Late Maastrichtian foraminiferids and diatoms from the Polish Carpathians (Ropianka Formation, Skole Nappe): a case study from the Chmielnik-Grabówka composite section

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ABSTRACT:

Well-preserved foraminiferids have been found in the Chmielnik-Grabówka section (Skole Nappe, Polish Carpathians). The Abathomphalus mayaroensis (late Maastrichtian) and Racemiguembelina fructicosa (early–late Maastrichtian) standard planktonic foraminiferal biozones have been recognized, based on the occurrence of their respective index species. Sediments of the R. fructicosa Zone contain diatoms, which are a rare component of Cretaceous flysch microfossil assemblages in the Carpathians. The diatom frustules and some foraminiferid tests are pyritized, probably after burial in the sediment, below the redox boundary or in the oxygen-deficient microenvironment inside the frustules or tests of microfossils; the presence of trace fossils and bio-turbational structures in the same bed indicate an oxygenated sea floor.

Key words: Carpathians; Skole Nappe; Cretaceous; Microfossils; Plankton; Foraminiferids; Diatoms; Flysch.

INTRODUCTION

Flysch sediments of the Carpathians are usually poor in diagnostic planktonic foraminiferids and, consequently, biostratigraphic resolution of many of their lithostratigraphic units is low. An exception is the ‘Senonian’–Palaeocene of the Ropianka Formation in the Skole Nappe, which contain abundant planktonic foraminiferids, including index taxa for standard biozones (Gasiński and Uchman 2009, 2011a, b). The Gansserina gansseri Zone (late Campanian–early Maastrichtian) and the Abathomphalus mayaroensis Zone (late Maastrichtian) are commonly recognized whereas the Racemiguembelina fructicosa Zone (early–late Maastrichtian) is rarely distinguishable north of the Mediterranean region (Nederbragt 1991; Robaszynski and Caron 1995; Li and Keller 1998; Arz and Molina 2002; Premoli-Silva and Verga 2004; Pérez-Rodrigues et al. 2012).

Well-preserved, partly pyritized foraminiferids of the R. fructicosa Zone, have been found in the Chmielnik-Grabówka section of the Skole Nappe (Text-fig. 1). The zone also contains pyritized diatoms, which are rarely reported from the Cretaceous flysch microfossil
assemblages in the Carpathians (Geroch and Nowak 1980). Although diatoms are a prominent group of modern phytoplankton, little is known about their ecological role in Cretaceous marine environments. This, in part, is due to the fact that diatom preservation is strongly controlled by taphonomic processes (Lohman 1960). The age and taxonomic composition of the microfossil assemblage reported herein make it a significant find. Its description and interpretation is the main aim of this paper as a contribution to the stratigraphy and palaeoecology of Upper Cretaceous flysch sediments.

GEOLOGICAL SETTING

The Skole Nappe is the most external major nappe of the Polish Flysch Carpathians on the northeastern bend of the Carpathian arc (Text-fig. 1A). It is composed of Lower Cretaceous–Miocene deep-sea sediments that accumulated in the Skole Basin of northern Neotethys and which were subsequently folded and thrust northward during the Miocene. The Upper Cretaceous–Palaeocene succession is dominated by turbiditic sediments of the Ropianka Formation (Kotlarczyk 1978 and references therein) (= the Inoceramian Beds in the older literature). It is overlain by Eocene deep-sea mudstone-dominated sediments of the Variegated Shale Formation (Rajchel 1990). The study region, south-east of Rzeszów, was described and mapped by Wdowiarz (1949), who distinguished lower, middle and upper levels in the Ropianka Formation (his Inoceramian Beds), which are together 500 m thick. Kotlarczyk (1978) subdivided the Ropianka Formation into the Cisowa Member (Turonian–lower Campanian), Wiar Member (lower Campanian–lower Maastrichtian), Leszczyny Member (lower Maastrichtian–Lower Palaeocene) and Wola Kozieniecka Member (Palaeocene) (Text-fig. 1C).

