Miliammina gerochi n.sp. – A MIDDLE JURASSIC RZEHAKINID (FORAMINIFERIDA) FROM QUASI-ANAEROBIC BIOFACIES

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Abstract: *Miliammina gerochi* n.sp. is so far the oldest reported representative of the superfamily Rzehakinacea from Jurassic sediments. Its occurrence is confined to the lower part of Harcygrund Shale Formation in the Pieniny Klippen Belt (Western Carpathians, Poland). This formation is represented by a "black shale" facies developed during the late phase of the Aalenian/Bajocian "regional anoxic/dysoxic event". Overall biofacies relationships indicate that *M. gerochi* n.sp., as a benthic agglutinated foraminifer, inhabited normal saline, middle to outer neritic palaeoenvironments under extremely dysoxic or even suboxic, food-rich conditions, and gradually disappeared with improving bottom water oxygenation, enhanced density of macrofaunal bioturbation, increasing sedimentation rate, and probably deepening of the basin. The *Miliammina gerochi* Assembage marks a very productive phase in the Klippen Basin history. Based on functional morphology and studies of modern *Miliammina* species, it can be speculated that this Jurassic species preferred an endobenthic microhabitat and probably thrived on/within benthic bacterial mats associated with suboxic conditions. Comparison between different habitats successfully colonized by rzehakinids suggests that since the Jurassic till the present, this group preferred stressed environments rich in food. Evolutionary relationships remain uncertain due to the lack of reported ancestors.

Abstrakt: Wczesnobajoska *Miliammina gerochi* n.sp., aglutynująca otwornica bentoniczna, jest jak dotychczas najstarszym znanym przedstawicielem nadrodziny Rzehakinacea. Jej występowanie ograniczone jest wyłącznie do dolnej części formacji łupków z Harcygrundu w pienińskim pasie skałkowym (Karpaty Zachodnie, Polska). Formacja ta odsłania się w postaci facji „czarnych łupków", reprezentujących późną fazę regionalnego wydarzenia beztlenowego na pograniczu aalenu i bajosu. Ogólne relacje biofacjalne wskazują, że *M. gerochi* n.sp. zasiedlała morze o normalnym zasoleniu, w środkowej i zewnętrznej strefie nerytycznej, w warunkach eutroficznych, przy bardzo silnym zubożeniu w tlen. Stopniowy zanik tego gatunku należy wiązać z poprawą natlenienia, wzrostem gęstości żerowania makrofauny bentonicznej, wzrostem tempa sedymentacji oraz prawdopodobnie z pogłębianiem się basenu. Zespół z *M. gerochi* n.sp. wskazuje na bardzo produktywną fazę w historii basenu skałkowego. Na podstawie morfologii tej formy oraz na podstawie badań współczesnej *Miliammina* można sugerować, że opisywany gatunek preferował endobentoniczny styl życia, zasiedlając maty bakteryjne związane z warunkami suboksycznymi. Porównanie różnych środowisk skutecznie kolonizowanych przez rzehakinidy wskazuje, iż grupa ta od jury do dzisiaj preferowała bogate w pokarm środowiska stresowe. Pochodzenie tej grupy i jej nowego gatunku nie zostało dotychczas wyjaśnione z powodu braku jednoznacznych przodków.

Key words: *Miliammina gerochi* n.sp., Rzehakinacea, benthic foraminifera, functional morphology, anoxic/dysoxic palaeoenvironment.

INTRODUCTION

There is an increasing amount of evidence to suggest that the evolution of foraminifera and other marine faunas is strongly related to anoxic facies. There is little doubt that fluctuations of the bottom- and intersticial-water oxygenation are especially responsible for changes in faunal associations. The widespread distribution of black shale facies often coincides with the disappearance and/or appearance of certain foraminiferal taxa or even whole groups. Some benthic foraminifera are limited to these facies, and are only present when oxygenation is low and disappear with improvements of bottom water ventilation (Kaiho, 1991).

Such assemblages have already been reported from "the Aalenian–Bajocian regional anoxic/dysoxic event" in the Pieniny Klippen Basin (Tyszka & Kaminski, 1995). The as-
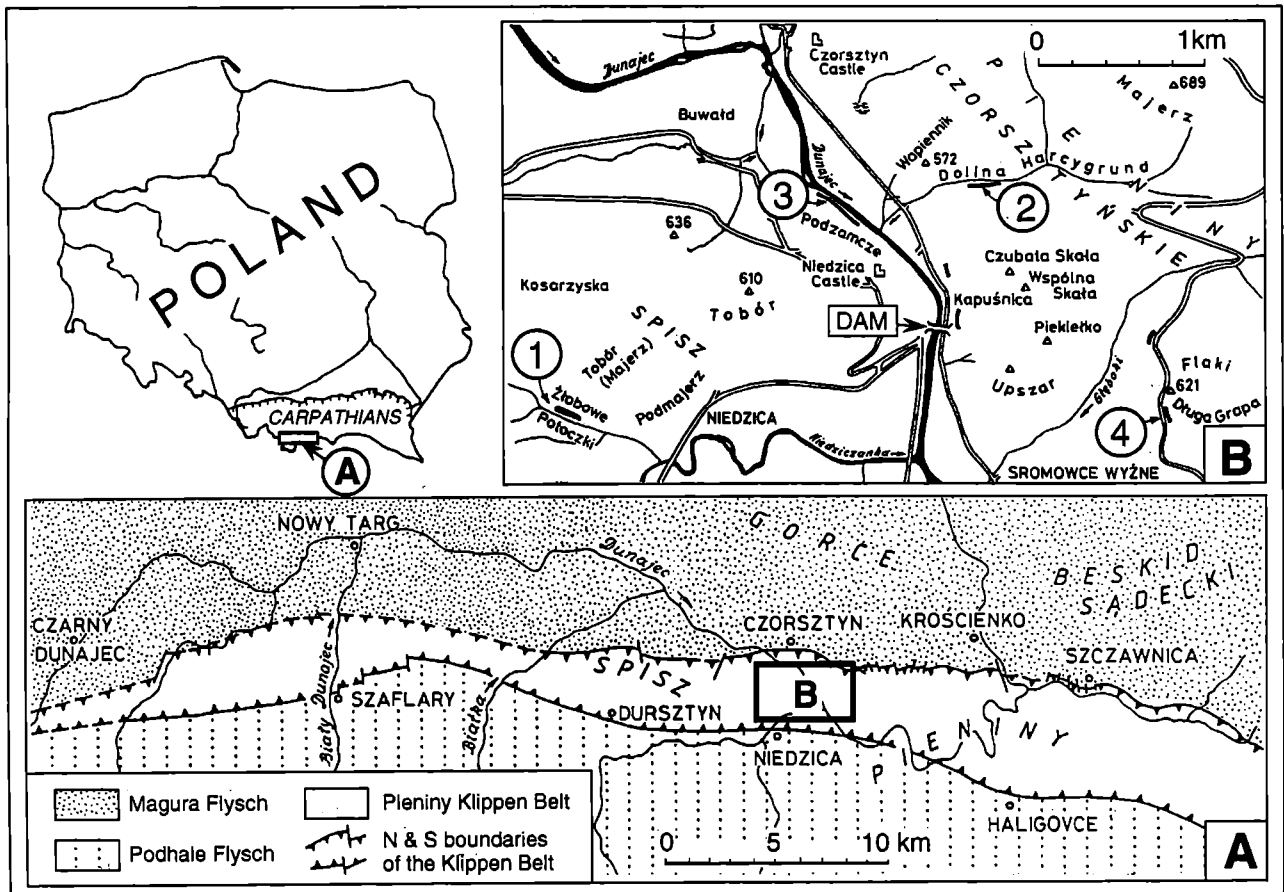
Fig. 1.   Location of the study area: A – position of the Polish part of the Pieniny Klippen Belt within the Carpathians (after Birkenmajer, 1977); **B** – detailed map (after Myczyński, 1973 – modified) showing distribution of examined outcrops, i.e.: 1. Żłobowe Potoczki, 2. Harcygrund Valley, 3. Podzamcze, 4. Cisowiec

