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Age and evolution of depositional environments of the supra-evaporitic deposits in the northern, marginal part of the Carpathian Foredeep: micropalaeontological evidence

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A rich assemblage of microfossils, including foraminifera, ostracodes and bolboforms (calcareous phytoplankton) have been found in the supra-evaporitic deposits of the *Pecten* Beds (Upper Badenian) and Krakowiec Clays (Sarmatian) of Middle-Miocene age, which occur in the Jamnica S-119 borehole near Tarnobrzeg, in the central part of the Carpathian Foredeep. Environmental conditions have been deduced from these microfossils. Comparison with other parts of the Carpathian Foredeep shows that microfauna distribution depended on location within the sedimentary basin and on hydrological conditions. Poorly-diversified and specific microfossils were associated with evaporites and overlying sediments (particularly within the lower *Pecten* Beds and Krakowiec Clays), indicating poorly-oxygenated near-bottom waters. Possibly, "Upper-Badenian" and "Sarmatian" biofacies had already differentiated by the end of the Badenian. Distribution of the Upper Badenian microfauna and bolboforms in the Polish part of the Carpathian Foredeep and beyond shows that there was faunal exchange between the eastern and western parts of the Polish section of the Carpathian Foredeep, and indicates connection between the Central Paratethys and Mediterranean basin areas.

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INTRODUCTION

Microfossils, particularly Miocene foraminifera from the Carpathian Foredeep between the Vistula and San rivers (Fig. 1), have been intensively studied for many years, mainly because of their relevance to economically important chemical deposits (Łuczkowska, 1960, 1964, 1967; Odrzywolska-Bieńkowa, 1966, 1972, 1974*a*, *b*). These studies, and related investigations in the other regions of the Carpathian Foredeep, were aimed mainly at using foraminifera biostratigraphically. Their palaeoenvironmental significance was alluded to only briefly. So far Miocene ostracodes and bolboforms (calcareous phytoplankton) from this area have only concerned the supra-gypsum deposits from the Jamnica borehole near Tarnobrzeg (Szczechura, 1995), where the author attempted to use ostracodes, foraminifera and bolboforms, particularly those newly found in the Miocene of the Central Paratethys, to formulate some ideas about environmental conditions. This study extends and develops these ideas.

Biostratigraphical and lithostratigraphical characteristics of the studied section, based on calcareous nannoplankton, were given by Gaździcka (1994, fig. 4). Verification of obtained results was possible due to the comparison between microfauna distribution in the Jamnica S-119 borehole and biofacies sequences from other areas.

GEOLOGICAL SETTING AND LITHOSTRATIGRAPHY

The Jamnica S-119 borehole is situated in southern Poland, near the town of Tarnobrzeg, between the Vistula and San rivers, in the northern part of the Carpathian Foredeep (Fig. 1). The area studied is surrounded by the Holy Cross Mountains in the north-west, and the Roztocze Upland (constituting a southern part of the Lublin Upland) in the east.

The Carpathian Foredeep, constituting the northern margin of the Central Paratethys, is filled by Miocene deposits and extends along the northern margin of Carpathians.

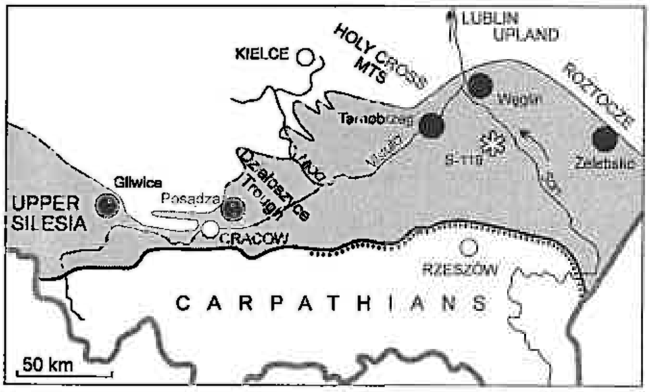

Fig. 1. Extent of the Middle Miocene (Badenian-Sarmatian) sea in the Fore-Carpathian Depression (stippled) showing the location of sampled sections

Palaeogeographically, it can be subdivided into eastern and western parts; the area studied belongs to the eastern part. The development of the Carpathian Foredeep, particularly its tectonic and palaeogeographical evolution, has been much researched (e.g. Ney *et al.*, 1974; Kwiatkowski, 1985; Oszczypko, 1996).

The supra-evaporitic deposits of the Jamnica S-119 borehole comprise two major lithological units (*cf.* Gaździcka, 1994; Czapowski, 1994): the *Pecten* Beds of Upper Badenian age and the Krakowiec Clays of Sarmatian age (Fig. 2). In the lower part of the profile, argillaceous marls occur. They gradually pass into the dark Krakowiec Clays. In the southeastern part of the Carpathian Foredeep, the *Pecten* Beds reach 50 m of thickness, while the thickness of the Krakowiec Clays exceeds 2500 m. These units are difficult to correlate widely (*cf.* Oszczypko, 1996) and so are included within one formation, the Machów Formation.

The 40 micropalaeontological samples were taken from the supra-evaporitic deposits of the Jamnica S-119 borehole at depths between 30.5 and 258.9 m (Fig. 2).

CHARACTERISTICS OF MICROFAUNISTIC AND MICROFLORISTIC BIOFACIES

PECTEN BEDS

FORAMINIFERA

Poorly diversified, small and strongly abraded (like in the flysch deposits) foraminifera occur just above the evaporites at a depth of 258.9 m. They include: *Bulimina elongata* d'Orbigny (Pl. I, Fig. 8), which dominates, *Heterolepa dutemplei* (d'Orbigny) (Pl. I, Figs. 6, 13), *Cibicides* sp. (Pl. I, Fig. 12), *Astrononion perfossum* (Clodius) (Pl. I, Fig. 11), *Haynesina depressula* (Walker et Jacob) (Pl. I, Fig. 10) and bolivinids (including *Bolivina pseudoplicata* Heron-Allen et Earland — Pl. I, Fig. 9), and rare specimens of: *Rosalina nana* (Reuss) (Pl. I, Figs. 1, 2), *Rosalina* sp. (Pl. I, Fig. 4), *Glandulina* cf. *ovula* d'Orbigny (Pl. I, Fig. 5), *Fissurina pulchella* (Brady) (Pl. I, Fig. 3), elphidids (including *Elphidium fichtelianum* (d'Orbigny) (Pl. I, Fig. 7) and polymorphinids. Variable amounts of pyrite occur throughout the Jamnica S-119 profile, and pteropod moulds also occur. The elphidids and rosalinids indicate a shallow shelf environment. A dominance of infaunal elements in this assemblage, as well as the state of preservation of the tests and their low diversity indicate a stressed environment, such as oxygen-deficient conditions and/or insufficient $CaCO_3$ saturation. Such environmental factors could led to the dissolution of the aragonitic pteropod shells.

Foraminifera, although still poorly preserved, increase in diversity at 255.8–255.7 m depth, where foraminiferal plankton represented by *Globigerina* div. sp. and *Velapertina* sp. (Pl. II, Figs. 10, 12) appear. Numerous, well-developed (large) and clearly diversified calcareous and agglutinated benthonic forms also occur. Among calcareous forms, the following species are common: *Sphaeroidina bulloides* d'Orbigny (Pl. III, Fig. 1), *Bulimina aculeata* d'Orbigny (Pl. II, Fig. 8), *Gyroidinoides* cf. *umbonatus* (Silvestri) (Pl. IV, Figs. 11, 13), *G.* cf. *soldanii* (d'Orbigny) (Pl. IV, Figs. 6, 9), *Hanzawaia boueana* (d'Orbigny) (synonym *Hanzawaia crassiseptata* Łuczkowska) (Pl. IV, Fig. 12), *Heterolepa dutemplei* (d'Orbigny) (Pl. I, Figs. 6, 13), *Pullenia bulloides* d'Orbigny (Pl. III, Fig. 2), *Cassidulina laevigata* (d'Orbigny) (Pl. III, Figs. 9, 11) and *Melonis pompilioides* (Fichtel et Moll) (Pl. II, Figs. 5, 6). Among agglutinated forms, besides *Spiroplectinella carinata* (d'Orbigny) (Pl. III, Fig. 5), *Textularia flexua* Venglinski (Pl. II, Fig. 1), *Haplophragmoides* sp. (Pl. II, Fig. 11) and ?*Deuterammina* sp. (Pl. II, Figs. 7, 9), also *Pavonitina styriaca* Schubert occurs (Pl. II, Fig. 4). Besides foraminifera, scarce radiolarians are also present. Many of these species also occur in the upper part of the *Pecten* Beds.

A similar foraminifera assemblage, but without *Velapertina* sp. and *Pavonitina styriaca* Schubert and enriched in numerous *Uvigerina liesingensis* Toula (Pl. II, Fig. 2), *U.* cf. *semiornata* d'Orbigny (Pl. II, Fig. 3), *U. peregrina* Cushman group, *Valvulineria complanata* (d'Orbigny) (Pl. IV, Figs. 8, 10), *Cibicidoides* cf. *pachydermus* (Rzehak) (Pl. III, Fig. 10) and *Cibicides ungerianus* (d'Orbigny) (Pl. III, Fig. 4) occurs in the sample from the depth of 252.7 m. Moreover, in the sample from 251.3 m depth, fine miliolids (characteristic of the Badenian), particularly *Sigmoilinita tenuis* (Czjzek) (Pl. IV, Figs. 5, 7) and *Trifarina angulosa* (Williamson) occur, associated with agglutinated, simple, nonseptate tests belonging to the Astrorhizidae. These species are mainly cosmopolitan, cold- and deep-water forms, preferring the outer shelf and beyond (Boltovskoy, 1984; Van Morkhoven *et al.*, 1986; Murray, 1991). Attention is particularly drawn to the presence of *Pavonitina styriaca* Schubert in the lower (but not lowermost) part of the *Pecten* Beds and the abundance of *Uvigerina peregrina* Cushman group in the upper part of the *Pecten* Beds.

Pavonitinids in the Upper Cretaceous-Pliocene deposits off the West Africa coast (including *Pavonitina styriaca* Schubert in the Miocene) are connected with deep-water environments (bathyal zone) and "...particular stress conditions in sea waters off West Africa, i.e. upwelling and turbidity currents..." (Seiglie and Baker, 1983).

Opinions on the *Uvigerina peregrina* Cushman group as a palaeoenvironmental indicator, particularly as far as concerns lowered oxygenation, are divided. Nevertheless, many researchers (e.g. Van der Zwaan *et al.*, 1986; Van Leeuwen, 1986; Quinterno and Gardner, 1987; Schnitker, 1993; Debenay and Redois, 1997) agree that this form preferred deep water (continental slope), cold, nutrient-rich waters.

And, the increasing abundance of zooplankton, particularly *Globigerina bulloides* d'Orbigny-like forms, as well as the growing abundance of phytoplankton and a mass appearance of peculiar agglutinated forms in the section between 255.8–251.3 m, seems to indicate the presence of upwelling and high food availability, with simultaneous oxygen deficit in the near-bottom waters (Boltovskoy and Wright, 1976; Moorkens, 1991; Debenay and Redois, 1997).

Thus, the foraminifera distribution in this part of the profile (258.9–251.3 m) indicates environmental instability, including amelioration (with an optimum at about 251.3 m) connected with the gradual influx of open, cold and nutrient-rich sea water, with increased dissolved oxygen at the surface. Simultaneously, a sea level rise was accompanied by a lower depositional rate (*cf.* Szczechura, 1995). These conditions encouraged specialised groups of foraminifera.

