STUDIA GEOLOGICA POLONICA

Vol. 124, Kraków 2005, pp. 297–324.

Methods and Applications in Micropalaeontology

Edited by J. Tyszka, M. Oliwkiewicz-Miklasińska, P. Gedl & M. A. Kaminski

APPLICATIONS μ

Anna WAŚKOWSKA-OLIWA[1]

Foraminiferal palaeodepth indicators from the lower Palaeogene deposits of the Subsilesian Unit (Polish Outer Carpathians)

(Figs 1–10)

Abstract. The presented research results are an attempt at establishing the relative depth of sediment deposition in the Subsilesian zone of the Carpathian basin. To estimate palaeodepth calcareous and agglutinated foraminifera were investigated, taking into account the preservation conditions, life environment, and bathymetrical preferences of individual species of the calcareous benthic forms. Micropalaeontological analysis were carried out on foraminiferal assemblages from the Palaeocene–Middle Eocene deposits of the Lanckorona-Żegocina Tectonic Zone and the Żywiec Tectonic Window (Subsilesian Unit), which are represented by the Szydłowiec sandstones (Palaeocene part), the Czerwin sandstones, the Gorzeń sandstones, the Radziechowy sandstones, the Lipowa beds as well as shales, that occur above or between these sandstones.

The microfauna assemblages indicate that a change in the sedimentation depth of the individual lithosoms is conspicuous in the Early Palaeocene. During the Early Palaeocene the depth was between the CCD and the foraminiferal lysocline (FL); however, during the Late Palaeocene and the Early Eocene a deepening related to the CCD is evident or local shallowing of the CCD. Deposition took place in the lower part of the range between the CCD and FL, achieving the maximum palaeodepth in the latest Palaeocene. The depth changes of the Subsilesian basin zone can be correlated with global trends of the raising level of the World Ocean, and also with a period of increased subsidence of the Carpathian basins.

Key words: palaeobathymetry, CCD, foraminiferal lysocline, Subsilesian Unit, Palaeocene, Eocene, foraminifera.

1 AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Department of General and Mathematical Geology, al. Mickiewicza 30, 30-059 Kraków, Poland. E-mail: oliwa@geol.agh.edu.pl

INTRODUCTION

The Subsilesian Unit appears in relatively small areas in the Outer Polish Carpathians. Exposures of this unit are concentrated along the northern and southern edge of the Silesian Nappe. The microfaunal analyses were carried out in the southern range, where the Subsilesian Unit is exposed in several tectonic windows within the Silesian Nappe or in the tectonic contact zone of the Silesian and Magura nappes. A number of tectonic windows occur along the axial zone of the antyclinal structure known as the Lanckorona-Żegocina Zone (Książkiewicz, 1972), which extends from Rajbrot village in the east to the Wadowice region in the west. Farther to the west, the next tectonic window that includes sediments of the Subsilesian Unit is called the Żywiec Tectonic Window (Geroch & Gradziński, 1955; Książkiewicz, 1972; Unrug, 1969). The sediments occurring within the Żywiec tectonic window series represent an age interval from the Lower Cretaceous to the Oligocene (Burtan *et al.*, 1974; Geroch & Gradziński, 1955; Geroch *et al.*, 1967; Książkiewicz, 1951a, b, 1972; Skoczylas-Ciszewska, 1960; Unrug, 1969).

The Subsilesian Unit was distinguished in the Polish Flysch Carpathians as an independent unit by Książkiewicz (1951 a, b) and shortly afterwards a group of geologists and palaeontologists began intensive geological and palaeontological investigations. The numerous descriptive works and papers in which foraminifera were used in order to establish the stratigraphic position, arose then. Among the most important works concerning the Palaeogene deposits of the Subsilesian Unit are: Geroch & Gradziński (1955), Liszkowa (1959), Skoczylas-Ciszewska (1960), Liszkowa & Nowak (1963), Huss (1966), Książkiewicz (1966), Geroch *et al.* (1967), Jurkiewicz (1967), Jednorowska (1975), Burtan *et al.* (1974) and Burtan (1978). A number of studies concentrated upon estimates of palaeodepth of the Palaeogene Carpathian basins, e.g.: Koszarski & Żytko (1965), Jurkiewicz (1967), Książkiewicz (1975), Sikora (1976), Geroch *et al.* (1979), Morgiel & Olszewska (1981), Olszewska (1981, 1984), Kotlarczyk (1991) and Malata (2000). Foraminifera have been used as useful bathymetric indicators most of these studies.

METHODS

The present paper encompasses the micropalaeontological analyses of foraminiferal assemblages from the Palaeocene–Middle Eocene. Micropalaeontological analyses were carried out in the southern range of the Subsilesian Unit outcrops. Eleven strongly tectonized profiles of Lower Palaeogene sediments of the Subsilesian Unit were investigated (Fig. 1). Examined materials were collected from: Pluskawka stream in the Żegocina Zone, Krzyworzeka, Lipnik, Czerwin, Foszczówka streams in the Wiśniowa Tectonic Window, Gościbia, Gorzeń Górny, Dąbrówka streams and Bachowice area in the Lanckorona Zone as well as Leśnianka and Żarnówka streams in the Żywiec Tectonic Window. The samples were collected from shaly sediments from thick sequences. The materials (300 g of dry shales or marls) were prepared by using standard micropalaeontological techniques in order to obtain microfossils. Repeated boiling and drying using Glauber Salt disinte-

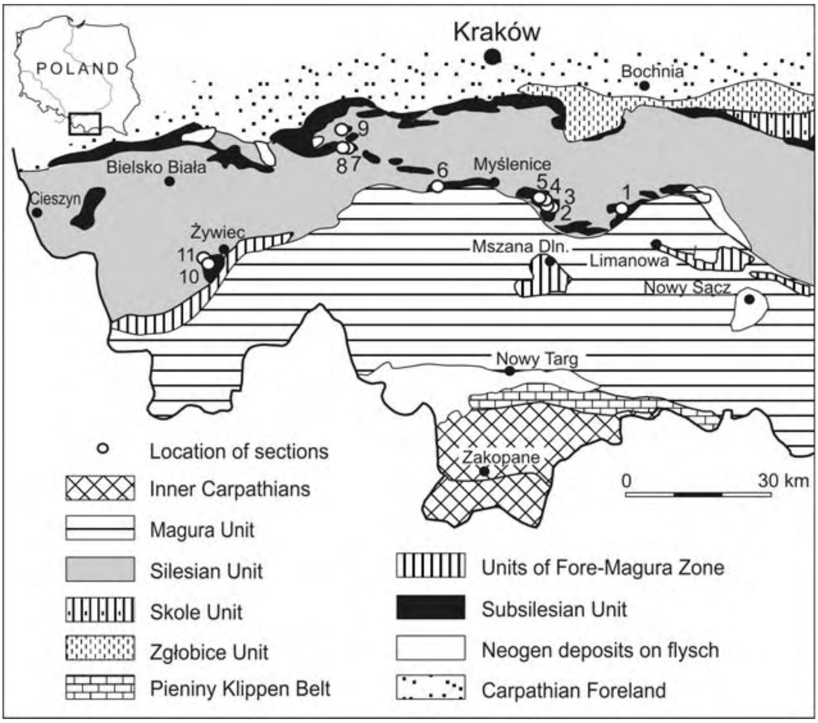


Fig. 1. Location of the studied area in the Polish Outer Carpathians (tectonic sketch-map after Malata *et al.*, 1996, modified). Location of sections, Żegocina zone: 1 – Nowe Rybie-Pluskawka; Wiśniowa Tectonic Window: 2 – Wiśniowa-Krzyworzeka, 3 – Wiśniowa-Foszczówka, 4 – Lipnik, 5 – Poznachowice-Czerwin; Lanckorona Zone: 6 – Jasienica-Gościbia, 7 – Gorzeń Górny, 8 – Gorzeń Dolny– Dąbrówka, 9 – Las Bachowicki; Żywiec Tectonic Window: 10 – Leśna-Leśnianka, 11 – Lipowa-Żarnówka

grated the samples, which were then washed through a set of sieves (100 and 63 μm screen) and dried. All specimens picked from the dry residue were statistically counted and taxonomically identified. For statistical analyses 5 fragments, which usually occur as crushed (e.g. tubular forms), were considered as a single foraminifer. The detailed data can be found in Waśkowska-Oliwa (2001). The basis of the bathymetrical analysis was the examination of the autochthonous faunas that were adopted from the repeatedly recurrent groups of the agglutinated foraminifera and well-preserved benthic calcareous forms (Figs 3, 4). As a rule, foraminiferal associations did not show signs of redeposition. Samples consisting of a minimum of 150 specimens were taken into account. SEM photos were made at the Scanning Electron Microscopy Laboratory of the Institute of Geological Sciences UJ (Kraków).

LITHOLOGY

The development of Lower Palaeogene sediments within the Subsilesian Unit is diverse. It is widely considered that there are mainly marly sediments representing a

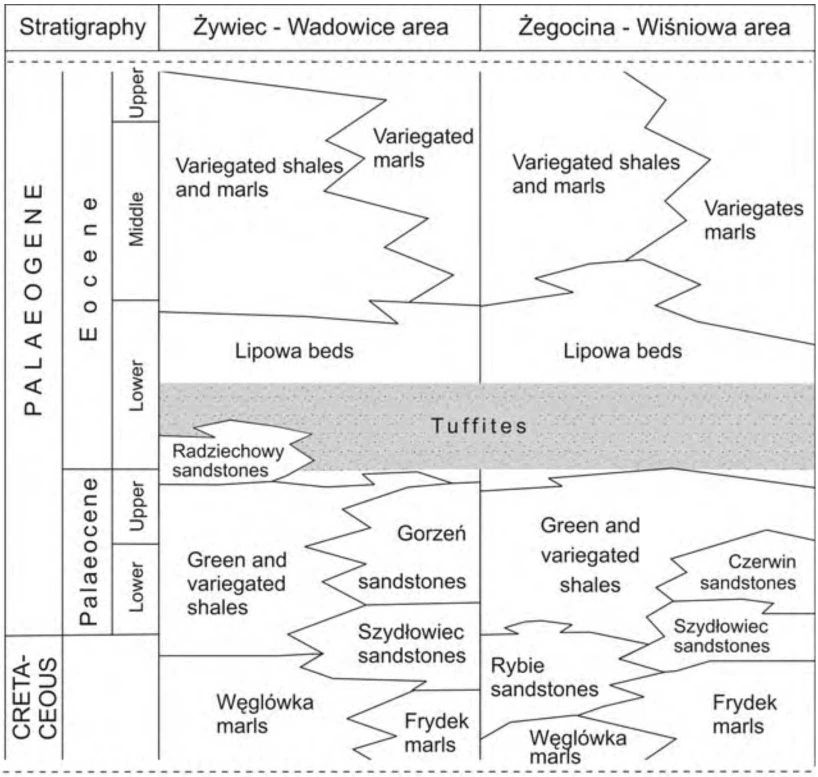


Fig. 2. Lithostratigraphical sketch of the Lower Palaeogene deposits in the Subsilesian Unit (on the basis of Książkiewicz *et al.*, 1962 and present study)

shallower facies: the Frydek-type marls or a deeper facies: the Węglówka marls below the Lower Palaeogene deposits (Skoczylas-Ciszewska, 1960; Książkiewicz, 1951a, b, 1956; Geroch & Gradziński, 1955; Liszkowa & Nowak, 1963; Geroch *et al.*, 1967; Unrug, 1969; Burtan *et al.*, 1974; Burtan, 1978). During the Late Cretaceous alongside the marls coarse-grained clastic sediments were deposited. As a result of this sedimentation the Rybie sandstones and conglomerates were deposited within the Żegocina Zone (Skoczyłas-Ciszewska, 1960; Unrug, 1969; Jugowiec-Nazarkiewicz & Jankowski, 2001; Gasiński *et al.*, 2001) as well as the Szydłowiec sandstones within the Wiśnowa and Żywiec tectonic windows and the Lanckorona Zone (Książkiewicz, 1951a, b; Geroch & Gradziński, 1955; Geroch *et al.*, 1967; Unrug, 1969, Burtan, 1974, 1978; Burtan *et al.*, 1974) (Fig. 2).

