DEEP WATER AGGLUTINATED FORAMINIFERA FROM THE JURASSIC/CRETACEOUS BOUNDARY AND PALEOENVIRONMENTAL SETTINGS OF THE MAIOLICA TYPE FACIES FROM THE CZORSTYN RIDGE (PIENINY KLIPPEN BELT, WESTERN CARPATHIANS)

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Abstract. Deep-water carbonates deposited on the Czorstyn elevated ridge of the Pieniny Klippen Belt paleogeographic domain record changes in agglutinated foraminifera morphogroups through the J/K boundary interval at the Erdútsky kostol section. Microfacies, abundance, taxonomic and morphogroup analyses of the agglutinated foraminifera show the response of the assemblages to the flux of organic matter. In the uppermost Tithonian C. brevis Zone a distinct high abundance assemblage is represented mostly by sessile epifaunal tubular agglutinated foraminifera such as *Rhizammina* and *Tolypammina,* pointing to an eutrophic setting. In the lowermost Berriasian C. alpina Zone the mobile epifaunal tubulothalamous taxa *Ammodiscus* and *Glomospira* and multilocular taxa *Cribrostomoides* and *Trochammina* increase while the epifaunal tubular agglutinated foraminifera decrease. The assemblage composition and the slender tubular foraminifera suggest oligotrophic settings. The infaunal foraminifera decrease and point to increasing oxygenation of the bottom and pore waters.

INTRODUCTION

The Pieniny Klippen Belt (PKB) represents a narrow arch structure spanning the northern part of Slovakia and a small Polish sector in the Pieniny Mountains. The PKB is commonly interpreted as arelict of a continental crust fragment positioned in the middle of the Penninic ocean (e.g., Plašienka 2003; Froitzheim et al. 2008) and includes a variety of tectonic and sedimentary units compressed into a narrow (a few kilometers) zone (Mišík et al. 1996; Plašienka & Mikuš 2015) (Fig. 1). The two most antithetical successions are the deep water development of the Kysuca unit and the shallower water facies of the Czorstyn unit (Birkenmajer 1977; Mišík et al. 1994; Mišík et al. 1996; Wierzbowski et al. 2004). The detailed biostratigraphy of the Lower Cretaceous Maiolica type formations in the Western Carpathians is based on calpionellids and calcareous dinoflagellate cysts including the Tithonian – Hauterivian Zones (Reháková 1995; Reháková 2000; Reháková & Michalík 1997). The tectono-sedimentary de-