In the uppermost part of the *Pecten* Beds (at depths of 245.5 and 244.5 m), the foraminiferal assemblage abruptly changes to a character typical of the Krakowiec Clays. The faunal changes here precede lithological changes. Abundant pyrite and rare pteropod moulds occur at 245.5 m depth, and a foraminiferal assemblage composed mainly of fine tests of "*Anomalinoides dividens*" Łuczkowska (Pl. VI, Fig. 11) representing the *Cibicides lobatulus* ecophenotype (*cf.* Szczechura, 1982), and single, tests miliolids characteristic of the Sarmatian biofacies. Variable amounts of "*Anomalinoides dividens*" occur in nearly all analysed samples above the *Pecten* Beds. Similar foraminiferal assemblages, usually dominated by "*Anomalinoides dividens*" and fine miliolids, occur up to 198.0 m. Undoubtedly, such fauna lived in stressed conditions, although the water was still probably fully marine (normal sea salinity) and shallow.

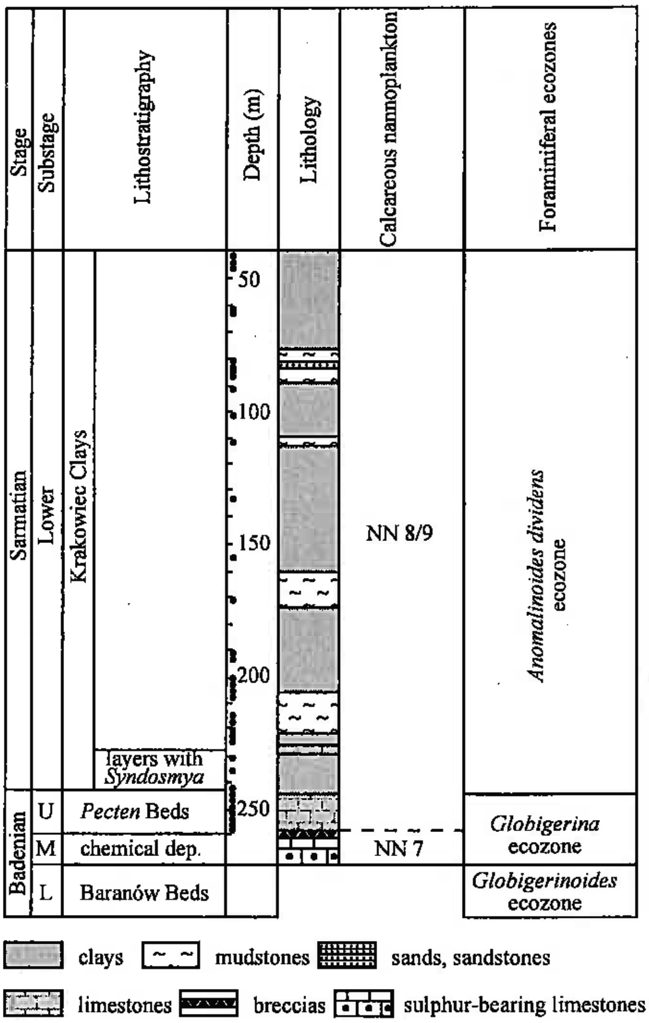

Fig. 2. Lithostratigraphy and biostratigraphy of sediments in the Jamnica S-119 section

OSTRACODES

In the Jamnica S-119 borehole, deposits immediately above the evaporites generally do not contain ostracodes. Single specimens of *Henryhowella asperrima* (Reuss) (Pl. VII, Fig. 8), *Pterygocythereis* sp., *Parakrithe dactylomorpha* (Ruggieri), *P. crystallina* (Reuss), *Krithe* div. sp. and *Argilloecia* sp. (Pl. VII, Fig. 12), occurring in samples from depths of 255.87, 255.7 and 252.7 m, are in most cases abraded and represent fully-marine, lower shelf or deeper biofacies.

In the sample from 251.3 m depth, the rich assemblage comprised in particular: *Cluthia miocenica* Szczechura (Pl. VII, Fig. 9), *Sagmatocythere* cf. *moncharmonti* (Ciampo) (Pl. VII, Fig. 6), *Krithe* sp. (Pl. VII, Fig. 11) and *Xylocythere carpathica* Szczechura (Pl. VII, Figs. 4, 5).

All these species are known from Badenian of the Central Paratethys and/or only from the Polish part of the Carpathian Foredeep (Brestenská and Jiříček, 1978; Szczechura, 1994, 1995) and are regarded as deep water species, largely representing the "psychrosphaeric" ostracodes, preferring cold and deeper, ocean-derived waters (Coles *et al.*, 1990; Corrége, 1993). *Xylocythere carpathica* Szczechura possesses features, deserving particular attention. *Xylocythere* species have a predilection for feeding on wood or decaying wood, i.e. they are xylophile (Steineck *et al.*, 1990; Van Harten, 1993). Van Harten (1992) and Corrége (1993) suggest that *Xylocythere* needs a fertile, nutrient-rich environment and can tolerate low pH levels. Van Harten (1992) described a *Xylocythere* species from hydrothermal vent fields in the Pacific, in low oxygen conditions and noted that comparable environments could form

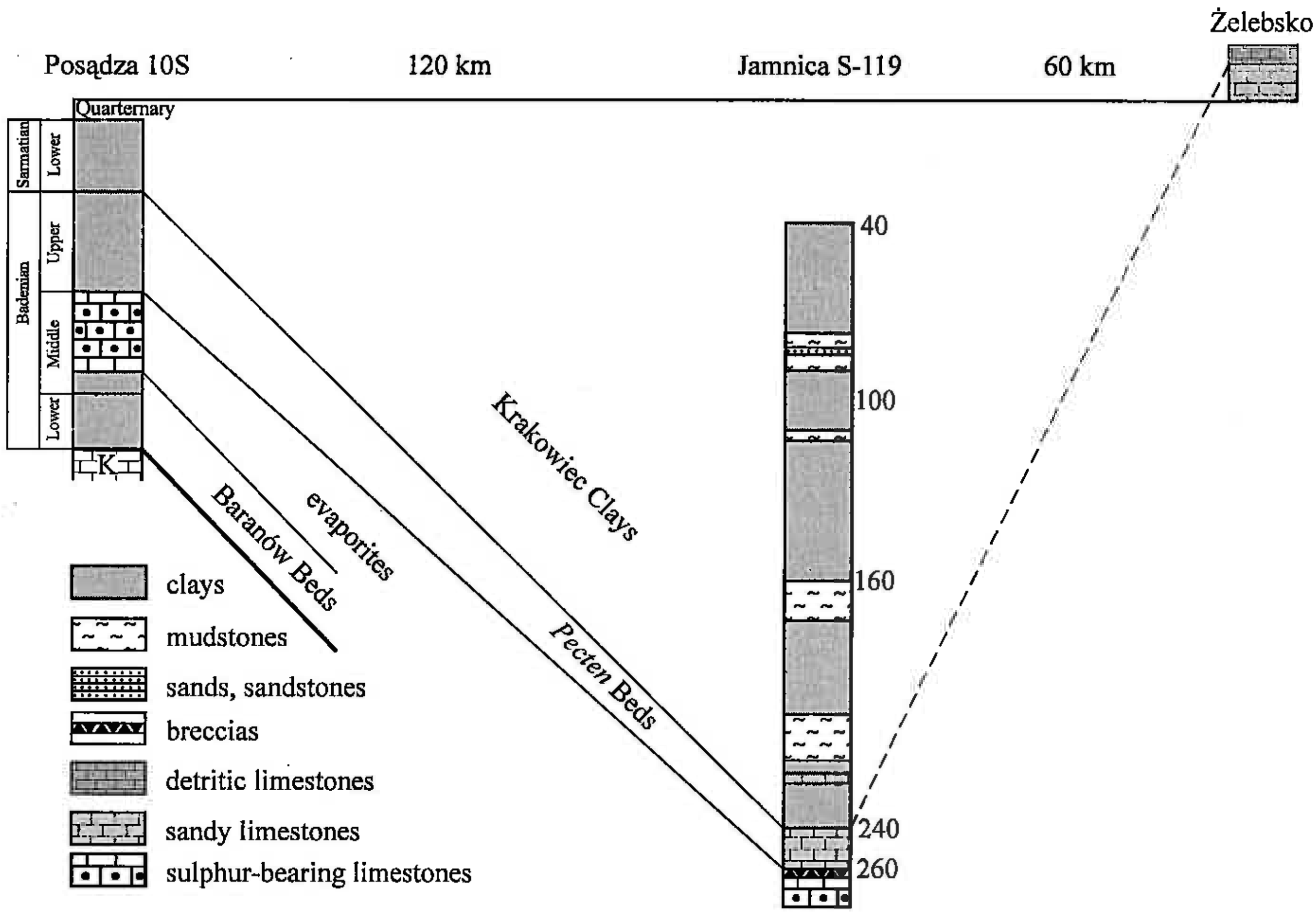

Fig. 3. Correlation of the selected Middle Miocene sections in the Carpathian Foredeep

around oxidisable masses of wood. Hydrothermal vents deliver vast amounts of chemical energy, particularly via sulphur. This energy is used via biogenic oxidation by chemoautotrophic bacteria for the reduction of carbon dioxide to organic carbon. It is possible that such processes supported *Xylocythere* in the Carpathian Foredeep.

Ostracodes are absent from depths between 245.5 and 244.5 m, i.e. from the uppermost part of the *Pecten* Beds.

BOLBOFORMS

Bolboforms belong to calcareous phytoplankton, which prefer the bathyal zones of open seas and a temperate climate (Murray, 1986; Kennett and Kennett, 1990; Diester-Haass, 1995). In the Jamnica borehole, the only bolboform species recognized, i.e. *Bolboforma badenensis* Szczechura (Pl. III, Figs. 7, 8) occurs in abundance in one sample (depth 251.3 m) from the *Pecten* Beds. Single, poorly preserved bolboforms occur also in samples from the Krakowiec Clays, where they accompany marine microfossils of Badenian character.

KRAKOWIEC CLAYS

FORAMINIFERA

In the sample from 242.5 m depth, from the boundary beds between the *Pecten* Beds and the Krakowiec Clays, foraminifera are rare and comprise mostly "*Anomalinoides dividens*" and miliolids.

Fairly abundant and moderately diversified (more than in deposits below), small and thin-shelled foraminifera occur in the sample from a depth of 235.0 m, associated with *Syndosmya*; these layers are known for its particularly rich macrofauna (especially gastropods). Foraminifera from this sample are represented mostly by bolivinids, such as *Bolivina moldavica* Didkovsky (Pl. VI, Fig. 2) and miliolids, such as *Miliolinella* sp. (Pl. VI, Figs. 14, 17), *Quinqueloculina* sp. (Pl. VI, Figs. 5, 6), *Affinetrina* sp. 1 (Pl. VI, Figs. 8, 12), *Affinetrina* sp. 2 (Pl. VI, Fig. 3), *Cycloforina* sp. (Pl. VI, Fig. 7), *Articulina* cf. *problema* Bogdanowicz (Pl. VI, Fig. 1) and ?*Articulina* sp. (Pl. VI, Fig. 4). Notably, there are a few thick-shelled articulinids, characteristic of detrital facies, and considerable amounts of *Cibicides lobatulus* (Walker et Jacob) (Pl. VI, Figs. 9, 10) accompanied by "*Anomalinoides dividens*" Łuczkowska.

Cycloforina karreri ovata (Serova) (Pl. V, Fig. 5) occurs at a depth of 229.1 m, while *Viesnerella* cf. *auriculata* (Egger) was found at a depth of 204. 5 m (Pl. V, Figs. 4a, b).

The microfauna between 198.0 and 35.0 m is generally scarce and poorly preserved. It includes foraminifera characteristic of both Sarmatian and Badenian biofacies.