Żegocina Zone

The Lower Palaeogene sediments are represented by variegated shales and marls in the Żegocina Zone (Skoczylas-Ciszewska, 1960; Unrug, 1969). Above the Rybie sandstones, there is a complex of green, non-calcareous, marly shales with rare intercalations of thin bedded, fine-grained, glauconite sandstones. Above the Rybie sandstones, there is a complex of green, non-calcareous, marly shales with rare intercalations of thin bedded, fine-grained, glauconite sandstones. These sandstones are overlain by red or cherry-red marly shales with intercalations of green, brown or grey shales.

The Wiśniowa Tectonic Window

The geological section of the Palaeogene deposits in the Wiśniowa Tectonic Window begins with the Szydłowiec sandstones (Fig. 2). The deposition of these sandstones started in the Late Cretaceous (Burtan, 1974, 1978; Burtan *et al.*, 1974). They are developed as coarse-grained partially conglomeratic, calcareous, thick-bedded, light grey sandstones. They consist of quartz grains, coated fragments of organodetric limestones (mainly bryozoans and algae) and include pieces of coal and calcareous green shales.

Above them there the Czerwin sandstones are developed (Fig. 2) (Burtan, 1974; 1978; Burtan *et al.*, 1974; Cieszkowski *et al.*, 2001) represented by a complex of sandstones and shales. The calcareous, fine-grained sandstones are thick- and medium-bedded. They consist of quartz grains, glauconite which gives them a green tint, as well as various calcareous clasts. The sandstones can be considered as allodapic limestones (Cieszkowski *et al.*, 2001). The sandstone layers are intercalated by greenish shales.

The Czerwin sandstones are overlain by a light marly, green shale complex (Cieszkowski *et al.*, 2001) with the rare intercalations of thin-bedded and fine-grained sandstones (Leśniak *et al.*, 2001). They pass up section into a series of green-brown shales called the Lipowa beds (Cieszkowski *et al.*, in print). Those mottled shales are green, green-grey and brown, sporadically red in colour. The sediments include scarce intercalations of thin- and medium-bedded, fine-grained quartz sandstones with isolated beds or ankeritic concretions.

The Lanckorona Zone

The geological profile of the Palaeogene deposits starts in the Lanckorona Zone with the Szydłowiec sandstones (Książkiewicz, 1951a, b) as in the Wiśniowa Tectonic Window. The Gorzeń sandstones occur above them (Książkiewicz, 1951a, b) (Fig. 2). The Gorzeń beds mostly consist of thin- to medium-bedded sandstones with intercalations of shales, but occasionally thick-bedded sandstone layers occur too. The sandstones are siliceous, grey and grey-greenish, graded, fine- or rarely medium-grained. Shales are usually clayey, grey and grey-greenish, more or less bioturbated. Over them occur green and green-brown shales (Liszkowa & Nowak, 1963; Geroch *et al.*, 1967). The shales are marly in the lower part of the section and clayey above. Within the clayey part of the complex, thin-bedded, fine-grained green-brown quartzite sandstones with glauconite occur. The complex of green-brown shales passes upwards into a complex of variegated shales and marls (Książkiewicz, 1951b, Geroch *et al.*, 1967). These are red, cherry red, green or grey in colour, with rare intercalations of thin-bedded, fine-grained sandstones bearing numerous of trace fossils. In the area where the Palaeocene flysch facies were not developed, clayey-marly sediments were deposited (Książkiewicz, 1956).

The Żywiec Tectonic Window

In the Żywiec Tectonic Window above the Szydłowiec sandstones there is a complex of marly and clayey green shales (Geroch & Gradziński, 1995; Unrug, 1969). This complex grades into a complex of variegated shales, which include intercalations of thin-bedded, fine-grained sandstones (Leśniak & Waśkowska, 2001). These sediments are overlain by the Radziechowy glauconite sandstones (Geroch & Gradziński, 1955; Neścieruk, 1998) (Fig. 2). These beds are developed in the form of sandy-shaley flysch consisting of two facies: sandy and sandy-shaley (Leśniak & Waśkowska-Oliwa, 2001). The thick-, medium- and thin-bedded green sandstones are usually medium- and coarse-grained. The marly shales are green-grey or green-brown in colour. There above them occur the Lipowa beds (Neścieruk, 1998). There are mainly made up of marly, striped and brown-green shales. The shales are occasionally intercalated by grey thin-bedded, fine-grained, sandstones.

All geological sections of the Subsilesian Unit are marked by presence of bentonized tuffite layers that occur within a complex of Lower Eocene shales (Książkiewicz, 1956; Burtan, 1978; Leśniak *et al.*, 2001). These tuffite layers seem to be a correlation horizon (Cieszkowski *et al.*, in print).

BIOSTRATIGRAPHY

The biostratigraphical analyses have been carried out on the strength of the foraminiferal assemblages, which were worked out for the Polish Flysch Carpathians by Olszewska (1997). This zonation is based upon foraminiferal associations which are common within the Carpathian sedimentary basins (i.e., agglutinated foraminifera). The additional advantage of this zonation is the list of the characteristic species for individual assemblages that include planktonic and benthic calcareous taxa, which are common components of the foraminiferal associations from the deposits of the Subsilesian Unit. The assemblages defined by Olszewska (1997) are clearly distinguishable in the micropalaeontological material from the sediments of the Subsilesian Unit. The current foraminiferal investigations introduce small modifications to the individual definitions of the boundaries. The biostratigraphical analysis is here presented only for purpose of this study, however the issue of biostratigraphy of the Subsilesian deposits will be the subject of a separate, more detailed paper.

***Rzehakina fissistomata* Zone (Interval zone)** – the interval between the LO of *Rzehakina inclusa* (Grzybowski) and the LO of *Rzehakina fissistomata* (Grzybowski) (Fig. 6: *2*) or/and LO of *Haplophragmoides mjatliukae* (Maslakova). The occurrence of numerous foraminifera representing the genus *Glomospira* is signifi-

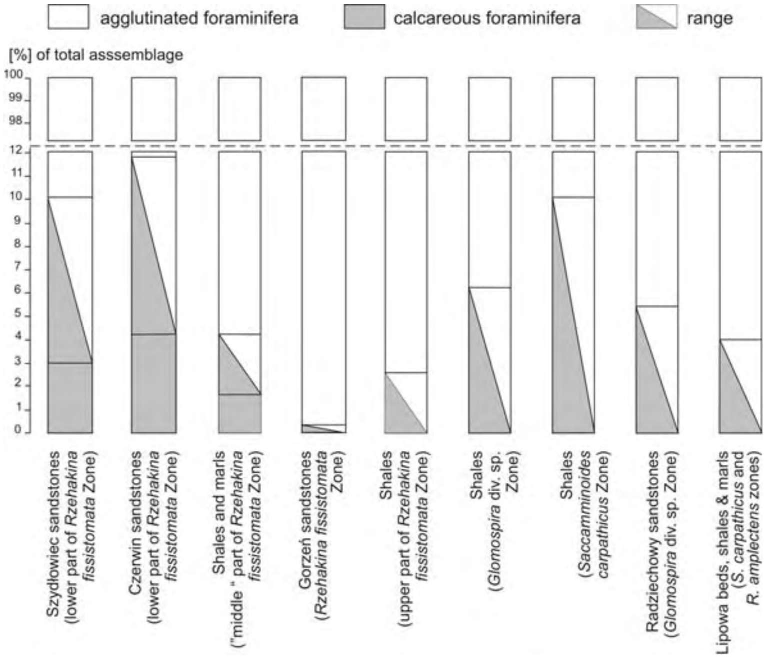


Fig. 3. Proportion of agglutinated and calcareous benthic foraminifera

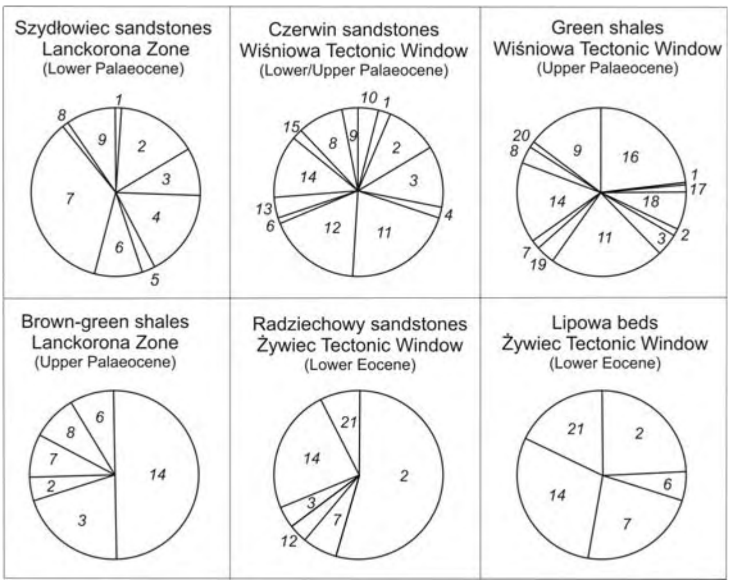
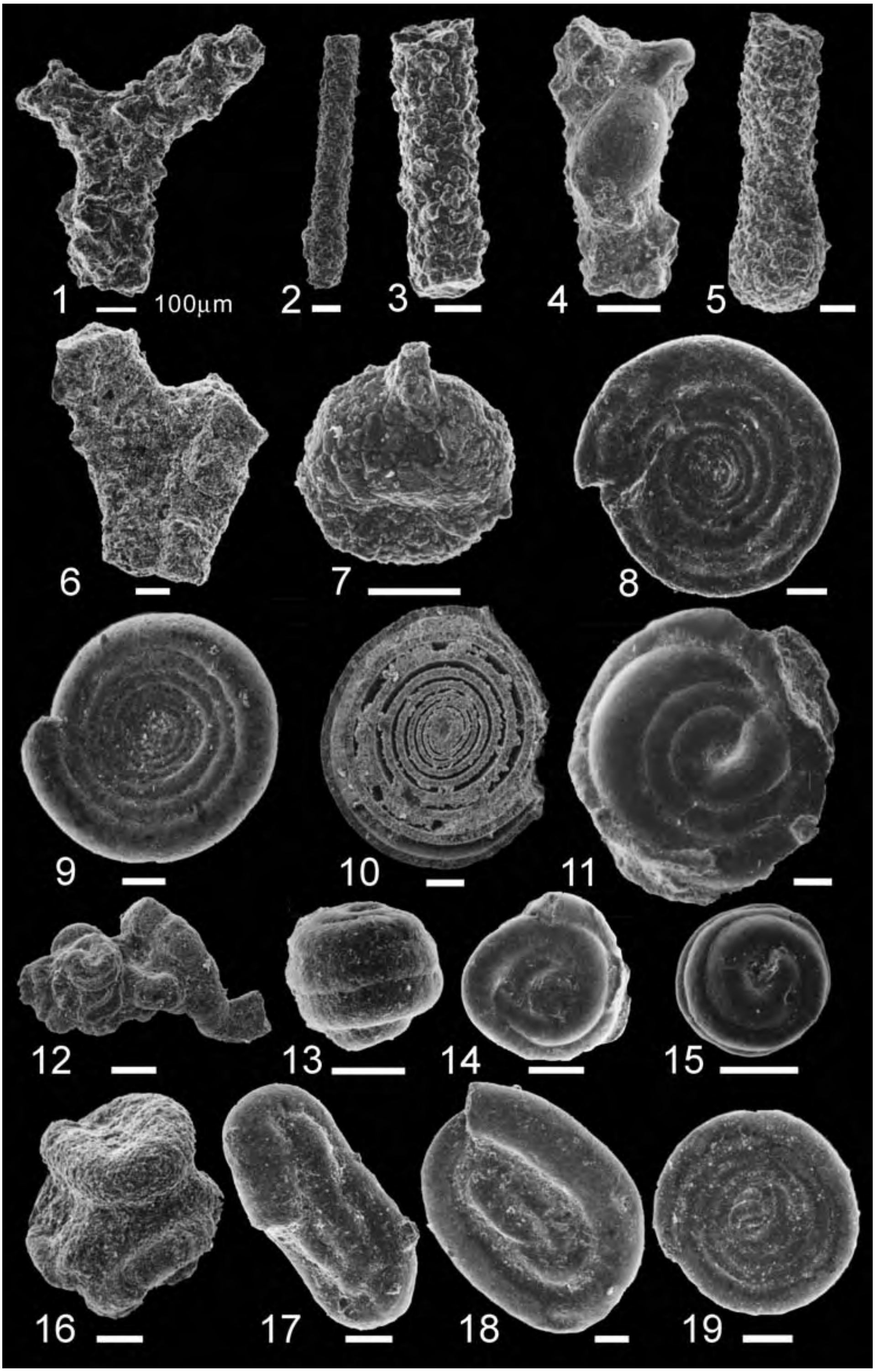


