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Isotopic events in the Early/Middle Badenian (Miocene) of the Upper Silesia Basin (Central Paratethys)

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Middle Miocene foraminifera from the Skawina Formation of the Upper Silesia Basin have been analysed. The stable oxygen and carbon isotope signatures in *Globigerinoides quadrilobatus* (shallow pelagic), *Globigerina bulloides* (deeper pelagic) and *Uvigerina* spp. (benthic) tests show a temporal pattern of changes in the sections studied. The foraminiferal assemblage biozones of the Badenian that were identified earlier, on the basis of taxonomic composition, correspond to changes in the foraminiferal $\delta^{18}O$ and $\delta^{13}C$ values. The CPN7/CPN8 transition – as the Moravian/Wielician border – is marked by distinct isotopic events: a $\delta^{18}O$ increase (IIAB/IIC boundary) followed by a $\delta^{13}C$ decrease (IIC/IID boundary).

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INTRODUCTION

The composition of foraminifer assemblages shows distinct lateral and temporal taxonomic changes in the Badenian of the Carpathian Foredeep and Vienna Basin. The temporal changes have been related to characteristic, well-defined assemblage biozones with the status of biostratigraphic zones (e.g., Alexandrowicz, 1963; Łuczkowska, 1964; Cicha *et al*., 1975). Palaeoecological research indicated that significant modifications of the taxonomic composition and hence constitution of new assemblage biozones in the profile occurred as a result of considerable environmental changes (Szczechura, 1982; Gonera, 2001; Bicchi *et al*., 2003). These Badenian foraminiferal biozones of the Carpathian Foredeep have the nature of ecozones.

The aim of the research conducted presently is to check the relationships between those foraminiferal biozones and geochemical parameters of the foraminiferal tests. Our studies concerned the Skawina Formation where as many as three such foraminiferal assemblage biozones are identified in the strata prior to the Badenian evaporites (Alexandrowicz, 1963). One of the geochemical features of the mineral skeleton of foraminifera are the ratios of stable oxygen and carbon isotopes (Elderfield, 2004). Several such studies have been already performed on Badenian foraminifera (e.g., Durakiewicz *et al*., 1997; Gonera *et al*., 2000, 2003; Báldi, 2006; Hohenegger *et al*., 2008; Kovačova and Hudačkova, 2009; Peryt and Gedl, 2010). We present new data on $\delta^{18}O$ and $\delta^{13}C$ values of foraminifers occurring below the Badenian evaporites and discuss their stratigraphic implications.

GEOLOGICAL SETTING

The area studied (Upper Silesia Basin) was a part of the Carpathian Foredeep Basin during the Middle Miocene (Fig. 1). The Middle Miocene sequence of the Upper Silesia Basin is well-known owing to studies of Alexandrowicz (1963), and subsequent updates of various aspects (e.g., Barwicz-Piskorz, 1997; Gedl, 1997; Gonera, 1997, 2001; Górka, 1997; Peryt, 1997; Sadowska, 1997; Szczechura, 1997; Witkowski and Gonera, 1997).

