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Coiling direction in Middle Miocene globorotaliids (Foraminiferida) – a case study in the Paratethys (Upper Silesia Basin, Poland)

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The paper deals with sub-evaporite Badenian deposits (Middle Miocene, Paratethys) that display a sudden appearance of globorotaliid taxa showing preferences in the taxonomic set and coiling direction. An interval of sinistrally coiled *Jenkinsella mayeri* with proportionally coiled *Globoconella bykovae* is at the bottom of the studied sequence. It is followed by an interval of proportionally coiled *Jenkinsella transsylvanica*. Proportionally coiled *Globoconella bykovae* with a small number of proportionally coiled *Jenkinsella transsylvanica* are at the top of the Moravian (CPN 7) substage (*Orbulina suturalis* alias Lagenidae Zone). The sub-evaporite part of the Wielician (CPN 8) substage (*Uvigerina costai* alias *Spiroplectammina* Zone) began with a globorotaliid-barren interval (IIC biozone). It is followed by biozone IID displaying three globorotallid peaks amongst globorotallid-barren deposits. Only globoconellas are present in all these three events. Proportionally coiled *Globoconella bykovae* appeared first. It is followed by proportionally coiled *Globoconella minoritesta* and sinistrally coiled *Globoconella bykovae* at the end of the biozone IID. Coiling preferences of globorotaliids have been compared to changes in the hydrographic regime unfolding during the CPN 7 and CPN 8 in the studied area of the Paratethys. The study discovers that the coiling of globorotaliids responded selectively to the hydrographic changes. *Globoconella bykovae* is highly opportunistic and can tolerate considerable temperature changes. Specimens of this taxon persist to coil proportionally during the sub-evaporite Badenian, except for the shift to sinistral coiling just prior to the Wielician evaporites. Sinistrally coiled *Jenkinsella mayeri* is the most sensitive to hydrographic changes. This taxon retreated at the onset of the temperature drop during the mid-Moravian cryptic cooling. This cooling is marked by the new jenkinsellid occurrence – proportionally coiled *Jenkinsella transsylvanica*. Proportionally coiled *Globoconella minoritesta* is present in the middle of the IID globorotaliid peaks. The globorotaliid coiling data, presented in this paper, has been calibrated to the global stratigraphy. The integrated data (foraminifera, nannofossils, oxygen and carbon stable isotopes, radiometric measurements) supports the view that the CPN 7/CPN 8 boundary is coeval to the Langhian/Serravalian one. In the Polish part of the Carpathian Foredeep, the boundary runs within the Skawina Formation.

Key words: Middle Miocene, Paratethys, foraminifera, globorotaliid, coiling direction.

INTRODUCTION

Coiling direction is an easily traceable morphological aspect of trochospiral foraminifera. These organisms show a tendency to coil their test in a clockwise (dextral, right-handed) or counterclockwise (sinistral, left-handed) direction (Boltovskoy and Wright, 1976). The sinistral to dextral (L/R) ratio within the recent planktonic foraminifera population has been established, among others, for *Neogloboquadrina pachyderma*, *Globorotalia crassaformis*, *Glob. hirsuta*, *Glob. truncatulinoides* and *Globigerina bulloides* (Ericson et al., 1954; Jenkins, 1967; Thiede, 1971; Lidz, 1972; Malmgren and Kennett, 1976; Reynolds and Thunell, 1986). A relationship between coiling direction and surface water temperature has been discovered based on the spatial distribution of the foraminifera populations of the above species. The data demonstrate that different species may respond in opposite ways, however, coiling direction and the ambient water temperature in which the specimens lived are indeed correlative (Ericson et al., 1961; Boltovskoy, 1962, 1973; Bandy, 1972).

Bolli (1971) was the first who recognized the patterns in coiling direction and its use in stratigraphy, and was followed by many evolutionary and phylogenetic studies. It was assumed that random coiling persists during the early evolutionary stage of morphospecies. Stratigraphically younger representatives of these taxa can exhibit a preferred dominance in coiling direction. Those that attain left or right preferred coiling direction during their early evolution maintain it as a rule and may temporally switch in different coiling directions, but do never show random coiling. Within the stratigraphic range of a single morphospecies, distinct oscillations in coiling directions can occur (Bolli, 1971).

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Some taxa prefer either dextral or sinistral coiling and the achieved coiling preference remains the same worldwide during the stratigraphic range of the species. There are also taxa preferring either dextral or sinistral coiling, but the preferred coiling direction can change from one geographic region to another at the same time. For example, such two chiral forms of individual morphospecies (left- vs. right-coiled) are represented by Langhian *Globorotalia praescitula* described from lower versus higher latitudinal areas (Majewski, 2010; Foresi et al., 2011; respectively).

This case of coeval geographical differences in coiling preference within one morphospecies is apparently dependent on the temperature of water. Bandy's (1960) opinion that biochemical processes effected by temperature are responsible for the different ratio of coiling has been argued (Tolderlund and Bé, 1971; Brunner and Kroon, 1988; Kucera and Kennett, 2002 with references therein). The state of coiling, its biases and swings occurring in both recent species and fossil morphospecies, is a feature worth to observe regardless of the controlling causes like temperature and/or other environmental factors. As a simply measurable single-valued morphological aspect in trochospiral foraminifera shells, coiling direction has high potential in chronology and stratigraphy. Stratigraphic studies using the variation in coiling direction have been broadly carried out on planktonic foraminifera. These studies demonstrate the stratigraphic utility of coiling direction changes, although the patterns exhibited are complex (Nagappa, 1957; Vella, 1974; Kennett, 1976; Olsson, 1970; Hofker, 1972; Eisenach and Kelly, 2006 with references therein). Though, some particular biochemical processes responsible for coiling preferences are still under discussion, this morphological feature is extensively recognized, traced, mapped and applied in stratigraphy and palaeogeography (e.g., Ericson, 1959; Bolli, 1971; Kennett, 1976; Reynolds and Thunell, 1986; Naidu and Malmgren, 1996; Little et al., 1997; Winter and Pearson, 2001; Pfuhl and Shackleton, 2004; Eisenach and Kelly, 2006).

For the Middle Miocene of the Paratethys, the record of globorotaliid coiling direction within the Badenian deposits had been performed by Vašiček (1953) in the vicinity of Brno, Czech Republic (Fig. 1). As the sub-evaporite Badenian (Skawina Formation) globorotaliids of the Upper Silesia Basin was described by Gonera (2013), the material is revisited now concerning coiling direction of the specimens (Fig. 1 and Table 1). The present study discusses the globorotaliid coiling preferences of sub-evaporite Badenian morphospecies in these sediments. The globorotaliid taxonomy concept applied by Gonera (2013) has been sustained into this paper. The convention of viewing the spiral side of tests by Bolli (1950) were followed to determine the coiling direction of globorotaliid specimens.

A relationship between the coiling preference and hydrography was tested by the palaeoecological method. The planktonic assemblage is considered with respect to symbiont-bearing and temperature-related groups of planktonic taxa vs. the percentage of a non-spinose deep-pelagic group of taxa (globorotaliid) in the assemblage. Accordingly, the planktonic foraminifera morphospecies have been grouped into broadly defined categories based on ecologic criteria, i.a. by Bé and Tolderlund (1971), Bé (1977), Bé and Hutson (1977), Boltovskoy et al. (1996), Simstich et al. (2003), Schiebel and Hemleben (2005) and Wilke et al. (2009). The basic hydrography indices of environment are expressed in the studied material by the proportion of these categories (groups of taxa). A comparison of the globorotaliid coiling with the palaeohydrographic indices is provided and the usefulness of the globorotaliid coiling preferences for stratigraphy is demonstrated in this paper.

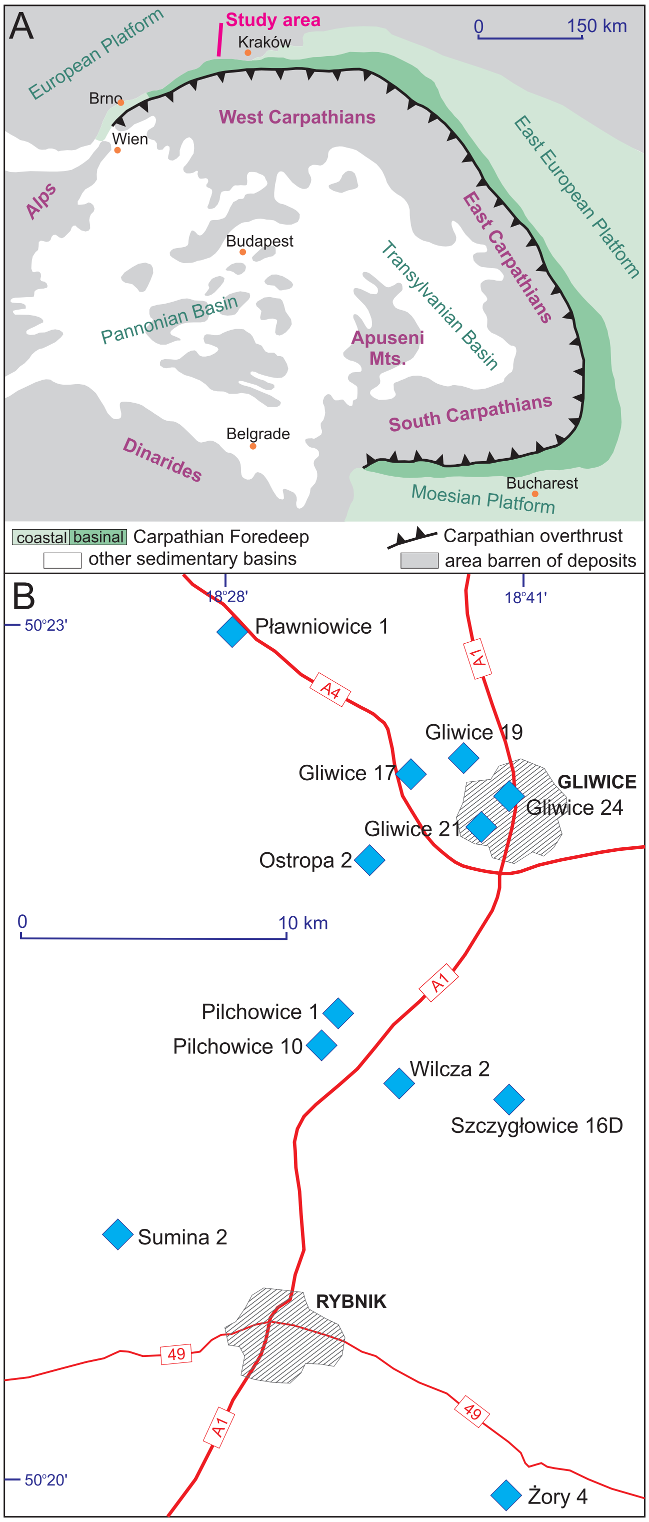

Fig. 1. Location map

A – distribution of Middle Miocene marine deposits in the Central Paratethys (modified after Seneš, 1971; Rögl, 1998); **B** – location of the studied boreholes.