Fig. 4. Examples of typical generic distribution among calcareous benthic foraminiferal assemblages (a full circle represents 100% of calcareous benthic foraminifera); *1 – Aragonia*, *2 – Dentalina*, *3 – Eponides*, *4 – Ellipsoglandulina*, *5 – Globobulimina*, *6 – Lenticulina*, *7 – Nodosaria*, *8 – Osangularia*, *9 – Pullenia*, *10 – Anomalinoides*, *11 – Gavelinella*, *12 – Gyroidinoides*, *13 – Lagena*, *14 – Nuttallides*, *15 – Nuttallinella*, *16 – Abysammina*, *17 – Anomalina*, *18 – Clinapertina*, *19 – Globocassidulina*, *20 – Pleurostomella*, *21 – Stilostomella*

cant for the upper boundary of this zone. According to Olszewska (1997), the age of this zone is Palaeocene. Taking the taxonomic qualities and quantitative proportions of specimens into consideration the foraminiferal assemblages included in *Rzehakina fissistomata* Zone form two clearly separate groups with a stratigraphic succession (Waśkowska-Oliwa, 2004). The older association (Pe-1) is characterised by the occurrence of a variety of genera and species of agglutinated and benthic calcareous foraminifera. The presence of relatively large number of specimens of *Hormosina* and *Caudammina* is distinctive for this assemblage. Representatives of *Hormosina excelsa* (Dylążanka) (Fig. 6: *8*), *Hormosina velascoensis* (Cushman) (Fig. 6: *10*), *Caudammina ovula* (Grzybowski) (Fig. 6: *11, 12*) and *Caudammina ovuloides* (Grzybowski) as well as other forms common in Late Cretaceous foraminiferal associations, e.g., *Glomospirella grzybowskii* (Jurkiewicz) (Fig. 5: *18*), *Glomospira diffundens* Cushamn & Renz (Fig. 5: *11*), *Remesella varians* (Glaessner) (Fig. 8: *2, 5*), *Dorothia* div. sp. occur within the standard assemblage. Occasionally *Chiloguembelina morsei* (Kline) (Fig. 10: *15*), *Subbotina triloculinoides* (Plummer) (Fig. 10: *13*) are present. The taxonomic composition of the younger association (Pe-2) is somewhat less diverse. The proportions of individual species change and cosmopolitan forms such as*: Recurvoides, Paratrochamminoides,* and *Rhabdammina* dominate the foraminiferal assemblages. Typical Late Cretaceous and Early Palaeocene forms are absent or are rarely represented by single specimens. *Nuttallides* and *Abysammina* are common among the group of calcareous bentonic foraminifera, occasionally *Acarinina primitiva* (Finaly), *Acarinina soldadoensis* (Bronnimann), *Subbotina linaperta* (Finaly), *Subbotina velascoensis* (Cushman), *Subbotina triloculinoides* (Plummer) occur among the group of planktonic foraminifera.

The older associations (Pe-1) have been recognised within the Szydłowiec sandstones, the Czerwin sandstones and in the lower part of the green shales. The younger associations (Pe-2) have been identified within the upper part of the green shales, the variegated shales of the Żegocina Zone, the sandstones of the Żywiec Tectonic Window, and the Gorzeń sandstones.

Fig. 5. Agglutinated foraminifera from the lower Palaeogene of the Subsilesian Unit. **1** – *Rhabdammina* sp., sample nr 273 Czerwin; **2** – *Rhabdammina linearis* Brady, 363 Lipnik; **3** – *Rhabdammina cylindrica* Glaessner, 349 Gościbia; **4** – *Rhabdammina* sp. with *Ammolagena clavata*, Jones & Parker), 311 Czerwin; **5** – *Hyperammina elongata* Brady, 266 Czerwin; **6** – *Nothia excelsa* (Grzybowski), 316 Czerwin; **7** – *Saccammina placenta* (Grzybowski), 261 Czerwin; **8** – *Ammodiscus tenuissimus* Grzybowski, 249 Gościbia; **9** – *Ammodiscus cretaceus* (Reuss), 264 Czerwin; **10** – *Ammodiscus cretaceus* (Reuss), 312 Czerwin; **11** – *Glomospira diffundens* (Cushman & Renz), 329 Gościbia; **12** – *Glomospira glomerata* (Grzybowski), 314 Czerwin; **13** – *Glomospira charoides* (Jones & Parker), 273 Czerwin; **14** – *Glomospira gordialis* (Jones & Parker), 363 Lipnik; **15** – *Glomospira charoides* (Jones & Parker), 363 Lipnik; **16** – *Glomospira irregularis* (Grzybowski), 184 Czerwin; **17** – *Glomospira serpens* (Grzybowski), 231 Czerwin; **18** – *Glomospirella grzybowskii* (Jurkiewicz), 311Gościbia; **19** – *Glomospirella* sp., 261 Czerwin. Scale bar = 100 μm


1
100µm
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

***Glomospira* div. sp. Zone (Acme zone)** – the interval of common occurrence of the genus *Glomospira*, between the LO of *Rzehakina fissistomata* (Grzybowski) and/or *Haplophragmoides mjatliukae* (Maslakova) and the FO of *Saccamminoides carpathicus* Geroch (Fig. 7: *5, 6*). Age – the early part of the Early Eocene. The foraminiferal assemblages which have been assigned to this zone were found in the variegated shales of the Żegocina Zone, the Lipowa beds, brown-green shales and the glauconite Radziechowy sandstones.

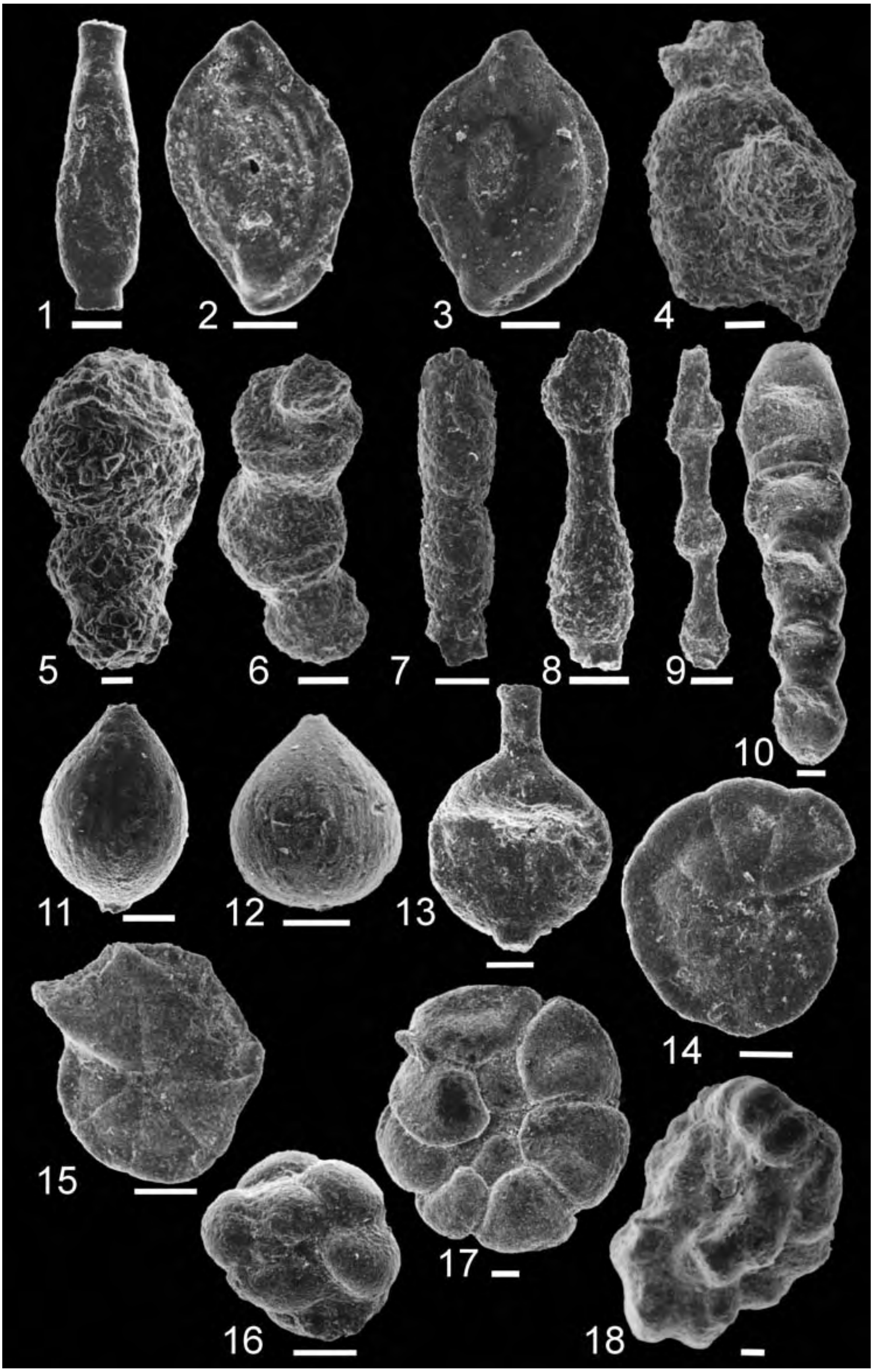
***Saccamminoides carpathicus* Zone (Total Range zone)** – the interval between the FO and LO of the index taxon. Age – late Early Eocene. This zone includes the foraminiferal associations in the variegated shales of Żegocina Zone, the Lipowa beds, and the green-brown shales.

***Reticulophragmium amplectens* Zone (Acme zone)** – the interval where specimens of the index taxon occur in large numbers, between the LO of *Saccamminoides carpathicus* Geroch and the FO of *Ammodiscus latus* (Grzybowski). Age – early part of the Middle Eocene. The foraminiferal assemblages specific for this zone appeared in the Lipowa beds, marls and shales of the Lanckorona Zone.

FORAMINIFERAL INDICATORS OF RELATIVE BATHYMETRY OF THE SUBSILESIAN UNIT

It is possible to assign a relative depth of sedimentation with relation to the depth of the calcium carbonate compensation depth (CCD) and foraminiferal lysocline (FL) on the basis of the analysis of the composition of the foraminiferal assemblages. The CCD is the depth where the amount of delivered calcareous material equals its dissolution (Gradziński *et al.*, 1986) and the FL is usually situated a few hundred meters above it (Kennett, 1982). A sudden increase in the amount of dissolution of calcareous foraminifera begins at the FL depth. In this case there are calcareous benthic foraminifera possessing shells resistant to dissolution within the interval between CCD and FL (Olszewska, 1981). The estimate of the palaeodepth is also possible thanks to findings the ecological conditions of particular species of foraminifera (Schnitker & Tjalsma, 1980; Corliss & Honjo, 1981; Tjalsma & Lohman, 1983; Olszewska, 1984; Morkhoven *et al.*, 1986).