velopment of the Czorstyn succession is documented by more than 40 complete post-Jurassic sections including an event of emersion of the so-called Czorstyn swell during mid-Cretaceous followed by karstification and later drowning (Mišík 1994; Aubrecht et al. 2006; Jamrichová et al. 2012). The Erdútsky Kostol klippe is situated in the Orava sector of the PKB north of the Zázrivá-Havrania village. The studied klippe (49°17'50.9"N, 19°13'13.5"E) occurs near the forest road, east of a much larger klippe forming Kozinec Mountain (Fig. 1C). The section is several meters thick in overturned position, exposing the upper part of red nodular limestones of the Czorstyn Limestone Formation (Kimmeridgian), and the lower part of the Maiolica-type Durstyn Limestone Formation with two members: the Korowa Limestone Member and Sobótka Limestone Member (Tithonian-Berriasian) (Fig. 1D). The upper boundary of the Durstyn Limestone Formation is formed by an exemplary paleokarst surface. The section continues with red organodetritic marlstones of the Chmielowa Formation (upper Albian). Previous biostratigraphic data from this section were provided by Jamrichová et al. (2012).
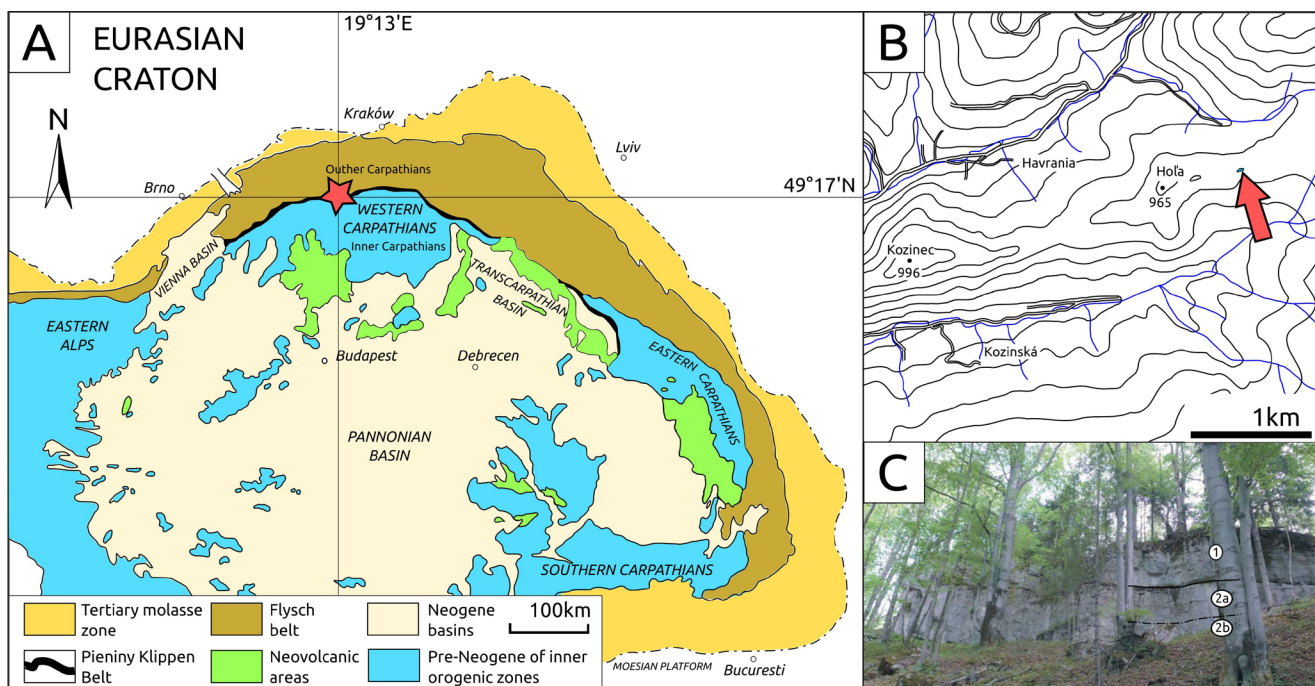
Fig. 1 - A) Sketch geological map of the Carpathians (after Kováč et al. 1998). Sampling locality in the Pieniny Klippen Belt shown by a star. B) Exact position of the section (GPS: 49°17'50.9"N, 19°13'13.5"E). C) The Erdútsky Kostol klippe, 1: Red nodular limestones of the Czorstyn Limestone Formation (Kimmeridgian), 2a: Reddish Maiolica type limestones of the Durstyn Limestone Formation – Korowa Limestone Member (Tithonian), 2b: Light gray Maiolica type limestones of the Durstyn Limestone Formation – Sobótka Limestone Member (Berriasian).

The J/K boundary interval in the Tethyan and Atlantic is marked by the boom of small, globular forms of *Calpionella alpina* Lorenz, 1902 accompanied by a sudden decline of *Crassicollaria* spp., defining the base of the lowermost Berriasian C. alpina Zone (Lopez-Martínez et al. 2013). Calcareous nannoplankton underwent a significant global radiation in the Tithonian–Berriasian (Bornemann et al. 2003), including the FO of two species: *N. steinmannii minor* (Kamptner, 1931) and *N. kamptneri minor* (Brönnimann, 1955) (Wimbledon et al. 2011).

The oldest assemblages of deep water agglutinated foraminifera (DWAF) are the so called Argo type fauna, known from the Tithonian of the Indian ocean (Kaminski et al. 1999) and in the Kimmeridgian of the North Atlantic (Luterbacher 1972). Mišík and Soták (1998) described cross sections of DWAF as so-called "microforaminifers" from the Callovian-Oxfordian deep water carbonates in the Slovak sector of the PKB. The term was derived from their particularly small size often below 200 µm, which is characteristic for the Argo type microfauna. The biostratigraphic distribution of the Lower Cretaceous DWAF is documented from the nearby

Outer Carpathian basins with flysch type successions (Geroch 1961; Geroch & Nowak 1984; Szydlo 1997; Szydlo 2004). From the PKB recent research has reported the occurrence of DWAF in the upper Valanginian – Hauterivian Maiolica type limestones of the Pieniny Limestone Formation from the deep water Kysuca succession (Podbiel unit) (Józsa & Reháková 2017).

