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Palaeoenvironments of the Middle Miocene evaporite-bearing deposits from the Działoszyce Trough, Carpathian Foredeep, Poland, based on microfaunal studies

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Analysis of microfossil distribution (foraminifera, ostracodes and bolboforms) in evaporite-bearing deposits from the Działoszyce Trough (northern Carpathian Foredeep) has allowed the distinction of three ecozones: the *Globigerinoides* ecozone (Lower Badenian), the *Globigerina* ecozone (Middle and Upper Badenian) including an evaporitic horizon, and the *Anomalinoides dividens* ecozone (Sarmatian). These ecozones are of ecostratigraphical significance and reflect major sea-level changes. The highest stands of sea-level correspond with the *Globigerinoides* ecozone and the upper part of the *Globigerina* ecozone, above the evaporites, and they are considered to relate to an influx of oceanic waters. Drastic climatic changes (cooling) and a sea-level fall that weakened bottom water circulation at the boundary between the *Globigerinoides* and *Globigerina* ecozones are considered the major factors which accounted for hypoxia (an oxygen-poor environment) that accompanied evaporitic deposition. The appearance of a specific ostracod assemblage (*Xylocythere carpathica* Szczechura and *?Microxestoleberis* sp.) in Upper Badenian deposits is linked with the occurrence of active submarine hydrocarbon seepages.

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Key words: Carpathian Foredeep, Middle Miocene, evaporites, microfossils (foraminifera, ostracodes and bolboforms), biostratigraphy, palaeogeography, palaeoecology.

INTRODUCTION

Miocene deposits from the Działoszyce Trough which is situated at the junction of the Vistula and Nida rivers (Figs. 1, 2), like those from other areas of the Carpathian Foredeep, have long been a subject of interest of geologists and palaeontologists (*cf.* Osmólski, 1972) owing to chemical deposits (mainly gypsum). The presence of sulphur deposits, formerly exploited, encouraged Osmólski to enter upon studies on their origin. These investigations (Osmólski, 1972), provided much information on the geological structure of the Działoszyce Trough margins, including the bio- and lithostratigraphy of the trough-fill, together with speculations on the origin of sulphur deposits.

These investigations are aimed at the analysis of environmental conditions that accompanied evaporitic deposition in the Działoszyce Trough, Carpathian Foredeep, chiefly on the basis of foraminifera, ostracodes and bolboforms. This study does not deal with the detailed taxonomy of the microfossils found in these deposits, as these are often poorly preserved, but is limited to the recognition of general distributional trends of microfossils in the evaporite-bearing deposits.

Rock samples used in these studies and collected from boreholes through the Miocene deposits mainly in the vicinity of Posądza were earlier investigated by Osmólski (1972). Not all of the samples are preserved but the material is nevertheless important due to the presence of microfossils, including some previously unknown from the Miocene of the Carpathian Foredeep. These microfossils are useful not only for palaeoenvironmental analysis but also for Middle Miocene biostratigraphy and palaeogeography. The material described here is housed at the Institute of Palaeobiology of the Polish Academy of Sciences in Warszawa (abbreviated ZPAL).

LOCATION AND LITHOLOGY

The research material comes from boreholes drilled in the vicinity of Posądza in the southwestern part of the Działoszyce Trough located on the northern margin of the Carpathian Foredeep, about 40 km NE of Kraków (Osmólski, 1972) (Fig. 1). Badenian and Sarmatian evaporite-bearing deposits,

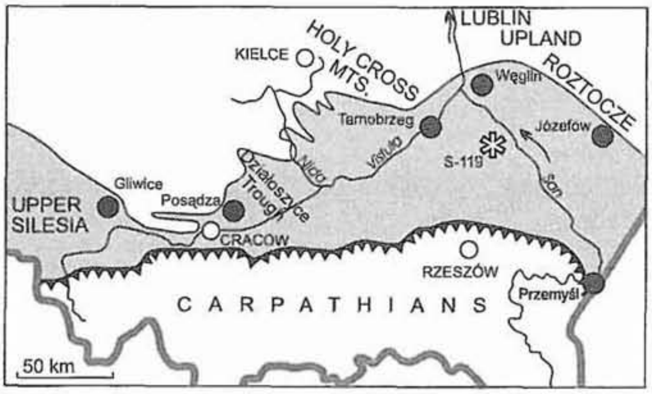


Fig. 1. Extent of the Middle Miocene (Badenian-Sarmatian) sea in the Fore-Carpathian Depression (stippled) showing location of the sections mentioned in the text

overlying Upper Cretaceous carbonates, were sampled. Deposits resting below the evaporites, and assigned by Osmólski (1972) to the Baranów Beds, are represented mostly by marls and marly clays passing upwards into clays (Fig. 3). Their total thickness is of up to 60 m. These beds contain the *Orbulina* cf. *suturalis* and *Uvigerina costai* Zones distinguished on the basis of foraminifera. The overlying chemical deposits contain intercalations of calcareous or non-calcareous clays, post-gypsum limestones and sulphur concentrations, and do not exceed 25 m in thickness. Osmólski (1972) notes that "...the whole of the complex of rocks belonging to the chemical beds is characterised by strong bitumen smell". The evaporites are overlain by clays, shaly clays and dark grey non-calcareous clays, between 3 and approximately 15 m thick. These rocks are assigned to the Chodenice Beds and pass upwards into the *Pecten-Spirialis* Beds composed of grey shaly clays overlain by greenish clays, up to some 40 m thick. The last beds include the *Neobulimina longa* and *Cibicides crassiseptatus* Zones. The lower part of the supra-gypsum deposits contains gypsum crystals, trace amounts of magnetite and pyrite, as well as tuffite interbeds.

Sarmatian deposits occurring fragmentarily in this part of the Działoszyce Trough are represented by shaly clays passing upwards into clays, from 0 up to 30 m thick. Lithologically, they are very similar to the underlying Upper Badenian supra-gypsum deposits.

The Posądza 10-S borehole has been considered a marker borehole, and the most important one for the investigations, because it is the best sampled. Samples from the boreholes Posądza 40-S, Posądza 12-S, Piotrkowice Małe 14-S and Szczytniki 11-S (Fig. 2) were used for comparative studies. The location of the boreholes is given in Osmólski (1972).

MATERIALS AND METHODS

Residual microfossils left on a 0.05 mm sieve were used for the investigations. Maceration was performed using Glauber's salt ($Na_2SO_4 \cdot 2H_2O$). In the case of foraminifera, 300 specimens (if this number was available) were selected from one sample. Percentage contributions of individual species (if particularly characteristic), genera or allied genera groups were calculated later, unless they composed < 2% of the assemblage (total percentage at least 80%) (Fig. 3). Predominantly adult individuals were selected because samples from the lower part of the section contained many juvenile forms. In the upper part, both beneath and above the gypsum, adult but very small foraminifera sometimes occurred in great numbers. These are omitted in Figure 2, although mentioned in the text.

The foraminifera taxonomy applicable for the Paratethys (not revised — except for the cases indicated) has been generally used in the study. However, there is no doubt that some foraminifera, especially deep-water, widespread and long-ranging forms, are known under different names. Foraminifera may also sometimes show much variability that was not always taken into account in older studies on the taxonomy of foraminifera from the Central Paratethys.

Ostracodes, typically rare in the studied samples, have been identified only tentatively as regards their usefulness for stratigraphy or palaeoecology. Bolboforms have been identified, and their relative frequency of occurrence has been estimated.

RESULTS

The distribution of foraminiferal biofacies in the Posądza 10-S borehole section (Tab. 1, Fig. 2) is as follows:

Foraminiferal assemblages from samples collected from depths of 101.8, 101.5 and 100.2 m include agglutinated and calcareous species (latter ones including both benthic and planktonic forms). Their tests are often poorly preserved and crumpled (as in flysch deposits). The most representative sample is that from a depth of 101.5 m, the residuum from which contains many calcareous fragments and quartz. Agglutinated foraminifera compose 9% of the foraminiferal assemblage. Plankton composes 27% of the total foraminiferal assemblage, 23% being represented mainly by the genera *Globoquadrina*, *Globigerinoides*, *Orbulina*, *Praeorbulina*, *Globoconella* and *Paragloborotalia*. Planktonic *Globigerina*-like forms constitute only 4%. However, only large, adult individuals were considered in the quantitative analysis.

Calcareous benthos (48% of the foraminiferal assemblage) is dominated by Uvigerina (19%), including *U.* cf. *macrocarinata* Papp et Turnovsky (Pl. II, Fig. 10), *U.* cf. *acuminata* Hosius (Pl. II, Fig. 12), *U. pygmoides* Papp et Turnovsky (Pl. II, Fig. 13) and *U.* cf. *grilli* Schmid. Nodosariaceans comprise 13% here, while the variable *Heterolepa dutemplei* (d'Orbigny) (Pl. III, Figs. 17–20) — 9%, and *Melonis pompilioides* (Fichtel et Moll) (Pl. V, Fig. 13) — 7% of the total foraminiferal assemblage.

Bolboforms are rare and small and represented by *B. reticulata* Daniels et Spiegler (Pl. IV, Figs. 6 and 7).

Ostracodes are scarce and poorly preserved, and belong to the following genera: *Krithe* (*K.* div. sp.), *Parakrithe* (*P.* div. sp.), *Paijenborchella* (*P. iocosa* Kingma), *Buntonia* (*B.* cf. *dertonensis* Ruggieri), *Pterygocythereis* [*P. jonesi* (Baird)], *Costa* [*C. tricostata* (Reuss)], *Bythocypris* [*B.* cf. *lucida* (Sequenza)], *Saida*, *Cytherella* (*C. pestiensis postdenticulata* Oertli), *Cnestocythere*, *Xestoleberis*, *Henryhowella* [*H. asperrima* (Reuss)], *Eucythere* (*E. alexanderi* Schneider), *Argilloecia* and *?Eucytherura*.

The sample from 95.3 m (residuum mainly of glauconite, some quartz and pyrite, and tuffaceous material) contains fairly abundant foraminifera although very poorly differentiated, frequently etched (Pl. IV, Fig. 2) or as moulds. Calcareous forms are dominant, with 70% planktonic, and *Globigerina* cf. *bulloides* d'Orbigny (Pl. IV, Fig. 2) the most common. The remainder of the assemblage is very poorly varied. It includes representatives of the variable *Uvigerina peregrina* group such as *U. venusta* Franzenau, *U. pygmaea* d'Orbigny and *U. romaniaca* Papp, Cicha et Ctyroka (*cf.* Van der Zwaan *et al.*, 1986; Haunold, 1993), recognised also in the younger Badenian of the Central Paratethys (Papp *et al.*, 1978).

Ostracodes are absent. Bolboforms (*B. reticulata* Daniels et Spiegler) are more frequent than in the previous sample.

The 89.0 m sample (residuum mainly pyrite, with some glauconite) is dominated by minute benthic calcareous foraminifera, including *Sphaeroidina bulloides* d'Orbigny that makes up to 32% of the foraminiferal assemblage, while *Globigerina*-like foraminifera [chiefly *Globigerina* cf. *bulloides* d'Orbigny *and Turborotalia quinqueloba* (Natland)] constitute 15%. The planktonic foraminifera tests appear etched and frequently only preserved as pyritic moulds. Agglutinated forms are represented mainly by pavonitinids (6% of the foraminiferal assemblage).