semblages are dominated by agglutinated foraminifera, such as *Verneuilinella pieninica* Tyszka & Kaminski and *Trochammina globoconica* Tyszka & Kaminski. These two species occur only within a certain horizon of black shales and are missing from all other facies. A similar assemblage has also been identified within the "black shales" of another lithostratigraphic unit (Harcygrund Shale Formation), but associated with the same "regional anoxic/dysoxic event" (Tyszka, 1995). It is interesting that this assemblage is dominated by one species of genus *Miliammina*, a representative of Rzehakinacea. This superfamily has thus far not been reported from the Middle Jurassic. The main purpose of this study is to describe this new species of *Miliammina*, and to evaluate factors controlling the distribution of this species and the associated fauna.

METHODS

A total of 14 surface samples from the Harcygrund Shale Formation of the Branisko Succession were collected for this study. The sample processing consisted of drying, weighing out 250 g samples, and disintegrating in a solution of sodium carbonate. The disintegrated samples were washed through sieves with mesh diameters of 105 and 600

μm. The foraminifera were picked from fractions 105–600 μm.

GEOLOGICAL SETTING

The study area is confined to the Polish part of the Pieniny Klippen Belt, which represents the axial part of the Western Carpathians (Fig. 1). *Miliammina gerochi* n.sp. has been identified from the Harcygrund Shale Formation, which was formally distinguished by Birkenmajer (1977). This unit was separated by him from the "Posidonien-schichten" of Uhlig (1890), and Horwitz (1937) and corresponds to the *Posidonia* shales or *Posidonia* member in the Kýsuca Succession in Slovakia (Scheibner, 1968; see Birkenmajer, 1977). The Harcygrund Shale Formation belongs to the Dunajec Group and is recognized in the Branisko, Pieniny, and Magura successions (Fig. 2). These sedimentary successions were deposited within the Pieniny Klippen Basin, which represented a part of the Western Tethys (Birkenmajer, 1960, 1977).

The formation within the Branisko Succession has been studied here. It is characterized by dark-grey to black shaly marlstones, silty marls and shaly marly limestones. The shales often contain thin shells and imprints of the bivalve
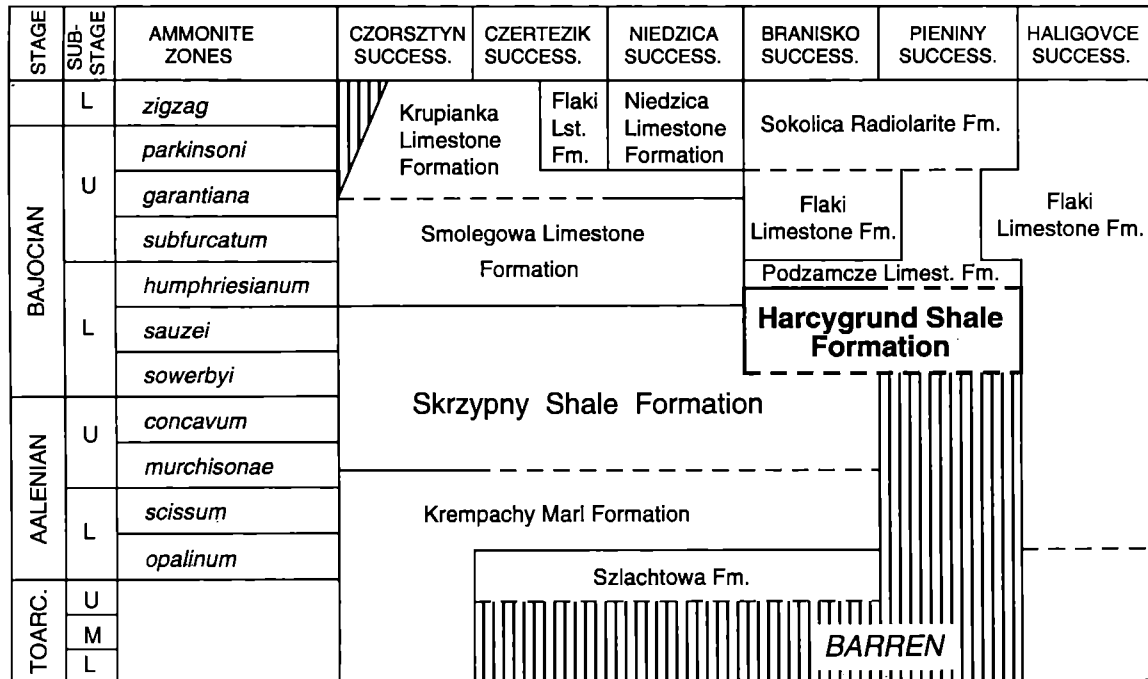
STAGE	SUB-STAGE	AMMONITE ZONES	CZORSZTYN SUCCESS.	CZERTEZIK SUCCESS.	NIEDZICA SUCCESS.	BRANISKO SUCCESS.	PIENINY SUCCESS.	HALIGOVCE SUCCESS.
	L	*zigzag*	Krupianka Limestone Formation	Flaki Lst. Fm.	Niedzica Limestone Formation	Sokolica Radiolarite Fm.		
BAJOCIAN	U	*parkinsoni*						
		garantiana	Smolegowa Limestone Formation			Flaki Limestone Fm.		Flaki Limestone Fm.
		subfurcatum						
		humphriesianum				Podzamcze Limest. Fm.		
	L	*sauzei*	Skrzypny Shale Formation			**Harcygrund Shale Formation**		
		sowerbyi						
AALENIAN	U	*concavum*						
		murchisonae						
	L	*scissum*	Krempachy Marl Formation					
		opalinum	Szlachtowa Fm.					
TOARC.	U							
	M		BARREN					
	L							

