Annales Societatis Geologorum Poloniae (2005), vol. 75: 249–271.

FORAMINIFERA FROM THE EOCENE VARIEGATED SHALES NEAR BARWINEK (MAGURA UNIT, OUTER CARPATHIANS), THE TYPE LOCALITY OF NOTH (1912) REVISITED

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Kender, S., Kaminski, M. A. & Cieszkowski, M. 2005. Foraminifera from the Eocene Variegated Shales near Barwinek (Magura Unit, Outer Carpathians), the type locality of Noth (1912) revisited. *Annales Societatis Geologorum Poloniae*, 75: 249–271.

Abstract: A rich deep-water agglutinated foraminifera (DWAF) fauna (approximately 50 taxa) is documented from the lower to middle Eocene Variegated Shales of the Magura Unit, Outer Carpathians. Four localities have been sampled from the Barwinek region, which are thought to correspond to those studied by Rudolf Noth in 1912. A stream section of variegated red and green shales outcrop near Zyndranowa (Poland), was logged and extensively sampled. A further two outcrops of red shales were sampled in stream sections near Vyšny Komarnik (Slovakia), and a stream section close to Olchowiec (Poland). The DWAF recovered closely resemble assemblages of the same age in localities throughout the Carpathians. The material under study in this report has been correlated using the first appearance of *Reticulophragmium amplectens*, dating the samples early Middle Eocene. Two DWAF assemblages have been differentiated. The '*Rhabdammina* Assemblage' is found mainly in green shales and is thought to be indicative of a high-energy slope or deep sea fan environment slightly reduced in oxygen; and the '*Paratrochamminoides* Assemblage' is found mainly in red shales and is thought to be indicative of a well-oxygenated condensed sequence. The two faunas are otherwise very similar in composition. Of the seven new species described by Noth in 1912, one has been identified in this report and re-described as *Paratrochamminoides deflexiformis* (Noth).

Key words: Foraminifera, Eocene, stratigraphy, palaeoecology, Magura Unit, Outer Carpathians.

Manuscript received 15 November 2004, accepted 22 November 2005

INTRODUCTION

The systematic description and documentation of species of agglutinated foraminifera in the Polish Carpathians was largely undertaken over a period of seven years by the pioneer of applied micropaleontology Józef Grzybowski (1894, 1896, 1898, 1901), and was subsequently continued by his students and associates in the early part of the 20th Century (Friedberg, 1901; Dylążanka, 1923). Because of the changes that have occurred in the field of micropalaeontology between then and now, in terms of taxonomy and species concepts, the revision of these early studies has been an important and ongoing task (see Bieda *et al.*, 1967; Kaminski *et al.*, 1993).

In 1912 Rudolf Noth, born in Barwinek who went on to study at the University of Vienna, published his PhD study of the microfauna from the Eocene Red Clays of Barwinek and Komarnik. This original material was lost during the Second World War, and consequently a re-collection of these localities has been long overdue. Noth identified 34 species of agglutinated foraminifera, of which 7 were described as new. Unfortunately all that remains of these specimens are his hand drawings and brief descriptions.

The microfauna of the Magura Unit received most attention in the 1960s (Bieda *et al.*, 1963; Bieda *et al.*, 1967; Geroch *et al.*, 1967; Jurkiewicz, 1967; Jednorowska, 1968), although the eastern Magura in this report has not been studied in detail before. The microfauna from the Barwinek area was briefly reported by M. Cieszkowski (1991) as part of a geological mapping programme in the area. More recently, Malata (in Oszczypko *et al.* 1990, 1999) examined the Krynica and Bystrica subunits (middle part of the Magura unit in Poland); Waśkowska-Oliwa (2001) examined Siary subunit (outer zone of the Magura); and Bubik (1995) examined the Bile Karpaty unit (innermost part of the Magura) in the Czech Republic. The Variegated Shales have tradi-

Fig. 1. Schematic tectonic map of the Polish Outer Carpathians (after Książkiewicz, 1975 and Geroch & Nowak, 1984)

tionally been difficult to study due to their illusiveness in the field, but mark an interesting period of deposition within the early Eocene greenhouse climate.

In this study we document the DWAF present in outcrops of Eocene Variegated Shales from four localities in the Barwinek area of the Outer Carpathians and analyse the possible depositional palaeoenvironments.

GEOLOGICAL SETTING OF THE AREA

The Outer Carpathians are situated to the north of the Pieniny Klippen Belt (Fig. 1). The first deposits from the Outer Carpathians date from the latest Jurassic and are thought to be the result of basin formation to the north of the Inner Carpathians. As the uplift of these older southern deposits took hold the Outer Carpathian basins grew, deepened, and sedimentation increased. This area (a geosyncline in Alpine terminology) became divided into several basins trending east-west. These basins are thought to have been physically separated, although evidence points to frequent and long lasting connections between them (Morgiel & Olszewska, 1981). The flysch was deposited mainly as thick turbidites eroded from the southern Inner Carpathians, and continued with minor breaks until the late Miocene (Ślączka & Kaminski, 1998; Morgiel & Olszewska, 1981).

The most extensive of the Outer Carpathian nappes, the Magura Nappe, contacts the Dukla, Pre-Magura and Silesian nappes in the north, and the Pieniny Klippen Belt in the south (Fig. 1). The western area is characterised by separate blocks and flat overthrusts, whereas narrow folds typify the east. Folds and thrusts strike SW–NE in the west and NW–SE in the east (Morgiel & Olszewska, 1981). A generalised lithostratigraphic section of the Magura unit is given in Fig. 2.

The largely non-calcareous Palaeogene Variegated Shales first appear in the lowest Eocene containing a rich microfauna of agglutinated foraminifera, the red and green colouring of the shales probably marking changes in oxygenation at the time. These shales do become marly in places, and local thin sandstone beds can also be seen. It is widely believed that these shales mark a broad return to pelagic sedimentation following the dominance of a deep-sea submarine fan environment typical of the Inoceramian Beds. Large sandstone beds either side of the sampled region are thought to be the result of local coarse-grained submarine fans, the Ciężkowice Sandstones appearing just above the Inoceramian Beds (Geroch *et al.*, 1967; Jednorowska, 1975; Ślączka & Kaminski, 1998). In formal stratigraphy (Oszczypko 1991, Cieszkowski & Waśkowska-Oliwa, 2001), the discussed Variegated Shales of the Magura unit are called the Łabowa Shale Formation and, intercalated with them, the Ciężkowice Sandstones are called the Skawce Sandstone Member.

Described outcrops of the Variegated Shales are located in the northern, marginal zone of the Magura Nappe which

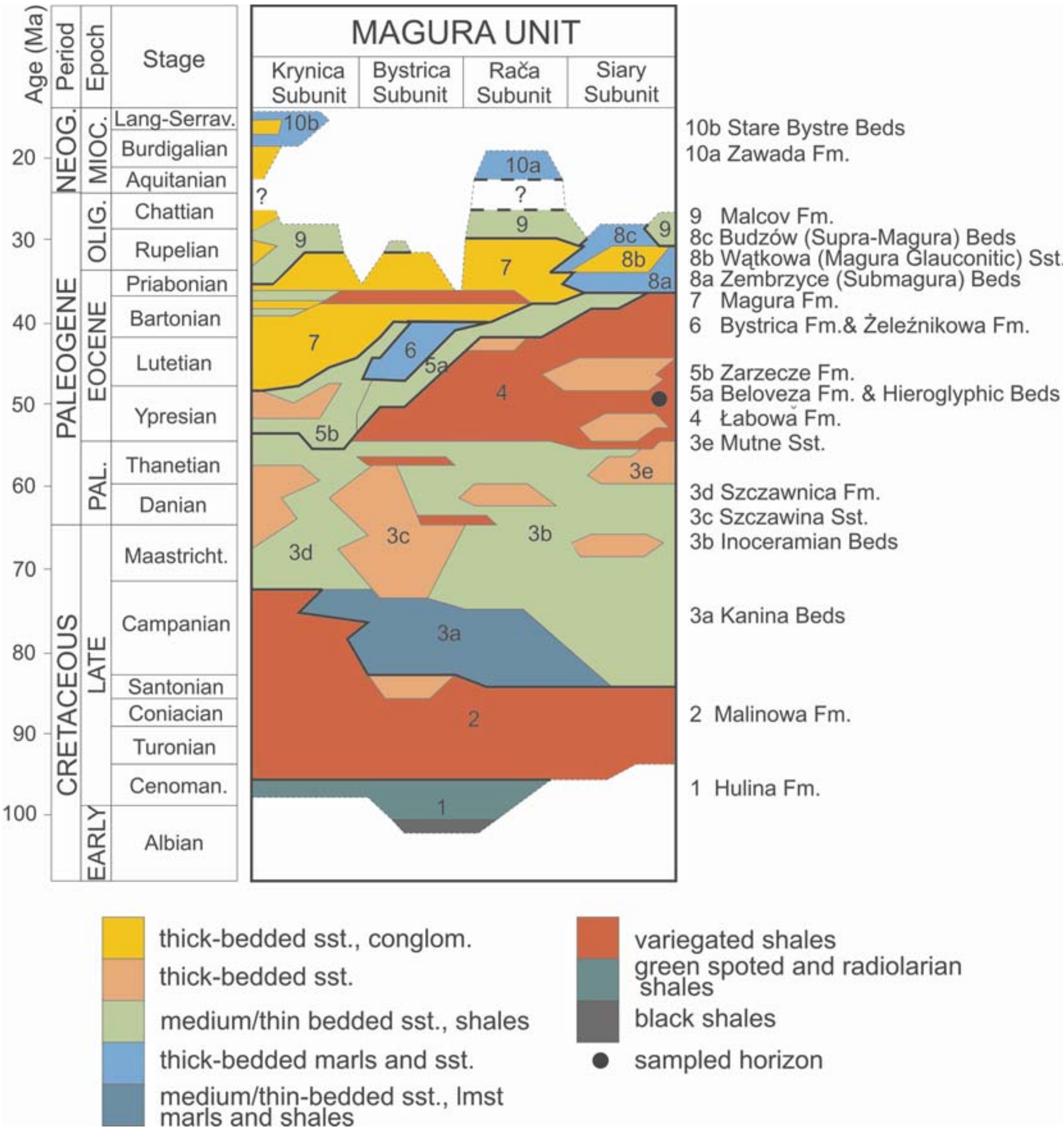


Fig. 2. Lithostratigraphic log of the Magura Unit (taken into consideration to Oszczypko, 1991; Oszczypko & Oszczypko-Clowes, 2002; simplified and partly changed)

is called the Siary Subunit. Lithostratigraphic position of these shales exposes lithostratigraphic log (Fig. 2). In the Siary Subunit variegated shales are unerlied by the Inoceramian Beds (Ropianka Beds), Senonian–Paleocene in age, and overlied by the Eocene Sub-Magura Beds and Glauconitic Magura Sandstones (Wątkowa Sandstones), and somewhere by the Oligocene Supra-Magura Beds or Malcov Beds (cf. Cieszkowski in: Ślączka *et al.* 1991. The Variegated Shales in Zyndranowa occur directly at the northern tectonic margin of the Magura Nappe. The Magura Nappe overthrusts there the Dukla Nappe.

METHODS AND MATERIALS

All of the samples in this study were collected from the Barwinek area of south-eastern Poland, and the Komarnik area of north-western Slovakia (Fig. 3). A total of 17 samples were studied. Samples Z0 to Z11 & S9 were collected in 1997 from a stream cut near Zyndranowa (locality 1), where a clear, near vertical section 3–4 m high and 10 m wide outcrops (Figs 4, 5). Sample S12 (locality 2), S8 & S13 (locality 3), and S15 (locality 4) were collected in 2003 from the banks of various nearby streams (Fig. 3).

The samples collected were boiled with sodium carbonate to remove the clay, and sieved at 63 μm. The dried residue was then sieved at 125 μm; the finer fraction has not been studied. All specimens of foraminifera were picked and placed into standard 32 square faunal slides. When working with a split fraction of a sample, the whole fraction was picked through to avoid any artificial sorting. The non-tubular foraminifera were moved to another slide, as there were generally far more tubular forms than any other (typically over 75% of the assemblage). The picking of specimens continued until there were more than 300 non-tubular forms in the slide, so as to give a fair statistical view of the non-tubular species present.