The Sarmatian biofacies is represented by elphidids, such as *Elphidium hauerinum* (d'Orbigny) (Pl. V, Figs. 1, 10) and *Porosononion granosum* (d'Orbigny) (Pl. V, Figs. 3, 6) found at 87.5 and 46.5 m, and *E.* cf. *obtusum* (d'Orbigny) (Pl. V, Fig. 8) and *E. aculeatum* (d'Orbigny) (Pl. V, Fig. 2) at 171.6 m. These forms are sometimes well formed and thick-shelled, but they are rare and may represent redeposited forms. Nonionids are represented by *Protelphidium bogdanoviczi* (Voloshina) (Pl. V, Fig. 7) — 87.5 m. *Ammonia beccarii* (Linne) (Pl. V, Fig. 9) is very rare.

"Badenian" forms appear in fine-grained sand residua, which also contain abundant plant detritus (for example depths 171.6; 156.0; 101.5; 87.5; 81.4; 60.8 and 46.5 m). Besides calcareous benthos, represented by *Bulimina*, *Uvigerina*, *Sphaeroidina*, *Pullenia*, *Valvulineria*, *Cassidulina*, *Gyroidinoides* and *Fursenkoina* (which are marine forms, preferring deeper seas), very fine planktonic foraminifera are usually present, such as *Globorotalia*, *Hastigerinella*, *Sphaeroidinella*, *Sphaeroidinellopsis* and *Globigerinita*, described for the first time from the Sarmatian of the Carpathian Foredeep. Abraded, undoubtedly redeposited Cretaceous foraminifera and Early Badenian amphisteginids also occur.

The above mentioned Sarmatian foraminiferal assemblages, from the lowermost of the Krakowiec Clays, are nearly monospecific, represented by small and thin-walled specimens. This indicates that environmental conditions were unfavourable, a continuation of the conditions prevailing during deposition of the uppermost *Pecten* Beds. A high organic content and scarcity of oxygen were the dominant environmental factors, caused probably by restricted connection with an open sea and limited circulation leading to stagnant conditions. These factors favoured a low bioprecipitation as a consequence of a deficiency of $CaCO_3$ (Kaiho, 1994; Asioli, 1995). Only certain microfaunal group could survive. The presence of such forms as *Bolivina*, *Cibicides*, *Articulina* and *Miliolinella* strongly suggests a normal marine salinity (Murray, 1991).

The foraminiferal assemblage found in slightly higher parts of the Krakowiec Clays, at 235.0 m, indicates a short-lived and minor amelioration. There is a higher diversity and greater proportion of miliolids and *Cibicides lobatulus* (Walker et Jacob). High frequencies of these "attaching" forms can suggest a shallow, high-energy environment, associated with the submarine vegetation. The appearance of very fine planktonic and benthonic foraminifera of "Badenian" type may indicate periodic influxes of open marine waters.

An increase in foraminiferal diversity, their taxonomic structure and well-developed tests suggest gradual shallowing and amelioration of the environment in the uppermost part of the section.

OSTRACODES

A rich *in situ* assemblage, of both adult and juvenile forms appears at the boundary between the *Pecten* Beds and the *Syndosmya*-bearing levels (at 242.5 m). It contains small, thin-shelled forms, such as *Callistocythere* sp. 1 (Pl. VI, Figs. 13, 15), *Leptocythere* sp. 1 (Pl. VIII, Fig. 4), *Leptocythere* sp. 2 (Pl. VIII, Figs. 6), *Cytherois sarmatica* Olteanu (Pl. VIII, Figs. 1–3) and *Polycope* sp. (Pl. VIII, Figs. 5, 8, 12). A similar assemblage occurs more or less continuously up to 198.0 m. At 235.0 m the ostracodes are more diversified, and contain such forms as *Loxoconcha* sp. (Pl. VIII, Figs. 7, 9), *Aurila mehesi* (Zalanyi) — represented mostly by juvenile forms, with a few abraded adult forms — and *Phlyctocythere* cf. *pellucida* (G. W. Müller) (Pl. VIII, Figs. 10, 11, 14).

In the sediments above 198.0 m, the ostracodes are less frequent, but are better calcified. They appear in fine-grained sands, together with marine "Badenian"-type foraminifera, and represent the well-known Sarmatian biofacies. The following forms deserve particular attention: *Leptocythere naca* (Mehes) (Pl. VII, Figs. 7, 10) — depth 46.5 and 87.5 m, *L.* cf. *cejcenensis* Zelenka (Pl. VII, Fig. 1, ?3) — depth 60.8 m, *L.* cf. *Leptocythere* sp. Zlinská et Fordinál (1995) (Pl. VII, Fig. 14), *Callistocythere* sp. 2 (Pl. VI, Fig. 16) and *Callistocythere* sp. 3 (Pl. VI, Fig. 18). In the sample from 81.4 m depth one can find ?*Leptocythere* sp. (Pl. VII, Fig. 13) and *Mediocytherideis* sp. (Pl. VII, Fig. 2).

Low ostracode diversity above 198.0 m indicates unfavourable environmental conditions. The shells are small and fragile, suggesting reducing conditions with a low pH (Van Harten, 1992, 1993). Simultaneously, *Polycope* and *Phlyctocythere* (these forms being recorded for the first time in the Miocene of the Central Paratethys) indicate normal marine salinity. Polycopids are generally known as marine, deep-water ostracodes, but in the Adriatic Sea they occur also in shallow water (Sokač, 1975). According to Tschigova (1971), polycopids are interstitial forms, enabling them to exist in harsh environmental conditions. Whatley (1996) suggested, that an abundance of polycopids corresponds with an eutrophic environment. Such biological properties in polycopids possibly helped adaptation to the inhospitable Sarmatian sea of the Carpathian Foredeep. Amelioration occurred at the beginning of sedimentation of the Krakowiec Clays (at 235.0 m depth), as indicated by increased ostracode diversity and abundance; all the forms here require normal marine salinity; *Phlyctocythere pellucida* (G. W. Müller) lives today in the Adriatic Sea and tolerates depths below 150 m (Bonaduce *et al.*, 1975), while representatives of *Cytherois* are mainly epineritic forms, dwelling on plants. *Cytherois* is also known from the present Adriatic Sea.

The low diversity and frequency of ostracodes in the upper part of the Krakowiec Clays points to unfavourable environmental conditions, but their thick, normal shells indicates that they lived in better oxygenated conditions, with higher levels of $CaCO_3$.

Summarizing these micropalaeontological observations on the supra-evaporitic beds of the Jamnica S-119 borehole, a shallow-marine (inner shelf) environment can be inferred after sedimentation of the evaporites. The waters were poorly oxygenated. An influx of more oxygenated and nutrient-rich open marine waters was short-lived and it accompanied a sea level rise with preceding higher turbulence. Renewed deterioration of environmental conditions, involving poor oxygenation, was caused by restricted circulation and a sea level fall, during the last phase of deposition of the *Pecten* Beds. This environment, though unfavourable for microfauna, was still fully marine. Such environmental conditions continued to the end of Sarmatian sedimentation. However, there was a late amelioration, with increased circulation bringing oxygen and $CaCO_3$.

COMPARISON WITH OTHER MIOCENE PROFILES OF THE CARPATHIAN FOREDEEP

The biofacies and lithostratigraphy of Jamnica S-119 borehole section seem atypical for the entire Carpathian Foredeep, where the thickness and depth of occurrence of the *Pecten* Beds and Krakowiec Clays, e.g. in the Tarnobrzeg region, is very variable (Gaździcka 1994, figs. 2–4).

BADENIAN BIOFACIES

Previous studies of the intra-gypsum deposits from boreholes in the Biłgoraj–Rozwadów area (Odrzywolska-Bieńkowa, 1974*b*; Kubica, 1992) recognized deep- and cold-water forminifera, including *Chilostomella oolina* Schwager and species known from the *Pecten* Beds in the Jamnica S-119 borehole (*cf.* p. 84). According to Sen Gupta and Machain-Castillo (1993), *Chilostomella oolina* Schwager and *Melonis barleeanum* (Williamson) (syn. of *M. pompilioides* Fichtel et Moll) are endobenthic forms, associated with a depressed oxygen level.

From the sub-gypsum deposits (Baranów Beds) belonging to the *Uvigerina costai* Zone, in the Tarnobrzeg–Chmielnik region, Łuczkowska (1964) reported deep-water forms, including numerous species of: *Uvigerina, Bulimina, Pullenia, Stilostomella, Nodosaria, Melonis, Sphaeroidina, Pseudotriplasia* and *Globigerina.* In the supra-gypsum deposits in this region, included in the *Neobulimina longa* Zone, Łuczkowska (1964) noted a mass occurrence of *Globigerina bulloides* d'Orbigny and buliminids, bolivinids, neobuliminids (all representing interstitial forms) and small spirialinids. Such an assemblage indicates a stressed near-bottom environment and, simultaneously, favourable conditions for microfauna in the surface waters of an open basin.

Miocene foraminiferal biofacies are different in the Działoszyce Trough, east of the area studied (Figs. 1, 2), in which the gypsum-bearing sediments have been studied by Osmólski (1972). Here, the gypsum-bearing sediments may directly overlie Cretaceous deposits, or may occur within Badenian deposits. In the Posądza 10-S borehole (*cf.* Osmólski, 1972, tab. 15, present paper Fig. 3), the evaporites overlie deposits with *Uvigerina costai* (representing the Baranów Beds), and are overlain by unfossiliferous, non-calcareous clays, included in the Chodenice Beds. In the dark, clayey, pyrite-bearing sediments directly underlying the gypsum-bearing sediments in this borehole (depth 85.5 m) one can find scarce radiolarians and abundant of low diversity foraminifera (pers. obs.). The latter are dominated by planktonic forms, containing mostly globigerinids, including the cold-water *Turborotalia quinqueloba* (Natland). Associated benthonic forms include both agglutinated forms, such as *Pseudotriplasia elongata* Małecki, and calcareous, mainly deep-water forms, such as *Sphaeroidina bulloides* d'Orbigny, *Cibicides ungerianus* d'Orbigny, *Uvigerina* div. sp., *Bulimina elongata* d'Orbigny, *Dentalina* sp., *Nodosaria* sp., *Cassidulina* cf. *carinata* Silvestri, *Valvulineria complanata* (d'Orbigny) and *Sigmoilitina tenuis* (Czjzek). Above the gypsum-bearing sediments (depth 54.6 m) preserved micro-organisms comprise little but diatoms and radiolarians, indicating a toxic environment in the near-bottom waters together with an open sea influence. This situation resembles that from the Tarnobrzeg–Chmielnik area.

A rich and diverse foraminifera assemblage occurs below the bed with *Uvigerina costai*, in the Posądza 10-S borehole, in Early Badenian glauconite-rich deposits with *Orbulina saturalis* Bronniman. This assemblage contains both benthonic (bathyal) deep- and cold-water forms, such as *Planulina ariminensis* (d'Orbigny), *Cibicidoides pachydermus* (Rzehak), *Siphonina reticulata* (Czjzek), *Anomalinoides helicinus* (Costa), *A. badenensis* (d'Orbigny), *Ehrenbergina* sp., *Fontbotia wuellerstorfi* (Schwager), *Oridorsalis* sp., and large lenticulinids, as well as warm-water plankton, composed mainly of representatives of *Globorotalia*, *Orbulina* and *Globigerinoides*. Such an assemblage clearly differs from the assemblages typical of the overlying sub-gypsum deposits and suggests radical environmental change prior to deposition of the evaporites.