The Chmielnik-Grabówka composite section studied herein is located in the eastern part of the village of Chmielnik, along the Wylewna stream (right-hand tributary of the Chmielniczanka (Ryjak) stream) running through the hamlet Grabówka (hence its name). The geology and palaeontology of the Chmielnik area was briefly documented by Friedberg (1900, 1903, 1908), Grzybowski (1903), Kropaczek (1917), Chlebowski et al. (1937), Wdowiarz (1949), Bromowiec (1974) and Malata (2001). The upper part of the Ropianka Formation crops out in small, isolated exposures along the Wylewna stream (Text-fig. 1B). It contains mostly turbiditic beds composed of fine-grained, rarely medium- or coarse-grained calcareous sandstones in the lower part, which grade into grey and bluish-grey marls and marly mudstones in the upper part. The sandstones are muscovitic, mostly thin-bedded, parallel- and ripple-laminated, with sharp bases. Beds up to 1.5 m thick occur in some outcrops. Some beds contain abundant plant detritus, and others mud clasts. The thickness of the marls or marly mudstones is approximately equal to that of the sandstones (up to 1 m in some beds). Packages with thicker marls are distinguished as the “Bacinules Marl”, and form lensoidal lithosomes in the upper part of the Ropianka Formation (Wdowiarz 1949; Kotlarczyk 1978; Geroch et al. 1979). Locally, sandy mudstones contain blocks of sandstones. They are interpreted as debris flow deposits and are called the Makówka Slump Debris (Kotlarczyk 1985).

The studied deposits represent the Leszczyny Member of the Ropianka Formation sensu Kotlarczyk (1978, 1988). They belong to the Hadle Kańczuckie-Chmielnik Thrust Sheet, a complex structure, with four anticlinal elements and internal thrusts (Wdowiarz 1949). The complex tectonics suggests stratigraphic repetitions along the observed succession within the composite section studied. Consequently, the section was subdivided into three segments, A, B and C, each treated separately and then correlated biostratigraphically.

MICROFOSSILS

The micropalaeontological analyses were based on 18 samples. Dried residuum was sieved, with a final sieve size of 0.063 mm. The best specimens were identified and described using a Zeiss Stemi SV 11 stereomicroscope. Selected forms of foraminiferids and diatoms were studied and photographed by means of a scanning electron microscope (SEM (HITACHI S-4700 with EDS Vantage Noram)).

Planktonic foraminiferids

Nearly all of the studied samples of the Chmielnik-Grabówka section (CG1–CG15) (Text-fig. 2) contain well-preserved index planktonic species (Text-fig. 3). Two samples (CG1, CG2) of segment C yielded Abathomphalus mayaroensis (Bolli) (Text-fig. 4L, M), the index taxon of the eponymous zone of the upper Maastrichtian (Robaszynski and Caron 1995). Well-preserved specimens of this species are rarely found in the Carpathian Realm. Racemiguembelina fructicosa has...
Text-fig. 2. The studied section with indication of the three segments A, B and C, samples occurrence of taxa and foraminiferal zones distinguished. Black circles indicates abundant occurrence, white circle indicates rare occurrence, index species in bold, shadowed in the middle – planktonic taxa, shadowed on the right hand side – diatoms.

Abm – Abathomphalus mayaroensis

Rhabdammina sp., Nothia isp.
Rzehakina spp.
Ammodiscus sp., Glomospira sp.
Karrerulina spp.
Spiroplectammina sp.
Caudammina gigantea
Bathysiphon sp.
Trochammina spp., Trochamminoides spp.
Reussella szajnochae
Racemiguembelina fructicosa
Heterohelix spp.
Globigerinelloides prairehillensis
Hedbergella holmdelensis
Hedbergella monmouthensis
Globotrucana arca
Globotrucana bulloides
Globotrubcanita stuarti
Globotrubcanita stuartiformis
Globotrubcanella havanensis
Globotrubcanella petaloidea
Contusotrubcanella contusa
Abathomphalus mayaroensis
Archeoglobigerina cretacea
Gavelinella spp.
Osangularia spp.
Reussella szajnochae
Allormorphina spp., Quadriformina spp.
Cibicidoides spp.
Stensioeina spp.
Bolivinoides spp.
Nodosaria s.l
Aulacodiscus sp.
unidentified diatoms