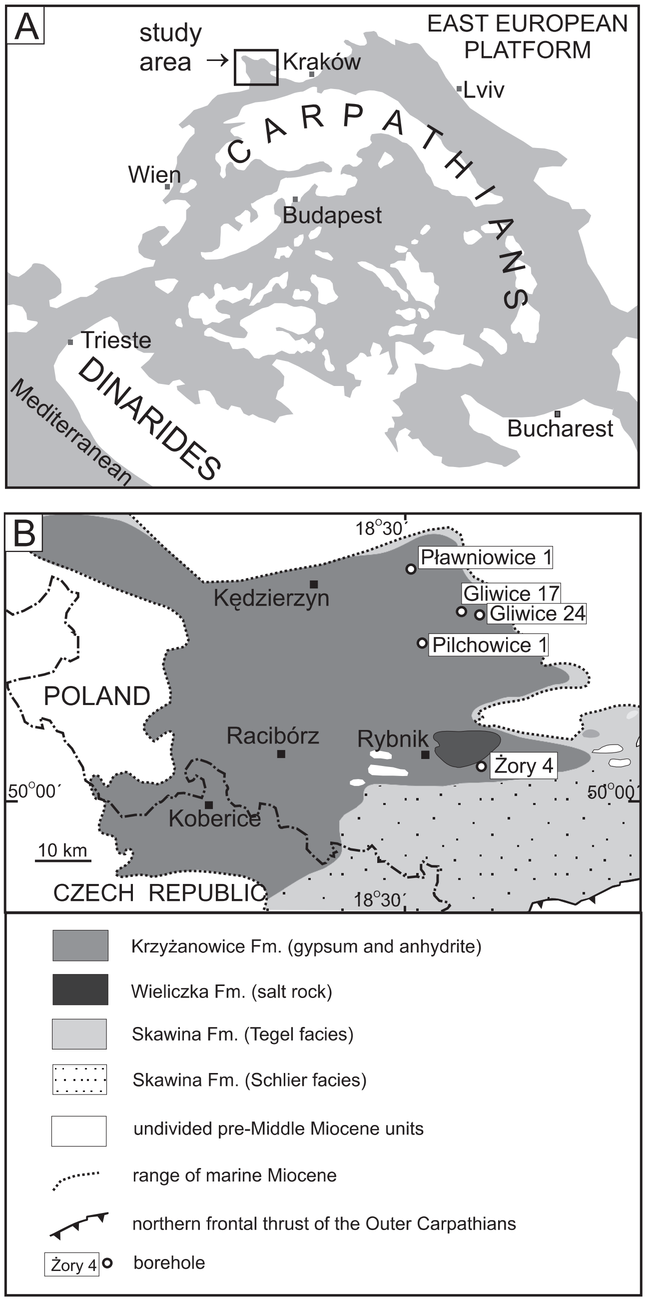

Fig. 1. Area studied

A – palaeogeographic reconstruction of the Central Paratethys (Early Badenian marine sedimentation; after Rögl, 1998); **B** – Upper Silesian Basin and the boreholes investigated

Four lithostratigraphic units have been proposed for those strata: the Skawina Fm., Krzyżanowice Fm. and Wieliczka Fm. (evaporites), and the Gliwice Fm. (Alexandrowicz *et al*., 1982). The Skawina Fm. consists of grey marly clays (Tegel) primarily, partially with sand or silty gravel admixtures and intercalations of shelly and organodetrital limstones or marls (Alexandrowicz, 1963, 1997). Evaporites consist of gypsum (e.g., Peryt *et al*., 1997) and, only in the Rybnik and Żory area, halite with claystone and anhydrite intercalations (Garlicki, 1979).

MATERIALS AND METHODS

We have studied the Skawina Fm. deposits in five boreholes located along a N–S transect of the Silesian Basin (Fig. 1). The material for this study (samples and lithological descriptions of boreholes) came from the collection and unpublished materials of Prof. S.W. Alexandrowicz. A complete set of foraminiferal biozones characteristic of the Badenian section below the evaporites was found in the deposits studied (Table 1; Gonera, 2001).

In the Pławniowice 1, Pilchowice 1 and Żory 4 boreholes, the Skawina Formation lies on the sands and silts with Cepaea and Congeria shells, plant fragments and pebbles of older rocks (Early Miocene Kłodnica Formation). The productive Carboniferous rocks (clayey shale with coal intercalations) comprise the basement of the Skawina Formation in the Gliwice 17 and Gliwice 24 boreholes. The Skawina Formation is developed as non-stratified marly clays (typical Tegel facies) in the Pilchowice 1 and Żory 4 profiles. In the other boreholes the deposits have some admixture of sand (Schlier facies) or are intercalated with silty gravel, rhodolith debris and/or sandstones (Fig. 2). In all the profiles studied, the Skawina Fm. is overlain by Badenian evaporites, developed in sulphate facies (silty shales with gypsum and/or anhydrite).