Observations documenting the mode of life among living benthic foraminifera show a relation between test morphology and microhabitat (Jones & Charnock 1985; Corliss & Chen 1988). Subsequent observations on modern foraminifera show that the whole fauna is controlled by parameters such as the flux of organic matter and oxygen concentrations in both bottom and pore water (Jorissen et al. 1995; Van der Zwaan 1999; De Rijk et al. 2000). Morphogroup analysis classifies the tests of foraminifera with similar morphologies into separate groups and helps to reconstruct these environmental factors. For this reason, morphogroup analysis is widely used also as a tool for paleoenvironmental interpretation of the Late Jurassic and Early Cretaceous deep marine environments (Nagy et al. 1995; Szydlo 2005; Reolid et al. 2008; Nagy et al. 2009). Both modern and fossil studies on the

relative size and total abundance of tubular agglutinated foraminifera show that they vary according to productivity changes (Kaminski & Kuhnt 1995).

This paper describes for the first time the taxonomic composition of high-resolution dated DWAF assemblages through the J/K boundary interval from the Western Carpathians. The quantitative, taxonomic and morphogroup data clarify the possible causes of environmental perturbations affecting the DWAF assemblages through the J/K boundary interval on the Czorstyn elevated ridge of the Pieniny Klippen Belt paleogeographic domain.

MATERIAL AND METHODS

A total of ten samples were collected through the J/K boundary interval for dissolution in acids and thin section preparation. Exactly 100 g of indurated limestones from each sample was slowly dissolved uncrushed in 5% hydrochloric acid. The residues containing acid treated assemblages (ATA's) were gently washed through 125 and 71 micron mesh sieves and dried. The >125 micron fractions with foraminifera were stored in microslides, counted and measured with an optical micrometer. The tubular morphotypes were divided into four categories depending on the thickness of the tubes. The length of the tubes in each category was counted as cumulative length (Fig. 3). SEM images were taken in the Slovak Academy of Sciences, Institute of Informatics using a Quanta FEG 250. Microslides with picked foraminifera are stored in the micropaleontology collections at the Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University in Bratislava. Type specimens are housed at the European Micropalaeontological Reference Centre, Micropress Europe, AGH University of Science & Technology, in Kraków, Poland.

RESULTS

Microfacies and biostratigraphic analyses

Following the earlier works of Jamrichová et al. (2012), samples were collected and revised in thin sections focusing on the J/K boundary interval. The reddish limestone samples from the Korowa Limestone Member below the J/K interval yielded a rich and diverse assemblage of calpionellids (*Crassicollaria - Calpionella* microfacies) (Fig. 2A). The presence of *Crassicollaria brevis* Remane, 1962 and abundant other *Crassicollaria* spp. represent the uppermost Tithonian Biozone in the Tethyan Crassicollaria Zone and Brevis Subzone. Other skeletal grains are represented mostly by echinoderm debris, gastropods, both thick and thin walled bivalve shell debris, ostracods, radiolarians (mostly Spumellaria with common Nassellaria) and calcareous benthic foraminifera, mostly *Spirillina* sp. (Fig. 2) and *Lenticulina* sp. The uppermost Tithonian sample from below the J/K boundary interval yielded the maximum occurrence of DWAF and is represented mostly by a calpionellid microfacies (*Crassicollaria – Calpionella* microfacies) (Fig. 2B) with abundant *Globochaete alpina* Lombard, 1945 commonly forming larger aggregates (Fig. 2C). Just at the level with the color change from reddish limestones of the Korowa Limestone Member to pale gray limestones of the Sobótka Limestone Member, a bloom of small, globular forms of *Calpionella alpina,* Lombard, 1902

