Globorotaliid intervals of the sub-evaporite Badenian (Middle Miocene) in the Upper Silesia Basin (Central Paratethys, Poland)

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Globorotaliids of the Skawina Formation (Badenian) come from deposits representing CPN 7 (*Orbulina suturalis* Zone) and CPN 8 sub-evaporite Wielician (*Globigerina druryi–G. decoraperta* Zone *alias Uvigerina costai* Zone) age. There are two taxonomic groups of globorotaliids in the studied material: globoconellids (*Globoconella bykovae* and *G. minoritesta*) and jenkinsellids (*Jenkinsella mayeri* and *J. transsylvanica*). There are five stratigraphically-rank intervals of these foraminifers prior to the Middle Badenian salinity crisis in Central Paratethys. The investigated Badenian begins with *G. bykovae–J. mayeri* association followed by the first occurence (FO) of *J. transsylvanica*. The closing member of the CPN 7 biozone is the *G. bykovae–J. transsylvanica* assemblage. The jenkinsellids disappear during CPN 7: *J. mayeri* first and *J. transsylvanica* after. Since the base of CPN 8 *in situ* jenkinsellids have not been noted in the Badenian deposits. The CPN 8 begins with a stratigraphic interval barren of globorotaliids (biozone IIC in the Polish Paratethys). It is followed by episodic appearances of globoconellids (*G. bykovae* and *G. minoritesta*) in the sub-evaporite Wielician (IID biozone in Poland). *G. minoritesta* has been found in only one case so far. The globorotaliid stratigraphic units are distinct and well-correlated with changes in climate and the circulation of water masses in Paratethys. This study provides additional data on Mi3 in Paratethys. It documents a cryptic cooling event in the late *Orbulina suturalis* Zone (mid CPN 7) located at the late IIA–B assemblage (*alias* upper lagenide zone) in regional biostratigraphic scale. The event is recorded by *J. transsylvanica* Acme, matching with circa 1‰VPDB δ^{18}O positive excursion. The event must have resulted in a considerable sea level drop – a trigger of the Moravian ecosystem demolition in the Paratethys environment.

Key words: Middle Miocene, Badenian, foraminifers, Globorotaliidae, Paratethys.

INTRODUCTION

Globorotaliids (Family Globorotaliidae Cushman, 1927) are trochospiral non-spinose planktonic foraminifera which appeared in the Paleocene (Loeblich and Tappan, 1988). Recent globorotaliids are deep-dwellers of the epipelagic zone (Bé, 1977; Hemleben et al., 1989) and show a wide latitudinal range: from subarctic to subantarctic regions. Living at a depth 100–200 m below sea surface the group is not as highly tuned to climate as the shallow-dwelling Globigerinina (e.g., *Globigerinoides*), nevertheless globorotallids display different relative abundances of particular species in respect of latitude.

Cenozoic globorotaliids evolved rapidly during the Cenozoic and their major radiation occurred in the Miocene (e.g., Kennett and Srinivasan, 1983). The family gave rise to many stratigraphic datums as the first and/or last appearance of selected members. Globorotaliids species are also used in global and regional biostratigraphic schemes for zone definitions (e.g., Iaccarino, 1985; Berggren et al., 1995).

The circum-Carpathian area was one of the marine Miocene basins located NE of the Neogene Mediterranean province. The area had been defined by Laskarev (1924) as Paratethys and categorized by Seneš (1959) as Central Paratethys (Fig. 1A). The Miocene marine deposits of this area are both coastal and basinal in origin (the summarising data in Steininger et al., 1985; Oszczypko et al., 2006); the latter of which contains a variety and abundance of planktonic foraminifera.

The globorotaliids appeared in the Paratethys during the Early Miocene Egerian (Cicha et al., 1998). The group was most fertile during the *Orbulina suturalis* Zone of Badenian – the interval of the largest marine expansion in the region (Fig. 2). The Carpathian Foredeep and the eastern part of the Intra-Carpathian Basin (comprising the Transcarpathian, Transylvanian and East Slovakian Neogene basins) were deep sea environments at that time. Environmental niches suitable to globorotaliids developed well in these parts of the Paratethys. Impoverished globorotaliids are present occasionally yet in the Late Badenian deposits and definitely are missing in the Sarmatian (Cicha et al., 1975, 1998).

Although the Badenian globorotaliids were described from numerous sites, sections and areas of the Paratethys, up to now the group has not been analysed as a biostratigraphic marker (neither as particular taxa nor as globorotaliid associations). The aim of this paper is to evaluate the biostratigraphic potential of the group.

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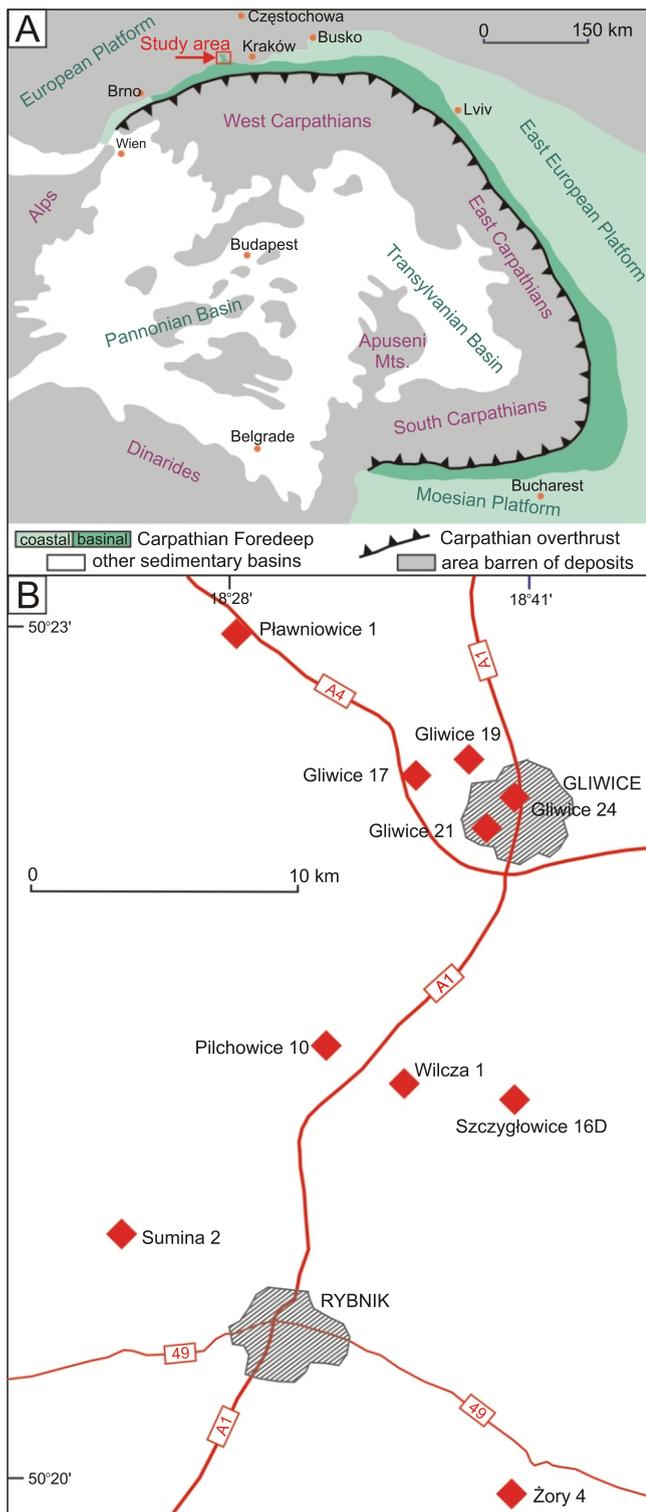
Fig. 1. Location map