Fig. 2. Location of the Harcygrund Shale Formation within Toarcian to Lower Bajocian lithostratigraphic scheme of the Klippen successions in the Pieniny Klippen Belt of Poland (after Birkenmajer, 1977)

Bositra buchi (Roemer), fine mica flakes, small pyrite concretions, and plant detritus (especially in the lower part of the unit). The thickness of the formation ranges from 70 to 100 m. The lower boundary with the Skrzypny Shale Formation is undefined (tectonic), the upper one is usually tectonic. A few localities reveal a transitional contact with the overlying Podzamcze Limestone Formation (Birkenmajer, 1977). The early Bajocian age of the Harcygrund Shale Formation is based on ammonites and represented by a biostratigraphical interval from the *Sonninia sowerbyi* Zone, through *Otoites sauzei* Zone, to the lowest part of *Stephanoceras humphriesianum* Zone (Myczyński, 1973).

Locality

Samples collected to the present studies have been taken from four localities (Figs. 1, 3):

Harcygrund Valley. Left side of the lower part of the valley (Myczyński, 1973: p. 28-29, figs. 1, 5, 6; Birkenmajer, 1977: figs. 7H, 16A; Tyszka, 1995: figs. 1, 2B, 22); type section of the formation; a 8 meter thick sequence of dark-grey marly limestones intercalated with dark-grey to black, often sandy marlstones is exposed; maximum thickness of limestone bands: 30–40 cm, usually 10–20 cm.

Żłobowe Potoczki. Left tributary stream of the Niedziczanka Stream near Niedzica village (Tyszka, 1995: figs. 1, 2B, 23); the left bank of the middle part of the Żłobowe Potoczki, exposed 2 m above the stream; a two-meter thick section of dark-grey to black shaly marlstones; layers dip 175/60, the whole complex tectonically contacts with vertical bands of green radiolarites (Czajakowa Radiolarite Formation); shales rarely intercalated with thin bands of dark-grey marly limestones showing a sort of "boudinage"-struc-

tures.

Podzamcze – right bank of the Dunajec River. Near Niedzica, below the castle; 2–3 m thick complex of dark-
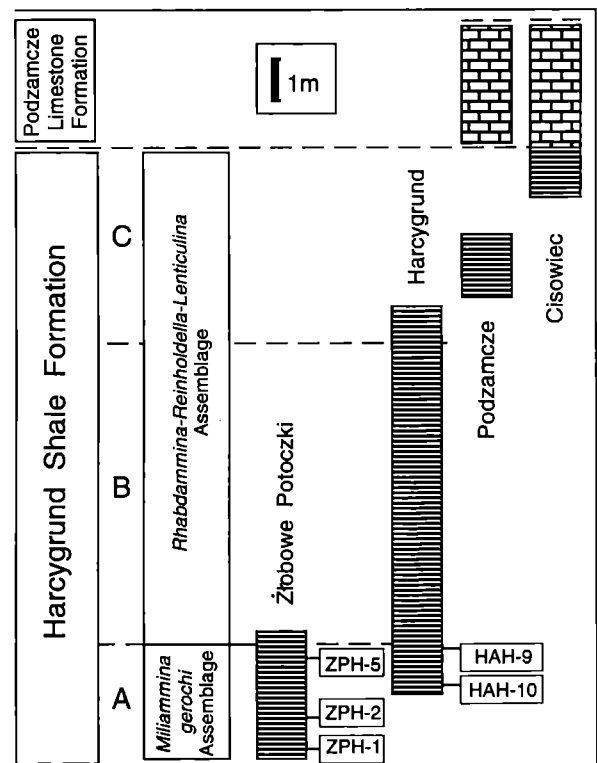

Fig. 3. Correlation of examined sections of the Harcygrund Shale Formation with defined foraminiferal assemblages; A, B, C – lithologic units described in text; ZPH-, HAH-samples revealing the *Milammina gerochi* Assemblage (for detailed sections see Tyszka, 1995)

grey and black shaly marlstones intercalated with thin (2–5 cm) bands of dark-grey spotty limestones (see Tyszka, 1995: figs. 1, 2B, 24); dark-grey marls prevail over hard spotty limestones. This complex has been attributed to the Harcygrund Shale Formation (see Birkenmajer, 1977). Previously, the upper part of this outcrop (above grey-blue spotted limestones and marls of the Podzamcze Formation) was identified as the lowermost unit of the "Supra-Posidonia Beds" (Myczyński, 1973: p. 51).

Cisowiec. East side of the Krośnica–Kąty road cutting through the Długa Grapa near Flaki (Kasiński *et al.*, 1981: fig. 1b; Tyszka, 1995: figs. 1, 2B, 25); a 2 m thick section of dark-grey shaly marlstones exposed in the core of the normal inclined fold; anticlinal flanks of the fold are composed of grey spotty limestones and marlstones of the Podzamcze Formation. The passage from dark-grey marlstones to overlying thin to thick bands of grey limestones intercalated with marlstones may represent the boundary between the Harcygrund and Podzamcze formations.

