina acuta, Nonion commune, Bolivina* and *Bulimina* without ornamentation represent typical low-oxic and high-nutrient taxa (Murray 2006) and their life preferences are not questioned.

(iii) The life preferences of *Uvigerina* spp., *Siphonina reticulata* and elongate biserial and triserial agglutinated morphotypes of agglutinated foraminifera can only be interpreted with more difficulty. However, based on the observations of Rathburn & Corliss (1994), *Siphonina* is codominant with *Uvigerina*. *Siphonina* represents the semi-infaunal omnivore; agglutinated elongate bi- and triserial morphotypes are infaunal detrivores and bacterial scavangers (Tyszka 1994; Reolid et al. 2008; Kaminski et al. 2006). In general, a dominance of agglutinated species reflects the oligotrophic character of the benthic ecosystem (Jorissen et al. 1998). Agglutinated species in general appear to be less influenced by the quality of food sources, and may have developed other feeding strategies (Koho 2008; Alve 2010). Summarising these observations, it can be concluded that the group brings together opportunistic omnivores which can survive interannual changes of quality and quantity of nutrients.

This group can be subdivided into three subgroups. "Outlier" *Lenticulina* spp. are considered oxyphylic (after Rosoff & Corliss 1992 and Kouwenhoven & Van Der Zwaan 2006). This high oxygen-consuming

Fig. 11. Classification of benthonic foraminifera taxa based on Non-metric Multidimensional Scaling (A) and ecological interpretations of groups as a source of paleoenvironment interpretation of OSL-1 borehole and sand pit Oslavany (B).


A
0.4
0.3
0.2
0.1
-0.1
-0.2
-0.3
Osl11
790cm
650cm
510cm
OslK1
Osl2
OslK2
OslK11
OslK4
Osl8
Osl4
Osl15
Osl9
OslK2a
Osl7
1010cm
Osl3
OslK9
OslK10
Osl13
960cm
290cm
915cm
940cm
530cm
550cm
Osl5
Osl14
Osl6
320cm
450cm
830cm
270cm
990cm
Osl12
Osl1
OslK12
810cm
670cm
690cm
310cm
410cm
250cm
Osl10
850cm/b
470cm
350cm
OsKl8
OslK6
610cm
730cm
330cm
770cm
900cm
1001cm
OslK7
390cm
bottom
1050cm
750cm
550cm
710cm
850cm/a
630cm
570cm
490cm
● OV-1 ○ section
B
Inner shelf
Outer shelf-bathyal
Oligotrophic
Interannual differences in nutrient input
Regular seasonal nutrient input
Agglutinated (mono-and biserial)
Siphonina reticulata
Uvigerina spp.
Lenticulina spp. well preserved
Lenticulina sp. (broken or abraded)
miliolids
Melonis + Pullenia + Sphaeroidina
large Cibicidoids
Cassidulina + Globocassidulina + Epistominella
Amphistegina spp.
Asterigerinata planorbis
monoserial nodosariids
Elphidium spp. keeled
Gyroidina spp.
Globulina spp.
Bolivina spp. sculpture
Elphidium unkeeled
Hoeglundina elegans
Bulimina striata
Cibicides sp. (small-sized)
Valvulineria akneriana
Ammonia spp.
Low-oxic, high-nutrient
Fursenkoina acuta
Nonion commune
Bolivina spp. smooth
Bulimina spp. smooth
Axis 2
stabile oligotrophic and oxic environment
oscillations of environmental parameters
increase nutrients
increase oxygen
seasonal influx of nutrient
continuos high abundance of nutrients

Fig. 11.

genus points to reduced oxygen content of the bottom water (Kaiho 1994; Van Der Zwaan et al. 1999). However, Kaiho (1994) considers *Lenticulina* spp. as a suboxic indicator. The subgroup of *Melonis, Pullenia, Sphaeroidina, Cassidulina, Globocassidulina, Epistominella* and monoserial lagenids indicates a strong influence of seasonal phytodetritus pulses from the occurrence of *Cassidulina, Globocassidulina* and *Epistominella* (Gooday 1993; Alve 2010) alternated with a period of low nutrient input during which *Melonis, Pullenia* and *Sphaeroidina* can utilize refractory organic material and degradation products (Jorissen et al. 1995; Fontanier et al. 2002; Alve 2010, Caulle et al. 2014). Thus monoserial lagenids with little-known ecological preferences could have similar trophic preferences as *Melonis, Pullenia* and *Sphaeroidina*. The last subgroup of *Globulina* spp., sculptate *Bolivina* spp. and *Bulimina* spp. could represent a transition between the *Cassidulina-Melonis* subgroup, characterizing seasonal nutrient pulses and group (i) requiring regular sources of nutrients.

Based on non-metric MDS and variance in the relative abundance of the most common benthic foraminiferal taxa, five intervals were recognized in the OSL-1 borehole. They were paleoecologically interpreted according to variegated abundances of groups (i) to (iv) (Fig. 12).

The benthic foraminiferal assemblages in all samples from the sand pit are characterized by mixing shallow water species (*Ammonia*, elphidiids) with deeper water ones (*Bulimina, Melonis, Uvigerina*, etc.), as well as oxiphylic (cibicidoids) with hypoxic (*Uvigerina, Bulimina, Bolivina*). The size-sorting, abrasion and damage of tests, as well as their recrystallization, show the strong affect of foraminiferal assemblages by postmortem transport and resedimentation. Paleodepth estimated from sedimentological data (first meters) indicates that deeper-water benthic assemblages must have been postmortally transported from a deeper part of the basin or reworked from older sediments.

4.3.2. Sporomorphs (pollen and spores)

Samples from the sand pit were completely sterile. Conversely the over-dominance of bisaccate conifers (mainly *Pinus* and *Cathaya*) and very small amounts of other pollen and spores were observed in all of the studied samples from borehole OSL 1. The whole borehole seemed to be very uniform except for changes in conifer frequency (the highest amounts were observed at 2.8-3.8 m and 6.8-9.3 m). In contrast to the sand pit, no sterile samples were recorded in the borehole.

A minor share of non-coniferous pollen was comprised of elements of subtropical Miocene Broadleaved forest (*Engelhardia, Platycarya, Quercoidites microhenrici, Tricolporopollenites liblarensis, Clerodendrum* type, *Olea*) as elements of deciduous woody warm-temperate Mixed-Mesophytic forest types (*Carya, Quercus, Betula, Celtis, Ulmus*).

The existence of coastal swamp was indicated by the pollen of Taxodiaceae. Findings of herbs and heliophilous elements such Poaceae, Caryophyllaceae and Chenopodiaceae origined as a consequence of more open areas. Mountain conifer-rich forest was represented by *Cathaya, Cedrus* and *Picea*. Scarce fresh water plants such as *Potamogeton, Sparganium* and algae (*Botryococcus*) could indicate fresh water influx.

The morphology of the land (sand dunes or mountainous areas) as well as the huge pollen production and accumulation in marine sediments distant from the seashore due to the great ability of air-transport could all have played a role in the overrepresentation of bisaccate conifers (Pinaceae). This construction is supported by the synchronously plentiful occurrence of dinoflagellates. A similar reason was described for the assemblages from the New Jersey margin, undoubtedly recording differential transport as well as differential preservation (Heusser 1978; Hopkins & McCarthy 2002).

Palynomorph content in sediments seemed to be interdependent on the oxido/redox potential (Martin & Drew 1970; Heusser 1978; Doláková et al. 2014; Holcova et al. 2015a). The taphonomic reasons could be related to the greater resistance of *Pinus* to oxidic conditions in water or sediment conditions. Increasing oxidation susceptibility is in direct relation to sporopollenin percentage of total wall content (Kwiatkowski & Lubliner-Mianowska 1957; Havinga 1964, 1967; Brooks 1971; Hopkins & McCarthy 2002).

Accumulations of bisaccate conifers were observed in many Lower Badenian cores of the Carpathian Foredeep (Hladilová et al. 1999; Kováčová et al. 2011).

Fig. 12. Results of the Non-metric Multidimensional Scaling and relative abundances of the most common benthic foraminifera taxa in the OSL-1 borehole and sand pit Oslavany.

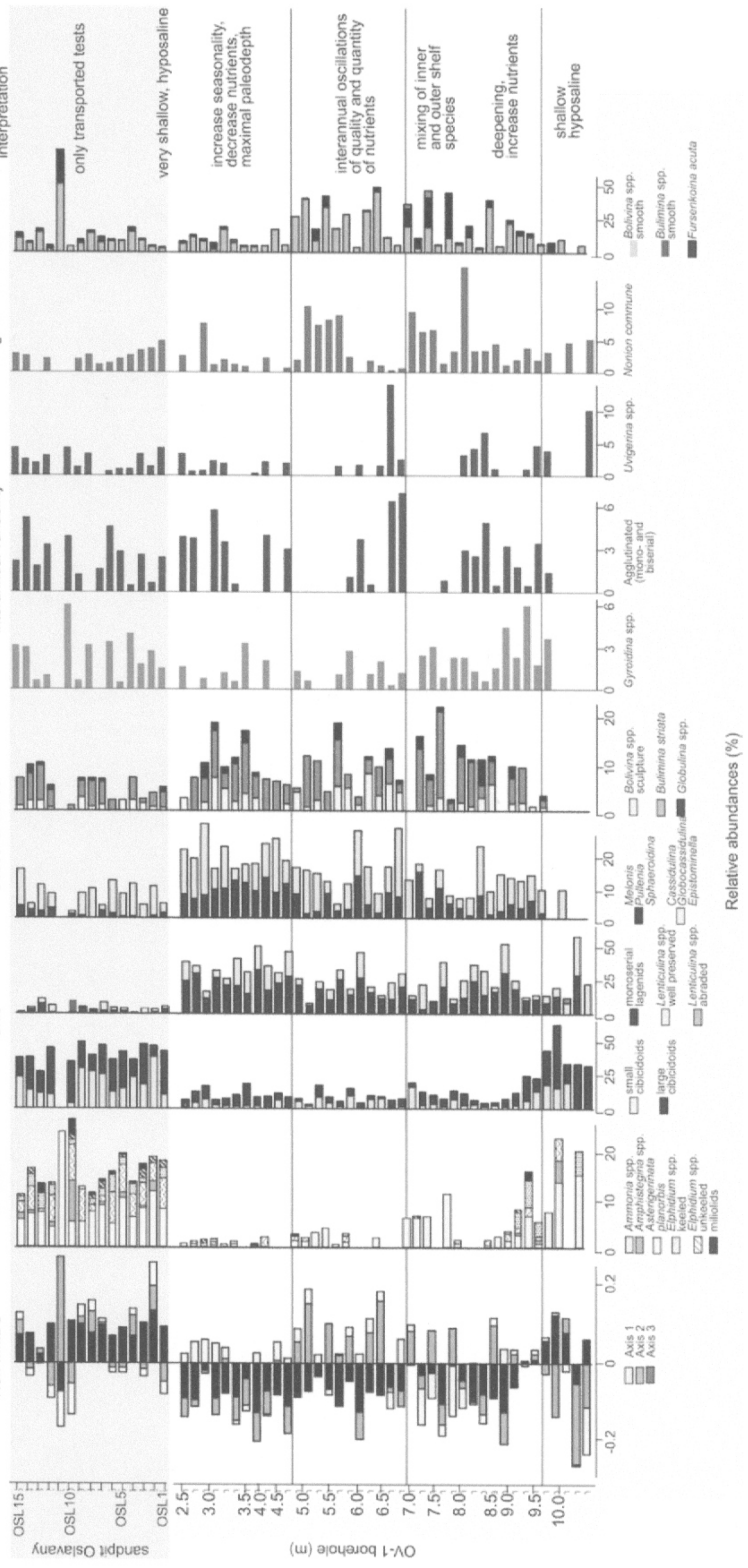

Non-MMDS
Inner shelf
Oxic
Seasonal-fluxes
Interannual variability
Regular nutrient source
Paleoecological interpretation
sandpit Oslavany
OSL15
OSL10
OSL5
OSL1
OV-1 borehole (m)
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
only transported tests
very shallow, hyposaline
increase seasonality, decrease nutrients, maximal paleodepth
interannual oscillations of quality and quantity of nutrients
mixing of inner and outer shelf species
deepening, increase nutrients
shallow hyposaline
Axis 1
Axis 2
Axis 3
Ammonia spp.
Amphistegina spp.
Asterigerinata planorbis
Elphidium spp. keeled
Elphidium spp. unkeeled
miliolids
small cibicidoids
large cibicidoids
monoserial lagenids
Lenticulina spp. well preserved
Lenticulina spp. abraded
Melonis
Pullenia
Sphaeroidina
Cassidulina
Globocassidulina
Epistominella
Bolivina spp. sculpture
Bulimina striata
Globulina spp.
Gyroidina spp.
Agglutinated (mono- and biserial)
Uvigerina spp.
Nonion commune
Bolivina spp. smooth
Bulimina spp. smooth
Fursenkoina acuta
Relative abundances (%)

Fig. 12.

Periodic changes of oryctocoenoses with diverse pollen spectra were followed by a strong dominance of conifers together with marine dinoflagellates and, afterward, the disappearance of all pollen and spores were also recorded in the same time in boreholes at Židlochovice 1 and 2. Above that succession, limestone layers were recorded (Dolákova et al. 2014). Conifer over-representation was typical for oligotrophic conditions and climatic instability. The specific climatic conditions – climatic instability and aridification with episodic intensive rain were associated with the Middle Miocene climatic transition in the study area (Doláková et al. 2014; Holcová et al. 2015a, b).

Part of the palynological samples from OSL 1 was observed under UV-fluorescence microscopy to detect reworked palynomorphs (according to Van Gijzel 1971 and Doláková & Burešová 2007). A predominant majority of conifer pollen proved to be of uniform intensity and colours of fluorescence. Only minute amounts of grains with noticeably weaker fluorescence (most probably reworked) were observed in the sample at 6.8 m. For that reason, we can consider practically all conifers as autochtonous.

4.4. Dinoflagellate cysts

Seven samples studied from the Oslavany borehole yielded palynological organic matter (i.e. organic particles larger than 10 μm) and dinoflagellate cysts. The latter are relatively rare in most samples studied except for the one from a depth of 8.3 m, where their ratio exceeds 6%. In remaining samples, they occur below 1%, being subordinate in relation to black and dark brown phytoclasts, which predominate in all samples; the sporomorph ratio oscillates between 15-20% in the three basal samples and the uppermost one, to a maximal value of almost 50% in samples from depths of 7.8 m and 5.6 m; the lowest sporomorph ratio occurs in a sample from a depth of 6.3 m.

Dinoflagellate cysts show both quantitative and qualitative diversity. Two basal samples yielded rare assemblages; the one from a depth of 9.8 m contains relatively frequent *Systematophora placacantha*, whereas the sample from a depth 9.4 m is dominated by *Polysphaeridium zoharyi*. The latter species forms an acme in the following sample (8.3 m); here its ratio reaches 83% compared to the previous sample (9.4 m) where its ratio is almost 90% (but the low frequency must be taken into account). The higher sample (7.8 m) contains a quantitatively impoverished assemblage but it shows relatively high taxonomical diversity. Assemblages from higher samples show decreasing frequencies of *P. zoharyi* (64% - 38% - 25% at depths of 6.3 m - 5.6 m - 3.8 m, respectively) and variable proportions of *Spiniferites pseudofurcatus* (13%, 30%, 28% in the same samples).

Palynofacies composition shows that the deposits in question were accumulated in a rather proximal zone without an increased land influx – there are no cuticles, and the frequent pollen grains were most likely wind-transported. High proportions of *Polysphaeridium zoharyi*, which is commonly associated with hypersalinar conditions (e.g., Wall & Dale 1969; Dale 1976; Wall et al. 1977; Morzadec-Kerfourn 1979, 1983; Bradford & Wall 1984; Edwards & Andrle 1992), point at lagoonal conditions, likely with increased water salinity. The latter presumably fluctuated slightly during the accumulation of the strata in question, since some samples are devoid of this species (9.8 m) or they contain a relatively low proportion, ca. 17% (7.8 m).

Interestingly, most samples (except for 7.8 m and 6.3 m) yielded rare specimens of *Impagidinium*, a genus believed to represent oligotrophic offshore waters (e.g. Morzadec-Kerfourn 1977; Wall et al. 1977; Harland 1983; Dale 1996; Rochon et al. 1999; Vink et al. 2000). Its presence may indicate a connection that might have existed between the lagoonal zone and the more offshore basin zone.

4.5. Interpretation

The results of the sedimentological studies can be well compared with the paleobiological data. Though the changes in the assemblages of individual fossil groups do not fully correlate, the main trends of paleoenvironmental changes are well comparable (Fig. 13).

The FA 1 is composed of weathered and only briefly transported material from the adjacent geological units (the Boskovice Basin, the Moravian Zone) that were reworked by marine transgression (transgressive lag). The coarse grain size and irregular development points to an undulated and relatively inclined surface and alluvial and fluvial delivery of material into the basin. The transgressive surface is located within FA

Fig. 13. Synthesis of the changes in paleobiological and sedimentological records in the Oslavany stratotype area.

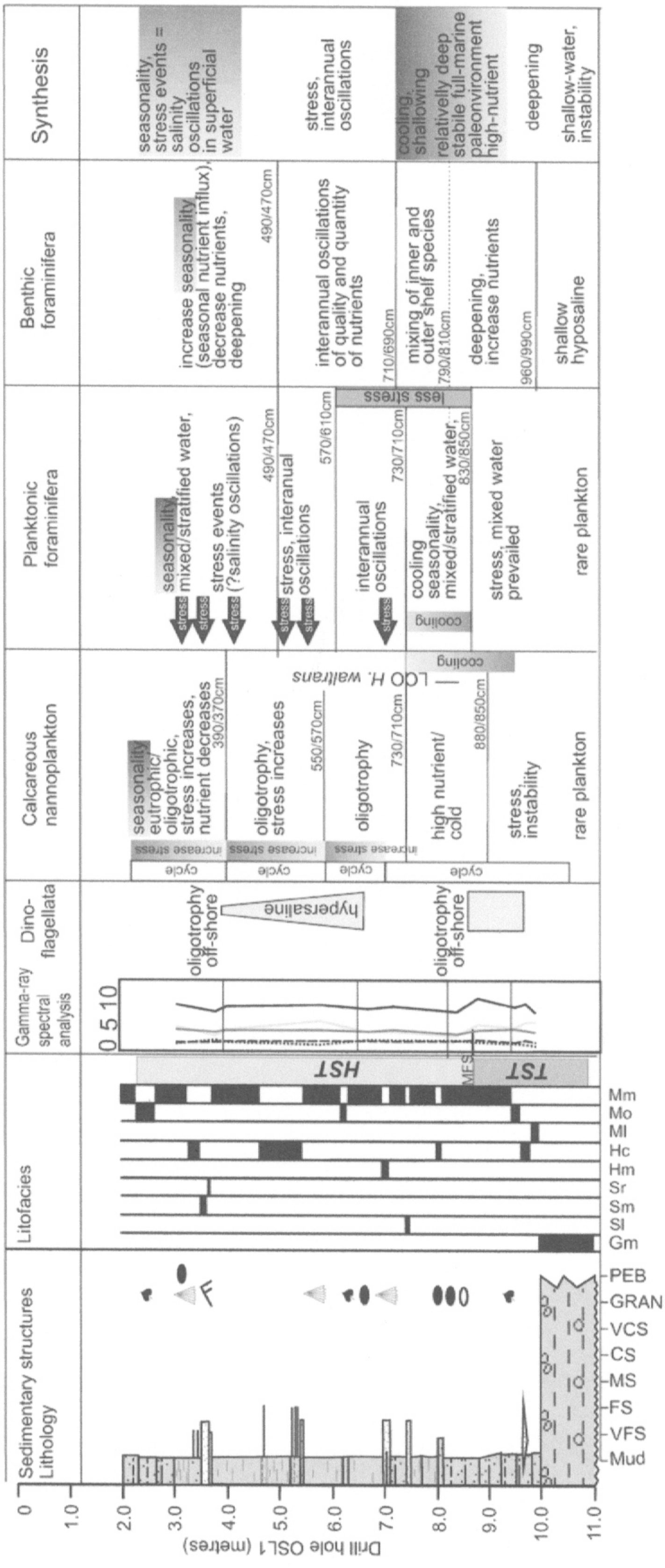

Drill hole OSL1 (metres)
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
Lithology
Sedimentary structures
Mud
VFS
FS
MS
CS
VCS
GRAN
PEB
Litofacies
Gm
Sl
Sm
Sr
Hm
Hc
Ml
Mo
Mm
HST
MFS
TST
Gamma-ray spectral analysis
0 5 10
Dino-flagellata
oligotrophy off-shore
hypersaline
oligotrophy off-shore
Calcareous nannoplankton
cycle
increase stress
seasonality eutrophic/ oligotrophic, stress increases, nutrient decreases
390/370cm
oligotrophy, stress increases
550/570cm
oligotrophy
730/710cm
high nutrient/ cold
880/850cm
stress, instability
rare plankton
LCO H. waltrans
cooling
Planktonic foraminifera
stress
seasonality, mixed/stratified water,
stress events (?salinity oscillations)
490/470cm
stress, interanual oscillations
570/610cm
interannual oscillations
730/710cm
cooling
cooling seasonality, mixed/stratified water,
830/850cm
stress, mixed water prevailed
rare plankton
less stress
Benthic foraminifera
increase seasonality (seasonal nutrient influx), decrease nutrients, deepening
490/470cm
interannual oscillations of quality and quantity of nutrients
710/690cm
mixing of inner and outer shelf species
790/810cm
deepening, increase nutrients
960/990cm
shallow hyposaline
Synthesis
seasonality, stress events = salinity oscillations in superficial water
stress, interannual oscillations
cooling, shallowing
relatively deep stabile full-marine paleonvironment high-nutrient
deepening
shallow-water, instability

Fig. 13.

1. Foraminiferal and calcareous nannoplankton assemblages refer to shallow marine conditions, with paleodepths of meters to the first tens of meters; salinity oscillations, plankton is nearly missing (samples from the base to around 990/960 cm).

The deposits of FA 2 are interpreted as deposited below the wave base level (offshore). They reflect Lower Badenian transgression on the margins of the Bohemian Masiff. The maximum flooding surface (MFS) is located in the lower part of the FA 2 succession (see Fig. 3A). Its position is connected with a change in the stacking pattern, and the "absolute minimum" of terrigenous sediment input, that is the highest concentrations of Th, K and U (cf. LÜNING et al. 2003; DOVETON & MERRIAM 2004; HALGEDAHL et al. 2009). The results of the grain size analyses were also used as a proxy for water depth (DUNBAR & BARRETT 2005). The foraminiferal and calcareous nannoplankton assemblages also show, that within the interval from 960 cm to around 850 cm, deepening continued to a depth suitable for plankton (outer shelf) with stress in the superficial layer (salinity oscillations). Hypersaline fluctuations are shown based on dinocyst assemblages. Maximum deepening can be expected between 850-800 cm, where a more stable full marine paleoenvironment with no stress events and enough nutrients is interpreted.

Thin interbeds of sandy and heterolitic facies represent the most probable evidence of storm actions. It well agrees with the paleobiological record in which the transport of inner shelf benthos to outer shelf has been interpreted for the interval at 700-800 cm. The interval can be characterized by gradual cooling accompanied by slight climatically induced shallowing.

The most significant paleobiological event was recorded at around 700 m where foraminiferal and calcareous nannoplankton assemblages point to an oligotrophic paleoenvironment with interannual oscillations of environmental parameters (nutrients, salinity in the upper part of the water column which fluctuated to hypersaline). The event is followed by a gradual decrease of stability of the environment; clear seasonal aspects in populations of individual organic groups are starting to appear around 450-400 m. It well agrees with climatic changes at the beginning of the Middle Miocene Climatic Transition in the Central Paratethys, including an increase of seasonality (mainly seasonality of rainfalls), cooling, aridification and the occurrence of catastrophic climatic events (heavy rainfalls) above the LCO of *Helicosphaera waltrans* (DOLÁKOVÁ et al. 2014; HOLCOVÁ et al. 2015a).