Upper Badenian foraminiferal microfauna occurs mainly in clayey intercalations underlying detrital limestones which outcrop in the Roztocze area, for example in Żelebsko near Biłgoraj (Figs. 1, 3) (Musiał, 1987; and pers. obs.). This assemblage contains numerous forms known from the central part of the Carpathian Foredeep (including forms preferring the deeper shelf), but zooplankton (nearly entirely composed of foraminifera) are conspicuously less abundant, indicating a more limited open sea influence. In the upper part of the Upper Badenian deposits, shallow-marine forms (including "*Anomalinoides dividens*" Łuczkowska) appear, while planktonic forms disappear.

The supra-evaporitic beds (*Pecten* Beds) from the Jamnica S-119 borehole, the Upper Badenian marls from Węglin and the clayey intercalations underlying detrital limestones in Żelebsko (Roztocze) (Figs. 1, 3), contain "psychrosphaeric" ostracodes (for example *Cluthia miocenica* Szczechura — Szczechura, 1986, 1995, 1996), as yet unreported from outside the Polish part of the Carpathian Foredeep. These forms are scarce and of limited diversity (only 4–5 genera have been found). They are more abundant and diverse in the supra-evaporitic beds of the same formation (Machów Formation — *cf.* M. Jasionowski, 1995) in boreholes from the Gliwice area (Gliwice 19 and 21), i.e. from the western part of the Carpathian Foredeep (Szczechura, in preparation) — see Fig. 1.

Besides ostracodes, *Bolboforma badenensis* Szczechura is common in both Upper Badenian, supra-evaporitic deposits from Jamnica S-119, Posądza 10-S, Gliwice 19 and 21 boreholes, as well as in Upper Badenian deposits from Roztocze (Węglin, Żelebsko). The same deposits, both in Roztocze (Węglin) and in the Gliwice borehole, contain *Bolboforma danielsi* Murray (Szczechura, 1997*a*).

SARMATIAN BIOFACIES

Sarmatian biofacies are more complex. In the Jamnica S-119 borehole, the boundary between the Badenian (*Pecten* Beds) and Sarmatian (Krakowiec Clays) is clear (although seemingly lower than suggested by Gaździcka, 1994) and the Sarmatian microfauna is rather poor and uniform. In the Działoszyce Trough (Osmólski, 1972, tab. 17), in the Posądza area, for example in the Szczytniki 11-S borehole, in dark Sarmatian clays some 70 m thick, "large elphidids", characteristic of Sarmatian shallow-water deposits (particularly sand and detrital limestones) and usually in brackish environments, occur above deposits dominated by "*Anomalinoides dividens*" Łuczkowska. In this borehole, within clayey deposits with *Syndosmya*! (sample from 58.7 m; pers. obs.), foraminifera are very small but abundant. Although "*Anomalinoides dividens*" and miliolids prevail, the foraminifera assemblage is fairly diverse, indicating a shallow-water environment, more favourable that in Jamnica S-119, possibly with rich submarine vegetation. Glabratellids occur, including *Rotaliella* cf. *roscoffensis* Grell, hitherto unknown from the Miocene of Central Paratethys, indicating normal salinity.

Łuczkowska and Rutkowski (1970) found alternating detrital and clayey Sarmatian deposits on the southern slopes of the Holy Cross Mountains (Łojowice, Staszów) with the Badenian microfauna which was considered by these authors as redeposited.

In boreholes from the Rzeszów area, there is a greater diversity of foraminiferal biofacies within the clayey-sandy Badenian and Sarmatian deposits (Głowacki *et al.*, 1966) and comparison with biofacies sequences from the other parts of the Carpathian Foredeep is difficult.

However, in clayey-calcareous deposits of the Krakowiec Clays from Hamernia near Sopot (Carpathian Foredeep, near the edge of the central part of Roztocze) (Szczechura, 1982; Musiał, 1987), infrequent planktonic foraminifera such as globigerinids and *Velapertina* sp. and some benthonic forms characteristic of the Late Badenian, accompany shallow-water benthonic forms characteristic of the Sarmatian, such as "*Anomalinoides dividens*" Łuczkowska, *Elphidium josephinum* (d'Orbigny), *E. hauerinum* (d'Orbigny) and *E. reginum* (d'Orbigny). Ostracodes are represented by the coexisting species: *Cytherois sarmatica* Olteanu and *Phlyctocythere pellucida* (G. W. Müller), both known from the lower part of the Krakowiec Clays in the Jamnica S-119 borehole, as well as *Hemicytheria omphalodes* (Reuss) and *Aurila merita* (Zalanyi), characteristic of shallow-water Sarmatian limestones, occurring for example in Biała Ordynacka. The small, thin-shelled and well-preserved shells, including juvenile forms indicate an *in situ* microfauna.

In sandy-calcareous Sarmatian deposits in Żelebsko (Roztocze), diverse foraminiferal assemblages contain characteristic Badenian elements. The boundary between the Badenian and Sarmatian is poorly defined. Bolivinids, cassidulinids, glabratellids (including *Rotaliella* cf. *roscoffensis*) as well as the shallow-water forms "*Anomalinoides dividens*" Łuczkowska and/or *Cibicides lobatulus* (Walker et Jacob) dominate among very small, entirely benthonic, typically Sarmatian foraminifera, known particularly from the lower part of these deposits. Elphidids are rare in this section. Domination by *Cibicides lobatulus* and/or "*Anomalinoides dividens*" and bolivinids indicates a stressed environment, unfavourable for foraminifera. Cassidulinids and glabratellids, though, suggest normal marine salinity. In the upper part of these deposits one can find more elphidids, a few miliolids, and new "attaching" forms, for example *Asterigerina*, *Patellina* and *Rosalina* species. Occasional "Badenian" forms seem to be reworked. The uppermost deposits are almost totally dominated by *Cibicides lobatulus* (Walker et Jacob). Foraminifera diversity in these Sarmatian deposits seems mostly to reflect the changing dynamics of a shallow-marine basin, isolated from the open sea.

Odrzywolska-Bieńkowa (1972), studying foraminifera in the Dzwola borehole from Roztocze, did not record "*Anomalinoides dividens*" Łuczkowska. Her studies focussed on lithothamnian limestones (regarded by her as reefal deposits), which pass into marly deposits with clayey intercalations. She ascertained that the Badenian foraminiferal biofacies pass gradually into Sarmatian foraminiferal biofacies (with the bivalve *Syndosmya* sp.!). Her biostratigraphy was based on elphidids and miliolids.

In Lower Sarmatian deposits from Żelebsko only ostracodes characteristic of the Sarmatian (i.e. *Cytherois sarmatica* Olteanu, *Callistocythere egregia* (Mehes) and *Leptocythere* cf. *diafana* Stancheva) occur. These are scarce, small and thin-shelled. Polycopids seem to be limited to Sarmatian of more central areas of the Carpathian Foredeep.

The upper part of this succession contains occasional Sarmatian species of *Aurila*, *Loxoconcha* and *Callistocythere*. Their thick shells resemble those of ostracodes appearing in, for example, shallow-water Sarmatian limestones outcropping in Biała Ordynacka and Wierzchowiska, deep within the northwestern part of Roztocze. In this region, the Sarmatian limestones directly overlie Cretaceous deposits.

DISCUSSION AND CONCLUSIONS

Sediment distribution and microfaunal biofacies succeeding the evaporites of the Jamnica S-119 borehole and elsewhere in the Polish part of Carpathian Foredeep were variable and complex. It is difficult to ascertain exactly which environmental factors controlled biofacies development.

Just before and just after evaporites formation, conditions were unfavourable (to different degrees) for a benthonic microfauna. Oxygen-deficient conditions promoted the development of mainly interstitial forms, adapted to a stressed environment, while preserved plankton (foraminifera, pteropods, radiolarians, diatoms) indicates connection with an open sea.

Environmental amelioration took place much later, during deposition of the upper part of the *Pecten* Beds, as reflected by a conspicuous increase in diversity and abundance of both microfauna and microflora at that time. It is possible that the rapid increase in abundance of zoo- and phytoplankton, caused by higher productivity, was linked with an influx of colder, ?upwelling waters from the ocean. Higher productivity could also have been facilitated by contemporaneous volcanic activity. Tuffites have been found in the Jamnica S-119 borehole and in other areas of the Carpathian Foredeep (Alexandrowicz and Pawlikowski, 1980).

Supra-evaporitic sedimentation and microfaunistic biofacies development was quite defferent in the marginal part of the Carpathian Foredeep (for example in Roztocze). In this region, the Ratyń limestones are regarded as an equivalent of the evaporites (Musiał, 1987; Roniewicz and Wysocka, 1997). The shallow-water supra-evaporitic environment was, like the evaporitic environment, characterized by changing sea level. Limestones and marls were deposited (for example around Żelebsko and Węglin), which due to better oxygenation supported fauna development. Diverse foraminiferal assemblages, including planktonic forms such as *Velapertina indigena* and globigerinids were much more conspicuous than in the central part of the Carpathian Foredeep, and these are accompanied by ostracodes (Szczechura 1982; Szczechura and Pisera, 1986; Musiał, 1987). Abundant attaching forms as *Planorbulina, Patellina* and *Spirilina*, as well as *Cibicides lobatulus*, suggest an energetic environment.

Common Late-Badenian ostracodes (including "psychrosphaeric" forms), foraminifera and bolboforms around Tarnobrzeg (Jamnica S-119 borehole), in the Działoszyce Trough (Posądza 10-S borehole), in Roztocze and Upper Silesia (Gliwice 19 and 21 boreholes) (Szczechura, 1994, 1995, 1997*a, b*; pers. obs.) suggest faunal exchange across this area. The fact that "psychrosphaeric" ostracodes and certain Late-Badenian bolboforms are scarce and of low diversity in the central part of Carpathian Foredeep and in the Roztocze area, but abundant and more diverse in the clayey deposits in the Upper Silesia, clearly indicates environmental diversity and faunal exchange. Conditions in the Upper Silesia region were much more favourable to life than in the central part of the Carpathian Foredeep and in the Roztocze area. Migration of microfauna was from the west to the east.

Species of shallow-water ostracodes, such as *Carinocythereis carinata* (Roemer) (Szczechura, 1996, 1997*b*) common to the Middle Miocene of both the Mediterranean area (France, Italy) and the Central Paratethys (Poland, Czech Republic, Bulgaria) proves a connection between these two basins.

From the beginning of the Sarmatian, marine environmental conditions rapidly deteriorated in the central part of Carpathian Foredeep and in the distal, tectonically isolated areas where deposition of the Krakowiec Clays dominated. This deterioration was probably caused by limited water circulation, leading to an oxygen deficiency, limitation of bioprecipitation, and increases in sedimentation rate and fluctuations of sea level.

Post-Badenian marine withdrawal took place gradually in distal areas of the Carpathian Foredeep. Those areas were more stable and characterized by sedimentation of clays and marls and enhanced water circulation. The biofacies changes in these areas likewise are gradational, with both Badenian and Sarmatian elements co-existing. Contemporaneous shallow water, nearshore or elevated regions of the Carpathian Foredeep show a higher diversity of sediments and associated biofacies. These shallow regions were particularly sensitive to sea level fluctuations, which controlled the litho- and biofacies. The preservation and morphology of the microfauna, particularly in detrital deposits, indicates a high $CaCO_3$ saturation and energetic conditions. Badenian and Sarmatian biofacies (including Sarmatian biofacies characteristic of detrital and clayey deposits) could coexist in the Late Badenian. Biofacies expression probably depended mainly on within-basin location and hydrodynamic conditions, in turn controlled by connections with the open sea, circulation patterns and sea-level fluctuations, associated with regression of the Miocene sea from the Carpathian Foredeep.