Sedimentary and trace-fossil structures

The Harcygrund Shale Formation can be subdivided into three informal lithologic units (facies) (Fig. 3), i.e.: (Unit A) a complex dominated by black marly shales (mudstones) with some intercalations of thin dark-grey marly arenaceous limestones (localities: Żłobowe Potoczki, upper part of the type section in the Harcygrund Valley); (Unit B) a unit formed of moderate to thick bands of dark-grey marly limestones intercalated with dark-grey to black arenaceous marly shales (lower and middle parts of the Harcygrund Valley locality); (Unit C) a complex dominated by dark-grey marly shales partly intercalated with thin dark-grey spotted limestones, representing passage beds to the Podzamcze Limestone Formation (localities: Cisowiec, Podzamcze).

Unit A. Shales of Unit A have revealed fine varve-like lamination caused by changes in the pronounced amount of fine arenaceous fraction of quartz and calcitic grains. Silt and clay form either flaser-like structures or laminae containing a high number of small and thin bivalve filaments (*Bositra buchi*) and sponge microscleres (rhax-type). The degree of bioturbation depends on the interval examined and varies from non-bioturbated (ichnofabric index 1 *sensu* Droser & Bottjer, 1986) to moderately bioturbated (ichnofabric index 3). Usually, the lamination structures are slightly disturbed by tiny *Chondrites*-like burrows (ichnofabric index 2). These burrows are either infilled with lighter-grey and coarser grains or with a black fine central part and a lighter and coarser surrounding ("halo-structure"). The maximum burrow diameter (MBD) reaches 1–2 mm in the upper part of the type locality (Harcygrund Valley). Microfacies are usually represented by arenaceous filament-spiculite marly wackestone.

Unit B. Sedimentary structures of Unit B show a microscale cross-lamination and normal gradation of fine sandy grains. Some samples have revealed frequent larger shells of *Bositra*, which are either broken or unbroken. Sponge microsleres are also relatively common. These primary structures are often more or less disturbed by burrows

(ichnofabric indices 2–5). Trace fossils are represented mainly by *Chondrites* and small *Planolites*. MBD ranges from 3 to 6 mm.

Unit C. Structures of Unit C do not distinctly differ from unit B but they are usually overprinted by bioturbation (ichnofabric indices 4–5). Ichnotaxa and MBD are very similar to those of unit B, locally, rare *Zoophycos* can be recognized (Podzamcze locality). Microfacies of both B and C units are classified as arenaceous spiculite-filament marly wackestone.

BENTHIC FORAMINIFERAL ASSEMBLAGES

Benthic foraminiferal associations are especially manifested by the distribution of two recurrent foraminiferal assemblages named after characteristic taxa, i.e. *Miliammina gerochi* n.sp. and *Rhabdammina–Reinholdella–Lenticulina* assemblages (Fig. 3).

Miliammina gerochi **n.sp. Assemblage.** This assemblage has been distinguished at two localities (Figs. 1, 3): Żłobowe Potoczki (samples: ZPH-1, -2, -5) and Harcygrund Valley (HAH-9, -10). The assemblage is characterized by the occurrence of a relatively high proportion of *Miliammina gerochi* (18–54%; mean 39.4%) associated with other agglutinated foraminifera limited to rare astrorhizids (*Rhabdammina/Hyperammina*) and single specimens of *Ammobaculites, Recurvoides, Trochammina*. Calcareous foraminifera are represented by nodosariids dominated by *Lenticulina* spp. and *Laevidentalina* spp., associated with a lower number of *Astacolus, Frondicularia, Nodosaria* (including *N. regularis*), and *Vaginulinopsis*; additionally, by variable proportions of poorly preserved epistominids (2–25%) and low proportions of ophthalminids, polymorphinids, and ramulinids. Epistominids may resemble smooth-test *Reinholdella* spp. and ornamented *Epistomina* spp. Single specimens of *Epistomina arcana* Antonova and *E. semiornata* (Schwager) have been identified.

Associated microfossils are represented by a moderate number of ostracods. Surprisingly, relatively high proportions (20–40%) of ornamented ostracods have been found. These sculptured ostracods may be attributed to the Progonocytheridae. Smooth ostracods are represented by the Bairdiacea, Schuleridae (genus *Praeschuleridea*), and Cytherellidae (genus *Cytherella*). Moreover, sponge spicules comprise a distinctive part of the benthic assemblage. The spicules are dominated by one axis forms, triactines, tetractines, and kidney- or bean-like forms. The number of spicules varies from single (Żłobowe Potoczki locality) to thousands (Harcygrund Valley locality) per 250 g sample. The assemblage also contains single echinoderm fragments and small gastropods, which are similar to those found in the upper part of the Skrzypny Shale Formation. Single to frequent spherical casts of radiolaria have also been found.

Rhabdammina–Reinholdella–Lenticulina **Assemblage.** This assemblage has been recognized at four localities: Harcygrund Valley (samples: HAH-2, -4, -7), Żłobowe Potoczki (ZPH-7), Podzamcze-right bank of the Dunajec River (LP-2, -3, -4), and Cisowiec (CH-2, -3) (Figs. 1, 3). Agglu-

tinated foraminifera are dominated by tubular astrorhizids (*Rhabdammina/Hyperammina*) and rare *Trochammina*, *Reophax*, *Ammobaculites*, and *Ammodiscus*. *Miliammina gerochi* does not occur within this association. Poorly preserved, often recrystallized specimens of epistominids are represented by smooth-test *Reinholdella*. Nodosariids composing a main part of the assemblage are dominated by *Lenticulina* and *Laevidentalina*. Other nodosariid genera, such as *Astacolus*, *Nodosaria*, *Pseudonodosaria*, *Vaginulinopsis*, are confined to single or frequent occurrences. Other groups are limited to single specimens of *Ramulina laevis* and *Spirillina* spp.

Associated microfossils are similar to the *Miliammina gerochi* n.sp. Assemblage, and are represented by a moderate number of ostracods, a variable amount of sponge spicules, and echinoderm fragments (including frequent crinoidal remains and echinoid spines). In addition to benthic fossils, single radiolaria have also been found.

