

LATE ALBIAN FORAMINIFERA FROM RECORD OF CARBONATE PLATFORM DROWNING ON THE TATRIC RIDGE, A PART OF THE CARPATHIAN DOMAIN: STRATIGRAPHIC AND PALAEOENVIRONMENTAL INFERENCES

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Abstract: The occurrence of planktonic and benthic foraminifers in the uppermost part of the Upper Albian carbonate platform in the Tatra Mountains, Inner Carpathians, Poland, is here documented. Study section (Żeleźniak gully, Kościeliska Valley, Tatra Mountains) encompass echinoderm-foraminiferal limestones, which lied directly below the hardground with stromatolites. These sediments terminated the carbonate sedimentation on the Tatric Ridge, which lasted through the Late Jurassic–Early Cretaceous. Planktonic foraminifers show that the breakup of carbonate platform took place in this area during the *Parathalmaninella appenninica* Zone (Upper Albian). The composition of benthic foraminiferal assemblages, including both agglutinated and calcareous taxa suggests that during the last phase of a carbonate platform development, the sea floor of elevated blocks occurred relatively deep, corresponding to the outer shelf depths. The comparison of foraminiferal morphogroups from the limestones shows that sea floor of this area was characterized by well-oxygenated bottom water conditions with an enhanced rate of primary organic matter flux.

Key words: Foraminifera, carbonate platform, biostratigraphy, palaeoecology, palaeenvironment, Lower Cretaceous, Tatra Mountains.

1. INTRODUCTION

Fragments of the Early Cretaceous carbonate platform is preserved in the Barremian–Albian sediments in the Tatra Mountains of the Inner Carpathians (Passendorfer, 1930; Lefeld, 1968; Mišik, 1990; Michalik & Soták, 1990). The occurrence of this platform during the Early Cretaceous was related to open marine conditions with pelagic and hemipelagic sedimentation in the Tatric area, which was a part of the of the Central Western Carpathian region, within the Western Tethys domain (Michalik, 1994). The palaeomagnetic data (Grabowski, 1997) from the Tatra Mountains indicate their proximity to the European plate at least in the post Early Aptian–pre-Coniacian time span. The development of the platform and its final demise (collapse-like) could be related to regional tectonics (Michalik, 1994). The shallow-water facies including the Urgonian-type benthic organisms demised in this

area at different times, since the Early Aptian through the Middle Albian (Masse & Uchman, 1997). The youngest demise of the carbonate platform took place within the Tatric Ridge, preceded there by sedimentation of phosphorous-rich limestones with stromatolites, which took place on elevated blocks (Krajewski, 1981). According to Krajewski (1981), this stage of sedimentation, characterized by cyclic development of hardgrounds, phosphatic mineralization and stromatolitic horizons occurred in open shelf environment under conditions of slow pelagic sedimentation.

Biostratigraphic studies on the Albian limestone succession from the Tatric sediments were carried out by Passendorfer (1930). He dated their base for the late Early Albian *Douvilleiceras mammilatum* ammonite Zone, and their top as the early Late Albian *Mortoniceras inflatum* Zone, as confirmed by stratigraphically important bivalves.