Fig. 2 - Microfacies from the Durstyn Limestone Formation. A) Radiolarian-calpionellid wackestone with gastropods and a diversified assemblage of calpionellids (*Crassicollaria* and *Calpionella*) (sample EK7). B) *Spirillina* sp. (Sample EK7). C) Aggregate of *Globochaete alpina* (Lombard) (sample: EK7). D) Radiolarian calpionellid wackestone with dominant small *C. alpina* and juvenile ammonites (Sample EK8.5).
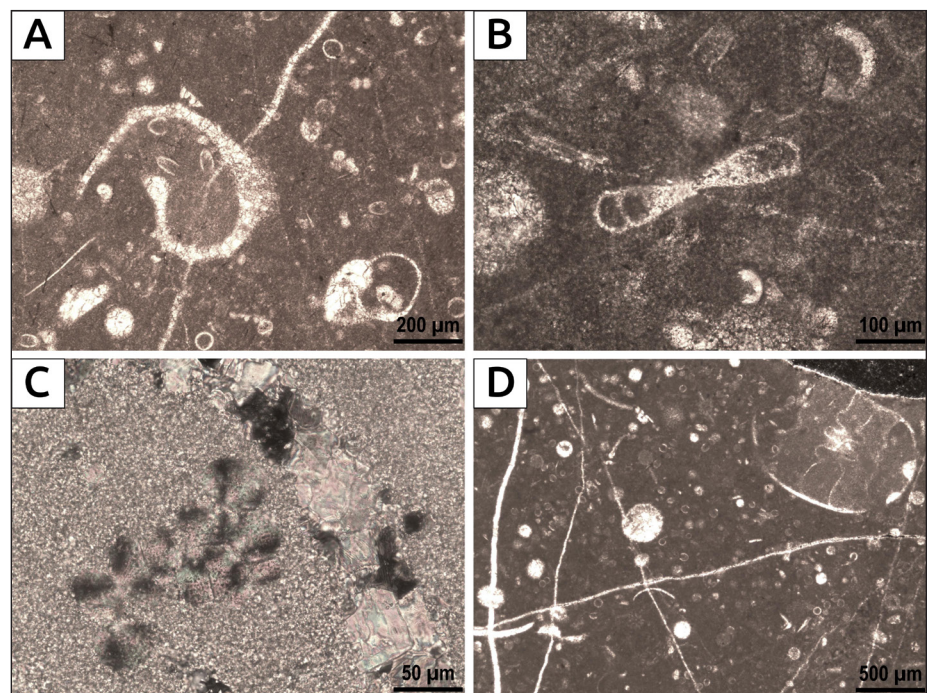
occurs, accompanied by a sudden decline of *Crassicollaria* spp., defining the base of the lowermost Berriasian *C. alpina* Zone. The microfacies also yielded abundant radiolaria (Nasellaria are rare), echinoderm fragments, ostracods, thin walled bivalve shell debris and juvenile ammonites (Fig. 2D).

Deep water agglutinated foraminiferal distribution

The DWAF show a contrasting quantitative distribution through the J/K boundary interval. While they are abundant in the uppermost Tithonian, they significantly decrease in the lowermost Berriasian (Fig. 3). This decrease is preceded by a significant peak in abundance and occurs at the transition between the reddish limestones of the Korowa Limestone Member and the light-colored limestones of the Sobótka Limestone Member. The assemblages are moderately diverse, between ten and seventeen taxa are recognized in the samples. The most abundant DWAF are fragments of tubular groups with a different length of both straight (*Rhizammina* sp.) (Pl. 1A) or meandering (*Tolypammina* spp.) types (Pl. 1B-D).

Among the polythalamous species, *Pseudomorulaeplecta franconica* (Gümbel, 1862) (Pl. 1U-W), *Cribrostomoides universus* (Haeusler, 1881), *Cribrostomoides* aff. *universus* (Haeusler, 1881), *Trochammina erdutensis* n. sp. (Pl. 1AG-AL) and *Verneuilinoides favus* (Bartenstein, 1937) (Pl. 1W-X) are common to abundant. Among them, the dominant species is represented by the biserial elongated *P. franconica* in the Tithonian; however, its abundance decreases in the Berriasian. The specimens of *P. franconica* reach the largest size among the multilocular agglutinated foraminifera. Less well represented is *Pseudoreophax cisovnicensis* Geroch, 1961 (Pl. 1Q-O). This species is present in all the samples, but it rarely exceeds 5% of the assemblage. In the Tithonian, *P. cisovnicensis* is accompanied by similar, but rare, specimens of *Scherochorella minuta* (Tappan, 1940) (Pl. 1L-N) and ?*Bicazammina* sp. (Pl. 1K). The occurrence of rare *Kutsevella* sp. was noted in a single sample (Pl. 1W-X; Fig. 3EK5). Tubulothalamous taxa are represented by *Glomospira charoides* (Jones & Parker, 1860) (Pl. 1F), *Glomospira gordialis* (Jones & Parker, 1860) (Pl. 1G) and *Ammodiscus* aff. *cretaceus* (Reuss, 1845) (Pl. E), and *Glomospira serpens* (Grzybowski, 1898) (Pl. 1H-I). *G. charoides* shows a low abundance in the Tithonian succession, not exceeding 10%, while in the Berriasian part of the

succession, it records a major increase, up to 30% (Fig. 3). The flatter relatives of the dominant *G. gordialis* and the less well represented *A.* aff. *cretaceus* (Pl. 1E) do not exceed 20% of the assemblage. *G. serpens* (Pl. 1H-I) is an accessory species and does not represent more than 3% of the assemblage. The monothalamous *Psamosphaera* sp. is also less represented and even more scattered.