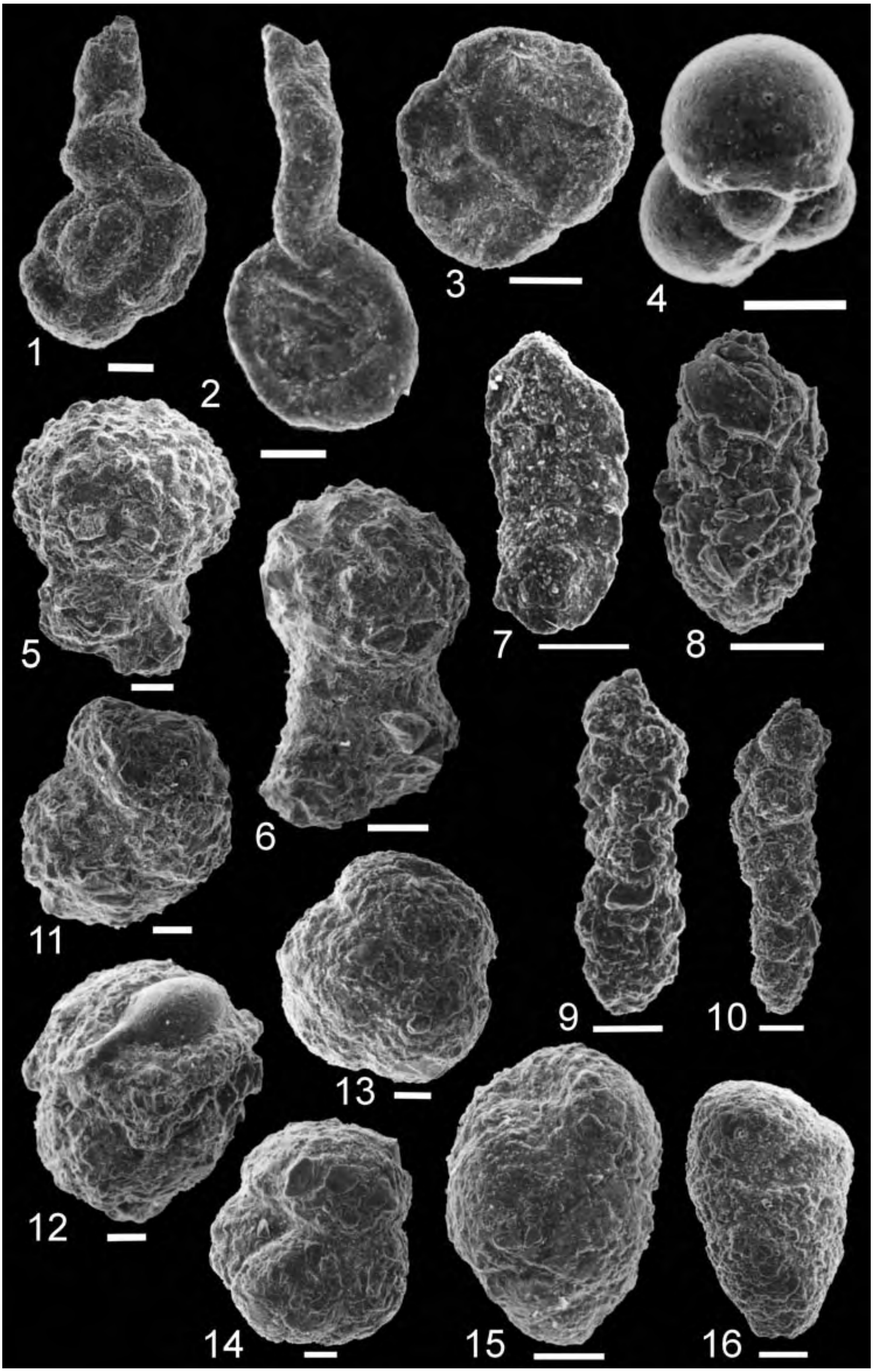
Fig. 6. Agglutinated foraminifera from the lower Palaeogene of the Subsilesian Unit. **1** – *Kalamopsis grzybowskii* (Dylążanka), sample nr 330 Gościbia; **2** – *Rzehakina fissistomata* (Grzybowski), 329 Gościbia; **3** – *Rzehakina epigona* (Rzehak), 311 Gościbia; **4** – *Aschemocella carpathica* (Neagu), 231 Czerwin; **5** – *Reophax pilulifer* Brady, 238 Gościbia; **6** – *Reophax scalaris* Grzybowski, 402 Lipowa; **7** – *Reophax elongatus* Grzybowski (281 Czerwin; **8** – *Hormosina excelsa* (Dylążanka), 329 Gościbia; **9** – *Hormosina excelsa* (Dylążanka), 351 Gościbia; **10** – *Hormosina velascoensis* (Cushman), 243 Foszczówka; **11** – *Caudammina ovula* (Grzybowski), 329 Gościbia; **12** – *Caudammina ovula* (Grzybowski), 314 Czerwin; **13** – *Hormosina* sp. 1, 329 Gościbia; **14** – *Haplophragmoides walteri* (Grzybowski), 273 Czerwin; **15** – *Haplophragmoides walteri* (Grzybowski), 314 Czerwin; **16** – *Paratrochamminoides uviformis* (Grzybowski), 363 Lipnik; **17** – *Trochamminoides coronatus* (Brady), 265 Czerwin; **18** – *Paratrochamminoides irregularis* (White), 239 Gościbia. Scale bar = 100 μm


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

The origin of the Szydłowiec sandstones is the result of Late Cretaceous–Early Palaeocene coarse-grained sedimentation in the Subsilesian Unit. From the Early Palaeocene the activity of turbidity density currents started to decline and shaly-sandstone as thin-bedded flysch was deposited. They are the so-called Czerwin sandstones in the Wiśniowa Tectonic Window and the Gorzeń sandstones in the Lanckorona Zone.

The Palaeogene foraminiferal assemblages form the Szydłowiec sandstones are dominated by agglutinated foraminifera, which make up on average from 90% to 98% (Fig. 3), and exceptionally 80% of the association. Planktonic foraminifera are usually absent or only occur occasionally (up to 1%). The calcareous benthic foraminifera are sparse, but appear in the each sample in amounts ranging from 2% to 10% (Fig. 3), and sporadically up to 20%. A similar composition characterises the foraminiferal assemblages occurring within the Czerwin sandstones. They consist nearly entirely of agglutinated taxa (from 89% to 96%) and a accompanied by calcareous benthic foraminifera (from 1% to 14%) (Fig. 3). The presence of the planktonic foraminifera is sporadic, but when they occur they make up a maximum of 5% of the assemblage and are poorly preserved. The calcareous benthic foraminifera from these two lithosomes are represented by: *Anomalina, Anomalinoides, Aragonia, Cibicidoides, Dentalina, Eponides, Ellipsoglandulina, Ellipsopolymorphina, Gavelinella, Globobulimina, Gyroidinoides, Guttulina, Lagena, Lenticulina, Nodosaria, Nodosarella, Nuttallides, Osangularia, Pullenia, Stensioeina* (Fig. 4). These genera are mostly regarded as deepwater taxa of the bathyal zone (Berggren & Aubert, 1975; Tjalsma & Lohman, 1983; Olszewska, 1984; Morkhoven *et al.*, 1986; Olszewska *et al.*, 1996). Although the calcareous benthos represent such a minor admixture compared with the whole association (merely a few percent), the fact of its great diversity is interesting. As a rule, the individual species occur in amount of a few specimens in each 300 g of dry sediment and are well preserved. Among the agglutinated benthos agglutinated forms with calcareous cement were found, including *Dorothia crassa* (Marsson) (Fig. 8: *3*), *Dorothia indentata* Cushman & Jarvis (Fig. 8: *4*), *Dorothia trochoides* (Marsson) and *Remesella varians* (Glaessner) (Fig. 8: *2, 5*). The latest mentioned taxon has been identified in relatively large numbers within some samples. The aggutinated benthos is diversified

Fig. 7 Agglutinated foraminifera from the lower Palaeogene of the Subsilesian Unit. **1** – *Paratrochamminoides heteromorphus* (Grzybowski), sample nr 266 Czerwin; **2** – *Lituotuba lituiformis* (Brady), 268 Czerwin; **3** – *Ammosphaeroidina pseudopauciloculata* (Mjatliuk), 311 Gościbia; **4** – *Praecystammina sveni* Gradstein & Kaminski, 203 Czerwin; **5** – *Saccamminoides carpathicus* Geroch, 273 Czerwin; **6** – *Saccamminoides carpathicus* Geroch, 312 Czerwin; **7** – *Spiroplectammina spectabilis* (Grzybowski) (327 Gościbia; **8** – *Karrerulina coniformis* (Grzybowski), 363 Lipnik; **9** – *Karrerulina conversa* (Grzybowski), 363 Lipnik; **10** – *Gerochammina conversa* (Grzybowski), 216 Czerwin; **11** – *Recurvoides nucleolus* (Grzybowski), 312 Czerwin; **12** – *Recurvoides* with *Ammolagena clavata* (Jones & Parker), 427 Lipowa; **13**, **14** – *Trochammina globigeriniformis* (Parker & Jones), 339 Gościbia; **15** – *Arenobulimina dorbignyi* (Reuss) 349 Gościbia; **16** – *Remesella varians* (Glaessner). Scale bar = 100 μm


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

with respect to species. It is represented by about 33–35 species per sample. Foraminiferal assemblages dominated by agglutinated forms with a constant but not large admixture of well-preserved, deepwater calcareous benthos are characteristic for environments above the CCD, but below FL.

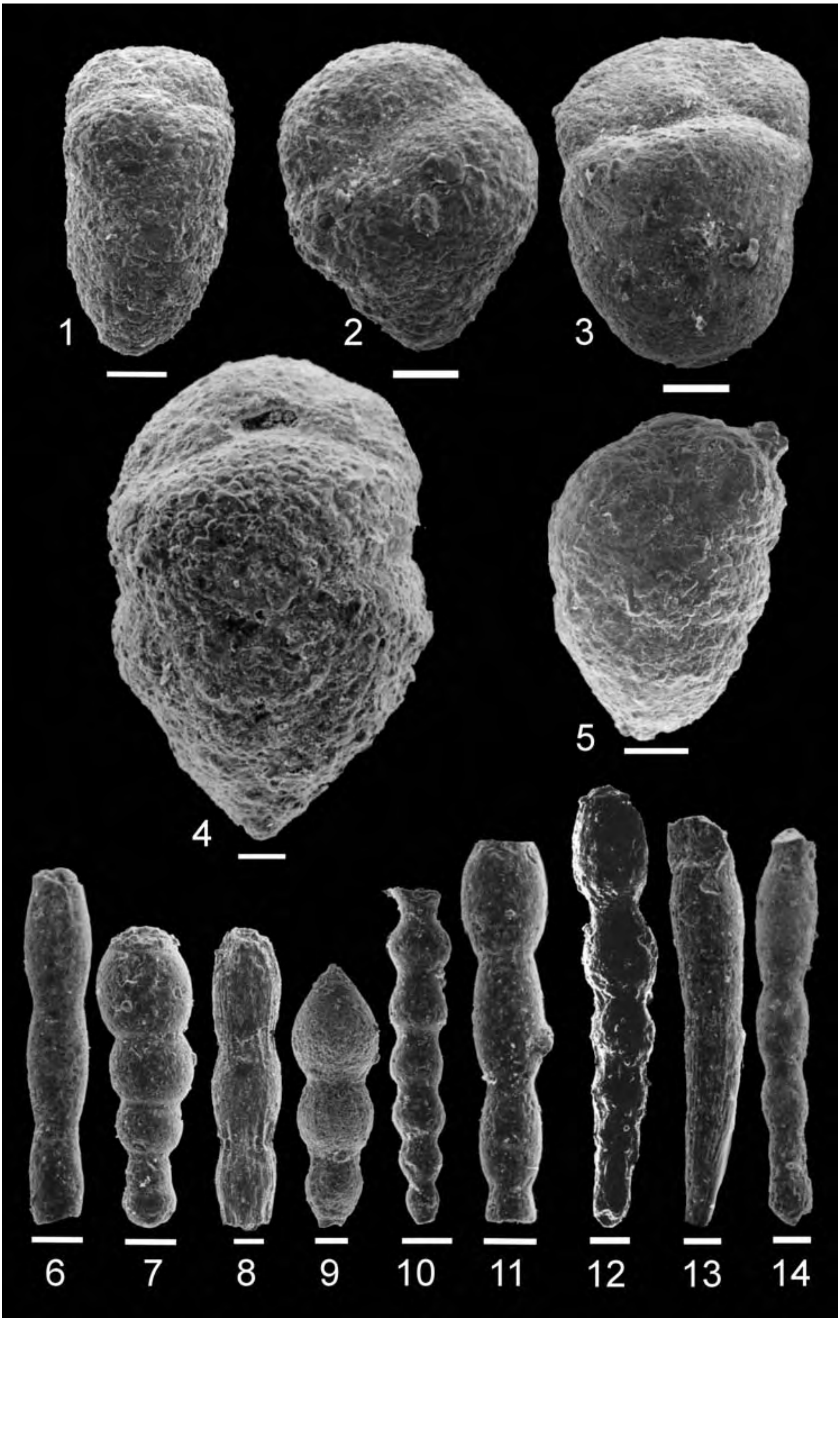
The stage of shaly sedimentation started at the beginning of the Late Palaeocene. The foraminiferal assemblages identified within the shale series (the upper part of Pe-1 as well as the lower part of Pe-2 of *Rzehakina fissistomata* Zone), which occur above flysch sediments, resemble a taxonomic composition of the foraminiferal associations represented by the Szydłowiec sandstones and the Czerwin sandstones. A permanent feature of these associations is the occurrence of calcareous benthic foraminifera in variable numbers. This fluctuates between 1% and 3% only sporadically reaching 15% of the association. The calcareous foraminifera consist solely of deepwater taxa. The agglutinated fauna represents on average 96% to 99% of the group (Fig. 3). Planktonic foraminifera are usually absent, and whenever they appear they make up only 1% of the assemblage and are very poorly preserved. The depth represented by this foraminiferal assemblage is typical for the depth range between CCD and FL.