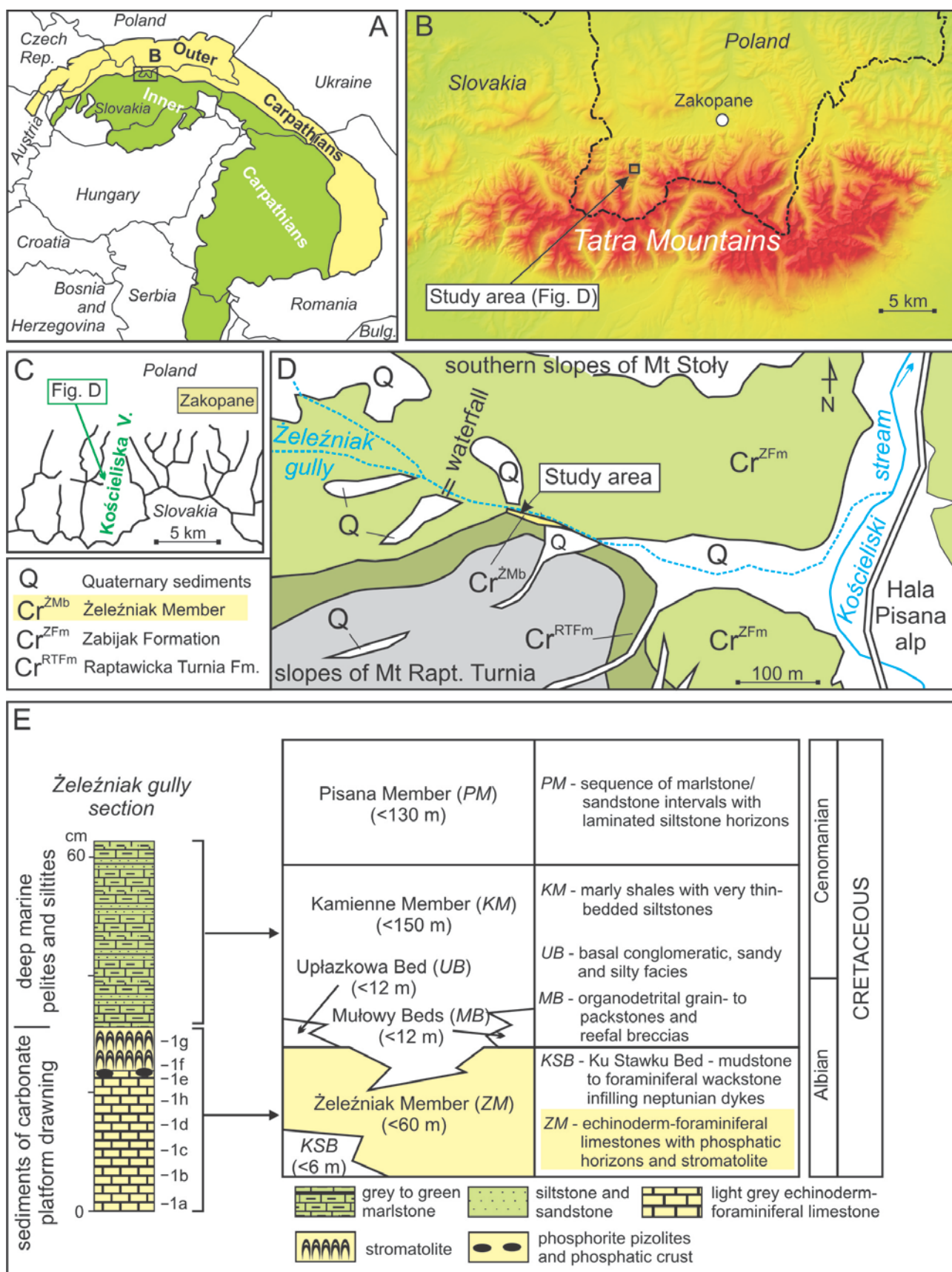


Figure 1. A – Simplified geological map of the Carpathians. B, C – Location of studied area in the Tatra Mountains (Inner Carpathians) on the contour map (map after Bryndal, 2014) and on simplified map of ridges, with position of the Kościeliska Valley. D – Geological map of the study area around the Żeleźniak gully, a left tributary of the Kościeliska Valley (map after Guzik, 1959). E – Albian–Cenomanian lithostratigraphic scheme of the Zabijak Formation and lithologic log of the studied Żeleźniak gully section (lithostratigraphy after Krajewski, 2003).

The present paper is related to the microfacies analysis of the topmost part of the organodetrical limestone succession, which is overlaid by hardground with stromatolites. These sediments have been deposited on elevated block within the Tatric Ridge. The purpose of this analysis is (a) to document the planktonic and benthic foraminiferal assemblages from these sediments, (b) to discuss the age of the youngest limestone succession and its palaeoecologic and palaeobathymetric implications using the foraminiferal data as the biogenic markers.