Results of morphogroup analysis

The assemblage of DWAF is subdivided into four main morphogroups (Fig. 3M1-M4). The M1 morphogroup is represented by epifaunal tubular sessile passive detritus feeders, both straight (*Rhizammina* sp.) and meandering (*Tolypammina* sp.). The fragmentation of tubes is various due to their common tendency to break. The individual fragments might belong to the same specimen and therefore it is difficult to estimate whether the M1 morphogroup represents the dominant morphogroup. However, there is a clear decreasing trend in abundance mainly shown by the attached *Tolypammina* spp. This might point to the absence of suitable substrate for attachment of these sessile foraminifera, which is represented, in such pelagic facies, mostly by the shells of molluscs. The fragments of the tubular species included in the M1 morphogroup were divided into four categories depending on the width of the test. The fragments with the largest tube diameter - between 150-200 µm - were abundant in the Tithonian samples (Fig. 3EK1-EK7), while in the Berriasian, specimens with a diameter greater than 150 µm are scarce or absent.

The M2 morphogroup is represented by tubular, but coiled specimens of *Glomospira* spp. and *A.* aff. *cretaceus*. These epifaunal species become particularly abundant after a major decline around the J/K boundary interval (Fig. 3EK7). The M3 morphogroup includes the epifaunal multilocular taxa *Cribrostomoides* spp. and *T. erdutensis* n. sp. In the Tithonian, this morphogroup is less well represented, but it increases in abundance in the stratigraphically highest Tithonian sample and in the lowermost Berriasian. The morphogroup M4 is represented by elongated tapered morphotypes such as *P. franconica, V. favus, P. cisovnicensis, S. minuta* and ?*Bicazammina* sp. The representatives of this deep infaunal morphogroup, particularly *P. franconica,* are abundant in the Tithonian, but gradually become insignificant in the Berriasian.
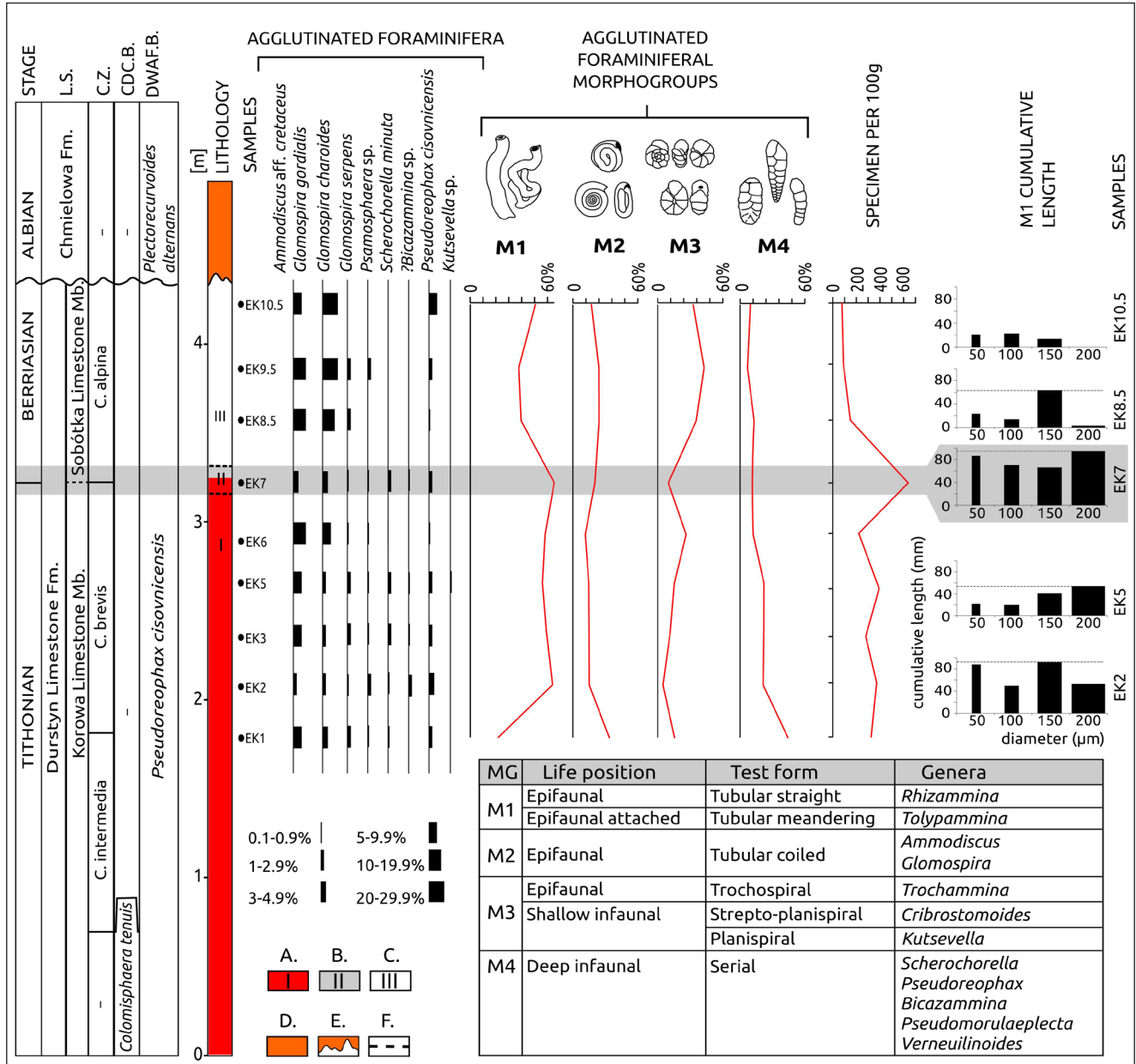
Fig. 3 - Stratigraphy of the lower part of the Erdútsky Kostol section. A: Reddish Maiolica type limestones. B: Jurassic/Cretaceous boundary interval. C: Light Maiolica type limestones. D: Red organodetritic limestones. E: Paleokarst surface. F: Gradual change from reddish to light Maiolica type limestones. C.B: Calpionellid zones. CDC.B: Calcareous dinoflagellate cysts biozones. DWAF.B: Deep water agglutinated foraminiferal biozones.