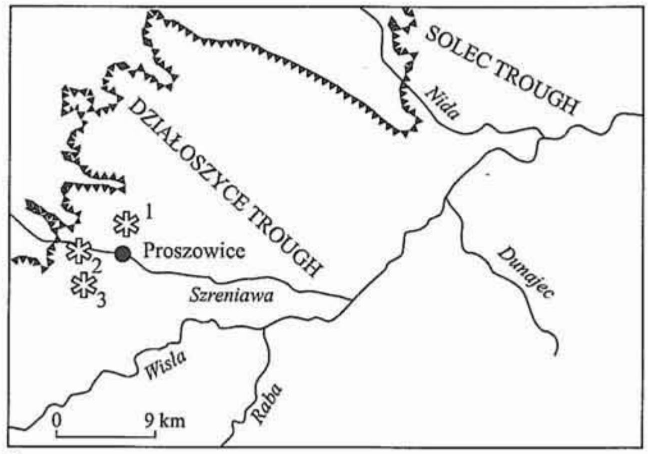
Ostracodes are absent. Bolboforms (*B. reticulata* Daniels et Spiegler) are more frequent than lower in the section.

The sample from 85.5 m (residuum with many calcareous fragments, some quartz and pyrite) is dominated by planktonic forms. The assemblage resembles that from the previous sample, though the minute form of *Alabaminella weddellensis* (Earland) (= *?Eponides pusillus* Parr) (Pl. IV, Figs. 12, 17, 18 and 23) is abundant in the very fine fraction.

Agglutinated foraminifera tests are rare; apart from infrequent *Pseudotriplasia elongata* Małecki, there are also poorly preserved tests resembling astrorhizids (?rhabdaminids).

Large dinoflagellates, rare diatoms, ostracodes (*Henryhowella*, *Argilloecia*, *Krithe*) and bolboforms (*B. reticulata* Daniels et Spiegler) are present here.

The foraminiferal assemblages from deposits immediately below the evaporites, in borehole Posądza 40-S, depths 29.6 and 29.0 m (*cf.* Osmólski, 1972, tab. 15), is similar to that from sub-gypsum deposits in borehole Posądza 10-S, although pavonitinids, in particular *Pseudotriplasia elongata* Małecki, are more abundant higher here. Plankton is also markedly more abundant than benthos and, moreover, the microfauna is very tiny here. Residuum from the 29.0 m sample contains abundant pyrite. The sub-gypsum sample collected from borehole Posądza 12-S, depth 46.1 m, largely comprises foraminiferal plankton (*Globigerina*-like and *Globorotalia*-like forms, including *Globorotalia prescitula* Blow) and single tests of *Sigmoilinita tenuis* (Czjzek) and *Lobatula* cf. *lobatula* (Walker et Jacob), together with gypsum and pyrite crystals. Samples from gypsum in borehole Posądza 10-S, depths 83.0, 79.0 and 72.6 m, have yielded no microfossils. However, in comparative samples collected from gypsiferous deposits in borehole Piotrkowice Małe 14-S, depth 37.1 m, infrequent tiny planktonic globigerinid and globorotaliid foraminifera were observed. Single globigerinoids, "nodosarids" and *Heterolepa dutemplei* (d'Orbigny) probably occur in a secondary deposit



- northern boundary of the Carpathian Foredeep; 1- Szczytniki 11-S; 2- Piotrkowice Małe 14-S; 3- Posądza 40-S, 12-S, 10-S

Fig. 2. Location of the studied sites in the Działoszyce Trough

because they are normally developed. Benthic calcareous foraminifera are represented by rare, minute *Cassidulina* sp., *Bolivina pseudoplicata* Heron-Allen et Earland (Pl. V, Figs. 8 and 11), *Pullenia bulloides* (d'Orbigny), *Elphidium* sp., relatively frequent agglutinated foraminifera of *Hyperammina* sp. (Pl. V, Figs. 14 and 19) and well preserved pteropod. *Bolboforma badenensis* Szczechura is also present here (Pl. V, Figs. 1–3). Diatoms are abundant in the 27.5 m sample (gypsum) from this borehole. No samples have been analysed from the Chodenice Beds of the borehole Posądza 10-S or other boreholes drilled in the Działoszyce Trough. According to Osmólski (1972), non-calcareous clays from this bed in borehole Posądza 10-S contain no fauna.

The 54.6 m sample (clay residuum) from borehole Posądza 10-S contains abundant radiolarians, diatoms, small bivalves, pteropod moulds and pyrite. Planktonic and benthic foraminifera are tiny, thin-shelled and rare. Only the agglutinated *Hyperammina* sp. is relatively numerous. One normal-sized specimen of *Globigerinoides trilobus* (Reuss) seems to be in a secondary deposit. *Bolboforma badenensis* Szczechura is also present.

The 51.0 m sample contains damaged (crumpled) pteropods, radiolarians and diatoms as well as pyrite. Planktonic foraminifera (all are *Globigerina*-like), mostly well developed, constitute 95% of the assemblage. *Bolboforma badenensis* Szczechura is also present here.

The 48.8 m sample (a little clay residuum with gypsum crystals, and rare pyritized pteropod moulds and single benthic gastropod shells) contains planktonic foraminifera (90% of microfossils, mainly *Globigerina*-like forms). *Bolboforma badenensis* Szczechura is also present here.

The 38.0 m sample — residuum largely shelly, with bivalves (teretinids), carbonized ?wood fragments, pyrite and rare quartz grains — contains diverse, well preserved, mainly benthic foraminifera, including agglutinated forms (13.5% of the foraminiferal assemblage), *Hansenisca* cf. *soldanii*

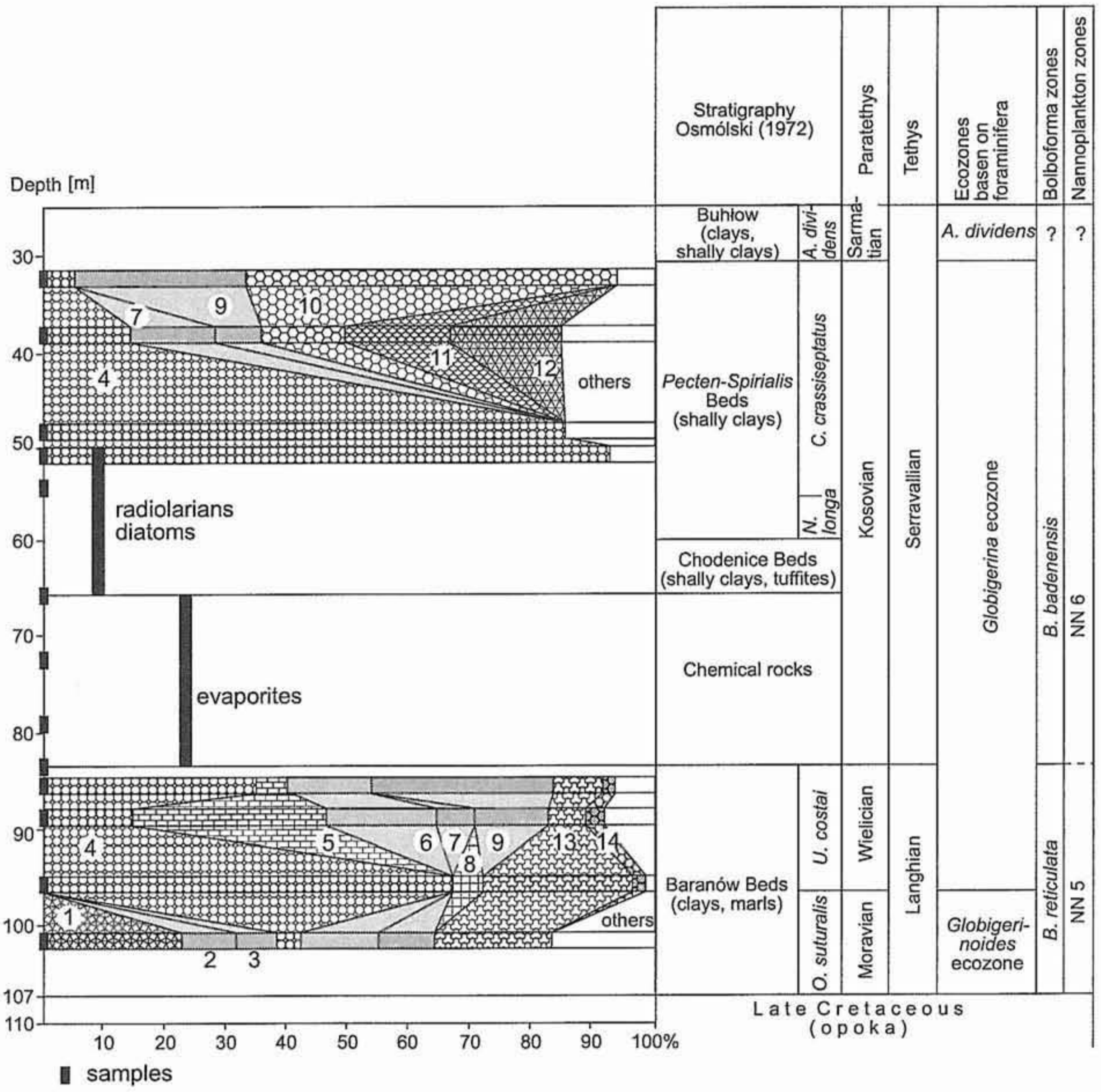


Fig. 3. Percentage of the most frequent species and/or species groups recorded in the Posądza 10-S borehole

1 — warm-water planktonic foraminifera; 2 — *Heterolepa dutemplei* (d'Orbigny); 3 — *Melonis pompilioides* (Fitchel et Moll); 4 — *Globigerina*-like planktonic foraminifera; 5 — *Sphaeroidina bulloides* d'Orbigny; 6 — Nodosariacea; 7 — arenaceous benthic foraminifera; 8 — *Valvulineria complanata* (d'Orbigny); 9 — Cibicididae and Parelloididae; 11 — *Bolivina pseudoplicata* Heron-Allen et Earland; 12 — *Hansenisca* cf. *soldanii* (d'Orbigny); 13 — *Uvigerina* div. sp.; 14 — *Bulimina* div. sp.

(d'Orbigny) (Pl. V, Figs. 10 and 12) — 18% and *Bolivina* div. sp. (mainly *B. pseudoplicata* Heron-Allen et Earland) — 17%. Miliolaceans are also numerous (15%), while the finest fraction contains abudant *Alabaminella weddellensis* (Earland) and a minute form of *?Eoeponidella* sp. (Pl. V, Figs. 20 and 21).

Foraminiferal plankton (chiefly globigerinids, single globorotaliids and 1 specimen of *Velapertina* sp.) constitutes 14% of the foraminiferal assemblage. *Bolboforma badenensis* Szczechura (rare) is present.

There are relatively abundant, minute thin-shelled ostracodes belonging to *Xylocythere carpathica* Szczechura and *?Microxestoleberis* sp.

