An imprint of the middle Miocene paleoceanologic and paleoclimatic events in a satellite sea during the Langhian: A case study from the Central Paratethys

KATARÍNA HOLCOVÁ[1], FILIP SCHEINER[1,3], NELA DOLÁKOVÁ[2], SLAVOMÍR NEHYBA[2], JITKA KOPECKÁ[4], ROSTISLAV BRZOBOHATÝ[2], ATILLA DEMENY[8], ŠÁRKA HLADILOVÁ[4], JURAJ HRABOVSKÝ[6], HENNING KUHNERT[7], RASTISLAV MILOVSKÝ[5], JANA RIGOVÁ[5], MICHAL SEKO[5] and TORSTEN UTESCHER[9]

[1]Institute of Geology and Palaeontology, Charles University, Albertov 6, 128 43 Praha 2, Czech Republic; holcova@natur.cuni.cz
[2]Institute of Geological Sciences, Masaryk University, Faculty of Sciences, Kotlářská 2, 611 37 Brno, Czech Republic
[3]Institute of Geology of the Czech Academy of Sciences, Rozvojová 269, 165 00 Praha 6 Lysolaje, Czech Republic
[4]Palacký University, Department of Biology, Faculty of Education, Purkrabská 2, 779 00 Olomouc, Czech Republic
[5]Earth Science Institute of the Slovak Academy of Sciences, Ďumbierska 1, 974 11 Banská Bystrica, Slovakia
[6]Earth Sciences Institute of the Slovak Academy of Sciences, Dúbravská cesta 9, 840 05 Bratislava, Slovakia
[7]MARUM — Zentrum für Marine Umweltwissenschaften, Universität Bremen, Leobener Straße 8, 28359 Bremen, Germany
[8]Institute for Geochemical Research, Hungarian Academy of Sciences, Budaorsi ut 45, H-1112 Budapest, Hungary
[9]Geological Institute, Nußallee 8, D-53115 Bonn, Germany

Abstract: The Langhian Central Paratethys sea represents a unique marine environment influenced by many factors as global climatic events, the middle Langhian closure of the Indian-Mediterranean Gateway and the local tectonic events. The multiproxy paleontological and geochemical data confirmed an anti-estuarine circulation regime as the basic circulation pattern during the Langhian. This is supported by a similarity in hydrography of surficial waters (surface mixed layer) between the Paratethys and the Mediterranean Sea which is even more apparent in the upper Langhian. It evokes gradually increased inflow of warm surface water to the Paratethys which might increase terrestrial temperatures. This could explain the delayed onset of cooling after the Middle Miocene Climatic Optimum in the study area. The significant differences between the Burdigalian and Langhian terrestrial climate were recorded only in seasonality of precipitation what might suggest establishment of the monsoon-like climate due to e.g. formation of the Carpathian mountain ridge. Nevertheless, the isotopic data comparison revealed differences regarding the bottom waters, pointing to an existence of the Paratethyan bottom waters especially during the lower Langhian. In the upper Langhian, specificity of this water decreased. We explain this fact by regional shallowing which restricted formation of the Paratethyan bottom water and enabled their substitution by a derivative originating from the intensive inflowing of the Mediterranean surficial waters. This shallowing can be correlated with global Ser-1 sea-level fall. In the study area, the sea-level fall is accompanying by occurrence of euryhaline assemblages what evokes its possible correlation with the Wieliczkian Salinity Crisis. The cyclical changes triggered by Milankovitch processes are clearly pronounced in both marine and terrestrial biotops. In marine realm, the cyclical changes reflected variation in intensity of primary productivity which might be connected with cyclical changes of intensity of water masses circulation.

Introduction

The Langhian epicontinental sea — the Central Paratethys — represents a dynamic environment experiencing many changes influenced by global, regional and local events.

The global changes are represented by the Middle Miocene Climatic Optimum (MMCO) peaking at 15 Ma and followed by cooling with peak at 13.8 Ma (Mi-3b event). This cooling regionally interacted with the middle Langhian closure of the Indian–Mediterranean Gateway which caused a transition from an estuarine to an anti-estuarine circulation regime in the proto-Mediterranean Sea (Kouwenhoven & van der Zwaan 2006). The opening, depth evolution and closing of marine gateways played a crucial role in the heat, salt and nutrient transport between oceans and marine basins. However, the process is not frequently studied in a chain of epicontinental basins of the Paratethys type which were connected to each other by several different gateways (e.g. Karami et al. 2011).