Table 1

Location of the studied sub-evaporite Badenian (Moravian and Wielician – pars) against the background of Central Paratethys stratigraphy

Chronostratigraphy (after Cicha et al., 1975)		Biozonation after:				Lithostratigraphy units mentioned in the text; after Alexandrowicz et al. (1982), Garlicki (1994)
STAGE	SUBSTAGE	Cicha et al. (1975), Papp et al. (1978), Rögl and Steininger (1984), Steininger at al. (1985)		Alexandrowicz (1963, 1997)	Łuczkowska (1964)	
Badenian (Middle Miocene)	KOSOVIAN (CPN 9)	Velapertina Zone	Bulimina-Bolivina Zone	**III B**	Hanzawaia crassiseptata Zone	not considered in this paper
	WIELICIAN (CPN 8)	Globigerina druryi–G. decoraperta Zone	Spiroplectammina Zone	**III A**	Neobulimina longa Zone	
				Wielician salinity crisis deposits: Krzyżanowice Fm. and Wieliczka Fm.		
				IID	Uvigerina costai Zone	Skawina Fm. and Pińczów Fm.
				IIC		
	MORAVIAN (CPN 7)	Orbulina suturalis Zone	Lagenidae Zone	**IIβ**	Orbulina suturalis Zone	
				IIB		
				IIA		

GEOLOGICAL SETTING

The Upper Silesia Basin was located in the peripheral, NW part of the Carpathian Foredeep of the Paratethys during the Miocene (Oszczypko et al., 2006). The sub-Miocene basement in the Upper Silesia Basin is represented by Carboniferous and Triassic deposits, and the thickness of Miocene deposits ranges from 60 to 600 m (Alexandrowicz, 1963; Gonera, 2001). Patches of Lower Miocene brackish and freshwater deposits (Karpatian stage; e.g., Peryt et al., 2005) occur locally at the base. They are covered by the marine Badenian (Skawina Fm. in Table 1) with an average thickness of 66 m in the study area. The Skawina Fm. consists primarily of grey marly clays, and partly of sand or silty gravel, with intercalations of shelly and biodetrital limestones and marls (Alexandrowicz, 1997). The Badenian evaporites occur in part of the Upper Silesia Basin, generally attaining a thickness of a few tens of metres (Garlicki, 1979). In the studied boreholes, they are included in the Krzyżanowice Fm. (14.5–57.2 m thick). The well-known Wieliczka Fm., consisting of halite, appears only in the vicinity of Rybnik-Żory (Garlicki, 1979, 1994).

Biostratigraphic subdivision of the Skawina Fm. deposits is based mainly on foraminifers (Table 1). Considerable faunal shifts were observed in the sequence, which led to the use of particular assemblages as assemblage biozones (Alexandrowicz, 1963). Palaeoecological methods revealed that the stratigraphic succession of foraminiferal assemblages correlates well to palaeoenvironmental changes, and these biozones were established as ecozones (Gonera, 2001, 2013). Climate and climate-driven circulation patterns of palaeocurrents were found to be controlling the succession of these biozones (Szczechura, 1982; Gonera et al., 2000; Gonera, 2001, 2013; Bicchi et al., 2003; Gonera and Bukowski, 2012).

In spite of the various names used for the particular Badenian biozones within the Central Paratethys, they show consistency and can be readily traced throughout this area (e.g., Steininger et al., 1985; Popescu and Brotea, 1994; Cicha et al., 1998; Łuczkowska, 1998; Báldi, 2006; Doláková et al., 2014; Báldi et al., 2017).

MATERIAL AND METHODS

Material for this paper comes from samples already analysed with regard to foraminiferal palaeoecology (Gonera, 2001), globorotaliid intervals (Gonera, 2013) and *Globigerina bulloides* coiling direction (Gonera et al., 2003). New samples from the Wilcza 2 borehole (Fig. 1) and one sample relatively rich in globorotaliids from the Wieliczka Salt Mine (sample no. 47 of Gonera et al., 2014) are also included. The sampled deposits are mudstones and marly claystones. Rock samples were prepared by the standard maceration procedure with H-peroxide, and then washed on a 0.1 mm sieve. The residue (fraction >0.1 mm) was analysed stereomicroscopically.

Altogether, the studied material consists of 173 rock samples of the Skawina Formation deposits. Thirty-eight samples had only low percentage (≤3.0%) of globorotaliids in the planktonic assemblage (see Gonera, 2001). As the first step of material filtering, these had been left out concerning coiling direction, but included into the hydrography database. For the remaining 135 rock samples of the Skawina Fm. deposits, globorotaliid taxa coiling ratios were presented (Table 1). Counting results for particular taxa are as follows: 112 *Globoconella bykovae*, 2 *G. minoritesta*, 59 *Jenkinsella mayeri,* and 56 *J. transsylvanica*. A full list of all counts can be found in Appendix 1*. The number of tests (>125 μm) examined for the taxa varied between 1 and 532 for *Globoconella bykovae*, 115–695 for *G. minoritesta*, 1–178 for *Jenkinsella mayeri,* and 3–364 for *J. transsylvanica*. In order to have a statistically significant database, referred here as counts, the coiling data of a particular taxon in the sample having <41 counts had been dropped out; it was usually case of low percentage (≤3%) taxon in the planktonic assemblage.

Filtering of data with the two-step procedure resulted in a trustworthy database with a statistically significant number of coiling counts, suitable to obtain credible results. Only the following counts were considered: 91 counts for *Globoconella bykovae*, 2 for *G. minoritesta*, 37 for *Jenkinsella mayeri* and 43 for *J. transsylvanica* (Table 2). The results of the present study are based on this database.

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* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1397

Table 2

Percentage of sinistrally coiled globorotaliid specimens

Chrono-stratigraphy	Biozone and globorotaliid episodes in IID		*Globoconella*		*Jenkinsella*	
			bykovae	*minoritesta*	*mayeri*	*transsylvanica*
WIELICIAN	IID	IID^3	**86.0 ±3.3** [3] 132-338/217 *	▨	▨	▨
		IID^2	▨	**48.2 ±1.7** [2] 115-695	▨	▨
		IID^1	**52.3 ±3.0** [3] 57-532/80	▨	▨	▨
	IIC		▨	▨	▨	▨
MORAVIAN	IIβ		**49.8 ±2.8** [29] 55-344/236	▨	▨	**49.7 ±3.5** [12] 40-313/93
	IIB		**47.5 ±4.9** [4] 56-326/209	▨	▨	**51.3 ±2.2** [31] 126-364/314
	IIA		**50.8 ±3.0** [51] 40-423/303	▨	**92.3 ±4.8** [37] 43-182/128	▨

Bold – average and standard deviation of the sub-evaporite Badenian; in the brackets – number of samples; asterisk – data on coiling counts (minimal, maximal, median); dashed area – barren of taxa in the particular biozone

The percentage of cool-water *versus* warm-water planktonic foraminifera in the sample is considered as the epipelagic temperature signature. *Globigerina bulloides* and *Turborotalita quinqueloba* are regarded as cool-water epipelagic dwellers. *Globoquadrina altispira*, *Globigerinoides quadrilobatus* and *Orbulina suturalis* are assumed to be warm-water epipelagic dwellers. The third considered group comprises globorotaliids as deeper-pelagic non-spinose taxa. The set of other indices has been applied to tie the switches in globorotaliid coiling to hydrography changes known to happen during the deposition of the studied sequence. The percentage of globorotaliids has been used to assess basin depth history. As the indication of both bathymetry and shoreline distance, the P/B ratio was used (Murray, 1976). The database on oxygen and carbon stable isotopes submitted by Gonera and Bukowski (2012) are reconsidered now as the tracers of temperature and carbon cycling, respectively.

RESULTS

MORAVIAN

Globorotaliids of biozone IIA are represented by *Globoconella bykovae* and *Jenkinsella mayeri*. Out of the total number of 60 examined rock samples, only one sample contains <3% of globorotaliids among planktonic foraminifera (Gliwice 21, 233.5 m). According to the first step of the material selection, this sample has been omitted.

The percentage of *G. bykovae* in the planktonic assemblage ranges from 0.3% (Gliwice 21, 267.6 m) to 89.5% (Pilchowice 1, 320.0 m) with the mean value of 33.5 ±26.2% (Fig. 2). Eight samples of insufficient *G. bykovae* coiling counts (≤40 specimens) recorded in the Gliwice 21 borehole have been omitted in sinistrality counts of the taxon. For the remaining 51 rock samples the median of sinistrally coiled specimens is 50.9% (Fig. 2 and Table 2), the percentage of *G. bykovae* among planktonic foraminifers varies from 1.8% (Gliwice 19, 270.0 m) to 89.5% (Pilchowice 1, 320.0 m), and the average value is 38.1 ±25.1%.

In the analysed 59 samples, the percentage of *J. mayeri* in the planktonic foraminiferal assemblage fluctuates from 0.5% (Pilchowice 10, 615.0 m) to 28.8% (Gliwice 21, 224.3 m) and the average is 9.1 ±7.2% (Fig. 2). The number of insufficient coiling counts (≤40 specimens) is 22; most of them in the Gliwice 21 (9 samples) and Gliwice 17 (6 samples) boreholes. The median of sinistrally coiled specimens is 92.5% in 37 rock samples (Fig. 2 and Table 2): the percentage of *J. mayeri* in planktonic foraminifera ranges from 2.0% (Gliwice 19, 289.0 m; Pilchowice 10, 605.0 m) to 28.8% (Gliwice 21, 224.3 m); average value is 12.0 ±7.3%.

Biozone IIB contains two globorotaliid taxa of *Globoconella bykovae* and *Jenkinsella transsylvanica*. Out of the total number of examined rock samples (33) only one contained <3% of globorotaliids among the planktonic foraminifera (Gliwice 21, 204.0 m). In the remain 32 samples *G. bykovae* occurs only in 16 and *J. transsylvanica* in all of rock samples (Appendix 1).