The 32.3 m sample (clay residuum with rare quartz and sulphides) contains fragments of juvenile bivalves and benthic gastropods) and well preserved pteropod. The microfauna is very poorly diversified and dominated by representatives of miliolids (61%) and *Cibicides* cf. *pseudoungerianus* (Cushman) (30%). Plankton is represented by *Globigerina* sp. (5% of the foraminiferal assemblage).

No Sarmatian samples from borehole Posądza 10-S was available (*cf.* Osmólski, 1972, tab. 15). Therefore, one Sarmatian sample from borehole Szczytniki 11-S, depth 58.7 m (*cf.* Osmólski, 1972, tab. 17) was analysed for microfauna. Residuum contains calcareous fragments, quartz, pyrite, small bivalves, diatoms, dinoflagellates and ?pteropods. Microfauna is dominated by tests of *Lobatula dividens* (Łuczkowska) (= *Anomalinoides dividens* Łuczkowska) (Pl. VI, Fig. 6), including both *L.* cf. *lobatula* (Walker et and Jacob) as well as *L. dividens* (Łuczkowska) forms and miliolids. There are minute tests of *Rotaliella* cf. *roscoffensis* Grell (Pl. VI, Figs. 11–13) that also occur in the Sarmatian deposits of Roztocze (present author's observations). Planktonic *Globigerina*-like foraminifera are rare and small (Pl. VI, Figs 16 and 17).

Minute, thin-shelled ostracodes (*Cytherois sarmatica* Olteanu, *Callistocythere* div. sp., *Leptocythere* div. sp., *Polycope* sp., and rare juvenile *Aurila* sp.) and single bolboforms are frequent. Bolboforms are represented by *Bolboforma badenensis* Szczechura and a poorly preserved specimen of *B. danielsi* Murray.

STRATIGRAPHY

The stratigraphy of Miocene deposits from the Działoszyce Trough has been based on macro- and microfossils (Osmólski, 1972), following micropalaeontological investigations in the Carpathian Foredeep, including Posądza, in particular by Alexandrowicz (1963), Łuczkowska (1964) and Odrzywolska-Bieńkowa (1964).

The current studies (see Fig. 3), confirm a bipartite biostratigraphical division of the sub-gypsum deposits assigned to the Baranów Beds and confirm the presence and extent of Sarmatian beds. The tripartite biostratigraphical division of the Badenian supra-gypsum deposits suggested by Osmólski (1972) is less obvious. The Chodenice Beds, considered to be noncalcareous, seem to have a larger vertical range than suggested by Osmólski (1972), and the *Pecten-Spirialis* Beds (which yielded no *Cibicides crassiseptatus*) show greater foraminiferal changes than noted by that author, probably due to a local, specific palaeoenvironmental changes.

The biozones, assigned here to individual ecozones, reflect environmental changes (see next section) and so have an ecostratigraphical significance.

The presence of *Praeorbulina* cf. *glomerosa* (Blow), *Orbulina* cf. *suturalis* Brönniman and *Lenticulina echinata* (d'Orbigny) in the lowermost samples from borehole Posądza 10-S (= *Globigerinoides* ecozone) suggest an Early Badenian (Moravian) age (Łuczkowska, 1978; Olszewska *et al.*, 1996). A correlation supported by the ostracodes *Eucythere alexanderi* Schneider and *Cytherella pestiensis postdenticulata* Oertli (Szczechura, 1996).

"*Uvigerina costai*" (*Uvigerina peregrina* group) and *Globoturborotalita* cf. *decoraperta* (Takayanagi et Saito) appear higher, at 95.3 m. According to Olszewska *et al.* (1996), the latter is characteristic of the Middle Badenian (Wielician) as are pavonitinids, in particular *Pseudotriplasia*, that occur in this sub-evaporite part of the section. The presence of *Velapertina* sp. in the supra-gypsum beds suggests a Late Badenian (Kosovian) age, and the occurrence of *Anomalinoides dividens* Łuczkowska at the top of the section (Osmólski, 1972, tab. 15) indicates the Sarmatian. Miliolids and ostracodes that accompany *Anomalinoides dividens* Łuczkowska in the 58.7 m sample from borehole Szczytniki 11-S also point to a Sarmatian age. Bolboforms in borehole Posądza 10-S, distinguish the *B. reticulata* biozone in the sub-gypsum deposits, and the *B. badenensis* biozone in the evaporites and the overlying deposits (Fig. 3). The boundary between these two biozones coincides with the base of the evaporites. Spiegler and Rögl (1992) suggest that the appearance of *B. badenensis* Szczechura corresponds to the lower limit of the nannoplankton Zone NN6, and so the evaporites lie within the NN6 Zone (Late Badenian), while the underlying deposits are of NN5 Zone age (see also Peryt, 1997). If *B. badenensis* Szczechura and *B. danielsi* Murray occur *in situ* in Sarmatian deposits of borehole Szczytniki 11-S then these deposits should also be included within Zone NN6. Because these nannoplankton zones, including NN6, are Middle Miocene (Czapowski, 1996; Rögl, 1996), the entire section from the Działoszyce Trough is Middle Miocene.

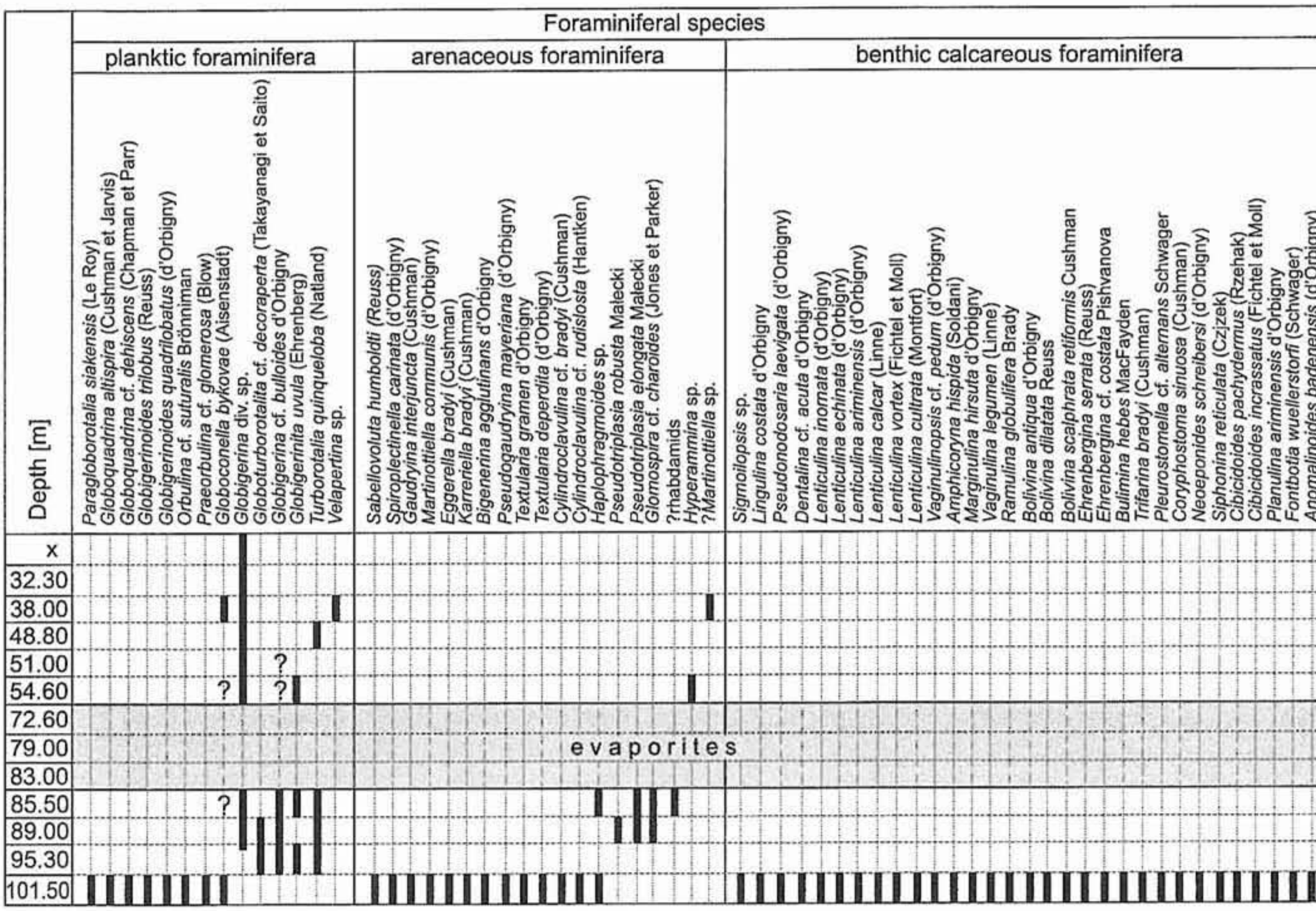
Olszewska *et al.* (1996), Łuczkowska (1998) and Zlinská (1998) suggested that the Lower Badenian (Moravian) corresponds to the Langhian of the Mediterranean, while the Middle Badenian (Welician), Upper Badenian (Kosovian) and Sarmatian correspond to the Serravallian; these authors refer, however, these substages to different calcareous nannoplankton biozones, i.e. within NN5–NN8 (Olszewska *et al.*, 1996) or NN5–NN8/9 (Łuczkowska, 1998), moreover they put the boundary between the Langhian and Serravallian within NN5 or NN6, respectively. Rögl (1996, 1998) includes these substages within zones NN4–NN7 and located the Langhian-Serravallian boundary within NN5. Recent work on the Mediterranean Middle Miocene (Foresti *et al.*, 1998) suggests correlation of the Langhian with NN5, and the Serravallian with NN6–NN8 (the boundary being at the NN5/NN6 boundary), and thus the Langhian-Serravallian boundary in the Działoszyce Trough section (Posądza 10-S borehole) should be placed immediately beneath the evaporites, if the bolboform biozonation is correct.

This correlation is supported by the upper limit of *Sphenolithus heteromorphus* (a Langhian/Serravallian boundary marker in the Mediterranean: Amorosi *et al.*, 1996) in deposits lying immediately below the sub-gypsum ones in other areas of the Carpathian Foredeep (Peryt, 1997).

PALAEOECOLOGY

The dramatic foraminiferal biofacies variations in the evaporite-bearing deposits of borehole Posądza 10-S (Fig. 3) seem, despite low frequency sampling, to reflect environmental changes, including both a pronounced climatic change at the transition between the Moravian and Wielician, and sea-level fluctuations during deposition. The climatic change recognized from foraminiferal studies (mainly planktonic foraminifera) in Badenian deposits elsewhere in the Carpathian Foredeep is expressed (Szczechura, 1982) as two ecozones: of *Globigerinoides* and *Globigerina*. These zones have also been applied in the present study. The range of the *Globigerinoides* ecozone different from this assumed herein, for example from the Korytnica section, resulted from the age of deposits (Middle Badenian) which was overstated by calcareous nannoplankton studies (Martini, 1977). Large benthic, i.e. warm-water, foraminifera are associated only with the *Globigerinoides*

Distribution of the most characteristic



x — sample from the borehole Szczytniki 11-S, depth 58.7 m

ecozone (Odrzywolska-Bieńkowa, 1972; Łuczkowska, 1975; Szczechura and Pisera, 1986; Rögl and Brandstätter, 1993).