We have analysed three foraminifer taxa constantly present in the deposits: *Uvigerina* spp., *Globigerina bulloides* d'Orbigny, 1826 and *Globigerinoides quadrilobatus* d'Orbigny, 1846. Such a choice allowed us to determine the isotopic composition of tests of organisms that lived on the sea floor (*Uvigerina*) and in near-surface waters (*Globigerina* and *Globigerinoides*), and to analyse the Skawina Formation along a the N–S transect of the sedimentary basin.

Uvigerina in the IIAB biozone (Alexandrowicz, 1963) was mainly represented by *U. semiornata* d'Orbigny, 1846 and the less common *U. macrocarinata* Papp and Turnovsky, 1953 (Fig. 3). In the IIC biozone, the *U. semiornata* specimens still dominated and were accompanied by *U. orbignyana* Czjzek, 1847. Those two taxa were present in the IID biozone, although in reverse proportions: *U. orbignyana* dominated, while *U. semiornata* were scarce. This set of uvigerinas was sampled for isotope studies. *Globigerina bulloides* and *Globigerinoides quadrilobatus* are common in the Skawina Beds, except in the top of the profile (IID) where the latter is scarce (Gonera, 1997, 2001). These foraminifera were picked from the size fraction larger than 125 µm. The numbers of specimens were selected in the quantities required to obtain the 2–3 mg necessary to analyse the $CaCO_3$ aliquot. $^{18}O/^{16}O$ and $^{13}C/^{12}C$ isotope ratios analysis was carried out for 110 aliquots collected from 58 rock samples (Table 2).

The determination of the $\delta^{18}O$ and $\delta^{13}C$ was carried out in the GeoZentrum Nordbayern Laboratory of the Friedrich-Alexander-Universität in Erlagen-Nürnberg, Germany. Carbonate powders were reacted with 100% phosphoric acid at 75°C using a *Kiel III* carbonate preparation line connected online to a *ThermoFinnigan 252* mass spectrometer. All values are reported in permil relative to V-PDB by assigning a $\delta^{13}C$ value of +1.95‰ and a $\delta^{18}O$ value of –2.20‰ to NBS19. Reproducibility was checked by replicate analyses of laboratory standards and is better than ±0.01–0.03‰.

Table 1

Position of the Skawina Formation (shaded area) within the Central Paratethys stratigraphy

Chronostratigraphy		Concepts of foraminiferal biostratigraphy: Cicha *et al.* (1975); Papp *et al.* (1978); Rögl and Steininger (1984)			Concepts of foraminiferal biostratigraphy: Alexandrowicz (1963, 1965)
Badenian	Kosovian	CPN9	Velapertina Zone	Rotalia Zone	IIIβ
				Bulimina-Bolivina Zone	IIIB
	Wielician	CPN8	*Globigerina druryi–G. decoraperta* Zone	zone with agglutinated foraminifera	IIIA, IIIα
					evaporite deposits
					IID, IIδ
					IIC, IIβ, IIγ
	Moravian	CPN7	*Orbulina suturalis* Zone	Lagenidae Zone	IIAB