The percentage of *G. bykovae* in planktonic foraminifera varies from 0.5% (Pilchowice 10, 575.0 m) to 45.0% (Gliwice 21, 202.2 m) with the mean value of 6.8 ±11.8% (Fig. 2). Only four samples remain reliable concerning coiling data according to the applied method, and the median of sinistrally coiled

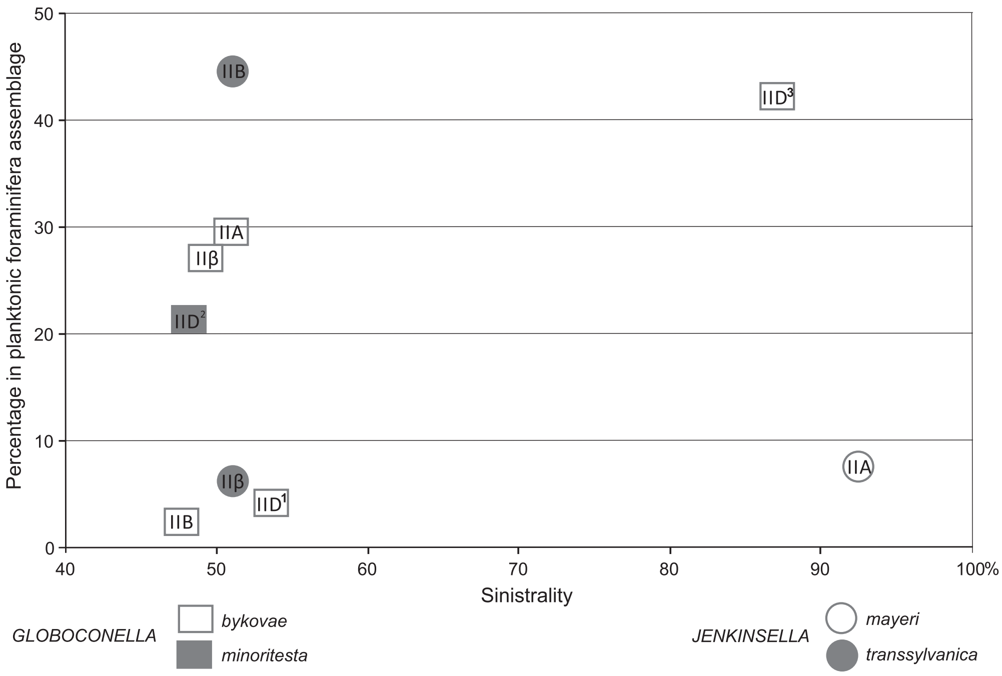


Fig. 2. Globorotaliid abundance (median) vs. sinistrality within Moravian biozones (IIA, IIB, IIβ) and globorotaliid episodes (IID^1, IID^2, IID^3) during the Wielician IID biozone

Sinistrality 47–53% is implemented as proportional coiling

G. bykovae specimens is 47.7% (Fig. 2 and Table 2). The percentage of *G. bykovae* in the planktonic foraminiferal assemblage ranges from 0.7% (Pławniowice 1, 142.0 m) to 45.0% (Gliwice 21, 202.2 m); average value is 20.2 ±19.4%.

In 32 samples of biozone IIB, *J. transsylvanica* accounts for from 2.5% of (Gliwice 21, 202.2 m) to 95.2% (Pilchowice 10, 565.0 m) among planktonic foraminifera, with an average value of 47.0 ±23.5% (Fig. 2). There are insufficient coiling counts (<40 specimens) in one sample (Gliwice 21, 202.2 m). The median of sinistrally coiled specimens in the other 31 samples is 51.1% (Fig. 2 and Table 2), and the *J. transsylvanica* percentage among planktonic foraminifera varies from 12.5% (Gliwice 19, 220.0 m) to 95.2% (Pilchowice 10, 565.0 m) with a mean value of 48.4 ±22.4%.

Biozone IIβ contains two globorotaliid taxa: *Globoconella bykovae* and *Jenkinsella transsylvanica*. Among all the examined rock samples, two samples contain the not required number of globorotaliids (≤3%) in the planktonic foraminiferal assemblage (Gliwice 19, 181.2 m; Żory 4, 105.0 m). *G. bykovae* is present in 35 samples more. *J. transsylvanica* is found in 26 of them (Appendix 1). The percentages *G. bykovae* among planktonic foraminifera ranges from 2.4% (Pławniowice 1, 139.0 m) to 63.6% (Pilchowice 10, 554.0 m) with the mean value 26.8 ±18.1% (Fig. 2). In six samples, the number of coiling counts is ≤40 specimens. In the other 29 samples, the median of sinistrally coiled *G. bykovae* specimens is 49.4% (Fig. 2 and Table 2). The percentage of *G. bykovae* among planktonic foraminifera of these 29 samples varies from 3.4% (Gliwice 19, 179.0 m) to 63.6% (Pilchowice 10, 554.0 m) with the mean value at 28.9 ±17.4%. The percentage of *J. transsylvanica* ranges from 0.7% (Wilcza 2, 96.0 m) to 69.0% (Pławniowice 1, 139.0 m) with the mean value 17.1 ±21.0% (Fig. 2). In the samples of this biozone the number of samples displaying insufficient coiling counts is 14 and only 12 samples are considered reliable coiling data. The median of sinistrally coiled specimens is 51.0% (Fig. 2 and Table 2), and the percentage of *J. transsylvanica* in these planktonic foraminiferal assemblage ranges from 5.6% (Gliwice 24, 163.0 m) to 69.0% (Pławniowice 1, 139.0 m) with the average 33.0 ±21.9%.

WIELICIAN

The IIC biozone is barren of globorotaliids (12 rock samples were checked). Globorotaliids are absent also in samples of the IID biozone, except for globorotaliids quantitatively significant occurrence (peaks) traced within few separated samples in the studied II D biozone material. Altogether, 30 rock samples of the IID biozone comprising peaks in 8 samples were checked; single *Globoconella bykovae* specimens in sample 81.0 m of the Wilcza 2 borehole is omitted from the globorotaliid coiling counting. The peaks comprise *Globoconella bykovae* in six samples and *Globoconella minoritesta* in two samples (Appendix 1).

There are different coiling preferences of *G. bykovae* present in the studied six samples. In three of them (Pławniowice 1, 133.0 and 130.0 m; Gliwice 19, 173.5 m) the mean value of sinistrally coiled specimens is 52.3 ±3.0% with the median 53.6%. The percentage of *G. bykovae* in the planktonic assemblage is from 3.5% (Gliwice 19, 173.5 m) to 11.7% (Pławniowice 1, 130.0 m) with the mean value 6.5 ±4.5%. In the other three samples of the *G. bykovae* quantitative peaks (Żory 4, 55.0 m; Sumina 2, 286.0 m; KSW sample no. 47) the mean value of sinistrally coiled specimens is 86.0 ±3.3% with the median 87.1%. The percentage of *G. bykovae* in the planktonic assemblage of these samples range from 12.3% (KSW sample no.

47) to 66.7% (Żory 4, 55.0 m) with the mean value 40.4 ±27.2%. In the two peaks of the *Globoconella minoritesta* (Bielszowice 7, 83.0 m; Gliwice 19, 172.0 m) the mean value of sinistrally coiled specimens is 48.2 ±1.7%. The percentage of *G. minoritesta* in the planktonic assemblage is 6.6% (Bielszowice 7, 83.0 m) and 35.8% (Gliwice 19, 172.0 m) with the mean value 21.2 ±20.6%.

The stratigraphic order of the globorotaliid events is shown in Figure 2 and Table 2. In the Gliwice 19 borehole, proportionally coiled *G. bykovae* (IID^1) in sample 173.5 m is followed by proportionally coiled *G. minoritesta* (IID^2) in sample 172.0 m of this borehole (Appendix 1, Table 2 and Fig. 2). The dominance of sinistrally coiled *Globoconella bykovae* (IID^3) is recorded in the Sumina 2 (sample 286.0 m) and Żory 4 (sample 55.0 m) boreholes, and in the Salt Breccia Member of the Wieliczka deposit (xenolith sample no. 47). In the presently studied material, sinistrally coiled *Globoconella bykovae* event (IID^3) is not traced in the same borehole jointly with any of the events mentioned above (Appendix 1). As this event is observed just few centimetres below the evaporites of the Krzyżanowice Fm. in the Sumina 2 borehole, this of the Wielician globorotaliid events is positioned as the youngest globorotaliid-bearing layer.

COMPARISON AND DISCUSSION

COMPARISON OF COILING DATA WITH COEXISTING GLOBOROTALIID MORPHOSPECIES

The taxa names of globorotaliids *Jenkinsella transsylvanica*, *Globoconella bykovae* and *G. minoritesta* are in use only in the Paratethys. These taxa names do not have counterparts even in the adjoining part of the Mediterranean Basin connected with the Paratethys through seaways (i.a. Rögl, 1998). Only *Globoconella bykovae* has been described apart from the Paratethyan area (e.g., Saito and Maiya, 1973; Fujiwara et al., 2008). This generates a significant obstacle to perform comparisons between the globorotaliid coiling data presented herein and non-Paratethys data. Comparison of coiling directions with non-Paratethys data is possible only if we assume that the *Globoconella bykovae*, *Jenkinsella transsylvanica* and *Globoconella minoritesta* are morphotypes of some of the globally known taxa.

The direct comparison of the coiling mode can be undertaken concerning *Jenkinsella mayeri* Cushman, Ellisor, 1939 and its synonymous *Globorotalia siakensis* LeRoy, 1939 (after Bolli and Saunders, 1982). A distinct change from proportional to sinistral *J. mayeri* occurred in the Miocene Zone N8 (notation after Blow, 1969). The sinistrality persisted until the extinction of the taxon at the end of the Middle Miocene (Winter and Pearson, 2001). In the studied Paratethys sediments, *J. mayeri* specimens are sinistrally coiled and abundant within the IIA biozone. They disappear at the base of the IIB biozone (Tables 1, 2 and Fig. 2). As *Orbulina suturalis* is present, thus the studied sediments can be not older than N9 (notation after Blow, 1969). The stratigraphic range of *J. mayeri* with sinistral coiling in the Upper Silesia Basin is consistent with data from Winter and Pearson (2001). *Jenkinsella mayeri* specimens show average percentages of ~9% (max. 28.8%) within the IIA biozone, which has been used as this taxon acme within the CPN 7 (Table 1). This Paratethyan interval correlates well with N9 sinistrally coiled *J. siakensis* acme A$_b$ in the Mediterranean sediments (Abdul Aziz et al., 2008; Hüsing et al., 2010). According to Hilgen et al. (2009), this acme ends at the top of N9; however, the data on coiling mode has not been provided so far. The A$_b$ *Paragloborotalia* (*J.*) *siakensis* is shown also by Foresi et al. (2011) in the Langhian GSSP, but the specimens are randomly coiled therein, without exact counts of coiling directions.