A further deepening cycle is expected in the upper part of the boreholes. The upper portion of FA2 is interpreted as deposited during normal regression (HST – highstand system tract). Identified "funnel shaped" cycles reflect short term temporal variations between the sediment supply and formation of accommodation space, thus they are interpreted as higher-frequency T-R cycles. The cycles are asymmetrical and show a thicker deepening/transgressive interval compared to the shallowing/regressive one, so they can be assigned as T cycles (ZECCHIN 2007). The rapid sediment supply and relatively rapid formation of accommodation are typical for the formation of T cycles in shallow marine settings, particularly during transgression. The analysis of fossil assemblages points to climate control of these cycles.

The petrography of FA 2 reveals a significant role of relatively resistant quartz-rich material, the provenance of which is mostly formed by the metamorphic rocks of the Moravian Zone and the absence of material from the Boskovice Basin. The value of the ZTR index for the studied deposits is relatively low and points to the small role of sediment recycling and significant input of the fresh weathered material. Deposits of the Boskovice Basin reveal a significantly higher ZTR index (NEHYBA et al. 2012). The provenance of the garnet and rutile can be predominantly located in the metapelitic rocks of the Moravian Zone, partly also to the Svratka Unit and Moldanubian. Similarly BURIÁNEK et al. (2012), who studied amphiboles and tourmalines from the Oslavany sand pit, located their sources into amphibolites and mica schists of the Moravian Zone. Because the closest occurrence of these rocks is located approximately 1-2 km NW off the locality, we have to suppose that the position of the shoreline during the deposition of the FA 2 must have been at least in this region (i.e. far beyond the extent of the Boskovice Basin; see Fig. 1B) or even more to the W - NW.

The deposits of FA 3 are interpreted as clastic coastline (foreshore and upper shoreface) deposits. A low energy coast is presumed due to the absence of evidence of storm activity (shoaling wave-dominated shoreface?, CLIFTON 2006). The gentle inclination of strata and low occurrence of coarse gravel suggest a dissipative shoreline dominated by low- to moderate-energy waves. The preservation of foreshore deposits is suggestive of a high accommodation setting. The difference in the provenance of FA 2 and FA 3 (i.e. variation in the source from the rocks of the Boskovice Basin) points to a change in the source area. The "cycles" reflected in the vertical distribution of Mz, mud and Th content and Th/K or Th/U ratios display almost symmetrical architecture (Zecchin 2007). The facies content within the cycles reflects Sl-Sp-Sl succession, which can be interpreted as foreshore-upper shoreface-foreshore variations, i.e. slight changes in the sea level. Similar variations in the strandplain sub-environments were also followed in the sand pit (Nehyba et al. 2009). These cycles reflect changes in the wave regime, which are typically climate-driven (Hampson 2000). The coincidence of the high formation of accommodation space and relatively high sediment supply favour such cycles.

The following factors all point to the interpretation of FA 3 as deposits of FSST (falling stage systems tract) connected with forced regression: the prograding and aggrading stacking pattern, position of FA 3 both above and basinward of FA 2, differences in depositional environment of FA 2 and FA 3, and the results of provenance study. The backward shift (towards SE-E) of the shoreline (several km) can be documented as compared with the state during the deposition of FA 2. The detached positions of these shorelines signify a relatively rapid sea level fall. In such a situation, the regressive surface of marine erosion (or the basal surface of forced regression) could severely reduce the thickness and areal extent of open marine deposits (i.e. FA 2). The foraminiferal and calcareous nannoplankton assemblages are characterized by prevailing allochtonous microfossils. Indigenous benthic foraminifera composed of *Ammonia* spp., *Elphidium* spp. and small cibicidoids were recorded only mainly at the bottom of the section. These indigenous foraminifera indicate a shallow-water environment and stress-conditions with short-time oscillations of environmental parameters (probably mainly salinity). The high occurrence of redeposition and allochtonous tests from the older sedimentary basin infill/basin cannibalisation (Ottnangian, Lower Badenian), or even of older deposits (Oligocene, Cretaceous), support the regression.

The concave shape of the upper surface of FA 2 indirectly confirms this interpretation, similarly as the relatively shallow gradient of the sea floor is supported by the evidence of coal swamp. The relatively significant thickness of deposits of FA 3 is probably connected with the significant rate of sediment delivery.

5. Discussion

The Badenian deposition in the Central Paratethys basins is connected with two sea-level/T-R cycles. The first one is the TB 2.3 sea-level cycle (Haq et al. 1988), which mostly coincides with the "Middle Miocene Climate Optimum" (Harzhauser & Piller 2007; Harzhauser et al. 2011); in the Austrian part of the Alpine-Carpathian Foredeep, it is coupled with the Styrian Tectonic Phase (Ćorić & Rögl 2004). Biostratigraphically, it can be correlated with the NN4 Zone. Deposits of this sea-level cycle are difficult to identify along the passive margin of the Carpathian Foredeep, which could be explained by the forebulge response to thrusting along the basin active margin (Flemings & Jordan 1990; Jordan & Flemings 1991; Beaumont et al. 1993; Crampton & Allen 1995; Catuneanu et al. 1997; Leszczyński & Nemec 2014); however, they might be preserved in the central/proximal parts of the Carpathian Foredeep basin (Tomanová-Petrová & Švábenická 2007).

The next TB 2.4 sea-level cycle (Haq et al. 1988) started close to the base of the NN 5 Zone (Hohenegger et al. 2014). The transition from the "Middle Miocene Climate Optimum" and subsequent "Middle Miocene Climate Transition" coincides with this widespread Badenian transgression that covered the entire Central Paratethys. Numerous preserved localities that are connected with this depositional cycle were recognised far west on the Bohemian Massif (Hladilová et al. 1993; Zágoršek et al. 2009; Holcová et al. 2015b). Such a stratigraphically rapid event and abrupt cratonward shoreline advance are explained here by the coincidence of both the eustatic sea-level rise and forebulge subsidence. The role of older basement faults and structures as zones of "preferred" basin protrusions is probable (cf. Leszczyński & Nemec 2014). Both TB 2.3. and TB 2.4. are third-order cycles with a duration of about 1 Ma.

Although the studied T-R cycle can be connected with TB 2.4., the depositional processes along the passive margins of peripheral foreland basins are quite complicated, because of the forebulge behaviour (uplift vs. subsidence), variations in sediment supply, amplitude and shape of eustatic/relative sea-level changes, the basin physiography, and geologic and tectonic history of the basement (Ettensohn 1994; DeCelles & Currie 1996; Currie 1997; Catuneanu et al. 1997, 1998; Catuneanu & Sweet 1999). Variations in the controlling factors in a single basin can produce different stratal patterns even in a single basin (Zecchin 2007), thus the evaluation of the architecture of high-frequency cycles is very important for the reconstruction of the depositional history of sedimentary successions.

The preservation of transgressive deposits is chiefly directed by the shoreline trajectory of the overlying bounding surface; steeper shoreline trajectories are beneficial for the preservation of the transgressive deposits. A balance between accommodation and sediment supply is supposed to be the main factor for the production of a steep transgressive shoreline trajectory. High accommodation and high sediment supply are typical for the production of accretionary transgressive shoreline trajectories and the preservation of transgressive deposits (Thorne & Swift 1991; Helland-Hansen & Gjelberg 1994; Helland-Hansen & Martinsen 1996; Zecchin 2007). These conditions are connected with the studied deposits of FA 2. The transgressive part was formed during a prevalence of accommodation over supply, whereas a slightly reduced rate of accommodation space formation led to normal regression in the upper part of FA 2. The whole FA 2 is thus connected with an overall lower-frequency transgressive part of the T.B. 2.4 cycle (i.e. with sea-level rise). The local preservation of deposits of TST could be connected with low-gradient settings, typical for shallow marine depositional environment (depositional environment of FA 2). Deposits of FA 3 are dominantly connected with forced regression with a prograding to aggrading stacking pattern. Forced regression is explained by sea-level fall (i.e. the regressive part of the T.B. 2.4. cycle). Continued forebulge subsidence produced significant accommodation space to be filled by continuous high sediment supply and the prograding stacking patterns of FA 3 transformed into aggrading ones. The rate of sediment supply can be relatively reduced by steeper topography. Thick regressive succession of coastline deposits (FA 3) was preserved due to high accommodation and sediment supply.

The recognised higher-frequency cycles are of the 4th to 5th order with an estimated time span of 10^2 to 10^3 ka. These cycles were most probably climate-driven. The modification of the architecture of these higher-frequency cycles was observed in the function of the overall progradational or retrogradational trend, of a lower-frequency cycle (Zecchin 2007). Higher-frequency cycles with thicker retrograding intervals are common in overall lower-frequency retrogradational trends, whereas symmetrical higher-frequency cycles with thicker prograding intervals are recognised in overall lower-frequency prograding trends.

6. Conclusions

The evaluation of two newly drilled boreholes in the close vicinity of the Oslavany sand pit, that is the holostratotype of the Moravian (Lower Badenian) deposits of the Carpathian Foredeep (Cicha in Papp et al. 1978), provide detailed data about the Lower Badenian transgression along the passive margin of this peripheral foreland basin. Three facies associations reflecting the evolution of the deposition and distinct basin margin paleogeography were identified.

The irregular base is covered by poorly weathered and briefly transported material from the adjacent basement geological units (the Boskovice Basin, the Moravian Zone) that were reworked by marine transgression (transgressive lag). These deposits represent the first facies association.

Facies association 2 is developed in the superposition of facies association 1. Open-marine (outer to inner shelf) deposits are connected with both transgressive and highstand systems tracts, the rapid formation of accommodation space and relatively high sediment supply. The position of the maximum flooding surface was identified according the "absolute minimum" terrigenous sediment input, the grain size and by foraminiferal and calcareous nannoplankton assemblages (stable full marine paleoenvironment with no stress events and enough nutrients). The position of the shoreline was located at least 1-2 km W-NW off the studied area. The deposits can be biostratigraphically correlated with the interval from the FO of *Orbulina* (14.6 Ma) to the LO of *Sphenolithus heteromorphus* (13.5 Ma). The LCO of *Helicosphaera waltrans* (14.3 Ma) followed by the FO of *Mendicodinium robustum* (about 14 Ma) were recorded. The beginning of the Middle Miocene Climatic Transition recorded in the studied sections started through storm events followed by an abrupt decrease of nutrient input and a gradual increase of interannual as well as seasonal variability. The increased salinity at the upper layer of the water column signaled the processes leading to the "Wieliczkian salinity event". Several high-frequency sea level cycles were identified within the second facies association.

The deposits of facies association 3 are interpreted as a product of low energy clastic coastline (foreshore and upper shoreface) deposits, which are connected with a falling stage systems tract. A basinward shift of the shoreline and detached positions of the successive shorelines were recognised. The foraminiferal and calcareous nannoplankton assemblages are characterized by prevailing allochtonous microfossils and the large role of redeposition from both older basin infill (Ottnangian, Lower Badenian), or even of older deposits (Oligocene, Cretaceous).

The transgressive-regressive cycle recorded in the studied sections is connected by both the global TB 2.4.

sea-level cycle and by forebulge subsidence. However, the recognized high-frequency cycles were climatically controlled. The Styrian tectonic phase caused the absence of the TB 2.3. cycle (with a globally high sea-level during the MMCO) in the study area.

Acknowledgements

The study is the result of specific research at Institute of Geological Sciences of Masaryk University and was also supported by the projects PRVOUK P44. We thank an unknown reviewer for critical and constructive comments on the manuscript.

References

Abdulaziz, H.A., Di Stefano, L.M., Foresi, F.J., Hilgen, S.M., Iaccarino, K.F., Kuiper, F., Lirer, G., Salvatorini, A. & Turco, E. (2008): Integrated stratigraphy and ^{40}Ar/^{39}Ar chronology of early Middle Miocene sediments from DSDP Leg 42A, Site 372 (Western Mediterranean). – Palaeogeography, Palaeoclimatology, Palaeoecology, **257**: 123-138.

Allen, J.L. & Johnson, C.L. (2011): Architecture and formation of transgressive-regressive cycles in marginal marine strata of the John Henry Member, Straight Cliffs Formation, Upper Cretaceous of Southern Utah, USA. – Sedimentology, **58**: 1486-1513.

Alve, E. (2010): Benthic foraminiferal responses to absence of fresh phytodetritus: A two year experiment. – Marine Micropaleontolology, **76**: 67-75.

Amorosi, A., Antonioli, F., Bertini, A., Marabini, S., Mastronuzzi, G., Montagna, P., Negri, A., Rossi, V., Scarponi, D., Taviani, M., Angeletti, L., Piva, A. & Vai, G.B. (2014): The Middle-Upper Pleistocene Fronte Section (Taranto, Italy): An exceptionally preserved marine record of the Last Interglacial. – Global and Planetary Change, **119**: 23-38.

Andreychouk, V., Worobiec, E., Gedl, P. & Worobiec, G. (2014): Origin of the palaeokarst in Miocene evaporites on the SW periphery of the Eastern European Platform in the light of palynological studies – a case study of the Zoloushka Cave, Bukovina, Western Ukraine. – Annales Societatis Geologorum Poloniae, **84**: 297-322.

Be, A.W.H. (1977): An ecological, zoogeographic and taxonomic review of Recent planktonic foraminifera. – In: Ramsey, A.T.S. (Ed.): Oceanic Micropaleontology, 1-100; London (Academic Press).

Beaumont, C., Quinlan, G.M. & Stockmal, G.S. (1993): The evolution of the Western Interior Basin: causes, consequences and unsolved problems. – In: Caldwell, W.G.E. & Kauffman, E.G. (Eds.): Evolution of the Western Interior Basin, Geological Association Canada Special Paper, **39**: 97-117.

Berggren, W.A., Kent, D.V., Swisher, C.C. iii & Aubry, M.-P. (1995): A revised Cenozoic geochronology and chronostratigraphy. – SEPM Special Publication, **54**: 129-212.

Boeckel, B., Baumann, K.-H., Henrich, R. & Kinkel, K. (2006): Coccolith distribution patterns in South Atlantic and Southern Ocean surface sediments in relation to environmental gradients. – Deep-Sea Research I, **53**: 1073-1099.

Bradford, M.R. & Wall, D.A. (1984): The distribution of Recent organic-walled dinoflagellate cysts in the Persian Gulf, Gulf of Oman, and northwestern Arabian Sea. – Palaeontographica, Abt. B, **192**: 16-84.

Brooks, J. (1971): Some chemical and geochemical studies on sporopollenin. – In: Brooks, J., Grant, P.R., Muir, M., van Gijzel, P. & Shaw, G. (Eds.): Sporopollenin, 351-407; London (Academic Press).

Brzobohatý, R. & Cicha, I. (1993): Carpathian Foredeep. – In: Přichystal, A., Obstová, V. & Suk, M. (Eds.): Geology of Moravia and Silezia. 123-128; Brno (MZM, PřF MU) (in Czech).

Buriánek, D., Tomanová-Petrová, P. & Otava, J. (2012): Where do the Miocene clastic sediments of the Brno region come from? – Acta Mus. Moraviae, Sci. Geology, **97** (1): 153-166.

Cachao, M. & Moita, M.T. (2000): *Coccolithus pelagicus*, a productivity proxy related to moderate fronts off Western Iberia. – Marine Micropaleontology, **39**: 131-155.

Caralp, M.H. (1989): Abundance of *Bulimina exilis* and *Melonis barleeanum*: Relationship to the quality of marine organic matter. – Geo-Marine Letters, **9**: 37-43.

Caulle, C., Koho, K.A., Mojtahid, M., Reichart, G.J. & Jorissen, F.J. (2014): Live (Rose Bengal stained) foraminiferal faunas from the northern Arabian Sea: faunal succession within and below the OMZ. – Biogeosciences, **11**: 1155-1175.

Catuneanu, O., Beaumont, C. & Waschbusch, P. (1997): Interplay of static loads and subduction dynamics in foreland basins: Reciprocal stratigraphies and the 'missing' peripheral bulge. – Geology, **25**: 1087-1090.

Catuneanu, O., Hancox, P.J. & Rubidge, B.S. (1998): Reciprocal flexural behaviour and contrasting stratigraphies: a new basin development model for the Karoo retroarc foreland system, South Africa. – Basin Research, **10**: 417-439.

Cicha, I., Rögl, F., Rupp, C. & Čtyroká, J. (1998): Oligocene-Miocene Foraminifera of the Central Paratethys. – Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft, **549**: 1-325.

Cicha, I. & Tejkall, J. (1958): Paleontologické poměry brněnských písků v okolí Oslavan a Syrovic (vněkarpatská pánev na Moravě). – Časopis Mineralogii Geologii, **3** (1): 1-15; Praha (In Czech).

Cita, M.B. & Zocchi, M. (1978): Distribution patterns of benthic foraminifera on the floor of the Mediterranean Sea. – Oceanological Acta, **1**: 445-462.

Clifton, H.E. (2006): A reexamination of facies models for clastic shorelines. – In Posamentier, H.W. & Walker, R.G. (Eds.): Facies Models Revisited. – SEPM Special Publication, **84**: 293-338; Tulsa.

Ćorić, S. & Rögl, F. (2004): Roggendorf-1 borehole, a key-section for Lower Badenian transgressions and the stratigraphic position of the Grund Formation (Molasse Basin, Lower Austria). – Geologica Carpathica, **55**: 165-178.

Crampton, S.L. & Allen, P.A. (1995): Recognition of forebulge unconformities associated with early stage foreland basin development: examples from the North Alpine foreland basin. – American Association of Petroleum Geologists, Bulletin, **79**: 1495-1514.

Čtyroký, P. (1991): Division and correlation of the Eggenburgian and Ottnangian in the S of Carpathian Foredeep in southern Moravia. – Západní Karpaty, Séria Geology, **15**: 67-109.

Dale, B. (1976): Cyst formation, sedimentation and preservation: factors affecting dinoflagellate assemblages in Recent sediments from Trondheimsfjord, Norway. – Review of Palaeobotany and Palynology, **22**: 39-60.

Dale, B. (1996): Dinoflagellate cyst ecology: modelling and geological applications. – In: Jansonius, J. & McGregor, D.C. (eds.), Palynology: principles and applications, **3**: 1249-1275. Dallas, Texas (American Association of Stratigraphic Palynologists Foundation).

De Rijk, S., Trolestra, S.R. & Rohling, E.J. (1999): Benthic foraminiferal distribution in the Mediterranean Sea. – Journal of Foraminiferal Research, **29**: 93-103.

De Verteuil, L. & Norris, G. (1996): Miocene dinoflagellate stratigraphy and systematics of Maryland and Virginia. – Micropaleontology, Supplement, **42**: 1-172.

Doláková, N. & Burešová, A. (2007): Use of fluorescent microscopy in the study of redeposited palynomorphs in the cave and marine sediments of Moravia (Czech Republic). – Acta Palaeobotanica, **47** (1): 275-279.

Doláková, N., Holcová, K., Nehyba, S., Hladilová, Š., Brzobohatý, R., Zagoršek, K., Hrabovský, J., Seko, M. & Utescher, T. (2014): The Badenian parastratotype at Židlochovice from the perspective of high resolution stratigraphy. – Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, **271**: 169-201.

Doveton, J.H. & Merriam, D.F. (2004): Borehole petrophysical chemostratigraphy of Pennsylvanian black shales in the Kansas subsurface. – Chemical Geology, **206**: 249-258.

Edwards, L.E. & Andrle, V.A.S. (1992): Distribution of selected dinoflagellate cysts in modern marine sediments. – In: Head, M.J. & Wrenn, J.H. (Eds.): Neogene and Quaternary Dinoflagellate Cysts and Acritarchs, p. 259-288; American Association of Stratigraphic Palynologists Foundation.

Fensome, R.A., Crux, J.A., Gard, I.G., Macrae, R.A. & Williams, G.L. (2008): The last 100 million years on the Scotian Margin, offshore eastern Canada: an event-stratigraphic scheme emphasizing biostratigraphic data. – Atlantic Geology, **44**: 93-126.

Flemings, P.B. & Jordan, T.E. (1990): Stratigraphic modeling of foreland basins: interpreting thrust deformation and lithosphere rheology. – Geology, **18**: 430-434.

Flores, J.A., Sierro, F.S., Francés, G., Vazquez, A. & Zamarreno, I. (1997): The last 100,000 years in the western Mediterranean: Sea surface water and frontal dynamics as revealed by coccolithophores. – Marine Micropaleontology, **29**: 351-366.

Folk, R.L. & Ward, W. (1957): Brazos River bar: a study in the significance of grain-size parameters. – Journal of Sedimentary Petrology, **27**: 3-26.

Fontanier, C., Jorissen, F.J., Licari, L., Alexandre, A., Anschutz, P. & Carbonel, P. (2002): Live benthic foraminiferal faunas from the Bay of Biscay: faunal density, composition, and microhabitats. – Deep-Sea Research I, **49**: 751-785.

Gedl, P. (1996): Middle Miocene dinoflagellate cysts from the Korytnica clays (Góry Świętokrzyskie Mountains, Poland). – Annales Societatis Geologorum Poloniae, **66** (2): 191-218.

Gedl, P. (1997): Palynofacies of the Miocene deposits in the Gliwice area (Upper Silesia, Poland). – Bulletin of the Polish Academy of Sciences, Earth Sciences, **45** (2-4): 191-201.

Gedl, P. (1999): Palaeoenvironmental and sedimentological interpretations of the palynofacies analysis of the Miocene deposits from the Jamnica S-119 borehole (Carpathian Foredeep, Poland). – Geological Quarterly, **43**: 479-492.

Gedl, P. (2004): Uwagi na temat paleośrodowiska sedymentacji osadów chemicznych miocenu zapadliska przedkarpackiego w świetle badań palinologicznych. – In: Mioceńskie złoża soli w rejonie przykarpackim (Miocene Salt Deposits in the Carpathian Region), 11-12.02.2004 Kraków, p. 5.

Gedl, P. (2005): In situ and recycled dinoflagellate cysts from Middle Miocene deposits at Bęczyn, Carpathian Foredeep, Poland. – Studia Geologica Polonica, **124**: 371-394.

Gedl, P. & Peryt, D. (2011): Dinoflagellate cyst, palynofacies and foraminiferal records of environmental changes related to the Late Badenian (Middle Miocene) transgression at Kudryntsi (western Ukraine). – Annales Societatis Geologorum Poloniae, **81**: 331-349.

Gooday, A.J. (1993): Deep-sea benthic foraminiferal species which exploit phytodetritus: characteristic features and controls on distribution. – Marine Micropaleontology, **22**: 187-205.

Gooday, A.J. (2003): Benthic foraminifera (Protista) as tools in deep-water palaeoceanography: environmental influences on faunal characteristics. – In: Southward, A.J., Tyler, P.A., Young, C.M. & Fuiman, L.A. (Eds.): Advances in Marine Biology, **46**: 3-90; London (Academic Press).

Gradstein, F.M., Ogg, J.G., Schmitz, M.D. & Ogg, G.M. (2012): The Geologic Time Scale 2012, 2-Volume Set. 1144 pp; New York (Elsevier).

Halgedahl, S.L., Jarrard, R.D., Brett, C.E. & Allison, P.A. (2009): Geophysical and geological signatures of relative sea level change in the upper Wheeler Formation, Drum Mountains, West-Central Utah: A perspective into exceptional preservation of fossils. – Palaeogeography, Palaeoclimatology, Palaeoecology, **277**: 34-56.

Hammer, Ø., Harper, D.A.T. & Ryan, P.D. (2001): PAST: Paleontological Statistics Software Package for Education and Data Analysis. – Palaeontologica Electronica, **4** (1): 1-9.

Hampson, G.J. (2000): Discontinuity surfaces, clinoforms, and facies architecture in a wave-dominated, shoreface-shelf parasequence. – Journal of Sedimentary Research, **70**: 325-340.

Haq, B.U., Hardenbol, J. & Vail, P.R. (1988): Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. – In: Wilgus, C.K., Hastings, B.S., Posamentier, H., van Wagoner, J., Ross, C.A. & Kendall, C.G.St.C. (Eds.):

Sea-level changes: An integrated approach. – SEPM Special Publication, **42**: 71-108.