Facial and biofacial succession. The foraminiferal succession of the Harcygrund Shale Formation has been subdivided into two successive assemblages: the *Miliammina gerochi* Assemblage and the *Rhabdammina–Reinholdella–Lenticulina* Assemblage. These assemblages can be used to help recognize stratigraphic succession of strata within the strongly folded formation. There is a co-occurrence of the same species of epistominids, i.e. *Epistomina arcana* and *E. semiornata* in the *Miliammina gerochi* Assemblage of the Harcygrund Formation, and in the *Epistomina* spp. Assemblage in the upper part of the Skrzypny Shale Formation (Tyszka, 1994b). These species are limited only to the interval in the Klippen successions and most likely, represent the lower part of the lower Bajocian. There are single appearances of small gastropods very similar to those that are common in the Skrzypny Formation. These gastropods have not been recognized in other stratigraphic intervals. It appears that the *Miliammina gerochi* Assemblage may corresponds to the assemblage with epistominids in the upper part of the Skrzypny Shale Formation (Fig. 2; Tyszka, 1994b).

Occurrence of a comparable assemblage with abundant calcareous foraminifera represented by *Quinqueloculina* (with a test shape similar to *Miliammina*) associated with epistominids was reported from the Skrzypny Shale Formation of the Czertezik Succession in the Slovakian part of the Klippen Belt (Scheibnerová, 1965) representing an interval from the *Ludwigia murchisonae* to *Sonninia sowerbyi* zones (*Hyperlioceras discites* Subzone) (Scheibner, 1964). The Harcygrund Shale Formation is dated as representing the time span from the *S. sowerbyi* Zone up to the lower part of the *Stephanoceras humphriesianum* Zone. Therefore, it is likely that the *Miliammina* Assemblage corresponds to the *S. sowerbyi* Zone. Support for this interpretation is given by the finding of ammonite *Hyperlioceras* cf. *discites* (Waagen) in the upper part of the type section in the Harcygrund Valley (Myczyński, 1973), i.e. in the same interval with the *Miliammina gerochi* Assemblage. Thus this foraminiferal assemblage probably represents the oldest part of the Harcygrund Shale Formation (Fig. 3).

PALAEOECOLOGICAL IMPLICATIONS OF THE *Miliammina gerochi* n.sp.

Oxygenation and organic matter input. Foraminifera of the Harcygrund Shale Formation are represented by relatively high abundances of inferred endobenthic and epibenthic morphogroups. The *Miliammina gerochi* Assemblage consists of 60–75% endobenthic forms dominated by rzehakinids with *M. gerochi* and nodosariids especially represented by *Lenticulina* and *Laevidentalina*, with a low contribution of *Pseudonodosaria* and *Frondicularia*. Epibenthic forms are dominated by epistominids and miliolids. Agglutinated tubular foraminifers (astrorhizids) are strongly restricted in occurrence.

Surprisingly, a high proportion of rzehakinids represented by *M. gerochi* distinguishes this association from others recognized in this study. This genus even reaches up to 50–52% of the whole foraminiferal assemblage in the lowermost part of the succession exposed at Żłobowe Potoczki (Fig. 3: samples ZPH-1, -2). Interestingly, the same interval is represented by black marlstones revealing either a fine varve-like lamination, non-disturbed by bioturbation or lamination with tiny *Chondrites*-like burrows that only slightly disturb the primary sedimentary lamination.

It is likely that such a benthic assemblage indicates a high food availability and a very low oxygenation of the bottom water. Locally preserved fine lamination and absent or sparse echinoderm remains with abundant meiofauna (foraminifers) suggest suboxic to extremely dysoxic conditions (*sensu* Tyson & Pearson, 1991). Relatively less abundant deep endobenthic foraminifers probably responded to a rise of the redox potential discontinuity which would have been located just beneath the water/sediment interface. This is also supported by a relatively high proportion of ornamented, epibenthic ostracods. Periodical anoxia and a high food availability probably adversely affected astrorhizids which are usually reported from mesotrophic environments (A. Gooday, *personal communication*).

It remains uncertain what kind of nutrition influenced the mass occurences of the *Miliammina gerochi* n.sp. Assemblage. Kuhnt and Kaminski (1990) have reported that rzehakinids are rare or absent in Late Cretaceous well-oxygenated environments but occur in high abundances only in oxygen-deficient environments with a high input of organic matter. Modern *Miliammina* is interpreted as an endobenthic form preferring the detrital/bacterial feeding strategy (Jones & Charnock, 1985). It can be speculated that enhanced numbers of benthic bacteria favoured large populations of these foraminifers. This phenomenon may be related to the "edge effect" which has recently been recognized at the upper boundary of the Central California Oxygen Minimum Zone (Mullins *et al.* 1985; Thompson *et al.*, 1985; Vercoutere *et al.*, 1985). Passing through extremely and severe dysoxic conditions (*sensu* Tyson & Pearson, 1991) causes the appearance of bacterial mats and an increase in faunal density. It is likely that benthic bacterial mats created a nutrition-rich subenvironment for this assemblage.

Opportunism. High dominance associated with "flood occurrences" of *Miliammina gerochi* n.sp. fits to the r-selec-

tion model of MacArthur and Wilson (1967). Early reproduction in response to a high food availability seems to be a probable explanation for such high abundances of this species. The association of some opportunistic foraminifera with high organic input and oxygen deficiency has been reported to be typical for oxygen minimum zone assemblages (Phleger & Soutar, 1973; Koutsoukos et al., 1990; Sen Gupta & Machain-Castillo, 1993; Kaminski et al., 1995).

Palaeobathymetric preferences. It is of interest to evaluate the palaeobathymetric preferences of the *Milammina gerochi* Assemblage. The co-occurrence of ornamented epistominids, low percentage of astrorhizids, relatively high proportions of sculptured ostracods and single well-preserved parts of crinoid columnals suggest a relatively shallow-water environment, which may be attributed to the middle-outer neritic zone. This paleodepth probably changed with the appearance of gravity flows, an enhanced number of astrorhizids and the disappearance of the shallow water *Miliammina* (Tyszka, 1994a, b). This depositional and palaeoenvironmental turnover may be attributed to the deepening of this part of the basin possibly enhanced by tectonic activity. The *Rhabdammina–Reinholdella–Lenticulina* assemblage may therefore represent a mixed assemblage with some amount of redeposited microfauna (possibly the epistominids).

This change is also well recognizable within successions of maximum burrow diameters (MBD) and bioturbation indices, manifested by an increase of both indicators upwards the sequence, suggesting a slight but progressive improvement in oxygenation. It may have been a response to better mixing of the bottom water through gravity flows and bottom currents induced by palaeotopographic changes of the basin Tyszka, 1994a.