BADENIAN

MORAVIAN (*GLOBIGERINOIDES* ECOZONE)

These foraminiferal assemblages show high diversity and contain several tens of species, both planktonic and benthic (Pl. I–IV). Planktonic foraminifera are abundantly represented by tropical or subtropical forms such as *Globoquadrina*, *Globigerinoides* and *Orbulina*. Benthic foraminifera include *Fontbotia wuellerstorfi* (Schwager), *Cibicidoides pachydermus* (Rzehak), *Anomalinoides helicinus* (Costa), *Eggerella bradyi* (Cushman) and *Siphonina reticulata* (Czjzek), indicating water deeper than upper bathyal. *Cibicidoides incrassatus* (Fichtel et Moll) and *Sphaeroidina bulloides* d'Orbigny also prefer bathyal waters (Van Morkhoven *et al.*, 1986). Moreover, these assemblages contain almost all the species quoted by Berggren (1972) as appearing in the Middle Miocene of the Atlantic!

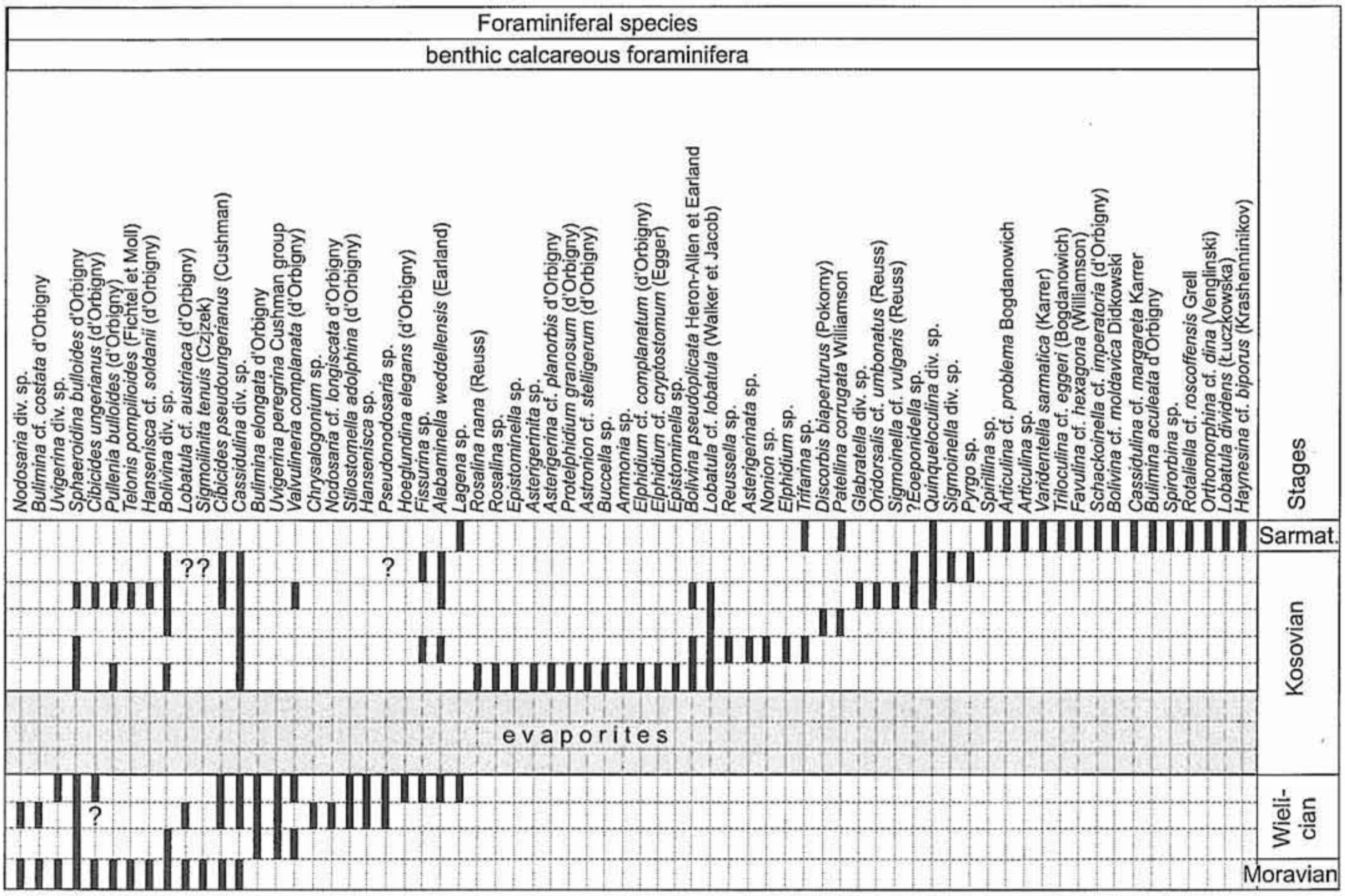
The deep-water character of Lower Badenian deposits from the Działoszyce Trough is confirmed by ostracodes, which include "psychrospheric" species described from elsewhere in the Carpathian Foredeep (Szczechura, 1994). Similar deep-water foraminiferal and ostracod biofacies also occur in outcrops in the vicinity of Kraków (Bonarka), Wadowice (Benczyn) and Pińczów (Gacki) (Szczechura, unpublished).

Elements of this biofacies are also present in Lower Badenian, predominantly argillaceous, deposits exposed in Korytnica, comprising the top of the Miocene succession (Szczechura, pers. obs.). Gonera (1994, 1997), used foraminifera to recognize the Middle Miocene bathyal zone in the northern part of the Polish Carpathians, for example south-east of Kraków. Gonera (1977) also found deep-water foraminifera in Lower Badenian deposits in Upper Silesia and recognized an abrupt change of foraminiferal assemblage suggesting a sea-level fall at the Moravian-Wielician transition.

The high diversity and the presence of endobenthic and epibentic forms [in particular the suspension-feeding *Fontbotia wuellerstorfi* (Schwager)] in the *Globigerinoides* ecozone indicate favourable, stable environmental conditions, well oxygenated waters with bottom water currents, and moderate oligotrophy (Corliss and Chen, 1988; Sen Gupta and Machain-Castillo, 1993). Warm-water (symbiont-bearing)

Table 1

foraminiferal species in the Posądza 10-S borehole



forms present among planktonic foraminifera also indicate oligotrophy (Spero and Lea, 1996; Brasier, 1995*b*).

WIELICIAN (*GLOBIGERINA* ECOZONE, SUB-EVAPORITIC DEPOSITS)

The 95.3 m sample collected from the *Globigerina* ecozone deposits is characterised by domination of planktonic foraminifera, and an absence of warm-water forms in favour of the cooler water forms *Globigerina* cf. *bulloides* d'Orbigny, *Turborotalia quinqueloba* (Natland) and *Globigerinita uvula* (Ehrenberg) (see Boersma, 1978). Cool-water planktonic foraminifera occur at least up to the top of the Badenian deposits. This change in planktonic foraminifera results from climatic and/or oceanographic changes at the transition between the Lower and Middle Badenian.

Benthic foraminifera also indicate climatic changes in the Early Badenian. The 95.3 m sample contains the *Uvigerina peregrina* group in abudance (unlike the sample from the underlying deposits), the appearance which in the Middle Miocene of NW Europe was considered by Von Daniels (1986) as indicating "a climatic change" (i.e. cooling) "or at least a change of water masses". Borsetti *et al.* (1986) attributed this cooling to the Middle Miocene Antarctic glaciation and the closure of the Tethys in the east. These microfaunal differences do not simply reflect changes in surface water temperature. Benthic foraminifera lack of bathyal forms and comprise only several opportunistic species able to survive in new and difficult environmental conditions. The lack of ostracodes confirms this situation.

The benthic foraminifera thus indicate a sea-level fall, though at most down to the lower neritic zone. The assemblage indicates limited contact with deep oceanic waters. The dominant endobenthic forms here, including representatives of *Uvigerina*, *Bulimina* and *Valvulineria*, tolerate stress and oxygen-poor bottom environment conditions (Corliss and Chen, 1988; Sen Gupta and Machain-Castillo, 1993; Brasier, 1995*a*) that seems to be a consequence of highly trophic surface waters and weaker bottom water circulation. Increase in productivity is seen here by the appearance en masse of cool-water (non-symbiotic) *Globigerina* cf. *bulloides* d'Orbigny associated with upwelling, increasing the flux of organic carbon to the sea-floor (Anderson, 1994; Brasier, 1995*a*; Murray, 1995; Reichart *et al.*, 1997; Rohling *et al.*, 1997), and in the *Uvigerina peregrina* group that prefers fertile waters (Quinterno and

Gardner, 1987; Katz and Miller, 1993; Fariduddin and Laubere, 1997). Both sea-level fall and climatic cooling are known to favour upwelling and, in consequence, eutrophication of the environment (Jonkers, 1984; Angel, 1994). Tuffaceous material found here probably enhanced this trend.

The increase in diversity of foraminifera from the 89.0 and 85.5 m samples, in particular the appearance of epibenthic "cibicids", and the increased contribution of lower neritic zone ostracodes in the 85.5 m sample suggest the bottom environment ameliorated, but remained eutrophic and oxygen-poor, as evidenced by the presence of pyrite, pteropod moulds, the etching of calcareous planktonic foraminifera (Pl. IV, Fig. 2) and the dwarfing of benthic forms. Another indicator of eutrophication is, the appearance en masse of *Alabaminella weddellensis* (Earland) (also present in the uppermost samples from borehole Posądza 10-S) in the 85.5 m sample. This species originates from Antarctica and is considered to prefer deep (bathyal zone), cool and fertile waters, associated with phytodetritus (Gooday, 1988; Van Leeuwen, 1989; Resig and Cheong, 1997; Fariduddin and Loubere, 1997; Wollenburg and Mackensen, 1998; King *et al.*, 1998). This species (as "*Eponides*" *pusillus*) was described from the Middle Badenian of the Vienna Basin (Rupp, 1986). The increasing number of bolboforms and the appearance of dinoflagellates and radiolarians also show an increase of primary productivity in surface waters.

The appearance of agglutinated forms, in particular pavonitinids, and *Glomospira* cf. *charoides* (Jones et Parker) (known from flysch deposits) may suggest turbiditic sedimentation, consequent on sea-level fall (*cf.* McCarthy and Mudie, 1998) and productivity increase (Boltovskoy and Wright, 1976; Haq *et al.*, 1987; Barbieri, 1998; Brett, 1998). Seiglie and Baker (1983) relate the presence of pavonitinids (including a species known from the Central Paratethys!) in the Miocene of the East Atlantic, offshore West Africa, to upwelling and turbidity currents; such environmental conditions seem favourable to epibenthic "cibicids" while simultaneously decreasing the amount of plankton in surface waters (Boltovskoy and Wright, 1976; Nini, 1996; Rohling *et al.*, 1997).