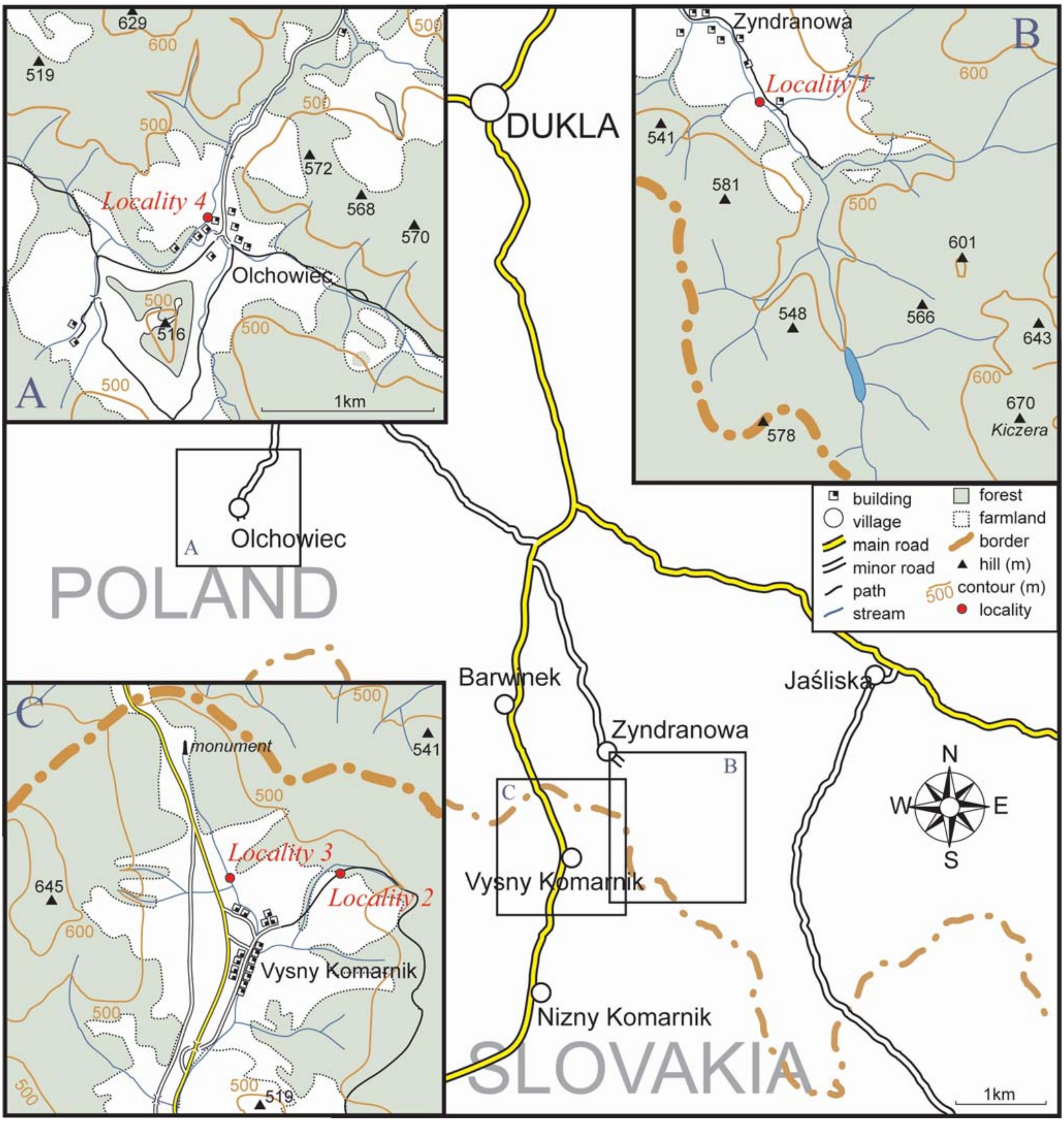


Fig. 3. Location of sampled localities in the Carpathian region. Locality 1: samples Z0–Z11 & S9; locality 2: sample S12; locality 3: samples S8 & S13; locality 4: sample S15. Scale for Fig. A–C is the same

RESULTS

All the samples (except Z8 & Z9) are non-calcareous and rich in DWAF, and many samples contain a high abundance of tubular forms. Samples Z8 & Z9 were collected from the marl horizon (Fig. 5) and are barren in DWAF but contain abundant calcareous nannofossils. The nannofossil assemblage from these samples gives a Priabonian (Late Eocene) to early Oligocene age, which is thought to be younger than the variegated shales. The marl is bounded by faults and contains discontinuous beds, and is thus considered to be a fault breccia made up of sediments from another unit. In all 24 genera and 50 species of DWAF were identified and documented with SEM photography (Table 1).

STRATIGRAPHY

The Variegated Shales have been dated as early or early middle Eocene using the FO of *Reticulophragmium amplectens* (Figs 6, 7; Table 1). All samples contain a relatively similar fauna (not inc. Z8 & Z9), which suggests there is no significant age difference between the upper and lower lim-

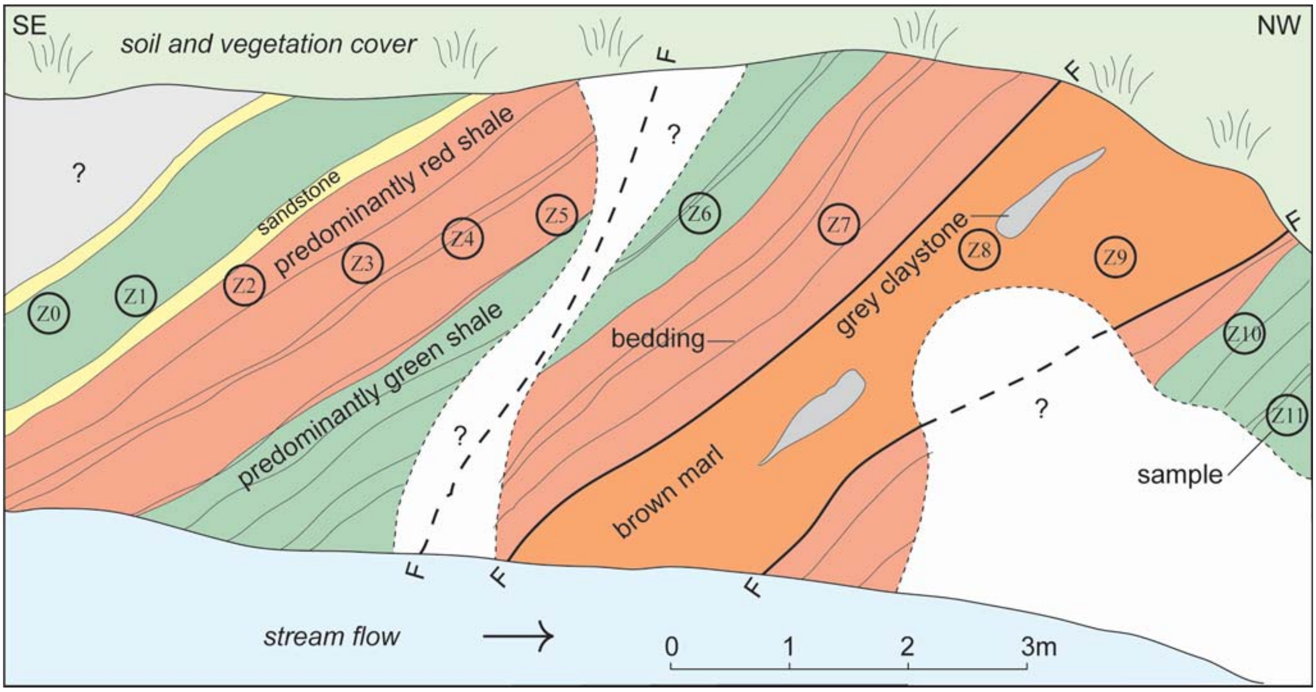


Fig. 4. Sketch of outcrop near Zyndranowa (locality 1) with location of samples Z0–Z11. Diagram represents a vertical section at the stream bank. Dashed faults are inferred

its of the sequence at locality 1. Samples from localities 2–4 are also of a comparable fauna.

The FO of *Reticulophragmium amplectens* occurs in sample Z7 (Fig. 6). This event has been used as a marker by many authors working on sediments from the Polish Carpathians (Geroch, 1960; Bieda *et al.*, 1967; Geroch *et al.*, 1967; Jurkiewicz, 1967; Jednorowska, 1968; Olszewska & Smagowicz, 1977; Morgiel & Szymakowska, 1978; Bąk *et al.*, 1997). It has also been recorded in sediments from Northern Morocco (Kaminski *et al.* 1996), Iberia Abyssal Plain (Kuhnt & Collins, 1996; Kuhnt & Urquhart, 2001), and the North Sea and Labrador Shelf (Gradstein & Berggren, 1981; Gradstein *et al.*, 1988, 1994; Kaminski *et al.*, 1989).

The zonation scheme of Geroch and Nowak (1984) shows the FO of *Reticulophragmium amplectens* to be at the base of the middle Eocene, about 49 Ma (Fig. 7). However, this scheme is based on numerous studies of material that has not been dated with more accurate calcareous forms (Bąk *et al.*, 1997). The lack of calcareous sediment in the Eocene Variegated Shales throughout much of the Carpathians has made comparisons with either planktonic foraminifera or calcareous nannofossil stratigraphy impossible in most instances. The exception is the Dukla unit where Olszewska and Smagowicz (1977) have calibrated agglutinated foraminifera to nannofossil and planktonic foraminiferal zones, and so therefore this is perhaps our best estimate for the Magura Unit. The zonation scheme of Olszewska (1997) shows the base of the Reticulophragmium amplectens interval Zone to occur at the base of the middle Eocene, but records the FO of this taxon in the S. carpathicus acme Zone (dated at about 52 Ma to 49 Ma).

The zonation scheme of Olszewska (1997) shows that the *S. carpathicus* acme Zone underlies the *R. amplectens* interval Zone (Fig. 7). This poses a problem if we are to assert that sample Z7 marks the true FO of *R. amplectens*, as the samples below contain no *S. carpathicus*. The *S. carpathicus* assemblage is known from the Magura Unit (E. Malata, pers. com., 2005) and also from the nearby Dukla Unit (Bąk, 2004), but we have not recovered any specimens of *S. carpathicus* from our samples. It is however entirely possible that samples Z10, Z11, S12 & S15 contain no specimens of *R. amplectens* or *S. carpathicus* by chance. K. Bąk (pers. com., 2005) has found the *Glomospira* acme to occur in the lowermost Eocene, and the FO of *S. carpathicus* to occur higher up in the sequence with an undiagnostic interval in between. It is therefore possible that samples Z10, Z11, S12 & S15 are from this undiagnostic interval (Fig. 7). The *Glomospira* assemblage is recorded in all units below the *S. carpathicus* assemblage (Bieda *et al.*, 1967; Geroch *et al.*, 1967; Jednorowska, 1968), but is not present in any of the samples from Zyndranowa. As the *Glomospira* assemblage ends at around 52 Ma (Olszewska, 1997), samples Z10, Z11, S12 & S15 are probably no older than this.

The upper age limit of the samples from Zyndranowa is less precise although it must lie within the *R. amplectens* assemblage Zone, the acme of which has been dated at between 47 Ma to 42 Ma by Olszewska (1997). Therefore, samples Z7 to Z0 lie somewhere between the base of the Middle Eocene (FO of *R. amplectens*; Olszewska, 1997) and 42 Ma (end of *R. amplectens* acme; Olszewska, 1997). However it seems likely that the samples are no older than early middle Eocene, because in the upper Eocene more advanced forms of *Reticulophragmium* have evolved (i.e. *R. acutidorsatum* and *R. rotundidorsata*) and these forms are lacking in our samples.