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

GEOLOGICAL SETTING

The Upper Silesia Basin is located in a part of Paratethys between the Moravian type area to the west (vicinity of Brno) and the type areas of both the Wielician (near Kraków) and the Kosovian (Ukrainian Carpathian Foredeep, south of Lviv) situated to the east.

Carboniferous and Triassic units are the basement of the Miocene deposition of the Upper Silesia Basin. The thickness of the Miocene cover ranges here from about 60 to about 600 metres. The sedimentation began in the Karpatian when brackish and freshwater deposits of the Kłodnica Formation (Alexandrowicz, 1997) formed. These deposits occur in patches and reach up to 70 m in thickness. The Badenian starts with the marine sediments of the Skawina Formation (the Moravian and the sub-evaporite Wielician) attaining 161.5 m in thickness (mean value 66.0 m). Evaporites of Wielician age (Wieliczka and Krzyżanowice formations) occur in a large part of the Silesia Basin (Garlicki, 1979). They are 14.5–57.2 m thick (mean value 30.9 m). *In situ* foraminifers are absent in the evaporites. Marine deposits of normal salinity of the Kosovian substage are developed in the supra-evaporite Badenian (Gliwice Formation). This unit attains 343.3 m in thickness (mean value 120.3 m) but locally is lacking. Upwards in the Gliwice Fm. foraminifers successively become impoverished both in terms of number of taxa and quantity of specimens. Finally foraminifers disappear in the overlying Kędzierzyn Formation. The Skawina Fm. and Gliwice Fm. are characterized by considerable temporal changes in the taxonomic set of foraminifera (Alexandrowicz, 1963). Particular assemblages were defined as assemblage biozones (5 and 6 in Fig. 2). Palaeoecological methods applied to characterize these assemblages revealed that this foraminiferal stratigraphic succession formed in a response to considerable palaeoenvironmental changes (Gonera, 2001). These changes were so significant that taxonomic differences of the consecutive biozones are conspicuous. Due to the environmental changes, ongoing populations of foraminifera were subject to elimination by ecological selection. These constraints led to taxonomic substitutions and occurrence of a new assemblage (biozone) adapted to the new circumstances.

Climate and climate-driven circulation patterns of the palaeocurrents have been pointed to as the crucial environmental factors controlling the Badenian biozones (Gonera, 2001). The biozones used in this paper are the ecozones formed as foraminiferal response to the first-order factors. Two principal circulation patterns in the studied Paratethys Basin have been recognised: anti-estuarine followed by estuarine (Fig. 2). In the Miocene Upper Silesia Basin the Mi3 record has been initially recognized by foraminifera (Gonera, 2001; Bicchi et al., 2003) and foraminiferal δ^{18}O levels (Gonera et al., 2003) and has been recently confirmed by radiometric data (Leeuw et al., 2010).

Through foraminiferal palaeoecology it has been interpreted that the Wielician evaporite sedimentation ceased because of the climate amelioration, resulted in both air humidity and eustatic sea level increases (Gonera, 2001). The new pattern of circulation established as the result of activation of both continental runoff of freshwater and seawater influx due to eustatic level rise. The interaction between these two water masses were balanced by estuarine circulation patterns at the studied area. Unlike the sub-evaporite Badenian, the youngest marine sediments display rich siliceous plankton: radiolarians (Barwicz-Piskorz, 1997) and diatoms (Witkowski and Gonera, 1997).

Chronostratigraphy			Biozonation after: 1 – Cicha et al. (1975); 2 – Papp et al. (1978a); 3 – Rögl and Steininger (1984); 4 – Steininger et al. (1985); 5 – Alexandrowicz (1963, 1997); 6 – Łuczkowska (1964)				Major palaeoenvironmetal events (after Gonera, 2001)	
			1–4		5	6	Circulation	Climate
Badenian (Middle Miocene)	Kosovian	CPN 9	*Velapertina* Zone	*Bulimina–Bolivina* zone	IIIB	*Hanzawaia crassiseptata*	E4 (vigorous estuarine)	
	Wielician	CPN 8	*Globigerina druryi–G. decoraperta* Zone	zone with agglutinated foraminifera	IIIA	*Neobulimina longa*	E3 (sluggish estuarine)	
					Evaporite deposits			
					IID	*Uvigerina costai*	E2 (sluggish anti-estuarine)	Mi3
					IIC			
	Moravian	CPN 7	*Orbulina suturalis* Zone	Lagenidae zone	IIβ	*Orbulina suturalis*	E1 (vigorous anti-estuarine)	
					IIB			
					IIA			

Fig. 2. Central Paratethys stratigraphic units and location of the Skawina Formation studied samples (shadowed)

MATERIAL AND METHODS

Material for this study comes from fourteen boreholes analysed already with regard to planktonic and benthic foraminiferal palaeoecology (Gonera, 2001). These boreholes crossed the Skawina Fm. deposits from the beginning of the Badenian transgression up to the Wielician salinity crisis. *Orbulina suturalis* Zone (CPN 7) and *Globigerina druryi–G. decoraperta* Zone (CPN 8) sediments occur in each borehole except for the Gliwice 17 borehole where the CPN 8 deposits are lacking. The boreholes are located along N–S transect of the Upper Silesia Basin (Fig. 1B). The thickness of the studied Skawina Fm. deposits ranges from 27.3 m (Szczygłowice 16D) to 161.5 m (Pilchowice 10). Globorotaliids have been re-analysed in lithologically different deposits (Appendix 1). Most of them are marly clays but there is also a number of sandy marls and several samples of marly clays comprising rhodolith debris.