Ephemeral and local improvement of environmental conditions prior to evaporite deposition is seen in sub-gypsum samples from other sections, for example, from boreholes Posądza 40-S and Posądza 12-S, where foraminiferal assemblages are unlike those from borehole Posądza 10-S. In borehole Posądza 12-S they suggest an extremely impoverished benthos. Thus before evaporitic deposition, the hostility of the bottom environment to foraminifera varied depending on local environmental conditions.

KOSOVIAN (*GLOBIGERINA* ECOZONE, EVAPORITIC AND SUPRA-EVAPORITIC DEPOSITS)

Samples from chemical deposits of the borehole Posądza 10-S have yielded no microfossils. However, the foraminifera assemblages, sometimes almost monospecific, dominated by *Hyperammina* sp., showing low frequencies and small tests, locally exclusive diatom assemblages, occur in comparative samples from evaporites (e.g. Piotrowice Małe 14-S borehole). They show a continuation of inhospitable marine though not necessarily shalow-water conditions. Bolboforms and other plankton show that open marine communication was reestablished with an influx of new water masses.

A few tiny foraminifera, both planktonic and benthic, in pyritic samples from above the gypsum (Posądza 10-S borehole, depth 54.6 m) unambiguously show a continuation of extreme stressed conditions, in particular bottom water anoxia, particularly as silica-shelled organisms (diatoms, radiolarians) and mouldic pteropods occur en masse there. The latter indicate high surface productivity of surface waters and sometimes upwelling (Hutchings *et al.*, 1994; Brasier, 1995*b*).

Contemporaneous volcanic activity may have contributed to the increased productivity. Planktonic and benthic foraminifera may have been suppressed by a scarcity of $CaCO_3$. Those benthic foraminifera preserved here indicate a sea-level fall down to the lower neritic zone.

An increase in planktonic foraminifera (Posądza 10-S borehole, depth 51.0 and 48.8 m), with very tiny *Globigerina*-like forms dominant and simultaneous dwarfed benthos suggests a high sea-level stand and amelioration as regards foraminifera, in particular in surface waters. A similar benthic foraminifera assemblage occurs in sub-recent sapropelic deposits associated with stagnant environments in the Eastern Mediterranean (Oggioni and Zandini, 1987).

The subsequent (sample depth 38.0 m) short-lived diversity increase, with better developed benthic foraminifera, including endo- and epibenthic forms, suggests a further sea-level rise (within the neritic zone). The appearance here of macrofauna (bivalves, including *?Teredo*, and gastropods) and almost unique abundant ostracodes, although represented by only *Xylocythere carpathica* Szczechura and *?Microxestoleberis* sp., confirm the bottom environment amelioration. The ostracodes, represented by both adult and juvenile forms, are *in situ*.

Planktonic and endobenthic agglutinated foraminifera are rare. As with the ostracodes, there is a domination by a few species, including those associated with a eutrophic environment (e.g. *Bolivina*, *Hansenisca*, some miliolids), that suggests an oxygen-poor environment. However, the ostracodes, among which *Xylocythere* is considered to be a wood-liking genus (Maddocks and Steineck, 1987; Szczechura, 1995), seems most important to understanding the palaeoenvironment. These ostracodes are represented by thin- and tiny-shelled forms with numerous large pores, suggesting fertile and oxygen-poor conditions, the shell porosity enabling gas exchange (Sen Gupta and Machain-Castillo, 1993; Van Harten, 1993). Van Harten (1992) found representatives of *Xylocythere* (in association with boring molluscs) in the Pacific, around hydrothermal vents. According to Van Harten (1992) the wood-rich environment resembles vent and seep areas, as both environments supply nutrients (from wood-degrading and chemoautotrophic bacteria respectively). A similar environment may be represented in the sample from borehole Posądza 10-S, particularly as the abundance of pyrite and wood fragments suggest a nutrient-rich and suboxic environment.

Areas with marine vents and/or seeps are common in modern seas and oceans, for example the Guaymas Basin, Mexico (Ayala-Lopez and Molina-Cruz, 1994), the Gulf of Mexico (Sen Gupta *et al.*, 1997), and they are microhabitats for laterally variable microfaunal assemblages, includings foraminifera known from the Miocene of the Działoszyce foredeep. Cold seeps and/or hydrothermal vents in the Late Badenian Paratethys might thus provide environmental eutrophy and toxicity and favoured the development of some microfossil groups (*cf.* Szczechura, 1995, 1997). As *Xylocythere carpathica* Szczechura (although in another microfaunal association) has also been found in the supra-gypsum deposits of other foredeep areas, for example in the vicinity of Tarnobrzeg (Jamnica) and in Upper Silesia (Gliwice) (Szczechura, 1997), such seepages might have occurred extensively over the foredeep.

SARMATIAN

ANOMALINOIDES DIVIDENS ECOZONE

The youngest Upper Badenian and Sarmatian deposits (Posądza 10-S borehole, depth 32.3 m and Szczytniki 11-S, depth 58.7 m) accumulated in a shallow-water basin (upper neritic zone, inner coastal environment) subject to slow sedimentation and poor circulation, and with poor communication with the open sea. The basin floor was covered by a subaquatic vegetation that favoured stagnant conditions. The epiphytic *Lobatula* cf. *lobatula* group (including "*Anomalinoides dividens*"), dominant in the higher Sarmatian deposits, suggest an increase in bottom currents. Numerous glabratellids, in particular *Rotaliella* forms comparable to species known from the intertidal zone of the Mediterranean Sea (Pawlowski and Zaninetti, 1993) and the shallow waters of the Gulf of Elat (Red Sea) (Pawlowski and Lee, 1991), preclude the possibility of fresh water (Murray, 1991). These were probably tidal flats flooded with normal and/or hypersaline waters.

Low diversity foraminifera and ostracodes with small and thin tests suggest a scarcity of $CaCO_3$ and/or low pH, typical of an environment with a low sedimentation rate and rich subaquatic vegetation (*cf.* Sen Gupta and Machain-Castillo, 1993; Kaiho, 1994; Asioli, 1995).

CONCLUSIONS

Microfossils from the Middle Miocene deposits of the Działoszyce Trough, northern Carpathian Foredeep, indicate marked hydrodynamic and climatic changes.

During the Early Badenian, this area was covered by a deep and well oxygenated bathyal sea, with warm surface waters and cool, ocean-origin, psychrospheric bottom waters (Szczechura, 1994). This Early Badenian sea-level highstand (in the Paratethys) seems to coincide with a global sea-level rise (Haq *et al.*, 1987; Kováč and Zlinská, 1998). The Middle Badenian climatic cooling and sea-level fall down to the lower neritic zone resulted in a slowing of bottom water circulation and the appearance of upwelling and turbidity currents that favoured eutrophication and bottom water hypoxia. The most stressful environmental conditions accompanied evaporite deposition and contemporaneous volcanism and tectonism. Tectonic activity was expressed as uplift in neighbouring areas (around Kraków, Pińczów, Wadowice, and the southern margin of the Holy Cross Mts.) (*cf.* p. 126) and changes in the relief of the Działoszyce Trough, recognized by Osmólski (1972). These movements may have locally given produced submarine thresholds and at least partial isolation, which encouraged hypoxia. The immigration of foraminifera adapted to these new environmental conditions, in particular pavonitinids, the *Uvigerina peregrina* group and *Alabaminella weddellensis* (Earland), shows that the isolation was not complete, particularly in the lowermost Middle Badenian.

The presence of plankton, including the new bolboform *B. badenensis* Szczechura in the evaporites, also precludes a total isolation of this part of the basin. Inflow of oxygenated surface waters may have co-existed with oxygen-depleted bottom waters in a stratified sea.

Similar climatic cooling, sea-level fall and/or limited communication with oceanic waters of the Atlantic and poorer water circulation, accompanied the formation of synchronous (Middle Miocene) and Messinian evaporite-bearing deposits in the Mediterranean area (Van Couvering *et al.*, 1976; Van der Zwaan, 1982; Chamley, 1983; Chamley *et al.*, 1986; Barbieri, 1998). Amelioration in the Upper Badenian probably reflected an expansion of oceanic waters, encouraging abundant plankton. *Bolboforma badenensis* Szczechura, known from synchronous deposits of the Mediterranean area (*cf.* Szczechura, 1997), shows better communication of this part of the Paratethys with (at least) southern Europe. The appearance then of a new microfauna, in particular of ostracodes (Szczechura, 1996, 1997, 1998), in the Polish part of the Carpathian Foredeep supports this conclusion.

The occurrence of the peculiar group of ostracodes — *Xylocythere carpathica* Szczechura and *?Microxestoleberis* sp. — and foraminifera, suggests that hydrocarbon seepages gave rise to fertile and oxygen-poor bottom environments. Anoxia in at least part of the Carpathian Foredeep was probably encouraged by volcanic activity in the Central Paratethys following evaporite deposition.

A marked shallowing, producing tidal flats and/or coastal banks and progressive isolation from an open sea, led to a considerable reduction in the planktonic fauna as early as in the Late Badenian. This correlates with a global sea-level fall at that time (Haq *et al.*, 1987; Kováč and Zlinská, 1998). The microfauna suggests a continuous deficit of oxygen in the near-bottom environment, while, in the Sarmatian,foraminifera such as *Rotaliella* and other glabratellids preclude a fresh water in this area (*cf.* Murray, 1991).