Table 1

Counts of agglutinated Foraminifera in the investigated samples

SPECIES / SAMPLE NUMBER	Z0	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	S8	S9	S12	S13	S15
Predominant colour (red or green)	G	G	R	G	R	R	G	R	.	.	G	R	R	G	R	R	R
Saccammina placenta	23	10	10	12	6	22	4	2	.	.	4	2	3	9	3	1	9
Psammosphaera spp.	17	6	14	21	12	26	12	5	.	.	38	9	19	3	.	2	.
Hyperammina spp.	.	.	6	3	1	1	.	2	.	.	2	.	1	.	1	.	1
Ammodiscus peruvianus	5	1	5	2	8	10	4	1	.	.	15	5	1	1	6	1	.
Ammodiscus tenuissimus	8	2	12	16	9	13	7	8	.	.	41	10	7	7	14	6	3
Ammodiscus sp. 1	6	3	.	1	2	.	3	6	.	.	.	.	.	.	1	.	3
Ammodiscus spp.	.	1	4	4	.	.	.	.	.	.	.	.	.	1	6	.	.
Glomospira charoides	28	25	13	5	23	13	17	3	.	.	41	27	24	13	29	15	42
Glomospira glomerata	5	9	8	9	7	13	.	.	.	.	.	.	.	1	.	.	3
Glomospira gordialis	12	.	13	13	8	.	8	18	.	.	23	64	.	13	1	.	19
Glomospira irregularis	3	2	.	8	3	11	2	3	.	.	3	.	2	.	1	.	.
Glomospira serpens	1	2	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.
Glomospira sp. 5	2	8	2	2	6	8	5	1	.	.	2	3	2	1	.	.	.
Subreophax scalaris	8	11	.	1	.	2	.	1	.	.	4	3	1	2	1	1	6
Subreophax splendidus	2	10	3	3	7	3	14	3	.	.	1	1	2	10	13	12	.
Aschemocella grandis	14	8	12	8	5	.	3	.	.	.	1	1	2	2	2	.	.
Reophax elongatus	3	1	2	1	.	5	1	1	.	.	2	1	2	1	1	.	.
Reophax pilulifer	7	3	8	4	13	26	21	16	.	.	24	24	24	18	22	3	.
Pseudonodosinella nodolosa	10	11	16	18	18	6	10	22	.	.	15	4	16	13	.	.	.
Lituotuba lituiformis	1	.	.	.	2	.	1	.	.	.	1	.	.	.	.	.	1
Paratrochamminoides deflexiformis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Paratrochamminoides draco	.	1	.	1	.	.	.	2	.	.	.	.	.	.	5	.	1
Paratrochamminoides gorayskii	.	1	.	1	2	.	.	.	.	.	1	1	.	2	.	2	.
Paratrochamminoides heteromorphous	1	4	1	1	.	1	3	3	.	.	1	.	.	2	4	.	.
Paratrochamminoides irregularis	3	1	1	1	1	1	2	4	.	.	.	.	.	.	.	.	4
Paratrochamminoides mitratus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Paratrochamminoides olszewskii	6	3	.	3	3	.	2	5	.	.	5	1	2	.	1	1	3
Paratrochamminoides spp.	10	5	6	3	2	6	2	3	.	.	.	.	.	.	16	.	1
Trochamminoides dubius	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	8
Trochamminoides folius	1	1	1	2	.	.	1	1	.	.	.	1	.	1	3	2	.
Trochamminoides proteus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.
Trochamminoides septatus	.	1	.	1	.	.	1	.	.	.	3	.	2	2	.	.	.
Trochamminoides subcoronatus	.	3	.	.	1	5	3	11	.	.	4	1	3	3	6	6	24
Trochamminoides variolarius	.	.	.	.	.	.	.	1	.	.	.	.	1	.	.	.	.
Trochamminoides velascoensis	.	1	.	.	.	2	2	.	.	.	.	.	.	.	.	.	.
Trochamminoides spp.	6	3	1	10	2	8	1	2	.	.	.	.	5	.	.	.	.
Troch-/Paratrochamminoides (frag.)	45	87	54	50	78	85	97	134	.	.	94	110	84	35	129	86	79
Haplophragmoides porrectus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Haplophragmoides stomatus	3	4	11	4	.	3	3	.	.	.	1	.	.	.	36	.	.
Haplophragmoides walteri	4	25	21	6	13	6	10	30	.	.	4	2	24	.	44	3	12
Haplophragmoides sp. 1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.
Budashevaella multicamerata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Cribrostomoides spp.	.	.	.	1	.	.	.	.	.	.	.	.	.	1	4	2	.
Recurvoides spp.	25	4	15	44	11	4	51	6	.	.	44	44	50	53	134	147	30
Spiroplectammina spectabilis	.	1	.	.	.	.	.	2	.	.	2	.	1	4	.	.	.
Trochammina spp.	5	2	.	.	.	7	.	.	.	.	.	.	.	.	.	.	.
Karrerulina coniformis	.	.	1	1	.	1	.	.	.	.	47	.	4	29	.	1	.
Karrerulina conversa	.	38	48	37	9	1	.	.	.	.	48	92	19	79	.	1	99
Reticulophragmium amplectens	35	3	14	7	48	11	14	5	.	.	.	.	18	.	.	2	.
Eggerella spp.	.	.	.	.	.	.	.	1	.	.	1	.	1	.	.	.	.
Lenticulina sp.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.

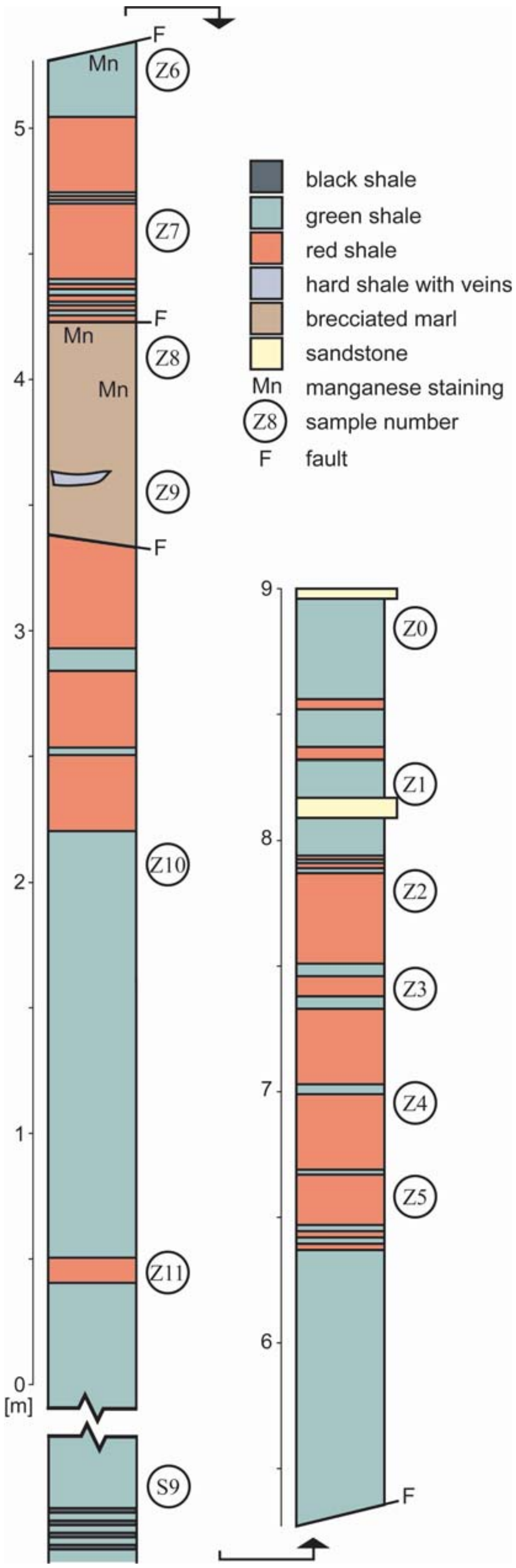


Fig. 5. Idealised lithological log of locality 1 with approximate sample intervals

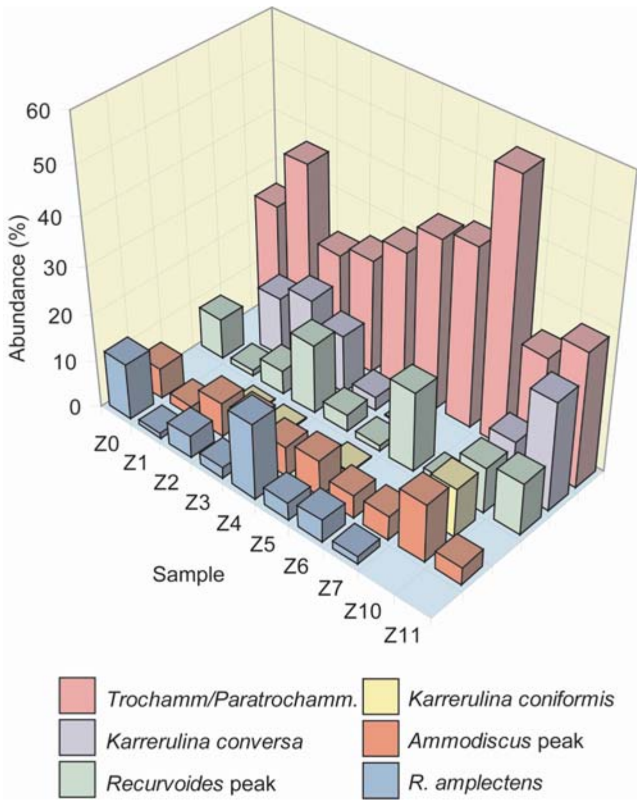


Fig. 6. Relative abundance of important species and faunal groups in the samples from Zyndranowa (locality 1)

ASSEMBLAGES

All samples show a broadly similar DWAF assemblage, but differences can be seen. A clear division can be drawn between two assemblages, and Fig. 8 shows that these are *largely* bound by colouration, although not entirely.

Rhabdammina Assemblage

The *Rhabdammina* Assemblage is usually recovered from the green shale, with a high content of tubular forms (mainly *Rhabdammina* spp.), and a high abundance of *Paratrochamminoides* spp. This assemblage contains *Glomospira*, *Ammodiscus*, *Haplophragmoides walteri*, *Karrerulina* spp., *Recurvoides* spp. and usually *Reticulophragmium amplectens*. Diversity is relatively high (average 30 spp. per sample).

Paratrochamminoides Assemblage

The *Paratrochamminoides* Assemblage is predominantly recovered from the red shale, with abundant *Paratrochamminoides* spp. and a medium to small proportion of tubular forms (*Rhabdammina* and *Rhizammina* spp.). This assemblage contains a high proportion of *Recurvoides* spp. in some samples, *Glomospira*, *Ammodiscus*, *Haplophragmoides walteri*, *Karrerulina*, and usually *Reticulophragmium amplectens*. Diversity is relatively high (average 27 spp. per sample).

REVISED SPECIES CONCEPTS

Figure 9 shows a reproduction of the hand-drawn sketches by Noth (1912) (sadly all that remains of the holotype material) in which 7 'new species' were illustrated. In

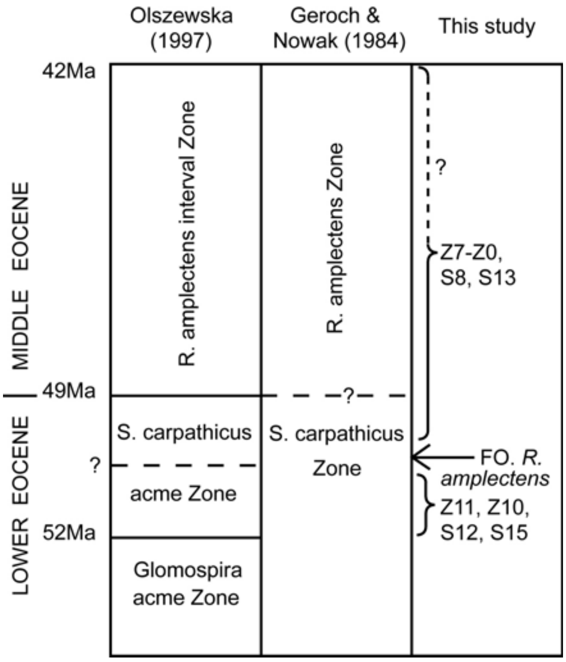


Fig. 7. The zonation schemes of Olszewska (1997) and Geroch & Nowak (1984) compared, with the inferred position of the samples described in this study

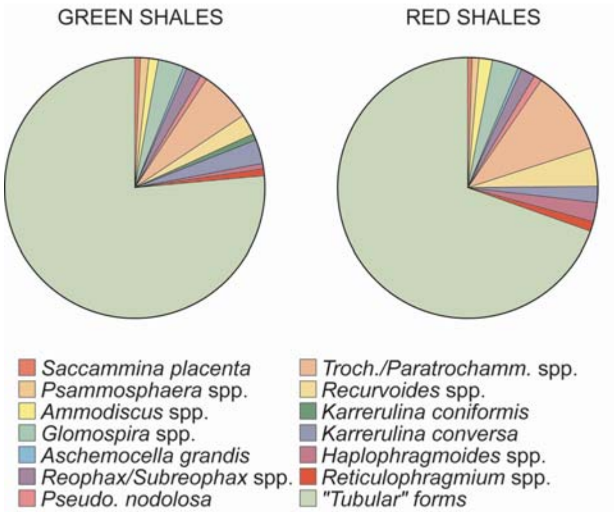


Fig. 8. Comparison of the average relative abundance of deep-water agglutinated foraminifera for the green and red shale horizons in all studied samples (except Z8 & Z9)

this study we have identified one specimen of *Trochammina deflexiformis* (Fig. 9) from sample S12, and we have transferred it to the genus *Paratrochamminoides*. We have found no other specimens belonging to the new species of Noth (1912), and indeed many of our specimens belonging to the *Paratrochamminoides* group are fragmentary or (as yet) unidentifiable.