The presence of clearly marine, planktonic foraminifera of Badenian character in the Krakowiec Clays or their age equivalents in the Carpathian Foredeep, needs explanation. These are usually interpreted as introduced forms: in the Tarnobrzeg region — Jamnica S-119 (Łuczkowska, 1964; Odrzywolska-Bieńkowa, 1974*a*; pers. obs.); Przemyśl region (Głowacki *et al.*, 1966); Upper Silesia (Alexandrowicz, 1958). They are similarly interpreted in the Carpathians (Oszczypko *et al.*, 1992), in the Trans-Carpathians (Pishvanova, 1969), and in the Pannonian Basin (Rögl and Müller, 1976).

The extent of this phenomenon indicates that marine influxes into the marginal basin in the Carpathian Foredeep occurred in the Sarmatian. Many authors (Rögl, 1985; Nevesskaja *et al.*, 1987; Chumakov *et al.*, 1992; Friebe, 1994) infer influxes of fully marine water into the Paratethys in the Sarmatian, from the Mediterranean region.

Thus, in the Badenian, supra-evaporitic microfaunal biofacies (particularly foraminiferal ones), characteristic of stressed, near-bottom environments, resemble foraminiferal biofacies of the sub-evaporitic beds (the upper part of the Baranów Beds). Both of these are radically different from the foraminiferal biofacies of Early Badenian, indicating Badenian environmental changes prior to deposition of the evaporites. These environmental changes involved a decrease of temperature, as indicated by disappearance of warm-water forms. Large benthonic foraminifera (Rögl and Brandstätter, 1993) and some groups of ostracodes (Szczechura, 1996) , as well as corals, also disappeared, while the bolboforms underwent diversification (Szczechura, 1997*a*). This diversification probably resulted from water mass exchanges in the Paratethys. The appearance of the *Uvigerina peregrina* Cushman group and pavonitinids and the dominance of globigerinids in the plankton is consistent with such an interpretation. Such forms suggest upwelling or turbidity currents bringing nutrients into the environment and reducing the oxygen level in the near-bottom waters. Oxygen-deficiency would be facilitated by the irregular bottom morphology of the Carpathian Foredeep.

The presence of "psychrosphaeric" ostracodes, both in the Early and Late Badenian of the Carpathian Foredeep (particularly in its Polish part) (Szczechura, 1986, 1994, 1995) confirms influxes of cold, near-bottom waters of oceanic origin into the northern part of Central Paratethys. These influxes came via the Mediterranean basins.

All these events can be closely correlated with events in the Mediterranean area (Zachariasse and Spaak, 1983; Chamley *et al.*, 1986; Demarcq, 1989). According to Demarcq (1989), the

"Serravallian Crisis" in the Mediterranean area, expressed by macro- and microfauna and phytoplankton, was caused by climatic changes (lowered temperature and humidity) from a subtropical to a warm Mediterranean, consistent with the Middle-Miocene global cooling.

The three main phases of development of the Middle-Miocene environment in the Carpathian Foredeep distinguished in this paper can be described in terms of three ecozones: *Globigerinoides* ecozone, *Globigerina* ecozone and *Anomalinoides dividens* ecozone (Figs. 2, 3) (*cf.* Szczechura, 1982, 1986, this paper; Szczechura and Pisera, 1986).

AGE

The lateral coexistence of different microfaunal biofacies in the Carpathian Foredeep and their changing distribution in time (particularly at the Badenian/Sarmatian transition), which depended on local palaeogeographical and palaeoenvironmental conditions, necessitates some revision of their biostratigraphical significance.

Velapertina sp. (among foraminifera) and *Bolboforma badenensis* Szczechura (among bolboforms) are recognized as biostratigraphical indicators of the Late Badenian age in the supra-gypsum deposits (the *Pecten* Beds, except for their uppermost part), in the Jamnica S-119 borehole (Szczechura, 1995, 1997*a*; Odrzywolska-Bieńkowa and Olszewska, 1996). *Bolboforma badenensis* represents a biostratigraphical indicator for the Late Badenian of the Central Paratethys and is known entirely from the NN6 Zone (Spiegler and Rögl, 1992). Among foraminifera from the Krakowiec Clays in the Jamnica S-119 borehole, *"Anomalinoides dividens"* Łuczkowska, *Elphidium hauerinum* (d'Orbigny), *E. aculeatum* (d'Orbigny) and *Porosononion granosum* (d'Orbigny) (Brestenská, 1974; Görög, 1992; Odrzywolska-Bieńkowa and Olszewska, 1996) occur besides miliolids characteristic of the Sarmatian.

Some foraminifera originally regarded as Sarmatian, for example *Elphidium hauerinum* (d'Orbigny), *Schackoinella imperatoria* (d'Orbigny), *Porosononion granosum* (d'Orbigny) and *Spirolina austriaca* (d'Orbigny) are known from the Badenian (for example in the Vienna Basin). In the Carpathian Foredeep, *"Anomalinoides dividens"* Łuczkowska coexists with index foraminifera of the Badenian (for example in Hamernia, this paper). Thus, the foraminifera from the Krakowiec Clays, included in the *A. dividens* ecozone, do not allow a precise age determination.

Among ostracodes found in the Jamnica S-119 borehole, the "psychrosphaeric" forms, particularly *Cluthia miocenica* Szczechura and *Xylocythere carpathica* Szczechura, found in the *Pecten* Beds (*cf.* Szczechura, 1995, 1996) are important for dating the Late Badenian. In the Krakowiec Clays, *Leptocythere naca* (Mehes) and *L.* cf. *cejcenensis* Zelenka, found in the upper part of the Krakowiec Clays, and *Aurila mehesi* (Zalanyi) and *Cytherois sarmatica* Olteanu occurring in the lower part, are characteristic of the Sarmatian (Cernajsek, 1974; Olteanu, 1989*a, b*; Zelenka, 1990).

Gaździcka (1994) included the supra-evaporitic beds in the Jamnica S-119 borehole to the NN7–NN8/9 calcareous nannoplankton zones. According to Berggren *et al.* (1995), these zones, particularly the NN8 Zone, should be included in the Middle Miocene, while Rögl (1996) also includes in the Middle Miocene the lower part of the NN9a/8 Zone. Thus, one should include the supra-evaporitic beds from the Jamnica S-119 borehole in the Middle Miocene, although Gaździcka (*op. cit.*) may have under-estimated the age of the supra-evaporitic beds from the Jamnica S-119 borehole.

My final opinion on the age of these deposits, including those tentatively assigned to Sarmatian, is based on the chronostratigraphy proposed by Odrzywolska-Bieńkowa and Olszewska (1996), and Piwocki and Ziembińska-Tworzydło (1997). Thus, I include them in the Middle Miocene.