Mixed assemblages (Cretaceous-Paleogene)

zones
been identified in samples CG5–CG7 (segment C; Text-fig. 2). This is the index species of the early–late Maastrichtian *R. fructicosa* Zone, preceding the *A. mayaroensis* Zone. Other epipelagic species, including *Globigerinelloides prairiehillensis* Pessagno, *Hedbergella monmouthensis* (Olsson) and *Heterohelix* spp., occur in high abundance in samples from the *R. fructicosa* Zone (Text-fig. 2). The foraminifers of sample CG15, which also contains pyritized diatoms, are relatively well-preserved and some of the planktonic foraminiferids are also pyritized. The pyritization is observed only among the tiny epipelagic *Hedbergella* spp.

and *Globigerinelloides* spp., with about 70% of the specimens pyritized. This sample falls within the early–late Maastrichtian *R. fructicosa* Zone (Robaszynski and Caron 1995; Premoli-Silva and Verga 2004; Gasiński and Uchman 2011a, b). The most characteristic species in sample CG15 include *R. fructicosa*, *Globotruncanita stuarti* (de Lapparent), *Globotruncanita stuartiformis* (Dalbiez), *Globotruncanata arca* Cushman, *Globotruncanata bulloides* Vogler (Text-fig. 3) and *Globigerinelloides prairiehillensis* Pessagno (Text-fig. 3O). Text-figs 3 and 4 show SEM micrographs of these species. Additionally, a few specimens of juvenile (larval stage) bivalve shells (glochidia?), fish teeth, as well as, fragment of crinoid cirri have been identified within sample CG15 (Text-figs 3R, 4A, B).

**Benthic foraminiferids**

Agglutinated foraminiferids are relatively rare, except for samples CG12 and CG14. They are dominated by the suspension feeder morphogroup *sensu* Jones and Charnock (1985), Nagy (1992) and Koutsoukos and Hart (1990). *Rhabdammina* sp. and *Nothia* sp. are abundant and constitute about 70% of the agglutinated foraminiferal assemblage. Less abundant are *Trochammina* spp., *Trochamminoides* spp., and *Caudammina* spp. (about 15% of the agglutinated foraminiferal assemblage) which belong to the epifaunal morphogroup. In samples CG11 and CG13, representatives of the infaunal morphogroup are rare, and include *Spiroplectammina* spp. and *Karrerulina* spp. Among the calcareous benthic foraminiferids, some species of *Allogromphila, Stensioloea, Cibicidoides* and *Bolivinoides* are dominant in samples CG1 and CG2 (ca. 15% of the whole foraminiferal assemblages), from the A. *mayaoroensis* Zone (Text-fig. 2). These genera are mainly characteristic of the Boreal Domain (Gasiński 1997 and references therein), however, they are also represented by widespread species, especially in the North African Cretaceous sediments (e.g. Ayad *et al.* 1997; Khalili 1998; Peryt *et al.* 2002). Their presence suggests an influence of Boreal waters in this part of the Skole Basin during the latest Maastrichtian (Gasiński and Uchman 2009, 2011a, b).

**Diatoms**

Ten diatom specimens, obtained together with the foraminifers, have been examined. They were yielded by samples CG15 (8 specimens) and CG15A (2 specimens), both from the basal part of segment A. Sample CG15 is from a 20–22 cm-thick dark grey marl, which overlies (with a transition) a 65 cm-thick, fine-grained sandstone with intraclasts at the base, and underlies a similar sandstone bed that is 20 cm thick. Sample CG15A was collected below the sandstone (Text-fig. 2).

All of the diatoms are completely pyritized (Text-fig. 3E). The pyrite crystals entirely mask the fine structure of the frustules, making species-level identification impossible (Text-fig. 3C D, F, H). Four valves are 150–180 μm in diameter and display sectors arranged in a cruciform pattern (Text-fig. 3A–C, F). This general morphology is characteristic of the genus *Aulacodiscus*, Ehrenberg, 1844 (Proschkina-Lavrenko 1949; Harwood and Nikolaev 1995; Strelnikova *et al.* 2004).