DISCUSSION

CALCITE COMPENSATION DEPTH

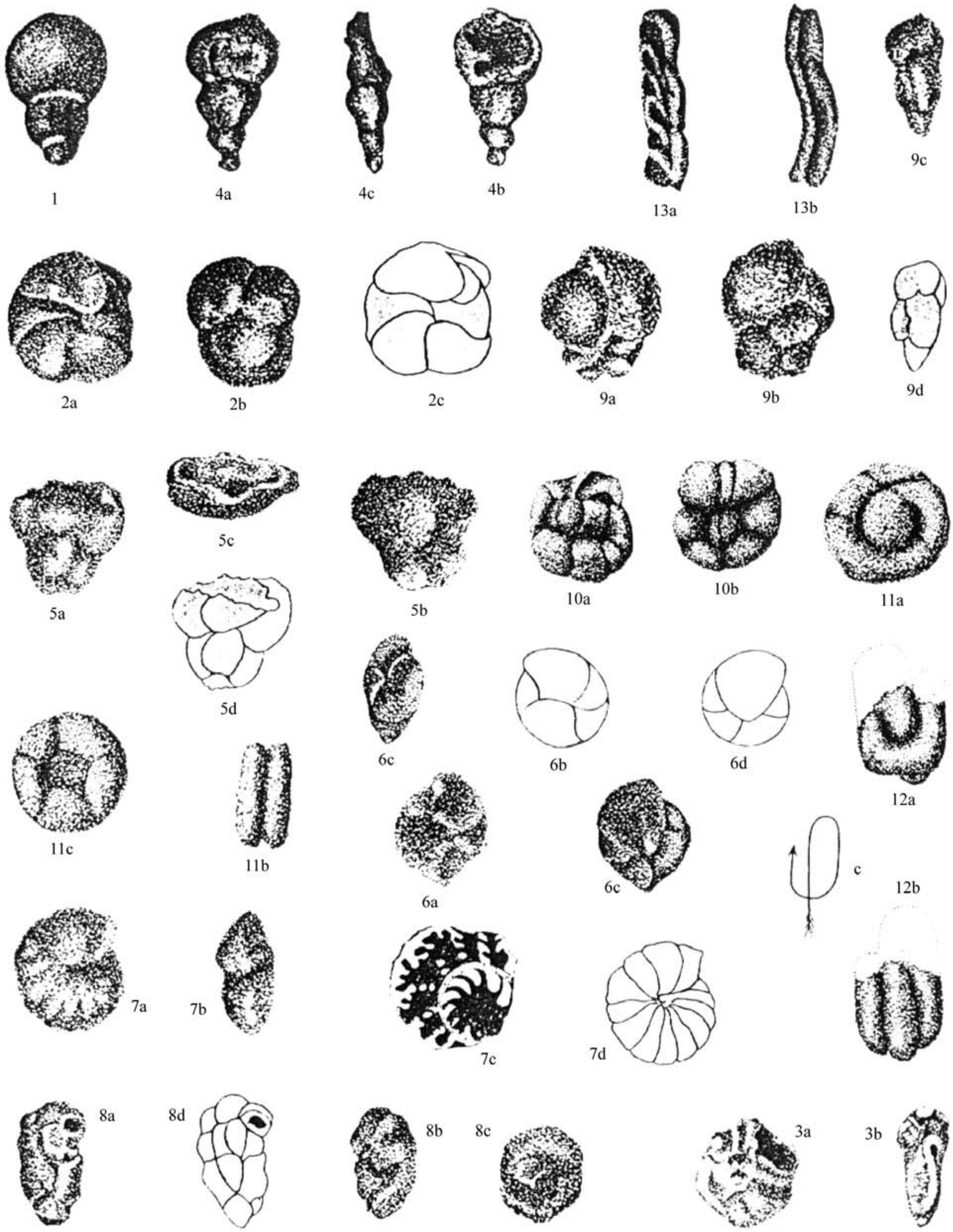
The Variegated Shales are non-calcareous, and are entirely devoid of any calcareous nannofossils or foraminifera (except one *Lenticulina* in sample S8). This suggests that the original environment in which the sediments were deposited was below the CCD.

The depth of the CCD in today's oceans ranges from about 2.5 km in the Pacific, to around 5 km in the North Atlantic, but this depth has not remained constant throughout geological time. The mean North Atlantic CCD is thought to have been falling during the early Palaeogene to a depth of over 3.5 km by the middle Eocene (Van Andel, 1975). At the time interval represented by the Variegated Shales, there was a short-lived shallowing of the CCD in the northern Atlantic (Labrador Sea) to a depth above 2.5 km (Kaminski, 1987). The Labrador Sea could be a reasonable analogy to the Carpathians, as it was located at approximately the same latitude and it was partially surrounded by land mass. A reduction in calcareous planktonic productivity would have reduced the flux of pelagic calcite to the sea floor, and raised the level of the CCD. This does not necessarily indicate an overall fall in planktonic productivity, as upwelling regions often produce a high abundance of siliceous microorganisms. Bąk (2004) has indeed recorded a peak in radiolarian occurrence within the Variegated Shale horizons in the Dukla Unit.

Gradstein and Berggren (1981) have reported that DWAF faunas are controlled mainly by the distribution of calcite within the environment, and are not particularly depth-dependant. Thus, determination of the palaeobathymetry on DWAF characteristics alone is not an accurate technique. Turbidite deposits, indicated by the high tubular content in many of the samples (Kaminski *et al.*, 1988; Bąk *et al.*, 1997), suggest that deposition here took place along the continental rise, near deep-sea fan lobes. The 'interbedded' horizons of low tubular content (largely the red horizons) may represent a basin-plain facies, or indicate a time when turbidite deposition would have been lower. Assuming that the depth of the area did not fluctuate drastically over the relatively short depositional history of the Variegated Shales, these two environments must have been relatively similar and, therefore, near the deepest part of the basin.

Fig. 9. Reproduction of the plate from Noth's paper of 1912. 1. *Reophax pilulifer*; 2. *Endothyra barwinekensis* n. sp.; 3. *Trochammina coronata* aff. *conglobata* n. sp.; 4. *Reophax scorpiurus*; 5. *Reophax textularoides* n. sp.; 6. *Trochammina nana*; 7. *Cyclammina pusilla*; 8. *Trochammina olszewskii*; 9. *Textularia aspera*; 10. *Trochammina deflexiformis* n. sp.; 11. *Ammodiscus carpathicus* n. sp.; 12. *Ammodiscus* cf. *fallax* n. sp.; 13. *Rhabdammina scalaria* n. sp. The only new species recognised in this study is 10a-b (*Paratrochamminoides deflexiformis*)

R. Noth: Foraminiferen von Barwinek und Komarnók.



Beiträge zur Palaeontologie und Geologie Oesterreich-Ungaras und des Orients. Bd. XXV, 1912.
Verlag v. Wilhelm Braumüller, k. u. k. Hof- u. Universitäts-Buchändler in Wien.

O. KOELTZ · REPRINT, KOENIGSTEIN

Golonka *et al.* (2000) have shown that the Magura Basin was receiving gravity deposits (fans, slumps, and turbidites) in the early Eocene. It is unknown whether or not oceanic crust had developed by this time (or indeed any other time) within any area of the Alpine-Carpathian basins. Oszczypko (1999) has suggested that the Magura basin formed oceanic crust in the Western Outer Carpathians (from late Jurassic to Oligocene), and by the Eocene had developed a subduction zone in the south. Oceanic crust is currently in the process of being formed today at around 2.5 km depth in the Red Sea (e.g., Cochran, 1983), and is the average accepted depth for crustal formation by Parsons and Sclater (1977). This model does not disagree with a depth of around 3.75 km offered by Książkiewicz (1975) who also assumed the existence of oceanic crust. There is however no direct evidence for oceanic crust, in the form of ophiolites or basaltic lavas, within the Flysch Carpathians, and subsidence analysis by Poprawa *et al.* (2002) suggests depths could have been as shallow as 1.5 km although probably more. We believe the depth of the Magura Basin is perhaps more likely to have been closer to 2.5 km or more, given the global CCD of this period and the presence of gravity deposits.

PALAEOECOLOGY

The high diversity assemblage within the Variegated Shales is well documented in other studies of the Magura Unit (Bieda *et al.*, 1967; Geroch *et al.*, 1967; Jednorowska, 1968; Cieszkowski, 1991), and points to a relatively unstressful oligotrophic environment with a supply of oxygen. There are broadly speaking two assemblages within the Variegated Shales (as described above) which are largely bound by colouration. Fig. 8 shows that when we see the averaged sample-composition for the two colourations compared, this relationship is borne-out. From fig. 8 we can say that: (1) the green shales contain a higher percentage of epifaunal tubular forms and infaunal *Karrerulina*; (2) the red shales contain a higher percentage of *Trochamminoides/ Paratrochamminoides* and infaunal *Recurvoides* forms.

The two assemblages share an otherwise remarkable similarity. The diversity of the green shales is slightly higher than that of the red shales, although this might be explained through the taxonomic lumping of the unidentified *Trochamminoides/Paratrochamminoides* species.

Several studies have examined how DWAF assemblages change with palaeoenvironment. Kuhnt and Kaminski (1989) defined several Cretaceous assemblages of DWAF from the Western Mediterranean, and their "flysch type, high diversity (*Paratrochamminoides* fauna)" fits well with the *Paratrochamminoides* Assemblage described above (although some of the species are extinct by the Eocene). This is a high diversity assemblage, and includes *Paratrochamminoides*, *Rhizammina*, and *Subreophax scalaris*. These authors have found that this assemblage occurs in well-oxygenated red shales with no carbonate content.

The "high latitude slope assemblages" fauna (Kuhnt & Kaminski, 1989) is analogous to the *Rhabdammina* fauna above. This is defined as low to medium diversity green sediments, containing (among others) *Glomospira*, *Rhabdammina* and *Recurvoides*, and is considered to be representative of a slightly oxygen-impoverished bottom water environment.

Bubik (1995) has successfully applied these same groups to Palaeogene assemblages in the inner part of the Magura Unit. The green flysch-type biofacies are thought to be representative of the slope environment influenced by deep-sea fans, and the red to be representative of abyssal depths (basin-plain facies).

Fauna

The domination of tubular forms (*Rhabdammina* and *Rhizammina*) has been recognised as a characteristic of high energy environments by many authors, with the tubular epifaunal suspension feeders being carried down slope by turbidite flows and redeposited as broken fragments (Kaminski *et al.*, 1988; Bąk *et al.*, 1997). This suggests that there is perhaps a marked difference between the environmental energy levels in the samples high in tubes, compared with the ones that are lower. The *Rhabdammina* assemblage may therefore have been redeposited from the shallower parts of the basin (where turbidite flows originate), with the *Paratrochamminoides* fauna representing the *in situ* assemblage deposited at a more stable abyssal environment.

The deep infaunal *Karrerulina apicularis* (Cushman), a modern species, has been shown by Kuhnt *et al.* (2000) to be living in the North Atlantic at sediment depths of up to 20 cm, where no other living foraminifera is found below 10 cm. If an analogy can be drawn between *K. apicularis* and *Karrerulina* spp. in the Variegated Shales (the morphology of the living and extinct forms is certainly very similar), then the presence of this assemblage would indicate a low sedimentation rate with oligotrophic conditions, where deeper sediments remain oxygenated. This is the environmental interpretation given by Bąk (2004) for the lower Eocene *Karrerulina*-rich interval found in the Dukla Unit. Our *Karrerulina*-rich samples, however, are mostly of a green colour and are associated with turbidites. In our case, the turbidity currents would have decimated or partially removed the epifaunal foraminiferal population and thereby favoured the infauna. *Recurvoides* was also found to be a deep infaunal form by Kuhnt *et al.* (2000), but to a lesser extent.

The red and green sediment

Red Clays form today over much of the ocean floor below the CCD, and in fact cover almost half of the Earth's surface. They are characterised more by the lack of any other type of sedimentary input, rather than by their red clay content as such. Sedimentation rates are typically extremely low as these deposits occur well away from continental margins (where they would be affected by terrigenous input), and away from areas of high surface water productivity. The red colouration is caused by the oxidation of iron within the sediments, as highly oxidised bottom water passes over the surface (Brown *et al.*, 1995). The red shale samples with a lower tubular content (Z2, Z7, S8, S13 & S15), therefore, are probably indicative of a condensed sequence, below the CCD, within a calm environment and unaffected by many life forms other than agglutinated foraminifera.

The origin of the green shale colouration has been assigned to the lower oxygenation of surface sediment by many authors (e.g. Gardner *et al.* 1977; Morlotti & Kuhnt, 1992; Bąk *et al.*, 1997). Gardner *et al.* (1977) proposed a model for the production of black, green and red clay at depth, which was based on colour changes with the increase in sediment oxygenation. Although the Gardner model showed that a change in organic carbon flux was the cause of this change, other factors can also affect sediment oxygenation. These include changes in the oxygenation of the bottom water-mass itself, and changes in the sedimentation accumulation rate. Thus the green shales may have been affected by any or all of these factors, but it seems likely that variations in sedimentation rate played a key role as the high tubular content suggests turbidite deposition. The *Rhabdammina* assemblage is predominantly green in colour. However some red horizons containing this fauna (Z4, Z5 & S12) could be indicating a similar high-energy environment with increased oxygen content in the bottom waters.

CONCLUSIONS

1. Agglutinated foraminifera are used to constrain the age of the samples of Variegated Shale, as there were no calcareous nannofossils present within these beds. The stratigraphically oldest samples Z11 and Z10 (Zyndranowa) are dated to between 52–50 Ma (Early Eocene), below the first occurrence of *Reticulophragmium amplectens*, but above the *Glomospira* assemblage. Samples S12 (Vyšny Komarnik) and S15 (Olchowiec) are included in this age estimation.

The first occurrence of *Reticulophragmium amplectens* is considered to be around 50 Ma (base of Middle Eocene), and is recorded in samples Z7–Z0 (Zyndranowa) and samples S8 and S13 (Vyšny Komarnik). The maximum upper age limit of these samples is considered 42 Ma (end of *Reticulophragmium amplectens* Zone).

Samples Z9 and Z8 (Zyndranowa) were dated to between 38 Ma and 35.5 Ma (middle – late Eocene) by calcareous nannofossils. There were no agglutinated foraminifera present in these samples, which consisted of marl rather than Variegated Shale. These marls are therefore considered to be of a different lithostratigraphic unit.