Harland, R. (1983): Distribution maps of recent dinoflagellate cysts in bottom sediments from the North Atlantic Ocean and adjacent seas. – Palaeontology, **26**: 321-387.

Harzhauser, M. & Piller, W. (2007): Benchmark data of a changing sea – Palaeogeography, palaeobiogeography and events in the Central Paratethys during the Miocene. – Palaeogeography, Palaeoclimatology, Palaeoecology, **253**: 8-31.

Harzhauser, M., Piller, W., Müllegger, S., Grunert, P. & Micheels, A. (2011): Changing seasonality patterns in Central Europe from Miocene climate optimum to Miocene climate transition deduced from the *Crassostrea* isotope archive. – Global and Planetary Change, **76**: 77-84.

Havinga, A.J. (1964): Investigation into the differential corrosion susceptibility of pollen and spores. – Pollen et Spores, **6**: 621-635.

Havinga, A.J. (1967): Palynology and pollen preservation. – Review of Palaeobotany and Palynology, **2**: 81-98.

Heller, P.L., Angevine, C.L., Winslow, N.S. & Paola, C. (1988): Two phase stratigraphic model of foreland-basin sequences. – Geology, **16**: 501-504.

Hemleben, C., Spindler, M. & Anderson, O.R. (1989): Modern Planktonic Foraminifera. – 363 pp.; New York (Springer).

Hermelin, J.O.R. (1992): Variations in the benthic foraminiferal fauna of the Arabian Sea: a response to changes in upwelling intensity? – In: Summerhayes, C.P., Prell, W.L. & Emeis, K.C. (Eds.): Upwelling Systems: Evolution Since the Early Miocene. – Geological Society London, Special Publications, **64**: 151-166.

Heusser, L. (1978): Spores and pollen in the marine realm. – In: Haq, B.U. & Boersma, A. (Eds.): Introduction to marine micropaleontology, 327-339; (Elsevier).

Hladilová, Š., Nehyba, S., Doláková, N. & Hladíková, J. (1999): Comparison of some relics of Miocene sediments on the eastern margin of the Bohemian Massif. – Geologica Carpathica, **50**: 31-33.

Hohenegger, J., Rögl, F., Ćorić, S., Pervesler, P., Fabrizio Lirer, F., Roetzel, R., Scholger, R. & Stingl, K. (2009): The Styrian Basin: a key to the Middle Miocene (Badenian/Langhian) Central Paratethys transgressions. – Austrian Journal of Earth Sciences, **102**: 102-132.

Hohenegger, J., Ćorić, S. & Wagreich, M. (2014): Timing of the regional Badenian Stage (Middle Miocene, Central Paratethys). – Geologica Carpathica, **65**: 55-66.

Holcová, K., Hrabovský, J., Nehyba, S., Hladilová, Š., Doláková, N. & Demeny, A. (2015a): The Langhian (Middle Badenian) Carbonate Production Event in the Moravian Part of the Carpathian Foredeep (Central Paratethys): A Multiproxy Record. – Facies, **61** (1): 1-26.

Holcová, K., Brzobohatý, R., Kopecká, J.& Nehyba, S. (2015b): Reconstruction of the unusual Middle Miocene (Badenian) palaeoenvironment of the Carpathian Foredeep (Lomnice/Tišnov denudational relict, Czech Republic). – Geological Quarterly, **59** (4): doi: 10.7306/gq.1249

Höll, C., Zonneveld, K.A.F. & Willems, H. (1998): On the ecology of calcareous dinoflagellates: the Quaternary eastern Equatorial Atlantic. – Marine Micropaleontology, **33**: 1-25.

Hopkins, J.A. & McCarthy, F.M.G. (2002): Post-depositional palynomorph degradation in Quaternary shelf sediments. – Palynology, **26**: 167-184.

Hüsing, S.K., Cascella, A., Hilgen, F.J., Krijgsman, W., Kuiper, K.F., Turco, E. & Winson, D. (2010): Astrochronology of the Mediterranean Langhian between 15.29 and 14.17 Ma. – Earth and Planetary Science Letters, **290**: 254-269.

Jordan, T.E. & Flemings, P.B. (1991): Large-scale stratigraphic architecture, eustatic variation, and unsteady tectonism: a theoretical evaluation. – Journal of Geophysical Research, **96**: 6681-6699.

Jorissen, F.J., Destinger, H.C. & Widmark, J.G.V. (1995): A conceptual model explaining benthic foraminifera microhabitat. – Marine Micropaleontology, **26**: 3-15.

Jorissen, F.J., Wittling, I., Peypouquet, J.P., Rabouille, C. & Relexans, J.C. (1998): Live benthic foraminiferal faunas off Cap Blanc, NW Africa: community structure and microhabitats. – Deep-Sea Research I, **45**: 2157-2188.

Kaiho, K. (1994): Benthic foraminiferal dissolved-oxygen index and dissolved oxygen levels in the modern ocean. – Geology, **22**: 719-722.

Kaminski, M.A., Silye, L. & Kender, S. (2006): Miocene deep-water agglutinated foraminifera from ODP Hole 909c: Implications for the paleoceanography of the Fram Strait area, Greenland Sea. – Micropaleontology, **51**: 373-403.

Koho, K.A. (2008): The Dynamic balance between food abundance and habitat instability: benthic foraminifera of Portuguese margin canyons. – Geologica Ultraiectina, **286**: 1-126.

Kopecká, J. (2012): Foraminifera as environmental proxies of the Middle Miocene (Early Badenian) sediments of the Central Depression (Central Paratethys, Moravian part of the Carpathian Foredeep). – Bulletin of Geosciences, **87**(3): 431-442.

Kouwenhoven, T.J. & Van der Zwaan, G.J. (2006): A reconstruction of late Miocene Mediterranean circulation patterns using benthic foraminifera. – Palaeogeography, Palaeoclimatology, Palaeoecology, **238**: 373-385.

Kováč, M. (2000): Geodynamic, paleogeographical and structural development of the Miocene Carpatho-Pannonian region. New view on the Slovak Neogene basins. 1-176; Bratislava (Veda) (In Slovak).

Kováčová, M., Doláková, N. & Kováč, M. (2011): Miocene vegetation pattern and climate change in the northwestern central Paratethys domain (Czech and Slovak Republic). – Geologica Carpathica, **62**: 251-266.

Kuhnt, T., Howa, H., Schmidt, S., Marié, L. & Schiebel, R. (2013): Flux dynamics of planktic foraminiferal tests in the south-eastern Bay of Biscay (northeast Atlantic margin). – Journal of Marine Systems, Suppl., **109-110**: 169-181.

Kwiatkowski, A. & Lubliner-Mianowska, L. (1957): Badanie składu chemicznego ptłku II Badania błon pyłkowich. – Acta Societatis Botanicorum Polonae, **26**: 501-514.

Leszczyński, S. & Nemec, W. (2014): Dynamic stratigraphy of composite peripheral unconformity in a foredeep basin. – Sedimentology, **62**(3):645-680.

Lüning, S., Adamson, K. & Craig, J. (2003): Frasnian organic-rich shales in North Africa; regional distribution and depositional model. – In: Artur, T., MacGregor-Duncan, S. & Cameron, N.R. (Eds.): Petroleum Geology of Africa: New Themes and Developing Technologies. – Geological Society of London, Special Publication, **207**: 165-184.

Malmergen, B.A. & Kennett, J.P. (1978): Late Quaternary paleoclimatic applications of mean size variations in *Globigerina bulloides* d'Orbigny in the Southern Indian Ocean. – Journal of Paleontology, **52**: 1195-1207.

Martin, P.S. & Drew, C.M. (1970): Additional Scanning Electron Photomicrographs of Southwestern Pollen Grains. – Journal of the Arizona Academy of Science, **6** (2): 140-161.

Miao, Q. & Thunell, R.C. (1993): Recent deep-sea benthic foraminiferal distribution in the South China Sea. – Marine Micropaleontology, **22**: 1-32.

Mojtahid, M., Griveaud, C., Fontanier, C., Anchutz, P. & Jorissen, F.J. (2010): Live benthic foraminiferal faunas along a bathymetrical transect (140-4800 m) in the Bay of Biscay (NE Atlantic). – Revue de Micropaléontologie, **53**: 139-162.

Morzadec-Kerfourn, M.T. (1977): Les kystes de dinoflagellés dans les sédiments récents le long des côtes Bretonnes. – Revue de Micropaléontologie, **20**: 157-166.

Morzadec-Kerfourn, M.T. (1979): Indicateurs écologiques du domaine littoral: végétation et plancton organique. – Océanis, **5**: 207-213.

Morzadec-Kerfourn, M.T. (1983): Interêt de dinoflagellés pour l'établissement de reconstruction paléogéographique: exemple du Golfe de Gabes (Tunésie). – Cahiers de Micropaléontologie, **4**: 15-22.

Murray, J.W. (2006): Ecology and Applications of Benthic Foraminifera. – 425 pp.; Cambridge (Cambridge University Press).

Okada, H. & McIntyre, A. (1979): Seasonal distribution of modern coccolithophores in the western North Atlantic Ocean. – Marine Biology, **54**: 319-328.

Nehyba, S. (2000): The cyclicity of the Lower Miocene deposits of the sw part of the Carpathian Foredeep as the depositional response to sediment supply and sea-level changes. – Geologica Carpathica, **51** (1): 7-17.

Nehyba, S. (2014): Soft-sediment deformation structures in Lower Badenian (Middle Miocene) foreshore sands and their trigger mechanism (Carpathian Foredeep Basin, Czech Republic). – Austrian Journal of Earth Sciences, **107** (2): 23-36.

Nehyba, S., Tomanová-Petrová, P., Gilíková, H. & Horáková, M. (2009): Some remarks to the knowledge about depositional environment of Lower Badenian deposits at Oslavany. – Geologické Výzkumy na Moravě a ve Slezsku, **16**: 17-20 (In Czech).

Nehyba, S., Roetzel, R. & Maštera, L. (2012): Provenance analysis of the Permo-Carboniferous fluvial sandstones of the southern part of the Boskovice Basin and the Zöbing Area (Czech Republic, Austria): implications for paleogeographical reconstructions of the post-Variscan collapse basins. – Geologica Carpathica, **63** (5): 365-382.

Nehyba, S. & Šikula, J. (2007): Depositional architecture, sequence stratigraphy and geodynamic development of the Carpathian Foredeep (Czech Republic). – Geologica Carpathica, **58** (1): 53-69.

Nehyba, S., Petrová-Tomanová, P. & Zágoršek, K. (2008): Sedimentological and palaeocological records of the evolution of the south-western part of the Carpathian Foredeep (Czech Republic) during the Early Badenian. – Geological Quarterly, **52** (1): 45-60.

Nemec, W. (2005): Principles of lithostratigraphic logging and facies analyses. – Institutt for geovitenskap, 1-28; Bergen (University of Bergen).

Papp, A., Cicha, I., Seneš, J. & Steininger, F. (1978): M-4 Badenien (Moravien, Wielicien, Kosovien). Chronostratigraphie und Neostratotypen. – Miozän der Zentralen Paratethys VI. – 594 pp.; Bratislava (VEDA).

Pezelj, D., Mandic, O. & Ćorić, S. (2013): Paleoenvironmental dynamics in the southern Pannonian Basin during initial Middle Miocene marine flooding. – Geologica Carpathica, **64**: 81-100.

Peryt, D. & Gedl, P. (2010): Palaeoenvironmental changes preceding the Middle Miocene Badenian salinity crisis in the northern Polish Carpathian Foredeep Basin (Borków quarry) inferred from foraminifers and dinoflagellate cysts. – Geological Quarterly, **54** (4): 487-508.

Peryt, D., Gedl, P. & Peryt, T.M. (2014): Foraminiferal and palynological records of the Late Badenian (Middle Miocene) transgression in Podolia (Shchyrets near Lviv, western Ukraine). – Geological Quarterly, **58** (3): 465-484.

Peryt, T.M., Karoli, S., Peryt, D., Petrichenko, O.I., Gedl, P., Ďurkovičova, J. & Dobieszyńska, Z. (1997): Westernmost occurrence of the Middle Miocene Badenian gypsum in Central Paratethys (Kobeřice, Moravia, Czech Republic). – Slovak Geological Magazine, **3**: 105-120.

Piller, W., Harzhauser, M. & Mandic, O. (2007): Miocene Central Paratethys stratigraphy – current status and future directions. – Stratigraphy, **4**: 151-168.

Powell, A.J. (1992): Dinoflagellate cysts of the Tertiary System. – In: Powell, A.J. (Ed.): A stratigraphic index of dinoflagellate cysts. p. 155-252; London (Chapman & Hall).

Powers, M.C. (1982): Comparison chart for estimating roundness and sphericity. – AGI Data Sheet **18**.

Rathburn, A.E. & Corliss, B.H. (1994): The ecology of deep-sea benthic foraminifera from the Sulu Sea. – Paleoceanography, **9**: 87-150.

Reading, H.G. (1996): Sedimentary Environments: Processes, Facies and Stratigraphy. – 3rd ed., 154-232; Oxford (Blackwell).

Reolid, M., Rodríguez-Tovar, F.J., Nagy, J. & Olóriz, F. (2008): Benthic foraminiferal morphogroups of mid to outer shelf environments of the Late Jurassic (Prebetic Zone, southern Spain): characterization of biofacies and environmental significance. – Palaeogeography, Palaeoecology, Palaeoclimatology **261**: 280-299.

Reynolds, A.D. (1999): Dimensions of paralic sandstone bodies. – AAPG Bulletin, **83**: 211-229.

Reynolds, L. & Thunell, R.C. (1985): Seasonal succession of planktonic foraminifera in the subpolar North Pacific. – Journal of Foraminiferal Research, **15**: 282-301.

Rigual-Hernández, A.S., Sierro, F.J., Bárcena, M.A., Flores, J.A. & Heussner, S. (2012): Seasonal and interannual changes of planktic foraminiferal fluxes in the Gulf of Lions (NW Mediterranean) and their implications for paleoceanographic studies: Two 12-year sediment trap records. – Deep-Sea Research I Oceanographical Research Papers, **66**: 26-40.

Rochon, A., De Vernal, A., Turon, J.-L., Matthiessen, J. & Head, M.J. (1999): Distribution of recent dinoflagellate cysts in surface sediments from the North Atlantic and adjacent seas in relation to sea-surface parameters. – American Association of Stratigraphy and Palynology in Continental Series, **35**: 1-146.

Rögl, F., Ćorić, S., Hohenegger, J., Pervesler, P., Roetzel, R., Scholger, R., Spezzaferri, S. & Stingl, K. (2007): The Styrian tectonic Phase – a series of events at the Early/Middle Miocene boundary revised and stratified (Styrian Basin, Central Paratethys). – Joannea Geologie Paläontologie, **9**: 89-91.

Rögl, F., Spezzaferri, S. & Ćorić, S. (2002): Micropaleontology and biostratigraphy of the Karpatian-Badenian transition (Early- Middle Miocene boundary) in Austria (Central Paratethys). – Courier Forschungs-Institut Senckenberg, **237**: 46-67.

Rohling, E.J., Jorissen, F.J., Vergnaud-Grazzini, C. & Zachariasse, W.J. (1993): Northern Levantine and Adriatic Quaternary planktic foraminifera; Reconstruction of paleoenvironmental gradients. – Marine Micropaleontology, **21**: 191-218.

Rosoff, D.B. & Corliss, B.H. (1992): An analysis of recent deep-sea benthic foraminiferal morphotypes from the Norwegian and Greenland seas. – Palaeogeography, Palaeoclimatology, Palaeoecology, **91**: 13-20.

Salmon, K.H., Anand, P., Sexton, P.F. & Conte, M. (2014): Upper ocean mixing controls the seasonality of planktonic foraminifer fluxes and associated strength of the carbonate pump in the oligotrophic North Atlantic. – Biogeosciences Discussion, **11**: 12223-12254.

Sen Gupta, B.K. & Machain-Castillo, M.L. (1993): Benthic foraminifera in oxygen-poor habitats. – Marine Micropaleontology, **20**: 183-201.

Schiebel, R., Bijma, J. & Hemleben, C. (1997): Population dynamics of the planktic foraminifer *Globigerina bulloides* from the eastern North Atlantic. – Deep Sea Research Part I: Oceanographic Research Papers, **44** (9-10): 1701-1713.

Schiebel, R. & Hemleben, C. (2005): Modern planktic foraminifera. – Paläontologische Zeitschrift, **79** (1): 135-148.

Schönfeld, J. (2001): Benthic foraminifera and pore-water oxygen profiles: a re-assessment of species boundary conditions at the western Iberian margin. – Journal of Foraminiferal Research, **31**: 86-107.

Sjoerdsma, P.G. & Van der Zwaan, G.J. (1992): Simulating the effect of changing organic flux and oxygen content on the distribution of benthic foraminifera. – Marine Micropaleontology, **19**: 163-180.

Tomanová-Petrová, P. & Švábenická, L. (2007): Lower Badenian biostratigraphy and paleoecology: a case study from the Carpathian Foredeep (Czech Republic). – Geologica Carpathica, **58**: 333-352.

Tucker, M. (Ed.) (1988): Techniques in Sedimentology. – 1-394; (Blackwell).

Tyszka, J. (1994): Response of Middle Jurassic benthic foraminiferal morphogroups to dysoxic/anoxic conditions in the Pieniny Klippen Basin, Polish Carpathians. – Palaeogeography, Palaeoclimatology, Palaeoecology, **110**: 55-81.

Van Der Zwaan, G.J., Jorissen, F.J. & De Stiger, H.C. (1990): The depth dependency of planktonic/benthonic foraminiferal ratios: constraints and applications. – Marine Geology, **95**: 1-16.

Van Gijzel, P. (1971): Review of the UV-fluorescence microphotometry of fresh and fossil exines and exosporia. – In: Brooks, J., Grant, P.R., Muir, M., van Gijzel, P. & Shaw, G. (Eds.): Sporopollenin. 659-685; London & New York (Academic Press).

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S. & Hardenbol, J. (1988): An overview of the fundamentals of sequence stratigraphy and key definitions. – In: Wilgus, C.K., Ross, C.A. & Posamentier, H. (Eds.): Sea-Level Changes: An Integrated Approach. – SEPM Special Publication, **42**: 39-45.

Vink, A., Zonneveld, K.A.F. & Willems, H. (2000): Organic-walled dinoflagellate cysts in western equatorial Atlantic surface sediments: distribution and their relation to environment. – Review of Palaeobotany and Palynology, **112**: 247-286.

Wade, B.S. & Bown, P.R. (2006): Calcareous nannofossils in extreme environments: the Messinian Salinity Crisis, Polemi Basin, Cyprus. – Palaeogeography, Palaeoclimatology, Palaeoecology, **233**: 271-286.

Walanus, A. & Nalepka, D. (1999): POLPAL. Program for counting pollen grains, diagrams plotting and numerical analysis. – Acta Paleobotany, Supplement, **2**: 659-661.

Walker, R.G. & James, N.P. (1992): Facies Models. Response to sea level changes. – 1-380; Toronto (Geological Association of Canada).

Wall, D. & Dale, B. (1969): The "hystrichosphaerid" resting spore of the dinoflagellate *Pyrodinium bahamense* Plate, 1906. – Journal of Phycology, **5**: 140-149.

Wall, D., Dale, B., Lohmann, G.P. & Smith, W.K. (1977): The environmental and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the north and south Atlantic Oceans and adjacent seas. – Marine Micropalaeontology, **2**: 121-200.

Wells, P. & Okada, H. (1997): Response of nannoplankton to major changes in seasurface temperatrure and movements of hydrological fronts over site DSDP 594 (south Chatham Rise, southeastern New Zealand), during the last 130 kyr. – Marine Micropalaeontology, **32**: 341-363.

Williams, G.L., Brinkhuis, H., Pearce, M.A., Fensome, R.A. & Weegink, J.W. (2004): Southern Ocean and global dinoflagellate cyst events compared: index events for the Late Cretaceous-Neogene. – Proceedings of the Ocean Drilling Project, Scientific Results, **189**: 1-98.

Winter, A., Jordan, R.W. & Roth, P.H. (1994): Biogeography of the living coccolithophores in the oceans. – In: Winter, A. & Siesser, W. (Eds.): Coccolithophores. 161-178; Cambridge (Cambridge University Press).

Zágoršek, K., Holcová, K., Nehyba, S., Kroh, A. & Hladilová, Š. (2009): The invertebrate fauna of the Middle Miocene (Lower Badenian) sediments of Kralice nad Oslavou (Central Paratethys, Moravian part of the Carpathian Foredeep). – Bulletin of Geosciences, **84** (3): 465-496.

ZEVENBOOM, D. (1995): Dinoflagellate cysts from the Mediterranean Late Oligocene and Miocene. – Ph.D. Thesis, University of Utrecht, 221 p.; Den Haag, The Netherlands (Cip-Gegevens Koninklijke Bibliotheek).

ZIVERI, P., BAUMANN, K.-H., BÖCKEL, B., BOLLMANN, J. & YOUNG, J. (2004): Biogeography of selected Holocene coccoliths in the Atlantic Ocean. – In: THIERSTEIN, H.R. & YOUNG J.R. (Eds.): Coccolithophores from molecular processes to global impact. 403-428; Berlin (Springer Verlag).

Manuscript received: April 1st, 2015.
Revised version accepted by the Bonn editor: December 14th, 2015.

Addresses of the authors:

SLAVOMÍR NEHYBA, NELA DOLÁKOVÁ, Institute of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic;
e-mail: slavek@sci.muni.cz, nela@sci.muni.cz

KATARÍNA HOLCOVÁ, Institute of Geology and Paleontology, Faculty of Sciences, Charles University in Prague, CZ-128 43 Praha 2, Czech Republic;
e-mail: holcova@natur.cuni.cz

PRZEMYSŁAW GEDL, Institute of Geological Sciences, Polish Academy of Sciences, Senacka 1, 31-002 Kraków, Poland;
e-mail: ndgedl@cyf-kr.edu.pl

Research paper

New information augmenting the picture of local environment at the LGM/LGT in the context of the Middle Danube region

The Holocene
2016, Vol. 26(9) 1345–1354
© The Author(s) 2016
Reprints and permissions:
sagepub.co.uk/journalsPermissions.nav
DOI: 10.1177/0959683616640051
hol.sagepub.com
SAGE

Zdeňka Nerudová,[1] Nela Doláková[2] and Jan Novák[3]

Abstract

Records of occupation by humans in the period following shortly after the Last Glacial Maximum (LGM; 21 ± 2 kyr cal. BP) are still very rare in Central Europe, since it is inferred that the extreme climatic conditions caused the decolonisation of previously settled areas. Our study focuses on the reconstruction of environmental conditions in the surroundings of the open-air Palaeolithic site, Brno-Štýřice III, which falls within this period. The research concentrated on the study of malacological, pollen and anthracological samples to reconstruct the climate shortly after the LGM. ^{14}C dating places the chronostratigraphic position of the site more precisely at the end of the LGM, more specifically into Last Glacial Termination (LGT); analysis of chipped stone industry identifies the occupation with the Epigravettian settlement. The site represents a significant example of the recurrent habitation of a microclimatically favourable microregion near a watercourse in order to utilise available sources of livelihood. The results of the pollen, anthracological and malacological analyses documented a more or less treeless character of surrounding landscape. The vegetation was mostly formed by a mixture of shrub tundra and grassy loess steppe vegetation. Open woodland with birch, willow and bird cherry occurred in relatively moist river banks and the lower slopes of hills with more favourable microclimatic conditions. Malacological collection highlights the presence of cool temperate species (*Pupilla loessica*, *Vallonia excentrica* and *Helicopsis striata*). In the surroundings of the studied site, the pollen analysis provided a reconstruction of parkland forest-steppe vegetation (with lack of temperate deciduous trees) typical for a cold and dry climate. Development of both dry and moist stands near the watercourse was recorded. Anthracological analysis is in support of similar outcomes, reconstructing the presence of open woodland with dominating birch and willow in the nearby surroundings.