Globorotaliids are numerous in all CPN 7 samples (138 in total) whereas only four of the 33 CPN 8 samples contain globorotaliids tests in amounts exceeding 1% of planktonic foraminifera. Due to statistic procedure requirements (i.e. reliability level of the counting) only the samples with globorotaliid abundancy exceeding 1% of planktonic foraminifera have been selected for quantitative analysis. Altogether 118 such samples have been examined (Appendix 1).

The analyses of globorotaliids have been performed in the fraction 125–430 μm. Due to the statistical treatment of data as many as 324 (on the average) globorotaliid tests per sample have been taxonomically identified and quantified. The volume of the residuum in analysed samples had been from 0.5 to 1.0 cm³.

RESULTS

TAXONOMY

Two globorotaliids subsets (genera) have been recognized in the studied sediments: *Globoconella* and *Jenkinsella* (system-atics after Kennett and Srinivasan, 1983). Both *Globoconella* and *Jenkinsella* are represented by two morphospecies (Figs. 3 and 4): *G. bykovae* (Subbotina et al., 1960) and *G. minoritesta* (Papp et al., 1978b), and *J. mayeri* (*sensu* Bolli and Saunders, 1982) and *J. transsylvanica* (Popescu, 1970), respectively.

STRATIGRAPHIC DISTRIBUTION

Percentages of *Globoconella*, *Jenkinsella*, *Globoquadrina altispira* (Cushman and Jervis, 1936), *Globigerina bulloides* d'Orbigny, 1826, *Globigerinella obesa* (Bolli, 1957), *Globigerinoides quadrilobatus* (d'Orbigny, 1846), *Turborotalita quinqueloba* (Natland, 1938) and *Orbulina suturalis* Bronnimann, 1951 had been counted. Frequency data of those taxa are considered here in the time-consecutive parts of Badenian and in regard to their ecological preferences (e.g., Bé, 1977). A simple classification of warmer vs. cooler taxa and their dwelling preferences have been applied as a basic data to ecological consideration. As taxonomic diversity is higher in warmer areas and lower in cooler ones (Bé, 1977) these datasets are auxiliary applied to justify interpretation on climate. Additionally, the index of planktonic foraminiferal diversity in the particular examined biozones (a number of the mentioned taxa) has been applied to appreciate the pelagic habitat. The recognized distinct assemblages of globorotaliids and their stratigraphic position are labelled tentatively by simple semi-acronyms (Table 1; Fig. 5).

IIA–B. The thickness of these sediments ranges from 14.5 m (Pławniowice 1) to 100.8 m (Gliwice 19). They have been analysed in 97 samples. Planktonic foraminifer frequency varied from 15% to 92% (mean value 61%) of total foraminifera. Pelagic foraminifer biocenoses have 3–8 taxa (median = 6). There is *Globigerinoides quadrilobatus* (mean value 18%) in the shallow epipelagic. In the deeper epipelagic *Globoconella bykovae* prevails (mean value 28%). *Jenkinsella* sp. div. (mean value 22%) and *Globigerina bulloides* (mean value 21%) are also very common. The biozone IIA–B is bipartite in regard of the globorotaliids set (Table 1).

Lower in the section there is *Globoconella bykovae–Jenkinsella mayeri* assemblage (interval *b–m*). The plank-
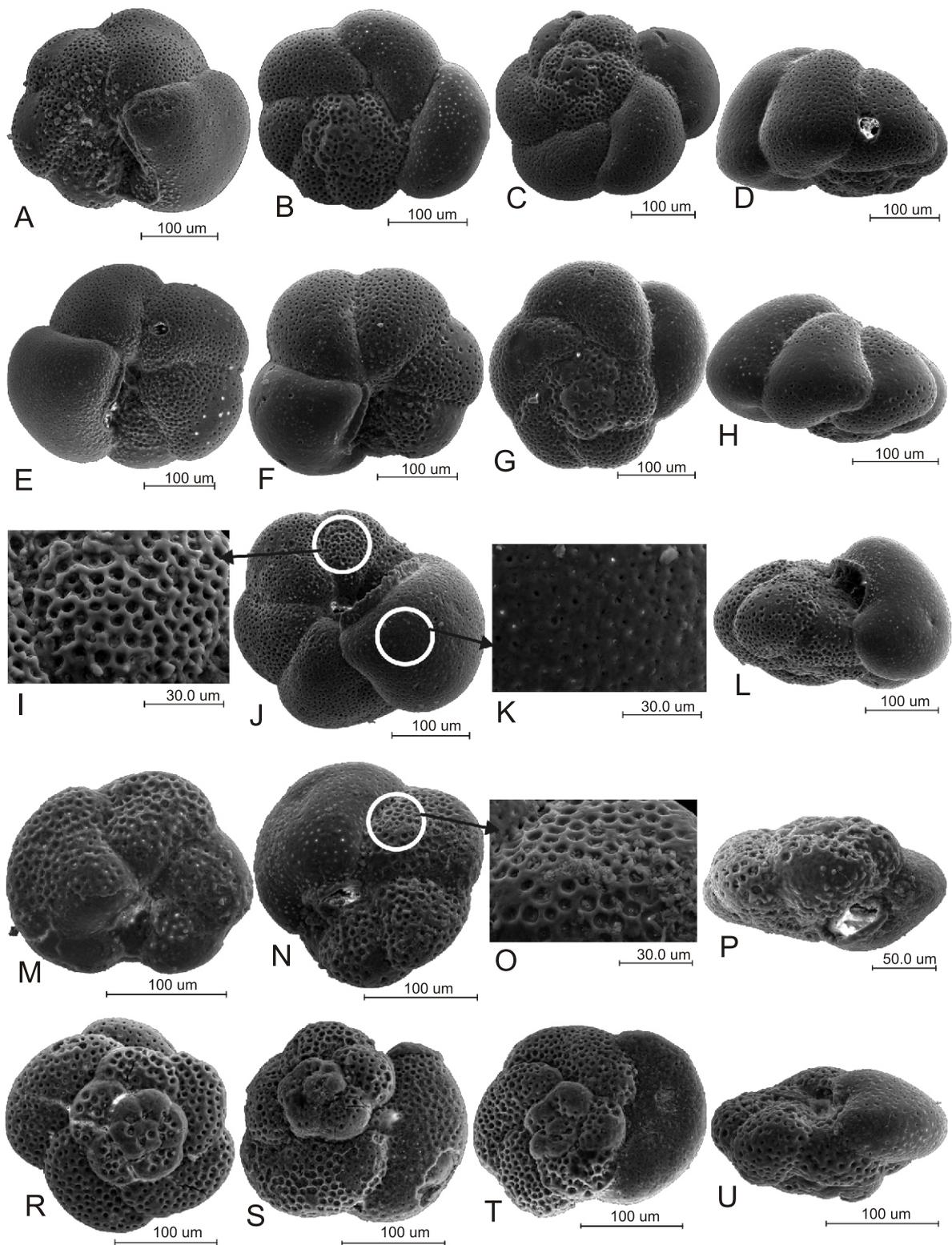
Fig. 3. SEM pictures of the Skawina Formation globorotaliids