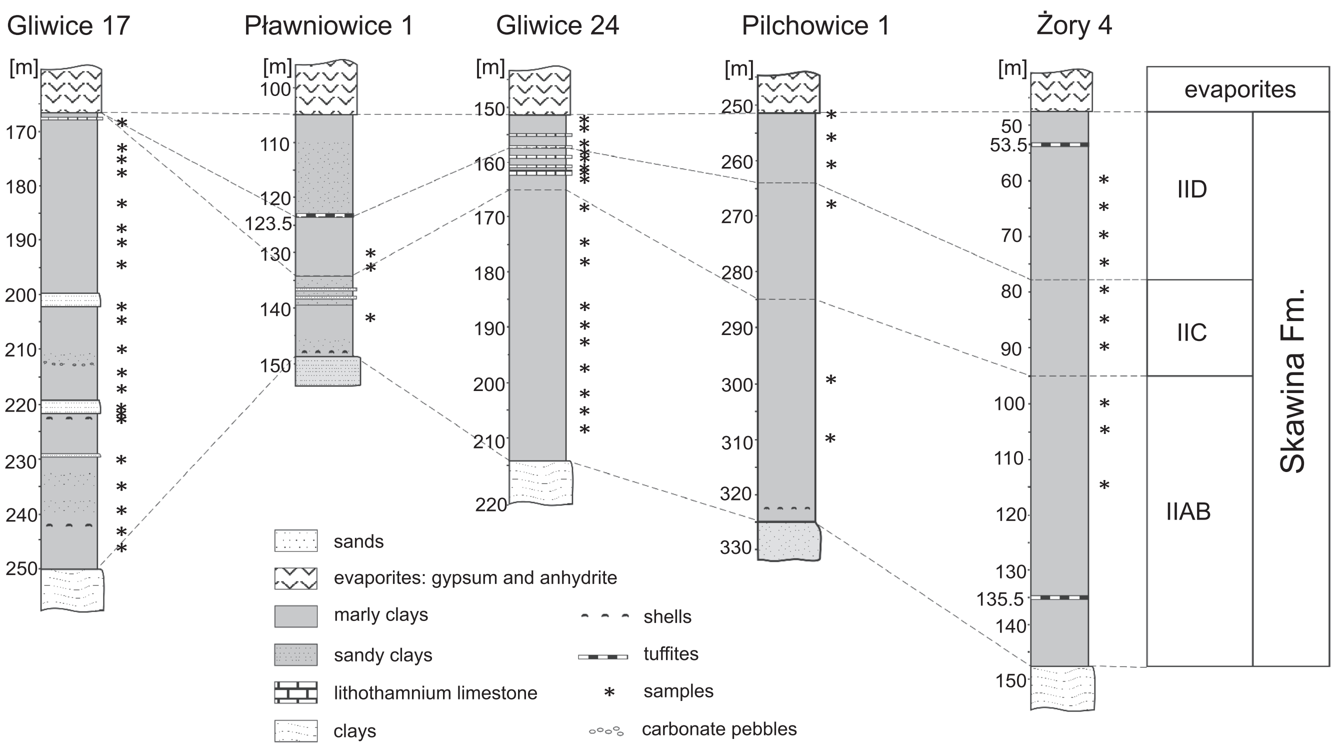

Fig. 2. Schematic lithological columns of the boreholes studied

RESULTS

The results of analyses are given in Table 2. Despite fluctuations, overall trends can be discerned regardless of the differences in absolute values for particular taxa in geographically separated boreholes (compare e.g., *Uvigerina* in the Pławniowice 1 and Żory 4 profiles on Table 2). Thresholds in the $\delta^{18}O$ and $\delta^{13}C$ values at the biozonal boundaries are distinct (Table 3). The results have been grouped within the biozones (Fig. 3), and the $\delta^{18}O$ and $\delta^{13}C$ relationships are specified in Figure 4. The average values within the particular biozones show differences, and general patterns in the stratigraphic column may be traced.

The greatest $\delta^{18}O$ change occurs on the IIAB/IIC boundary. The average $\delta^{18}O$ value increases from +1.3‰ (IIAB) to +2.1‰ (IIC) and +2.5‰ (IID) in *Uvigerina*. In *Globigerina bulloides* the $\delta^{18}O$ value increases from –0.1‰ (IIAB) to +1.3‰ (IIC) and +1.9‰ (IID), while in *G. quadrilobatus* the average $\delta^{18}O$ value decreases from –1.1‰ (IIAB) to –1.5‰ (IIC).