SYSTEMATIC DESCRIPTIONS

Phylum **FORAMINIFERA** d'Orbigny, 1826
Class **ROTALIATA** Mikhalevich, 1980
(= class **GLOBOTHALAMEA** Pawlowski et al., 2013)
Order **Trochamminida** Saidova, 1981
Superfamily Trochamminoidea Schwager, 1877
Family Trochamminidae Schwager, 1877
Genus *Trochammina* Parker & Jones, 1859

Type species: *Trochammina inflata* (Montagu, 1808)

Trochammina erdutensis n. sp.

Pl. 1AD-AI

Derivatio nominis: from the Erdútsky Kostol Klippe above the Zázrivá village, Havrania Valley in North Slovakia.

Holotype: specimen illustrated on Pl. 1, fig. AD. Holotype and figured paratypes are deposited in slide no. 7/28B-3, in the collections of the European Micropalaeontological Reference Centre at Micropress Europe, AGH University of Science & Technology, in Kraków, Poland.

Paratypes: specimen illustrated on Pl. 1, figs. AE-AI.

Material: common as free specimens in nine acid treated samples stored in microslides.

Type locality: Erdútsky Kostol Klippe, northeast of Zázrivá - Havrania Village (49°17'50.9"N, 19°13'13.5"E).

Type level: uppermost Tithonian (C. brevis Zone) to lowermost Berriasian (C. alpina Zone)

Description. Test is convex-slightly concave, with inflated chambers and a low spire. The peripheral outline is circular (rounded), slightly lobate. Sutures are straight and relatively shallow. The growth rate of the chambers in the final whorl is low. Aperture is a long and low interomarginal to umbilical arch bordered by a thin lip. Umbilicus is deep and narrow (Pl. 1AF, AH, AI).

Remarks. The spiral side is slightly convex, with 5 to 6,5 inflated chambers increasing slowly in size. The wall is coarse grained with larger carbonate grains in the center of each chamber on the dorsal side, which are dissolved in the acid treated assemblages (Pl. 1AD, AH). The largest specimens found were up to 0.4 mm (Pl. 1AG) but most of the adult specimens vary in size between 0.28 and 0.32 mm. Neagu & Neagu (1995) illustrated a somewhat similar specimen as *Trochammina concava* Siebold & Siebold, 1960 (Pl. 5, figs 1-3) from the Tithonian of the Eastern Carpathians; however, their illustrations do not show the distinct larger grains situated in the center of the each chamber on the dorsal side as on *T. erdutensis* n. sp. The original descriptions and illustrations of Seibold & Seibold (1960) (Pl. 8, fig. 8) from the Upper Jurassic of Germany describe a specimen with a rather lower spire with a concave umbilical side, faster growth rate of chambers, and the absence of an apertural lip. Other upper Jurassic species were reported as *Trochammina kumaensis* Levina in Dain, 1972 (Pl. 25; figs 4, 5, 7, 8) and *Trochammina sablei* Tappan, 1955 (pl. 14; figs 6-9). These species differ also in possessing a low spire and wide umbilical area without a lip. Similar species were illustrated by Stelck & Wall (1955) (Pl. 2; figs 1-3, 6) from the Lower Cretaceous as *T. wetteri* Stelck & Wall. In the original description the authors do not provide the description of the aperture due to preservation issue and the number of chambers in the last whorl is declared as five however, on Pl. 2, fig. 6 also a six chambered specimen is illustrated.