A–L – *Globoconella bykovae*: Sumina 2, 325.0 m (A – umbilical view, B – dorsal view); Gliwice 17, 183.0 m (C – dorsal view, D – edge view); Gliwice 17, 230.0 m (E – umbilical view); Pławniowice 1, 130.0 m (F – umbilical view); Gliwice 24, 163.0 m (G – dorsal view, H – edge view); Żory 4, 55.0 m (I – ultrastructure, J – umbilical view, K – ultrastructure); Gliwice 21, 190.0 m (L – edge view); **M–U** – *Globoconella minoritesta*: Gliwice 19, 172.0 m (M, N – umbilical view, O – ultrastructure, P – edge view, R–T – dorsal view, U – edge view)
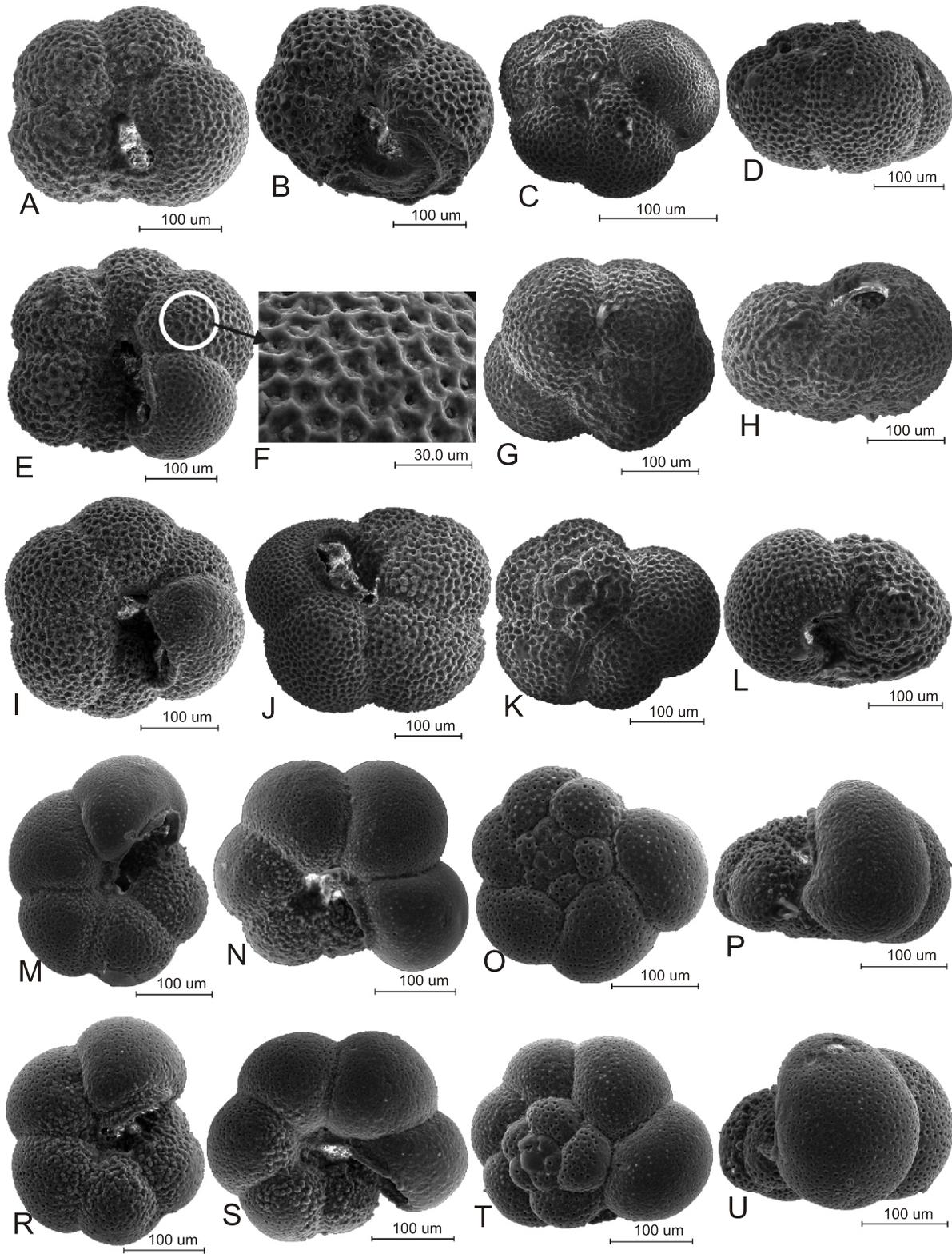
Fig. 4. SEM pictures of the Skawina Formation globorotaliids

A–L – *Jenkinsella mayeri*: Wilcza 1, 132.0 m (A – umbilical view, B – umbilical view); Gliwice 17, 222.3 m (C – dorsal view, D – edge view); Gliwice 19, 245.0 m (E – umbilical view, F – ultrastructure); Gliwice 21, 243.0 m (G – dorsal view, H – edge view, I – umbilical view); Pilchowice 10 m, 595.0 m (J – umbilical view); Gliwice 24, 200.0 m (K – dorsal view, L – edge view); **M**–**U** – *Jenkinsella transsylvanica*: Gliwice 24, 186.4 m (M – umbilical view, N – umbilical view); Gliwice 17, 202.5 m (O – dorsal view, P – edge view); Pławniowice 1, 139.0 m (R – umbilical view, S – umbilical view); Żory 4, 130.0 m (T – dorsal view, U – edge view)