Based on the resemblance of morphology, *Globoconella bykovae* can be considered as the morphotypes of either *Fohsella peripheroronda* or *Globorotalia praescitula* (Gonera, 2013). Both are globally known taxa and common components of the Mediterranean Middle Miocene planktonic foraminiferal assemblage (Iaccarino, 1985). In the studied material, *Globoconella bykovae* specimens are proportionally coiled up to the IID^3 influx – only in this exceptional event the specimens display a strong bias to sinistrality (Fig. 2 and Table 2). Within the fohsellids, the proportions of coiling direction have been documented from their appearance during early phylogeny, from long-ranging *Fohsella peripheroronda* to *F. peripheroacuta*, all with strong preference for sinistral coiling (Bolli, 1950). This bias to sinistrality in fohsellids was raised by Eisenach and Kelly (2006) in the Serravalian M8 biozone (notation after Berggren et al., 1995). The fohsellids younger than *Fohsella peripheroronda* are not displayed in the Mediterranean Miocene (Cita and Blow, 1969; Iaccarino, 1985; Hilgen et al., 2009; Foresi et al., 2011). The presence of *Fohsella* cf. *peripheroacuta* is mentioned by Lirer and Iaccarino (2005), yet with no coiling data. In the Paratethys, *F. peripheroacuta* is shown by Rögl (1985) as a Wielician globorotaliid, but data on coiling direction is not given. Another possibility is that *G. bykovae* specimens of the studied Paratethys sediments are morphotypes of *Globorotalia praescitula*. The proportionally coiled *Globoconella bykovae* specimens display the same coiling mode as *Globorotalia praescitula* described from the Mediterranean Langhian by Foresi et al. (2011). Sinistrally coiled *Globoconella bykovae* (IID^3 event) cannot be compared to the Mediterranean globorotaliids at present, as the lack of advanced data on coiling mode of the Mediterranean *F. peripheroronda* and *G. praescitula*. Because of the current lack of data, the documented coiling patterns in the study area (basinal part of the Carpathian Foredeep in the Upper Silesia Basin) cannot to be compared to that in other areas of the Paratethys.

The specimens of *J. transsylvanica* and *G. minoritesta* demonstrate morphological resemblance to well-known globorotaliids: *Globorotalia challengeri* Srinivasan and Kennett 1982 and *Globorotalia miotumida* Jenkins 1960, respectively. Until now, there have been no systematic studies on the coiling preferences, just occasionally mentioned in the literature (e.g., Scott et al., 1990). As in the Mediterranean Miocene sediments, none of the mentioned Paratethyan taxa has been shown. Therefore, until an advanced study on the taxonomy of these taxa is written, the comparison of coiling to global data in the present work has its limitations. However, the mentioned Paratethyan globorotaliids confirm Bolli's (1971) opinion on a proportional coiling pattern at the initial stage of phylogeny of the species at its stratigraphic appearance.

GLOBOROTALIID COILING PREFERENCES *VERSUS* BASIN HYDROGRAPHY INDICES

Quantitative data on the hydrographic indices of the analysed samples within the studied Badenian are displayed in Table 3. The number of samples used to evaluate hydrography overcomes by ~28% these used to globorotaliid coiling counts (compare the data in Tables 2 and 3).

Sinistrally coiled *Jenkinsella mayeri* (*J. mayeri*^{SINI}) occurs in the studied sediments within biozone IIA. The specimens disappear at the base of biozone IIB, and they do not occur in the

Table 3

Hydrographic indices (average and standard deviation) of the sub-evaporite Badenian biozones

Biozone	P/B ratio			Percentage of symbiont bearing globigerinina				Percentage of globorotaliids	
				Cool-water *		Warm-water **			
IID [30]	**35.7 ± 31.3** [22]	IID^3	**23.1 ±12.3** [3]	**99.4 ± 1.7** [22]	**52.5 ±26.7** [3]	**1.9 ± 2.7** [3]	**7.1 ±1.7** [2]	**0.3 ± 0.1** [2]	**40.4 ±27.2** [3]
		IID^2	**29.0 ±13.0** [2]		**73.5 ±15.9** [2]		**5.4 ±4.7** [2]		**21.2 ±20.6** [2]
		IID^1	**36.0 ±15.9** [3]		**43.4 ±40.2** [3]		**46.8 ±35.2** [3]		**6.5 ±4.5** [3]
IIC [12]	**61.7 ±29.4** [12]			**97.0 ±3.9** [12]		**3.3 ±4.0** [7]		**0.0** [12]	
IIβ [38]	**61.5 ±19.9** [38]			**25.3 ±28.1** [37]		**36.0 ±25.0** [37]		**37.4 ±25.9** [37]	
IIB [33]	**66.7 ±12.6** [33]			**15.6 ±15.7** [33]		**27.6 ±15.8** [32]		**49.0 ±22.5** [33]	
IIA [60]	**54.2 ±12.5** [60]			**28.4 ±18.3** [59]		**25.4 ±16.5** [60]		**41.9 ±25.2** [60]	

In the bracket – number of samples considered for particular biozones; * – means Globigerina bulloides and *Turborotalita quinqueloba*; ** – means *Globoquadrina altispira, Globigerinoides quadrilobatus* and *Orbulina suturalis*

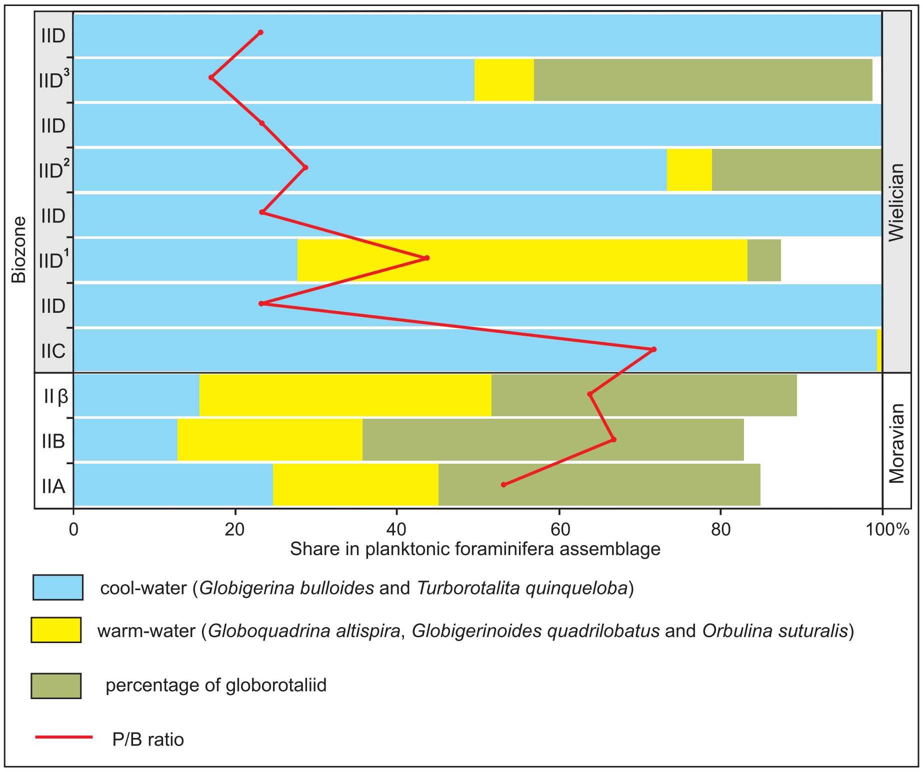


Fig. 3. Planktonic foraminifera eco-groups vs. P/B ratio (median) of the sub-evaporite Badenian in the study area

1 – cool-water (*Globigerina bulloides* and *Turborotalita quinqueloba*), 2 – warm-water (*Globoquadrina altispira*, *Globigerinoides quadrilobatus* and *Orbulina suturalis*), 3 – percentage of globorotaliids, 4 – P/B ratio

upper part of the Skawina Fm. (Gonera, 2013). At the IIA/IIB boundary, the P/B ratio increases by ~14% (Fig. 3), while the percentage of warm-water planktonic forms in the plankton foraminiferal assemblage remains similar (only ~3% increase). These two biozones show a faunal shift regarding the decrease of cool-water taxa (~12%) and an increase of globorotaliids (~8%). This results in a relative decrease of *Globigerina bulloides* and *Turborotalita quinqueloba* percentage in planktonic foraminiferal assemblage, while the percentage of deepest-dwelling globorotaliid planktonic forms increases.

The change at the IIA/IIB boundary is very pronounced regarding oxygen and carbon stable isotopes (Table 4). There is a δ^{18}O increase in both benthic and planktonic foraminifers and a simultaneous decrease in $\Delta\,\delta^{18}$O between pelagic and bottom dwellers in the basin (Fig. 4). The palaeoenvironmental change at the IIA/IIB boundary has been already inferred by Gonera (2013) as the imprint of the mid-Moravian cryptic cooling in the study area. At the IIA/IIB boundary, δ^{13}C shows a remarkable shift (Fig. 4). There is a slight decrease in δ^{13}C within benthic foraminifera tests and a pronounced increase within planktonic foraminifera tests (~0.05 and ~0.41‰, respectively). Particularly pronounced is the $\Delta\,\delta^{13}$C of the IIB biozone comparing to that of the IIA biozone (0.76 and 0.30‰, respectively). These measurements allow assuming that nutrients supply increased and the productivity intensified due to IIB cooling, thus phytoplankton drained isotopically lighter carbon causing ^{13}C uplift in planktonic foraminifera tests. The process was very intense, as inferred based on the comparison of *Globigerina bulloides* ^{13}C contents between the biozones of IIA and IIB. The decay of phytodetritus at the sea floor enhanced the bottom waters in ^{12}C. Due to the incorporation of the lighter carbon, the *Uvigerina* tests were richer in ^{12}C than the uvigerinas of the IIA biozone (Fig. 5). Biozone IIB displays a significantly different state of the considered hydrographic indices compared to those of biozone IIA. These new conditions eliminated *J. mayeri* $^{\mathrm{SINI}}$ from the environment.