The most noticeable $\delta^{13}C$ change occurs at the IIC/IID boundary. The $\delta^{13}C$ values in *Uvigerina* (0‰ in IIAB and

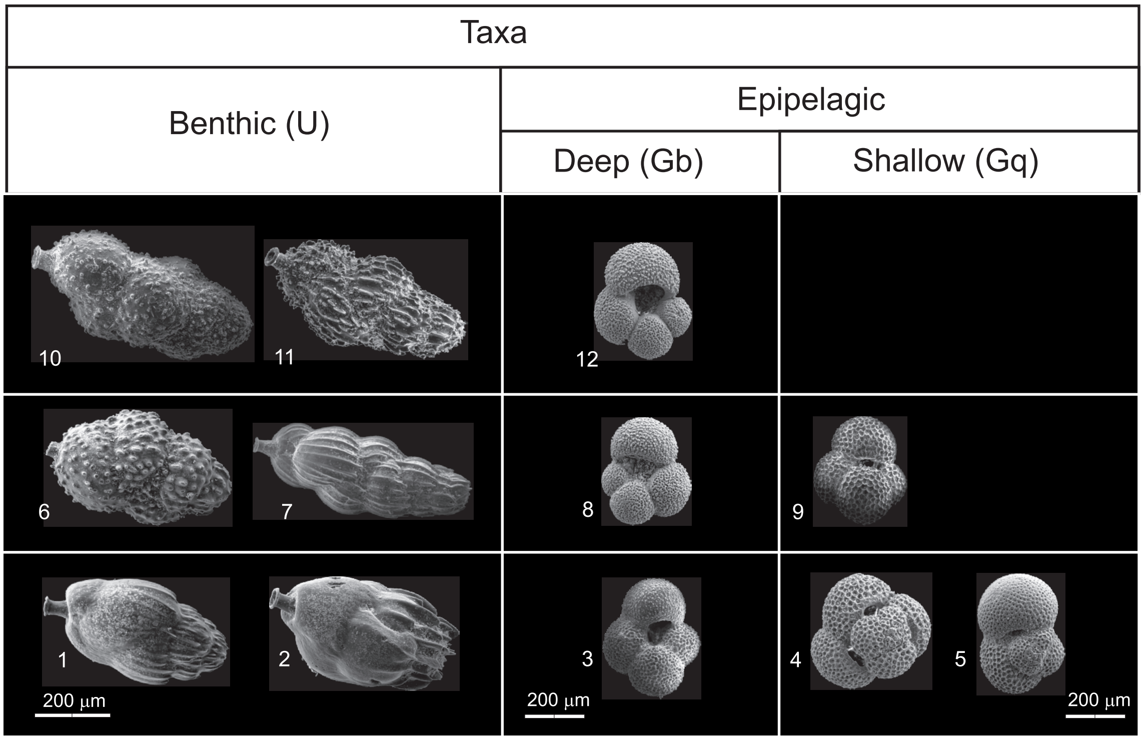

Fig. 3. SEM pictures of the taxa studied

U – *Uvigerina* spp., Gb – *Globigerina bulloides*, Gq – *Globigerinoides quadrilobatus* s.l.; IIAB biozone: 1 – Gliwice 24 (205.0 m), 2, 5 – Pilchowice 1 (310.0 m), 3, 4 – Gliwice 24 (178.0 m); IIC biozone: 6 – Pławniowice 1 (130.0 m), 7 – Gliwice 24 (161.0 m), 8 – Pilchowice 1 (268.0 m), 9 – Pławniowice 1 (130.0 m); IID biozone: 10 – Pilchowice 1 (261.0 m), 11 – Gliwice 24 (152.0 m), 12 – Gliwice 24 (157.0 m)