T a b l e 1

Mean value and standard deviation (in brackets) of the most common planktonic foraminifera taxons in the Skawina Formation biozones (data after Gonera, 2001)

CHRONOSTRATIGRAPHY	Foraminiferal stratigraphy			Globorotaliids intervals (number of samples in breckets)	TAXON						
					WARMER					COOLER	
					SHALLOW	DEEPER				SHALLOW	DEEPER
					Globigerinoides quadrilobatus	*Orbulina suturalis*	*Globoquadrina altispira*	*Globoconella*	*Jenkinsella*	*Turborotalita quinqueloba*	*Globigerina bulloides*
WIELICIAN	sub-evaporite part	CPN 8	**IID**	*mi* (1)	1.0	1.0		35.7		25.5	36.7
				b (25)	4.6 (6.1)	1.7 (0.6)		21.5 (27.3)		41.2 (34.8)	72.2 (36.0)
			IIC	barren (7)	barren						99.9 (0.32)
MORAVIAN		CPN 7	**IIβ**	*b–t* (41)	22.9 (20.8)	11.9 (14.7)	6.3 (10.0)	27.4 (22.9)	11.7 (16.8)	7.4 (11.8)	29.8 (33.4)
			IIA–B	*t* (33)	18.6 (17.7)	10.7 (11.7)	3.8 (4.5)	8.8 (12.0)	47.1 (24,7)	1.4 (1.9)	12.1 (10.2)
				b–m (64)	18.2 (12.2)	4.5 (6.7)	6.2 (7.9)	33.4 (24.8)	9.6 (7.4)	2.8 (3.8)	26.0 (18.7)

globorotaliid levels: *b–m – Globoconella bykovae–Jenkinsella mayeri, t – Jenkinsella transsylvanica, b–t – G. bykovae–J. transsylvanica, b – G. bykovae, mi – G. minoritesta*

tonic foraminiferal frequency in this unit is 15–83% (median 56%). In shallow pelagic waters *G. quadrilobatus* (median = 15%) occurs. Deeper epipelagic waters are dominated by *G. bykovae* (median = 30%) and *G. bulloides* (median = 23%), with the third most abundant taxon being *Jenkinsella mayeri* (median = 8%). In this lower globorotaliids horizons the number of planktonic foraminifera taxa varies from 4 to 8 (median = 7).

Higher in the section *Jenkinsella transsylvanica* is present (interval *t*). The planktonic foraminifera frequent vary here from 40–92% (median = 68%). A median of shallow-dwelling species (*G. quadrilobatus*) is 13%. In deeper pelagic waters *J. transsylvanica* dominates (median = 44%), though there are minor amounts of *Globigerina bulloides* (median = 8%), *Globigerinella obesa* (median = 7%) and *Orbulina suturalis* (median = 5%). The number of planktonic taxa in this upper globorotaliids horizons varies from 3 to 8 (median = 6).

At the border of these remarkable two globorotallids levels a major change in deeper-dwellers is recorded: *Jenkinsella mayeri* disappears and *Jenkinsella transsylvanica* appears. The first appearance of *Jenkinsella transsylvanica* tests is regarded as the beginning of this taxon interval. The taxon very quickly becomes the only globorotaliid in the section (Appendix 1). The

taxon constitutes almost half of all planktonic specimens in its acme stratigraphic zone (Table 1). It is accompanied by some specimens of *Globigerinoides quadrilobatus*, *Globigerina bulloides* and *Orbulina suturalis* which double their percentage in comparison to the lower part of IIA–B biozone. In the upper globorotallid level there is a significant increase of planktonic foraminifera percentage compared to the earlier globorotaliid level.

IIβ. The biozone has been not recorded in Gliwice 17 and Wilcza 1 boreholes. Its thickness in the remaining boreholes ranges from 5.5 m (Gliwice 24) to 30.0 m. (Żory 4). Planktonic foraminifera frequency in this closing biozone of the CPN 7 is 19–96% (median = 55%), and thus is lower than that noted in IIA–B biozone. The number of taxa is from 3 to 8 here (median = 6). The diversified set of planktonic foraminifer taxons, analogous to IIA–B biozone, is in IIβ incidentally substituted by monotypic biocenosis of *Globigerina bulloides*. Such intercalations, where *G. bulloides* constitutes 90% of planktonic tests, had been traced in Gliwice 19 (177.0 m, 179.0 m), Gliwice 21 (181.0 m), Gliwice 24 (158.0 m, 159.0 m, 161.0 m) and Sumina 2 (305.0 m); because of a negligible number of globorotaliid tests these samples are not included in Appendix 1. Compared to the
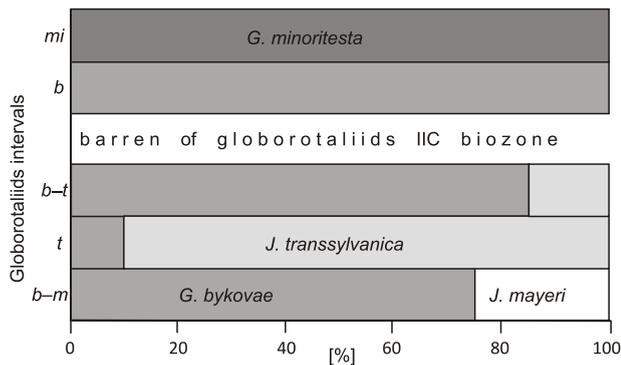
Fig. 5. General scheme of the stratigraphic distribution of the globorotaliids levels in the sub-evaporite Badenian sediments of the Silesian Basin (Central Paratethys)

Explanations as in Table 1

preceding biozone (IIA–B) there is a significant increase of the *Turborotalita quinqueloba* specimens. This taxon with *G. quadrilobatus* (median = 16) as the shallow-dwellers of this biozone constitute one fifth of the whole planktonic foraminifera. In deeper pelagic waters there is a high number of *G. bykovae* (median = 24%) and *Globigerina bulloides* (median = 14). Small quantities of *O. suturalis* (median = 7), *Jenkinsella transsylvanica* (median = 5) and *Globoquadrina altispira* (median = 2%) are also present here. *G. bykovae* dominants in the globorotaliid assemblage, accompanied by small amounts of *G. transsylvanica* in just half of the analysed samples.