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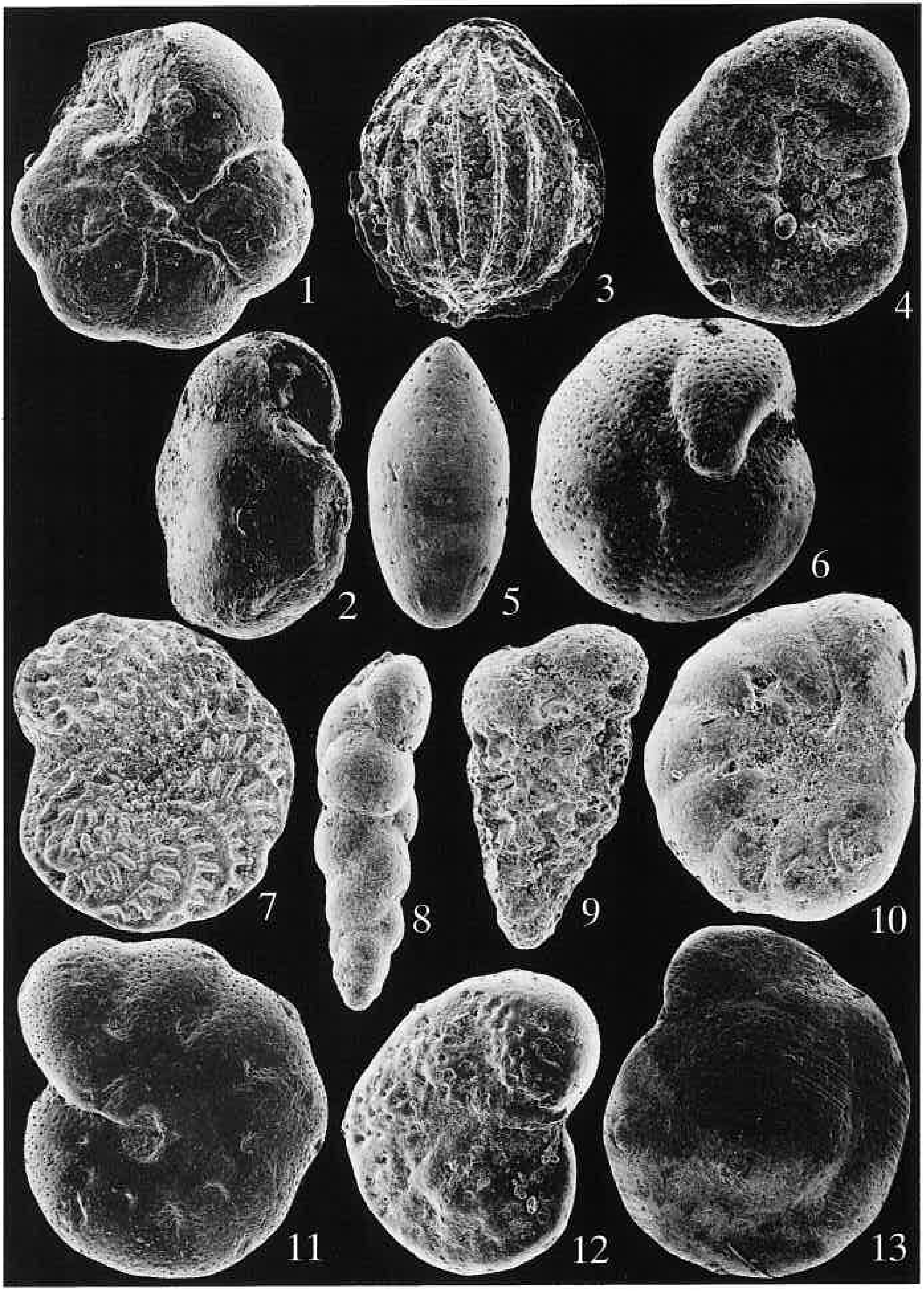
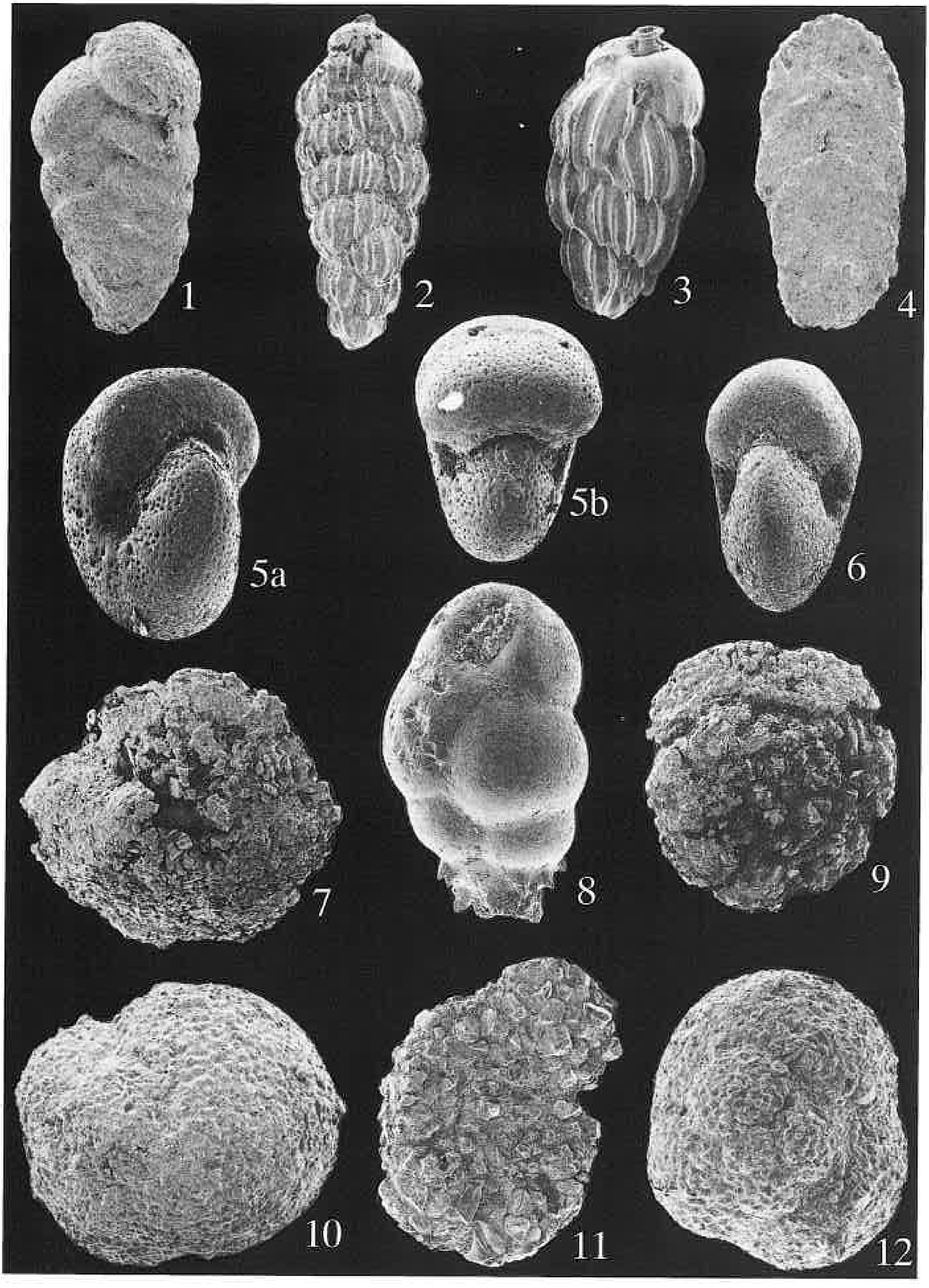
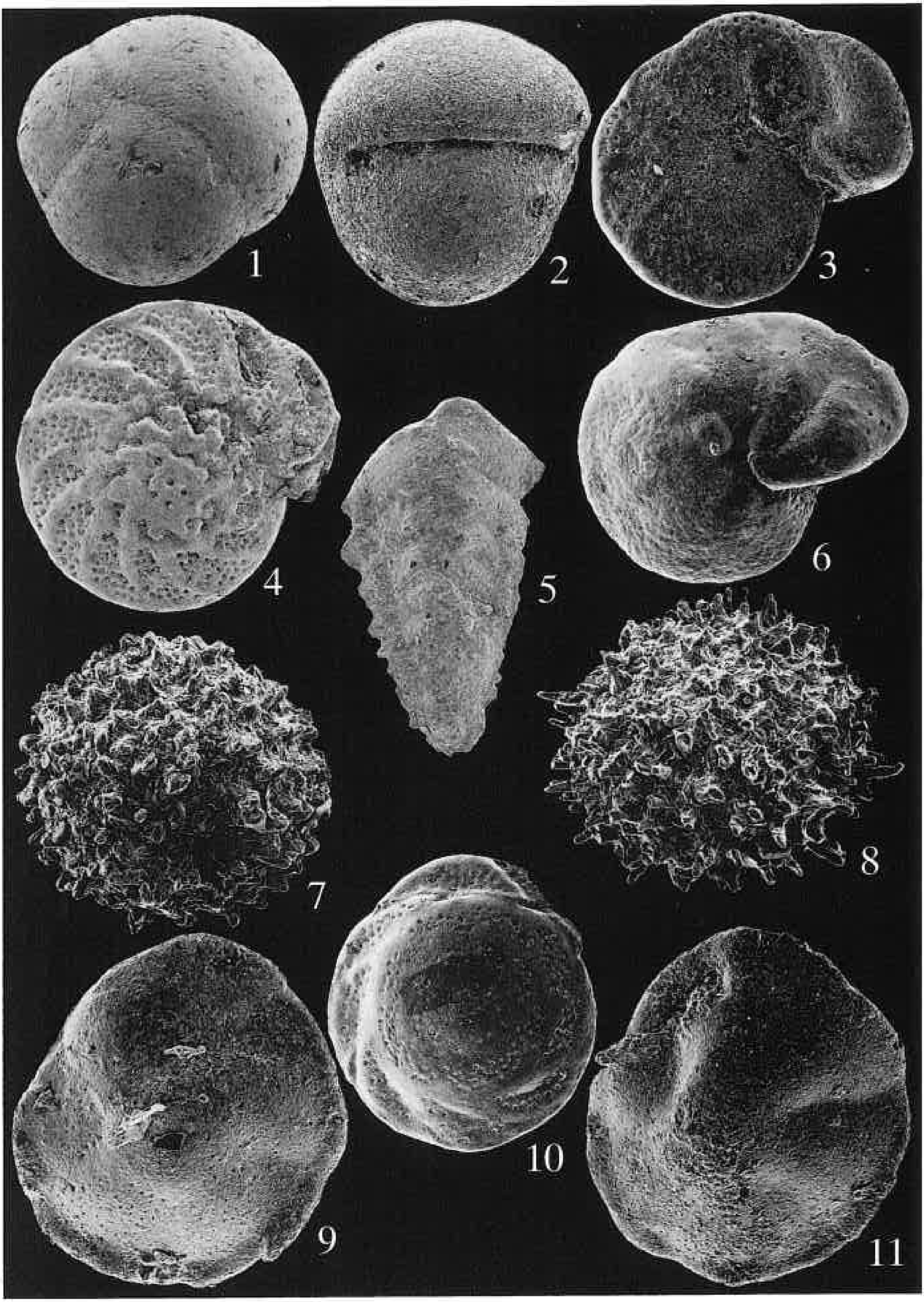


***1, 2**. Rosalina nana* (Reuss); ZPAL F. XLI/165, 166; x 200. ***3**. Fissurina pulchella* (Brady); ZPAL F. XLI/158; x 260. ***4**. Rosalina* sp.; ZPAL F. XLI/159; x 260. ***5**. Glandulina* cf. *ovula* d'Orbigny; ZPAL F. XLI/169; x 64. ***6, 13**. Heterolepa dutemplei* (d'Orbigny); ZPAL F. XLI/168, 169; x 130. ***7**. Elphidium fichtelianum* (d'Orbigny); ZPAL F. XLI/155; x 105. ***8**. Bulimina elongata* d'Orbigny; ZPAL F. XLI/156; x 105. ***9**. Bolivina pseudoplicata* Heron-Allen et Earland; ZPAL F. XLI/160; x 220. ***10**. Haynesina depressula* (Walker et Jacob); ZPAL F. XLI/157; x 210. ***11**. Astrononion perfossum* (Clodius); ZPAL F. XLI/167; x 210. ***12**. Cibicides* sp.; ZPAL F. XLI/162; x 220

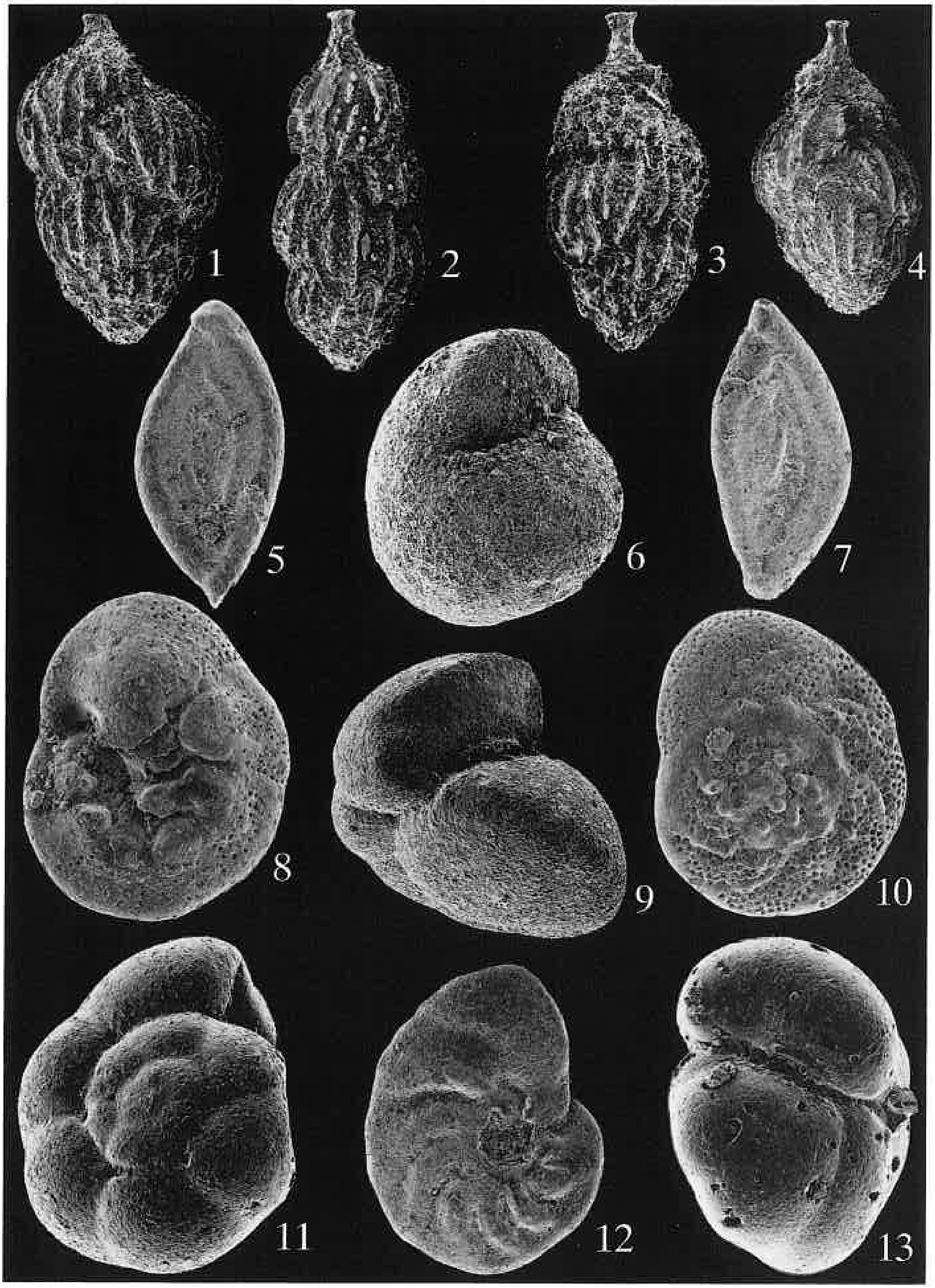


1. *Textularia flexua* Venglinski; ZPAL F. XLI/174; x 52. ***2***. *Uvigerina liesingensis* Toula; ZPAL F. XLI/183; x 60. ***3***. *Uvigerina* cf. *semiornata* d'Orbigny; ZPAL F. XLI/185; x 70. ***4***. *Pavonitina styriaca* Schubert; ZPAL F. XLI/178; x 44. ***5, 6***. *Melonis pompilioides* (Fichtel et Moll); ZPAL F. XLI/53, 52; x 100. ***7, 9***. ?*Deuterammina* sp.; ZPAL F. XLI/78, 79; x 9. ***8***. *Bulimina aculeata* d'Orbigny; ZPAL F. XLI/60; x 150. ***10, 12***. *Velapertina* sp.; ZPAL F. XLI/180, 182; x 130. ***11***. *Haplophragmoides* sp.; ZPAL F. XLI/57; x 54