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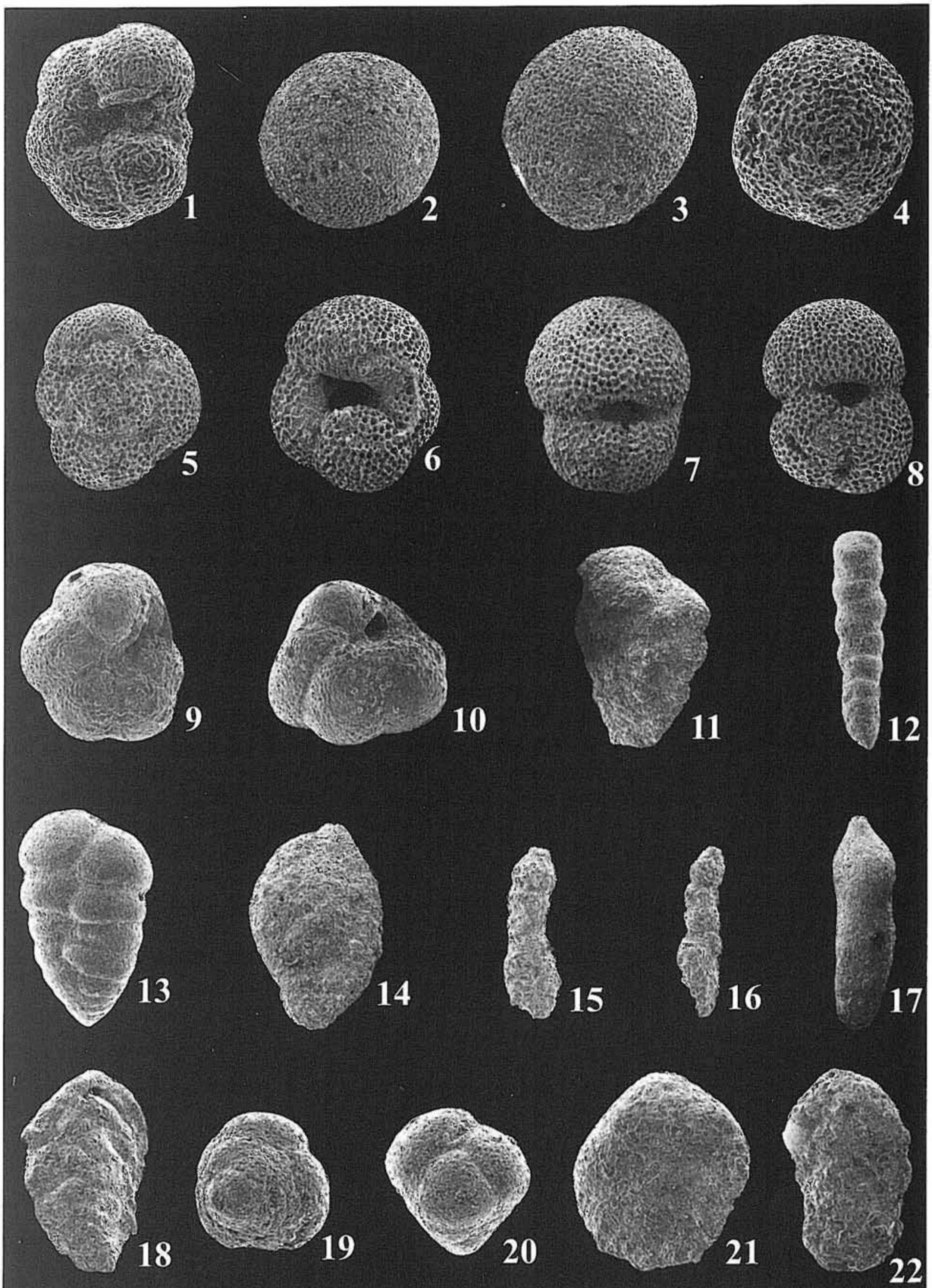
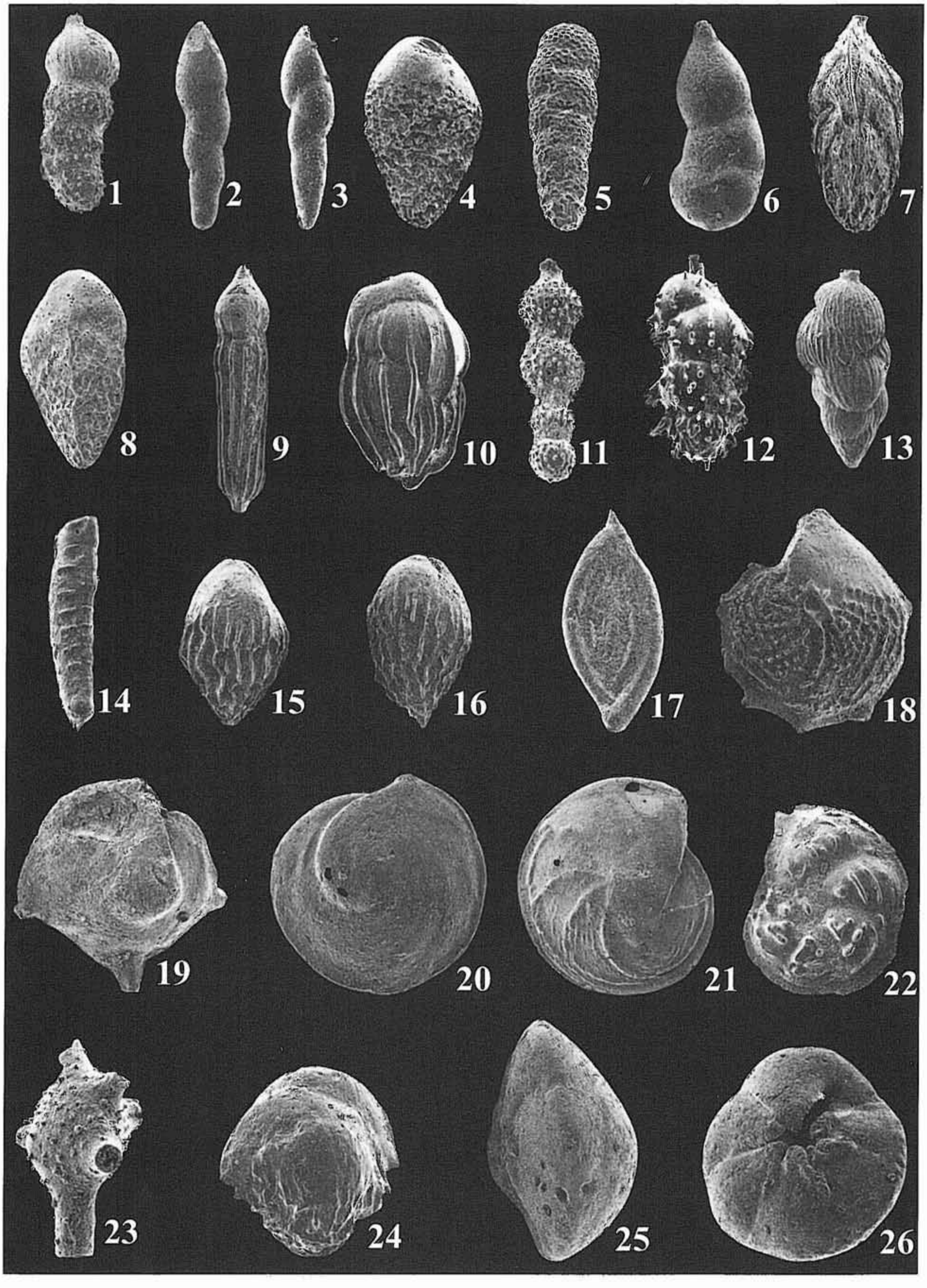
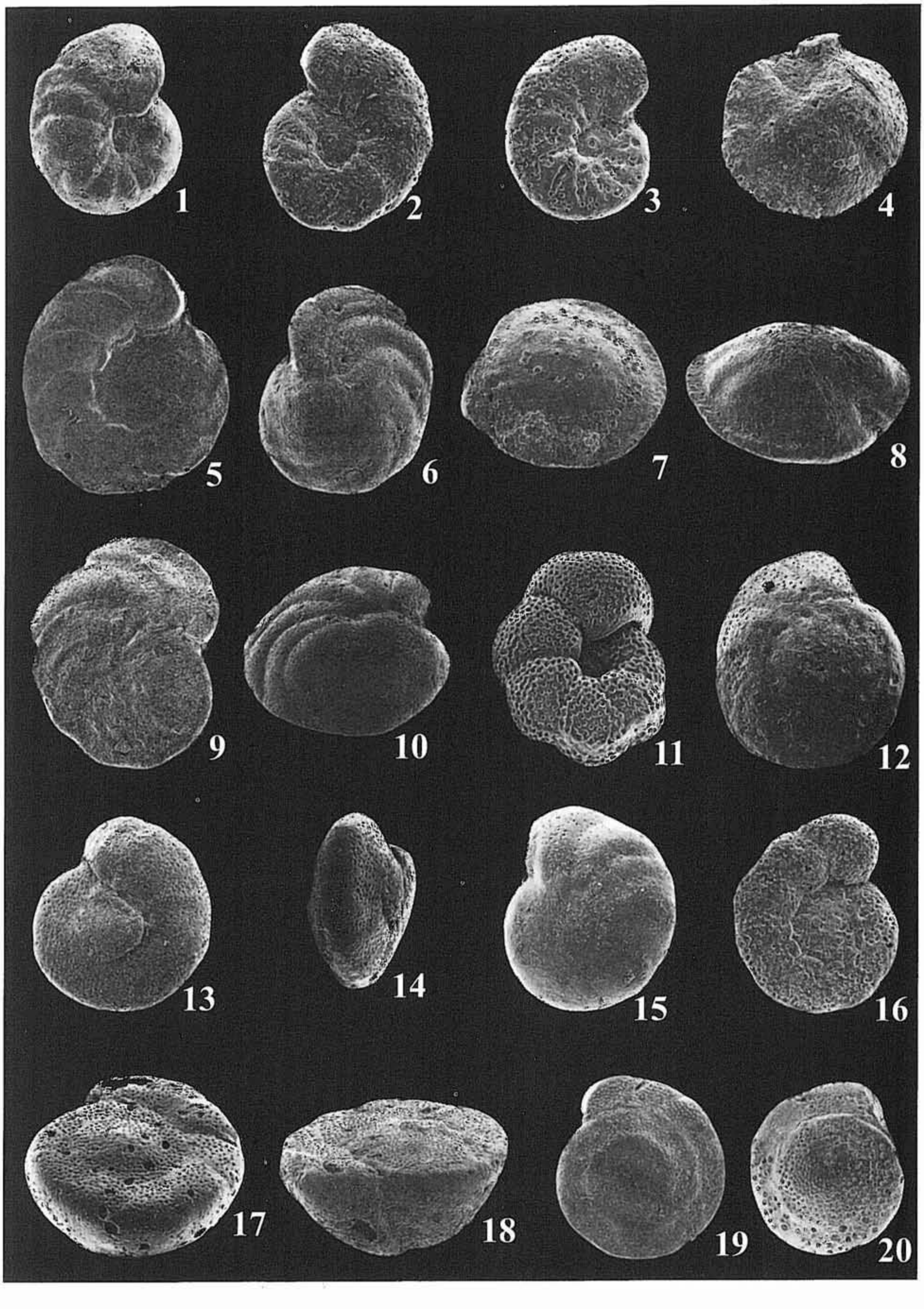