2. A diverse fauna (>50 species total, average 29 species per sample) of agglutinated foraminifera is documented. Two faunal assemblages have been identified as the predominantly green coloured *Rhabdammina* Assemblage (high in tubular forms and *Paratrochamminoides*), and the predominantly red coloured *Paratrochamminoides* Assemblage (low in tubular forms and higher in *Paratrochamminoides*). The two assemblages are otherwise very similar. The green shales have been found to contain a slightly higher faunal diversity, which could be explained by the difficulty in identifying *Paratrochamminoides* on a species level (as the red shales typically contain higher abundance of *Paratrochamminoides*).

3. Of the 7 new species described by Noth (1912), only *Trochammina deflexiformis* has been identified in this report and re-described as *Paratrochamminoides deflexiformis* (Noth).

4. The Variegated Shales have been interpreted as being formed below the CCD, at a depth of around 2.5 km or more during the early Eocene (although possibly shallower). The *Rhabdammina* Assemblage is thought to represent a high-energy turbidite-dominated slope environment, where rapid deposition caused a reduction in the oxygen content of the sediments, a reduction of the epifauna, and a green colouration. The *Paratrochamminoides* Assemblage is thought to represent a lower energy deep-water environment with low sedimentation rates (i.e. a condensed sequence).

SYSTEMATIC PALAEONTOLOGY

The list of taxa below follows the Kaminski (2004) classification of agglutinated foraminifera. Species identifications are based largely on the taxonomic work of Kaminski and Geroch (1993) and Kaminski *et al.* (1988, 1989, 1996). For the sake of brevity, only primary references and revisions of primary types are cited.

Family RHABDAMMINIDAE Brady 1884
Subfamily RHABDAMMINININAE Brady 1884
Genus *Rhabdammina* M. Sars in Carpenter 1869

Rhabdammina spp.
Fig. 10A–C

Material: Abundant in most samples.
Remarks: Test tubular, medium thickness, slightly flattened, apertures at both ends of the tube, test outer surface slightly rough with angular quartz grains.

Subfamily BATHYSIPHONINAE Avnimelech 1952
Genus *Nothia* Pflaumann 1964

Nothia spp.
Fig. 10D

Material: Common in most samples.
Remarks: Test tubular, large, thin walled, very flattened, apertures at both ends of tube, surface finely agglutinated quartz grains.

Family RHIZAMMINIDAE Brady 1879
Genus *Rhizammina* Brady 1879

Rhizammina spp.
Fig. 10E

Material: Abundant in most samples.
Remarks: Test tubular, slender, thick walled, usually not flattened, apertures at both ends of tube, wall made up of fine to coarsely agglutinated angular quartz grains.

Family SACCAMMINIDAE Brady 1884
Subfamily SACCAMMININAE Brady 1884
Genus *Saccammina* Carpenter 1869

Saccammina placenta (Grzybowski 1898)
Fig. 10F

1898. *Reophax placenta* Grzybowski: p. 276–277, pl. 10, figs 9, 10.

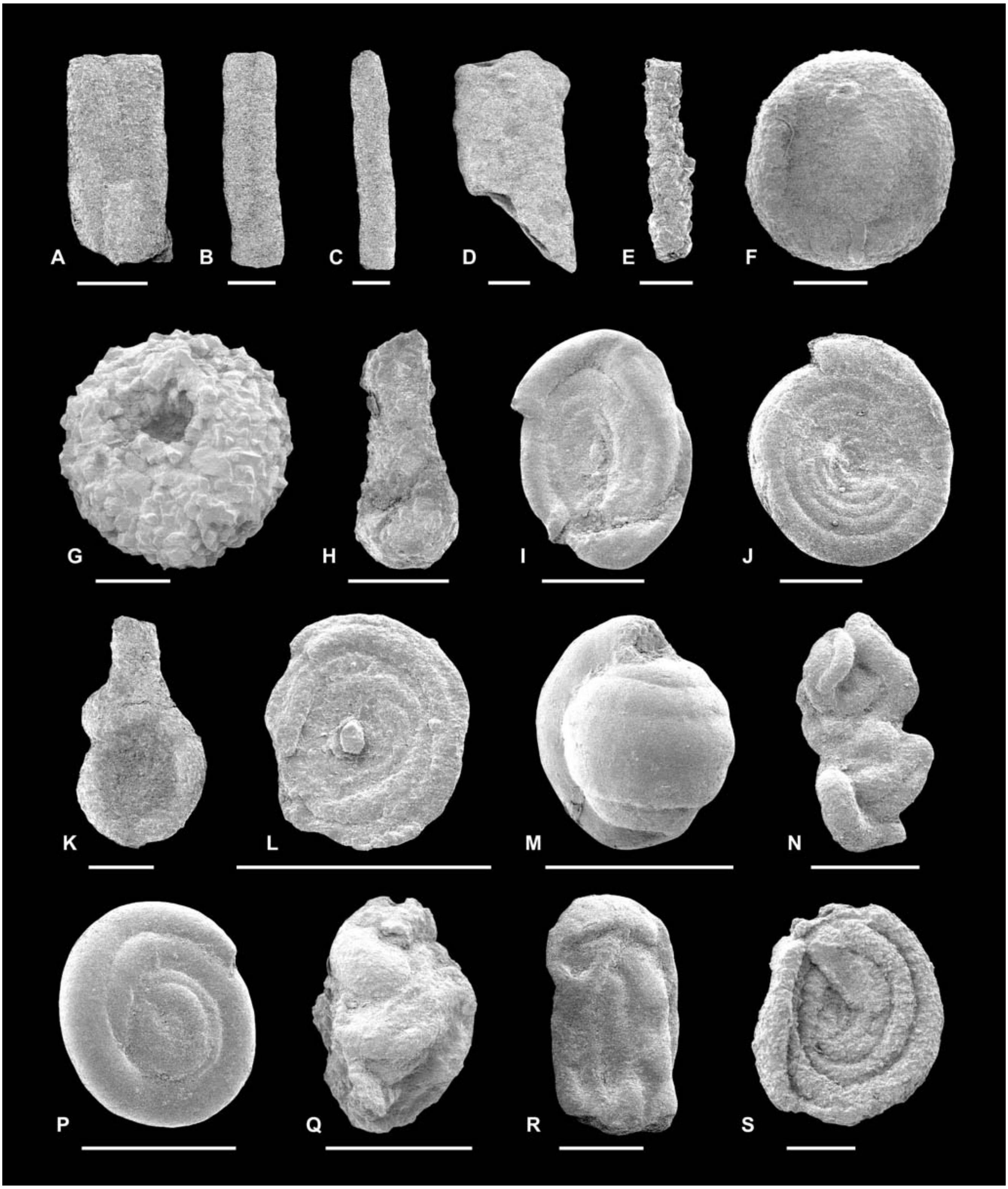


Fig. 10. Foraminifera from the Variegated Shales near Barwinek. **A–C** – *Rhabdammina* spp. (Z1, Z1, Z1); D – *Nothia* sp. (Z1); **E** – *Rhizammina* spp. (Z1); **F** – *Saccammina placenta* (Grzybowski) (Z0); **G** – *Psammosphaera* sp. (Z1); **H** – *Hyperammina* sp. (S8); **I** – *Ammodiscus peruvianus* (Berry) (Z0); **J, K** – *Ammodiscus tenuissimus* (Grzybowski) (Z4, S8); **L** – *Ammodiscus* sp.1 (Z0); **M** – *Glomospira charoides* (Jones & Parker) (Z2); **N** – *Glomospira glomerata* (Grzybowski) (Z1); **P** – *Glomospira gordialis* (Jones & Parker) (Z2); **Q** – *Glomospira irregularis* (Grzybowski) (Z4); **R** – *Glomospira serpens* (Grzybowski) (Z5); **S** – *Glomospira* sp. 5 (Z0). Scale bar 300 µm

1993. *Saccammina placenta* (Grzybowski): Kaminski & Geroch; p. 249, pl. 2, figs 5–7.

Material: 120 specimens from 15 samples.
Remarks: All forms with finely agglutinated wall and apertural neck, ranging in size from small to large.
Distribution: Widely known from the Maastrichtian to Eocene of the Western Tethys and Atlantic.

Family PSAMMOSPHAERIDAE Haeckel 1894
Subfamily PSAMMOSPHAERINAE Haeckel 1894
Genus *Psammosphaera* Schulze 1875

Psammosphaera spp.
Fig. 10G

Material: 184 specimens from 15 samples.
Remarks: All single chambered forms with coarsely agglutinated walls, aperture is a small indentation or is not visible, range in size from small to large. Usually has a less compressed test than *Saccammina placenta*.

Family HYPERAMMINIDAE Eimer et Fickert 1899
Subfamily HYPERAMMININAE Eimer et Fickert 1899
Genus *Hyperammina* Brady 1878

Hyperammina spp.
Fig. 10H

Material: 18 specimens from 9 samples.
Remarks: All forms comprising tubular test with rounded proloculus at one end. Ranging in size from medium to very small, medium to finely agglutinated.

Family AMMODISCIDAE Reuss 1862
Subfamily AMMODISCINAE Reuss 1862
Genus *Ammodiscus* Reuss 1862

Ammodiscus peruvianus (Berry 1928)
Fig. 10I

1928. *Ammodiscus peruvianus* Berry: p. 342, pl. 27.

Material: 65 specimens from 14 samples.
Distribution: A cosmopolitan species from late Cretaceous to Eocene, originally described from Peru.

Ammodiscus tenuissimus (Grzybowski 1898)
Fig. 10J, K

1898. *Ammodiscus tenuissimus* Grzybowski: p. 282, pl. 10, fig. 35.

Material: 163 specimens from 15 samples.
Distribution: Common from the Upper Cretaceous to Palaeogene of the Alpine-Carpathian region.

Ammodiscus sp. 1
Fig. 10L

Material: 25 specimens from 8 samples.
Remarks: Flattened planispiral test, chamber increasing in size gradually with each whorl, smooth outer surface, very thin wall, very small size. Differs from *Ammodiscus tenuissimus* by its thinner wall and generally (but not always) smaller size.

Ammodiscus spp.

Material: 16 specimens from 5 samples.
Remarks: All unidentified forms of *Ammodiscus*, usually smooth walled with slightly glomospiral coiling.

Subfamily USBEKISTANIINAE Vyalov 1977
Genus *Glomospira Rzehak* 1885

Glomospira charoides (Jones & Parker 1860)
Fig. 10M

1860. *Trochammina squamata* Jones & Parker var. *charoides* Jones & Parker: p. 304.
1990. *Glomospira charoides* (Jones & Parker): Berggren & Kaminski; pl. 1, fig. 2.

Material: 310 specimens from 15 samples.
Distribution: Originally described from the modern Mediterranean. *G. charoides* is also a common cosmopolitan species in Cretaceous to Palaeogene flysch deposits.

Glomospira glomerata (Grzybowski 1898)
Fig. 10N

1898. *Ammodiscus glomeratus* Grzybowski: p. 285, pl. 11, fig. 4.

Material: 55 specimens from 8 samples.
Distribution: Common in the Upper Cretaceous to Palaeogene of the Carpathians.

Glomospira gordialis (Jones & Parker 1860)
Fig. 10P

1860. *Trochammina squamata* Jones & Parker var. *gordialis* Jones & Parker: p. 304.
1990. *Glomospira gordialis* (Jones & Parker): Berggren & Kaminski; pl. 1, fig. 1.

Material: 192 specimens from 11 samples.
Distribution: Originally described from the modern Mediterranean. A cosmopolitan species from Cretaceous to Recent.

Glomospira irregularis (Grzybowski 1898)
Fig. 10Q

1898. *Ammodiscus irregularis* Grzybowski: p. 285, pl. 11, figs 2, 3.
1993. *Glomospira irregularis* (Grzybowski): Kaminski & Geroch; p. 256, pl. 6, figs 6–8b.

Material: 38 specimens from 10 samples.
Distribution: Upper Cretaceous to lower Palaeogene throughout the Alpine-Carpathian region.

Glomospira serpens (Grzybowski 1898)
Fig. 10R

1898. *Ammodiscus serpens* Grzybowski: p. 285, pl. 10, figs 31–33.
1993. *Glomospira serpens* (Grzybowski): Kaminski & Geroch; p. 256, pl. 6, figs 2–5.

Material: 5 specimens from 3 samples.
Distribution: Upper Cretaceous to Eocene of the Carpathians and Alps.

Glomospira sp. 5
Fig. 10S

1996. *Glomospira* sp. 5 Kaminski *et al.*: p. 11, pl. 1, figs 5–8.

Material: 42 specimens from 12 samples.
Remarks: Medium to large test, planispiral to glomospiral coiling, coarsly agglutinated. Differs from *Ammodiscus tenuissimus* by coarser test and glomospiral coiling, differs from *Glomospira irregularis* by coarser test and more regular planispiral coiling.
Distribution: Also recorded from the Palaeocene and lower Eocene of the Tangier Unit, Northern Morocco (Kaminski *et al.*, 1996).

Family HORMOSINELLIDAE Rauser et Reitlinger 1986
Genus *Subreophax* Saidova 1975

Subreophax scalaris (Grzybowski 1896)
Fig. 11A, B

1896. *Reophax guttifera* Brady var. *scalaria* Grzybowski: p. 277, pl. 8, fig. 26.
1988. *Subreophax scalaris* (Grzybowski): Kaminski *et al.*; p. 187, pl. 2, figs 16, 17.