Stratigraphic distribution. Common in the Maiolica type limestones of the upper Tithonian – lower Berriasian Durstyn Limestone Formation (Czorstyn Unit, Pieniny Klippen Belt, Western Carpathians).

Discussion

During Late Jurassic, common eutrophic conditions in the Tethyan realm lead to blooms of radiolarians (Weissert & Mohr 1996; Danelian & Johnson 2001; Wierzbowski et al. 2004). In the studied samples of the Erdútsky Kostol Section, alongside the calpionellids, the radolarians represent the most abundant constituents of the microfacies (Fig. 2A, D). Such high productivity environments are favorable for the development of sessile detritus feeders (Kaminski & Kuhnt 1995), as those included in the M1 morphogroup. A short-term high positive excursion of the M1 morphogroup is noted, predating the C. alpina Zone (Fig. 3A-B). As reported by Kaminski & Kuhnt (1995), larger diameters of tubular foraminifera (M1 morphogroup) occur when the flux of organic carbon to the sea floor is comparatively high. The results of cumulative length analysis performed in this study show that the largest specimens of the M1 morphogroup are predominantly present in the Tithonian samples (Fig. 3EK1-EK7), whereas in the lowermost Berriasian they are rather scarce or even lacking (Fig. 3EK8,5-EK10,5). Such sparse occurrence of large specimens and their unimodal size distribution, consisting entirely of very small forms, is typical of modern oligotrophic waters of the Sargasso Sea (Kaminski & Kuhnt 1995). On the contrary, the increase of cumulative length of the sessile epifaunal M1 morphogroup with large diameter (Fig. 3M1 cumulative length charts) and infaunal M4 morphogroup (Fig. 3M4) indicates higher rates of sea floor carbon flux in the Tithonian samples. This excursion of the M1 morphogroup might be correlated with the positive carbon isotope excursions noted immediately above the J/K boundary in the both Boreal and Tethyan regions (Dzyuba et al. 2013). However, according to the calpionellid biostratigraphy in the Erdútsky Kostol Section the M1 morphogroup excursion still occurs in the uppermost Tithonian C. brevis Zone (Fig. 3), while Dzyuba et al. (2013) noted this phenomenon slightly above the base of the C. alpina Zone.

After the sudden drop of the M1 morphogroup at the base of the early Berriasian C. alpina Zone, the mobile epifaunal species of morphogroups M2 and M3 start to flourish (Fig. 3). Such composition of the assemblage suggests oligotrophic environmental conditions (Jorissen et al. 1995). Several authors reported low $\delta^{13}C$ values on a re-

PLATE 1

A - *Rhizammina* sp. EK9. B-D - *Tolypammina* spp. B. EK1, C. EK9, D. EK7. E - *Ammodiscus* aff. *cretaceus* (Reuss), EK8.5. F - *Glomospira charoides* (Jones & Parker), EK2. G - *Glomospira gordialis* (Jones & Parker), EK6. H-I. *Glomospira serpens* (Grzybowski), H. EK2, I. EK1. J. - *Caudammina* sp., EK2. K - ?*Bicazammina* sp., EK7. L-N - *Scherochorella minuta* (Tappan), L-N EK7. Q-O - *Pseudoreophax cisovnicensis* Geroch, Q-P. EK1, R. EK10.5, O. EK3. S-T - *Pseudomorulaeplecta franconica* (Gümbel), S. EK9, T. EK3. U-V - *Verneuilinoides favus* (Bartenstein), U. EK2, V. EK6. W-X - *Kutsevella* sp., EK5. Y-Z - *Cribrostomoides universus* (Haeusler), EK7. AA-AC - *Cribrostomoides* aff. *universus* (Haeusler), AC. EK1, AA-AB. EK10,5. AD-AI - *Trochammina erdutensis* n. sp., AD. EK2, AE. AF. AH. EK1, AI. EK3, AG. EK6. Scale bar = 100 μm.