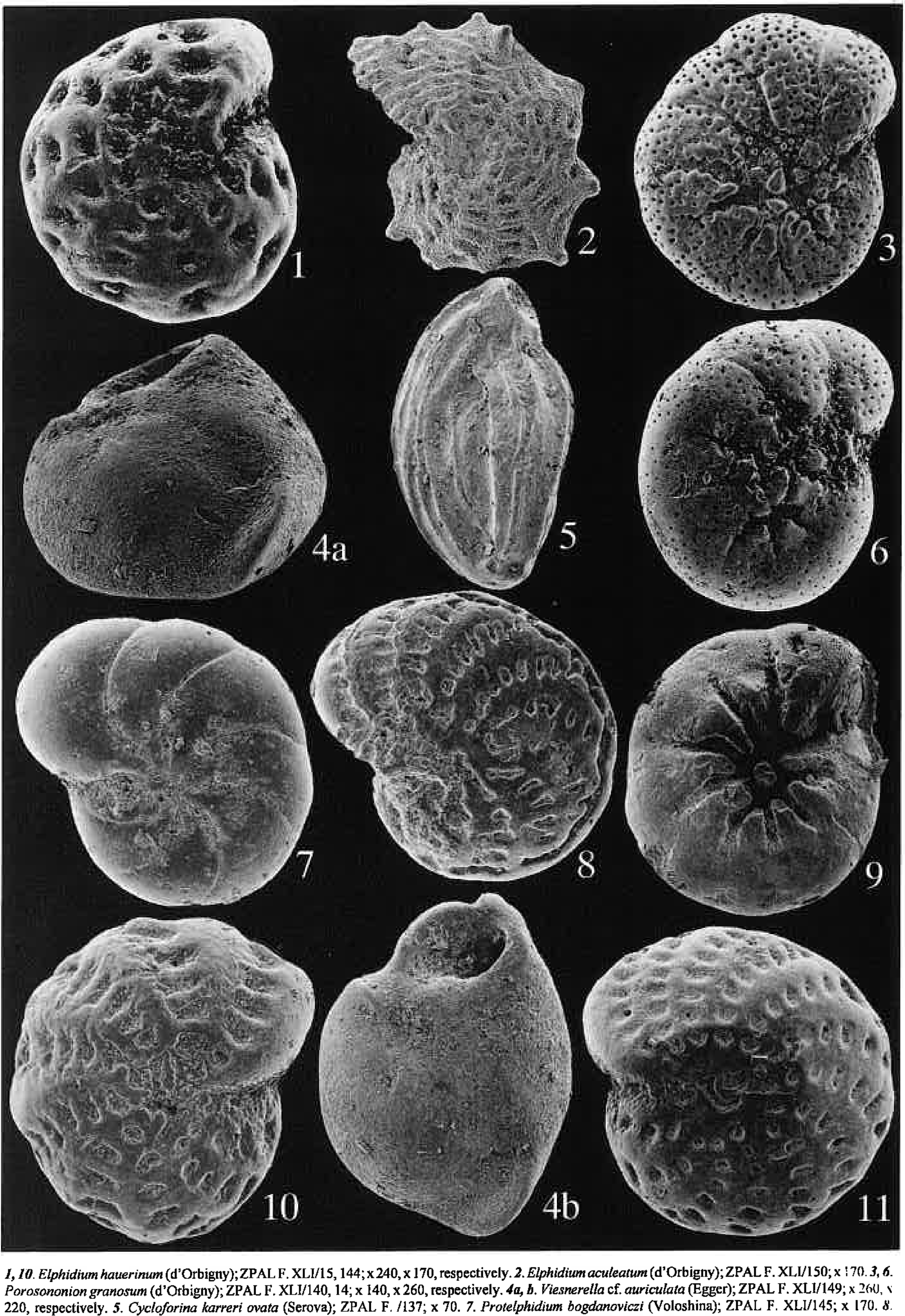
1. ***Sphaeroidina bulloides*** d'Orbigny; ZPAL F. XLI/187; x 130; ***2.*** ***Pullenia bulloides*** d'Orbigny; ZPAL F. XLI/50; x 150. ***3, 6.*** ***Cibicides*** sp.; ZPAL F. XLI/58, 59; x 115, x 125, respectively. ***4.*** ***Cibicides ungerianus*** (d'Orbigny); ZPAL F. XLI/184; x 105. ***5.*** ***Spiroplectinella carinata*** (d'Orbigny); ZPAL F. XLI/193; x 60. ***7, 8.*** ***Bolboforma badenensis*** Szczechura; ZPAL V. XXIII/3, 2; x 380. ***9, 11.*** ***Cassidulina laevigata*** (d'Orbigny); ZPAL F. XLI/42, 43; x 300. ***10.*** ***Cibicidoides*** cf. ***pachydermus*** (Rzehak); ZPAL F. XLI/56; x 85

PLATE IV

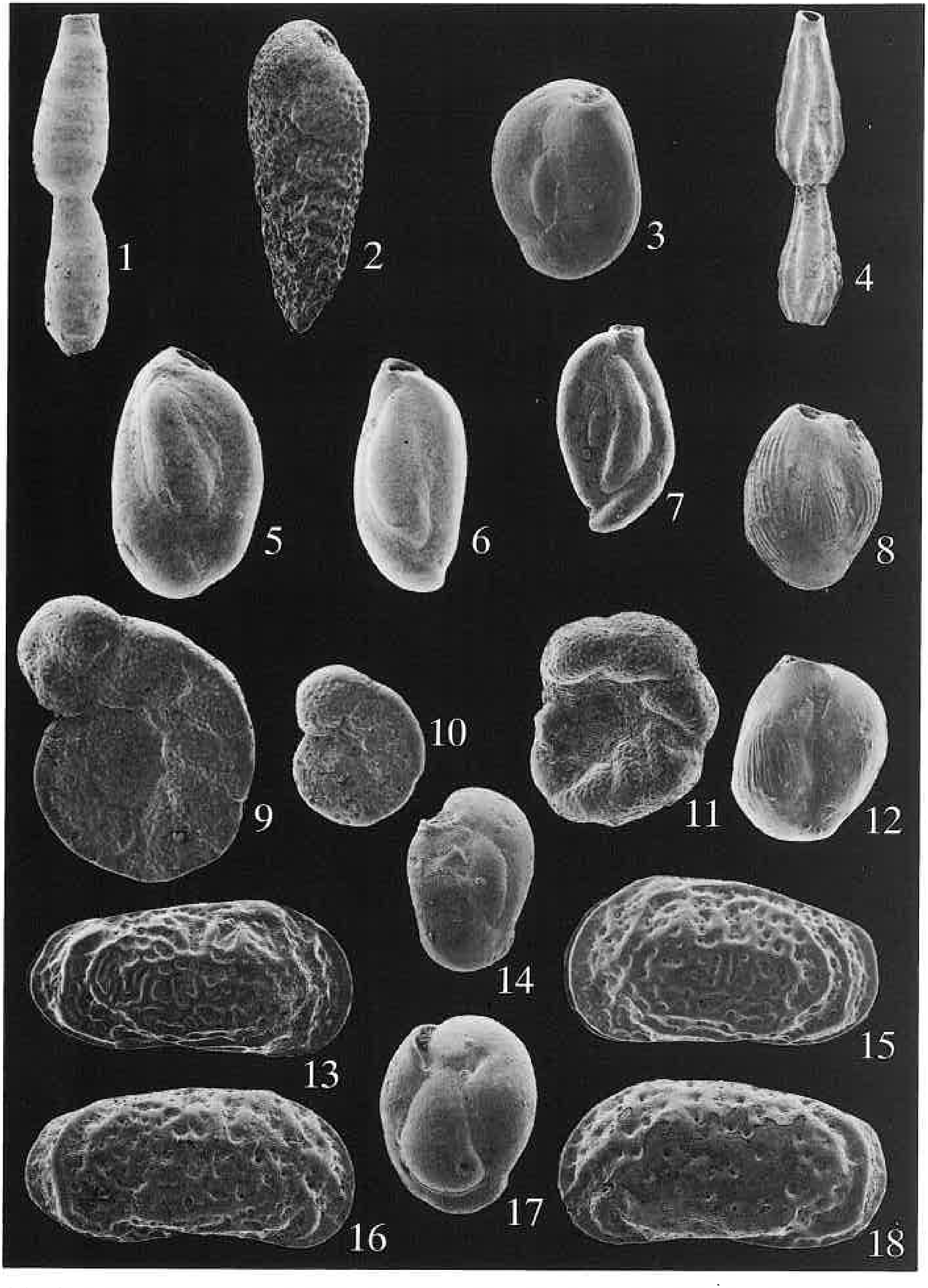


***1–4**. Uvigerina peregrina* Cushman group; ZPAL F.XLI/64, 63, 3, 75; x 130, x 120, x 120, x 120, respectively. ***5, 7**. Sigmoilinita tenuis* (Czjzek); ZPAl F. XLI/195, 196; x 310. ***6, 9**. Gyroidinoides* cf. *soldanii* (d'Orbigny); ZPAL F. XLI/54, 55; x 120, x 140, respectively. ***8, 10**. Valvulineria complanata* (d'Orbigny); ZPAL F. XLI/189, 190; x 125, x 170, respectively. ***11, 13**. Gyroidinoides* cf. *umbonatus* (Silvestri); ZPAL F. XLI/45, 46; x 285, x 330, respectively. ***12**. Hanzawaia boueana* (d'Orbigny); ZPAL F. XLI/70; x 150