Material: 41 specimens from 12 samples.
Distribution: Common in the Upper Cretaceous to Palaeogene flysch sediments of the Alpine-Carpathian region.

Subreophax splendidus (Grzybowski 1898)
Fig. 11C

cf. 1898. *Reophax splendida* Grzybowski: p. 278, pl. 10, fig. 16.

Material: 84 specimens from 14 samples.
Distribution: Upper Cretaceous and Palaeogene in the Caucasus, Carpathians and Alps.

Family ASCHEMOCELLIDAE Vyalov 1966
Genus *Aschemocella* Vyalov 1966

Aschemocella grandis (Grzybowski 1898)
Fig. 11D, E

1898. *Reophax grandis* Grzybowski: p. 277, pl. 10, figs 13–15.
1993. *Aschemocella grandis* (Grzybowski): Kaminski & Geroch; p. 249, pl. 2, figs 8–10.

Material: 58 specimens from 11 samples.
Distribution: Well known from Poland and the North Sea in upper Cretaceous to early Miocene sediments.

Family REOPHACIDAE Cushman 1927
Genus *Reophax* de Montfort 1808

Reophax elongatus (Grzybowski 1898)
1898. *Reophax elongatus* Grzybowski: p. 279, pl. 10, figs 19, 20.

Material: 21 specimens from 12 samples.
Distribution: A cosmopolitan species common in the Eocene and Oligocene in Tethys, Atlantic Ocean and Norwegian Sea.

Reophax pilulifer (Brady 1884)
Fig. 11F, G

1884. *Reophax pilulifer* Brady: p. 292, pl. 30, figs 18–20.

Material: 213 specimens from 14 samples.
Distribution: Common cosmopolitan species from Late Cretaceous to Recent.

Family HORMOSINIDAE Haeckel 1894
Subfamily HORMOSININAE Haeckel 1894
Genus *Pseudonodosinella* Saidova 1970

Pseudonodosinella nodulosa (Brady 1879)
Fig. 11H

1879. *Reophax nodulosa* Brady: p. 52, pl. 4, figs 7, 8.

Material: 159 specimens from 12 samples.
Remarks: Described by Grzybowski (1898) as *Reophax subnodulosa*, regarded by Kaminski & Geroch (1993) as a synonym of *Reophax nodulosa* (Brady).
Distribution: Cosmopolitan species from Eocene to Recent, although questionably recorded from the Upper Senonian by Jednorowska (1968).

Family LITUOTUBIDAE Loeblich et Tappan 1984
Genus *Lituotuba* Rhumbler 1895

Lituotuba lituiformis (Brady 1879)
Fig. 11I, J

1879. *Trochammina lituiformis* Brady: p. 59, pl. 5, fig. 16.

Material: 6 specimens from 5 samples.
Distribution: Consistent cosmopolitan species from Cretaceous to Recent.

Genus *Paratrochamminoides* Soliman 1972

Paratrochamminoides deflexiformis (Noth 1912)
Fig. 11K1, K2

1912. *Trochammina deflexiformis* Noth: p. 26, figs 10a, b.
1996. *Paratrochamminoides* sp. 4: Kaminski *et al.*; p. 16, pl. 3, figs 10, 11.
2004. ?*Paratrochamminoides* sp. 4: Kaminski & Kuhnt; p. 283, fig. 6.

Neotype: Deposited in the Grzybowski Collection, Geological Museum of the Jagiellonian University, Krakow Poland.
Material: 1 specimen from 1 sample (the neotype).
Description: Test large, round in outline, glomospiral to irregularly planispiral, consisting of 6 bead-shaped chambers in the last whorl, with 8–9 visible chambers in all. Chambers in the final whorl do not increase in size markedly. Sutures are straight between chambers, and are reasonably well defined. The last whorl is almost planispiral, with the final chamber offset towards the centre of the test on one side. Test wall finely agglutinated with a rough texture, aperture not visible.
Remarks: Transferred to *Paratrochamminoides* due to its glomospirally enrolled test and large bead-shaped chambers. *Paratrochamminoides* sp. 4 (Kaminski *et al.* 1996) belongs to this species. The specimens from Morocco were described as glomospirally coiled (occasionally uncoiling), up to three whorls, 8–10 chambers in last whorl, chambers subspherical, increasing slowly in size, and a thick, finely agglutinated wall. This species name has in the past been incorrectly used to describe a species of *Recurvoides* (e.g., Geroch, 1960; Webb, 1973).
Distribution: *Paratrochamminoides deflexiformis* is found in the Palaeocene and lower Eocene of the Tangier Unit, Northern Morocco; Maastrichtian of the Innoceramian Beds, Magura Unit; and in the Palaeocene of the Lizard Springs Formation, Trinidad.

Paratrochamminoides draco (Grzybowski 1901)
Fig. 11L

1901. *Trochammina draco* Grzybowski: p. 280, pl. 8, fig. 10.
1993. *Paratrochamminoides draco* (Grzybowski): Kaminski & Geroch; p. 277, pl. 16, figs 5a–c.

Material: 10 specimens from 5 samples.
Distribution: Magura Unit of the Polish Carpathians.

Paratrochamminoides gorayskii (Grzybowski 1898)
Fig. 11M

1898. *Ammodiscus gorayskii* Grzybowski: p. 283, pl. 11, fig. 5.
1993. *Paratrochamminoides gorayskii* (Grzybowski): Kaminski & Geroch; p. 255, pl. 5, figs 8a–d.

Material: 10 specimens from 7 samples.
Distribution: Palaeogene of the Carpathians; also observed from

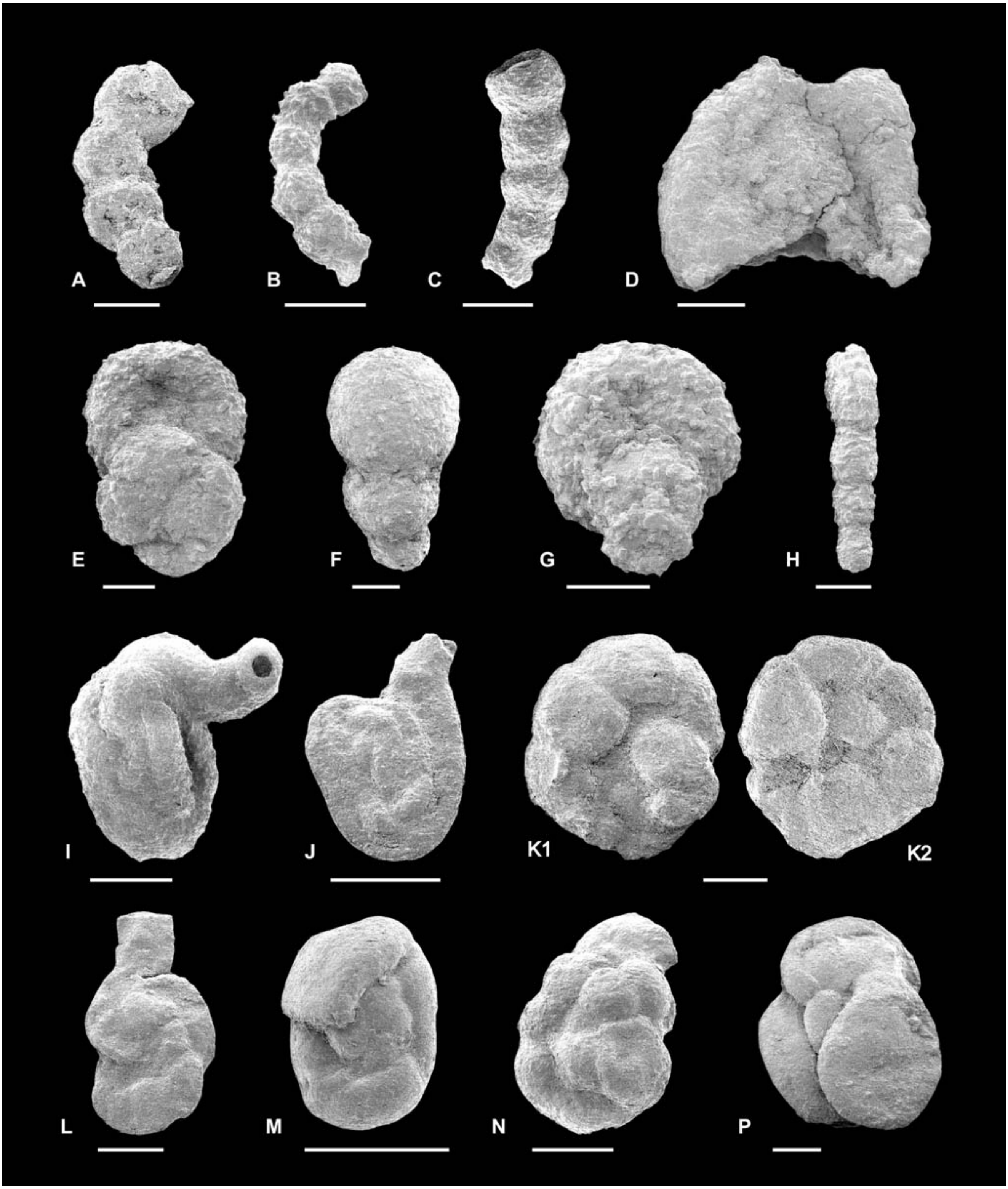


Fig. 11. Foraminifera from the Variegated Shales near Barwinek. **A, B** – *Subreophax scalaris* (Grzybowski) (S8, Z1); **C** – *Subreophax splendidus* (Grzybowski) (Z2); **D, E** – *Aschemocella grandis* (Grzybowski) (Z0, Z3); **F, G** – *Reophax pilulifer* (Brady) (S9, Z0); **H** – *Pseudonodosinella nodulosa* (Brady) (Z1); **I, J** – *Lituotuba lituiformis* (Brady) (Z4, S15); **K** – *Paratrochamminoides deflexiformis* (Noth) (S12, S12); **L** – *Paratrochamminoides draco* (Grzybowski) (S15); **M** – *Paratrochamminoides gorayskii* (Grzybowski) (Z1); **N** – *Paratrochamminoides heteromorphus* (Grzybowski) (S12); **P** – *Paratrochamminoides irregularis* (White) (Z0). Scale bar 300 μm

the Eocene at Site 647 in the Labrador Sea, and the Numidian Flysch of Northern Morocco.

Paratrochamminoides heteromorphus (Grzybowski 1898)
Fig. 11N

1898. *Trochammina heteromorpha* Grzybowski: p. 286, pl. 11, fig. 16.
1993. *Paratrochamminoides heteromorphus* (Grzybowski): Kaminski & Geroch; p. 258, pl. 7, figs 3a–5b.

Material: 21 specimens from 10 samples.
Distribution: Upper Cretaceous and Palaeogene throughout the Carpathians; also occurs in Morocco and Trinidad.

Paratrochamminoides irregularis (White 1928)
Fig. 11P

1928. *Trochamminoides irregularis* White: p. 307, pl. 42, fig. 1.
1990. *Paratrochamminoides irregularis* (White): Kuhnt; p. 320; pl. 5, fig. 10.

Material: 18 specimens from 9 samples.
Distribution: First recorded from the Palaeocene Velasco Formation of Mexico. This species is cosmopolitan.

Paratrochamminoides mitratus (Grzybowski 1901)
Fig. 12A

1901. *Trochammina mitrata* Grzybowski: p. 280, pl. 8, fig. 3.
1993. *Paratrochamminoides mitratus* (Grzybowski): Kaminski & Geroch; p. 278, pl. 16, figs 4a, b; 6a, b.

Material: 3 specimens from 1 sample.
Distribution: Palaeocene of the Polish Carpathians. Also found in Morocco.

Paratrochamminoides cf. *olszewskii* (Grzybowski 1898)
Fig. 12B, C

1898. *Trochammina olszewskii* Grzybowski: p. 298, pl. 11, fig. 6.
1993. *Paratrochamminoides olszewskii* (Grzybowski): Kaminski & Geroch; p. 257, pl. 7, figs 1a–2b.

Material: 35 specimens from 12 samples.
Remarks: Includes forms with a coarser agglutinated wall than the type species, otherwise similar form.
Distribution: Campanian to Palaeocene of the Polish Carpathians.

Paratrochamminoides spp

Material: 54 specimens from 10 samples.
Remarks: All forms with streptospiral, trochospiral, glomospiral or triloculine coiling, with rounded or elongate chambers.

Family TROCHAMMINOIDAE Haynes et Nwabufo-Ene 1998
Genus *Trochamminoides* Cushman 1910

Trochamminoides dubius (Grzybowski 1898)
Fig. 12D

1901. *Ammodiscus dubius* Grzybowski: p. 274, pl. 8, figs 12, 14.
1970. *Trochamminoides dubius* (Grzybowski): Neagu; p. 38, pl. 2, fig. 20.

Material: 14 specimens from 3 samples.
Distribution: Found in the Upper Cretaceous to Palaeogene throughout the Carpathians; also recorded from the Tangier Unit, Northern Morocco, Gubio Italy, and the Lizard Springs Formation, Trinidad.