Keywords

Anthracology, LGM/LGT, malacology, Middle Danube region, Palaeolithic settlement, palynology

Received 12 November 2015; revised manuscript accepted 22 February 2016

Introduction

The period of the so-called Last Glacial Maximum (LGM), which is part of the Late Pleniglacial (e.g. Magyari et al., 2014a, 2014b), is defined on the basis of the regression of sea level (Yokoyama et al., 2000) or the related maximum extent of glacier ice (Clark et al., 2009; Ehlers et al., 2013), which occurred between 26.5 and 20/19.0 kyr cal. BP. At the same time, the LGM period is generally considered to be climatically extreme, conditions in which the hitherto known Palaeolithic settlements retreat from exposed areas into preferential (more sheltered) refuges. In Germany, for instance, this period is usually described as the time of resettlement of the original occupied areas that became re-colonised only with the onset of the Magdalenian permeating from France (Terberger, 2013; Terberger and Street, 2002). Similarly, the reduction in the number of significant sites has also been noted in Moravia in the past (Oliva, 2005; Svoboda et al., 2002; Valoch, 1996, 2010).

The climatic conditions considerably influenced Central, Western and Northern Europe during the highest phase of the Weichsel glaciation. The palaeoclimate in the Middle Danube region during the LGM is reconstructed as mean summer temperature of about 11°C with mild September (ca. 7°C). Winter began in November (−5°C), and in January and February, the temperature dropped down to −11°C to 12°C. The proposed mean annual precipitation peaked in July and August (3 mm/day), then it fell to its annual minimum of 1 mm/day in October, staying at an average 1–2 mm/day through winter (Davies et al., 2003). The Czech Republic and the adjacent territories were part of a relatively narrow (about 400 km wide) zone delimited by the front of the continental glacier in the north and by the Alps in the south (extent of glaciation, e.g. Ehlers et al., 2013).

The reconstruction of Late Pleniglacial vegetation has traditionally been based on interpreting pollen data. Many pollen records of the period of the Last Glacial in Central Europe show a shift in pollen from dry steppe/shrub tundra to a birch/juniper woodland followed by a birch/pine forest (e.g. Amann et al., 2013; Jankovská and Pokorný, 2008; Magyari et al. 2014a, 2014b;

---

[1] Moravian Museum, Historical Museum, Centre for Cultural Anthropology, Czech Republic
[2] Institute of Geological Sciences, Faculty of Science, Masaryk University, Czech Republic
[3] Laboratory of Archaeobotany and Palaeoecology, Faculty of Science, University of South Bohemia, Czech Republic

Corresponding author:
Zdeňka Nerudová, Moravian Museum, Historical Museum, Centre for Cultural Anthropology, Zelný trh 6, Brno, CZ-65937, Czech Republic.
Email: znerudova@mzm.cz

Willis et al., 2000). Nevertheless, palaeobotanical data from LGM sites in eastern-central Europe generally confirm the existence of not only parkland landscapes with coniferous trees (such as *Pinus sylvestris*, *Pinus cembra*, *Larix*, *Picea* and *Juniperus*) but also more demanding tree taxa (*Abies*, *Corylus*, *Quercus*, *Fagus*, *Fraxinus*, *Ulmus*, *Taxus* or *Carpinus*; see Jankovská and Pokorný, 2008; Willis and Van Andel, 2004). Taking into account new palaeobotanical and molluscs data, the local conditions in the whole area of the Czech Republic were more favourable (for more discussion, see Horsák et al., 2010; Jankovská and Pokorný, 2008; Juřičková et al., 2014; Ložek, 2001, 2009). The aim of this study is to present the new information about the local climatic conditions during the LGM/LGT period based on the results of excavation of a Palaeolithic site.

Archaeological background

From the archaeological point of view, the LGM period in Central Europe is characterised by the end of Gravettian in the so-called Kostenki-Willendorf phase (around 24–25 kyr cal. BP) and the onset of Magdalenian colonisation, which proceeded from Western Europe through the north German lowlands as far as Moravia, where it arrived in around 17–18 kyr cal. BP (Neruda, 2010; Neruda et al., 2009). Despite the generally adopted awareness of the decolonisation of the climatically exposed regions of Central Europe in the LGM and the following period that preceded the Magdalenian colonisation, in recent years, we applied ourselves to the study of an archaeological site, the occupation of which falls within the period, when the LGM petered out, and the LGT that followed, on the grounds of ^{14}C dating (Nerudová and Neruda, 2015). The evidence of the local more favourable conditions can be documented not only by palaeorecords in vegetation but also by archaeological evidence. On the basis of the cultural classification or geomorphological position we can associate with the short period between the end of the Gravettian and before the onset of the Magdalenian in Moravia almost 49 sites. Contrary to the previous Gravettian, the re-analyses of the settlement dynamics revealed significant changes. On the basis of reconstruction of settlement strategy of the Epigravettian sites we can conclude that the majority of localities are situated within the interval of 200–250 m a.s.l.; the sites are mostly oriented towards the east through to north-east and are usually much closer to (mostly) small river in protected areas (Nerudová and Neruda, 2015).

Regional setting, site characteristics and stratigraphy

The excavation site Brno-Štýřice III (global positioning system (GPS): World Geodetic System 1984 (WGS-84): 49°11′2.5505″N, 16°35′41.6602″E; S-JTSK: 1161873.78, 599243.33 – the centre of the locality) is located in the south-western part of Brno, approximately 300 m to the south of the current bank of the Svratka River (Figure 1). Here, at an elevation of 210 m a.s.l. (10 m above the river level) is a step in the lower terrain which on the west side rises up into a low but steep cliff of Lower Devonian conglomerates known as Červený kopec (Red Hill) with a maximum height of 311.42 m a.s.l. The Quaternary cover of the region is formed by an accumulation of aeolian (loess) and colluvial sediments deposited on a terrace consisting of gravels with clay matrix and sandy gravels of Quaternary age, which were detected at a depth of 6–8 m. A coring revealed that the sequence of Pleistocene sediments at the locality is up to 10 m thick in places and is not divided by any distinct fossil soils. Towards the superposed layers, the sequence of loess and loess sediments is covered by an orange silty sediment C (weakly developed soil followed by Holocene stratigraphy brown earth; see Nerudová et al., 2012: Figure 2). Within the whole area under investigation, Holocene soil inclusive of the A- and B-horizons is only preserved in higher parts (i.e. at the W and SW edge of the excavated surface). In the central part of the slope, only a relic of the B-horizon is preserved, and in the NE and E parts of the investigated area (i.e. in the lowest parts), the B-horizon is not preserved at all. This being the reason why the A-horizon settled immediately on the Pleistocene sediments.

The site of Brno-Štýřice III was first investigated by K Valoch; in 1972, he conducted small-scale rescue excavations there; nevertheless, the excavations yielded a representative collection of chipped stone industry as well as the remains of animal bones and blobs of ochre (Valoch, 1975). The assemblage was dated later on (Valoch, 1980, 1996; Verpoorte, 2004: 262); for more discussion, see Nerudová and Neruda (2014). The next large-scale rescue excavations were carried out in 2009 and 2011–2014. They revealed the extent of settlement, a new site (in 2009 – Štýřice IIIa), and yielded a large amount of lithics and osteological material.

Archaeological finds of the Palaeolithic age were found in the uppermost part of the Late Weichselian loess cover, which formed a 25-cm-thick (approximately) layer of orange-brown loess-like sediment (weakly developed soil). This layer was almost continuously present over the entire investigated area as it followed the inclination of the terrain, which was quite steep in certain places. There was a relatively sharp border between the horizon with archaeological finds and the underlying sediments. Although the lithic artefacts and bones were deposited in loess-like sediment, the base of the superposed chernozem horizon A sporadically intruded (e.g. the upper part of a mammoth jawbone; Nerudová et al., 2012). The first radiocarbon date was obtained from a charred bone of reindeer (Valoch, 1980, 1996), the next dating (performed by A Verpoorte in 2001 from the same sample; see Nerudová and Neruda, 2014: Table 4), yielded a date very similar to the previous one (Verpoorte, 2004). The evidence of human activities falling the site within the Epigravettian period (Nerudová, 2015; Valoch, 1975). Sampling during the last seasons of excavations provides us to perform the palaeobotanical analysis.

Materials and methods

The collection of samples

The collection of samples was carried out within the archaeological research of the site in 2009 and 2011–2014 (Figure 2; e.g. Nerudová and Neruda, 2014). We took samples of varying volumes: individual bigger charcoals (0.5–2 cm) macroscopically distinguishable in the course of preparation of the archaeological layer (all bigger samples taken during excavation were determined as fragments of burnt bones; Roblíčková et al., 2015) and target sediment samples of 5–10 L from the places with dispersed pieces of charcoal or bones. For the pollen analysis, we took samples of 0.5–1 L volume.

The extractions of the charcoal, molluscs and bones from the sediment samples were subjected to the standard flotation procedure using staggered sieves with a mesh size of 0.25 mm.

Radiocarbon dating

New radiocarbon dating was performed using the accelerator mass spectrometry (AMS) method in the laboratory in Oxford, where samples underwent standard laboratory procedure (Bronk Ramsey et al., 2004b). Animal bones (mammoth molars and mandible) coming from a distinct archaeological context served for the dating because of the volume required, since no other suitable material was available (the abundance and size of charcoals was very low, at the limit of the method; see Bronk Ramsey et al., 2004a). Before dating, the bones were not cleaned using chemical methods; they were only determined. The standard process in Oxlab is measurement of bone collagen by ultrafiltration

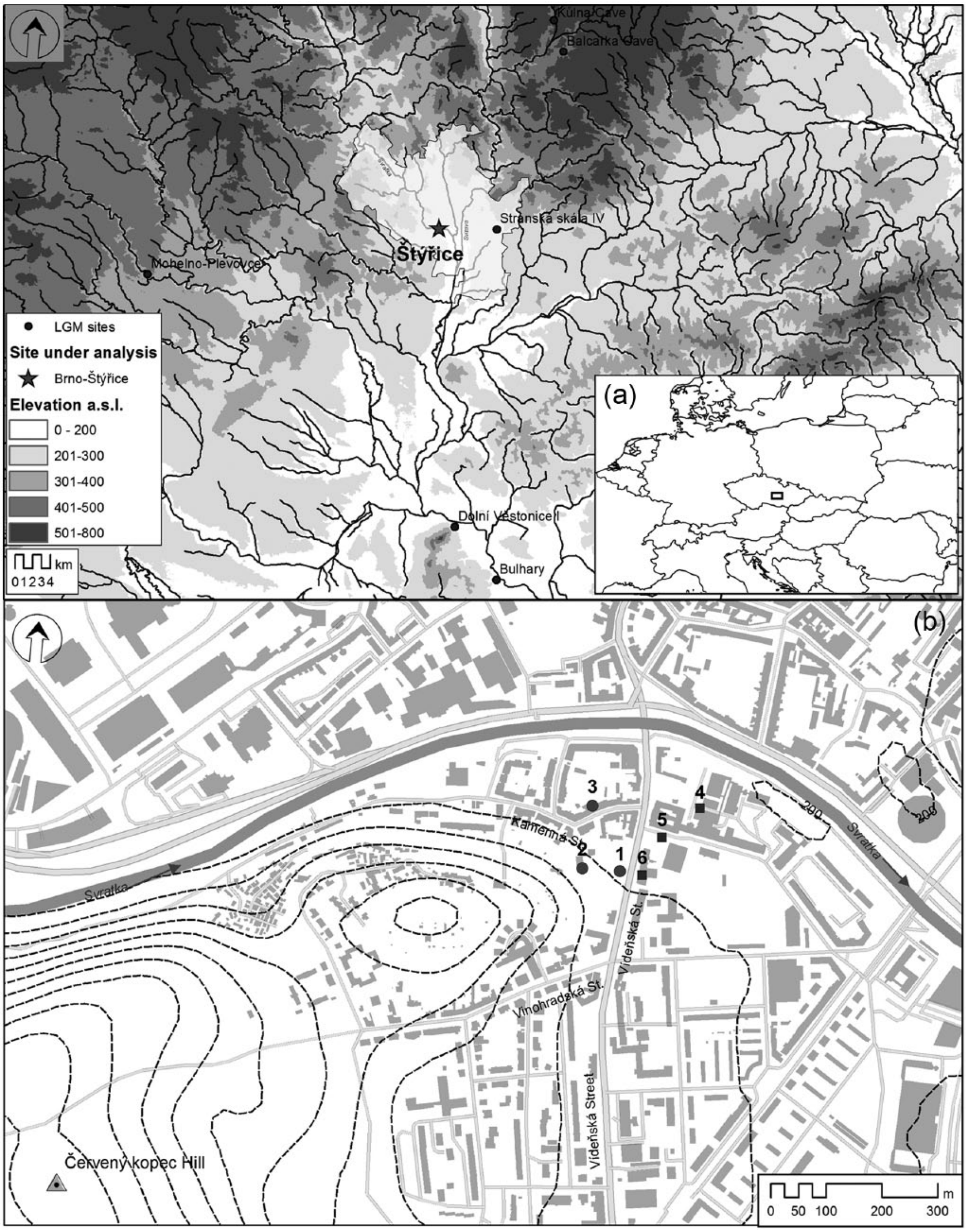


Figure 1. (a) Moravia region with LGM/LGT sites mentioned in the text and (b) microregion of the Brno-Štýřice with Palaeolithic finds.
1: Štýřice III; 2: Štýřice IIIa; 3: Kamenná St; 4: Hospital; 5: Polní St; 6: Vídeňská St no. 15; squares: isolated or sporadic finds; circles: extent sites.
Source: Digitalisation – Z. Nerudová.

method (Bronk Ramsey et al., 2004b). Isotopic fractionation has been corrected for using the measured ^{13}C values measured on the AMS, the quoted ^{13}C values are measured independently on a stable isotope mass spectrometer (see Bronk Ramsey et al., 2004a, 2004b).

Laboratory preparations and analysis of fossil samples

Palynological samples were picked from squares 83 and 95 (two samples from each of them). An accumulation of charred bones and overburnt sediment was detected in square 95, consequently a sediment was taken for palynological analysis; unfortunately, the pollen record from square 95 was very poor (see Table 2). Palynological samples were treated with HCl (20%), HF, KOH and HCl (10%) and heavy liquid $ZnCl_2$ (density = 2 g/cm^3) for standard maceration. The omission of acetolyse enabled clearer identification of contemporary pollen contamination. The final residue was diluted with glycerol. A Nikon Alphaphot 2 light microscope with 400× and 1000× magnifications was used for palynological observations. Taxa identification was mainly done according to Reille (1995) and Beug (2004). The pollen diagram was created using the POLPAL programme (Walanus and Nalepka, 1999).

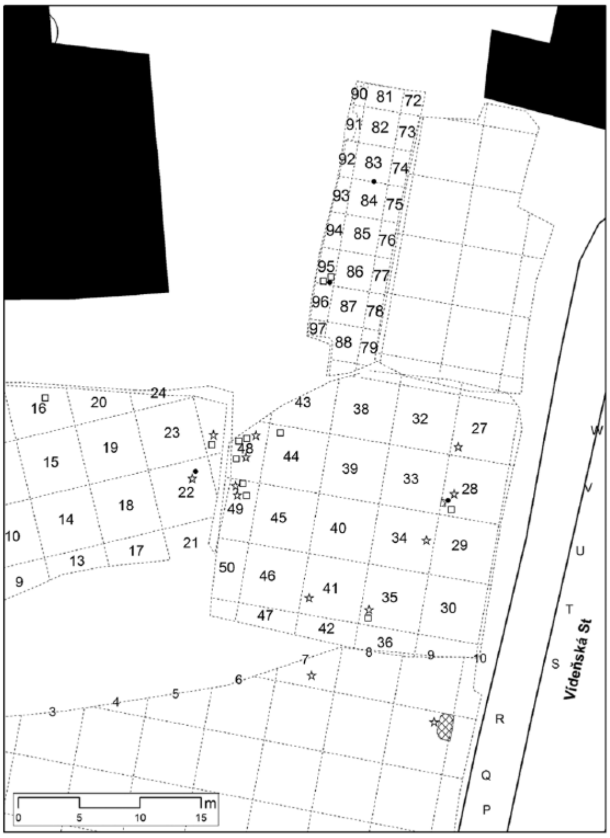


Figure 2. Detail plan of the Brno-Štýřice III site (excavations 2009–2014) and positions of taken samples for analyses.
Black dot: pollen sample; asterisk: molluscs; square: charcoals.
Source: Digitalisation – Z. Nerudová.

The charcoal analysis was performed only on fragments from the largest fraction (>1 mm). The charcoals were identified using an episcopic interference microscope (Nikon Eclipse 80i) with 200–500 magnification and the reference collection. The additional standard identification keys were also used (Heiss, 2000; Schweingruber, 1990). The species abundance was expressed in the number of charcoal fragments (e.g. proposed by Delhon, 2006) and charcoal anthracomass (e.g. Carcaillet and Thinon, 1996). The individual taxa were weighted with an accuracy of 0.001 g. The sediment anthracomass (milligram of charcoal per kilogram of sediment; Talon et al., 1998) was derived from the charcoals larger than 1 mm.

Mollusc shells for malacological studies were derived from individual sediment samples taken with the bone samples for laboratory processing.

Results

Radiocarbon dating

Most recent radiocarbon dating was done on samples taken during the excavations in 2009 and 2011. Only a single date from a mammoth molar was obtained because of the low collagen content of the other samples. Dating of other samples from the 2012 excavation was successful. From a total of four samples, only two dates were obtained, and these dates were similar to the previous ones (Table 1). Sample of burnt bone (OxA-28114) gave a good yield of carbon on combustion, and a CN ratio of 7, which indicates that there is some pyrolysed collagen remaining. In addition, the stable isotope ratio (d^{13}C) was −22.2, which is acceptable for a large mammal. For this reason, the sample was OxA'ed. Dating of the next two samples of charred bones taken from the excavation in 2014 unfortunately failed because of very low yield.

Table 1. 14C data from Brno-Štýřice III.

OxA-26961: 15,625 ± 75 BP (excavation 2009; molar, *Mammuthus primigenius*)
OxA-28298: 15,215 ± 70 BP (excavation 2012; molar, *Mammuthus primigenius*)
OxA-28114: 14,870 ± 90 BP (excavation 2012; charred bone, *Mammuthus primigenius*)

Table 2. List and abundances of pollen grains.

	Square 83	Square 95
Arboreal pollen (AP)		
Alnus	2	
Betula	6	
Corylus	1	
Ephedra	1	
Pinus sylvestris	35	
Pinus cembra	24	
Rosaceae type *Rubus*	1	1
Nonarboreal pollen (NAP)		
Artemisia	1	
Asteraceae, Cichorioideae	4	
Asteraceae, Asteroideae	5	2
Brassicaceae type *Cardamine*	1	1
Chenopodiaceae	6	1
Chrysosplenium	6	
Cyperaceae	2	
Daucaceae	1	
Ericaceae	1	
Helianthemum	1	
Persicaria	1	
Plantago	1	
Poaceae	10	1
Glyceria type	2	
Ranunculaceae	3	
Caltha	2	
Delphinium	4	
Thalictrum/Illecebrum	5	
Veronica	3	
Sporophyta		
Botrychium	1	
Lycopodium	1	
Polypodiaceae smooth	1	
Sphagnum	1	
Bryophyta	2	
Algae		
Botryococcus braunii	16	1
Pediastrum	1	
Circulisporis	6	
Fungi	xx	x
Glomus	3	
Tertiary redepositions undetermined	21	

Pollen analysis

A very interesting pollen spectrum was found in samples from square 83. Predictably about one-fifth of the total number of the determined pollen grains and spores consisted of palynomorphs redeposited from the older Tertiary sediments. Woody plants were relatively amply represented by pollen grains of pine with a slight prevalence of common *Pinus sylvestris* over *Pinus cembra*. Other species that were determined include *Betula* – finding of three grains in a clump testifies to a short transport, less commonly *Alnus* and sporadically *Corylus* (Figure 3). From the pollen grain ratios of woody species (arboreal pollen (AP)) 52%

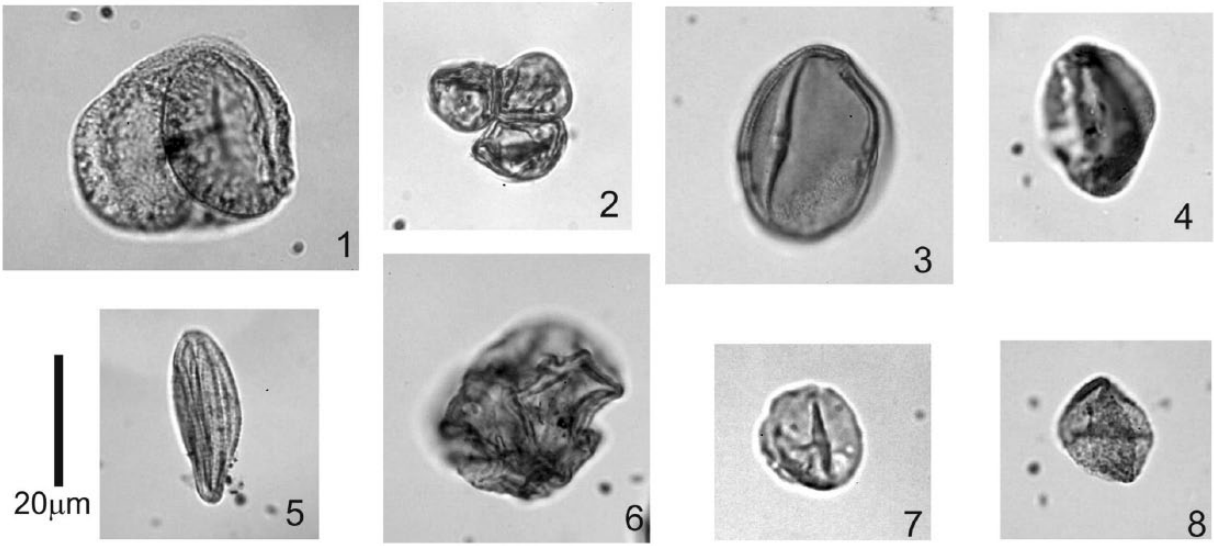


Figure 3. Photographs of the main pollen types (square 83), magnification 1000×.
1: *Pinus cembra* type; 2: *Betula* – three grains; 3: *Helianthemum*; 4: Rosaceae type *Rubus*; 5: *Ephedra*; 6: *Glyceria* type; 7: *Thalictrum*; 8: *Caltha*.
Source: Photograph – N. Doláková.

and herbs (nonarboreal pollen (NAP)) 48%, the character of vegetation appears to be a moderately forested landscape to parkland (Table 2). However, the proportion of woody plants (in which pollen of *Pinus* markedly prevails) can be greatly overvalued because of prodigious pollen production and the great flying range of pine pollen grains. The herbal constituent of the spectrum included the representatives of both drier and waterlogged habitats; for example, grasses Poaceae, floscular Asteraceae, *Artemisia*, or Chenopodiaceae occurred in drier areas, ascertained were *Delphinium* or *Veronica*. Bushes such as *Ephedra, Rubus* type or *Helianthemum* and Ericaceae were also represented. Elements characteristic for damp, waterlogged habitats or watersides such as Cyperaceae, *Glyceria*, *Caltha*, *Chrysosplenium* or scarce spores of *Sphagnum* were also found. Colonies of aquatic *Botryococcus braunii* were relatively abundant; those of the *Pediastrum* were sporadic. A paucity of thermophilic woody species together with taxa typical for cold periods of the Quaternary such as *Helianthemum*, *Thalictrum* and *Ephedra* determines the character of the climate.

Anthracological analysis

A total of 89 charcoal fragments and 6 charcoal species from 13 samples were identified. Anthracological samples were distinguished by the low presence of small pieces of charcoals (the most common charcoal size was 2–3 mm). The anthracomass of analysed samples was very low. A significant feature of the entire assemblage of samples was a considerable prevalence of carbonised bone fragments over wood charcoals.