The microfauna occurring in the Palaeocene Gorzeń sandstones is typical for a depth close to CCD. The foraminiferal associations that are represented only by agglutinated taxa – almost exclusively siliceous fauna (agglutinated species with calcareous cement have been found sporadically in the single samples), indicate this type of deposition.

The foraminiferal associations representing the Upper Palaeocene shaly deposits (Pe-2 of *Rzehakina fissistomata* Zone) and also the Lower Eocene sediments (*Glomospira* div. sp. Zone and *Saccamminoides carpathicus* Zone) are twofold: they consist of exclusively siliceous-agglutinated taxa or mixed groups of agglutinated-calcareous fauna. Associations including only siliceous-agglutinated foraminifera occur in the Upper Palaeocene sediments more frequently and represent more than 35% of the samples. However, this number is lower and make up 25% of the assemblages in the Lower Eocene deposits. Within the mixed agglutinated-calcareous associations the following average composition of particular foraminiferal groups were found:

– Upper Palaeocene shales – agglutinated benthos: 98–99%, calcareous benthos: 1–2% (exceptionally up to 9%) (Fig. 3);

Fig. 8. Agglutinated and calcareous benthic foraminifera from the lower Palaeogene of the Subsilesian Unit. **1** – *Dorothia bulleta* (Carsey), sample nr 278 Czerwin; **2** – *Remesella varians* (Glaessner), 278 Czerwin; **3** – *Dorothia crassa* (Marsson), 278 Czerwin; **4** – *Dorothia intendata* Cushman & Jarvis, 423 Pluskawka; **5** – *Remesella varians* (Glaessner), 332 Gościbia; **6** – *Dentalina gracilis* d'Orbigny, 314 Czerwin; **7** – *Nodosaria* sp. (314 Czerwin; **8** – *Nodosaria velascoensis* Cushman, 314 Czerwin; **9** – *Dentalina catenula* Reuss, 419 Foszczówka; **10** – *Stilostomella* sp., 314 Czerwin; **11** – *Dentalina gracilis* d'Orbigny, 419 Foszczówka; **12** – *Stilostomella* sp., 165 Leśnianka; **13** – *Dentalina megapolitana* Reuss, 314 Czerwin; **14** – *Dentalina gracilis* d'Orbigny, 314 Czerwin. Scale bar = 100 μm


1
2
3
4
5
6
7
8
9
10
11
12
13
14

– sample from the most Lower Eocene shales (*Glomospira* div. sp. Zone) – agglutinated benthos: 94–99%, calcareous benthos 1–6% (exceptionally up to 13%);

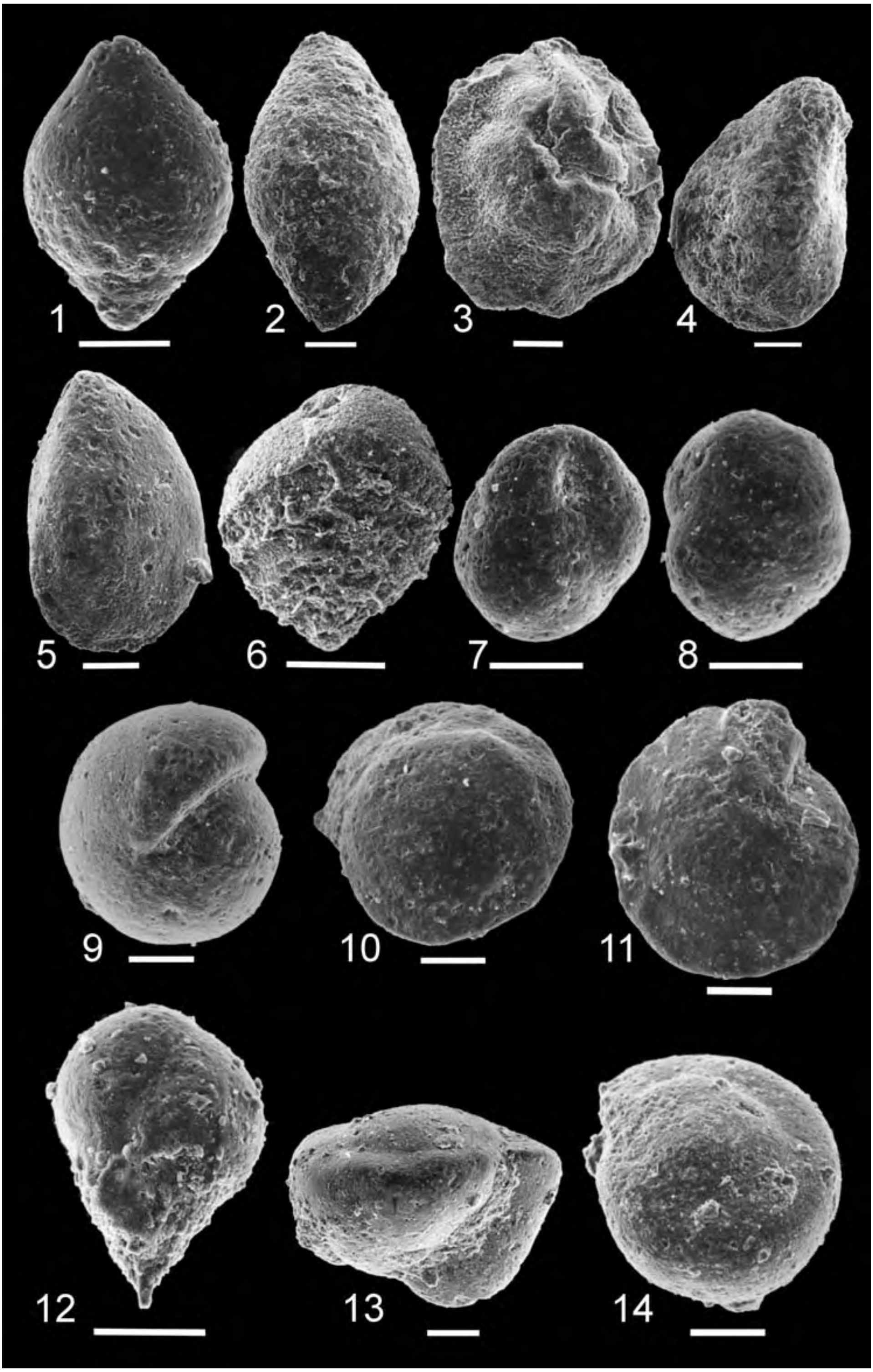
– Lower Eocene shales (*Saccamminoides carpathicus* Zone) – agglutinated benthos: 90–97%, calcareous benthos 3–10% (exceptionally up to 16%).

The amount of poorly preserved planktonic foraminifera is variable between 0–2% within the analysed sequence of deposits.

The Eocene calcareous benthic taxa are less diversified in comparison to the Early Palaeocene foraminiferal assemblages. Among this foraminiferal group the genera: *Abysammina, Eponides, Nuttallides, Osangularia* and *Quadrimorphina* (Fig. 4) are the most frequent. Definitely the most numerous and characteristic calcareous benthic species is *Nuttallides truempyi* (Nuttall) (Fig. 10: *3, 4*), a form that is resistant to dissolution. This species is typical of foraminiferal associations occurring in the bathial zone (Berggren & Aubert, 1976; Tjalsma & Lohman, 1983; Olszewska, 1984; Hulsbos *et al.*, 1989; Morkhoven *et al.*, 1986; Kuhnt & Collins, 1996; Olszewska *et al.*, 1996;). Foraminiferal assemblages with the predominant component of calcareous benthic species, containing *Nuttallides truempyi* (Nuttall), are described from the depth between FL and CCD (Olszewska, 1981, 1984) in the Polish Outer Carpathians. The studied composition of foraminiferal associations (both qualitative and quantitative) and the preservation state of calcareous fauna indicates just that depth, pointing to the lower part of this range. If coeval mixed agglutinated-calcareous associations occur alternately with associations consisting of only siliceous-agglutinated foraminifera, it can be assumed that they are characteristic of depths close to the CCD. Malata (2001) has determined similar depths for the same type foraminiferal associations coming from the Magura Nappe. The great participation of siliceous-agglutinated assemblages as well as the lowest number of calcareous forms in the mixed foraminiferal groups have been observed within Upper Palaeocene deposits. This suggest either the deposition of the shaly sediments took place at significantly deeper palaeodepths in relation to the others, or the locally CCD was at a shallower depth during the Late Paleocene.