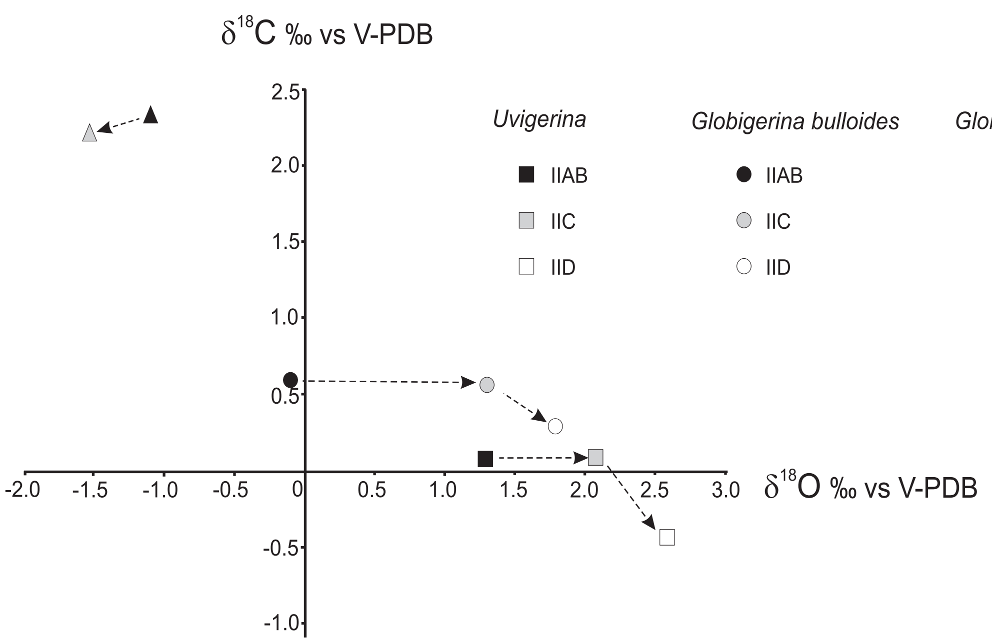

Fig. 4. Plot of average foraminiferal ^{18}O and ^{13}C values of the Skawina Formation

Letter indices as in text and in Table 1 and Figure 3

Table 2

Stable isotope results of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) of the foraminifera tests

Borehole	Biozone	Depth [m]	$\delta^{18}O$ [‰V-PDB]			$\delta^{13}C$ [‰V-PDB]		
			U	Gb	Gq	U	Gb	Gq
Pławniowice 1	IIC	130.0	1.37	–0.73	–1.59	0.32	0.46	2.39
		133.0	1.32	0.18	–1.38	0.04	0.45	2.21
	IIAB	142.0	1.16	0.76	–1.24	0.18	1.55	2.69
Gliwice 17	IIAB	168.8	1.71			0.2		
		173.0	2.00			0.08		
		175.2	1.49	–0.43		0.39	0.74	
		177.6		–0.69			0.13	
		183.0	1.82	0.83		0.36	1.63	
		187.5	1.45	0.4		0.04	0.45	
		190.3	1.98	1.09		0.03	1.02	
		194.5	1.18	0.49		–0.22	0.85	
		202.5	1.45	0.33		0.03	0.75	
		204.8	1.3	–0.64		–0.04	0.72	
		210.0	0.84			0.16		
		214.5	0.89			0.15		
		217.0	0.98	–1.00		0.05	0.84	
		220.0	0.85			0.59		
		222.3	0.85			–0.35		
		225.5	0.74	–0.82		0.05	0.64	
		230.0	0.94	–0.78		–0.06	0.2	
		235.0	0.75	–0.34		–0.04	0.31	
		239.0	0.81	–0.16		0.92	0.73	
		243.5	0.81			0.25		
		246.3	1.33			–0.14		
Gliwice 24	IID	152.0	2.66	1.94		–0.28	0.33	
		153.6	2.28	1.57		–0.39	0.43	
		157.0	2.52	1.95		–0.01	1.00	
	IIC	158.0	2.41	1.67		0.07	0.47	
		159.0	2.43	1.76		0.1	0.05	
		161.0	2.5	2.17		–0.03	0.38	
		162.0	0.96	–0.22	–1.58	0.09	0.54	1.98
	IIAB	163.0	1.71	1.39	–1.26	0.09	0.57	2.3
		168,0	1.38	–0.28	–0.56	–0.15	0.26	1.61
		174.5	1.75	0.13	–1.02	–0.06	0.14	2.14
		178.0	1.2	–1.1	–1.71	0.03	0.6	2.62
		186.4	1.35		–1.25	0.04		2.61
		189.2	1.66	0.23		–0.22	0.2	
		192.2	1.35	0.61		–0.13	0.56	
		197.6	1.19	–0.18		0.16	0.59	
		202.0	1.22	–0.77		–0.08	0.27	
		205.0	0.69	–0.8	–1.15	–0.09	0.15	2.16
		208.0	0.83	–0.41		–0.34	0.18	
Pilchowice 1	IID	252.0	1.91			–1.35		
		256.0	2.66	2.09		–0.28	0.07	
		261.0	2.73	1.73		–0.62	0.02	
	IIC	268.0		1.53			0.37	
	IIAB	300.0	1.63			–0.14		
		310.0	1.03	–0.38	–1.57	–0.2	0.3	1.95