In the charcoal samples obtained from the Epigravettian layer, the dominant tree was *Betula* (34.8%), followed by abundant charcoal of *Salix* (27.0%) and *Padus* (21.3%). The presence of *Picea/Larix* (11.2%) was relatively common. Only scarce occurrences of *Hippophae* (4.5%) and Ericaceae (1.1 %) were recorded (Figure 4).

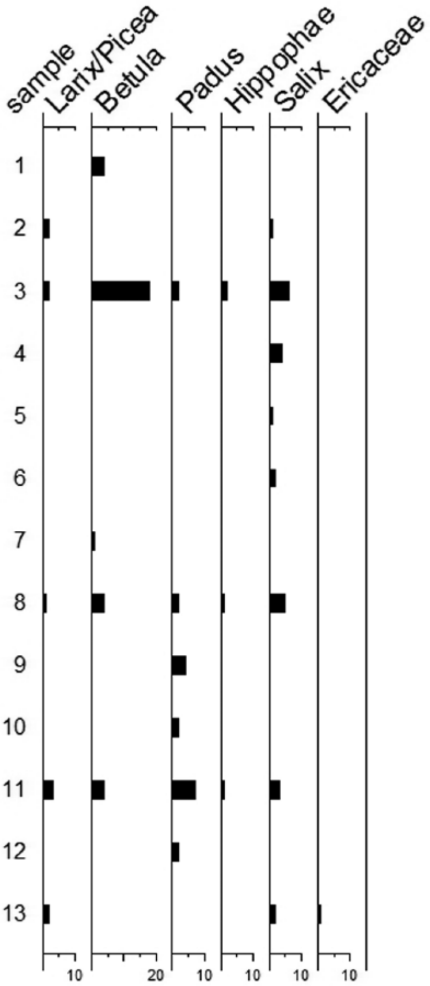


Figure 4. Number of charcoals in the study samples.

Malacological analysis

The first representatives of malacofauna that were found are *Pupilla loessica* (9 pcs), *Vallonia excentrica* (1 pc) and *Helicopsis striata* (1 pc) coming from the hearth area (square 9/Q, excavation 2009; determination by L. Juřičková; Nerudová et al., 2012). Other individuals of the *Pupilla loessica* species (determination by M. Horsák) were found during the next season of excavation (i.e. 2012): square 35 (6 pcs), square 48 (2 pcs), square 49 (1 pc), square 26 (1 pc) and square 22 (1 pc).

Discussion

Proxy data serving for the reconstruction of palaeoclimate could not be obtained through systematic sampling, because neither the state of preservation and the character of the Pleistocene sediments nor the character of rescue archaeological excavations allowed it. Despite several pollen samples taken, only one was positive for determination, and in this single case, it was taken close below the archaeological layer level (at its base). Relatively numerous shells of bivalves were found solely in relation to laboratory processing of large fragments, especially mammoth bones; at the same time, it has to be stressed that microfauna was not ascertained at all. In view of the soil chemistry influenced by post-deposition processes, the shells were always preserved only in the sediment and close to scarce bigger bone fragments or hearths; contrary to the surrounding area, such environment is always more calciferous, which facilitated their preservation (Nerudová et al., 2012; environmental requirement in general, for example, in Juřičková et al. (2014)). Determination of the osteological material was greatly impeded by its fragmentary character and severe surface deterioration, even in bones of large mammals with thick compact bones (Roblíčková et al., 2015). However, although we took all of the macroscopically apparent charcoals, and also the entire sediment from the places of hearths, the numerous tiny burnt fragments turned out to be animal bones, not woody species. Nevertheless, both archaeological and palaeobotanical analyses brought interesting, mutually complementary and corresponding results that are in harmony with the radiocarbon dating of the site.

Pollen analysis indicates scarcity of temperate woody species at the site and the presence of taxa typical for cold periods of the Quaternary determining the character of the climate as cold and dry. Parkland vegetation with the development of both drier and waterlogged habitats near water streams was reconstructed.

According to the determination of *malacozoological analysis*, the ascertained individuals belong to the typical representatives of loess steppe, since in the late glacial *Pupilla loessica* fades away (Horáčková et al., 2015; Horsák et al., 2010; Ložek, 1990, 2001, 2006).

Anthracological analysis recorded a dominance of *Betula*, common presence of *Salix*, *Padus*, *Picea/Larix* and only scarce occurrence of *Hippophae* and Ericaceae in study samples. These results indicate a cold, dry climate which is consistent with results and reconstructions. The matrix of landscape was probably more or less treeless. Open woodland with *Betula*, *Salix*, *Padus* and *Picea/Larix* was restricted to relatively moist banks of the river and protected valley. We can find the recent vegetation analogy in the river banks in southern Siberia (Magyari et al., 2014a) or northern Mongolia. The mixture of *Salix*, *Padus*, *Betula* (e.g. *Betula fusca*), *Picea obovata* and *Hippophae rhamnoides* formed typical vegetation composition in the vicinity of rivers or streams.

The cold and dry climate at the site is also indicated by the representatives of mammoth steppe fauna (of which most plentiful was exactly the *Mammuthus primigenius*, with *Equus germanicus*, *Rangifer tarandus* or *Coleodonta antiquitatis* as accessory species) and the results of analyses of carbon and nitrogen isotopes. Numerous fragments of animal bones could have resulted from deliberate human activity, substituting bones for shortage of wood in a period of shortage during the glacial maximum. Similar practices were ascertained, for instance, in Předmostí I-06 (Beresford-Jones et al., 2010), Dolní Věstonice II (Beresford-Jones et al., 2010; Svoboda, 1991a) or Grub-Kranawetberg (Bosch et al., 2012), and researches show the use of bones as fuel was a ‘common behavioural pattern during the Middle and Upper Palaeolithic in Northern Europe’. The use of bones as fuel was described in detail in the contribution by Bosch et al. (2012) since a more detailed analysis of this phenomenon is not a subject of this study.

This is where the results of radiocarbon dating and other scientific analyses diverge to some degree. After calibration (CalPal: Weninger and Jöris, 2008, and IntCal2014: Reimer et al., 2013), all of the data acquired from the site of Brno-Štýřice III so far form two peaks with an interval of roughly 1000 years GrN 9350: 17,620 ± 120 cal. BP and OxA 26961: 18,880 ± 90 cal. BP, that is, just after the stated interval of LGM (21 ± 2 kyr cal. BP). All new ^{14}C dates were obtained from the mammoth bones and mandibles, representing the only material found at the site from which it was possible to at least partly obtain any dates; these bones were found in close proximity to stone artefacts and within the same archaeological layer. Tools were also found in the sediment within the mandibles. We consider this close contextual association to be strong presumptive evidence for the contemporaneity of the lithic industry and mammoth bones, and considering the homogeneity of the dates, it is very possible that the site’s occupants gathered the remains of mammoth carcasses.

However, the results of the pollen, anthracological and osteological analyses documented a similar character of surrounding habitats. The landscape was more or less treeless. The vegetation was mostly formed by shrub tundra vegetation with grassy loess steppe. Open woodland with birch and willow occurred in relatively moist river banks (of the nearest Svratka River) and foot of a hill (the Červený kopec Hill) with more favourable microclimatic conditions (Ložek, 2001, 2009).

V. Ložek (2010) states,

> loess provides most evidence on the glacial environments in dry warm areas of Central Europe, which – in contrast to the conditions in north-western Europe – … never had the character of northern tundra, but of cold continental steppes and barren lands of Inner Asia instead. A clear testimony brings the loess fossil fauna, primarily the almost ubiquitous snails, the communities of which were preserved in the loess in secondarily undisturbed original appearance, enabling a critical comparison with similar recent snail assemblages of Inner Asia.

Nevertheless, on the grounds of our environmental analyses, manifestations of a slight warming in this period were not corroborated. Considering that the improvement of climatic conditions in the period shortly after the LGM (LGT) was only moderate, the changes in vegetation and fauna were probably relatively small; the microclimatic factor that enables surviving of typical zoocenoses (e.g. snails) in microclimatically suitable conditions in the face of the generally prevailing climate has to be considered as well (e.g. Horsák et al., 2015; Juřičková et al., 2014; Ložek, 1990, 2001, 2006).

Regretfully at present, we do not have larger quantity of data regarding the LGT environment in archaeological context available for the studied region. Therefore, we have to rely on information characterising the previous last cold oscillation instead.

If we take into account published isotopic data for mammoth in Europe and results of analyses of carbon and nitrogen isotopes in Brno-Štýřice III (Roblíčková et al., 2015), the results fit well together and generally confirm a cool steppe environment with low precipitation (Kovács et al., 2012; Pryor et al., 2013). The isotopic values from Brno-Štýřice III correspond to the Late Gravettian environment, especially in Moravia region (Roblíčková et al., 2015).

For the Middle Danube region in the LGM period, the landscape is characterised as a combination of cold loess steppe and mosaic parkland (Feurdean et al., 2014; Heiri et al., 2014). In central and eastern part of Europe, the major vegetation type of megabioms of the type cold deciduous trees is represented by *Alnus*, *Betula*, *Salix* and *Populus. Picea*, *Pinus*, *Abies*, *Larix* and *Juniperus* represent coniferous trees. Grass and shrubs are represented by

Ericaceae, *Calluna*, *Hippophae*, Poaceae, Cyperaceae and other NAPs. *Artemisia* and Chenopodiaceae/Amaranthaceae represent xerophytic herbs (Feurdean et al., 2014; Heiri et al., 2014).

We have to consider the station at Stránská skála IV the nearest analogous and at the same time archaeological site. The Epigravettian site, dated at 18,220±120 and 17,740 uncal. yr BP, yielded evidence of hunting of *Equus*, which prevailed, *Rangifer tarandus*, *Bos*, *Mammuthus* and *Coleodonta antiquitatis*. The mollusc successions acquired is indicative of a major biological rearrangement of the sediment since together with *Pupilla loessica*, also a striatic fauna was found, if it were a homogeneous successions (Svoboda, 1991b). Herb assemblage was also acquired from this site, and stratigraphy made its assessment complicated (the Epigravettian industry was situated in the uppermost part of the Weichselian loess also in this area; thus, it became secondarily turned into soil by the superposed Holocene horizon). Together with less climatically demanding woody species (*Betula*, *Salix*, *Pinus*, *Corylus* and *Alnus*), the sample also contained herbs (Cyperaceae, Poaceae, *Artemisia*, Asteraceae-Tubiflorae, Ericaceae, *Lythrum*, Chenopodiaceae and Silenaceae), ferns (Polypodiaceae) and moss (*Sphagnum*; Svoboda, 1991b).

In the South Moravian region, the profiles in Dolní Věstonice II or in Bulhary can be considered the closest regional and temporal analogous situation. Pollen analyses indicate that towards the end of the Weichselian interpleniglacial, coniferous trees (pine and spruce) were prevalent in Dolní Věstonice II, although more demanding woody species such as oak and beech also appear sporadically. Pollen grains of these more demanding species were also ascertained in the filling of the calva from triple burial at this site. According to H. Svobodová (2002), the herb spectrum points to forest–steppe character of the environment (Svobodová, 1991). Water and peat environment in the surroundings is indicated by *Myriophyllum*, *Sparganium*, *Potamogeton*, *Trapa natans* and algae (Svobodová, 1991). Anthracological analysis supports the presence of *Larix*, *Picea/Larix*, *Pinus sylvestris*, *Pinus cembra*, *Betula*, *Hippophae* and *Juniperus* at this site (Svoboda et al., 2015).

Anthracological analyses from the nearby Dolní Věstonice I confirmed the occurrence of pine, spruce and larch; further analyses testify to fir, perhaps also poplar (see Beresford-Jones et al., 2010; Svobodová, 2002). In the pollen spectrum, obtained from the core situated near the Bulhary Village and reaching down to about 10 m of aeolic loess layers and some 40–50 cm in thickness of compressed organogenic sediments (the moss peat and algal gyttja; 25,675+2.750–2.045 BP; Hv 10,855), coniferous species prevailed, birch, juniper, but also scattered temperate deciduous trees (*Ulmus*, *Acer*, *Quercus* and *Tilia*) were found, and these could grow at favourable sites in relation to relief. Unfortunately, the result of pollen analysis from this locality reconstructed vegetation closely before LGM. In the assemblages, over 200 types of palynomorphs (pollen, spores, etc.) have been found, which indicates a very rich flora and vegetation growing in at least six different biotopes of the Pálava Hills region (Rybníčková and Rybníček, 2014). The spectrum indicates grass and herb plant steppe community. The vegetation also comprised aquatic and swamp plants and ferns (Rybníčková and Rybníček, 1991, 2014; Svoboda et al. 2002).

Not only anthracological or pollen results but also various malacological analyses corroborate that the sporadic but several times observed findings of temperate deciduous trees could indicate the existence of refugia, which were preserved in more favourable enclaves – on southerly oriented slopes of the Pálava Hills – after the climatic deterioration (Juřičková et al., 2014; Ložek, 2006, 2009). According to Musil (1999, 2003), we can presume that such refuge areas facilitating growth of woody species requiring higher temperatures could have persisted since the previous interglacial; for the area of Moravia, Ložek (2009) or Horáčková et al. (2015) and Juřičková et al. (2014) argue for their existence on the grounds of malacozoological studies.

We know of pollen spectra capturing the LGM period from several sites in the Moravian Karst, for example, the Kůlna (layer 6; see Svobodová, 1988) or Barová (Seitl et al., 1986) and the Balcarka Caves (Doláková, 2010). At Balcarka Cave, prevailing herbs were found together with pollen of *Betula* in the sediment dated at 28,360 uncal. BP, captured inside the cave (Doláková, 2010). Within layers 11 and 12 in the Barová Cave (Seitl et al., 1986), the share of woody species increased and decreased several times (amounting up to 56% in the central part) – with prevalent *Pinus*, present *Betula*, *Alnus*, *Picea* and *Corylus*. In the herb spectrum, Poaceae and Asteraceae prevailed; *Helianthemum*, *Selaginella*, and *Ephedra* were present. Broadleaved trees requiring higher temperatures were not captured at the site. Nevertheless, alder, spruce and hazel do not represent typical tundra vegetation, either. Watercourses and the rugged relief (compare Lisá et al., 2013) probably made the climate more moderate in these areas.

The presence of macrofossil and charcoal records from the period shortly after LGM is still very rare in Central Europe. In addition to the presented site of Brno-Štýřice III, another significant site in the broader regional context is Mohelno-Plevovce (Škrdla et al., 2015); upon the anthracological analysis, it reconstructs the vegetation shortly (19,690±120 cal. BP) after the LGM. The results of anthracological analysis indicate cold and dry shrub tundra vegetation, patches of open woodland with *Salix*, *Betula* and *Juniperus* and grassy loess steppe (Škrdla et al., 2015).

Similar climatic and vegetation conditions, closely compared with the Central Europe LGM climate, were described in detail from Altai region in southern Siberia. This region is recently regarded as the best known modern analogue of the last Pleniglacial of central Europe (Horsák et al., 2010). The results of studied spectrum of snail taxa indicates, that the full-glacial landscapes of Central European lowlands were not completely dominated only by open and dry loess steppe, but they contained a significant component of shrubby vegetation, patches of wet habitats and probably also areas of woodland at sites with a more favourable climate (Horsák et al., 2010).

Conclusion

At Brno-Štýřice III, evidence of human occupation in the end of the last (Weichselian) glacial was situated in the uppermost part of the Last Weichselian loess affected by intense Holocene processes of turning into soil. As a typical aeolian calcareous sediment, loess facilitates preservation of a certain type of material, especially terrestrial snails.

Despite unfavourable deposition conditions, we managed to ascertain new information augmenting the picture of local environment of the LGM/LGT in the context of the Middle Danube region. Although this information confirms the contemporaneous incidence of plant assemblages favouring lower temperatures, at the same time, it is evident that humans chose suitable temperate refuges close to water resources for their settlement, where they were adequately suggest more favourable microclimatic conditions protected from extremes of the climate.

The ascertained species composition of anthracological samples differs from the collections from other Central European LGM sites (e.g. Dolní Věstonice IIa; Svoboda et al., 2015); this may be influenced by the position and character of settlement. Abundant presence of charcoals of *Salix* and *Padus* corresponds to microclimatically more favourable situation of the site near a watercourse. Scanty representation of woody species charcoals against very abundant presence of charcoals from bones is indirect evidence of scarcely represented woody species in the vicinity of the studied site, whereas it has to be mentioned that low abundance of charcoal was probably recorded also at other archaeological sites dated back to the LGM period (Předmostí).

The charcoal analysis reconstructed the presence of sparse birch groves in the vicinity. These groves were probably tied to microclimatically favourable conditions (e.g. damper northern slopes) within the prevailing cold steppe or steppe–tundra. Recently, it is possible to come across analogous types of vegetation in Siberia (Horsák et al., 2010, 2015; Magyari et al., 2014a) or Mongolia. These habitats are characterised by both low temperatures during winter season and cold dry winds and very low rainfall, which impose large limitations on the presence of dense coniferous forests (dark tajga forests). Numerous fragments of animal bones could have resulted from deliberate human activity.

We would like to point out the importance of the results, especially in the context of the still poor known archaeological background, which is based mainly on the nonstratified sites. At Brno-Štýřice III, occupation by humans and species composition of vegetation was apparently influenced by the mentioned vicinity of a large waterway. Keeping to the outcomes of radiocarbon dating together with other analyses, we draw a temporal link of the settlement in Brno-Štýřice III more probably with the LGT period. The site is an exemplification of a microclimatically favourable refuge area serving for humans towards the end of Upper Palaeolithic, the period for which absence of archaeological evidence in a considerable part of Europe corroborates the decolonisation of vast areas prior to the onset of the Magdalenian settlement. We hope that the results will be helpful in the discussion concerning the climatic conditions and LGM/LGT central European occupation.

Acknowledgements

We are very grateful to Michal Horsák and Lucie Juřičková for determination of mollusc fauna and Martina Roblíčková for many valuable comments on the faunal composition. We would like to mention the anonymous reviewers for their valuable comments on this manuscript.

Funding

The research reported here was financially supported by the Ministry of Culture of the Czech Republic by institutional financing of long-term conceptual development of the research institution (the Moravian Museum, MK000094862; Z. Nerudová), institutional support of Institute of Geological Sciences, Masaryk University – 312222 (N. Doláková) and GAČR 13-11193S (J. Novák).

References

Amann M, Klimont Z and Wagner F (2013) Regional and global emissions of air pollutants: Recent trends and future scenarios. *Annual Review of Environment and Resources* 38(3): 1–55.

Beresford-Jones DG, Johnson K, Pullen AG et al. (2010) Burning wood or burning bone? A reconsideration of flotation evidence from Upper Palaeolithic (Gravettian) sites in the Moravian Corridor. *Journal of Archaeological Science* 37(11): 2799–2811.

Beug HJ (2004) *Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete*. München: Verlag Dr. Friedrich Pfeil.

Bosch MD, Nigst PR, Fladerer FA et al. (2012) Humans, bones and fire: Zooarchaeological, taphonomic, and spatial analyses of a Gravettian mammoth bone accumulation at Grub-Kranawetberg (Austria). *Quaternary International* 252: 109–121.

Bronk Ramsey C, Higham T and Leach P (2004a) Towards high-precision AMS: Progress and limitations. *Radiocarbon* 46: 17–24.

Bronk Ramsey C, Higham T, Bowles A et al. (2004b) Improvements to the pretreatment of bone at Oxford. *Radiocarbon* 46: 155–163.

Carcaillet C and Thinon M (1996) Pedoanthracological contribution to the evolution of the upper treeline in the Maurienne Valley (North French Alps): Methodology and preliminary data. *Review of Palaeobotany and Palynology* 91(1–4): 399–416.

Clark PU, Dyke AS, Shakun JD et al. (2009) The Last Glacial Maximum. *Science* 325: 710–714.

Davies W, Valdes P, Ross C et al. (2003) The human presence in Europe during the Last Glacial Period III: Site clusters, regional climates and resource attractions. In: Van Andel TH and Davies SW (eds) *Neanderthals and Modern Humans in the European Landscape during the Last Glaciation: Archaeological Results of the Stage 3 Project* (McDonald Institute for Archaeological Research Monographs). Cambridge: McDonald Institute for Archaeological Research, pp. 191–220.

Delhon C (2006) Palaeo-ecological reliability of pedo-anthracological assemblages. In: Dufraisse A (ed.) *Charcoal Analysis: New Analytical Tools and Method for Archaeology* (BAR International Series no. 1483). Oxford: British Archaeological Reports, pp. 9–24.

Doláková N (2010) Palynologické výsledky studia sedimentů jeskyně Balcarka (2007). In: Nerudová Z (ed.) *Jeskyně Balcarka v Moravském krasu. Interdisciplinární studie*. Anthropos Vol. 31 (N. S. 23). Brno: Moravské zemské muzeum, pp. 51–54.

Ehlers J, Astakhov V, Gibbard PL et al. (2013) GLACIATIONS Late Pleistocene in Eurasia. In: Elias SA (ed.) *Encyclopedia of Quaternary Science*. 2nd Edition. Amsterdam: Elsevier, pp. 224–235.

Feurdean A, Perşoiu A, Tanţău I et al. (2014) Climate variability and associated vegetation response throughout Central and Eastern Europe (CEE) between 60 and 8 ka. *Quaternary Science Reviews* 106: 206–224.

Heiri O, Brooks SJ, Renssen H et al. (2014) Validation of climate model-inferred regional temperature change for late-glacial Europe. *Nature Communications* 5: 4914.

Heiss AG (2000) Anatomy of European and North American woods – An interactive identification key. Available at: http://www.holzanatomie.at/ (accessed 22 August 2006).

Horáčková J, Ložek V and Juřičková L (2015) List of malacologically treated Holocene sites with brief review of palaeomalacological research in the Czech and Slovak Republics. *Quaternary International* 357: 207–211.

Horsák M, Chytrý M, Hájková P et al. (2015) European glacial relict snails and plants: Environmental context of their modern refugial occurrence in southern Siberia. *Boreas* 44: 638–657.

Horsák M, Chytrý M, Pokryszko BM et al. (2010) Habitats of relict terrestrial snails in southern Siberia: Lessons for the reconstruction of palaeoenvironments of full-glacial Europe. *Journal of Biogeography* 37: 1450–1462.

Jankovská V and Pokorný P (2008) Forest vegetation of the last full-glacial period in the Western Carpathians (Slovakia and Czech Republic). *Preslia* 80: 307–324.

Juřičková L, Horáčková J and Ložek V (2014) Direct evidence of central European forest refugia during the last glacial period based on mollusc fossils. *Quaternary Research* 82: 222–228.

Kovács J, Moravcová M, Újvári G et al. (2012) Reconstructing the paleoenvironment of East Central Europe in the Late Pleistocene using the oxygen and carbon isotopic signal of tooth in large mammal remains. *Quaternary International* 276–277: 145–154.

Lisá L, Škrdla P, Havlín ND et al. (2013) The role of abiotic factors in ecological strategies of Gravettian hunter–gatherers within Moravia, Czech Republic. *Quaternary International* 294: 71–81.

Ložek V (1990) Molluscs in loess, their paleoecological significance and role in geochronology – Principles and methods. *Quaternary International* 7–8: 71–79.

Ložek V (2001) Molluscan fauna from the loess series of Bohemia and Moravia. *Quaternary International* 76–77: 141–156.

Ložek V (2006) Last Glacial paleoenvironments of the West Carpathians in the light of fossil malacofauna. *Anthropozoikum* 26: 73–84.

Ložek V (2009) Refugia, migrace a brány II. Ve světle dnešních poznatků. *Živa* 5: 194–198.

Ložek V (2010) Spraš a sprašová step – přehlížený biom ledových dob I. Spraš – zemina dvou tváří. *Živa* 3: 98–101.

Magyari EK, Kuneš P, Jakab G et al. (2014a) Late Pleniglacial vegetation in eastern-central Europe: are there modern analogues in Siberia? *Quaternary Science Reviews* 95: 60–79.

Magyari EK, Veres D, Wennrich V et al. (2014b) Vegetation and environmental responses to climate forcing during the Last Glacial Maximum and deglaciation in the East Carpathians: Attenuated response to maximum cooling and increased biomass burning. *Quaternary Science Reviews* 106: 278–298.