IIC. The sediments of this biozone appear only in four amongst the fourteen studied boreholes (Gonera, 2001). Three of them are examined in the present paper (Pilchowice 10, Wilcza 1, Żory 4). The thickness of the biozone varies from 6.9 m (Wilcza 1) to 34.0 m (Pilchowice 10). The planktonic foraminifera percentage is 78–100% (median = 88%). In all the studied samples there are solely *Globigerina bulloides* tests (median = 100%). This initial biozone of the Wielician (*Uvigerina costai* Zone or CPN 8) is barren of globorotaliids.

IID. The sediments of this biozone are present in all boreholes, apart from Gliwice 17. The thickness ranges from 5.4 m (Gliwice 21) do 30.1 m (Żory 4). Planktonic foraminiferal frequency widely differs in this biozone. It ranges from 1 to 100% (median = 20%). *Globigerina bulloides* dominates in this biozone (median = 91%) though *Turborotalita quinqueloba* also commonly occurs (median = 38%). The presence of globorotaliids – if they are present at all – is highly episodic in IID. The more numerous specimens (median = 17%) are noted in four of the boreholes and they are represented solely by globoconellids. In three of the boreholes (Pławniowice 1, Sumina 2 and Żory 4) they are *Globoconella bykovae* (median 9%) and in one borehole (Gliwice 19) *Globoconella minoritesta* (36% of planktonic foraminifera). The stratigraphic order of these two appearances cannot be concluded and it is tentatively put that *G. minoritesta* is the later representative (Table 1; Fig. 5). Besides the aforementioned taxons, single specimens of *Globigerinella obesa* (median = 4%), *Globigerinoides quadrilobatus* (median = 3%) and *Orbulina suturalis* (median = 2%) are present in some of the IID biozone samples. It is also noteworthy that there are no *Jenkinsella* or *Globoquadrina altispira* specimens present.

INTERPRETATION

The Middle Miocene succession of globorotaliids in the Upper Silesia Basin documents the state and attitude of these deep epipelagic foraminifers to environmental changes (Gonera, 2001). During IIA–B biozone the water-exchange between the Paratethys and relatively open marine realm had a vigorous anti-estuarine circulation pattern (E1 in Fig. 2). This type of flow had been established due to the latitudinal gradient of atmospheric temperature between the Paratethys and Tethys waters. Based on foraminifers the temperature of the surface waters was ca. 20°C (Szczechura, 1982; Gonera, 2001). Warmer and lighter surface waters inflowing from lower latitudes had undergone cooling northward (Upper Silesia Basin). The descending cooler waters flowed out as a bottom current. As can be inferred based on foraminiferal data (Gonera, 2001) the basin depth ranged from outer shelf (north margin) to upper bathyal (south margin). The sea level stand was high enough to assure the effective water-exchange between Paratethys and its alimentary (Tethys) basin(s). Warm epipelagic water and the significant depth of the Upper Silesia Basin caused a strong temperature-controlled stratification of water column. Vertical mixing of the basin waters was negligible, if it occurred at all, during this phase. Some water exchange in this direction ran mainly in costal areas especially in the cooler north part of the Paratethys (Gonera, 2001).

A characteristic pattern of life resources and their stability in the environment had been established under this effective anti-estuarine circulation during the IIA–B biozone. Life resources (nutrients and oxygen) were generally poor (especially in pelagic realm) but their stability was very high. These conditions gave rise to and then sustained K-selection in foraminiferal community. For that we have the IIA–B assemblage as an excellent example of very high species diversity in both benthic and planktonic foraminifers. Benthic species settled both on the bottom surface and within the sediment although the infaunal varieties have prevailed. Organic matter was entirely used as a constant and predictable resource of food during this time interval. Detritus oxidation or reducing conditions were negligible. The sediments of this biozone were highly bioturbated and well-homogenized. This feature indicates that although temperature controlled stratification the basin bottom was sufficiently oxygenated to maintain and sustained infaunal feeders of macrofauna.

Globorotaliids of the E1 (IIA–B biozone) reveal stratigraphic bipartition: the *Globoconella bykovae*–Jenkinsella *mayeri* assemblage precedes the *Jenkinsella transsylvanica* assemblage. This bipartition is supported by the δ^{18}O data (Fig. 6). *Globigerina bulloides* tests of the *G. bykovae–J. mayeri* level display a δ^{18}O average value: +0.4 ± 1.2‰ after Durakiewicz et al. (1997) and –0.7 ± 0.4‰ after Gonera and Bukowski (2012). In the samples of *J. transsylvanica* level there is an δ^{18}O value +0.7‰ (single data in Durakiewicz et al., 1997) and has an average value of +0.4 ± 0.5‰ after Gonera and Bukowski (2012). The δ^{18}O difference between these two globorotaliids assemblages is apparent from the Gliwice 17 data (Appendix 1). *Globigerina bulloides* δ^{18}O of the *Jenkinsella transsylvanica* assemblage is interpreted as a cryptic cooling event, and directly precedes the Mi3 event suggested by Gonera (2001) into the IIC biozone (Fig. 2). This nearly 1‰ VPDB increase in δ^{18}O indicates that epipelagic temperature could dropped circa 5°C. In this context it is worth to note that planktonic foraminifera per-
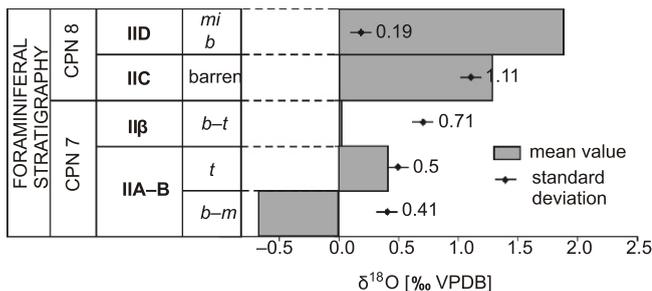
Fig. 6. Oxygen isotopic differences in the globorotaliid levels (data on *Globigerina bulloides* measurements after Gonera and Bukowski, 2012)

centage in the *J. transsylvanica* level is noticeably higher (median = 68%) compared to the *G. bykovae*–*J. mayeri* assemblage (median = 56%). This difference had been noted by Alexandrowicz (1963). This author distinguished the IIB assemblage overlaying the assemblage IIA which is taxonomically analogous to the upper lagenide zone of the Vienna Basin. It can now be inferred that the IIB assemblage appearance is the earliest signal of the Mi3 environmental cooling.