Tab. 2 cont.

Borehole	Biozone	Depth [m]	δ^{18}O [‰V-PDB]			δ^{13}C [‰V-PDB]		
			U	Gb	Gq	U	Gb	Gq
Żory 4	IID	60.0	2.57			–0.78		
		65.0	2.6	1.97		–0.52	–0.09	
		70.0	2.55			–0.38		
		75.0	2.9			0.37		
	IIC	80.0	2.63	2.1		0.01	0.84	
		85.0	2.82	2.05		–0.02	0.61	
		90.0		2.3			1.1	
	IIAB	100.0	1.96		–1.03	–0.09		2.33
		105.0			–1.16			2.68
		115.0	2.07	0.45	–0.13	0.09	0.85	2.41

For explanations see Figure 3

+0.1‰ in IIC) decrease to –0.4‰ in IID. In *G. bulloides*, the respective values are +0.6‰ (IIAB) and +0.5‰ (IIC), and decrease to +0.3‰ (IID). For *G. quadrilobatus*, we obtained data only for the lower part of the profile, i.e. IIAB and IIC biozones, where the δ^{13}C values reach +2.4 and +2.2‰, respectively.

The strongest change in δ^{18}O content of the deeper pelagic foraminifers (*G. bulloides*) takes place at the IIAB/IIC border where there is an increase by 1.4‰ (from –0.1 to +1.3‰). A significant change in δ^{18}O occurs also at this boundary in the benthic foraminifers (*Uvigerina*); from +1.3 to +2‰. In the younger deposits (IID biozone), a further increase in δ^{18}O is noted: of 0.6‰ for *Globigerina bulloides* and 0.5‰ for *Uvigerina*. The difference between those benthic and pelagic foraminifers ($\Delta\delta^{18}$O) underwent continuous reduction during this interval of the Badenian: from 1.4‰ in IIAB to 0.8‰ in IIC and 0.7‰ in IID.

The δ^{13}C changes are not as prominent as in the case of the δ^{18}O values. At the IIAB/IIC boundary, the average δ^{13}C value decreases by 0.1‰ in *G. bulloides* (from +0.6 to +0.5‰) and increases by 0‰ in *Uvigerina* (from +0 to +0.1‰). Noticeable δ^{13}C change occurs between the IIC and IID biozones. At this boundary there is a distinctive drop in δ^{13}C values of both planktonic and benthic foraminifers. The average δ^{13}C values decrease by 0.5‰ in *Uvigerina* tests (from +0.1 to –0.4‰) and by 0.2‰ in *Globigerina bulloides* (from +0.5 to +0.3‰).

IMPLICATIONS

The subdivision of the Badenian Stage into three parts is based on distinct faunal turnovers registered in marine deposits across the Central Paratethys (Table 1). In this chronostratigraphic concept, the Moravian and Kosovian are defined as time spans of normal marine sedimentation (Brestenská, 1978*a*), and thus they are easily defined by marine planktonic index taxa (*Orbulina suturalis* and *Velapertina indigena* respectively).

By contrast, the Wielician hallmark is of evaporites – the deposits of a salinity crisis developed in the Central Paratethys (Peryt, 2006; de Leeuw *et al*., 2010, with references therein).