The IIB sediments contain another *Jenkinsella* species. It is proportionally coiled *J. transsylvanica* (*J. transsylvanica* $^{\mathrm{PROP}}$). The favourable habitat conditions of this period induced an acme of the morphospecies. Upward, within the IIβ biozone, strong reduction in the *J. transsylvanica* content (still proportionally coiled) occurs. In this youngest biozone of the Moravian substage (CPN 7) there is a slight drop in the P/B ratio compared to the previous IIB biozone (Fig. 3 and Table 3). While the percentages of cool-water taxa remain similar (only ~3% increase) these two biozones differ as regards warm-water ones (~13% increase) and the globorotaliid content (~10% decrease). At the first sight, these foraminiferal indices of the IIβ and IIA biozones are similar, but there is a pronounced difference in the oxygen and carbon stable isotope values. The δ^{18}O is 0.72‰ higher in planktonic foraminifers and 0.9‰ higher in *Uvigerina*. Thus, the basin temperature during the IIβ biozone was much cooler than during IIA. On the other hand, the surface temperature of IIβ was warmer than of IIB, but the bottom temperature was even cooler than of IIB (Fig. 5). Dissimilarity between IIA and IIβ is also observed as regards δ^{13}C. During the final Moravian biozone (IIβ), δ^{13}C in both bottom and pelagic waters was higher than during IIA: 0.09 and 0.56‰, respectively (Fig. 5). Both IIβ planktonic and benthic tests incorporate the carbon reached in ^{13}C. The change to these warmer and nutrient-poor pelagic waters was the feature discriminating *J. transsylvanica* $^{\mathrm{PROP}}$ from the basin, as only low amounts are still present in some IIβ samples. As globorotaliids, this taxon retreated from the studied sediments due to the definitive disappearance of the Moravian biotope at the base of the Wielician IIC biozone in the study area of the Paratethys (Alexandrowicz, 1963; Gonera, 2001).

Globoconella bykovae is a relatively common and long-lasting globorotaliid in the study area. The taxon is proportionally coiled at the beginning of biozone IIA and persists in this coiling pattern during the Moravian biozones. This coiling pattern was kept unchanged in spite of the changes in basin hydrography indices, even when the number of taxon's individuals is low and tentatively diminishes during biozone IIB. As all the globorotaliids, *G. bykovae* disappears in the Wielician biozones, except for a single specimen in the studied samples. At the beginning of the Wielician, the continuous presence of globorotaliids in the sediment ended. After the Moravian/Wielician boundary, there were solely episodic influxes of waters carrying globorotaliids into the study area. These influxes carried only globoconellas.

Table 4

Isotopic composition of planktonic (*Globigerina bulloides*) and benthic (*Uvigerina* spp.) foraminifera (mean value and standard deviation) in the sub-evaporite Badenian (database after Gonera and Bukowski, 2012)

BIOZONE [+]	δ^{18}O [‰ V-PDB]		δ^{13}C [‰ V-PDB]	
	Uvigerina spp. [*]	*Globigerina bulloides* [*]	*Uvigerina* spp. [*]	*Globigerina bulloides* [*]
IID [8]	2.50 ±0.27 [8] IID^3 No data IID^2 No data IID^1 1.35 ±0.04 [2]	1.86 ± 0.21 [5] IID^3 No data IID^2 No data IID^1 –0.28 ±0.64 [2]	?0.58 ±0.36 [8] IID^3 No data IID^2 No data IID^1 0.18 ±0.20 [2]	0.15 ±0.22 [5] IID^3 No data IID^2 No data IID^1 0.46 ±0.01 [2]
IIC [8]	2.60 ± 0.19 [7]	2.00 ± 0.22 [7]	0.07 ± 0.14 [7]	0.64 ± 0.37 [7]
IIβ [13]	1.64 ± 0.35 [11]	0.16 ± 0.88 [10]	0.09 ± 0.17 [11]	0.58 ± 0.44 [10]
IIB [11]	1.41 ± 0.27 [11]	0.32 ± 0.54 [9]	–0.06 ± 0.13 [11]	0.71 ± 0.41 [9]
IIA [15]	0.92 ± 0.19 [14]	–0.58 ± 0.31 [9]	0.08 ± 0.34 [14]	0.43 ± 0.26 [9]

[+] number of rock samples analysed in regard to oxygen and carbon stable isotopes, [*] number of δ^{18}O and δ^{13}C data

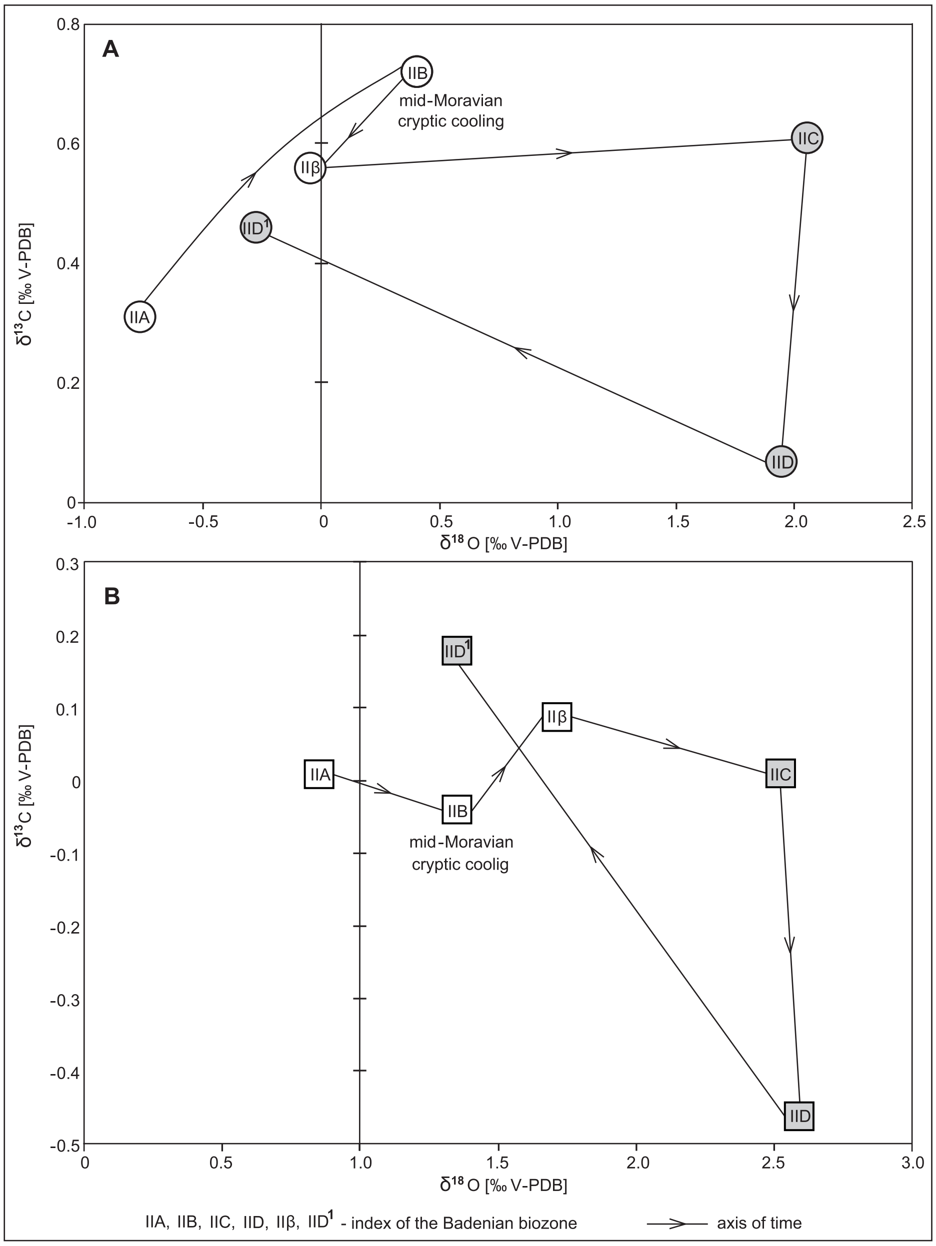


Fig. 4. Foraminiferal oxygen vs. carbon stable isotope values (median) of the sub-evaporite Badenian

A – plot of *Globigerina bulloides* (planktonic); **B** – plot of *Uvigerina* spp. (benthic); for more data see Table 4

The hydrographic features, which eliminated the globorotaliids, are described below.

The P/B ratio slightly increased at the IIβ/IIC boundary and, simultaneously, the polytypic (rich in taxa) planktonic foraminiferal assemblage has been substituted by a monotypic (poor in taxa) population. A bloom of cool-water *Globigerina bulloides* (Table 3 and Fig. 3) can be reconstructed. The IIβ/IIC boundary is very pronounced in regard to the oxygen stable isotope (Table 4 and Fig. 4). There is a δ^{18}O increase in both planktonic and benthic foraminifera: 2.1 and 0.8‰, respectively (Fig. 5). Noteworthy is the continuous increase in δ^{18}O throughout the Moravian. Nevertheless, in pelagic realms the decrease happened in the warmer interval of the IIβ biozone (Fig. 5). Strong cooling is reflected in the pelagic assemblage of biozone IIC, and, combined with decreasing $\Delta\delta^{18}$O, must be the result of strong shallowing of the basin. This newly established shallower depth caused disappearance of globorotaliids from the environment. In the IIC biozone, the δ^{13}C increased in *Globigerina bulloides* tests and slightly decreased in *Uvigerina*s. These δ^{13}C contents in the IIC and IIB biozones are slightly similar regarding $\Delta\delta^{13}$C: 0.6‰ in IIC and 0.76‰ in IIB (Fig. 5). The causes of such δ^{13}C content were the same as in the IIB interval, although they are pronounced stronger within the IIC biozone. The water column during IIC was much cooler, poorly stratified and shallower than any time before, thus the globorotaliids lost their habitat in the study area.