DISCUSSION

The evolutionary relationships of *Miliammina gerochi* n.sp. remain uncertain owing to the lack of reported ancestors and a gap in the record of rzehakinids until the late Callovian (Seibold & Seibold, 1960; Oesterle, 1968). It is even uncertain whether *Miliammina* originated from an agglutinated foraminiferal lineage or came directly from the superfamily Miliolacea already well established in the Jurassic represented by the genus *Quinqueloculina*. Support for the latter explanation is provided by the contemporaneous appearance of *Quinqueloculina* in the same basin within a shallower palaeobathymetric zone of the Czertezik Succession (Scheibnerová, 1965).

Modern *Miliammina* is a typical and often predominant form in very shallow-water environments (littoral to outer sublittoral) ranging from estuaries, through lagoons, to marshes and mangroves. For instance, modern *Miliammina fusca* with its marsh and marginal sea preferences appears as

one of the most euryhaline species, tolerating salinities from 0 to 23 per mille (Boltovskoy & Wright, 1976; Jones & Charnock, 1985). Another recent species, *Miliammina arenacea*, dominates within cold-water upper bathyal assemblages of the Antarctic slope (Lindenberg & Auras, 1984). Scheibnerová (1976) interpreted the Aptian *Miliammina inferior* Ludbrook as an inner sublittoral form, found in basin margin and intrabasinal ridge facies of the Cretaceous Great Australian Basin. The Late Jurassic *Miliammina jurassica* (Haeusler) was often reported from the shallow sponge bioherm facies ("Schwammfazies") and seldom from the deeper "Bankfazies" (Seibold & Seibold, 1960; Oesterle, 1968). In the present study, the overall faunal benthic associations also suggest shallow-water preferences for the Jurassic *Miliammina gerochi* n.sp.

It is interesting that from the Jurassic until the Holocene, *Miliammina* (or rzehakinids in general) have successfully colonized stressed environments, such as suboxic habitats, hyposaline marshes and lagoons sponge bioherms, and cold water bathyal depths. All these habitats have something in common, i.e., a high food supply.

The *Miliammina gerochi* n.sp. Assemblage marks a very productive phase in the Klippen Basin history. The high organic matter input associated with the development of anoxic conditions was probably linked with the formation of the oxygen minimum zone and hydrodynamic turnover from stratified, stagnant water column to more dynamic "upwelling" type circulation. This model is additionally supported by the contemporeanous formation of phosphatic concretions within the middle neritic part of the basin (upper part of the Skrzypny Shale Formation). It seems likely that the palaeoenvironmental change was brought about by sea-level rise and deepening of the Branisko palaeobathymetric zone within the Klippen Basin (Tyszka, 1995; Tyszka & Kaminski, 1995). This deepening is indicated by: (a) disappearance of *Miliammina gerochi*; (b) disappearance of ornamented epistominids; (c) increasing proportion of astrorhizids.

SYSTEMATIC PALEONTOLOGY

Order FORAMINIFERIDA Eichwald, 1830
Suborder TEXTULARIINA Delage & Herouard, 1896
Superfamily RZEHAKINACEA Cushman, 1933
Family RZEHAKINIDAE Cushman, 1933
Genus Miliammina

Milliamina gerochi n.sp.
Fig. 4 A–D; Fig. 5 A–F

Etymology: In memory of Professor Stanisław Geroch.
Material: Holotype (sample ZPH-2) and 7 paratypes (samples