2. GEOLOGICAL SETTING

The Tatra Mountains form the highest part in the Central Western Carpathians (Fig. 1A, B), built of a Paleozoic crystalline core and a Mesozoic (Early Triassic–Late Cretaceous) sedimentary sequence. These rocks belong to the High-Tatric autochthonous cover and the overthrust High-Tatric and Sub-Tatric nappes (Książkiewicz, 1962; Andrusov, 1965; Passendorfer, 1983; Froitzheim et al., 2008), forming the so-called Tatricum, a part of the Inner Carpathians (Plašienka, 2003). The youngest part of the sedimentary sequence in the Polish part of the Tatra Mountains, mid-Cretaceous in age, is referred to the Zabijak Formation (Krajewski, 2003). The studied sediments belong to the basal unit of this Formation, distinguished as the Żeleźniak Member (Krajewski, 2003; Fig. 1E). This Member is represented by foraminiferal, echinoderm and echinoderm-foraminiferal wackstones, packstones and grainstones, with several phosphorite horizons. Its topmost part is partly covered by composite hardground with phosphorite pebble lag and phosphatic stromatolites. The thickness of the Żeleźniak Member is highly variable, ranging from 1.5 m (the studied area) to 60 m. It reflects changes in sedimentary morphology of the sea floor due to tectonic processes, which took place during deposition of these sediments (Krajewski, 2003).

3. MATERIAL AND METHODS

The section studied is located in the Polish part of the Tatra Mountains, where the Albian limestones crop out in the Żeleźniak gully, a left tributary of the Kościeliska Valley, about 100 m below 3-m-high waterfall (Fig. 1B–D). The section comprises the uppermost part of the Żeleźniak Member (Fig. 1E), which contains ca 20 cm thick succession of echinoderm-foraminiferal packstone, covered by hardground with phosphorite pebble lag and phosphatic stromatolites, 10 cm thick.

High degree of limestone lithification difficult with extraction of microfossils from these sediments. Therefore, the foraminifers were analysed in 14 thin sections, made from 8 samples, collected with an average sample interval 3–5 cm (Fig. 1E). This technique facilitates an identification of the great majority of genera, and partly of the species, providing a basis for characterizing assemblage compositions, which can be applicable in stratigraphic studies and palaeoecological analysis. Such quantitative analysis, related to the latter aspect, is here proposed based on the morphogroup analysis of the agglutinated and calcareous taxa.

Photomicrographs of foraminifers were taken using a stereoscopic microscope Nikon SMZ1500 with digital camera. The material is housed in the Institute of Geography, Pedagogical University of Cracow, Poland.

4. FORAMINIFERAL ASSEMBLAGES

The foraminiferal material includes both planktonic and benthic (agglutinated and calcareous) foraminifers (Table 1).

Small forms of *Hedbergella* spp. with *Hedbergella delrioensis* (Carsey) (Plate I: O) and *Hedbergella praelibya* Petrizzo and Huber (Plate I: M, N) dominate among the planktonic taxa, associated by other non-keeled forms belonging to *Favusella washitensis* Carsey (Plate I: K, L) and *Globigerinelloides* sp. (Plate I: P). Keeled forms are less frequent, being represented by *Parathalmaninella appenninica* (Renz) (Plate I: A, B), *Parathalmaninella balernaensis* (Gandolfi) (Plate I: C), *Pseudothalmanninella* cf. *ticinensis* (Gandolfi) (Plate I: F), *Pseudothalmanninella* cf. *subticinensis* (Gandolfi) (Plate I: G, H), and *Praeglobotruncana* cf. *delrioensis* Plummer (Plate I: J). Frequencies of planktonic Foraminifera are relatively low, 7–15 specimens per 1 cm². A few of them are filled with pyrite.