This cryptic cooling became a trigger factor to a profound faunal turnover: IIA–B association vanishing and IIβ appearing (Fig. 2). The *J. transsylvanica* cryptic cooling, as recorded by ca. 1‰ VPDB δ^{18}O increase, must have induced an approximate 100 m eustatic sea level drop. This lowering should have initiated a slope displacement processes leading to mixing of the coeval costal sediments but also the older ones – first of all, poorly consolidated earlier Moravian. Sea level fall also caused the flow efficiency of the current to became sluggish through most likely a cession of some of the shallower corridors and seaways in the Paratethys (E2 in Fig. 2). It was still the anti-estuarine circulation but was less effective than in E1. The surface waters were inflowing and the bottoms were flowing out, although the efficiency of those was diminished compared to E1. In the IIβ biozone (*G. bykovae*–*J. transsylvanica* globorotaliid interval) we have δ^{18}O value of –0.48‰ (single data in Durakiewicz et al., 1997) and δ^{18}O average value +0.02 ± 0.71‰ (Fig. 6). It means that in the IIβ biozone pelagic waters were warmer than in *J. transsylvanica* cryptic cooling, however cooler than in *G. bykovae*–*J. mayeri* interval.

Cooling and shallowing of the basin allowed for a vertical mixing of epipelagic waters. Water salinity was still normal marine but food, oxygen and temperature conditions of the biotope became far off those of the IIA–B biozone. The majority of K-selection species of the IIA–B biozone was removed from the community.

Common signs of redeposition presented in the IIβ biozone sediments include the allochthoneity of foraminifers as well as rhodolith debris. The admixture of these elements into silty marls of IIβ biozone occurs especially frequently near the NE border of the Upper Silesia basin and thus the Kraków–Częstochowa Mesozoic ridge could be a potential source area. From there these and other shallow-water components and mineral particles (glauconite) were spread by slump processes and/or activity of currents.

The pelagic assemblage of the IIβ biozone is similar to that of the IIA–B biozone but in the first one the intermittent occurrences of *Globigerina bulloides*–*Turborotalita quinqueloba* association are present. The planktonic foraminifer percentage of

the IIβ biozone varies highly from sample to sample. Generally the group is less frequent than in the IIA–B biozone. *Globoconella bykovae* had arrived into globorotaliids community of this closing biozone of the CPN 7. In some samples this taxon occurs with *J. transsylvanica*.

The first biozone of Wielician – IIC – is barren of globorotaliids, and *Globigerina bulloides* is the only planktonic foraminifer present. The average δ^{18}O value of *G. bulloides* tests is +1.3 ± 1.1‰ (Fig. 6), i.e. significantly higher than in the CPN 7 biozones. The CPN 8 base corresponds to the intense drop of temperature due to global Mi3 event (cf. Gonera, 2001; Gonera et al., 2000, 2003; Baldi, 2006; Peryt and Gedl, 2010; Harzhauser et al., 2011; Gonera and Bukowski, 2012; Key et al., 2013). In the Upper Silesia Basin the percentage of planktonic foraminifers considerably increased; although it was only this one mentioned taxon. Vertical mixing of water has been activated, so a nutrient supply and food resources has been rich but unstable, irregular in appearance (Gonera, 2001). This factor operated as an environmental stress which conditioned the benthic and pelagic foraminifera. As a consequence a community typical to r-*selection* had been settled. At the bottom only two opportunistic taxa were able to adapt succesfully to these circumstances: *Valvulineria* and *Cibicides*. In the pelagic realm the species able to successfully adapt was *Globigerina bulloides*. Further intensification of these causes which removed the IIA–B biozone community and formed the IIβ one had led to the establishment of the IIC biozone community.

The IID biozone environment displays a further drop in temperature. In the time-consecutive parts of the Badenian it is the one directly underlying the Wielician evaporites. The average δ^{18}O value of *G. bulloides* tests is +1.9 ± 0.2‰ (Fig. 6). It is worth to note that IID *Globigerina bulloides* of the Wieliczka Mine (vicinity of Kraków) displays an average δ^{18}O value is +2.3 ± 0.2‰ (after Gonera et al., 2012). The IID biozone deposits near Busko show the average δ^{18}O value of 2.0 ± 0.6‰ (Peryt, 2013).

Upper Silesia Basin bathymetry was sublittoral during this biozone. Normal marine water salinity and E2 circulation pattern had been sustained. The set of foraminifers and type of sediments indicate oxic conditions. So, these features remain similar to the IIC environment. What was a new environmental factor in the IID zone it were constantly maintained organic-rich conditions caused by a vertical extending of the surface mixed layer in a cooler climate. In the shallow (coastal) areas of the Paratethys this deepening had led to intensify of nutrient supply to photic zone and increase the productivity of pelagic waters. Besides the overall cooling, this was the main factor favouring the *Globigerina bulloides* acme. These environmental features which where first interpreted through foraminiferal palaeoecological approach (Gonera, 2001) are now supported by δ^{13}C data (Gonera and Bukowski, 2012). Globorotaliids arrived to the Upper Silesia Basin during the IID biozone. As can be stated based on the studied material the meaningful number of globorotaliids (17–67% of planktonic foraminifera) occurs only twice during this biozone. The peak of *Globoconella bykovae* is noted in three of the analysed boreholes (Pławniowice 1, Sumina 2, Żory 4). The appearance of *Globoconella minoritesta* has been noted in the Gliwice 19 borehole. As yet any borehole in which these (or any other) globorotaliids are recorded more than one time during IID was found. The interpretation of this is that during IID of the E2 circulation the basin has been invaded at least twice by larger marine inflows of deeper epipelagic waters. One of them was carrying *G. bykovae* and the second *G. minoritesta*. The inflows were intense enough to carry the most deep epipelagic foraminifers.

DISCUSSION

The described globorotaliid intervals are distinctive with regards to taxonomic set. Due to the globorotaliid life-span (deep epipelagic water of marine currents) these foraminifers are capable to be effectively carried to overall connected seas and distributed up to their ecological limits (bathymetry and temperature first of all). Thereby it should be expected that the discovered changes in Middle Miocene Silesia Basin globorotaliids are also recorded in other areas throughout the Parathethys.