Trochamminoides folius (Grzybowski 1898)

1898. *Trochammina folium* Grzybowski: p. 288, pl. 11, figs 7–9.
1993. *Trochamminoides folius* (Grzybowski): Kaminski & Geroch; p. 261, pl. 9, figs 1a–4b.

Material: 14 specimens from 10 samples.
Distribution: Palaeogene of the Carpathians.

Trochamminoides proteus (Karrer 1866)
Fig. 12E, F

1866. *Trochammina proteus* Karrer: pl. 1, fig. 8.
1928. *Trochamminoides proteus* (Karrer): White; p. 308, pl. 42, fig. 2.

Material: 3 specimens from 1 sample.
Remarks: Coiling initially glomospiral, later nearly planispiral. Chambers globular, increasing in slowly size, with typically 6–9 chambers (or up to 12 in largest specimens) in the last whorl.
Distribution: Cosmopolitan species found in upper Cretaceous to Palaeogene sediments.

Trochamminoides septatus (Grzybowski 1898)
Fig. 12G

1898. *Ammodiscus septatus* Grzybowski: p. 283, pl. 11, fig. 1.
1993. *Trochamminoides septatus* (Grzybowski): Kaminski & Geroch; p. 255, pl. 5, figs 9a–c.

Material: 10 specimens from 6 samples.
Distribution: Generally a rare species; also found in Gubbio, Italy and Morocco.

Trochamminoides subcoronatus (Grzybowski 1896)
Fig. 12H, I

1896. *Trochammina subcoronata* Grzybowski: p. 283–284, pl. 9, fig. 3a–c.
1988. *Trochamminoides subcoronatus* (Grzybowski): Kaminski *et al.*; p. 192, pl. 4, fig. 19.

Material: 70 specimens from 12 samples.
Remarks: All planispiral forms with 6–8 bead-shaped chambers in last whorl.
Distribution: Found throughout the Alpine-Carpathian flysch from the upper Cretaceous to Palaeogene.

Trochamminoides variolarius (Grzybowski 1898)
Fig. 12J

1898. *Trochammina variolaria* Grzybowski: p. 288, pl. 11, fig. 15.
1993. *Trochamminoides variolarius* (Grzybowski): Kaminski & Geroch; p. 261, pl. 9, figs 5a–6c.

Material: 2 specimens from 2 samples.
Distribution: Common in the Carpathian flysch, also occurs North Sea, Celebes Sea, Morocco, and Switzerland from the late Cretaceous and Palaeogene.

Trochamminoides velascoensis (Cushman 1926)
Fig. 12K

1926. *Trochamminoides velascoensis* Cushman: p. 583, pl. 15, figs 2a, b.

Material: 5 specimens from 3 samples.
Remarks: Forms with planispiral coiling and elongate chambers; differs from *Trochamminoides subcoronatus* by more elongate chambers.
Distribution: Originally described from the Velasco Formation of Mexico.

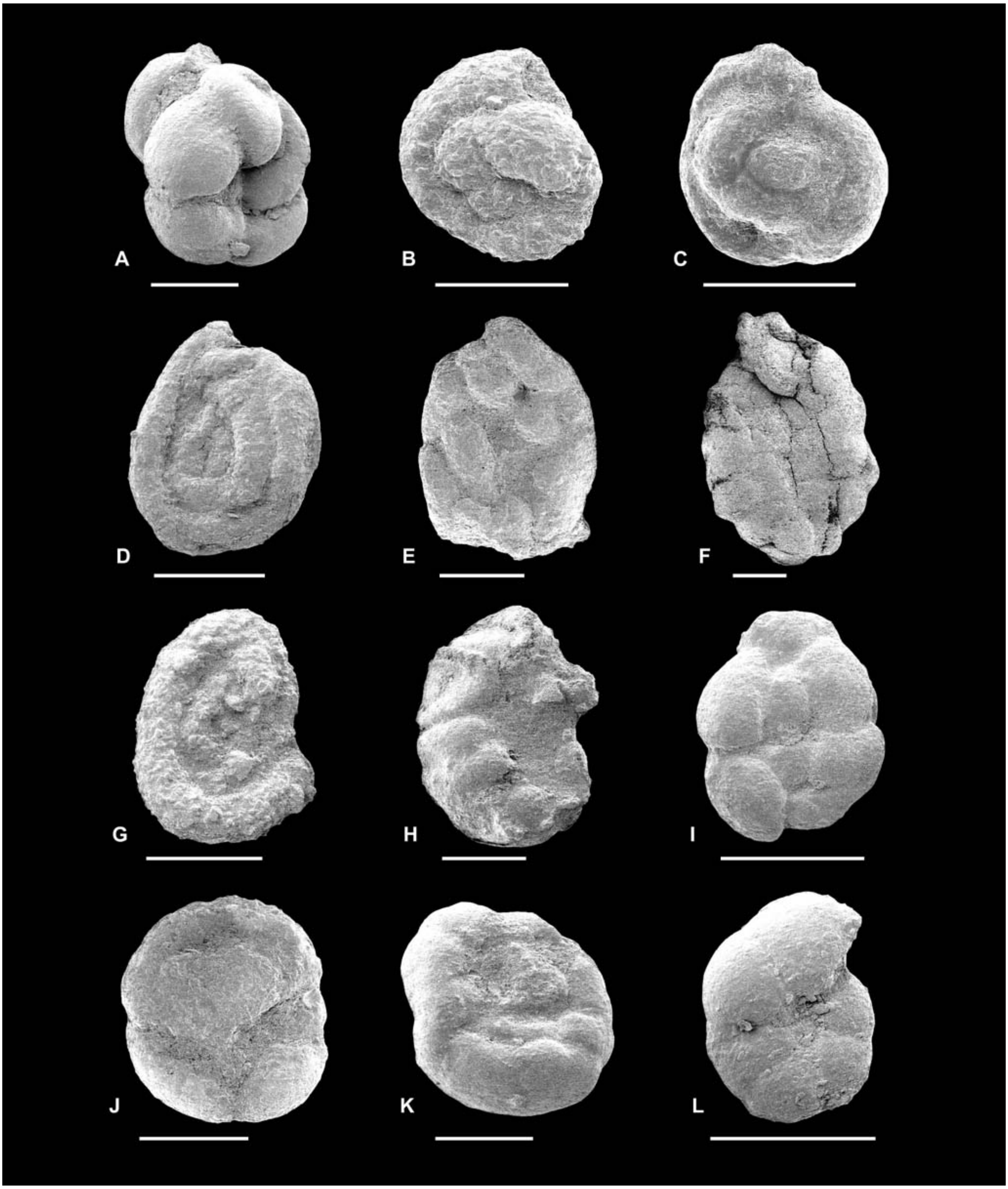


Fig. 12. Foraminifera from the Variegated Shales near Barwinek. **A** – *Paratrochamminoides mitratus* (Grzybowski) (S15); **B, C** – *Paratrochamminoides* cf. *olszewskii* (Grzybowski) (Z4, Z1); **D** – *Trochamminoides dubius* (Grzybowski) (S15); **E, F** – *Trochamminoides proteus* (Karrer) (S12, S12); **G** – *Trochamminoides septatus* (Grzybowski) (Z3); **H, I** – *Trochamminoides subcoronatus* (Grzybowski) (S12, Z1); **J** – *Trochamminoides variolarius* (Grzybowski) (S8); **K** – *Trochamminoides velascoensis* (Cushman) (Z5); **L** – *Haplophragmoides stomatus* (Grzybowski) (S12). Scale bar 300 μm

Trochamminoides spp.

Material: 38 specimens from 9 samples.
Remarks: All planispiral forms with bead-shaped or elongate chambers.

Trochamminoides/Paratrochamminoides spp.

Material: 1247 specimens from 15 samples.
Remarks: All unidentifiable forms with bead-shaped or elongate chambers. Coiling mode largely not deciphered. Mostly fragmentary, juvenile, or poorly preserved forms.

Family HAPLOPHRAGMOIDIDAE Maync 1952
Genus *Haplophragmoides* Cushman 1910

Haplophragmoides porrectus (Maslakova 1955)

1955. *Haplophragmoides porrectus* Maslakova: p. 47, pl. 3, figs 5, 6.

Material: 1 specimen from 1 sample.
Remarks: Only one fragmentary specimen found, exhibiting distinctive heavy sutures and rounded chambers.
Distribution: Recorded from the Palaeogene of the Carpathians, Tasman Sea, Labrador Margin, Morocco and Trinidad.

Haplophragmoides stomatus (Grzybowski 1898)
Fig. 12L

1898. *Trochammina stomata* Grzybowski: p. 290, pl. 11, figs 26, 27.
1993. *Haplophragmoides stomatus* (Grzybowski): Kaminski & Geroch; p.264, pl. 11, figs 1a–d (lectotype).

Material: 65 specimens from 8 samples.
Distribution: Cosmopolitan species known from Upper Cretaceous to Palaeogene.

Haplophragmoides walteri (Grzybowski 1898)
Fig. 13A

1898. *Trochammina walteri* Grzybowski: p. 290, pl. 11, fig. 31.
1993. *Haplophragmoides walteri* (Grzybowski): Kaminski & Geroch; p. 263, pl. 10, figs 3a–7c.

Material: 204 specimens from 14 samples.
Distribution: A common Palaeocene to Eocene species from flysch-type sediments throughout the Carpathians, and deep-sea sediments worldwide.

Haplophragmoides sp. 1
Fig. 13B

Material: 3 specimens from 1 sample.
Remarks: Medium to large, involute planispiral coiling, flattened perifori, smooth wall, 12 chambers in last whorl slowly increasing in size. Simple undifferentiated wall. Differs from *Haplophragmoides walteri* with more chambers in last whorl, differs from *Reticulphragmium amplectens* by having simple test wall.

Family AMMOSPHAEROIDINIDAE Cushman 1927
Subfamily RECURVOIDINAE Alekseychik-Mitskevich 1973
Genus *Budashevaella* Loeblich et Tappan 1964

Budashevaella multicamerata (Voloshinova 1961)
Fig. 12C

1961. *Circus multicamerata* Voloshinova & Budasheva: p. 201, pl. 7, figs 6a–c, pl. 8, 1a–c.

Material: 1 specimen from 1 sample.
Distribution: Known from Palaeocene to Miocene. Common in high-latitudes of the Atlantic and Pacific Oceans.

Genus *Cribrostomoides* Cushman 1910

Cribrostomoides spp.

Material: 8 specimens from 4 samples.
Remarks: Forms with planispiral test, involute, chambers increasing rapidly in size. Medium to large sized test, medium agglutinated wall.

Genus *Recurvoides* Earland 1934

Recurvoides spp.
Fig. 13D, E

Material: 662 specimens from 15 samples.
Remarks: Small to large streptospiral test, medium to coarsely agglutinated, chambers increasing rapidly in size. Early chambers obscured by coarse outer wall.

Family SPIROPLECTAMMINIDAE Cushman 1927
Subfamily SPIROPLECTAMMININAE Cushman 1927
Genus *Spiroplectammina* Cushman 1927

Spiroplectammina spectabilis (Grzybowski 1898)
Fig. 13F

1898. *Spiroplecta spectabilis* Grzybowski: p. 293, pl. 12, fig. 12.
1984. *Spiroplectammina spectabilis* (Grzybowski): Kamiński; p. 31, pl. 12, figs 1–9; pl. 13, figs 1–8.

Material: 10 specimens from 5 samples.
Distribution: Widely distributed worldwide Palaeogene species.

Family TROCHAMMINIDAE Schwager 1877
Subamily TROCHAMMININAE Schwager 1877
Genus *Trochammina* Parker & Jones 1859

Trochammina spp.

Material: 14 specimens from 3 samples.
Remarks: All trochamminids compressed or otherwise. Usually poorly preserved.

Family PROLIXOPLECTIDAE Loeblich & Tappan 1985
Genus *Karrerulina* Finlay 1940

Karrerulina coniformis (Grzybowski 1898)
Fig. 13G

1898. *Gaudryina coniformis* Grzybowski: p. 295, pl. 12, fig. 7.
1993. *Karrerulina coniformis* (Grzybowski): Kaminski & Geroch; p. 269, pl. 13, figs 1–4.

Material: 84 specimens from 7 samples.
Distribution: Predominantly Eocene; known also from the Lower Eocene of Trinidad, North Atlantic ODP sites, and Gubbio.

Karrerulina conversa (Grzybowski 1901)
Fig. 13H

1901. *Gaudryina conversa* Grzybowski: p. 285, pl. 7, figs 15, 16.
1993. *Gerochammina conversa* (Grzybowski): Kaminski & Geroch; p. 279, pl. 13, figs 5a–11.

Material: 471 specimens from 11 samples.
Distribution: Cosmopolitan species, predominantl Palaeocene to Oligocene.