These circumstances sustained also during the younger Wielician (IID) biozone. The percentage of planktonic speci-

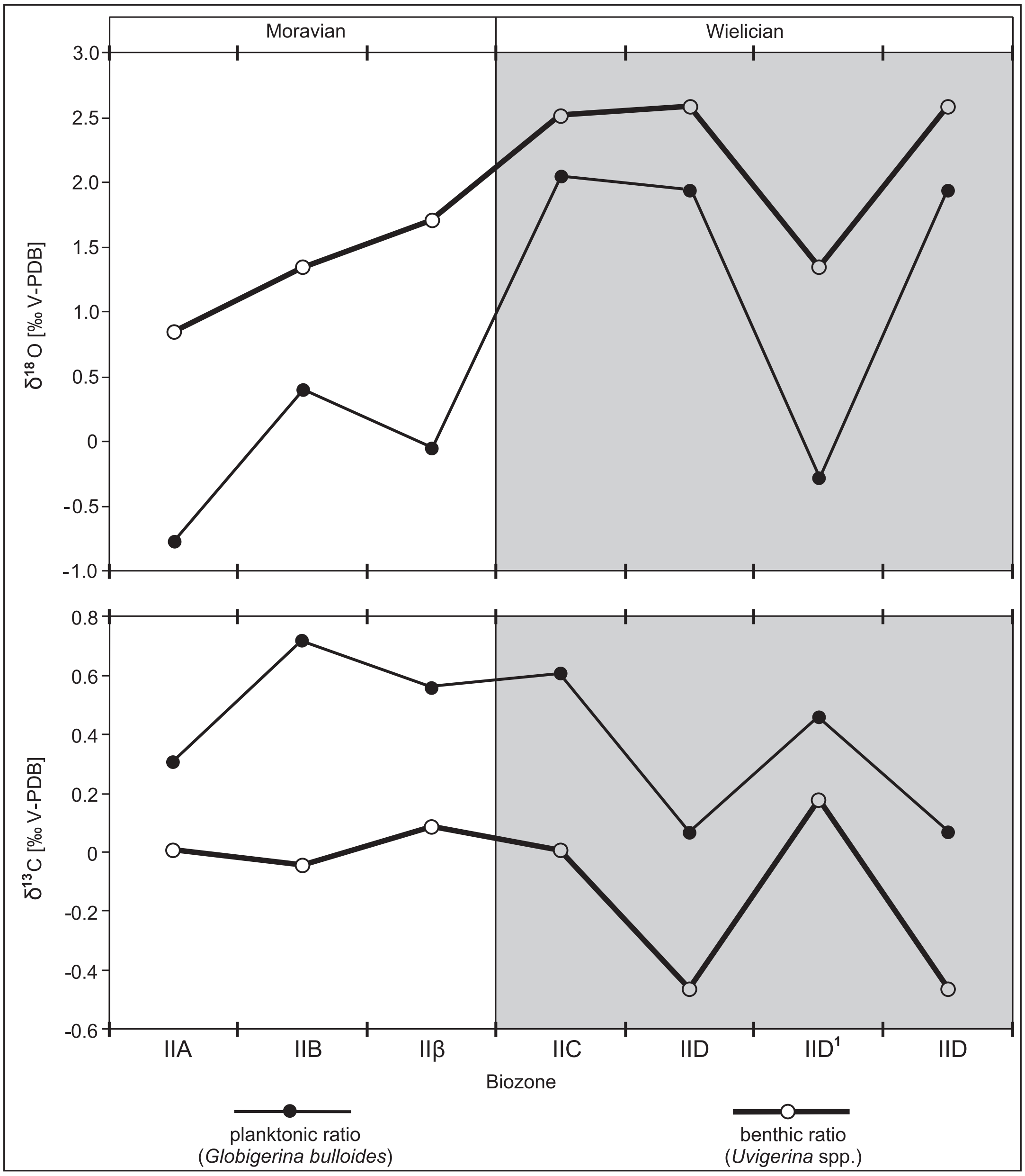


Fig. 5. Foraminiferal surface vs. bottom oxygen and carbon stable isotope range (median) calculated for the sub-evaporite Badenian

For more data see Table 5

mens in the foraminiferal assemblage diminished considerably, albeit there were the same cool-water taxa (Fig. 3 and Table 3). Thermal stratification of the water column, as can be referred based on δ^{18}O, remained similar to that of the IIC biozone (Fig. 4 and Table 4). Yet, the conspicuous change is in the ^{13}C content. The IID biozone is distinguished by a low content of ^{13}C, as noted below (Fig. 5). The drop was 0.5‰ both in planktonic and in benthic foraminifers. The δ^{13}C attains the lowermost values within the sub-evaporite Badenian: 0.07 and –0.46‰, respectively (Fig. 5). It is characteristic that this drop in stable isotope values was observable both in the pelagic and benthic organisms of the basin. This is a fundamental difference between the previous biozones (IIB and IIC) showing a δ^{13}C decrease only in the bottom waters, coupled with a δ^{13}C increase in the surface water. The drop of δ^{13}C within the whole water column during the IID was supposedly caused by the cessation of ^{12}C capture by phytoplankton. The above-discussed hydrography during the IID interval was interrupted by three influxes of fully marine waters from outside of the basin, always globorotaliid-bearing. The *Globoconella bykovae* species is present in two of these influxes: IID^1 and IID^3 (Fig. 3 and Table 3).

During the first influx (IID^1) the P/B ratio is doubled compared to the non-flux IID period (Fig. 3 and Table 3). Warm-water taxa (*Globoquadrina*, *Globigerinoides*, *Orbulina*, *and Globigerinella*) account for 56% of the planktonic foraminiferal assemblage. Globorotaliids make up only a small proportion of the planktonic foraminifera with proportionally coiled *Globoconella bykovae*. The oxygen and carbon stable isotope data are scarce for zone IID^1. Nevertheless, a difference between IID and IID^1 is remarkable in both stable isotopes (Fig. 4 and Table 4). During this influx the $\Delta\delta^{18}O$ value is higher (1.63‰) compared to that of IID (0.63‰), indicating a considerable increase in thermal stratification of the water column. The difference is also in the $\delta^{13}C$ content – it is much higher in IID^1 than in IID (Fig. 4 and Table 4). Noteworthy is that the $\delta^{13}C$ increase is observable in both planktonic and benthic foraminifers (Fig. 5). This $\delta^{13}C$ increase in the entire IID^1 water column could be due to the return of $\delta^{12}C$ capture by phytoplankton.

The *Globoconella bykovae* coiling is proportional in both IID^1 influx and the IIβ biozone samples. Among the globorotaliids of IID^1 the *J. transsylvanica* tests are rare, like in the IIβ biozone. These two differ in the P/B ratio, in spite of the similar set of warm-water symbiont-bearing planktonic foraminifera (Gonera, 2001). The difference between IID^1 and IIβ samples (Gliwice 19, 173.5 m; Pławniowice 1, 130 m and 133 m) is in the $\delta^{18}O$ and $\delta^{13}C$ contents; nevertheless, these data are scarce within IID^1 (Table 4; Figs. 4 and 5).

The samples of the second *Globoconella bykovae*-bearing influx contain sinistrally coiled specimens. The P/B ratio of this influx is the lowermost among all the deposits studied (Fig. 3 and Table 3). This scanty planktonic assemblage is dominated by cool-water symbiont-bearing globigerinas (*G. bulloides*, *G. quinqueloba*) and *Globoconella bykovae* $^{\mathrm{SINI}}$. The assemblage comprises only single specimens of warm-water planktonic foraminifera: *Globigerinoides* and *Orbulina*. Apparently, the planktonic foraminiferal assemblages are less diverse than those recognized within the lower parts of the sub-evaporite Badenian. Unfortunately, there is no stable isotope data providing information on the hydrographic conditions of this event. *Globoconella bykovae* persisted proportionally coiled during the Moravian and sub-evaporitic Wielician and changed the coiling pattern to sinistral within this particular influx.

Before the *Globoconella bykovae* $^{\mathrm{SINI}}$-bearing influx, there has been proportionally coiled *Globoconella minoritesta* (*G. minoritesta* $^{\mathrm{PROP}}$) discovered within the IID^2 influx (Fig. 2 and Table 2). The P/B ratio of this influx is ~29% (Fig. 3 and Table 3). Cool-water symbiont-bearing taxa dominate in the planktonic foraminiferal assemblage (74%). *Globoconella minoritesta* $^{\mathrm{PROP}}$ is the only and common globorotaliid herein (~21%). Warm-water planktonic foraminifera (*Globigerinoides* and *Orbulina*) are rare in the assemblage. It is essential to mention here that before this particular influx, termed IID^2, *Globoconella minoritesta* specimens do not occur in the older Badenian sediments (Appendix 1).

THE GLOBOROTALIID DATA *VERSUS* THE ADJACENT SEAS OF THE PARATETHYS

The three discovered influxes carrying outer marine water into the IID basin brought different globorotaliid species, as detected in some of the studied boreholes. In one of them (Gliwice 19) the depth distance between the IID^1 and IID^2 influxes is merely 1.5 m, thus the thickness of globorotaliid-bearing sediments must be rather thin compared to the Moravian globorotaliid levels (intervals). Thus, sampling density seems to be the pivotal factor to reveal the presence of the influxes. In the studied boreholes, the sampling interval in the Wielician deposits of the Skawina Fm. varies from 1.3 m (Gliwice 24) to 17.0 m (Pilchowice 10) and is 4.7 ±1.9 m in the remaining boreholes. This sampling coverage seems insufficient to find out a complete set of the influxes within particular sections (boreholes). The discovered globorotaliid events of the sub-evaporite Wielician seems to be a promising tool in high-resolution stratigraphy to position the Wielician evaporites in particular areas and to map this salinity crisis (Peryt, 2006).

In the studied material, the gypsum deposits of the Krzyżanowice Fm. are located either above IID^1 (Pławniowice 1 borehole) or above IID^2 (Bielszowice 7 and Gliwice 19 boreholes). The third influx (IID^3) precedes the Krzyżanowice Fm. deposits in the Sumina and Żory 4 boreholes. It is present in one of the Breccia Member salt xenoliths of the Wieliczka halite deposit (sample no. 47 in Gonera et al., 2014). This youngest influx (IID^3) is located within the halite sedimentation area of the Carpathian Foredeep Wielician (Wieliczka Formation), delineated by Garlicki (1979) and Bukowski (2011). Thus, the halite sedimentation areas sustained longer under the terrigenous part of the Skawina Formation – it was up to the third globorotaliid influx. In halite-free areas, the Skawina Formation sedimentation terminated earlier, not persisting so long as in the halite sedimentation areas. The submitted globorotaliid data can serve as an indirect evidence on the not isochronous deposition of the Wielician salinity crisis facies. In the study area, it implies that the boundary of the Skawina and Krzyżanowice Fm. is diachronous.

The Wielician globorotaliid events preceded the evaporite formation in the basinal part of the Polish Carpathian Foredeep Basin (this paper). In the coastal part of the basin, these events has been either absent (Gonera and Kulka, 1979; Peryt, 2013) or detected in one of the boreholes, but no data on coiling has been given (Łuczkowska, 1964).