Table 3

Foraminiferal isotopic composition of the Skawina Formation biozones

Biozone	Number of data	δ^{18}O	δ^{13}C
		Average (standard deviation in brackets) and median	Average (standard deviation in brackets) and median
IID	6	Gb: 1.88 (0.19); 1.95	Gb: 0.29 (0.40); 0.20
	10	U: 2.54 (0.27); 2.59	U: –0.42 (0.46); –0.39
IIC	3	Gq: –1.52 (0.12); –1.58	Gq: 2.19 (0.21); 2.21
	10	Gb: 1.28 (1.11); 1.72	Gb: 0.53 (0.28); 0.47
	8	U: 2.06 (0.72); 2.42	U: 0.07 (0.11); 0.06
IIAB	11	Gq: –1.10 (0.44); –1.16	Gq: 2.31 (0.34); 2.33
	26	Gb: –0.10 (0.71); –0.23	Gb: 0.59 (0.39); 0.58
	36	U: 1.29 (0.41); 1.26	U: 0.04 (0.25); 0.03

Index taxa as in Table 2 and Figure 3

These deposits occur across most of Carpathian Foredeep. *Globigerina druryi* and/or *G. decoraperta* have been accepted as the index taxa of the Wielician substage (Cicha *et al*., 1975). Nevertheless, other foraminiferal indicators are often applied in stratigraphic practice. The Agglutinated Foraminifera Zone, also known as the *Uvigerina costai* Zone (Łuczkowska, 1964) or the *Pseudotriplasia* Zone (Papp *et al*., 1978) as well as the onset of the *Globigerina bulloides* acme (Gonera, 1997) are among commonly used Wielician indicators. The Moravian/Wielician biotic change is well-recognized in, for example, the K-5 and ŽI-2 boreholes (Danube Lowland Basin) representative of one of the Badenian faciostratotypes (Brestenská, 1978*b*).

Foraminiferal palaeoecology shows a climatically driven environmental change at the Moravian/Wielician boundary (also known as CPN7/8) correlated with the Mi3 event (Gonera, 2001; Gonera *et al*., 2003; Harzhauser *et al*., 2011) i.e. the change from the Middle Miocene Climate Optimum to the Middle Miocene Climate Transition. Our isotopic analyses provide chemostratigraphic evidence of the lower boundary of the Wielician. The results of the oxygen and carbon stable isotopes indicate that this stratigraphic boundary is characterized by strong, environmentally controlled, isotopic change. Due to the air temperature decrease (the resulted in foraminiferal $\delta^{18}O$ increase) sea surface productivity was enhanced ($\delta^{13}C$ decrease, *Globigerina bulloides* acme), in the environmental change at the beginning of the Wielician.

CONCLUSIONS

1. The stable oxygen and carbon isotope ratios in the tests of *G. quadrilobatus* (shallow pelagic), *G. bulloides* (deeper pelagic) and *Uvigerina* (benthic) show temporal changes in the Skawina Formation prior to the Badenian evaporite deposition.

2. The foraminiferal assemblage biozones of the Skawina Fm. identified in the 1960s are distinctive units in terms of the $\delta^{18}O$ and $\delta^{13}C$ ratios of their foraminiferal tests. Changes in the isotopic composition coincide with biozonal boundaries: the IIAB/IIC boundary coincides with a strong increase in $\delta^{18}O$, while the IIC/IID boundary coincides with notable decrease in $\delta^{13}C$.

3. The foraminiferal C and O stable isotope events detected below the Badenian evaporite can be applied as stratigraphic markers in correlation across the Carpathian Foredeep.

4. The general C and O isotopic trends in foraminifers of the Skawina Formation are not affected by the presence of sand and/or rhodolith debris occurring in various parts of the profiles (most frequently in the IIC biozone). Such shallow-water facies are apparently not *in situ* and represent slump deposits in the Tegel sedimentation area.

5. The lower boundary of the Wielician substage lies at change from the Middle Miocene Climate Optimum to the Middle Miocene Climate Transition, at the point where a normal marine environment (*Orbulina suturalis* Zone) starts to transform into salinity crisis environments of the Central Paratethys. In the Polish Carpathian Foredeep this turning point is located within the Skawina Formation.

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