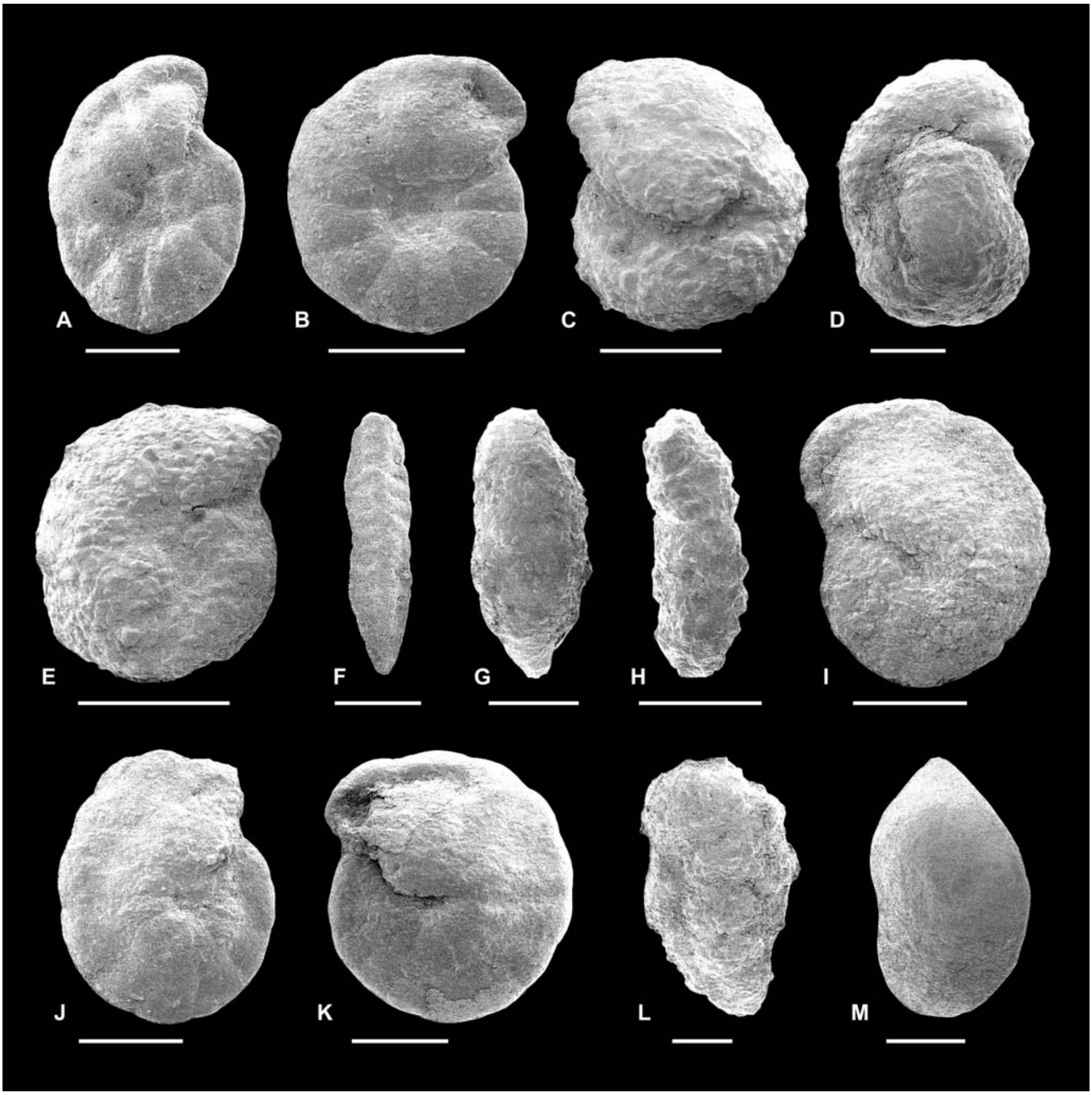


Fig. 13. Foraminifera from the Variegated Shales near Barwinek. **A** –*Haplophragmoides walteri* (Grzybowski) (S12); **B** – *Haplophragmoides* sp. 1 (S12); **C** – *Budashevaella multicamerata* (Voloshinova) (S13); **D, E** – *Recurvoides* spp. (S8 apertural view, S12); **F** – *Spiroplectammina spectabilis* (Grzybowski) (S8); **G** – *Karrerulina coniformis* (Grzybowski) (S8); **H** – *Karrerulina conversa* (Grzybowski) (S8); **I, J** – *Reticulophragmium intermedium* (cf. *amplectens*) (Mjatliuk) (Z0, Z2); **K** – *Reticulophragmium amplectens* (Grzybowski) (Z5); **L** – *Eggerella* sp. (S8); **M** – *Lenticulina* sp. (S8). Scale bar 300 µm

Family CYCLAMMINIDAE Marie 1941
Subfamily ALVEOLOPHRAGMIINAE Saidova 1981
Genus *Reticulophragmium* Maync 1955

Reticulophragmium amplectens (Grzybowski 1898)
Fig. 13K

1898. *Cyclammina amplectens* Grzybowski: p. 292, pl. 12, figs 1–3.

1993. *Reticulophragmium amplectens* (Grzybowski): Kaminski & Geroch, p. 266, pl. 11, figs 5–7c.

Material: *Reticulophragmium* spp. 157 specimens from 10 samples.

Distribution: Common from early Eocene to latest Eocene sediments of the Carpathians, North Sea, Norwegian Sea, and Labrador Sea.

Reticulophragmium intermedium (Mjatliuk 1970)
Fig. 13I, J

1970. *Cyclammina* (?) *intermedia* Mjatliuk: p. 89, pl. 21, fig. 6; pl. 28, figs 1a–c.

Material: *Reticulophragmium* spp. 157 specimens from 10 samples.
Remarks: Test wall contains alveoles as in *Reticulophragmium amplectens*, but is smaller than *R. amplectens*, and has fewer chambers. In edge view, it is otherwise similar in appearance. The species is believed to be the precursor of *R. amplectens*.
Distribution: Originally described from the lower Eocene of the Ukrainian Carpathians, the species is also known from the North Sea, Norwegian Sea, and Labrador Sea.

Family EGGERELLIDAE Cushman 1937
Subfamily EGGERELLINAE Cushman 1937
Genus *Eggerella* Cushman 1935

Eggerella sp.
Fig. 13L

Material: 3 specimens from 3 samples.
Remarks: High trochoid spire, early stages 4, 5 chambers per whorl, later stage 3 chambers per whorl. Coarsely agglutinated.

Suborder LAGENINA Lankester 1885
Family VAGINULINIDAE Reuss 1860
Genus *Lenticulina* Lamarck 1804

Lenticulina sp.
Fig. 13M

Material: 1 specimen from 1 sample.
Remarks: Large, laterally compressed, uncoiling calcareous test. Smooth wall. Chambers are not visible through test.
Distribution: Cosmopolitan.

Acknowledgements

This study was originally carried out as an MSc project in Micropalaeontology at U.C.L. We would like to thank AAPG student Grants-in-Aid programme and the EEC-Socrates programme for the essential funding provided in support of this project. We thank Jim Davy for his continued help throughout with the preparation of material and SEM photography, to Robert Pepera for his kind assistance with transportation in the Carpathians, and to Marta Bąk for her assistance with sample preparation at the Jagellonian University in Kraków. This is contribution nr. 72 of the Deep-Water Agglutinated Foraminiferal Project.

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Streszczenie

OTWORNICE Z EOCEŃSKICH PSTRYCH ŁUPKÓW W REJONIE BARWINKA (PŁASZCZOWINA MAGURSKA, KARPATY ZEWNĘTRZNE) W KLASYCZNYCH STANOWISKACH NOTHA (1912)

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Niniejsza publikacja stanowi opracowanie mikrofauny otwornicowej z eoceńskich łupków pstrych serii magurskiej z okolic Barwinaka, miejscowości usytuowanej na S od Dukli. Mikrofaunę otwornicową z występujących tam stanowisk pstrych łupków opisał w roku 1912 Rudolf Noth. Niestety, zebrane i zdeponowane przez niego we Wiedniu materiały mikropaleontologiczne zostały zniszczone w czasie wojny. Ich bezpośrednia rewizja okazała się zatem niemożliwa, a ponowne zbadanie zespołów ze stanowisk Notha wymagało zdobycia nowego materiału. W tym celu pobrano próbki do nowych badań mikropaleontologicznych z wystąpień pstrych łupków reprezentujących serię magurską w czterech miejscowościach w rejonie Barwinka (Fig. 1, 2). Opróbowane stanowiska znajdują się na terenie Polski w miejscowościach Zyndranowa (punkt 1) i Olchowiec (punkt 4) oraz w miejscowości Vyšny Komarnik na Słowacji (punkty 2 i 3) (Fig. 3). Z punktów 2, 3 i 4 pobrano pojedyncze próbki, natomiast odsłonięcie w punkcie 1 w Zyndranowej opróbowano kompleksowo. Jest to odsłonięcie w skarpie brzegowej potoku Panna. Występujące tu utwory reprezentowane są przez łupki czerwone i zielonawe (Fig. 4, 5)

Omawiane wystąpienia pstrych łupków zlokalizowane są w północnej, brzeżnej strefie płaszczowiny magurskiej, zwanej podjednostką Siar. Pozycję stratygraficzną tych łupków ilustruje załączony schemat litostratygraficzny (Fig. 2). Badane utwory są usytuowane ponad warstwami inoceramowymi (*vel.* ropianieckimi) wieku senon – paleocen, natomiast w ich nadkładzie występują reprezentujące eocen górny, warstwy podmagurskie i glaukonitowe piaskowce magurskie (piaskowce z Wątkowej), a lokalnie także warstwy malcowskie wieku oligoceńskiego (por. Cieszkowski w: Ślączka *et al.* 1991) . W Zyndranowej pstre łupki

występują u samego czoła płaszczowiny magurskiej, która nasuwa się tu na jednostkę dukielską.

Przy prawie całkowitym braku nanoplanktonu wapiennego, do określenia wieku badanych pstrych łupków, reprezentujących formację łupków z Łabowej (fm.) (Oszczypko, 1991), posłużyć mogły jedynie otwornice aglutynujące. Najstarsze zespoły wystąpiły w próbkach Z11 i Z10 z Zyndranowej. Są one datowane na wczesny eocen, czyli poniżej pierwszego pojawienia się *Reticulophragmium amplectens*, ale powyżej zespołu z *Glomospira*. Podobny wiek mają zespoły w próbach S12 (Vyšny Komarnik) i S15 (Olchowiec).

Uważa się, że pierwsze pojawienie się *Reticulophragmium amplectens* mialo miejsce około 50 Ma (spąg eocenu środkowego). Gatunek ten został znaleziony w próbkach Z7 – Z0 z Zyndranowej oraz S8 i S13 z Vyšnego Komarnika. Najwyższy wiekowy zasięg zespołów otwornicowych z tych próbek jest określany na 42 Ma (koniec zony *Reticulophragmium amplectens*).

W profilu w Zyndranowej próbki Z9 i Z8 są pozbawione otwornic. Ich datowanie na interwał między 38 Ma a 35,3 Ma (środkowy – wczesny eocen) ustalono w oparciu o występujący w nich nanoplankton wapienny. Reprezentowane są one przez brązowe, miękkie margle, które należą do innej jednostki litostratygraficznej i w obrębie pstrych łupków są jedynie tektonicznie zaklinowane.

Udokumentowana i sfotografowana przy pomocy SEM bogata mikrofauna składa się z otwornic aglutynujących (całościowo w liczbie ponad 50 gatunków, a przeciętnie 29 gatunków na próbkę) (Tabela 1; Fig. 9–12). Zidentyfikowano dwa zespoły otwornicowe, z których pierwszy to zespół z *Rhabdammina* w zielonych łupkach, a drugi – zespół z *Paratrochamminoides*, pochodzący z łupków czerwonych. Oba zespoły są bardzo do siebie podobne, ale zespół z *Rhabdammina* wykazuje nieco większe zróżnicowanie taksonomiczne. Stwierdza się tu liczną obecność, trudnych do identyfikacji gatunkowej form z rodzaju *Paratrochamminoides*.

Spośród siedmiu nowych gatunków opisanych przez Notha (1912) z okolic Barwinka, tylko gatunek *Trochmmina deflexiformis* jest tutaj uznany za ważny. W niniejszej publikacji jest on zredefiniowany jako *Paratrochamminoides deflexiformis* (Noth). Oryginalne rysunki Notha przedstawia Fig. 8.

Omawiane pstre łupki deponowane były we wczesnym eocenie w środowisku morskim poniżej CCD, na głębokości zbliżonej do 2,5 km a później w środowisku jeszcze głębszym. Zespół z *Rhabdammina* prawdopodobnie reprezentuje środowisko o wyższej energii usytuowane blisko skłonu kontynentalnego i zdominowane przez turbidity. W tych warunkach szybka sedymentacja powodowała zmniejszenie zawartości tlenu w osadzie i jego zielone zabarwienie. Zespół z *Paratrochamminoides* reprezentuje głębokowodne środowisko o niższej energii i spowolnionej sedymentacji (sekwencja skondensowana).

Lista oznaczonych taksonów oparta jest o klasyfikację otwornic aglutynujących wg Kaminskiego (2004). Identyfikacja gatunków bazuje głównie na pracach taksonomicznych Kamińskiego i Gerocha (1993) oraz Kaminskiego *et al.* (1988, 1989, 1996).