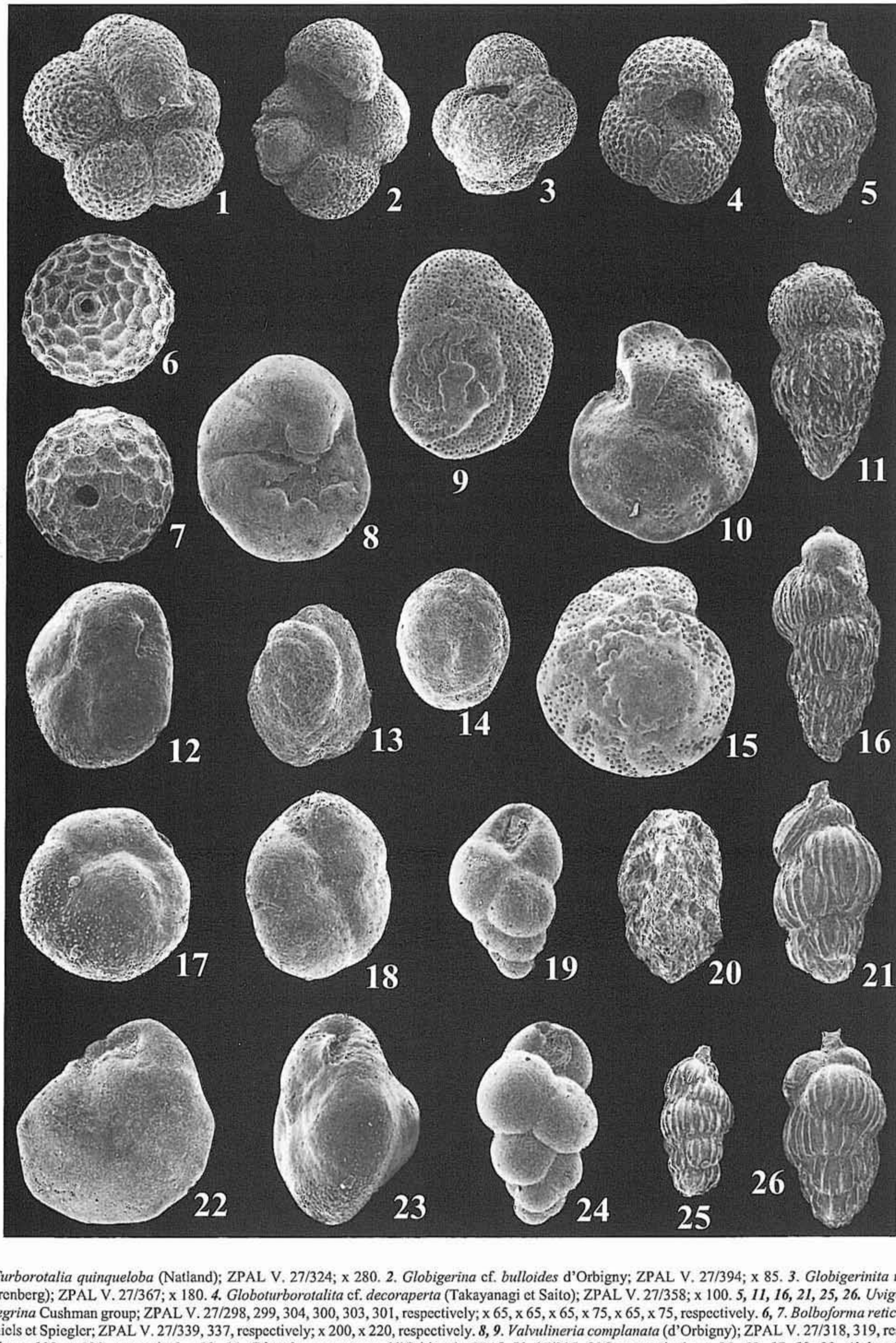
1. Paragloborotalia siakensis (Le Roy); ZPAL V. 27/170; x 120. *2. Orbulina* cf. *suturalis* Brönniman; ZPAL V. 27/76; x 65. *3, 4. Praeorbulina* cf. *glomerosa* (Blow); ZPAL V. 27/80, 130, respectively; x 100, x 120, respectively. *5, 6. Globoquadrina altispira* (Cushman et Jarvis); ZPAL V. 27/64, 63, respectively; x 85, x 100, respectively. *7. Globigerinoides trilobus* (Reuss); ZPAL V. 27/68; x 75. *8. Globigerinoides quadrilobatus* (d'Orbigny); ZPAL V. 27/66; x 75. *9, 10. Globoconella bykovae* (Aisenstadt); ZPAL V. 27/287; x 150. *11. Pseudogaudryina mayeriana* (d'Orbigny); ZPAL V. 27/89; x 36. *12. Martinottiella communis* (d'Orbigny); ZPAL V. 27/91; x 36. *13. Karreriella bradyi* (Cushman); ZPAL V. 27/99; x 75. *14. Sigmoilopsis* sp.; ZPAL V. 27/97; x 100. *15, 16. Bigenerina agglutinans* d'Orbigny; ZPAL V. 27/94, 93, respectively; x 90. *17. Cylindroclavulina* cf. *rudislosta* (Hantken); ZPAL V. 27/95; x 20. *18. Spiroplectinella carinata* (d'Orbigny); ZPAL V. 27/159; x 50. *19, 20. Eggerella bradyi* (Cushman); ZPAL V. 27/165, 164, respectively; x 150. *21. Textularia gramen* d'Orbigny; ZPAL V. 27/118; x 50. *22. Sabellovoluta humboldti* (Reuss); ZPAL V. 27/83; x 25. Borehole Posądza 10-S, depth 101.5 m; Lower Badenian (Moravian)



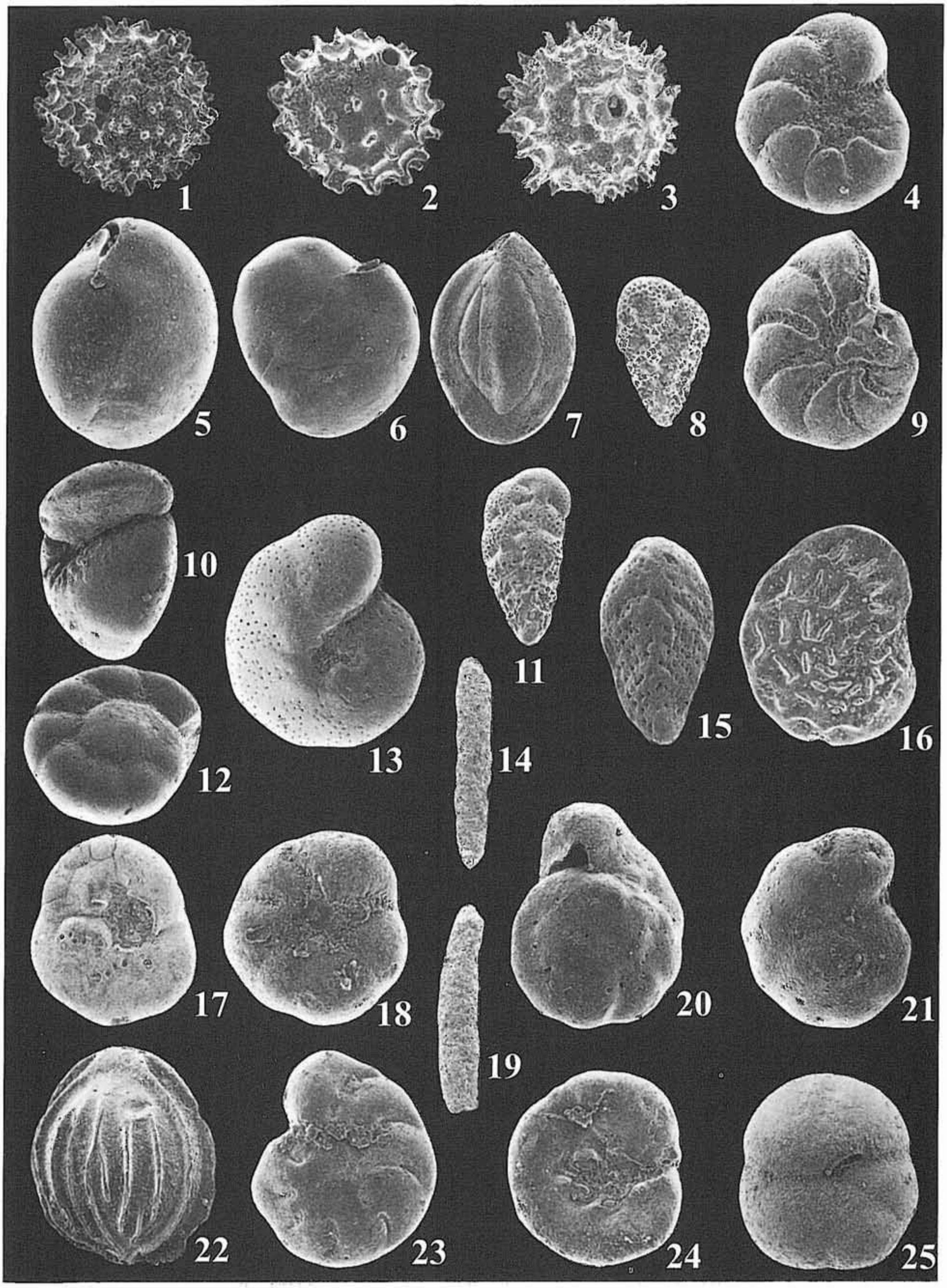
1. *Marginulina hirsuta* d'Orbigny; ZPAL V. 27/281; x 45. ***2, 3.*** *Pleurostomella* cf. *alternans* Schwager; ZPAL V. 27/32, 41, respectively; x 50. ***4.*** *Bulimina hebes* MacFayden; ZPAL V. 27/136; x 120. ***5.*** *Coryphostoma sinuosa* (Cushman); ZPAL V. 27/131; x 100. ***6.*** *Vaginulinopsis* cf. *pedum* (d'Orbigny); ZPAL V. 27/24; x 50. *Trifarina bradyi* (Cushman); ZPAL V. 27/177; x 110. ***8.*** *Bolivina scalphrata retiformis* Cushman; ZPAL V. 27/286; x 110. ***9.*** *Dentalina* cf. *acuta* d'Orbigny; ZPAL V. 27/17; x 35. ***10.*** *Uvigerina* cf. *macrocarinata* Papp et Turnovsky; ZPAL V. 27/175; x 75. ***11.*** *Amphicoryna hispida* (Soldani); ZPAL V. 27/150; x 60. ***12.*** *Uvigerina* cf. *acuminata* Hosius; ZPAL V. 27/174; x 80. ***13.*** *Uvigerina pygmoides* Papp et Turnovsky; ZPAL V. 27/59; x 40. ***14.*** *Vaginulina legumen* (Linne); ZPAL V. 27/108; x 20. ***15, 16.*** *Bulimina costata* d'Orbigny; ZPAL V. 27/72, 73, respectively; x 55. ***17.*** *Sigmoilinita tenuis* (Czjzek); ZPAL V. 27/181; x 85. ***18.*** *Lenticulina echinata* (d'Orbigny); ZPAL V. 27/1; x 25. ***19.*** *Lenticulina calcar* (Linne); ZPAL V. 27/117; x 35. ***20.*** *Lenticulina vortex* (Fichtel et Moll); ZPAL V. 27/4; x 35. ***21.*** *Lenticulina inornata* (d'Orbigny); ZPAL V. 27/14; x 25. ***22.*** *Lenticulina ariminensis* (d'Orbigny); ZPAL V. 27/110; x 20. ***23.*** *Ramulina globulifera* Brady; ZPAL V. 27/183; x 100. ***24.*** *Ehrenbergina serrata* (Reuss); ZPAL V. 27/109; x 80. ***25, 26.*** *Neoeponides schreibersi* (d'Orbigny); ZPAL V. 27/276, 9, respectively; x 90, x 50, respectively. Borehole Posądza 10-S, depth 101.5 m; Lower Badenian (Moravian)