Diatoms from sample CG15 (Text-fig. 3G, H, I, J) are unidentifiable due to the absence of any diagnostic features. Lenticular frustules (Text-fig. 3G-J) are characteristic of a number of Late Cretaceous genera, including e.g., *Stellarima, Nikolaevia* and *Coscinodiscus*. Some specimens (Text-fig. H-J) have a diameter 150–200 μm, round shape and lenticular, convex valve faces. The specimen illustrated in Text-fig. 3G is represented by a cylindrical frustule, which is 180 μm in diameter and displays a flat or slightly concave valve face. The marine genus *Aulacodiscus* first appeared in the Cretaceous and is known up to the Recent (Proschkina-Lavrenko 1949; Nikolaev *et al.* 2001; Sims *et al.* 2006). It is common in the numerous Late Cretaceous diatom floras of middle and high latitudes, e.g., the Campanian of the Kanguk Formation, Devon Island, Canadian High Arctic (Witkowski *et al.* 2011), the Maastrichtian Marca Shale Member of the Moreno Formation in California, USA (Nikolaev *et al.* 2001; Davies 2006), the Campanian–Maastrichtian of the Ural Mountains and the the West Siberian Plain (Strelnikova 1974) and the Campanian–Maastrichtian of Central Russia near Saratov (Oreshkina *et al.* 2013).

**DISCUSSION**

**Biostratigraphic framework**

Because of tectonic complications, the three segments of the Chmielniak-Grabówka composite section were studied separately, and then correlated biostratigraphically.

The *A. mayaroensis* and *R. fructicosa* zones, have been recognized based on the occurrence of their respective index species. The *A. mayaroensis* Zone is recognized in two samples of segment C, located in the uppermost part of the studied section. The *R. fructicosa* Zone was recognized in all three segments, indicating that they are at least partly coeval (Text-fig. 2).
The standard foraminiferal zonation by Robaszynski and Caron (1995, p. 6) has been modified recently by Ogg and Hinnov (2012, p. 810, fig. 27.6). Above the *A. mayaroensis* Zone, the highest foraminiferal zone of the Maastrichtian in the scheme of Robaszynski and Caron (1995), they propose two additional zones, namely the zones of *Pseudoguembelina hariaensis* and of *Plummerita hantkenionoides*. In fact, the *P. hariaensis* Zone was also recognized by Robaszynski and Caron (1995), but in their “heterohelicid” scheme, in a position correlated with the *A. mayaroensis* Zone of their “globotruncanid” zonation. Both zones never appear in the same standard biozonation. Additionally, between the zones of *R. fructicosa* and *Gansserina gansseri*, Ogg and Hinnov (2012) recognize the *Pseudoguembelina palpebra* Zone. This zone was not used in the Robaszynski and Caron (1995) scheme but it was recognized earlier by Li and Keller (1998), Huber et al. (2008) and Pérez-Rodrígues et al. (2012). It seems that Ogg and Hinnov’s zonation combines the Tethyan and Boreal schemes, based on globotruncanids and heterohelicids respectively. Such a combination may have, however, rather limited application, as representatives from both domains can co-occur in only restricted areas (ecotones?).

Microfossil palaeoecology

The analyzed foraminiferal assemblage resembles those reported earlier from the coeval stratigraphic interval of the Skole Nappe (Gaj and Bąkowiec sections: Gasiński and Uchman 2009, 2011). The foraminiferids of the Chmielnik-Grabówka section are dominated by planktonic taxa (Text-fig. 2). Similarly to the Bąkowiec section, the number of the epipelagic planktonic taxa (i.e. Heterohelix spp., Globigerinelloides prairiehillensis, Hedbergella holmdelensis, H. monmouthensis, R. fructicosa) increases upwards, toward the top of the Maastrichtian (A. mayaroensis Zone), which suggests similar factors influencing depositional environment in the studied part of the Skole Basin (Gasiński and Uchman 2011).