Musil R (1999) Životní prostředí v posledním glaciálu na území Moravy. *Acta Musei Moraviae – Scientiae geologicae* 84: 161–186.

Musil R (2003) The Middle and Upper Palaeolithic game suite in central and southeastern Europe. In: Van Andel TH and Davies SW (eds) *Neanderthals and Modern Humans in the European Landscape during the Last Glaciation: Archaeological Results of the Stage 3 Project* (McDonald Institute for Archaeological Research Monographs). Cambridge: McDonald Institute for Archaeological Research, pp. 167–190.

Neruda P (2010) Chronologická pozice paleolitického osídlení jeskyně Balcarky ve středoevropském kontextu. In: Nerudová Z (ed.) *Jeskyně Balcarka v Moravském krasu. Interdisciplinární studie*. Anthropos Vol. 31 (N. S. 23). Brno: Moravské zemské muzeum, pp. 83–95.

Neruda P, Nerudová Z and Čulíková V (2009) Loštice I – Kozí vrch. Magdalénienská stanice v Horním Pomoraví. *Acta Musei Moraviae – Scientiae sociales* 94: 39–64.

Nerudová Z (2015) On site settlement activities: The example of the Epigravettian Site of Brno-Štýřice III (Czech Republic). *Anthropologie (Brno)* 53: 245–256.

Nerudová Z and Neruda P (2014) Štýřice III (Koněvova St. or Vídeňská St.) – An Epigravettian Site in Brno (Czech Republic). *Interdisciplinaria Archaeologica Natural Sciences in Archaeology* V: 7–18.

Nerudová Z and Neruda P (2015) Moravia between Gravettian and Magdalenian. In: Sázelová S, Novák M and Mizerová A (eds) *Forgotten Times and Spaces: New Perspectives in Paleoanthropological, Paleoetnological and Archeological Studies*. Brno: Institute of Archaeology of the CAS, Masaryk University, pp. 378–394, 549–598.

Nerudová Z, Neruda P, Lisá L et al. (2012) Záchranný výzkum mladopaleolitických lokalit v Brně-Štýřicích v kontextu osídlení Brněnska. *Archeologické rozhledy* 64: 591–627.

Oliva M (2005) *Palaeolithic and Mesolithic Moravia*. Brno: Moravské zemské muzeum.

Pryor A, O’Connell TC, Wojtal P et al. (2013) Investigating climate at the Upper Palaeolithic site of Kraków Spadzista Street (B), Poland, using oxygen isotopes. *Quaternary International* 294: 108–119.

Reille M (1995) *Pollen et Spores d’Europe et d’Afrique du nord*. Marseille: Laboratoire de Botanique Historique et Palynologie.

Reimer PJ, Bard E, Bayliss A et al. (2013) IntCal13 and MARINE13 radiocarbon age calibration curves 0–50 000 years cal BP. *Radiocarbon* 55: 1869–1887.

Roblíčková M, Nerudová Z and Nývltová Fišáková M (2015) Analýza zvířecích kostí epigravettienské lokality Brno-Štýřice III z výzkumných sezón 2012–2014. *Archeologické rozhledy* 68: 627–653.

Rybníčková E and Rybníček K (1991) The environment of the Pavlovian – Palaeoecological results from Bulhary, south Moravia. In: Eder-Kovar J (ed.) *Palaeovegetational Development in Europe and Regions relevant to its Paleofloristic Evolution* (Proceedings of the Pan – European Palaeobotanical Conference, Vienna, 19–23 September 1991). Vienna: Museum of Natural History, pp. 73–79.

Rybníčková E and Rybníček V (2014) Palaeovegetation in the Pavlovské vrchy hills region (South Moravia, Czech Republic) around 25,000 BP: The Bulhary core. *Vegetation History and Archeobotany* 23: 719–728.

Schweingruber FH (1990) *Microscopic Wood Anatomy*. Birmensdorf: Swiss Federal Institute of Forestry Research.

Seitl L, Svoboda J, Ložek V et al. (1986) Das Spätglazial in der Barová-Höhle im Mährischen Karst. *Archäologisches Korrespondenzblatt* 16: 393–398.

Svoboda J (1991a) *Dolní Věstonice II – Western Slope*. ERAUL 54. Liège: Service de Préhistoire, Université de Liège.

Svoboda J (1991b) Stránská skála. Výsledky výzkumu v letech 1985–1987. *Památky archeologické* 82: 5–47.

Svoboda JA, Havlíček P, Ložek V et al. (2002) *Paleolit Moravy a Slezska* (Dolnověstonické studie, Vol. 8). Brno: Archeologický ústav AVČR.

Svoboda J, Hladilová Š, Horáček I et al. (2015) Dolní Věstonice IIa: Gravettian microstratigraphy, environment, and the origin of baked clay production in Moravia. *Quaternary International* 359–360: 195–210.

Svobodová H (1988) Pollenanalytische Untersuchung des Schichtkomplexes 6–1 vor der Kůlna- Höhle. In: Valoch K (ed.) *Die Erforschung der Kůlna Höhle 1961–1976*. Anthropos Vol. 24 (N. S. 16). Brno: Moravské zemské muzeum, pp. 205–210.

Svobodová H (1991) Pollen analysis of the Upper Paleolithic triple burial at Dolní Věstonice. *Archeologické rozhledy* 43: 505–510.

Svobodová H (2002) Vývoj vegetace. In: Svoboda JA, Havlíček P, Ložek V et al. *Paleolit Moravy a Slezska* (Dolnověstonické studie, Vol. 8). Brno: Archeologický ústav AVČR, pp. 48–51.

Škrdla P, Nejman L, Bartík J et al. (2015) Mohelno – A terminal Last Glacial Maximum industry with microlithic tools made on carenoidal blanks. *Quaternary International*. Epub ahead of print 19 June. DOI: 10.1016/j.quaint.2015.05.055.

Talon B, Carcaillet Ch and Thinon M (1998) Études pedoanthracologiques des variations de la limité supérieure des arbres au cours de l’Holocéne dans les Alpes Francaises. *Géographie physique et Quarternaire* 52: 1–14.

Terberger T (2013) Le Dernier Maximum glaciaire entre Rhine et le Danube un réexamen critique. In: Bodu P, Chehmana L, Klaric L et al. (eds) *Le Paléolithique supérieur ancien de l’Europe du Nord-Ouest Réflexions et synthèses à partir d’un projet collectif de recherche sur le centre et le sud du Bassin parisien. Actes du colloque de Sens (15–18 avril 2009)*. Paris: Bulletin de la Société Préhistorique Francaise, Memoire no. 56, pp. 415–443.

Terberger T and Street M (2002) Hiatus or continuity? New results for the question of pleniglacial settlement in Central Europe. *Antiquity* 76: 691–698.

Valoch K (1975) Paleolitická stanice v Koněvově ulici v Brně. *Archeologické rozhledy* 27: 3–17.

Valoch K (1980) La fin des temps glaciaires en Moravie (Tchécoslovaquie). *L’Anthropologie* 84: 380–390.

Valoch K (1996) *Le Paléolithique en Tchéquie et en Slovaquie*. Grenoble: Jérôme Millon.

Valoch K (2010) Europäische Beziehungen des mährischen Magdalénien. In: Połtowicz-Bobak M and Bobak D (eds) *The Magdalenian in Central Europe: New Finds and Concepts*. Rzeszów: Mitel, pp. 9–21.

Verpoorte A (2004) Eastern Central Europe during the Pleniglacial. *Antiquity* 78: 257–266.

Walanus A and Nalepka D (1999) POLPAL – Program for counting pollen grains, diagrams plotting and numerical analysis. *Acta Paleobotanica* 2: 659–661.

Weninger B and Jöris O (2008) A ^{14}C age calibration curve for the last 60 ka: The Greenland-Hulu U/Th timescale and its impact on understanding the Middle to Upper Paleolithic transition in Western Eurasia. *Journal of Human Evolution* 55: 772–781.

Willis KJ and Van Andel TH (2004) Trees or no trees? The environments of central and eastern Europe during the Last Glaciation. *Quaternary Science Reviews* 23: 2369–2387.

Willis KJ, Rudner E and Sümegi P (2000) The full-glacial forests of Central and Southeastern Europe. *Quaternary Research* 53: 203–213.

Yokoyama Y, Lambeck K, De Deckker P et al. (2000) Timing of the Last Glacial Maximum from observed sea-level minima. *Nature* 406: 713–716.

Zeitschrift für Geomorphologie Vol. 59,3 (2015), 393–412 Article

Reflections of Prehistoric and Medieval human activities in floodplain deposits of the Únanovka Stream, South Moravia, Czech Republic

Jan Petřík, Libor Petr, Klára Šabatová, Nela Doláková,
Hana Lukšíková, Alena Dohnalová, Leona Chadimová,
David Blaško, and Peter Milo

with 7 figures and 2 tables

Summary. Floodplain sediments of the Únanovka Stream's catchment were investigated utilizing the methods of sedimentology and paleoecology. The development of human settlements in the stream catchment and dating from the Prehistoric through the Medieval, have been compared with floodplain evolution. Paleoecological data were obtained from the pollen record and plant macroremains. Bulk samples of the sediments were analyzed for phosphates, magnetic susceptibility, and grain size; macroremains were dated using the radiocarbon method. Floodplain structure were explored by combination of geophysical methods and drilling. The floodplain base was formed during the beginning of the Neolithic, where a sandy, organic silt layer was formed upon a sandy gravel basement, under a deciduous forest environment. From approximately the late neolithic, when a silty loam sediment started accumulation, direct paleoecological evidence of agriculture has been recorded. Since the beginning of the Middle Ages, the dominant vegetation was of a ruderal character, with Alder. From the High Middle Ages, the processes of accumulation and erosion in the neighboring region accelerated.

Key words: Holocene, floodplain, paleoecology, human activities, settlement pattern

1 *Introduction*

Human settlements have always been closely connected to rivers and streams, which have been important in terms of subsistence strategies in Central Europe (e. g. Jäger 1962, Lisá et al. 2013, Rulf 1983, Toth et al. 2011). Therefore, rivers and their floodplains have been crucial factors in the settlement of the cultural landscape. This relationship was more pronounced after the transition to agriculture, when water became essential for livestock. Simultaneously, human influences on the landscape in Central Europe can be traced back to the beginnings of agriculture (Lang & Nolte 1999, Lüning 1996). This influence led to the deforestation of the landscape, establishment of fields, and an increase in the level of erosion. The processes leading to the aggradation of the floodplain, aside from human influences (Kadlec 2009), were also significantly influenced by changes of climate as well as vegetation; however, the most significant factors were the geology and geomorphology. The character of the vege-

DOI: 10.1127/zfg/2015/0167
www.borntraeger-cramer.de
0372-8854/15/0167 $ 5.00

tation cover during the Holocene became increasingly influenced by human activities, primarily in the areas of prehistoric settlements. The significant relationships of Great Moravian communities (from the 9th century AD) and the floodplain environment has been observed for a long time in the Czech Republic (e. g. Opravil 1983, Poláček 2001, Macháček et al. 2007, Kadlec 2009). Direct interventions upon watercourses were characteristic during the Middle Ages (the construction of mills, ponds, bridges, etc.).

The trends in fluvial activities corresponds with both soil erosion and the history of land usage (Dotterweich 2008, 203). Research of river floodplains, in terms of their relationship to archeology in the Czech Republic, is still rather marginal. Some aspects of this type of research have been focused on the Podkrušnohoří landscape, where large surface mines created a unique opportunity to study the construction of floodplains on a scale of many kilometers, as well as the associated archaeological records (for example in the Lužicky Stream basin (Neustupný 1985)). Another example would be the middle Polabí area, with the occurrence of the Tišice site, where the archaeological and palynological results were linked (Dreslerová & Pokorný 2004). The most intensively studied localities in relationship to this subject have been the floodplain of the Morava River near Mikulčice (Opravil 1962, 1978, 1983, Poláček 1997, Svobodová 1990) and Pohansko near Břeclav (Doláková et al. 2010).

Floodplain sediments have already provided some important profiles, portraying the history of the Holocene environment. Accordingly, it is assumed that anthropic interventions should have affected most of the floodplains, starting from the Middle Ages (Ložek 1998). Evidence from throughout Central Europe shows that during the Neolithic period, and until the Bronze Age, soil erosion was not very significant (Wunderlich 2000, Kalis et al. 2003). Starting with the Late Bronze Age, this situation changed to a system primarily dominated by human impacts (Starkel et al. 2006). According to the geomorphic activities in German rivers, it was concluded that periods of increased alluvial sedimentation were triggered by land use changes and extremes of precipitation; while the general trends in climate change played only a minor role (Hoffman et al. 2008).

However, in the case of eastern Central Europe, the role of prehistoric occupations effects upon the evolution of floodplains is somewhat unclear. The erosion and accumulations of the alluvial plain, in regions having had intensive prehistoric occupations, are probably the results of human activity. One disadvantage of the paleoecological record in the floodplains are the frequent hiatus activities, which are inherent in the dynamics of water flow, as well as the difficulties in distinguishing changes due to climate change from anthropogenic impacts (Zolitschka et al. 2003).

The main aim of the present paper is to date and describe land use changes in a small catchment of the Únanovka Stream, according to the evolution of the floodplain. The sedimentological record of the floodplain covers the period between the Neolithic emergence of agriculture until the Medieval time of colonization, all of which is directly linked to the archaeological record. The Únanovka floodplain was chosen like a typical example of of the deep and narrow valley on the east edge of the Bohemian Massif and its opening into the lowlands of the Carpathian Foredeep in the East. This situation is providing floodplain sediments as well as evidence of long-term human occupation in a relatively distinct area of the small catchment.

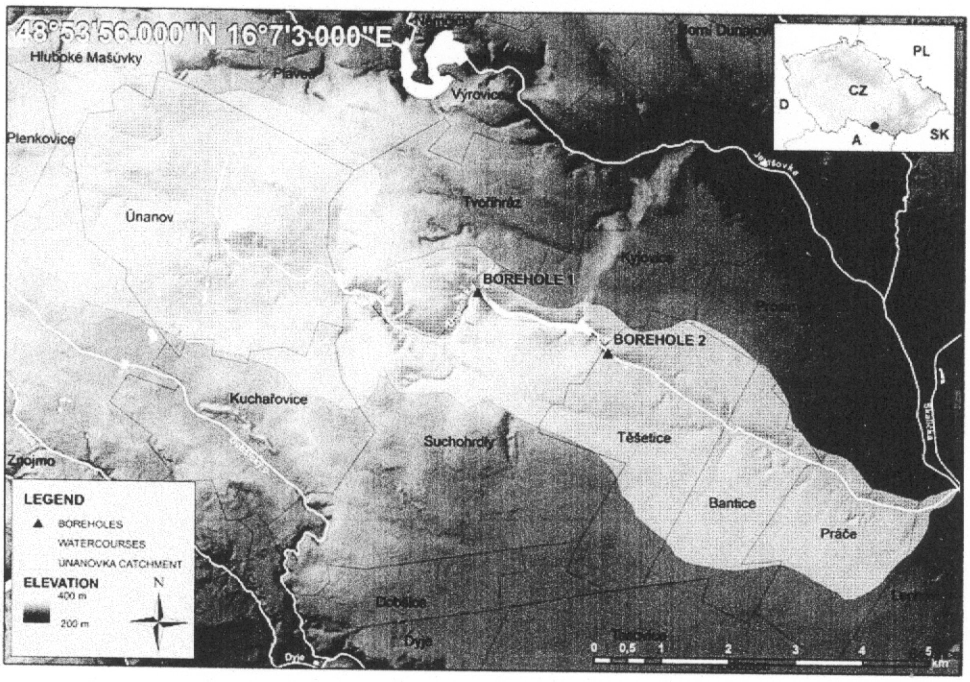


Fig. 1. Map of the Únanovka River catchment and the position of the Boreholes.

2 *Site description*

The catchment of the Únanovka Stream is located on the border of the Bohemian-Moravian Highlands, the Jevišovická Hills, and the Dyje-Svratka Valley, all belonging to the Inner-Carpathian lowlands (SW Moravia, Czech Republic). The Únanovka Stream originates in the cadastral area of Únanov, at an altitude of about 280 meters. The confluence of the Únanovka Stream with the Jevišovka River is at an altitude of about 185 meters. The extent of the catchment is approximately 12 km^2 (Vlček et al. 1984, 281). A narrow and deep valley crosses the morphologically-significant edge of the Dyje Massif (fig. 1), continuing into the flat lowlands of the Carpathian Foredeep. A part of the area is covered with scattered river terrace sediments and loess. A geological survey of the Těšetice-Kyjovice ("Sutny") archeological site has shown that this area is built up of loess on which cambisols developed. Towards the western part of the site, the granite bedrock appears, and the soil thickness covered by forest declines.

3 *Archaeological evidence and occupation history*

The catchment area has been covered by archaeological research for several decades. Quantification of the recorded archaeological evidence providing last review (table 1).

Neolithic agricultural settlements are located on the gentle slopes along the Únanovka Stream, on the loess and loess loams deposits, and occasionally around a

Table 1. The table shows archaeological evidence from a range of 3 km from both boreholes.

	Nr. of sites	Burial activity	Settlement activity	Other activity	Isolated finds
Palaeolithic	4				4
Neolithic	11	1	8		2
Eneolithic	19	4	13		2
Bronze Age	21	9	12		
Early Iron Age	15	7	8		
Iron Age	2		2		
Early Middle Ages	3	1	2		
High Middle Ages	3		1	2	
Modern Times	2		1	2	
Without dating	14	5	5		4

former small stream. Each of the Neolithic cultures detected within this area occupied the same general residential location. Such situation is the same as in the area of the nearby Jevišovka River.

The occupation strategy was changing during the early Eneolithic period. The settlements still lived in Neolithic landscapes; however, were shifted into micro-elevated positions, which are now also covered by forest (Tvořihrázský les woodland). Sites settled by the early Baden Culture (Boleraz phase) significantly appear in elevated positions. There are very common examples of the activities of the Bell Beaker Culture (late Eneolithic) in the studied microregion, whose settlement strategies are already closer to those of the Early Bronze Age.

There was a significant increase of the appearance of the Bronze Age settlement and in the Hallstatt period on the plateau in the eastern portion of this area, as well as at elevated positions and slopes. From the Těšetice area alone, there are seven dated sites from the Bronze Age and the Hallstatt period (cf. Podborský et al. 2005, 13–42; Šabatová 2013).

The records of activity from late Iron Age in the studied micro-region are very rare. On the other hand, in the greater region along the Únanovka Stream, there is evidence of settlements and funeral activities (Meduna 1980, 154–155, 274–275).

The development of Early Middle Age settlement structures in the region as well as of the regional center (Znojmo "Fort" and Znojmo Castle) have been systematically captured (Procházka 2009, 244, 246–247, Šabatová 2013 with the available literature). At the end of the Early Hill Fort period, the old settlements had stabilized in their population structure, which persisted for the rest of the Middle Ages and into the Modern era, except some extinct villages.

From an archaeological point of view, it is very difficult to say to what extent the settlement of forested areas (Tvořihrázský les woodlands) are contiguous, and what role deforestation of the area played during the period of most intensive prehistoric activity. Based on the significant population decline since its early history, and starting over again with the reforestation of today's forested area, it is possible to consider the role of deforestation. In the Tvořihráz area, there are two extinct villages (Měřínský 1969, 11; Nekuda 1961, 39). The first military mapping of the area recorded 4 fishponds (1763–1764) located in the floodplains of the Únanovka, in the area before the stream reaches the village of Těšetice. The maps of the second military survey shows all ponds in the Únanovka floodplain to have been emptied. The Bohunice Pond near the location of Borehole 1 was undoubtedly renewed at the beginning of the 20th Century, and the Únanovsky Pond has also been renewed. The current flow of the Únanovka Stream, along some parts, has been artificially modified in connection with the construction of ponds; apparently in an effort to maximize the economic exploitation of the alluvial meadows. The Těšetice dam, built on the Únanovka Stream, was built between 1981 and 1983.

4 *Methods*

The first borehole (Borehole 1) was located in the space above the floodplain dam under the "Starý zámek" hillfort. This borehole was choosed after a complex field survey of the sediments, and profiles were sampled by using the percussion drilling set equipment (by Eijkelkamp). Floodplain structure in the area of Borehole 1 had been mapped by transect of boreholes combined with elecrical resistivity tomography (ERT) and ground penetrating radar (GPR) methods in length of 70 meters (fig. 2, fig. 5). There were used instruments SAS 1000 (ABEM Instrument) with Wenner configuration of electrodes for ERT (steps by 1 meter) and RAMAC X3M (GEOSCIENE MALÅ) with 500 MHz and 250 MHz antenna for GPR.

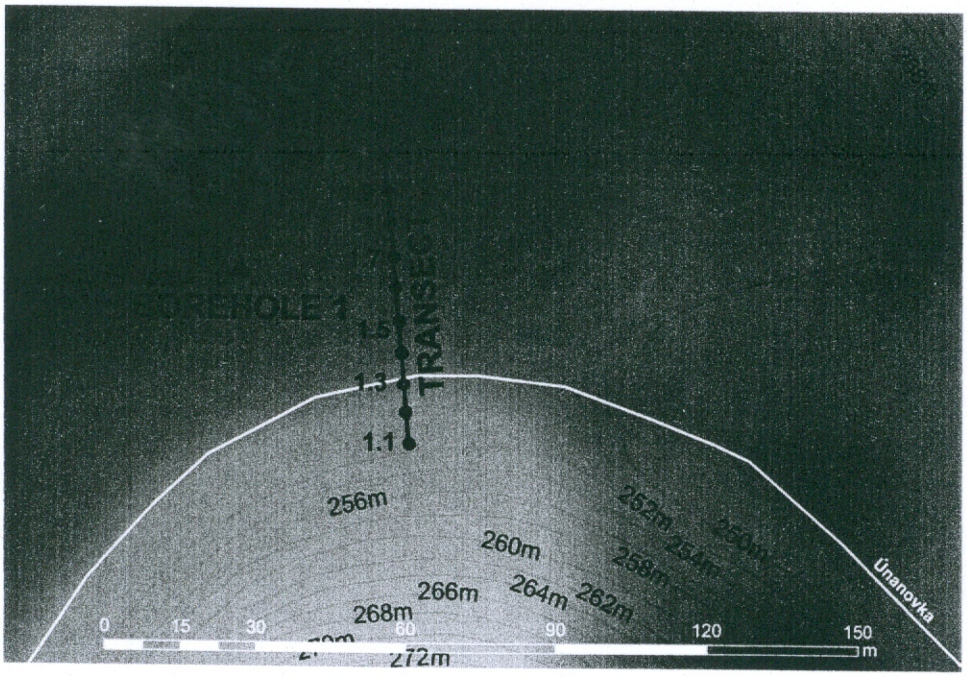


Fig. 2. Position of Borehole 1, and borehole transect in the Únanovka floodplain.

The second to be analyzed, Borehole 2, was located below the current dam in the floodplain of the Únanovka Stream (Valová 2007). This distribution of boreholes was designed for the purpose of a spatial comparison of valley sections (fig. 1, fig. 2).

The drill cores were divided into sample sections of ten centimeters. All cores are described of in terms of centimeters below the present surface.

Field descriptions of the lithostratigraphic units, pollen analysis, radiocarbon dating, and laser granulometry were applied to both cores. In addition, samples from Borehole 1 were analyzed for pH, magnetic susceptibility, phosphates, loss on ignition, and plant macroremains. Grain size distribution was determined by use of the Retsch AS200 (for fractions over 0.063 mm), and by a CILAS 1064 (fractions below 0.063 mm).

Phosphates (calculated as P_2O_5) from a soil sample were extracted with hydrochloric acid (according to Cawanagh et al. 1988), and then determined colorimetrically. Loss on ignition (LOI) was measured at 550 °C (mainly measured as the proportion of organic matter) and at 950 °C (mainly representing carbonates) by the standard methodology (e. g. Heiri et al. 2001). Measurement of the magnetic susceptibility (MS) of dried samples (weighing 23 g) was carried out on a Kappabridge KLY-2 instrument (Agico, Ltd.). To plot the data, a non-standard MS mass was expressed as $m^3.kg^{-1} \times 10^{-9}$ (with ± 2 % error of measurement) for each sample.