The majority of foraminiferal assemblages from the Lower Eocene glauconite Radziechowy sandstones consist of siliceous-agglutinated taxa (Leśniak & Waśkowska-Oliwa, 2001). These associations are as a rule little taxonomic varied and they include "*Rhabdammina*-fauna" *sensu* Gradstein & Berggren (1981) and Olszewska (1984), the environment of which is situated below the CCD. However, the calcification of shales separating sandstone beds and the presence of calcareous

Fig. 9. Calcareous benthic foraminifera from the lower Palaeogene of the Subsilesian Unit. **1** – *Ellipsoglandulina obesa* Hanzlikova, 315 Czerwin; **2** – *Ellipsoglandulina velascoensis* (Cushman), 238 Gościbia; **3** – *Nuttallinea florealis* (White), 330 Gościbia; **4** – *Lenticulina* sp., 184 Czerwin; **5** – *Lenticulina* sp., 420 Foszczówka; **6** – *Aragonia ouezzaensis* (Rey), 278 Czerwin; **7, 8** – *Globocassidulina inexculpta* (Franzenau), 314 Czerwin; **9** – *Pullenia coryelli* White, 423 Pluskawka; **10, 11** – *Eponides subcandidulus* (Grzybowski), 231 Czerwin; **12** – *Guttulina* sp., 432 Pluskawka; **13, 14** – *Gyroidinoides globosus* (Hagenow), 429 Pluskawka. Scale bar = 100 µm


1
2
3
4
5
6
7
8
9
10
11
12
13
14

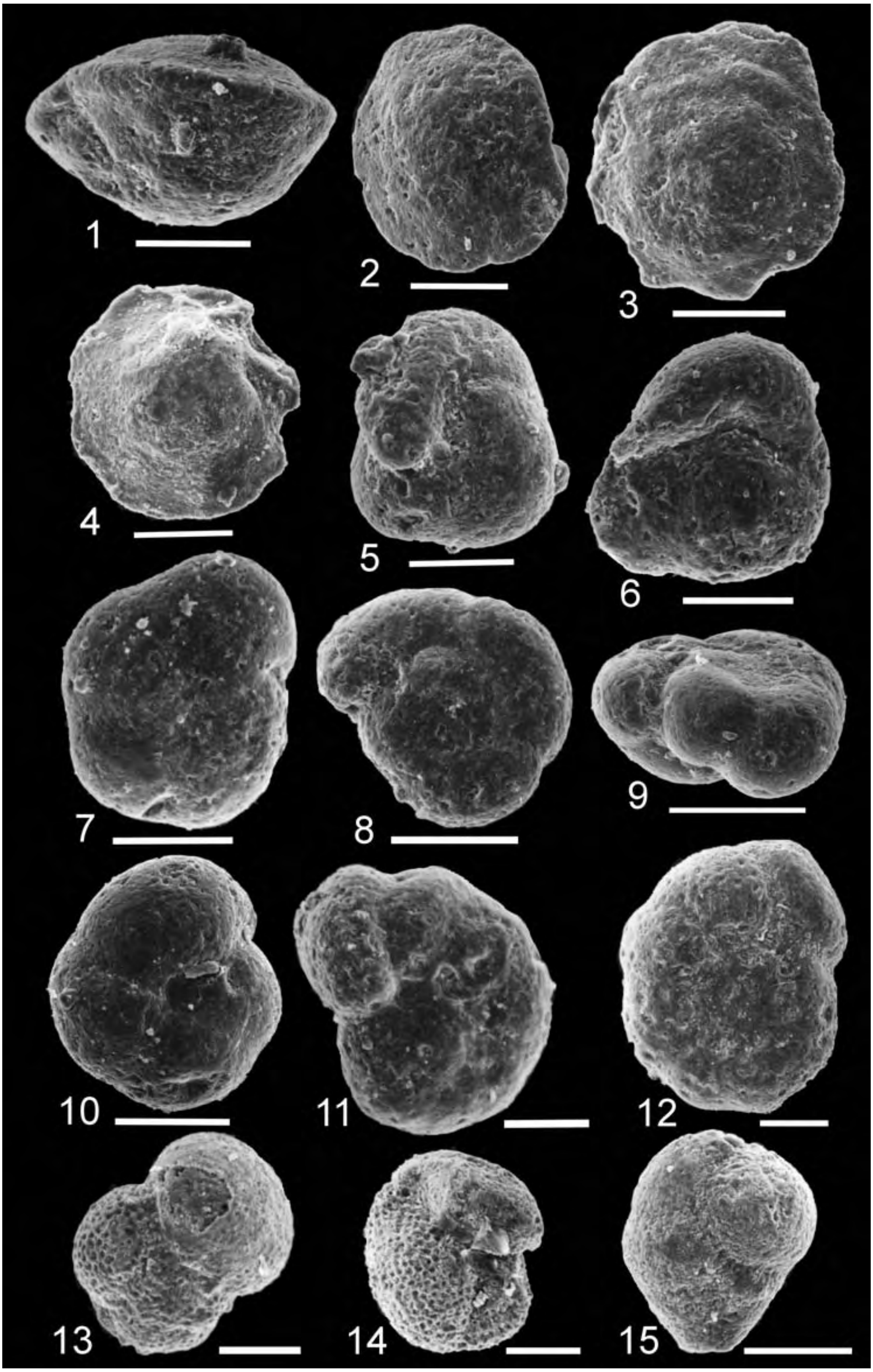
benthic and planktonic foraminifera within some samples can imply depths above but very close to the CCD. The glauconite Radziechowy sandstones were formed mainly as a result of deposition from the low and rarely medium concentration density currents (Leśniak & Waśkowska-Oliwa, 2001), which came down from the Baška Cordillera separating the Silesian and Subsilesian basins (Eliáš, 1998). The model of the submarine cone analysis indicates the deposition of these sandstones in the lower part of the slope and/or in a basin plain (Leśniak & Waśkowska-Oliwa, 2001). Thus, the sedimentary environment of these sandstones was high-energy. For this reason, the fauna of agglutinated foraminifera adapted to such regime, a including those species most resistant to change, i.e., primitive species. The composition of this microfauna may not reflect the actual palaeobathymetrical conditions, and associations may chiefly reflect the energy of the sedimentary environment. An influence of the high rate of sedimentation, which prefers the development of agglutinated fauna and a reduction of calcareous foraminifera at the same time, was emphasised by Miller *et al.* (1982) as well as Kaminski *et al.* (1989). A similar situation is observed in the Lipowa beds that overlain the Radziechowy sandstones. These deposits represent fine-rhythmical, shaly-sandy flysch in which sandstone layers are placed variously. The foraminiferal assemblages consist of a mixed agglutinated-calcareous fauna, and occur within thick shaly intervals. However, sections including more frequent sandstone layers are characterised by less diverse siliceous-agglutinated foraminiferal fauna (the "*Rhabdammina*-fauna").

The foraminiferal assemblages, representing sediments of the Subsilesian Unit and occurring between FL and CCD, correspond to the Palaeogene associations of group 2 *sensu* Olszewska (1984) indicating the bathyal zone which can be compared to the Upper Cretaceous "Velasco" type Tethyan associations (Olszewska, 1984).

DISCUSSION

The palaeontological record implies that sedimentation took place at different palaeodepths during the Early Palaeogene in the Subsilesian Unit. Foraminiferal assemblages of the Upper Cretaceous marly sediments indicate sedimentation environment above the FL during the Maastrichtian (Liszkowa & Morgiel, 1981; Gasiński *et al.*, 1999; Cieszkowski *et al.*, 2000; Machaniec & Malata, 2003). Deposition took place in the external shelf – upper slope during the Early Maastrichtian

Fig. 10. Calcareous benthic and planktonic foraminifera from the lower Palaeogene of the Subsilesian Unit. **1, 2** – *Eponides umbonatus* (Reuss), 314 Czerwin; **3, 4** – *Nuttallides truempyi* (Nuttall), 217 Czerwin; **5, 6** – *Abysammina poagi* Schnitker & Tjalsma, 363 Lipnik; **7** – *Abysammina quadrata* Schnitker & Tjalsma, 314 Czerwin; **8** – *Quadrimorphina profunda* Schnitker & Tjalsma, 314 Czerwin; **9, 10** – *Quadrimorphina profunda* Schnitker & Tjalsma, 315 Czerwin; **11** – *Gavelinella danica* (Brotzen), 231 Czerwin; **12** – *Gavelinella danica* (Brotzen), 264 Czerwin; **13** – *Globigerina triloculinoides* Plummer, 279 Czerwin; **14** – *Subbotina velascoensis* (Cushman), 217 Czerwin; **15** – *Chiloguembelina morsei* (Kline), 191 Czerwin. Scale bar = 100 μm


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

and in middle part of the slope, partly in the lower continental slope at the end of the Late Maastrichtian (Machaniec, 2002). Marly sedimentation was disrupted by the deposition of a shaly-sandy series (the Szydłowiec and Czerwin sandstones) in the Late Cretaceous and Palaeocene. The micropalaeontological indicators suggest deposition of these sediments at a greater depth than the Upper Cretaceous marls, namely between FL and CCD. Only the Gorzeń sandstones (developed in the Lanckorona Zone) could have been deposited close to CCD partially below this boundary. The flysch sedimentation, which is represented by sandy-clayey turbidities, withdrew gradually and during the Late Palaeocene mainly silty turbidities and/or hemipelagic and pelagic sediments formed as shaly series were deposited. At the beginning of the Late Palaeocene the sedimentation clearly took place between the FL and CCD but at significantly deeper palaeodepths than during the Early Palaeocene. However, the depth of sedimentation was greatest and reached a position close to the CCD at the end of the Late Palaeocene as well as during the Early Eocene. The shaly deposits from this interval show the slightest calcification and are devoid of carbonates. The hemipelagic sedimentation was locally interrupted in the Early Eocene, the sandy-shaly series: the Radziechowy sandstones from the Żywiec Tectonic Window were deposited. The estimation of their depositional depth is rather difficult.

Considering the influence of high-energetic environment of sedimentation on the composition of some foraminiferal associations it is suggested that probably the Radziechowy sandstones and overlying Lipowa beds were deposited above the CCD but still close to it.

The Magura, Silesian and Skole basins reached a maximum paleodepth, as well as the Subilesian Zone in the same time interval (Poprawa *et al.*, 2002). The reduction of sediment calcification within deepwater basins was among other things connected with raising sea-level which took place in the World Ocean at the beginning of the Late Palaeocene (Haq *et al.*, 1988; Ross & Ross, 1990; Leszczyński & Malik, 1996;). At that time a lowering of the CCD level in the World Ocean is recorded (van Andel, 1975; Kennett, 1982; Gradziński *et al.*, 1986;). For the North Atlantic the depth of this level was assessed at 3000 m in the Late Cretaceous, but in the Early Eocene at 3500 m (van Andel, 1975). The global tendency of lowering the CCD in oceans during the Palaeocene additionally indicates the great depths of the discussed basin. The analysis of the Outer Carpathians sedimentary basins revealed that a stage of increased subsidence caused by the flexural bend of the basement is evident from the end of the Late Cretaceous till the Late Eocene (Poprawa *et al.*, 2002). Such a mechanism of subsidence explains the decrease in activity of source areas among basins (Poprawa *et al.*, 2002) by lower influence of turbidite sedimentation of the Upper Palaeocene series represented by the Szydłowiec, Czerwin and Gorzeń sandstones. The amount of subsidence for the geological profile of the Subsilesian Unit of the Eastern Polish Outer Carpathians is estimated in the range of 1000 m in from the Palaeocene to the Middle Eocene (Poprawa *et al.*, 2002). The decrease of the activity of source areas led to a decline in sedimentation rate as well as facies standardisation manifested in the deposition of deepwater pelagic sediments and hemipelagic variegated shales (Poprawa *et al.*, 2002) below the CCD within the Skole and Silesian basins (Olszewska & Geroch, 1991; Malata, 2000, 2001). Similar sediments were deposited in a shallower environment just above the CCD or in its range within the Subsilesian basin zone.

CONCLUSIONS

The Lower Palaeocene flysch, hemipelagic and pelagic sediments occur within the Lanckorona-Żegocina Zone and the western Żywiec Tectonic Window. They are represented by: the Palaeocene Szydłowiec sandstones (topmost part), the Czerwin sandstones and Gorzeń sandstones (foraminiferal *Rzehakina fissistomata* Zone), the Lower Eocene Radziechowy sandstones (*Glomospira* div. sp. Zone) and the Lipowa beds (*Glomospira* div. sp. and *Saccamminoides carpathicus* zones) as well as the shaly-marly complexes of Palaeocene–Middle Eocene age.

The foraminiferal assemblages found within these sediments mainly consist of agglutinated foraminifera. Well-preserved calcareous benthic forms complete their composition. The calcareous benthic foraminifera are mostly bathyal, dissolution-resistant, deepwater species. The planktonic foraminifera are poorly preserved and make up a small percentage of the foraminiferal assemblages. The foraminiferal associations suggest that the relative palaeodepth of sedimentation of the studied deposits took place between the FL and CCD. The change in quantitative proportions of calcareous components in the autochthonous foraminiferal assemblages within individual geological profiles of the Subsilesian Unit indicates a fluctuation of depth during the analysed time interval. The Late Palaeocene and Early Eocene sediments were deposited at deeper palaeodepths related to the CCD with comparison to sediments of the Lower Palaeocene, probably in an environment close to CCD and reached maximum depths in the latest Palaeocene.