gional scale through the J/K boundary interval in the Tethyan area, which indicate a lower flux of organic matter caused by reduced productivity (Weissert & Channell 1989; Weissert & Mohr 1996; Prokoph et al. 2008). This trend might be reflected by the change in morphogroup composition in the Erdútsky Kostol Section at the base of the C. alpina Zone. In concomitance, a notable positive excursion among mobile tubulothalamous taxa (morphogroup M2; Fig. 3) - especially *G. charoides* - occurs above the J/K boundary. In modern Mediterranean settings, *G. charoides* displays the highest relative abundances in the deepest and most oligotrophic areas with very low carbon fluxes (De Rijk et al. 2000; Kaminski et al. 2005). In the Green Canyon area of the Gulf of Mexico, *G. charoides* was observed in relatively high proportions in areas of natural hydrocarbon seepage (Kaminski 1988), and it was observed in higher abundances at "hydrothermal mud" sites in the proximity of active hydrothermal vents at the Juan de Fuca Ridge (Jonasson et al. 1995). A similar rapid proliferation of tubulothalamous taxa was observed in the mid-Cretaceous "Hatteras Fauna" (Kaminski et al. 1999), as well as in lower Eocene sediments (Kaminski et al. 1989; Ortiz 1995; Galeotti et al. 2004). Thomas (2003) suggested that similar "*Glomospira* blooms" during the Paleocene Eocene Thermal Maximum (PETM) are linked to the release of methane hydrates. The same interpretation may be suggested for the decrease of Nassellaria, as O'Dogherty & Guex (2002) concluded that in some cases Nassellaria are less resistant to environmental stress and are more common in stable environments.

According to the TROX model of Jorissen et al. (1995) the decrease of deep infaunal morphogroups points to better oxygenation of the pore waters. Similarly the low abundance of the M4 morphogroup in the Lower Berriasian points to these conditions. The sedimentation of the Durstyn Limestone Formation took place on the Czorstyn elevated ridge, possibly characterized by better oxygenated bottom waters with respect to the deeper poorly oxygenated bottom waters of the Kysuca/Pieniny successions. Whether the DWAF variation through the same interval in the bathymetrically deeper Pieniny Limestone Formation reflects decreased oxygen conditions needs to be verified.

According to Rogov et al. (2010), in both the Boreal and Tethyan realms extinction rates through the J/K boundary interval do not change, not only among the foraminifera, but also in bivalves and ammonites. In contrast, this interval is rather characterized by an increase of provincialism and higher speciation rate. Similarly, the estimated mean standing diversity of the agglutinated foraminifera was not affected at the J/K boundary (Kaminski et al. 2010). The results of this study show only a slight diversity decrease represented by the absence of some rare infaunal species such as ?*Bicazammina* sp. and *S. minuta* above the boundary, which might reflect an increase in oxygenation. These species occur in younger strata in the Carpathian Cretaceous (Cetean et al. 2008).

Conclusions

Detailed sampling of the Maiolica type limestones of the Durstyn Limestone Formation through the J/K boundary interval records changes in the quantity and morphogroup composition of deep water agglutinated foraminifera. The record through the boundary interval show that the assemblages in the uppermost Tithonian (C. brevis Zone) have a different composition with respect to those of the lowermost Berriasian (C. alpina Zone).

Morphogroup analysis suggests environmentally induced changes controlling the flux of organic matter that influenced the agglutinated benthic foraminiferal composition. A remarkable decrease in the abundance of DWAF occurred above the J/K boundary compared with the Tithonian assemblages. The uppermost Tithonian assemblages yielded abundant representatives of the sessile epifaunal tubular morphogroup M1 with a short term positive excursion just below the J/K boundary, followed by a sharp decline in the lowermost Berriasian. This decrease in abundance reflects a change from eutrophic to oligotrophic conditions. The absence of tubular agglutinated foraminifera with diameter exceeding 150 μm in the lowermost Berriasian also points to oligotrophic conditions. The decrease in sessile *Tolypammina* spp. may also reflect the absence of larger skeletal grains in the substrate. The increased abundance of tubulothalamous taxa in the lowermost Berriasian, especially *G. charoides,* also suggest oligotrophic conditions or might also

indicate the presence of methane in the environment. The abundant epifaunal foraminifera and the gradual decline of the infaunal foraminifera included in the morphogroup M4, however, do show that the pore waters were well oxygenated.

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