The analyses of the macroremains used a fraction of the sediment, sized from 0.25 to 0.063 mm. In total, 29 samples were analyzed. A stereoscopic microscope with magnifications of 10 × and 30 × was used. Fruits, seeds, mosses, and twigs with buds were collected from the sediments. The fruits and seeds were determined using special keys (Cappers et al. 2006). To the extent possible, twigs and buds were determined using keys (Bažant & Ešnerová 2010; Červenka & Cigánová 1989), and compared with recent buds of woody plants. The results were processed in POLPAL software (Walanus & Nálepka 2004).

Samples for the pollen analyses were prepared by the standard acetylation method, including the use of hydrochloric and hydrofluoric acids. Part of the samples from Borehole 2 were used to increase the number of pollen grains subject to concentration, with use of $ZnCl_2$ heavy liquid. The pollen diagram was compiled using POLPAL software (Walanus & Nalepka 2004).

Two samples from Borehole 2 were radiocarbon dated in Poznań, Poland. The radiocarbon datings of the samples from Borehole 1 were carried out using AMS in a laboratory in Athens, Georgia, USA.

5 *Results*

5.1 *Borehole 1*

Borehole 1 was divided into the following lithostratigraphic units (fig. 3): Unit 1 (385 cm and below) made up of angular gravel fragments of granite and quartz; which passes into Unit 2 (385–355 cm), with organic rich sandy gravel; gradually transitioning into Unit 3 (355–305 cm) of dark brownish-gray organic rich sandy silt; followed by Unit 4 (305–235 cm) of brownish-gray silty loam; Unit 5 (235–185) of brownish silty loam with plant residues; and Unit 6 (185 cm – present surface) of grayish silty

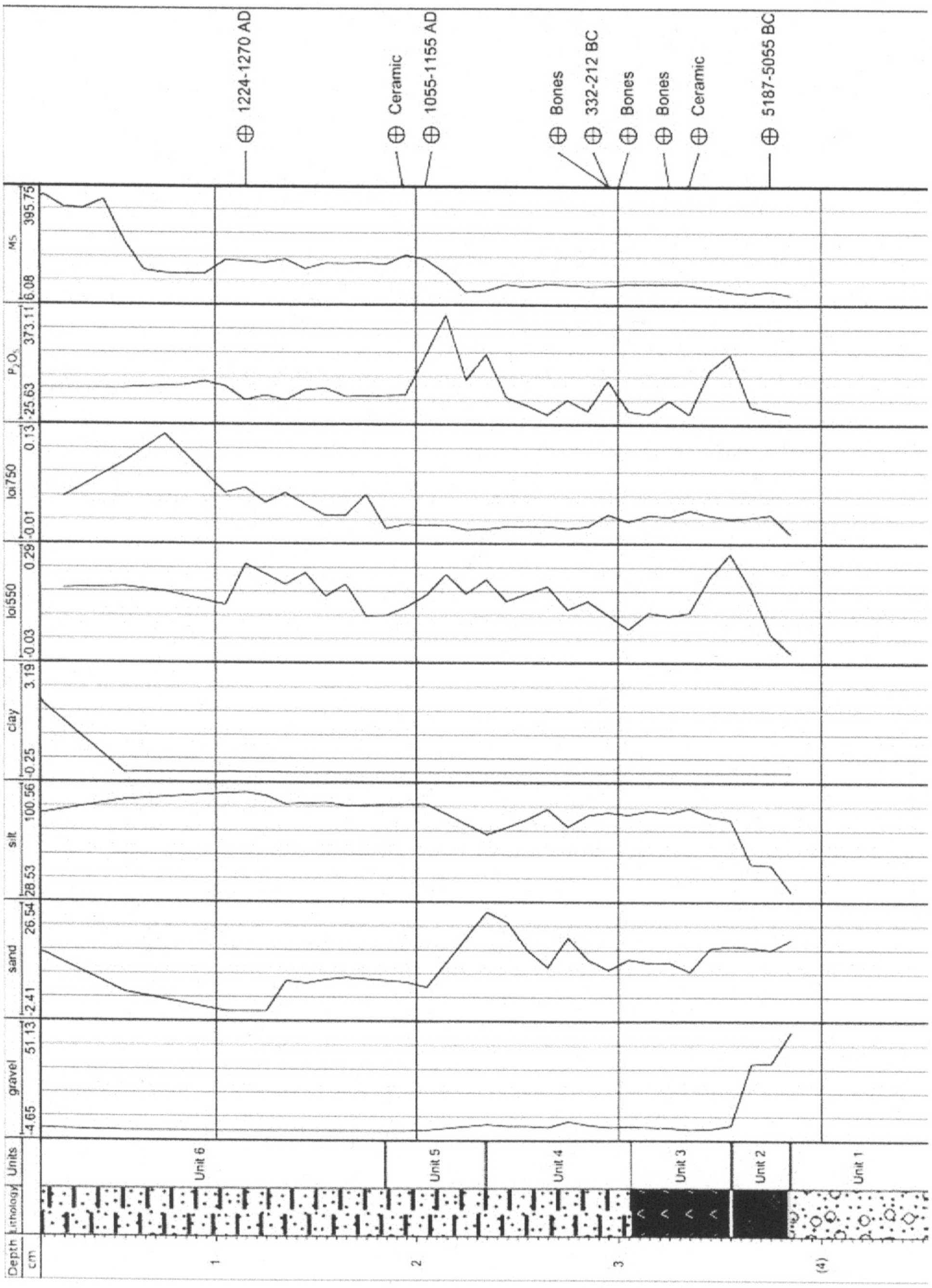


Fig. 3. Distribution of lithology, representation grain fractions, results of loss on ignition, phosphates, magnetic susceptibility, findings of artifacts and bones, and radiocarbon dating in Borehole 1.

loam and soil A-horizon on top (35 cm – present surface). The layer sequences corresponds to the floodplain structure recorded by transect of ten boreholes (fig. 2, fig. 4), which has been combined with ERT and GPR measurements in the vicinity. There is undulated sandy gravel on the base illustrated by higher electric resistivity (fig. 5), covered by an organic rich sandy silt with plant residues ("boggy soil"), which transisting to the silts (fig. 4).

According to the radiocarbon dating of the layer of basal sand containing plant residues (375 cm), the layer corresponds to the Neolithic period (C-14 calibrated date 5211–5008 BC). This layer has a nice visible correlation with the acidic soil reaction, and with the low enhancement of magnetic susceptibility. Phosphate values are low, showing an increasing trend with a sharp peak at 355 cm, which correlates with a high proportion of organic matter.

Units 3 and 4 fall within the time-span from the Eneolithic to the Iron Age (C14–260 ± 60). These are characterized by low enhancement of magnetic susceptibility; relative enrichment in the silt fraction, compared to older or younger sedi-

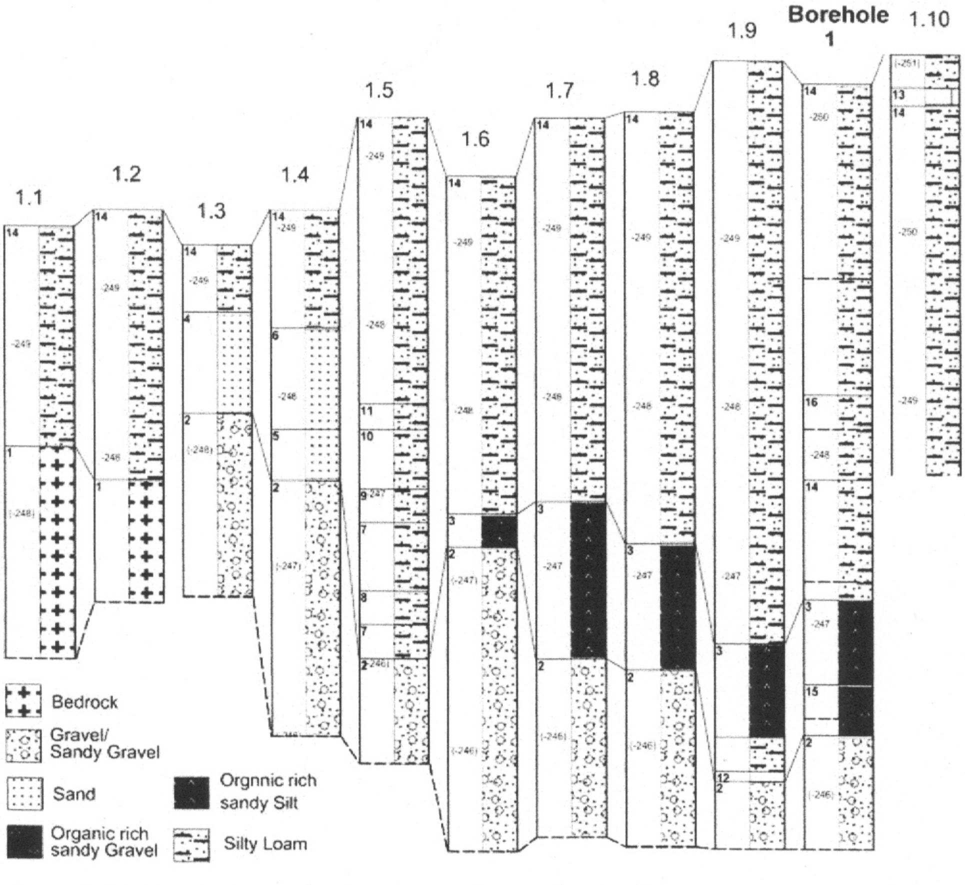


Fig. 4. Lithology and stratigraphy of a cross-section of the Únanovka floodplain (based on the borehole transect).

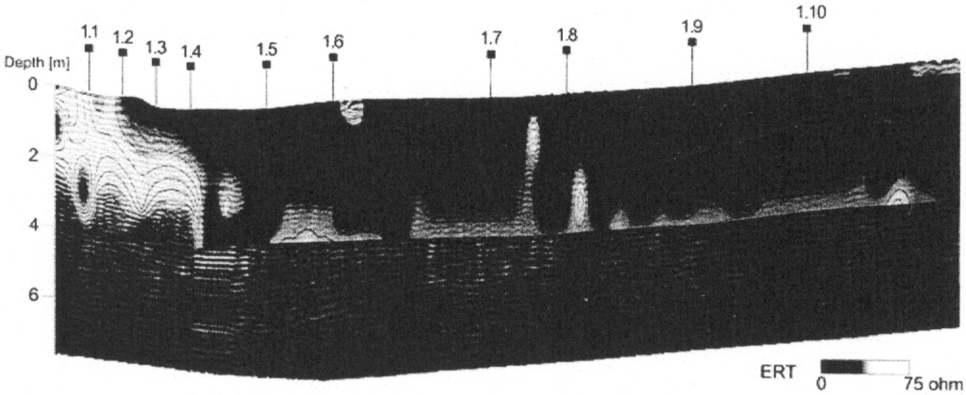


Fig. 5. ERT and GPR of a cross-section of the Únanovka floodplain combined with position of the boreholes.

ments; and oscillating values of organic phosphates, with the highest values on the basis of the actual sequence. At the depth of 325 cm, fragments of ceramics or daubing were identified. The bone fragments of large mammals were identified at depths of both 305 cm and 295 cm (fig. 3).

In the middle part of the profile (Unit 4, which corresponds to the Roman and Migration period), the magnetic susceptibility values and the phosphate content are significantly lower when compared to the sediments from the Middle Ages. The sedimentation rate is lower than during the Middle Ages, but higher than in older periods.

Unit 5 corresponds with the Middle Ages; however, the sedimentation rate is higher, as well as the proportions of both the silt fraction and carbonate precipitates. The magnetic susceptibility shows a slight enhancement, compared with previous periods; but does not reach the values of modern times. The C-14 dates in the period from 1105 AD to the Early Middle Ages show a significant enhancement in the magnetic susceptibility, as well as the proportion of fine clastic materials. The phosphate values are the highest in the entire profile; however, the scarce organic materials do not reach their highest values. At the depth of 185 cm, fragments of ceramics and daub were identified.

The uppermost part of the profile (0–75 cm) corresponds to the Modern Age. It is characterized by a high enhancement of magnetic susceptibility (up to five times higher values of magnetic susceptibility than in the other parts of the profile – diameter 313 $m^3.kg^{-1} \times 10^{-9}$). At the same time, a decreased sedimentation rate and decreased proportion of carbonate precipitates were detected.

5.1.1 *Macroremains analyses*

Results are shown in figure 6. Two samples from the 29 samples analyzed contained no macroremains (from depths of 250 and 260 cm); 3 samples only included fragments of seeds of *Sambucus* sp. (from depths of 300, 310, and 320 cm). Samples coming from depths between 300 to 380 cm generally contain higher amounts of charcoal.

At a depth of 380 cm (around 5211–5008 BC, Neolithic period), *Drepanocladus aduncus* was found. This moss grows in wetlands on damp soils, rocks, and even

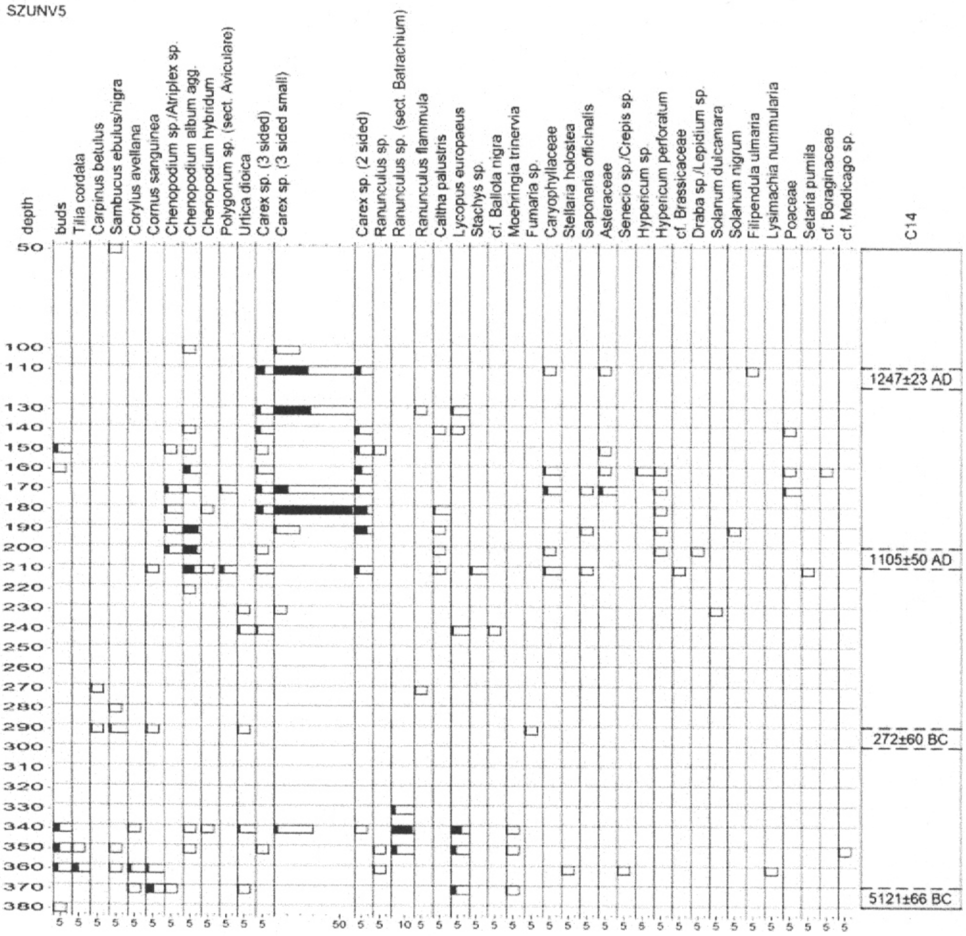


Fig. 6. Distribution of plant macroremains in Borehole 1.

wood. At a depth of 370 cm, a fragment of the moss *Eurynchium* sp. was identified. In the Czech Republic, there are only two species of *Eurynchium angustirete* and *E. striatum*. Both mosses have similar ecological habitats; they grow on humic soils in semi-shaded or shaded locations.

At the lower parts of the studied section (366–166 BC in 290–300 cm, Iron Age), up to 260 cm, species of trees (for example *Tilia* or *Carpinus*) and shrubs (*Corylus*, *Cornus* sp.) occurred. At a depth of 280–290 cm, a bud of Salix sp. was found; and at a depth of 260–270 cm, a bud of cf. *Alnus glutinosa* was retrieved. Species of herbs predominantly included species from forests and forest margins (*Moehringia trinervia*, *Stellaria holostea*), from wetlands and river banks (*Lycopus europaeus*, *Urtica dioica*), and probably also from aquatic plants (*Ranunculus* sp. Sect. *Batrachium*).

From a depth of 240 cm (1034–1207 AD in 200–210 cm, Medieval Ages), the amounts of macroremains of *Carex* sp. increased. In the lower parts of the studied section, only rarely did these species occur. Except for the wetland species (*Carex* sp., *Caltha palustris*), there were also a growing number of ruderal species (*Chenopodiaceae*). Trees and shrubs were disappearing. From a depth of 150 cm, a few fragments of the acorn of *Quercus* sp. and some undetermined buds appeared.

5.1.2 *Pollen analysis*

The ratio of tree pollens (AP) and herbs (NAP) in the pollen spectrum in the 360 and 350 cm layers were about 85 % (fig. 7). The ratio decreased to 55 % in the samples from 320, 330, and 340 cm. In the NAP (360 and 350 cm), *Corylus* dominates (30 %); later subsiding. Similarly, the frequency of *Tilia* and *Betula* decreases. *Pinus* and *Picea* have a constant share of about 10 %; less well represented are *Quercus*, *Ulmus*, *Fraxinus*, *Alnus*, *Fagus*, and *Abies*. The pollen spectrum is dominated by grasses and sedge. There are smaller amounts of Caryophyllaceae and Chenopodiaceae, with cereal pollen occurring from 350 cm. The share of microcharcoal particles caught in the pollen spectrum rose.

The concentrations of pollen grains in the preparations were very low, although their quality remained high. In the layers from 310 cm (and above), only rare pollen grains (mainly pine) were recorded, which made it impossible to obtain representative amounts of pollen grains.

5.2 *Borehole 2*

The additional borehole (#2) was divided into the following lithostratigraphic units: Unit 1 (360–260 cm) of grayish-green clayey gravel; followed by Unit 2 (260–50 cm) of grayish-green silty clay, with 50 cm sandy soil horizon on the top.

The AP/NAP ratio of Borehole 2 is around 20 to 30 %. *Pinus* appears to present a strong occurrence in the pollen spectra (around 10 %), and its extent is within the 115–126 cm layers (to 25 %) (fig. 7). *Corylus* had the opposite tendency, with its share falling from 15 % at 325 cm to less than 5 % at 115 cm. A similar trend was also observed in the case of *Carpinus* and *Tilia*. Floodplain forest tree species (*Alnus* and *Salix*) have around a 10 % share of the pollen spectra. *Quercus*, *Tilia*, *Fraxinus*, *Picea*, and *Ulmus* almost disappeared from the pollen spectra. The sporadic occurrence of *Picea*, *Abies*, and *Fagus* pollens were limited to those samples from 205 to 325 cm. Conversely, the pollen of *Sambucus nigra* is present in the layers from 115 to 205 cm. The herbal part of the pollen spectrum is dominated by grasses and Chenopodiaceae. Other pollen taxa, i. e. cereals or *Polygonum aviculare*, *Rumex acetosella*-type, *Plantago lanceolata*, and *Humulus*/*Cannabis*, were less-well represented. Additionally, wetland and aquatic vegetation (Cyperaceae, *Myriophyllum spicatum*, *Typha*, *Filipendula*) were recorded.

6 *Discussion*

6.1 *Questions about Neolithic impact*

The eldest sediments acquired in Borehole 1 were dated from the Early to Mid-Holocene (the period prior to the beginnings of agricultural prehistory). These sediments have a stony and sandy character, without the accumulation of flood loams and

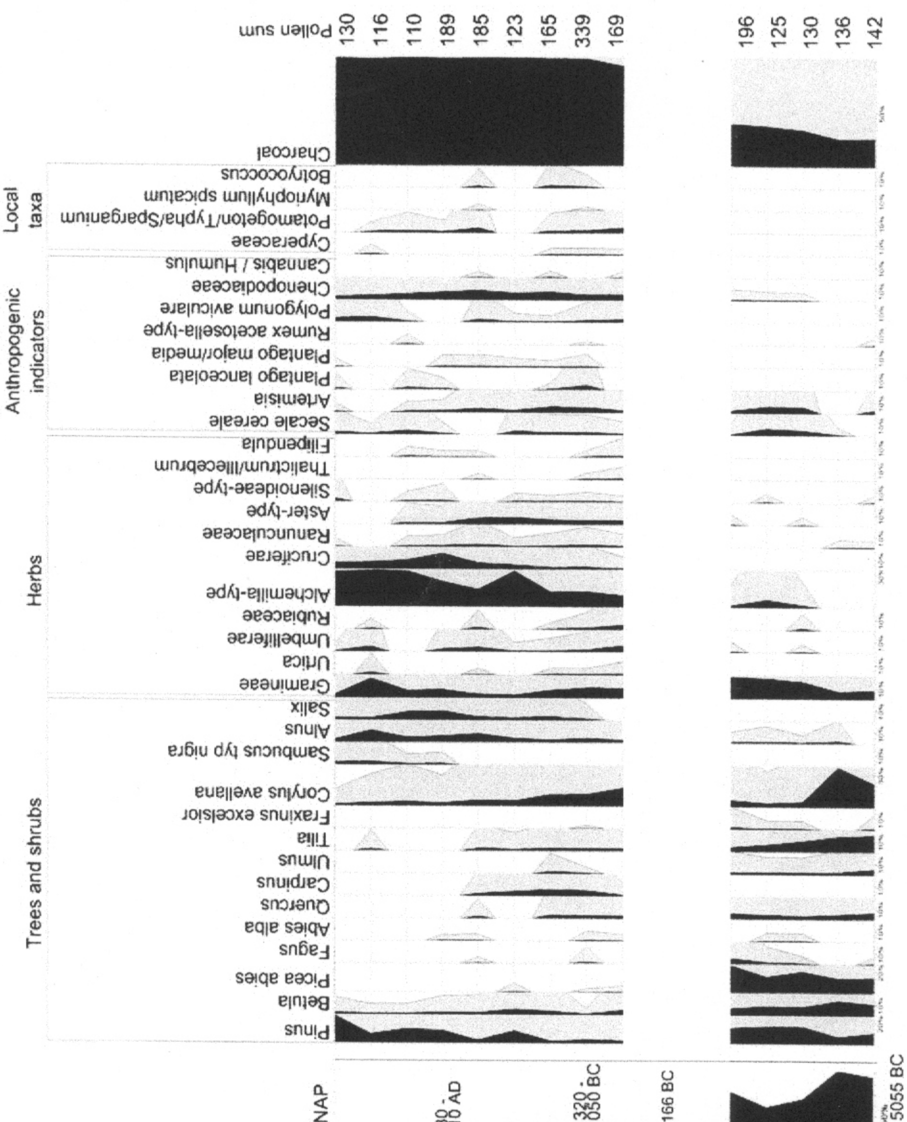


Fig. 7. Pollen diagram sequention of Borehole 1 (depth of 360 to 300 cm) and Borehole 2 (depth of 325 to 115 cm).

flushes. The main phases in the floodplain development of the Únanovka Stream are analogs to the developments in the lower reaches of major rivers in the area. One such river is the Morava, where an early holocene floodplain was formed by deposits of gravel and sand bars (Kadlec et al. 2009, Grygar et al. 2010), causing peat formation between depressions, followed by these structures having been covered with silty flood deposits. A *Corylus* husk, dating from the organic horizon (Borehole 1, Unit 2), and which had accumulated in a depression between sandy gravel bars, provided a radiocarbon date corresponding to the Early Neolithic (table 2). The record of the macroremains detected in this portion of the section does not show well-developed alluvial vegetation, but instead reflects forest communities (fig. 6). The surrounding vegetation was composed of mixed oak forests (*Quercetum mixtum*), and the rock outcrops were probably covered by pine (fig. 7). A significantly deep valley has a great impact on the diversity of vegetation, because many plant communities can be expected in a relatively small area. Influences of agricultural and other human activities were not evident in the pollen record. This is quite surprising, because Neolithic settlements had been detected 1 km downstream and 1 km upstream from the study area. Neolithic agriculture is generally assumed to have been on a small scale and intensity (Jockenhövel 1997); therefore, the effects of land use in the pollen record might not be detectable (Dreslerová 2012, 206).