Acknowledgements

T. Słomka (AGH), M. Cieszkowski (ING UJ) and A. Joniec (AGH) are sincerely acknowledged for their valuable and helpful discussion. J. Faber (IZ UJ) for SEM work. M. A. Kaminski (UCL) kindly reviewed the manuscript and made corrections to the English text. Researches supported by the AGH grant No.1172/PO4/20000/19 and the AGH grant No. 11.11.140.159.

REFERENCES

Berggren, W. A. & Aubert, J., 1975. Paleocene benthonic foraminiferal biostratigraphy, paleobiogeography and paleoecology of Atlantic-Tethyan regions: Midway-Type fauna. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 18: 73–192.

Berggren, W. A. & Aubert, J., 1976. Eocene benthonic foraminiferal biostratigraphy and paleobathymetry of Orphan Knoll (Labrador Sea). *Micropaleontology*, 22: 327–346.

Burtan, J., 1974. *Detailed Geological Map of Poland*, 1:50 000, sheet Mszana Dolna (in Polish). Instytut Geologiczny.

Burtan, J., 1978. *Explanations to the Detailed Geological Map of Poland*, 1:50 000, sheet Mszana Dolna (in Polish). Instytut Geologiczny.

Burtan, J., Sokołowski, S., Liszkowa, J., Szotowa, W. & Szczurowska, J., 1974. The problem of the Flysch Carpathians and of the deep basement in the tectonic window at Wiśniowa (in Polish with

English summary). *Biuletyn Instytutu Geologicznego*, 273: 97–179.

Cieszkowski, M., Leśniak, T. & Waśkowska-Oliwa, A., 2001. Lower Paleogene sediments of the Subsilesian Unit in the Wiśniowa Tectonic Window (Outer Carpathians, Poland). *Biuletyn Państwowego Instytutu Geologicznego*, 396: 34–35.

Cieszkowski, M., Leśniak, T., Środoń. J. & Waśkowska-Oliwa, A., in prep. Tuffites in the Lower Eocene deposits of the Subsilesian Unit (West Outer Carpathians, Poland). *Geological Quarterly*.

Cieszkowski, M., Waśkowska-Oliwa, A. & Machaniec, E., 2000. Lithofacies and micropaleontological data of the Upper Cretaceous deposits of the Subsilesian Unit in the Sułkowice Tectonic Window (Outer Carpathians, Poland). *Slovak Geological Magazin*, 6: 205–207.

Corliss, B. H. & Honjo, S., 1981. Dissolution of deep-sea benthonic foraminifera. *Micropaleontology*, 27: 365–378.

Eliáš, M. 1998. Sedimentology of the Subsilesian Unit. *Czech Geological Survey Special Papers*, 48 pp.

Gasiński, M. A., Jugowiec, M. & Ślączka, A., 1999. Late Cretaceous foraminiferids and calcareous nannoplankton from the Węglówka Marls (Subsilesian Unit, Outer Carpathians, Poland). *Geologica Carpathica*, 50: 1–11.

Gasiński, M. A. & Leśniak, T., Piotrkowski, M., 2001. Latest Maastrichtian Foraminiferal *Abathomphalus mayaroensis* Zone in the Subsilesian Unit (Polish Outer Carpathians). *Bulletin of the Polish Academy of Sciences, Earth Sciences*, 49, 89–97.

Geroch, S. & Gradziński, R., 1955. Stratigraphy of the Sub-Silesian series in the tectonic window of Żywiec (Western Carpathians) (in Polish with English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 24: 3–62.

Geroch, S., Jednorowska, A., Książkiewicz M. & Liszkowa J., 1967. Stratigraphy based upon microfauna in the Western Polish Carpathians. *Biuletyn Instytutu Geologicznego*, 211: 185–282.

Geroch, S., Krysowska-Iwaszkiewicz, M., Michalik, M., Prochazka, K., Radomski, A., Radwański, Z., Unrug, Z., Unrug, R. & Wieczorek, J., 1979. Sedimentation of the Węgierka Marls (Late Senonian, Polish Flysch Carpathians) (in Polish with English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 49: 102–134.

Gradstein, F. M. & Berggren, W. A., 1981. Flysch-type agglutinated foraminifera stratigraphy and the Maastrichtian to Paleogene history of the Labrador and North seas. *Marine Micropaleontology*, 6: 211–268.

Gradziński, R., Kostecka, A., Radomski, A. & Unrug, R., 1986. *Outline of sedimentology* (in Polish). Wydawnictwa Geologiczne, 628 pp.

Haq, B. U., Hardenbol, J. & Vail, P. R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change. *In*: Wilgus C. K., *et al.* (eds), Sea level changes – An Integrated Approach. *Society of Economic Paleontologists and Mineralogists. Special Publication*, 42: 71–108.

Hulsbos, R. E., Kroon, D., Jansen, H. S. M. & van Hinte, J. E., 1989. Lower Eocene benthic foraminifera and paleoenviroment of the outer Vřring Plateau, Norwegian Sea (DSDP Site 338). *Micropaleontology*, 35: 256–273.

Huss, F., 1966. Agglutinated foraminifera of the Węglówka unit of the Subsilesian series (in Polish with French summary). *Prace Geologiczne. Komisja Nauk Geologicznych. Polska Akademia Nauk. Oddział w Krakowie*, 34: 7–71.

Kaminski, M. A., Gradstein, F. M. & Berggren, W. A., 1989. Paleogene benthic foraminifer biostratigraphy and paleoecology at Site 647, Southern Labrador Sea. *In*: Srivastava S. P. *et al.* (eds), *Proceedings of the Ocean Drilling Program, Scientific Results*, 105: 705–729.

Kennett, J., 1982. *Marine Geology*. Prentice Hall, 813 pp.

Koszarski, L. & Żytko, K., 1965. Bathymetrical conditions of the Carpathian geosyncline (in Polish). *Kwartalnik Geologiczny*, 9: 943–944.

Kotlarczyk, J. (ed.), 1991. Paleontology and bathymetry (in Polish). *Materiały XIV Konferencji Paleontologów w Karpatach Rzeszowskich.* Instytut Geologii i Surowców Mineralnych AGH, Wydawnictwa Własne, No. 24, 74 pp.

Książkiewicz, M., 1951a. *General Geological Map of Poland*, 1:50 000, sheet Wadowice (in Polish). Państwowy Instytut Geologiczny.

Książkiewicz, M., 1951b. *Explanation to the General Geological Map of Poland*, 1:50 000, sheet Wadowice (in Polish). Państwowy Instytut Geologiczny, 283 pp.

Książkiewicz, M., 1956. The Jurassic and Cretaceous of Bachowice (Western Carpathians) (in Polish with English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 24: 117–405.

Książkiewicz, M., 1962 (ed.), *Geological Atlas of Poland. Stratigraphic and facial problems*, 1:600 000, book 13, Cretaceous and Early Tertinary in the Polish External Carpathians (in Polish with English summary). Instytut Geologiczny.

Książkiewicz, M., 1966. Contributions to the geology of the Wadowice region (in Polish with English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 36: 365–406.

Książkiewicz M., 1972. *Geology of Poland*, vol. 4., *Tectonics*. Part 3. The Carpathians (in Polish). Wydawnictwa Geologiczne, 228 pp.

Książkiewicz, M., 1975. Bathymetry of the Carpathian Flysch Basin. *Acta Geologica Polonica*, 25: 309–367.

Kuhnt, W. & Collins, E. S., 1996. Cretaceous to Paleogene benthic foraminifers from the Iberia Abyssal Plain. *Proceedings of the Ocean Drilling Program, Scientific Results*, 149: 203–216.

Leśniak, T. & Waśkowska-Oliwa, A., 2001. Siliciclastic deposits (Palaeogene) of the Subsilesian Unit in the Żywiec area (in Polish with English summary). *Zeszyty Naukowe AGH – Geologia*, 27: 51–70.

Leśniak, T., Waśkowska-Oliwa, A. & Cieszkowski, M., 2001. Lower Paleogene sediments of the Subsilesian unit in the Wiśniowa Tectonic Window (in Polish with English summary). *"Nauki o ziemi w badaniach podstawowych, złożowych i ochronie środowiska na progu XXI wieku"*. Jubileusz 50-lecia, 28 – 29 czerwca 2001, Kraków. Wydział Geologii, Geofizyki i Ochrony Środowiska AGH: 49–41.

Leszczyński, S. & Malik, K., 1996. Carbonates in flysch of the Polish Outer Carpathians (in Polish with English summary). *Przegląd Geologiczny*, 44: 151–158.

Liszkowa, J., 1959. Microfauna from beds with exotics at Bachowice (in Polish with English summary). *Biuletyn Instytutu Geologicznego*, 131: 49–110.

Liszkowa, J. & Morgiel, J., 1981. Microfauna of the Frydek type in Outer Carpathians, Poland (in Polish with English summary). *Biuletyn Instytutu Geologicznego*, 331: 83–102.

Liszkowa, J. & Nowak, W., 1963. Older Cretaceous members of the Frydek Subsilesian series (in Polish with English summary). *Kwartalnik Geologiczny*, 7: 235–255.

Jednorowska, A., 1975. Small foraminiferal assemblages in the Paleocene of the Polish Western Carpathians (in Polish with English summary). *Studia Geologica Polonica*, 67: 1–149.

Jugowiec-Nazarkiewicz, M. & Jankowski, L., 2001. Nannoplakton biostratigraphy of the Żegocina marls; a aspect of the geologic setting of the Lanckorona-Żegocina Zone (in Polish with English summary). *Przegląd Geologiczny*, 49: 1186–1190.

Jurkiewicz, H., 1967. Foraminifers in the Sub-Menilitic Palaeogene of the Polish Middle Carpathians (in Polish with English summary). *Biuletyn Instytutu Geologicznego*, 210: 5–128.

Machaniec, E., 2002. Paleobathymetry of the Late Cretaceous Węglówka Marls of the Subsilesian Unit (Polish Outer Carpathians). *Geologica Carpathica, special issue*, 53: 75–76.

Machaniec, E. & Malata, E., 2003. Paleodepth indications of the Late Cretaceous foraminiferal assemblages of the Subsilesian and Fore-Magura units (Polish Outer Carpathians). *In*: Vlahovic, I. (ed.), *22nd IAS Meeting of Sedimentology – Opatija 2003. Abstracts book*, 113 p.

Malata, E., 2000. Foraminiferal assemblages of the Magura nappe (Polish outer Carpathians) and their paleobathymetrical implications. *Slovak Geological Magazin*, 6: 172–174.

Malata, E., 2001. *Biostratigraphical interpretation of small foraminiferal assemblages in the middle part of the Magura Nappe (Polish Flisch Carpathians)* (in Polish). Jagiellonian Library. Unpublished PhD thesis, Jagiellonian University, Kraków, 267 pp.

Malata, E., Malata, T. & Oszczypko, N., 1996. Litho- and biostratigraphy of the Magura Nappe in the eastern part of the Beskid Wyspowy Range (Polish Western Carpathians). *Annales Societatis Geologorum Poloniae*, 66: 269–284.

Miller, K. G., Gradstein, F. M. & Berggren, W. A., 1982. Late Cretaceous to Early Tetiary agglutinated benthic foraminifera in the Labrador Sea. *Micropaleontology*, 28: 1–30.

Morgiel, J. & Olszewska, B., 1981. Biostratigraphy of the Polish External Carpathians based on agglutinated foraminifera. *Micropaleontology*, 27: 1–30.

Morkhoven, F. P., Berggren, W. A. & Edwards, A., 1986. *Cenozoik cosmopolitan deep-water benthic foraminifera*. BCRE-Relf-Aquitain: 1–267.

Neścieruk, P., 1998. The Klippe in Leśna against the background of western margin of the Żywiec Tectonic Window (in Polish with English summary). *Biuletyn Państwowego Instytutu Geologicznego*, 384: 23–36.