Fig. 4. SEM photographs. **A.** *Miliammina gerochi* n.sp. – holotype; sample ZPH-2; *1* – side view; *2* – oblique view; *3* – apertural view; *4* – side view; *5* – peripheral view; *6* – detailed view of the aperture; *7* – agglutinated texture of the test. **B.** *Miliammina gerochi* n.sp. – paratype; sample ZPH-2; *1* – side view; *2* – peripheral view; *3* – apertural view; *4* – detail view of the aperture. **C.** *Miliammina gerochi* n.sp. – paratype; sample ZPH-5; *1* – side view; *2* – peripheral view. **D.** *Miliammina gerochi* n.sp. – paratype; sample ZPH-5; *1* – side view; *2* – peripheral view; *3* – apertural view
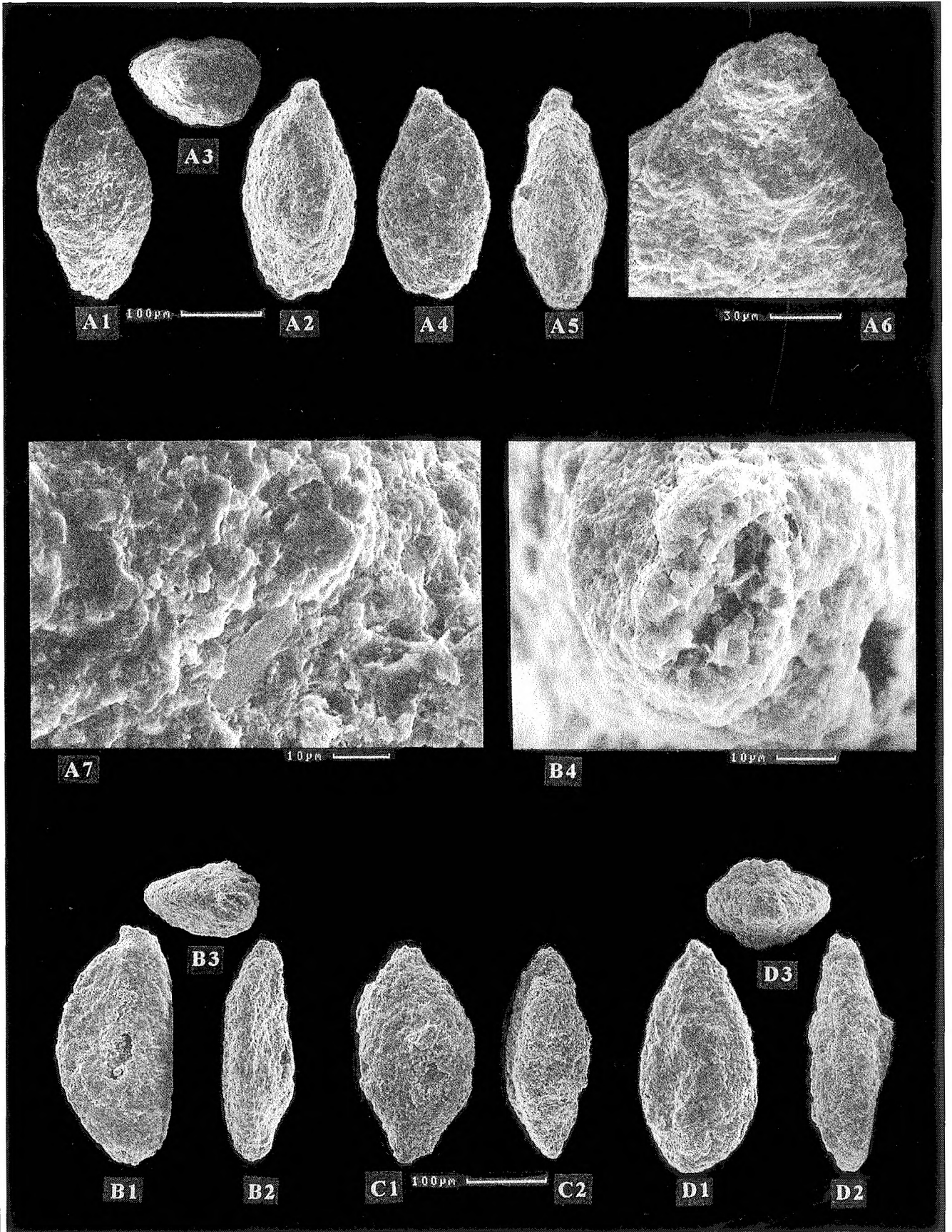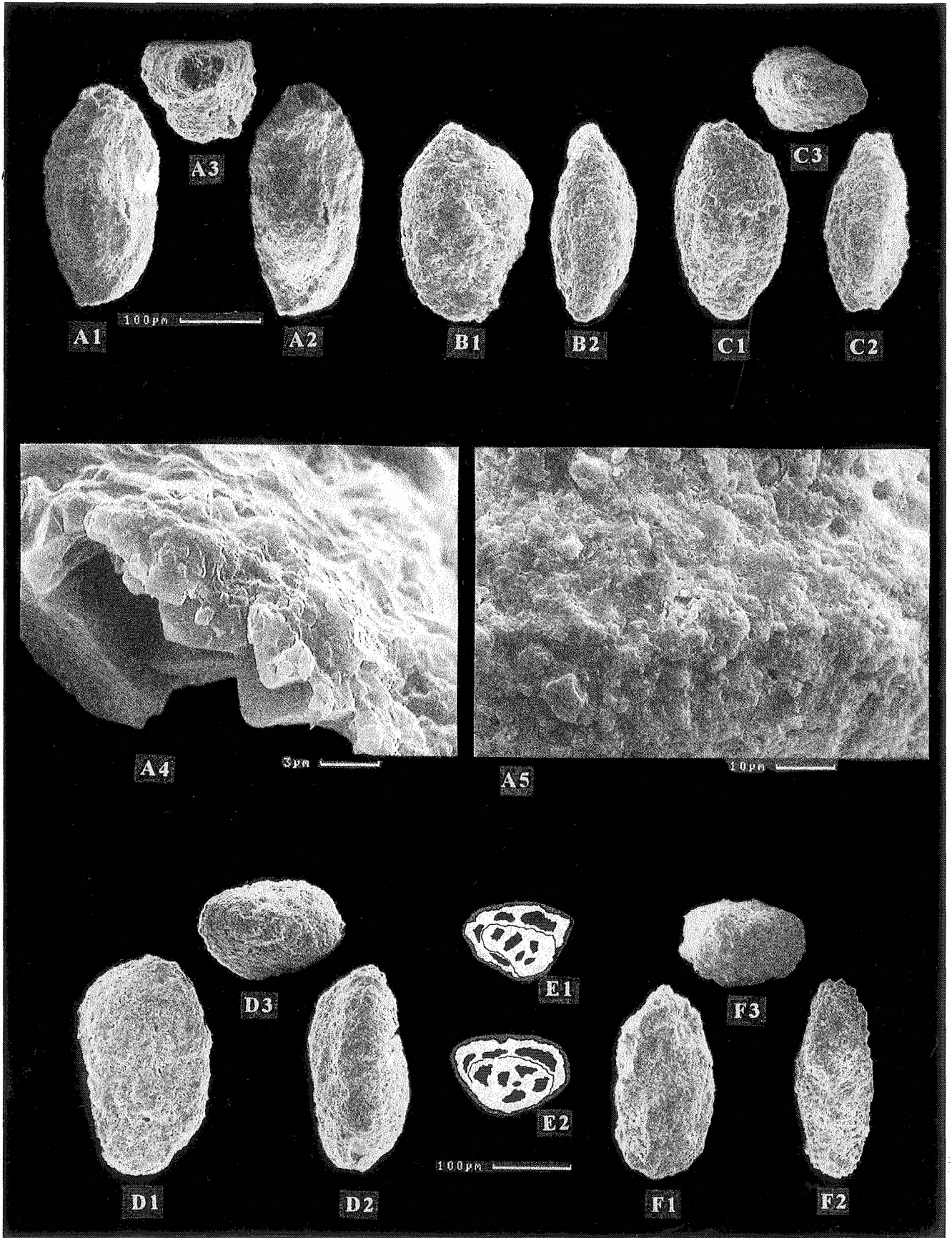
ZPH-2 and ZPH-5).

Type-locality: Żłobowe Potoczki near Niedzica and lower part of the Harcygrund Valley (recently flooded by the Czorsztyn artificial lake), Pieniny Klippen Belt, Polish part of the Western Carpathians.

Type-level: Harcygrund Shale Formation; samples ZPH-1, -2, -5 (Żłobowe Potoczki) and HAH-9, -10 (the Harcygrund Valley).

Diagnosis: A very small, elongated spindle-shaped species of *Miliammina*, characterized by its triangular to trapezoidal cross-section and rounded periphery.

Description: Test free, very small, elongate, slightly flattened spindle-shaped; triangular to trapezoidal in apertural view; periphery rounded. Coiling arrangement not stable, tending to resemble quinqueloculine-like pattern (chambers one-half coil in length are successively added 144° apart creating in chambers five planes 72° apart) which is not well observed in cross-section probably due to diagenetic cementation and recrystallization of inner parts of tests (Fig. 5: E1, E2). Sutures indistinct, sometimes slightly depressed. Surface is smooth, wall very thin, finely agglutinated. Primary cement has not been recognized, most likely it was originally organic and then silicified. Aperture forms a single rounded to ovate opening at the end of the final chamber, either with or without a short neck. Better preserved apertures show a delicate lip (Fig. 4: B1-B4).