The increase of silt fractions as well as considerable amounts of organic materials in Unit 2 of Borehole 1 is significant. Possible explanations include: change of the riverbed facies, regime change from the Early to the Middle Holocene, and an increase of pedogenic processes. For example, in forested floodplains, trees fall into and across rivers, and there is also a high input of organic materials of all sizes – from the microscopic to tree trunks. Even in small floodplains (with small trees), organic debris forms small dams (Brown 2001, 112). On the other hand, this organic-rich layer, and its transition into silty loam, was detected across most of the floodplain in the bore-hole transect (fig. 2, fig. 4). These results suggest that the transition of sandy gravels into organic-rich sandy silts, and then into silty loams, was a general trend over all stratigraphy of the Únanovka alluvial zone. Organic rich sandy/silty loam/silt in the Únanovka floodplain could be analogous to the organic-rich silt-clay loam layers detected across the alluvial sediments from the Wetterau (dated to the Atlantic period by A. Lang and S. Nolte (1999, 209)). Little evidence of soil erosion for the Neolithic period is known from colluvial and small alluvial deposits (Dotterweich 2008, Rommens et al. 2006).There is significant synchronicity of the silt increase in the organic sediments in Borehole 1, Unit 2 and the emergence of neolithic agriculture. Additionally, the transition to a silt floodplain in Borehole 1, Unit 3 is synchronous with the Late Neolithic and Bronze Age periods (according to the depth age model), when it is assumed a different land usage than in the neolithic existed. The synchronicity of these sedimentation changes, as well as the chronology of the main prehistoric land-use changes, provide support for an anthropic explanation for the primary developmental events of the floodplain.

However, the roles of climate as well as the related processes of forest development and forest soil pedogenesis as factors influencing the changes in the floodplain's development cannot be fully excluded. It can be assumed to have been a consequence of the initial Early Neolithic erosion and floodplain formation.

Table 2. Radiocarbon data; OxCal v4.1.5 Bronk Ramsey (2009), r: 5 Online: https://c14.arch.ox.ac.uk/oxcal/OxCal.html.

Bore-hole	Layer cm	Lab. code	Material	Age, years BP	$\delta^{13}C$ ‰ ^{14}C	Calibration (2δ), years BC/AD	Period
2	210–205	POZ-33593	mud	1725 ± 35	–	240–401 AD	subatlantic, turn of the Roman period and Migration period
2	300–305	POZ-33594	mud	2970 ± 40	–	1371–1052 BC	subboreal, Middle and Late Bronze Age
1	110–120	UGAMS# 5372	seed	760 ± 40	−27.4	1187–1295 AD	turn of the Early and High Middle Ages
1	200–210	UGAMS# 5373	seed	910 ± 30	−25.6	1034–1207 AD	the last phase of Early Middle Ages
1	290–300	UGAMS# 5374	seed	2180 ± 30	−25.0	366–166 BC	subatlantic, Late Iron Age (middle La Tène)
1	370–380	UGAMS# 5375	seed	6150 ± 30	−24.2	5211–5008 BC	early Neolithic (Linearbandkeramik Culture)

6.2 *Eneolithic and Bronze Age human impacts on floodplain sediments*

Once the sedimentation in the alluvial zone of the Únanovka had become a silty loam, the sedimentation mode was relatively constant with oscillations of the silt/sand ratio during the period just before the onset of the Iron Age (fig. 3, lithological Units 2 and 3). On the other hand, the pollen record shows the following changes in vegetation: declining hazel; wood vegetation made up of oak, spruce, or pine; the appearance of ruderal species (*Artemisia* and *Chenopodium*). The increases in human activity during the Eneolithic and Bronze Age (lithological Unit 3) is indicated by both the pollen record and the presence of microcharcoals (fig. 7), with the increases of human activities' affects on the vegetation being noticeable. These are not merely documented as minor oscillations in the sedimentological or palaeoenvironmental records between the Eneolithic and Bronze Age, though there are significant shifts in the archaeological record in these periods. A more permanent and widespread role of the field systems is proposed for the Late Neolithic European landscape (BEHRE 2000) as well as the use of slash and burn practices (GEHRT et al. 2002) and grazing in the woodlands (LÜNING, 1996). According to A. ZIMMERMANN (1996), the population density and land use didn't change much between the Late Neolithic and Bronze Age; this construct fits with our interpretations because there are no traces of change in the sedimentation regime, and the vegetation is only gradually affected.

6.3 *Human impacts and vegetation cover from Halstatt to the Migration period*

The sample from the depth of from 205 to 210 cm in Borehole 2 (dated as 230–410 AD, the transition of the Roman and Migration periods) shows the influence of humans related to the retreat of forest trees such as *Abies*, *Carpinus*, *Fagus*, *Picea*, *Quercus*, and *Ulmus*. Light-loving plants including *Pinus*, *Betula*, and various shrubs (e. g. *Sambucus*-type) spread again into deforested areas and light woodlands. Increased percentages of Chenopodiaceae, Asteraceae, and *Sambucus* indicates increased nitrification of the substrate as the result of human activity. In the case of Borehole 1, the paleoecological evidence from this period is missing, and the extent of the sedimentary record (if any proceeded) is probably restricted only to the older portion of lithological Unit 4 or the top of Unit 3 (according to depth-age extension).

The only prior archeobotanical research relating to the prehistory of this region was conducted at the Sutny site by E. OPRAVIL (1961). This research was based on anthracologically rich materials (a total of 966 fractions), mostly from Hallstatt period (early Iron Age) objects. According to the anthracological analyses of Hallstat period materials, it was concluded that the most widespread tree cover was represented by communities of *Quercion pubescentis* association, which is also the main form of forest vegetation at the present time. An interesting finding was charcoal from *Acer tataricum*, which had recently appeared in southern Slovakia from the Hallstatt period, but which were not recorded in the boreholes. This period is generally characterized by the expansion of the genus *Abies*, even into lower altitudes; up to that time it had been dominated by mixed stands of oak (RYBNÍČEK & RYBNÍČKOVÁ 2001). In the lowland areas, *Fagus* and *Abies* did not attain the same extent as they did at higher elevations (JANKOVSKÁ 1997), which were not such an extensive influence upon humans and agriculture. Nevertheless, these plant types were sporadically detected in the lowlands (e. g. SVOBODOVÁ 1990, MACHÁČEK et al. 2007, DOLÁKOVÁ et al. 2010) as well as in the charcoal spectra from archaeological locations (findings by P. Kočár). At the same time, we observe a decreasing curve for *Ulmus*, *Tilia*, *Fraxinus*, and *Corylus*; which indeed could affect the occurrence of other species. The decline in *Ulmus* pollen curves (or *Carpinus*) is sometimes regarded as a phenomenon caused by anthropic feeding of the leafy branches of this tree to cattle (Jeník 1970; Jankovská 1997).

The archaeological evidence of human habitation disappears at the beginning of Roman period, with this trend lasting until the beginning of Migration period. There haven't been any significant documented changes in the given palaeoenvironmental record. The increase in pine (a pioneer tree species) may indicate the overgrowth of abandoned lands, perhaps by the exploitation and degradation of the forest. Due to the length of transport of the pine palynomorphs we cannot say with certainty how broad the development of this area was.

6.4 *Medieval human impact*

Changes during the Middle Ages are reflected in Borehole 1 (parts of Unit 5, all of Unit 6), quantitatively as well as qualitatively. At the transition from the Early to the High Middle Ages (radiocarbon date of 1187–1295 AD), the indicators suggest a high degree of anthropogenic impacts. First, the deposition rate is many fold higher than in the previous period. During this period, the height of the deposition rate is a clear indication of rapid changes in land use. Analogous temporal depositional growth rates have been recorded, for example in central Belgium (e. g. Rommens et al. 2006). Analysis of the macroremains demonstrated the presence of humid plants, with a transition to ruderal taxa (see *Chenopodium album*, fig. 6). The increase in magnetic susceptibility could be related to the high content of the fine fraction, corresponding to transported particles from the upper soil horizon by anthropogenic pollution during this period (Evans & Heller 2003); additionally, from the atmospheric fallout of magnetic particles produced by industry, burning of fossil fuels, metallurgical processes, etc. (Evans & Heller 2003). Currently, there is a peak in the level of phosphates in the sediments, with no correlation to the content of organic matter. Anthropic phosphate is evidence of intensive human or cattle occupation of the surrounding area. The main medieval changes are supported by radiocarbon dating (fig. 3) as well as the sedimentological evidence; there is growth in the number of carbonates, which is probably related to loess soil erosion during the High Middle Ages (as well as in modern times). The organic matter content is lower than that which would correspond with the observations of Rommens et al. (2006) for this period. Other values, except for the growth in the rough grain fractions, did not show any greater deviations. The increases of sand may indicate the contribution of exogenous materials originating from the erosion on fields or the weathering of forest soils during forest clearing caused soil erosion. It is clear from written sources that the forests were used economically as a source of wood during the Middle Ages. Alluvial environments in the High Middle Ages reflected the development of eutrophic-exacting vegetation (e. g. *Urtica*), recorded in the macroremains from the Borehole 1 profile. The return of Oak macroremains at a depth of 150 cm is interesting. This appears to be related to the existence of Medieval and Modern economic forests. For both the High Middle Ages and Modern times it is necessary to take into account the regulation of artificial water channels related to the creation of ponds as well as other further modifications of artificial watercourses.

7 *Conclusions*

A significant part of the Holocene (5211–5008 BC to the present) has been recorded in the floodplain sediments of the Únanovka Stream. The floodplain is situated in a deep narrow valley, with the Bohemian Massif to the west, and opening into the Carpathian Foredeep to the east. Both the sedimentary and paleoecological records are incomplete because of the depositional characteristics of the alluvial environment. Therefore, several logs were documented in order to obtain paleological information about the development of the small catchment. Synchronicity with the introduction of agriculture, the Neolith/Eneolith transition to floodplain developmental events, and the exponential increase in sediment accumulation are linked to the growing human impacts. Changes in the sand and silt grain-size fraction probably relates to the changes in land use (forest logging, plowing). The initial phase of this change began in the early Neolithic period, along with the slow transition from sandy gravel to organic-rich sandy silt, and then finally into silty sediment. This trend was noted in nearly all reference cores. An alternative explanation of the sedimentological change between the Early and Middle Holocene is based on climatic shifts, with the related process of forest development and soil pedogenesis. For the Neolithic, forest environments with shrubs were detected, with cereals appearing at the end of the Neolithic or in the Eneolithic. In the Eneolithic, an increase of cereals, as well as signs of deforestation, were detected. In subsequent periods, until the Iron Age, we see minor oscillations of the sedimentary record, and gradual changes of the vegetation. Since the Bronze Age, the floodplain has appeared covered by nitrophilous vegetation.

Although there is an absence of traces of human habitation for the Roman and Migration periods in the archaeological record, there is no evidence for contemporary changes of the environment. Starting with the Early Middle Ages that situation had changed. A moist floodplain, with a transition to ruderals, was detected in the area of Borehole 1. Based on radiocarbon dating, this corresponds to the late Hillfort period. Trees and shrubs disappeared, and a high phosphate concentration (which does not correlate to the maximum for organic matter) indicates intense human activity. The sedimentological record indicates a high erosion rate. All the data gathered from this portion of the study indicates a high degree of anthropogenic activity, which corresponds with recent archaeological data (the evidence of settlement activities). The High Middle Ages and the Modern period are both characterized by high degrees of erosion of the upper soil horizons and the bedrock loess. Human impacts are also reflected in the enhancement of the magnetic susceptibility of the soil, due to increasing anthropogenic pollution of the topsoil or by the erosion and transport of the upper soil horizon particles. This is probably connected with tillage in the catchment, or economic usage of the forest.

Acknowledgements

We would like to thank Svatava Kubešová for determinations of the mosses. Miriam Nývltová Fišáková, for determinations of the osteological fragments. Lenka Lisá for consultation of the sedimentological and geochemical data, as well as for general remarks on the manuscript. Petr Košut, Miroslav Popelka, Jan Bandura, Ondřej Kielar and Richard Bíško for carrying out of fieldwork. Šárka Hladilová for determining of molluscs. Jakub Müller for ERT measurement.

Michal Hlavica for the creation of figures 1 and 2. Also, to the Schlumberger company for providing the Petrel software. This paper is an outcome of the project "Historical land use of the Bohemian–Moravian Upland in Prehistory and Middle Ages" id. code DF13P01OVV005.

References

Behre, K. E. (2000): Der Mensch öffnet die Wälder – zur Entstehung der Heiden und anderer Offenlandschaften. – Rundgespräche der Kommission für Ökologie **18:** 103–116.

Bronk Ramsey, C. (2009): Bayesian analysis of radiocarbon dates. – Radiocarbon **51**(1): 337–360.

Brown, A. G., Cooper, L., Salisbury, C. R. & Smith, D. N. (2001): Late Holocene channel changes of the Middle Trent: channel response to a thousand-year flood record. – Geomorphology **39**(1–2): 69–82.

Cappers, R. T. J., Bekker, R. M. & Jans, J. E. A. (2006): Digital Seed Atlas of the Netherlands [http://seeds.eldoc.ub.rug.nl/root/] (24. 7. 2010).

Cavanagh, W. G., Hirst, S. & Litton, C. D. (1988): Soil phosphate, site boundaries and change point analysis. – Journal of Field Archaeology **15:** 67–83.

Doláková, N., Roszková, A. & Přichystal, A. (2010): Palynology and natural environment in the Pannonian to Holocene sediments of the Early Medieval centre Pohansko near Břeclav (Czech Republic). – Journal of Archaeological Science **37**(10): 2538–2550.

Dotterweich, M. (2008): The history of soil erosion and fluvial deposits in small catchments of central Europe: Deciphering the long-term interaction between humans and the environment – A review. – Geomorphology **101**(1–2): 192–208.

Dreslerová, D. (2012): Les v pravěké krajině II. – Archeologické rozhledy. **64:** 199–236.

Dreslerová, D. & Pokorný, P. (2004): Vývoj osídlení a struktury pravěké krajiny na středním Labi. Pokus o přímé srovnání archeologické a palynologické evidence. – Archeologické rozhledy **56:** 739–762.

Evans, M. E. & Heller, F. (2003): Environmental Magnetism: Principles and Applications of Enviromagnetics. – International Geophysics, Series **86**, Academic Press, 299 pp.

Gehrt, E., Geschwinde, M. & Schmidt, M. W. I. (2002): Neolithikum, Feuer und Tschernosem oder – Was haben die Linienbandkeramiker mit der Schwarzerde zu tun? – Archäologisches Korrespondenzblatt **32:** 21–30.

Grygar, T., Světlík, I., Lisá, L., Koptíková, L., Bajer, A., Wraye, D. S., Ettler, V., Mihaljevič, M., Nováková, T., Koubová, M., Novák, J., Máčka, Z. & Smetana, Z. (2010): Geochemical tools for the stratigraphic correlation of floodplain deposits of the Morava River in Straznicke Pomoravi, Czech Republic from the last millennium. – Catena **80**(2): 106–121.

Heiri, O., Lotter, A. F. & Lemcke, G. (2001): Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. – Journal of Paleolimnology **25:** 101–110.

Hoffmann, T., Lang, A. & Dikau, R. (2008): Holocene river activity: analysing ^{14}C-dated fluvial and colluvial sediments from Germany. – Quaternary Science Reviews.

Jankovská, V. (1997): Vývoj vegetačního krytu střední Evropy od konce poslední doby ledové do současnosti. – Lesnická práce. **76**(11): 409–412.

Jockenhövel, A. (1997): Deutsche Agrargeschichte. – Ulmer-Verlag, Stuttgart

Kadlec, J., Grygar, T., Světlík, I., Ettler, V., Mihaljevič, M., Diehl, J. F., Beske-Diehl, S. & Svitavská-Svobodová, H. (2009): Morava River floodplain development during the last millennium, Strážnické Pomoraví, Czech Republic. – Holocene **19:** 499–509.

Kalis, A. J., Merkt, J. & Wunderlich, J. (2003): Environmental changes during the holocene climatic optimum in central Europe – human impact and natural causes. – Quarternary science reviews **22:** 33–79.

Lang, A. & Nolte, S. (1999): The chronology of Holocene alluvial sediments from the Wetterau, Germany, provided by optical and 14C dating. – The Holocene **9**(2): 207–214.

Ložek, V. (1998): Postglacial Development of Bohemia River Valleys in the Light of Malacology. – GeoArcheoRhein, Festschr. W. Schirner, A. Ikinger, Münster, 81–89.

Lüning, J., Jockenhövel, A., Beneder, H. & Capelle, T. (1996): Anfänge und frühe Entwicklung der Landwirtschaft im Neolithikum. – Deutsche Agrargeschichte, Vor- und Frühgeschichte, Ulmer, Stuttgart, **15**, 139 pp.

Macháček, J., Doláková, N., Dresler, P., Havlíček, P., Hladilová, Š., Přichystal, A., Rozsková, A. & Smolíková, L. (2007): Raně středověké centrum na Pohansku u Břeclavi a jeho přírodní prostředí. – Archeologické rozhledy **59:** 278–314.

Meduna, J. (1980): Die latènezeitlichen Siedlungen und Gräberfelder in Mähren. – Brno, 358 pp.

Měřínský, Z. (1969): Lokalizace a povrchový průzkum zaniklé osady Psáry u Tvořihráze (okres Znojmo). – Vlastivědný věstník moravský **21:** 8–12.

Nekuda, V. (1961): Zaniklé osady na Moravě v období feudalismu. – Brno, 226 pp.

Neustupný, E. (1985): K holocénu Komořanského jezera. On the Holocene period in the Komořany Lake area. – Památky archeologické **76:** 9–70.

Opravil, E. (1961): Vegetační poměry Znojemska v době halštatské. – Acta Musei Moraviae, Scientiae geologicae **46:** 81–99.

Opravil, E. (1962): Paleobotanický výzkum slovanského hradiska Na valech u Mikulčic. – Archeologické rozhledy **14:** 475–484.

Opravil, E. (1978): Rostlinná společenstva v okolí Mikulčic v období předvelkomoravském a velkomoravském. – Archeologické rozhledy **30:** 67–75.

Opravil, E. (1983): Údolní niva v době hradištní. – In: Studie Archeolgického ústavu Československé akademie věd Brno **11**(2): 1–77.

Podborský, V. et al. (2005): Pravěk mikroregionu potoka Těšetičky/Únanovky. K problematice sociálních struktur – Der Urzeit der Mikroregion im Umfeld des Baches Těšetička/Únanovka. Zur Problematik der Urzeitlichen Sozialstrukturen. – Brno, 262 pp.

Poláček, L. (1997): Údolní niva a sídelně – archeologický výzkum velkomoravských mocenských center. – In: Niva z multidisciplinárního pohledu II, Brno. 52–55.

Poláček, L. (2001): K poznání přírodního prostředí velkomoravských nížinných hradišť. – In: Velká Morava mezi východem a západem, Spisy AÚ AVČR Brno **17:** 315–325.

Procházka, R. (2009): Vývoj opevňovací techniky na Moravě a v českém Slezsku v raném středověku – Die Entwicklung der Befestigungstechnik in Mähren und Tschechisch-Schlesien im Frühmittelalter. – Spisy Archeologického ústavu AV ČR Brno, 383 pp.

Rommens, T., Verstraeten, G., Bogman, P., Peeters, I., Poesen, J., Govers, G., Van Rompaey, A. & Lang, A. (2006): Holocene alluvial sediment storage in a small river catchment in the loess area of central Belgium. – Geomorphology **77:** 187–201.

Rybníček, K. & Rybníčková, E. (2001): Vegetace a přírodní prostředí jako pozadí archeologických kultur ČR, 28 000–1 000 B.P. – In: Podborský, V. (ed.): 50 let archeologických výzkumů Masarykovy Univerzity na Znojemsku, MU Brno, Brno, 301–310.

Šabatová, K. (2013): Archeologické doklady lidských aktivit v prostoru Tvořihrázského lesa. – Studia Archaeologica Brunensia **18**(1): 21–38.

Starkel, L., Soja, R. & Michczynska, D.J. (2006): Past hydrological events reflected in Holocene history of Polish rivers. – Catena **66:** 24–33.

Svobodová, H. (1990): Vegetace jižní Moravy v druhé polovině prvního tisíciletí – Vegetation of Southern Moravia between 500–1,000 A.D. – Archeologické rozhledy **42:** 170–205.

Valová, P. (2007): Geologický a petrografický výzkum na neolitickém sídlišti Těšetice-Kyjovice se zřetelem na kvartérní sedimenty. – Bachelor Thesis manuscript, Brno.

Vlček, V. (ed.) (1984): Zeměpisný lexikon ČSR – Vodní toky a nádrže. – Academia, Praha.

Walanus, A. & Nalepka, D. (2004): PolPal [http://www.ib-pan.krakow.pl/bazy_prog/polpal2004/PolPalM.htm] (24. 7. 2010).

Wunderlich, J. (2000): Prähistorische und historische Bodenerosion im Amöneburger Becken – Abgeleitet aus einer Sequenz datierter Kolluvien Berichte der Kommission für Archäologische Landesforschung in Hessen **5:** 9–15.

Zimmermann, A. (1996): Zur Bevölkerungsdichte in der Urgeschichte Mitteleuropas. – In: Campen, I., Hahn, J. & Uerpmann, M. (Eds.): Spuren der Jagd – Die Jagd nach Spuren. Tübinger Monographien zur Urgeschichte **11:** 49–61.

Zolitschka, B., Behre, K. E. & Schneider, J. (2003): Human and climatic impact on the environment as derived from colluvial, fluvial and lacustrine archives – examples from the Bronze Age to the Migration period, Germany. – Quarternary Science Review **22**(1): 1021–1052.

Manuscript received: June 2014; accepted: September 2014.

Addresses of the authors: Jan Petřík, Department of Geological Sciences, Masaryk University, Kotlářská 2, 60200, Brno, CZE; Institute of Archaeology and Museology, Faculty of Arts, Masaryk University, Arna Nováka 1, 60200, Brno, CZE. E-Mail: petrik.j@mail.muni.cz – Libor Petr, Department of Botany and Zoology, Masaryk University, Kotlářská 2, 60200, Brno, CZE. E-Mail: petr.libor@gmail.com – Klara Šabatová, Institute of Archaeology and Museology, Faculty of Arts, Masaryk University, Arna Nováka 1, 60200, Brno, CZE. E-Mail: sabatova@phil.muni.cz – Nela Doláková, Department of Geological Sciences, Masaryk University, Kotlářská 2, 60200, Brno, CZE. E-Mail: nela@sci.muni.cz – Hana Lukšíková, Institute of Archaeology and Museology, Faculty of Arts, Masaryk University, Arna Nováka 1, 60200, Brno, CZE. hana.luksikova@gmail.com – Alena Dohnalová, Department of Geological Sciences, Masaryk University, Kotlářská 2, 60200, Brno, CZE. E-Mail: alena.dohnalova@mail.muni.cz – Leona Chadimová, Institute of Geology ASCR, v. v. i., Rozvojová 269, 165 00, Prague 6, CZE. E-Mail: gkoptikova@gli.cas.cz – Blaško David, Department of Geological Sciences, Masaryk University, Kotlářská 2, 60200, Brno, CZE. E-Mail: 309581@mail.muni.cz – Milo Peter, Institute of Archaeology and Museology, Faculty of Arts, Masaryk University, Arna Nováka 1, 60200, Brno, CZE. E-Mail: 101090@mail.muni.cz