The *Globoconella bykovae* and *Jenkinsella mayeri* globorotaliid interval of the Upper Silesia Basin (IIA biozone) is coeval to the Židlahovice parastratotype section described by Holcová and Demeny (2012) and Doláková et al. (2014). The globorotaliids younger than IIA biozone are barren in sediments of the Židlahovice boreholes. Described by Rupp and Hohenegger (2008), the globorotaliid association from the Badenian stratotype section is much similar to that of the IIβ biozone (i.e. the youngest globorotaliid level of the Moravian) and it followed the Badenian deposits considered by Doláková et al. (2014). The proposed *Globorotalia transsylvanica* Biozone (Filipescu and Filipescu, 2014–2015) is coeval with the IIB – at least as regards the dominant taxon. Examining the coiling pattern of *Globorotalia bykovae*, found by Báldi et al. (2017) below the Soltvadkert Trough evaporites of the Pannonian Basin, might be useful for intra-Paratethys stratigraphic correlation. In relation to the Wielician globorotaliid events described in this paper, the pivotal correlation aspect is the coiling preferences of the two globorotaliid peaks described by Kováčová and Hudáčková (2009) within the CPN 8 in the Slovak part of the Vienna Basin. It appears necessary to make a common practice to examine the secondary features of planktonic foraminifera tests like the coiling preference in the case of globorotaliid tests. It is believed that, if coiling direction counts become routine in planktonic foraminifera analyses in the Paratethys, the collected data can serve as a base for a higher-resolution stratigraphy.

CALIBRATION OF THE STUDIED MATERIAL TO GLOBAL STRATIGRAPHY

The GSSP (Global Stratigraphy Section and Point) data are considered to achieve the calibration of the studied material to global stratigraphy. According to Fornaciari et al. (1997) the top of the Langhian historical stratotype coincides with the First Occurrence (FO) of *Orbulina universa* and the First Common Occurrence (FCO) of the nannoplankton *Helicosphera walbersdorfensis*. The morphospecies *Orbulina universa* is not mentioned from the Serravalian GSSP and no particular index taxon is recommended for this Point (Hilgen et al., 2009). In this stratotype section coccoliths *Sphenolithus hetereomorphus* Last (Common) Occurrence – L(C)O slightly postdates and *Helicosphera walbersdorfensis* (FCO) predates the Langhian/Serravalian boundary (Hilgen et al., 2009). Accordingly, the boundary is bracketed by these coccolith events within the Serravalian GSSP (Hilgen et al., 2009).

In the Paratethys, the youngest orbulinid is *Orbulina suturalis* (Cicha et al., 1998). Using the orbulinids datum index taxa (Blow, 1969) we are obliged to claim that the studied deposits are not younger than global Zone N9. After Lehotayova (1982), Dudziak and Łuczkowska (1991), Peryt et al. (1997), Peryt (1997), Chira (1999) and Garecka (2014), *Sphenolithus heteromorphus* specimens (without quantitative data) occur within the sub-evaporite Badenian. In the Upper Silesia Basin (Gliwice 17, Gliwice 19 and Gliwice 21 boreholes), *Helicosphera walbersdorfensis* is absent in the sub-evaporite Badenian (Peryt, 1997) or occurs only as single specimens east of the basin (Garecka, 2014). *Helicosphera walbersdorfensis* specimens occasionally occur within the Wielician gypsum deposits of the adjoining areas of the Upper Silesia Basin (Gaździcka, 1994; Peryt et al., 1997). Apparently, there are no calcareous index taxa (orbulinids, *H. walbersdorfensis* FCO) to tie the studied globorotaliid events to the global stratigraphy. Nevertheless, the (bio)stratigraphic events correlated to the Middle Miocene climate changes can be used to calibrate the discovered coiling preferences of the Paratethyan globorotaliid and globorotaliid intervals to the global stratigraphy. The references on *Globigerina quinqueloba, Paragloborotalia siakensis*, stable isotopes and radiometric data are here applied as the guiding tool to perform this stratigraphic calibration.

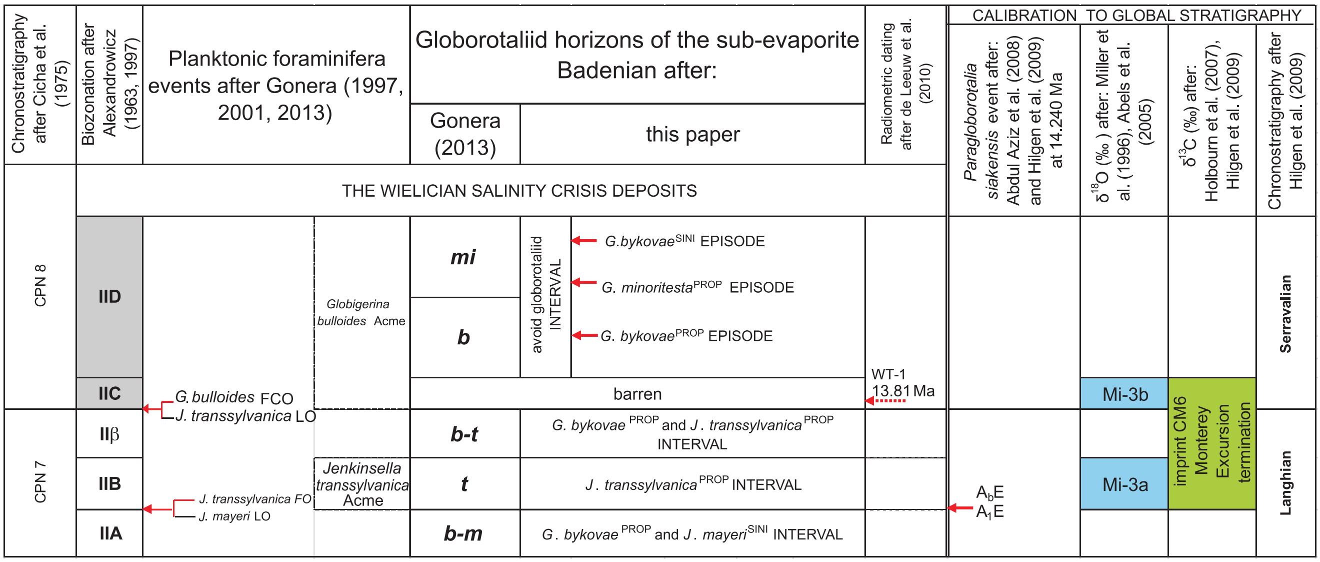
The *Globigerina* cf. *quinqueloba* Acme End (AE) discovered within the Blue Clay Formation ~0.5 m above the Serravalian GSSP is dated at 13.74 Ma by Hilgen et al. (2009). In the studied Paratethyan deposits, the *Globigerina quinqueloba* first common occurrence (acme) is recorded as early as biozone IIβ in three samples: 162.0 m in the Gliwice 24 borehole, and 310.0 and 300.0 m in the Sumina 2 borehole (Table 5). It accounts for 14, 30 and 39% of the planktonic foraminiferal assemblage, respectively. As stated above, the IIβ foraminiferal biozone represents an interval reflecting the disappearance of the Moravian ecosystem – a step-by-step elimination of taxa typical of the Moravian IIA and IIB assemblages (ecozones), before the new Wielician ecosystem assemblages of IIC and IID began. *Globigerina quinqueloba* is common in the IIC and IID assemblages of the Upper Silesia Basin (Gonera, 2001). In these deposits, *G. quinqueloba* with quantitatively significant peaks (up to 100%) interfingers with *Globigerina bulloides* (Gonera, 2001). This pattern of the taxa distribution continues up to the evaporitic layers and even above it, within the *Neobulimina longa* Zone deposits (Table 1; Alexandrowicz, 1963; Łuczkowska, 1964; Gonera, 2001). *Globigerina quinqueloba* AE, which is positioned either at the base of the evaporites or at the top of the *Neobulimina longa* biozone deposits, is within the Wielician according to Gonera (1997).

Considering the *Globigerina quinqueloba* Acme as coeval in the Mediterranean and Paratethys, the contrary appears in regard to *Globigerina quinqueloba* AE *versus Sphenolithus heteromorphus* L(C)O in these two basins. In the Serravalian GSSP, *Sphenolithus heteromorphus* L(C)O, dated by Hilgen et al. (2009) at 13.654 Ma, occurs after *G.* cf. *quinqueloba* AE (Hilgen et al., 2009). In the studied Paratethys area, the events happened in a reversed sequence: *G. quinqueloba* AE occurs after the *S. heteromorphus* last occurrence (Gonera, 1997; Peryt, 1997). There is an absolute age of 13.62 ±0.10 Ma available for the *Neobulimina longa* Zone deposits dated by the intercalated tuffite (Bukowski et al., 2010).

Application of the evolutionary datums of low-latitude fohsellids (Blow, 1969) or temperate-latitude globorotaliids (Berggren et al., 1995) in the Paratethys record is impossible. The obstacle is the Paratethyan globorotaliid taxonomy: *Globoconella bykovae*, *Globoconella minoritesta* and *Jenkinsella transsylvanica* under these names are essentially restricted to this area. The only exception is *Jenkinsella mayeri*,

Table 5

Calibration of the globorotaliids (intervals, events, coiling patterns) to the global stratigraphy data



Chronostratigraphy after Cicha et al. (1975)	Biozonation after Alexandrowicz (1963, 1997)	Planktonic foraminifera events after Gonera (1997, 2001, 2013)		Globorotaliid horizons of the sub-evaporite Badenian after: Gonera (2013)	Globorotaliid horizons of the sub-evaporite Badenian after: this paper		Radiometric dating after de Leeuw et al. (2010)	CALIBRATION TO GLOBAL STRATIGRAPHY: *Paragloborotalia siakensis* event after: Abdul Aziz et al. (2008) and Hilgen et al. (2009) at 14.240 Ma	$\delta^{18}O$ (‰) after: Miller et al. (1996), Abels et al. (2005)	$\delta^{13}C$ (‰) after: Holbourn et al. (2007), Hilgen et al. (2009)	Chronostratigraphy after Hilgen et al. (2009)
CPN 8	THE WIELICIAN SALINITY CRISIS DEPOSITS										
	IID		*Globigerina bulloides* Acme	***mi***	avoid globorotaliid INTERVAL	*G.bykovae*^{SINI} EPISODE *G. minoritesta*^{PROP} EPISODE					Serravalian
				b		*G. bykovae*^{PROP} EPISODE					
	IIC	*G. bulloides* FCO *J. transsylvanica* LO		barren			WT-1 13.81 Ma		Mi-3b	imprint CM6 Monterey Excursion termination	
CPN 7	IIβ			***b-t***	*G. bykovae*^{PROP} and *J. transsylvanica*^{PROP} INTERVAL						Langhian
	IIB	*J. transsylvanica* FO *J. mayeri* LO	*Jenkinsella transsylvanica* Acme	***t***	*J. transsylvanica*^{PROP} INTERVAL			A_bE A_1E	Mi-3a		
	IIA			***b-m***	*G. bykovae*^{PROP} and *J. mayeri*^{SINI} INTERVAL						

discussed by Gonera (2013), as a global-range taxon assigned to the Paratethyan Miocene. Here, Bolli and Saunders (1982) are followed in the resolution that *Paragloborotalia siakensis* is a junior synonym of *Jenkinsella mayeri*. The taxon coiling is proportional until N8, and then becomes sinistrally coiled up to its Middle Miocene extinction (Nagappa, 1957; Bolli and Saunders, 1985; Winter and Pearson, 2001). Abundant and sinistrally coiled *J. mayeri* within the Paratethys IIA biozone retreats at the top of this biozone (Fig. 2 and Table 2). The *J. mayeri* AE at the top of biozone IIA is prominent and the correlation of this event to the Mediterranean records is an important achievement.