Agglutinated foraminiferids are relatively rare and the suspension feeder morphogroup (sensu Jones and Charnock 1985), Nagy (1992) and Koutsoukos and Hart (1990) dominates. Only samples CG12–CG15 contain relatively abundant agglutinated taxa belonging mainly to the suspension feeder morphogroup (Nothia sp., Rhabdammina sp.), which are typical of environments influenced by turbiditic sedimentation (Gasiński and Uchman 2011 and references therein). Usually, abundance of planktonic foraminiferids is inversely related to the abundance of agglutinated benthic taxa (Gasiński 1998). This inverse relationship is clear in the studied section, suggesting that most of the nutritional suspension was consumed by planktonic taxa, causing a shortage of food for benthic taxa. With respect to palaeobathymetry, calcareous benthic foraminiferids are rare in almost all samples, except for samples CG1 and CG2 (Text-fig. 2) in the topmost Maastrichtian. They display a wide bathymetric range above the calcite compensation depth.

The frustules of the studied diatoms from the Ropianka Formation are large, thick-walled valves, suggesting their benthic affiliation (Sims et al. 2006). Most of the Recent Aulacodiscus species belong to littoral benthic communities, living mainly on sandy substrates and preferentially in warm waters (Hernandez-Becerril et al. 1994). Accordingly, the extinct species of Aulacodiscus may also be regarded as indicative of shallow-marine environments (Proschkina-Lavrenko 1949; Strelnikova 1974; Witkowski et al. 2011).
The presence of a few fragments of juvenile bivalves, fish teeth and remnants of crinoids, together with benthic and planktonic foraminifers, indicates the presence of rich benthic and pelagic faunal assemblages. However, these fossils could have not been in situ, because the sediments were deposited by density currents, mostly turbidites. Mixing of the microfauna is evident in samples CG8 and CG9, taken from debris flow sediments, where Cretaceous and Palaeogene taxa co-occur [Subbotina cf. yeguaensis (Weinzierl and Aplin), Subbotina cf. triloculinoides (Plummer), Schackoïna sp.]. These samples are not included in the stratigraphic considerations.

**Preservation of diatoms**

Diatoms from samples CG15 and CG15A are pyritized, as indicated by their EDS analysis (Text-fig. 3E). The pyritization was not caused by anoxia on the sea floor, as the presence both of trace fossils (Chondrites, Planolites, Palaeophycus, Phycosiphon incertum, Nereites irregularis, ?Thalassinoides) (Text-fig. 5A–D) and bioturbation structures (probably Thalassinoides) in the diatom-bearing bed (sample CG15B; Text-fig. 3D) indicates an oxygenated sea floor. On the other hand, pyritization could have taken place within the sediments, either below the redox boundary, or in the organic-rich, oxygen-deficient microenvironment within the frustules. The redox boundary was located at a shallow depth, as is indicated by the dark grey colour of sediments in sample CG15. In this sample, pyritized diatoms and some pyritized planktonic foraminiferids co-occur with non-pyritized foraminiferids. It is probable that these pyritized microfossils (diatoms and planktonic foraminiferids) had been exhumed from sediments elsewhere, transported, redeposited and mixed with non-pyritized, calcareous tests of foraminiferids.

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Maastrichtian have been recognized in the Chmielnik-Grabówka composite section, based on the occurrence of their respective index species. The former is represented in only two samples from segment C, located in the uppermost part of the studied section. The latter zone was recognized in all three segments of the studied section, indicating that they are at least partly coeval. Additionally, pyritized diatoms are present in the R. fruticosa Zone, which is an unusual occurrence in Cretaceous flysch microfossil assemblages of the Carpathians. The pyritization was not caused by anoxia, because the presence of trace fossils and bioturbation structures in the diatom-bearing beds indicate an oxygenated sea floor. The pyritization probably took place in the sediment, either below the redox boundary or in the organic-rich, oxygen-deficient microenvironment within the frustules. The redox boundary was located at a shallow depth, as is indicated by the dark grey colour of sediments in sample CG15. In this sample, pyritized diatoms and some pyritized planktonic foraminiferids co-occur with non-pyritized foraminiferids. It is probable that these pyritized microfossils (diatoms and planktonic foraminiferids) had been exhumed from sediments elsewhere, transported, redeposited and mixed with non-pyritized, calcareous tests of foraminiferids.

CONCLUSIONS

The Abathomphalus mayaroensis and Racemiguembelina fruticosa planktonic foraminiferal zones of the


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