The interaction of global climatic cooling and sea-level drop at 13.8 Ma with regional paleoceanographic evolution triggered by closure of the Indian–Mediterranean

Gateway formed conditions leading to the Badenian (or Wieliczkian) Salinity Crisis (the BSC) in the Central Paratethys (de Leeuw et al. 2010). The BSC is usually considered to be the local Central Paratethys event. However, the evaporites appeared in the comparable time interval e.g. in the SE Mediterranean (Egypt; Ied et al. 2011).

Moreover, the global and regional processes could interact with the local tectonic events during Langhian (the Styrian tectonic phase; Rögl 1998). The tectonic activity might influence the land orography and subsequently atmospheric circulation causing e.g. irregular distribution of rainfalls. (Kováč et al. 2017).

The aim of this work is detailed interpretation of the Langhian paleoenvironment in the Western Carpathian segment of the Central Paratethys and identification of local and global factors which led to establishment of this paleoenvironment.

Material and methods

We have synthesized previously published multiproxy data from the following cores located in the Moravian segment of the Carpathian Foredeep in the Czech Republic: RY-1 (GPS location: 49°16’27.2” N and 17°04’24.8” E; Kopecká 2012); ZIDL-1 and ZIDL-2 (GPS locations: 49°02’29.9” N and 16°37’19.1” E; 49°02’29.8” N and 16°37’22.8” E, respectively; Doláková et al. 2014); OV-1 (GPS location: 49°06’49.2” N and 16°20’14.2” E; Nehyba et al. 2016); BRUS-1 (GPS location: 49°32’23.8” N 17°01’36.5”; E Kopecká et al. 2018), LOM-1 (GPS location: 49°23’56.7” N and 16°24’32.5” E; Holcová et al. 2015; Scheiner et al. 2018). We also supplemented with newly obtained datasets from the core ŠO-1 (SE part of the Danube Basin; Holcová et al. 2019).

The following datasets were used for paleoceanological interpretations: (i) Paleobiological proxies: composition of calcareous nannoplankton, foraminiferal and mollusc assemblages, palynomorphs, in some sections also otoliths, bryozoa, Ostracoda, dinoflagellates and brachiopods. (ii) Sedimentological proxies: lithofacial analysis, the gamma-ray spectra, in some profiles also analysis of heavy mineral associations. (iii) Geochemical proxies: Carbon and oxygen isotopic values as well as Mg/Ca-ratio using various foraminiferal taxa characterizing different positions within the water column: (1) *Globigerina bulloides*: sub-surfacial waters during periods of an enhanced productivity; (2) *Globigerinoides trilobus*: surficial stratified waters during summer seasons with possible salinity and temperature oscillations; (3) epifaunal *Cibicidoides* spp.: bottom waters; (4) infaunal *Melonis pompiloides*: pore waters. We used the δ^{13}Corg, TOC/TIC and the n-alkane based indices to estimate the production rate and to determine the origin of the organic matter.

Stratigraphical correlation

The following biostratigraphical events were used for correlation: (1) *Orbulina suturalis* occurs in the whole core sections, i.e. the studied sequences is younger than 14.6 Ma (=the First Occurrence of *Orbulina suturalis* in the Mediterranean; (2) The last common occurrence (LCO) of *Helicosphaera waltrans* is dated at 14.357 Ma in the Mediterranean area; in the Central Paratethys might be slightly older than in the Mediterranean — estimated at 14.38–14.39 Ma. The event was recorded in the majority of studied sections. (3) *Sphenolithus heteromorphus* was recorded in the whole thickness of the cores. Its Last Occurrence in the Mediterranean was dated at ~13.4 Ma which indicates that the top core sediments must be older than 13.4 Ma.

Paleotemperatures, paleosalinity and precipitation

The Mg/Ca derived temperature ranges of the surface and bottom waters turned out to be comparable with modern subtropical regions what agree with paleontological interpretation (otoliths). However, no cooling trend was recorded in the time interval 14.45–14.35 Ma as was expected at this period following the Middle Miocene Climatic Optimum. However, decreased bottom sea-water temperatures is estimated for the E part of the Danube basin (ŠO-1 core; 14.6–13.4 Ma) from gradually increased δ^{16}O. On the other hand, δ^{16}O is problematic paleotemperature proxy in the epicontinental sea, and increased δ^{16}O values might indicate also salinity changes. Increased salinity in the upper Langhian is expected from occurrence of euryhaline benthic foraminifera as well as from hypersaline dinoflagellates.