Remarks: Quinqueloculine arrangement is well-known from miliolid genus *Quinqueloculina*. Some species of this genus, such as *Q. agglutinans* d'Orbigny, 1839 or *Q. berthelotiana* d'Orbigny, 1839 also agglutinate fine particles (Bender, 1995). The question appears whether they should be placed into the genera *Quinqueloculina* or *Miliammina*. The absence of a calcitic miliolid wall suggests closer affinity with the purely agglutinated *Miliammina* (Fig. 5: A4).

Measurements (μm): Holotype length – 290; max. thickness – 161; min. thickness – 148. Paratypes length – 258-303; max. thickness – 148-181; min. thickness – 90-123 (figured specimens).

Stratigraphic distribution: lower Bajocian.

Deposition of types: Coll. A-II-109, Geological Museum, Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

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Fig. 5. SEM photographs and microdrawings. **A.** *Miliammina gerochi* n.sp.; sample ZPH-2; *1* – side view; *2* – peripheral view; *3* – apertural view. **B.** *Miliammina gerochi* n.sp. – paratype; sample ZPH-5; *1* – side view; *2* – peripheral view. **C.** *Miliammina gerochi* n.sp. – paratype; sample ZPH-2; *1* – side view; *2* – peripheral view; *3* – apertural view. **D.** *Miliammina gerochi* n.sp. - paratype; sample ZPH-5; *1* – side view; *2* – peripheral view; *3* – apertural view. **E.** *Miliammina gerochi* n.sp. – paratype; sample ZPH-2; *1-2* – two cross-sections of the same specimen. **F.** *Miliammina gerochi* n.sp. – paratype; sample ZPH-2; *1* – side view; *2* – peripheral view; *3* – apertural view

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Streszczenie

Miliammina gerochi n.sp. – ŚRODKOWOJURAJSKA OTWORNICA (NADRODZINA RZEHAKINACEA) Z BIOFACJI QUASI-ANAEROBOWEJ

Jarosław Tyszka

Ewolucja otwornic bentonicznych wydaje się być między innymi uzależniona od okresowego występowania warunków silnego zubożenia w tlen. Długotrwałe występowanie warunków anoksycznych wiązane jest często ze wzmożonym wymieraniem jednych i pojawianiem się innych gatunków oraz nowych grup taksonomicznych. Warunki bliskie anoksyczności (suboksyczne) sprzyjają rozwojowi szczególnych zespołów mikrofauny bentonicznej, zdominowanych przez gatunki oportunistyczne. Przykłady takich zespołów związanych z regionalnym wydarzeniem beztlenowym na pograniczu aalenu i bajosu zostały już wcześniej opisane w formacji łupków ze Skrzypnego z obszaru pienińskiego pasa skałkowego (Tyszka, 1994b). Niniejsze opracowanie dotyczy dolnobajoskiej formacji łupków z Harcygrundu stanowiącej w dolnej partii stratygraficzny ekwiwalent górnej części formacji łupków ze Skrzypnego (Myczyński, 1973; Birkenmajer, 1977; Fig. 1, 2). Formacja ta jest reprezentowana przez facje „czarnych łupków", w której stwierdzono występowanie biofacji quasi-anaerobowej, zdominowanej przez *Miliammina gerochi* n.sp., nowy gatunek aglutynującej otwornicy bentonicznej. Niniejszy gatunek jest głównym przedmiotem badań.

M. gerochi n.sp. jest jak dotychczas najstarszym znanym przedstawicielem nadrodziny Rzehakinacea. Jej występowanie jest ograniczone wyłącznie do dolnej części formacji łupków z Harcygrundu w pienińskim pasie skałkowym (Fig. 3). *M. gerochi* n.sp. tworzy od 18 do 54% zespołu i współwystępuje z nodosaridami, zdominowanymi przez *Lenticulina* spp. i *Laevidentalina* spp., gladkościennymi epistominidami, astrorhizidami oraz innymi otwornicami bentonicznymi. Ponadto, stosunkowo liczne są ornamentowane i nieornamentowane małżoraczki, spikule gąbek, filamenty małża *Bositra buchi*; rzadkie natomiast, małe ślimaki oraz fragmenty szkarłupni. Zespół ten występuje w osadzie laminowanym, częściowo zabużonym przez drobne skamieniałości śladowe zbliżone do ichnorodzaju *Chondrites*. Ogólne relacje biofacjalne wskazują, że *M. gerochi* n.sp. zasiedlała morze o normalnym zasoleniu, w środkowej i zewnętrznej strefie nerytycznej, w warunkach eutroficznych, przy bardzo silnym zubożeniu w tlen. Na podstawie morfologii tej formy (Fig. 4, 5) oraz na podstawie badań współczesnej *Miliammina* można sugerować, że opisywany gatunek preferował endobentoniczny styl życia, zasiedlając maty bakteryjne związane z warunkami suboksycznymi. Zespół z *M. gerochi* n.sp. wskazuje na bardzo produktywną fazę w historii basenu skałkowego. Wysoka dostawa materii organicznej związana była z występowaniem strefy minimum tlenowego, wytworzonego poprzez cyrkulację typu „upwellingowego". Taki typ cyrkulacji potwierdza fakt występowania równowiekowych konkrecji fosforytowych w nieco płytszych facjach basenu skałkowego (Tyszka, 1995; Tyszka & Kaminski, 1995). Stopniowy zanik *M. gerochi* oraz jej zespołu należy wiązać z poprawą natlenienia, wzrostem gęstości żerowania makrofauny bentonicznej, wzrostem tempa sedymentacji oraz prawdopodobnie z pogłębianiem się basenu. Nadległe osady górnej części formacji łupków z Harcygrundu charakteryzują się już brakiem pierwotnej laminacji osadu oraz reprezentowane są przez zespół *Rhabdammina–Reinholdella– Lenticulina*.

Porównanie różnych środowisk kolonizowanych przez rzehakinidy wskazuje, iż grupa ta od jury do dzisiaj kolonizowała bogate w pokarm środowiska stresowe (np. suboksyczne, dysoksyczne lub brakiczne). Pochodzenie tej grupy i jej nowego gatunku nie zostało dotychczas wyjaśnione z powodu braku jednoznacznych przodków.