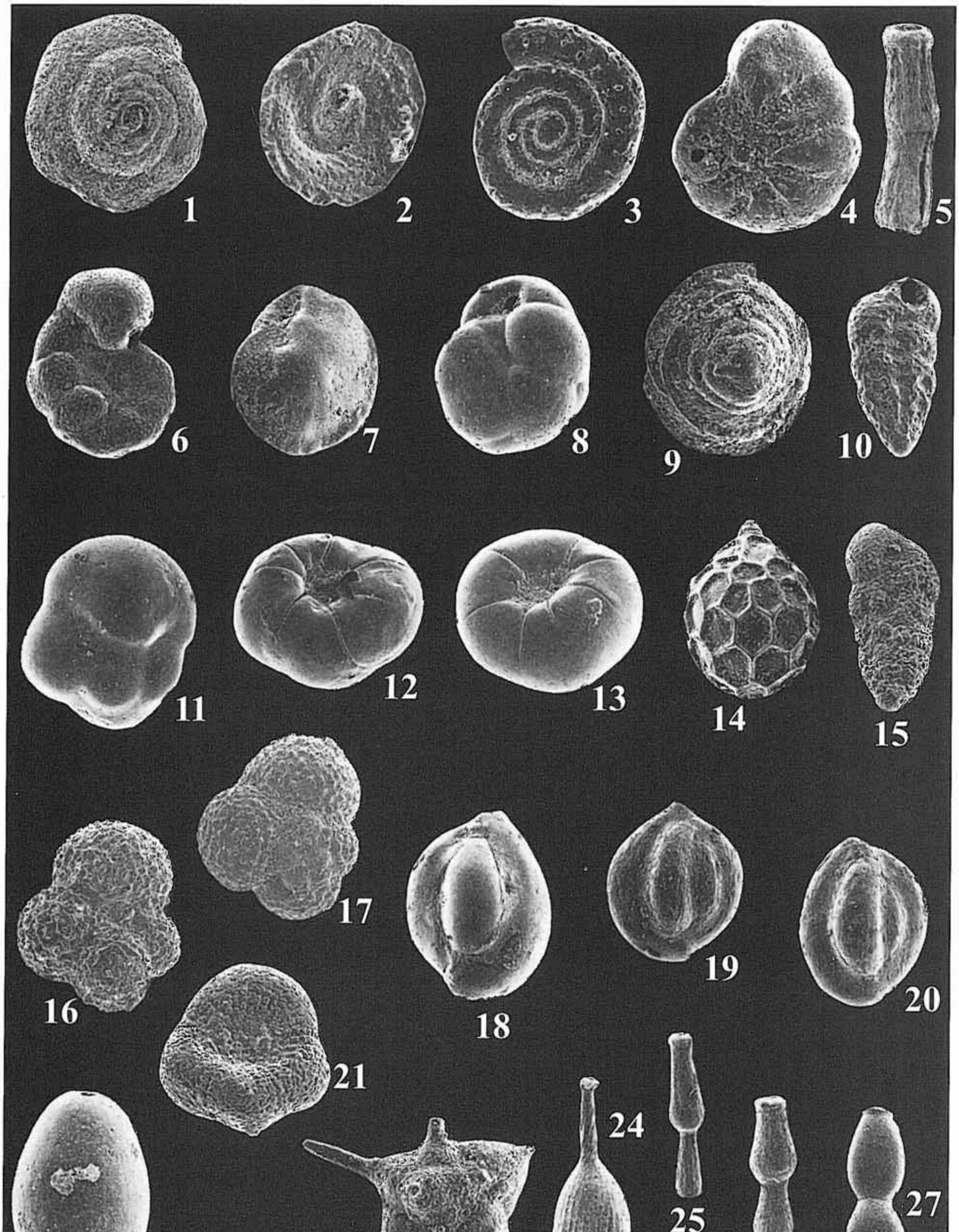
1–3. *Anomalinoides helicinus* (Costa); ZPAL V. 27/116, 35, 34, respectively; x 80. *4*. *Siphonina reticulata* (Czjzek); ZPAL V. 27/264; x 100. *5, 6*. *Fontbotia wuellerstorfi* (Schwager); ZPAL V. 27/25, 28, respectively; x 40, x 35, respectively. *7, 8, 12*. *Cibicidoides pachydermus* (Rzehak); ZPAL V. 27/279, 262, 54, respectively; x 110, x 120, x 70, respectively. *9, 10*. *Planulina ariminensis* d'Orbigny; ZPAL V. 27/123, 257, respectively; x 85, x 50, respectively. *11*. *Anomalinoides badenensis* (d'Orbigny); ZPAL V. 27/35; x 45. *13–15*. *Cibicidoides incrassatus* (Fichtel et Moll); ZPAL V. 27/103, 103,105, respectively; x 60. *16*. *Lobatula* cf. *austriaca* (d'Orbigny); ZPAL V. 27/143; x 80. *17–20*. *Heterolepa dutemplei* (d'Orbigny); ZPAL V. 27/141, 254, 251, 251, respectively; x 60, x 80, x 45, x 50, respectively. Borehole Posądza 10-S, depth 101.5 m; Lower Badenian (Moravian)



1. Turborotalia quinqueloba (Natland); ZPAL V. 27/324; x 280. *2. Globigerina* cf. *bulloides* d'Orbigny; ZPAL V. 27/394; x 85. *3. Globigerinita uvula* (Ehrenberg); ZPAL V. 27/367; x 180. *4. Globoturborotalita* cf. *decoraperta* (Takayanagi et Saito); ZPAL V. 27/358; x 100. ***5, 11, 16, 21, 25, 26.** Uvigerina peregrina* Cushman group; ZPAL V. 27/298, 299, 304, 300, 303, 301, respectively; x 65, x 65, x 65, x 75, x 65, x 75, respectively. ***6, 7.** Bolboforma reticulata* Daniels et Spiegler; ZPAL V. 27/339, 337, respectively; x 200, x 220, respectively. ***8, 9.** Valvulineria complanata* (d'Orbigny); ZPAL V. 27/318, 319, respectively; x 110, x 130, respectively. ***10, 15.** Cibicides ungerianus* (d'Orbigny); ZPAL V. 27/315, 316, respectively; x 85. ***12, 17, 18, 23.** Alabaminella weddellensis* (Earland); ZPAL V. 27/553, 554, 329, 553, respectively; x 360, x 340, x 320, x 400, respectively. ***13, 14.** Glomospira* cf. *charoides* (Jones et Parker); ZPAL V. 27/671, 673, respectively; x 130. ***19, 24.** Bulimina elongata* d'Orbigny; ZPAL V. 27/342, 343, respectively; x 180. *20. Pseudotriplasia elongata* Małecki; ZPAL V. 27/315; x 60. *22. Cassidulina* cf. *carinata* Silvestri; ZPAL V. 27/126; x 280. ***1, 2, 5, 8, 9–12, 15–19, 21–26*** — borehole Posądza 10-S, depth 85.5 m; ***3, 6, 7, 20*** — borehole Posądza 40-S, depth 29.0 m; ***4, 13, 14*** — borehole Posądza 10-S, depth 89.0 m; Middle Badenian (Wielician)



1–3. *Bolboforma badenensis* Szczechura; ZPAL V. 27/520, 414, 417, respectively; x 240. ***4***. *Protelphidium granosum* (d'Orbigny); ZPAL V. 27/692; x 220. ***5***. *Sigmoinella* cf. *valvularis* (Reuss); ZPAL V. 27/450; x 150. ***6***. *Sigmoinella banatiana* Łuczkowska; ZPAL V. 27/447; x 100. ***7***. *Quinqueloculina badenensis* d'Orbigny; ZPAL V. 27/514; x 120. ***8, 11***. *Bolivina pseudoplicata* Heron-Allen et Earland; ZPAL V. 27/436, 437, respectively; x 240. ***9***. *Elphidium* cf. *cryptostomum* (Egger); ZPAL V. 27/709; x 200. ***10, 12***. *Hansenisca* cf. *soldanii* (d'Orbigny); ZPAL V. 27/511, 512, respectively; x 75, x 100, respectively. ***13***. *Melonis pompilioides* (Fichtel et Moll); ZPAL V. 27/495; x 120. ***14, 19***. *Hyperammina* sp.; ZPAL V. 27/434, 435, respectively; x 55. *Bolivina dilatata* Reuss; ZPAL V. 27/484; x 150. ***16***. *Elphidium* cf. *complanatum* (d'Orbigny); ZPAL V. 27/698; x 200. ***17***. *Asterigerinita* sp.; ZPAL V. 27/699; x 240. ***18***. *Buccella* sp.; ZPAL V. 27/712; x 200. ***20, 21***. ?*Eoeponidella* sp.; ZPAL V. 27/504, 505, respectively; x 340. ***22***. *Fissurina* sp.; ZPAL V. 27/458; x150. ***23***. *Astrononion* cf. *stelligerum* (d'Orbigny); ZPAL V. 27/695; x 220. ***24***. *Rosalina* sp.; ZPAL V. 27/703; x 240. ***25***. *Sphaeroidina bulloides* d'Orbigny; ZPAL V. 27/497; x 100. ***1, 7, 8, 10, 12, 13, 15, 20, 21, 25*** — borehole Posądza 10-S, depth 38.0 m, Upper Badenian (Kosovian); ***2, 3, 8, 11, 14, 19*** — borehole Piotrkowice Małe 14-S, depth 37.1 m, Middle Badenian (Wielician); ***4, 9, 16, 17, 18, 23, 24*** — borehole Posądza 10-S, depth 54.6 m; ***5, 6, 22*** — borehole Posądza 10-S, depth 32.3 m; Upper Badenian (Kosovian)



1, 2. *Spirorbina* sp.; ZPAL V. 27/601, 602; x 220, respectively. ***3.*** *Spirillina* sp.; ZPAL V. 27/603; x 220. ***4.*** *Haynesina* cf. *biporus* (Krashenninikov); ZPAL V. 27/612; x 220. ***5.*** *Articulina* sp.; ZPAL V. 27/609; x 50. ***6.*** *Lobatula dividens* (Łuczkowska); ZPAL V. 27/572; x 60. ***7.*** *Cassidulina* sp.; ZPAL V. 27/589; x 180. ***8.*** *Cassidulina* cf. *margareta* Karrer; ZPAL V. 27/590; x 220. ***9.*** *Patellina corrugata* Williamson; ZPAL V. 27/505; x 220. ***10.*** *Bolivina* sp.; ZPAL V. 27/596; x 150. ***11–13.*** *Rotaliella* cf. *roscoffensis* Grell; ZPAL V. 27/622, 617, 620, respectively; x 280. ***14.*** *Favulina* cf. *hexagona* (Williamson); ZPAL V. 27/620; x 200. ***15.*** *Bolivina* cf. *moldavica* Didkowski; ZPAL V. 27/595; x 150. ***16, 17.*** *Globigerina* sp.; ZPAL V. 27/ 632, 635, respectively; x 220, x 280, respectively. 18. *Triloculina* cf. *eggeri* (Bogdanowich); ZPAL V. 27/568; x 75. ***19, 20.*** *Varidentella sarmatica* (Karrer); ZPAL V. 27/579, 578, respectively; x 120. ***21, 23.*** *Schackoinella* cf. *imperatoria* (d'Orbigny); ZPAL V. 27/582, 581, respectively; x 260, x 220, respectively. ***22.*** *Oolina* sp.; ZPAL V. 27/598; x 200. ***24.*** *Lagena* sp.; ZPAL V. 27/616; x 100. ***25, 26.*** *Articulina* cf. *problema* Bogdanowich; ZPAL V. 27/618, 617, respectively; x 55. ***27.*** *Orthomorphina* cf. *dina* (Venglinski); ZPAL V. 27/597; x 100. Borehole Szczytniki 11-S, depth 58.7 m; Sarmatian