The land temperatures (mean annual temperatures, the coldest and the warmest month temperatures) also agree with subtropical climatic belt and they persisted at the same level from the uppermost Burdigalian (Karpatian). The significant differences were recorded in seasonality of precipitation what suggests monsoon-like climate due to e.g. formation of the Carpathian mountain ridge.

Paleodepth

Estimation of the maximum paleodepth is very problematic and has not been reliably resolved. While variegated biotops of the photic zone (sea-grass meadows, algal bioherms, wave influenced sandy sea-floor…) can be recognized from benthic foraminifera and mollusc assemblages with high certainty, the depocentre paleodepths could be estimated only tentatively. The depocentre paleodepth was interpreted from otoliths, ostracods and Mg/Ca derived temperature of the surface and bottom waters. Depths between 200–300 m is estimated from otoliths, though also deeper conditions cannot be excluded (to 500 m). Ostracods indicate maximal paleodepth around 200–300 m. The Mg/Ca derived temperature showed water thermal gradient ~7 °C between 100 m (*G. bulloides*) and sea-floor (*Cibicidoides* spp.) and ~8 °C between 50 m (*G. trilobus*) and sea-floor. Though thermal gradient strongly depends on circulation patterns, these differences do not contradict the paleontological interpretation of paleodepth.

Though paleobathymetric interpretation of maximum paleodepth is problematic, the sea-level fall correlable with the pronounced global Ser 1 event can be reliable detected in studied sections. The sea-level fall is connected with occurrence of euryhaline markers between planktic as well as shallow-water protists corroborates correlation with the onset of the Wieliczkian salinity crisis near the Langhian/Serravallian boundary.

Cyclical oscillations of paleoenvironmental proxies, nutrients

The cyclostratigraphic analysis based on paleobiological and geochemical proxies in the Langhian of the Vienna Basin was published by Hohenegger et al. 2009. Identified cycles were correlated with cyclical variation in the solar radiation (Milankovitch processes). The cyclical changes of comparable length are very characteristics also for our sections. The cyclicity is the most pronounce in relative abundances of *Globigerinoides* spp., *Globigerina bulloides* and high-nutrient benthic markers what suggests cyclical changes in quantity and/or quality of nutrients. In the central part of basin, the primary productivity was based on intrabasinal sources (phytoplankton bloom), locally in marginal part of basin also a phytodetritus input may play a role (cyclical bloom of small-sized *Epistominella*). But decisive role of intrabasinal primary production in marine nutrient webs evokes the hypothesis about solar-radiation triggered cyclical changes of intensity of primary productivity which might be connected with cyclical changes of intensity of water masses circulation. It could include the oscillation of intensity of coastal seasonal upwelling suggested e.g. for the eastern coast of the Carpathian Foredeep.

Moreover, the cyclical changes in palynomorph assemblages indicate that solar radiation triggered also cyclical evolution in composition of terrestrial plants.

Circulation patterns

The comparison of the isotopic and the paleobiological data suggests that an anti-estuarine circulation regime was the prevailing circulation pattern during the studied interval (Fig. 1). The initiation of this circulation regime might be indicated by the Pteropoda event (14.2–14.5 Ma) because the anti-estuarine circulation allowed and simplified migration of planktic organisms to the Central Paratethys. The Paratethyan surficial waters show a high degree of similarity with the Mediterranean during this time interval, which is even more apparent in the upper Langhian.

During the interval with the presence of *Helicosphaera waltrans* (~14.6–14.4 Ma) the Paratethyan bottom waters differed from the Mediterranean ones at the same depth. We assume that the Paratethys probably had its own bottom waters of a regional provenance, which had a different temperature/salinity than the Mediterranean ones at the same depth.

We suggest that the change in the chemistry of the Paratethyan bottom waters in the following time interval (~14.4–13.9 Ma) could be caused by a restriction or isolation of their source area, thus not enabling their formation. It could be due to the shallowing of the basin as indicated by the paleobiological data. The bottom waters were probably not fully evolved or substituted by a derivative originating from the intensive inflowing of the Mediterranean surficial waters during this time interval.

Acknowledgements: The study was supported by the projects PROGRES Q45 and by the Center for Geosphere Dynamics (UNCE/SCI/006).