Olszewska, B., 1981. Paleoecological characteristics of small foraminifers from the Lower Eocene claystones with clinoptilolite from the Polish part of Outer Carpathians (in Polish with English summary). *Biuletyn Instytutu Geologicznego*, 331: 69–82.

Olszewska, B., 1984. A paleoecological interpretation of the Cretaceous and Paleogene foraminifers of the Polish Outer Carpathians (in Polish with English summary). *Biuletyn Instytutu Geologicznego*, 346: 7–62.

Olszewska, B., 1997. Foraminiferal biostratigraphy of the Polish Outer Carpathians: A record of basin geohistory. *Annales Societatis Geologorum Poloniae*, 67: 325–337.

Olszewska, B. & Geroch, S., 1991. Bathymerical meaning of foraminifera of the Paleocene of the Skole uinit (in Polish). *Materiały XIV Konferencji Paleontologów w Karpatach Rzeszowskich. Instytut Geologii i Surowców Mineralnych.* AGH, Wydawnictwa własne, No. 24: 30–32.

Olszewska, B., Odrzywolska-Bieńkowa, E., Giel, M. D., Pożaryska, K. & Szczechura, K., 1996. *Foraminiferida* Eichwald, 1830. *In*: Limanowska, L. & Piwocki, M. (eds), *Geology of Poland. Atlas of characteristic fossils. Cenozoik. Tertiary. Paleogene.* v. 3, part 3a, Państwowy Instytut Geologiczny, 45–215.

Poprawa, P., Malata, T. & Oszczypko, N., 2002. Tectonic evolution of the Polish part of Outer Carpathian's sedimentary basins – constraints from subsidence analysis (in Polish with English summary). *Przegląd Geologiczny*, 50: 1092–1108.

Ross, C. A., & Ross, J. R. P., 1990. The Paleozoic sea-level curve. *In*: Harland, W. B. *et al.* (eds), *Sequence Stratigraphy. Views from the North American Craton.* Geological Society of America. Special Papers, 306: 187–192.

Schnitker, D. & Tjalsma, L. R. C., 1980. New genera and species of benthic foraminifers from Paleocene and Eocene deep water deposits. *Journal of Foraminiferal Research*, 10: 235–241.

Sikora, W., 1976. Cordilleres of the West Carpathians in the light of plate tectonics (in Polish with English summary). *Przegląd Geologiczny*, 24: 336–249.

Skoczylas-Ciszewska, K., 1960. Geology of the Żegocina Zone (Western Flysch Carpathians) (in Polish with English summary). *Acta Geologica Polonica*, 4: 485–591.

Tjalsma, R. C. & Lohman, G. P., 1983. Paleoeocene–Eocene bathial and abyssal benthic foraminifera from the Atlantic Ocean, *Micropaleontology, Special Publication*, 4: 90 pp.

Unrug, R., 1969. Geological guide to Western Flysch Carpathians (in Polish). *Wydawnictwa Geologiczne*, 260 pp.

van Andel, T. H., 1975. Mesozoic/Cenozoic calcite compensation depth and the global distribution of calcareous sediments. *Earth Planet Scientific Letters*, 26: 187–194.

Waśkowska-Oliwa, A., 2001. *Analysis of small foraminifera assemblages from Maastrychtian and Lower Palaeogene deposits of the Subsilesian Unit in the Żywiec Tectonic Window and Lanckorona –Żegocina Zone* (in Polish). Jagiellonian Library. Unpublished PhD thesis, 258 pp.

Waśkowska-Oliwa, A., 2004. Paleocene foraminiferal assemblages of the Subsilesian unit (Polish Flysch Carpathians) (in Polish). *In*: Muszer, J. (ed.), *Zapis paleontologiczny jako wskaźnik paleośrodowisk.* XIX Konferencja Naukowa Paleobiologów i Biostratygrafów PTG, Wrocław 2004.09. 16-18. Książka abstraktów: 92–94.

Waśkowska-Oliwa, A. & Leśniak, T., 2003. Biostratigraphy and palaeoecology of Early Palaeogene deep water foraminiferal assemblages from the Subsilesian Unit in the Żywiec Tectonic Window (Polish Outer Carpathians). *Bulletin of the Polish Academy of Sciences*, 51: 11–27.

APPENDIX

List of foraminifera taxa occurring in discussed deposits in alphabetical order.

Agglutinated foraminifera

Ammobaculites midwayensis Plummer
Ammobaculites wazaczi (Grzybowski)
Ammodiscus cretaceus (Reuss)
Ammodiscus glabratus Cushman & Jarvis
Ammodiscus incertus (d'Orbigny)
Ammodiscus latus Grzybowski
Ammodiscus peruvianus Berry
Ammodiscus planus Loeblich
Ammodiscus tenuissimus Grzybowski
Ammolagena clavata (Jones & Parker)
Ammosphaeroidina pseudopauciloculata (Mjatliuk)
Arenobulimina dorbignyi (Reuss)
Aschemocella carpathica Neagu
Bathisiphon sp.
Caudammina ovuloides (Grzybowski)
Caudammina ovula (Grzybowski)
Cystammina sveni Gradstein & Kaminski
Dorothia crassa (Marsson)
Dorothia intendata Cushman & Jarvis
Dorothia oxycona (Reuss)
Dorothia retusa (Cushman)
Dorothia trochoides (Marsson)
Gerochammina lenis (Grzybowski)
Gerochammina tenuis (Grzybowski)
Glomospira charoides (Jones & Parker)
Glomospira diffundens Cushman & Renz
Glomospira glomerata (Grzybowski)
Glomospira gordialis (Jones & Parker)
Glomospira irregularis (Grzybowski)
Glomospira serpens (Grzybowski)
Glomospirella biedae Samuel
Glomospirella grzybowskii (Jurkiewicz)
Haplophragmoides bulloides (Beisel)
Haplophragmoides kirki Wickenden
Haplophragmoides mjatliukae Maslakova
Haplophragmoides porrectus Maslakova
Haplophragmoides suborbicularis (Grzybowski)
Haplophragmoides walteri (Grzybowski)
Hormosina exscelsa (Dylążanka, 1923)
Hormosina velascoensis (Cushman)
Hyperamina elongata Brady
Hyperammina dilatata Grzybowski
Hyperammina kenmilleri Kaminski
Kalamopsis grzybowskii (Dylążanka)
Karrerulina coniformis (Grzybowski)
Karrerulina conversa (Grzybowski)
Karrerulina horrida (Mjatliuk)
Lituotuba lituiformis (Brady)

Nothia excelsa (Grzybowski)
Paratrochamminoides contortus (Grzybowski)
Paratrochamminoides deformis (Grzybowski)
Paratrochamminoides draco (Grzybowski)
Paratrochamminoides heteromorphus (Grzybowski)
Paratrochamminoides irregularis (White)
Paratrochamminoides mitratus (Grzybowski)
Paratrochamminoides multilobus (Dylążanka)
Paratrochamminoides olszewskii (Grzybowski)
Paratrochamminoides uviformis (Grzybowski)
Praecystammina globigerinaeformis Krasheninnikov
Psamminopelta gradsteini Kaminski & Geroch
Psamosphaera fusca Schultze
Recurvoides div. sp.
Remesella varians (Glaessner)
Reophax duplex Grzybowski
Reophax elongatus Grzybowski
Reophax guttifer Brady
Reophax nodulosus Brady
Reophax pilulifer Brady
Reophax scalaris Grzybowski
Reophax trinitanensis (Cushman & Renz)
Reticulophragmium amplectens (Grzybowski)
Rhabdammina cylindrica Glaessner
Rhabdammina discreta Brady
Rhabdammina robusta (Grzybowski)
Rhizammina indivisa Brady
Rzehakina epigona (Rzehak)
Rzehakina fissistomata (Grzybowski)
Rzehakina minima Cushman & Renz
Saccamina grzybowskii (Schubert)
Saccammina placenta (Grzybowski)
Saccammina scrabosa Mjatliuk
Saccamminoides carpaticus Geroch
Spiroplectammina navarroana Cushman
Spiroplectammina spectabilis (Grzybowski)
Subreophax splendidus (Grzybowski)
Textularia sp.
Thalmannammina subturbinata (Grzybowski)
Tritaxia amorpha (Cushman)
Trochammina altiformis Cushman & Renz
Trochammina bulloidiformis (Grzybowski)
Trochammina globigeriniformis (Parker & Jones)
Trochammina quadriloba (Grzybowski)
Trochamminoides coronatus (Brady)
Trochamminoides proteus (Karrer)
Trochamminoides variolarius (Grzybowski)

Calcareous benthic foraminifera

Abysammina poagi Schnitker & Tjalsma
Abysammina quadrata Schnitker & Tjlasma
Anomalina acuta Plummer

Anomalina praecuta Vasilenko
Anomalina sp.
Anomalinoides capitanus (Gümbel)
Anomalinoides midwayensis (Plummer)
Anomalinoides rubiginosus (Cushamn)
Anomalinoides semicribratus (Beckman)
Anomalinoides umbilicata (Brotzen)
Aragonia ouezzanensis (Rey)
Aragonia velascoensis (Cushman)
Bulimina sp.
Cibicides sp.
Cibicidoides havanensis (Cushman & Bermudez)
Cibicidoides sp.
Clinapertina complanata Tjalsma & Lohman
Clinapertina subplanispira Tjlsma & Lohman
Dentalina catenula Reuss
Dentalina gracilis d'Orbigny
Dentalina megapolitana Reuss
Dentalina multicostata d'Orbigny
Elipsopolimorphina sp.
Ellipsoglandulina cocnicana Olbertz
Ellipsoglandulina obesa Hanzlikova
Ellipsomorphina sp.
Ellipsonodosaria sp.
Ellipsopolimorphina velascoensis (Cushman)
Eponides subcandidulus (Grzybowski)
Eponides umbonatus (Reuss)
Gavelinella affinis (Hantken)
Gavelinella danica (Brotzen)
Globobulimina sp.
Globocassidulina inexculta (Franzenau)
Guttulina adhaerens (Olszewski)
Guttulina problema d'Orbigny
Gyroidiinoides nitidus (Reuss)
Gyroidina turgida (Hagenow)
Gyroidinoides girardanus (Reuss)
Gyroidinoides globosus (Hagenow)
Lagena emaciata Reuss
Lenticulina abscisa (Grzybowski)
Marginulinopsis sp.
Nodosarella sp.
Nodosaria limbata d'Orbigny
Nodosaria monile Hagenow
Nodosaria velascoensis Cushman
Nonion havanense Cushman & Bermudez
Nonion sp.
Nuttallides truempyi (Nuttall)
Nuttallinella florealis (White)
Osangularia plummerae Brotzen
Osangularia velascoensis (Cushman)
Pleurostomella acuta Hantken
Pleurostomella eocena Gümbel
Pleurostomella sp.

Pseudonodosaria cylindracea (Reuss)
Pullenia coryelli White
Quadrimorphina allomorphinoides (Reuss)
Quadrimorphina profunda Schnitker & Tjalsma
Saracenaria sp.
Stensiöina beccariiformis (White)
Stilostomella sp.
Valvulineria alpina Hillebrandt

Planktonic foraminifera

Acarinina nitida (Martin)
Acarinina primitiva (Finaly)
Acarinina soldadoensis (Brönnimann)
Acarinina cf. *wilcoxensis* (Cushman & Ponton)
Chilogümbelina wilcoxensis (Cushman & Ponton)
Chilogümbelnia morsei (Kline)
Globigerina inscisa Hilebrandt
Globigerina quadrata White
Globigerina turgida Finaly
Globoconusa kozlowskii (Brotzen & Pożaryska)
Morozovella aequa (Cushman & Renz)
Morozovella subbotinae (Morozowa)
Parasubbotina inaequispira (Subbotina)
Parasubbotina cf. *pseudobulloides* (Plummer)
Parasubbotina varianta (Subbotina)
Subbotina linaperta (Finaly)
Subbotina triangularis (White)
Subbotina triloculinoides (Plummer)
Subbotina velascoensis (Cushman)
Truncorotalites pseudotopilensis (Subbotina)