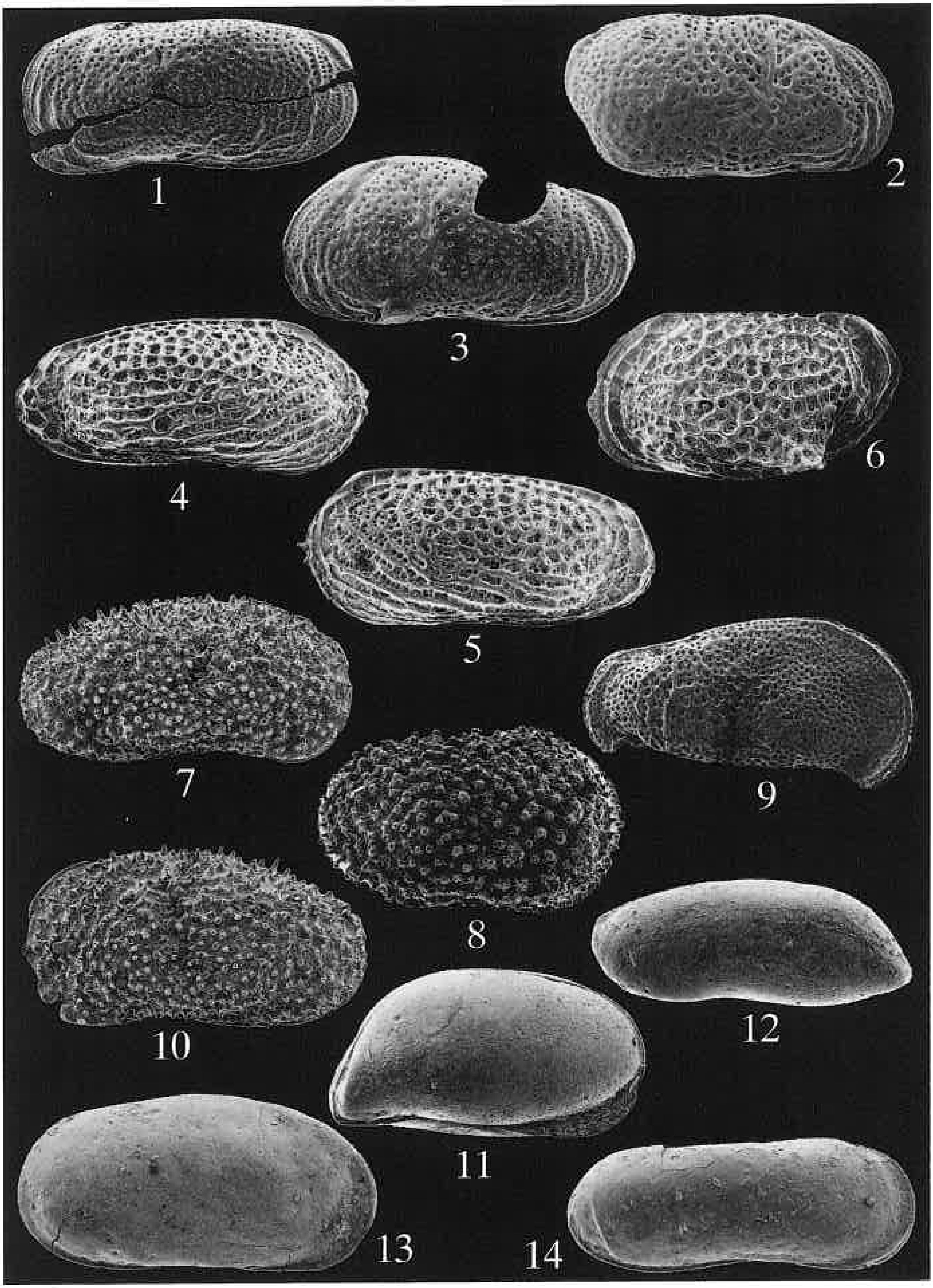
PLATE V



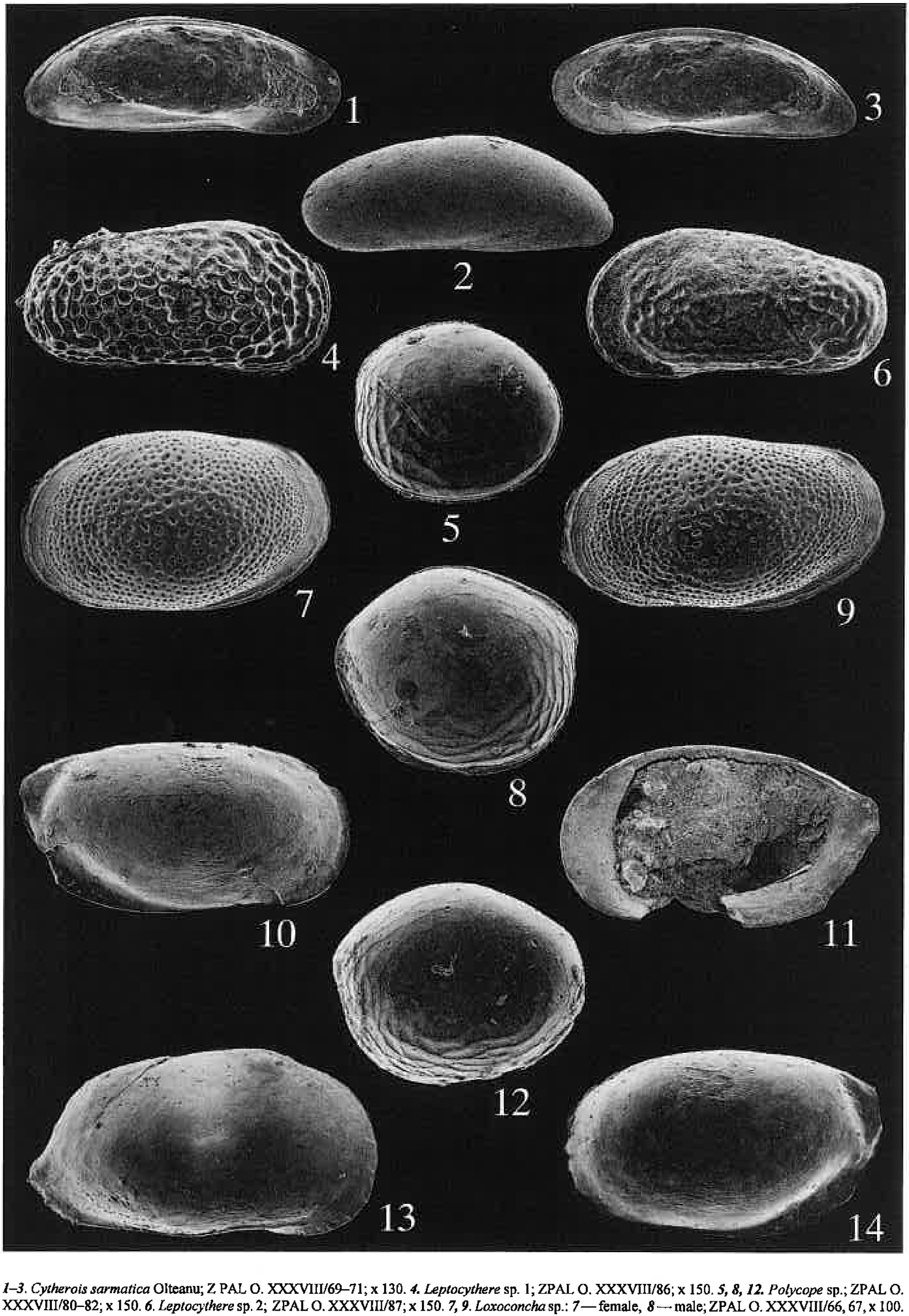
1, 10*. Elphidium hauerinum* (d'Orbigny); ZPAL F. XLI/15, 144; x 240, x 170, respectively. ***2****. Elphidium aculeatum* (d'Orbigny); ZPAL F. XLI/150; x 170. ***3, 6****. Porosononion granosum* (d'Orbigny); ZPAL F. XLI/140, 14; x 140, x 260, respectively. ***4a, b****. Viesnerella* cf. *auriculata* (Egger); ZPAL F. XLI/149; x 260, x 220, respectively. ***5****. Cycloforina karreri ovata* (Serova); ZPAL F. /137; x 70. ***7****. Protelphidium bogdanoviczi* (Voloshina); ZPAL F. XLI/145; x 170. ***8****. Elphidium* cf. *obtusum* (d'Orbigny); ZPAL, F. XLI/152; x 220. ***9****. Ammonia beccarii* (Linne); ZPAL F. XLI/153; x 170. ***11****. Elphidium* cf. *flexuosum* (d'Orbigny); ZPAL F. XLI/141; x 130



1. *Articulina* cf. *problema* Bogdanowicz; ZPAL F. XLI/131; x 70. ***2.*** *Bolivina moldavica* Didkovsky; ZPAL F. XLI/129; x 125; ***3.*** *Affinetrina* sp. 2; ZPAL F. XLI/208; x 60. ***4.*** ?*Articulina* sp.; ZPAL F. XLI/139; x 85. ***5, 6.*** *Quinqueloculina* sp.; ZPAL F. XLI/125, 126; x 140. ***7.*** *Cycloforina* sp.; ZPAL F. XLI/197; x 75. ***8, 12.*** *Affinetrina* sp. 1; ZPAL F. XLI/200, 199; x 65. ***9, 10.*** *Cibicides lobatulus* (Walker et Jacob); ZPAL F. XLI/134, 133; x 75. ***11.*** *Anomalinoides dividens* Łuczkowska; ZPAL F. XLI/124; x 85. ***13, 15.*** *Callistocythere* sp. 1; ZPAL O. XXXVIII/76, 73; x 130. ***14, 17.*** *Miliolinella* sp.; ZPAL. F. XLI/205, 206; x 90, x 105, respectively. ***16.*** *Callistocythere* sp. 2; ZPAL O. XXXVIII/24; x 110. ***18.*** *Callistocythere* sp. 3; ZPAL O. XXXVIII/27; x 110



1, 3. *Leptocythere* cf. *cejcenensis* Zelenka; Z PAL O. XXXVIII/30, 62; x 105, x 110, respectively. ***2.*** *Mediocytherideis* sp.; ZPAL O. XXXVIII/60; x 85. ***4, 5.*** *Xylocythere carpathica* Szczechura; ZPAL O. XXXVIII/1, 3; x 140. ***6.*** *Sagmatocythere* cf. *moncharmonti* (Ciampo); ZPAL O. XXXVIII/5, x 130. ***7, 10.*** *Leptocythere naca* (Mehes); ZPAL O. XXXVIII/ 22, 23; x 130. ***8.*** *Henryhowella asperrima* (Reuss) (juvenile form); ZPAL O. XXXVIII/6; x 85. ***9.*** *Cluthia miocenica* Szczechura; ZPAL O. XXXVIII/4; x 180. ***11.*** *Krithe* sp. (juvenile form); ZPAL O. XXXVIII/13; x 150. ***12.*** *Argilloecia* sp. (juvenile form); ZPAL O. XXXVIII/9; x 180. ***13.*** *?Leptocythere* sp.; ZPAL O. XXXVIII/61; x 120. ***14.*** *Leptocythere* cf. *Leptocythere* sp. Zlinská et Fordinál (1995); ZPAL O. XXXVIII/28: x 105



1–3. *Cytherois sarmatica* Olteanu; Z PAL O. XXXVIII/69–71; x 130. ***4.*** ***Leptocythere*** sp. 1; ZPAL O. XXXVIII/86; x 150. ***5, 8, 12.*** *Polycope* sp.; ZPAL O. XXXVIII/80–82; x 150. ***6.*** *Leptocythere* sp. 2; ZPAL O. XXXVIII/87; x 150. ***7, 9***. *Loxoconcha* sp.: ***7*** — female, ***8*** — male; ZPAL O. XXXVIII/66, 67, x 100. ***10, 11, 14***. *Phlyctocythere* cf. *pellucida* (G. W. Müller); ZPAL O. XXXVIII/64, 65, 90; x 120, x 105, x 120, respectively. ***13***. *Aurila mehesi* (Zalanyi); ZPAL O. XXXVIII/85; x 80

Errata:

The paper "The Upper Cretaceous carbonate-dominated sequences of the Polish Lowlands" by Krzysztof Leszczyński (Geol. Quart., vol. 41, number 4) contains Table 1 (p. 528) with incorrectly constructed Cenomanian-Coniacian interval. The table should read as follows:

Table 1

Subdivision of the Upper Cretaceous (including the Upper Albian and Lower Paleocene) and sedimentary cyclicity in Central Poland

Coniacian	Upper	*Inoceramus involutus*	*Magadiceramus subquadratus*	K4-I
	Middle		*Volviceramus involutus*	
	Lower	*Inoceramus schloenbachi*	*Cremnoceramus crassus-deformis*	
Turonian	Upper	*Inoceramus costellatus*	*Cremnoceramus brongniarti*	
			Cremnoceramus waltersdorfensis	
			Mytiloides incertus	
			Inoceramus costellatus	
	Middle	*Inoceramus lamarcki*	*Inoceramus lamarcki*	K3-IV
			Inoceramus apicalis	
		Inoceramus labiatus	*Mytiloides hercynicus*	
	Lower		*Mytiloides labiatus*	
			Mytiloides kossmati	
			Mytiloides hattini	
Cenomanian	Upper	*Calycoceras naviculare*		K3-III
	Middle	*Acanthoceras rhotomagense*		
	Lower	*Mantelliceras mantelli*		K3-II
Albian	Upper	*Stoliczkaia dispar*		K3-I