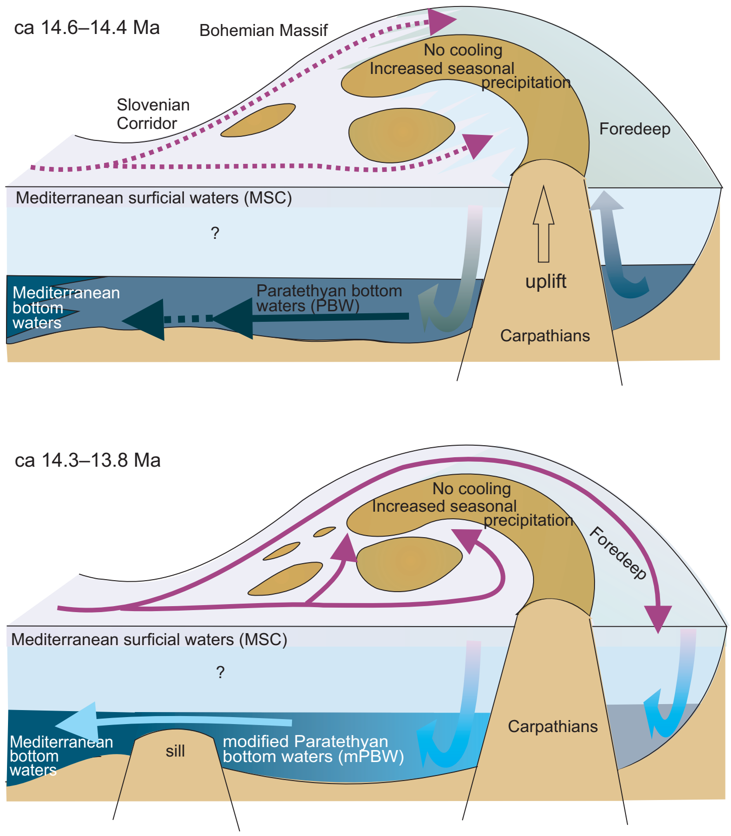

Fig. 1. Simplified model of the Langhian circulation patterns (modified after Holcová et al. 2019).

References

de Leeuw A., Bukowski K., Krijgsman W. & Kuiper K.F. 2010: Age of the Badenian salinity crisis; impact of Miocene climate variability on the circum-Mediterranean region. *Geology* 38, 715–718.

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 the multiproxy study. *Neues Jb. Geol. Paläontol. Abh.* 271, 169–201.

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.

Holcová K., Brzobohatý R., Kopecká J. & Nehyba S. 2015: Reconstruction of the unusual Middle Miocene (Badenian) palaeoenvironment of the Carpathian Foredeep (Lomnice/Tisnov denudational relict, Czech Republic). *Geol. Quarterly* 59, 654–678.

Holcová K., Kopecká J. & Scheiner F. 2019: An imprint of the Mediterranean middle Miocene circulation pattern in a satellite sea during the Langhian: a case study from the 710 Carpathian Foredeep (Central Paratethys). *Palaeogeogr., Palaeoclim., Palaeoecol.* 514, 336-348.

Ied I.M., Holcová K. & Abd-Elshafy E. 2011: Biostratigraphy and paleoecology of the Burdigalian–Serravallian sediments in Wadi Sudr (Gulf of Suez, Egypt): comparison with the Central Paratethys evolution. *Geol. Carpath.* 62, 3, 233–249.

Karami M., De Leeuw A., Krijgsman W., Meijer P. T. & Wortel M. 2011: The role of gateways in the evolution of temperatureand salinity of semi-enclosed basins: An oceanic box model for the Miocene Mediterranean Sea and Paratethys, *Global Planet. Change* 79, 73–78.

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). *Bull. Geosci*. 87, 431–442.

Kopecká J., Holcová K., Nehyba S., Hladilová Š., Brzobohatý R. & Bitner M.A. 2018: The earliest Badenian *Planostegina* bloom deposit: reflection of anunusual environment in the westernmost Carpathian Foredeep (Czech Republic). *Geol. Quarterly* 62, 1, 18–37.

Kouwenhoven T.J. & Van der Zwaan G.J. 2006: A reconstruction of late Miocene Mediterranean circulation patterns using benthic foraminifera. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 238, 1–4. 373–385.

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 Geol. Slovaca* 9, 75–114.

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

Scheiner F., Holcová K., Milovský R. & Kuhner H. 2018: Temperature and isotopic composition of seawater in the epicontinental sea (Central Paratethys) during the Middle Miocene Climate Transition based on Mg/Ca, $\delta^{18}O$ and $\delta^{13}C$ from foraminiferal tests. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 495, 60–71.