The *Paragloborotalia siakensis* acmes have been recorded in many sections of the Mediterranean Miocene, but the events are not indexed in the unified manner (cf. Abdul Aziz et al., 2008; Hilgen et al., 2009). The *Paragloborotalia siakensis* A$_1$E locates within the Langhian part of the Serravalian GSSP section and has been dated at 14.250 Ma (Hilgen et al., 2009). This is dated by Abdul Aziz et al. (2008) at 14.240 Ma (A$_b$E) and is coeval with the Mi-3a cooling event. In the study area, the retreat of *Jenkinsella mayeri* ^{SINI} is followed by *J. transsylvanica* ^{PROP} AB (Acme Beginning). This *J. transsylvanica* interval (IIB biozone) has been discovered as a cryptic cooling period based on the isotopic data of the studied sections (Gonera, 2013). Thus, there is a correspondence between the Paratethyan sinistral *J. mayeri* Acme End at the onset of the IIB biozone cryptic cooling and the Mediterranean *Paragloborotalia siakensis* A$_1$E at the Mi-3a cooling. The Paratethyan sinistral *J. mayeri* of the IIA biozone correlates well with the Mediterranean sinistrally coiled *J. siakensis* bioevent A$_1$E alias A$_b$E. The *J. transsylvanica* FO, immediately followed by its acme, is coeval with the onset of the Moravian cryptic cooling interval (IIB biozone) in the studied material. The *J. transsylvanica* displays proportional coiling during this period (Table 2 and Fig. 2). Thus, both acmes of the Paratethyan (IIA biozone) sinistrally coiled *J. mayeri* and the Mediterranean *J. siakensis* A$_b$ end with the onset of the Mi-3a phase of the climate cooling dated by Hilgen et al. (2009) at 14.250 Ma, i.e. at the end of biozone N9.

Holbourn et al. (2007) also found higher δ^{18}O values in the interval from 14.229 to 14.071 Ma. This is consistent with the Paratethys isotopic record: the IIB biozone displays cooler conditions compared to the IIA interval. The cryptic cooling interval in the Paratethys (IIB biozone) is followed by isotopically recorded (*Globigerina bulloides* δ^{18}O) warming of the IIβ biozone (Gonera, 2013). In the same section, Holbourn et al. (2007) demonstrated a warming recorded by δ^{18}O between 14.025 and 13.874 Ma, i.e. until the end of the Langhian. The Paratethyan IIβ biozone may correlate with this warming.

The IIC biozone displays cooling in both isotopic and foraminifera data (Durakiewicz et al., 1997; Gonera et al., 2000; Gonera, 2001; Gonera and Bukowski, 2012). This climate cooling at the beginning of the Wielician was formerly named Mi3 Event (Gonera, 2001; Bicchi et al., 2003). Considering the new developments in the area, it should be dated at the Mi-3b Event and coeval with the beginning of the Serravalian. This cooling is recorded upward continuously in the Wielician deposits, and interrupted by three globorotaliid influxes bringing some of the warm-water symbiont-bearing planktonic foraminifers into the basin (Fig. 3 and Table 3). These planktonic foraminifera are most numerous in IID^1 and scarcer in the remaining two influxes (IID^2 and IID^3). Unfortunately, the oxygen and carbon stable isotope measurements of these influxes are non-systematic and sporadic, but they indicate the δ^{18}O content lower than in the IID background samples (Fig. 4 and Table 4). The three warmer swings above Mi-3b had been also recorded by Holbourn et al. (2007) and dated at 13.705, 13.620 and 13.500 Ma, respectively. The remarkable correlation of these global events with the herein presented Paratethys globorotaliid influxes (IID^1, IID^2 and IID^3) cannot be ignored. The Paratethyan globorotaliid species associated with these three influxes are *Globoconella bykovae* ^{PROP}, *Globoconella minoritesta* ^{PROP} and *Globoconella bykovae* ^{SINI}.

The Serravalian GSSP is located by Hilgen et al. (2009) at the E3 alias Mi-3b Event of the δ^{18}O record (Woodruff and Savin, 1991; Miller at al., 1991; Flower and Kennett, 1994; Abels et al., 2005). The strong swing to δ^{18}O positive values at this Event is regarded as the termination of the Middle Miocene Climate Transition. This is the CM6 Event of the δ^{13}C record and means the isotope maximum at the end of the Monterey carbon isotopic excursion (Miller et al., 1991; Jacobs et al., 1996). At the Serravalian GSSP, astronomically dated at 13.82 Ma, the oxygen and carbon isotope records reveal shifts to heavier values as the signatures E3 alias Mi-3b and CM6, respectively (Hilgen et al., 2009).

In the basinal part of the Polish Carpathian Foredeep, the tuffite layer named WT-1 is radiometrically dated at 13.81 ±0.08 Ma (de Leeuw et al., 2010). On the other hand, Dudziak and Łuczkowska (1991) stated that this tuff layer (WT-1) is located within siliciclastics of biozone IIC, i.e. within the lowermost part of the *Uvigerina costai* Zone (Table 5). Based on these data, we have a good reason to date the beginning of the Wielician in the Polish part of the Carpathian Foredeep just before 13.81 ±0.08 Ma, which is coeval to the onset of the Ice House age (Mi-3b event) after Hilgen et al. (2009). Thus, the IIB cryptic cooling in this area should be correlated with the upper Langhian Mi-3a Event (Table 5). In the database presented in Gonera and Bukowski (2012) and reconsidered in this paper, the *Globigerina bulloides* δ^{13}C values of the IIB, IIβ and IIC biozones characterize the interval from Mi-3a to Mi-3b (Fig. 5). These highest δ^{13}C values embrace the Moravian/Wielician boundary in the studied material, displaying therein an imprint of the ending of the Monterey carbon isotope excursion.

The presented concept of the Langhian/Serravalian boundary within the Skawina Fm. is not discrepant with the Serravalian GSSP in regard to the *Sphenolithus heteromorphus* L(C)O and *Discoaster floridanus* LO resolutions after Hilgen et al. (2009). These index taxa are present in both the Moravian (biozones IIA, IIB and IIβ) and Wielician (IIC and IID biozones) sediments (Peryt, 1997). The range of *Sphenolithus heteromorphus* in the Upper Silesia Basin deposits justified the Serravalian GSSP positioning at the beginning of biozone IIC, i.e. at the base of the Wielician substage. The present paper supports and further confirms the opinion postulated by Rögl and Müller (1978), Łuczkowska (1998) and Hohenegger et al. (2014) on the Langhian/Serravalian boundary placed at the *Orbulina suturalis*/*Uvigerina costai* (alias Lagenidae/*Spiroplectammina*) Zone boundary in the Central Paratethys (Table 5). In the Polish part of the Paratethys, this boundary is found within the deposits of the Skawina Formation.

CONCLUSIONS

1. The Paratethyan *Jenkinsella transsylvanica* and *Globoconella minoritesta*, as the morphospecies appearing in the studied section, confirm Bolli's (1971) observation on the first exhibiting proportional coiling in early phylogeny of any taxa.

2. The considered indices of coiling patterns vs. hydrography demonstrate that sinistrally coiled *Jenkinsella mayeri* (*J. mayeri* $^{\mathrm{SINI}}$) is utterly sensitive to hydrographic changes. This is based on the observation that the taxon retreats from the basin when relatively warm pelagic waters became cooler at the IIA/IIB biozone boundary. On the other hand, proportionally coiled *Globoconella bykovae* (*G. bykovae* $^{\mathrm{PROP}}$) was found highly opportunistic to changing habitat conditions. This taxon showed proportional coiling throughout all the noticeable environmental changes through the Moravian and the sub-evaporite Wielician (IID^1), and altered its coiling pattern to sinistral within the warmer water influx (IID^3) just prior to the salinity crisis. Proportionally coiled *Jenkinsella transsylvanica* and *Globoconella minoritesta* are present under particular environmental circumstances (*J. transsylvanica* $^{\mathrm{PROP}}$ during the IIB interval; *G. minoritesta* $^{\mathrm{PROP}}$ during the IID^2 influx) and retreat as the favourable environmental conditions vanished.

3. The correlation of Serravalian GSSP with the Paratethys Moravian/Wielician boundary has been achieved by the discovered globorotaliid bioevents coupled with the Middle Miocene climate changes. According to the Paratethys biostratigraphy, this GSSP corresponds to the *Orbulina suturalis*/*Uvigerina costai* (alias Lagenidae/*Spiroplectammina*) Zone boundary. In the study area, this boundary is coeval with the IIβ/IIC biozone transition within the Skawina Fm.

4. The recognized globorotaliid events of IID^1, IID^2 and IID^3 interposing the sub-evaporite Wielician records are pivotal to resolve the dating of the Wielician evaporites within adjoining areas of the Paratethys: are they isochronous, or non-isochronous?

5. The beginning of the cryptic cooling biozone (IIB) corresponds to the disappearance of sinistrally coiled *Jenkinsella mayeri* and the appearance of proportionally coiled *J. transsylvanica*. The event is coeval with the *Paragloborotalia siakensis* A$_b$E of the Mediterranean Middle Miocene sections and termed as Mi-3a, one of the cooling events of the Middle Miocene Climate Transition period. The disappearance of globorotaliids at the IIβ/IIC biozone boundary corresponds to a pronounced drop of temperature due to the Mi-3b cooling event with the advance of the Middle Miocene Ice House period.

6. In the studied material, the highest ^{13}C content in *Globigerina bulloides* tests of the IIB, IIβ and IIC biozones brackets the Moravian-Wielician boundary (CPN 7/CPN 8). This sign is the imprint of the termination of the Monterey carbon isotopic excursion attributed to the global Langhian/Serravalian boundary.

7. The evidences on the globorotaliid coiling pattern, presented in this paper, make us hope to develop a commonly used method of stratigraphic correlation between any regions within the Paratethys or outside.

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