The globorotaliid events (and their stratigraphic intervals) offer a reliable supporting method for intra-Parathethyan correlation – independent of the index taxa of the *Orbulina suturalis* Zone (CPN 7) and the *Globigerina druryi*–G. *decoraperta* Zone (CPN 8). At present the straight identification of these globorotaliid levels can to be performed regarding some lower Badenian sections. Such an approach can to be tentatively applied to globorotaliids of the Badenian stratotype section of the Baden-Sooss (Rupp and Hohenegger, 2008). The absence of *Jenkinsella mayeri* (*Paragloborotalia* of Rupp and Hohenegger, 2008), the presence of *Globoconella bykovae* accompanied by *Jenkinsella transsylvanica* allow to refer their set to the *Globoconella bykovae*–*Jenkinsella transsylvanica* level of the Upper Silesia Basin. Two significant percentages of *Globoconella bykovae* in planktonic foraminifera set have been detected by Kovačová and Hudáčková (2009) in the Slovak part of the Vienna Basin, in the Devinska Nova Ves CPN 8 deposits. As these appearances are positioned at the some stratigraphic interval as in the Upper Silesia basin it may indicate the doubling of *Globoconella bykovae* interval of the Upper Silesia Basin. In the more marginal, shallow-water deposits the globorotaliid intervals identification is probably also possible but indirect. The good example of this seems to be the lastly recovered two episodes of "mesotrophic or nearly oligotrophic conditions" during the IID biozone in the northern Carpathian Foredeep Basin near Busko (Peryt, 2013). Maybe these events, marked "S3" and "S4" (Peryt, 2013), reflect the same influxes of open marine waters which had carried *Globoconella bykovae* and *Globoconella minoritesta* into the Upper Silesia Basin during the IID span. The question of these episodic influxes of open marine waters during the IID biozone may give some assumption to justify the volume of marine water evaporated vs. the volume of Wielician evaporites.

The Parathethys as a set of fringing marine basins of Mediterranean were more sensitive to eustatic sea level fluctuations causing waxing and wanning of marine biotas. This is also the case for globorotaliids, but the basic obstacles to perform a wider correspondence (at least Mediterranean-Parathethys) of the globorotaliid intervals are overcoming taxonomic differences. Thereby a comparison between assemblages of Parathethys and surrounded marine basins is difficult. The only taxonomic consent concerning Parathethys and world-ocean globorotaliids is *Jenkinsella mayeri*. We can see the morphological similarity of *Jenkinsella transsylvanica* to *Globorotalia challengeri* Srinivasan and Kennett, 1981. *Globoconella bykovae* is morphologically similar to *Globorotalia praescitula* (Blow, 1959). Nevertheless Subbotina et al. (1960) suggested its similarity to G. *foshi* (*sensu* Cushman and Ellisor, 1939). Which world-ocean taxon does G. *minoritesta* resemble? Taking into account its biconvexity, fourth chamber in the last whorl and highly extended last chamber compared to the penultimate chamber it appears to be very similar to G. *miotumida* Jenkins 1960.

The recognized temporal changes in Silesian globorotaliids correlate well with large-scale palaeoenvironmental events such as the Middle Miocene climate event Mi3 and the marine circulation mode in the considered area. If carefully examined in the other areas of Parathethys, this globorotaliid issue shall give an image on the spatial distribution of the here described globorotaliid units in the Parathethys. This would be an additional tool to a detailed stratigraphic correlation within the Parathethyan Miocene. Spatial distribution of each of these particular globorotaliid intervals shall provide additional arguments to a more precise reconstruction of the Middle Miocene seaways operating in the Parathethys. It is also a future and promising method to trace the Parathethys–Tethys connecting currents – if the taxonomic justification with at least the Mediterranean Miocene will be performed. These resolutions are not possible until basic comparative analyses will be performed.

CONCLUSIONS

1. Three globorotaliids stratigraphic intervals have been recognized in the CPN 7 sediments (*Orbulina suturalis* Zone of the Moravian substage). Two of them are located within the biozone IIA–B: *Globoconella bykovae*–*Jenkinsella mayeri* association followed by *Jenkinsella transsylvanica*. During the final biozone of the CPN 7 (IIβ in Poland) *Globoconella bykovae* is present accompanied by rare specimens of J. *transsylvanica*. Jenkinsellids do not appear beyond CPN 7/CPN 8 boundary: J. *mayeri* disappears first followed by J. *transsylvanica*.

2. Two globorotaliids intervals have been recognized in the CPN 8 sediments (*Uvigerina costai* zone of the Wielician substage). Globorotaliid absence in IIC biozone is followed by a separate occurrence of *Globoconella bykovae* and *Globoconella minoritesta* in the IID biozone.

3. The appearance of *Jenkinsella transsylvanica* corresponds with the $\delta^{18}O$ positive excursion circa 1‰ VPDB in *Globigerina bulloides* tests. This is interpreted as cryptic cooling event of Mi3 recorded in Late Moravian (CPN 7). This first step of Middle Miocene climate deterioration caused both the J. *mayeri* irreversible disappearance and the temporal retreat G. *bykovae* from the Upper Silesia Basin.

4. As much as a 100 m sea level drop may be generated by cryptic cooling event of the J. *transsylvanica* level. These factors justify the pronounced environmental change and turnover the hitherto foraminiferal community. Firstly, during the cooling episode itself there was a substitution of the upper lagenide assemblage (IIA) by planktonic-rich assemblage IIB. Later – in the IIβ biozone – due to the shoaling slump processes were activated leading to a successive destruction of the Moravian ecosystem. Together with the onset of the next cooling event (IIC biozone) the Moravian ecosystem had been totally demolished. A new ecosystem – this of Wielician – with *Globigerina bulloides* acme in pelagic waters has been established. The globorotaliid-barren interval IIC preceded two significant influxes of open marine water masses carrying G. *bykovae* and G. *minoritesta* – both during the IID biozone, which directly preceded the Wielician evaporitic sedimentation.

5. Globorotaliid life-span makes it possible for a quick and easy dispersion of specimens within marine areas and thus favours the group as datums in stratigraphy. The clearly defined globorotaliid levels of the Skawina Fm. are able to be an effective and precise correlation tool within the Parathethys. Taxonomic

alignments of Paratethys to apart-Paratethys globorotaliids is required; ongoing opinions on Paratethys–Tethys connection(s) in both stratigraphic and palaeogeographic solutions could be much extended after obtain these additional data.

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