Among the benthic forms, a content of agglutinated and calcareous foraminiferal groups is nearly the same. The agglutinated benthos (53% of the total number of benthic specimens) is moderately diversified, without a significant dominance of a single species. The most frequent are specimens from genera *Trochammina* (Plate II: M), *Pseudonodosinella* (Plate II: E), *Eobigerina* (Plate II: H, I), and *Recurvoides/Plectorecurvoides* (Plate II: O–Q), which are associated with forms belonging to *Glomospira* (Plate II: D), *Ammobaculites* (Plate II: F), *Thalmannammina* (Plate II: N), *?Gerochammina* (Plate II: G), *Verneulinoides* (Plate II: L), *?Tritaxia* (Plate II: J), and *Dorothia* (Plate II: K).

Table 1. Abundances for foraminiferal taxa in the Upper Albian limestone, Źeleźniak Member (Zabijak Formation), Tatra Mountains, Inner Carpathians; number of specimens in 6 cm² (mean surface of thin section of the rock)

| | Echinoderm – foraminiferal limestone | | | | | Limestone with hardground and stromatolite | | |
|---|--------------------------------------|--------|--------|--------|--------|--|--------|--------|
| | Źel-1a | Źel-1b | Źel-1c | Źel-1d | Źel-1h | Źel-1e | Źel-1f | Źel-1g |
| Agglutinated: | | | | | | | | |
| <i>Ammobaculites</i> sp. | 2 | 1 | 2 | 3 | . | . | . | . |
| <i>Ammobaculites</i> sp. | . | . | . | 2 | 1 | . | . | . |
| <i>Dorothyia gradata</i> | 5 | . | 1 | 3 | 2 | 1 | . | 1 |
| <i>Dorothyia/Marsonella</i> spp. | 6 | . | 1 | 4 | 2 | 1 | . | . |
| <i>Eobaculites variabilis</i> | 7 | 3 | 2 | 6 | 6 | 1 | . | . |
| <i>Gerochammina stanislawi</i> | . | . | 4 | . | . | . | . | . |
| <i>Glomospira gordialis</i> | . | . | 4 | . | . | . | . | . |
| <i>Plectrochammina alternans</i> | . | 1 | 1 | . | . | . | . | . |
| <i>Pseudonodosinella troyeri</i> | 4 | 3 | 1 | 11 | 4 | 1 | . | 1 |
| <i>Recurvirostra imperfectus</i> | . | . | . | . | 1 | . | . | . |
| <i>Recurvirostra</i> sp. | 5 | 6 | 2 | 7 | 6 | . | . | . |
| <i>Reophax</i> sp. | 1 | . | 4 | . | . | . | . | . |
| <i>Rhabdammina</i> sp. | 2 | 2 | 1 | 2 | 2 | 2 | . | . |
| <i>Rhizammina</i> sp. | 1 | . | . | . | . | . | . | . |
| <i>Verneuilinoides neocomiensis</i> | 1 | . | 2 | . | . | . | . | 1 |
| <i>Thalmanmina meandertornata</i> | . | 1 | 1 | 6 | 3 | . | . | . |
| ? <i>Tritaxia</i> sp. | . | . | . | . | 1 | . | . | . |
| <i>Trochammina</i> sp. | 7 | 2 | . | 9 | 2 | . | . | . |
| Calcareous benthic: | | | | | | | | |
| <i>Astacolus</i> sp. | . | . | 1 | 1 | . | 1 | . | . |
| <i>Cibicides</i> sp. | . | 1 | 4 | 4 | 3 | . | 3 | . |
| <i>Dentalina</i> sp. | 4 | . | 1 | 2 | 4 | . | . | 2 |
| <i>Epistominella</i> sp. | . | . | 1 | 3 | 1 | . | . | . |
| <i>Gavelinellids</i> | 11 | 7 | 8 | 28 | 10 | 4 | 3 | 3 |
| <i>Oolina</i> sp. | . | 3 | 1 | 1 | . | . | . | 1 |
| <i>Gyrogoninoides</i> sp. | 1 | . | 1 | 4 | . | . | . | 1 |
| <i>Laevidentalina</i> sp. | . | . | 2 | . | . | . | . | . |
| <i>Lagena</i> sp. | 2 | . | . | . | . | . | . | . |
| <i>Lenticulina</i> sp. | 1 | 1 | 1 | 2 | . | . | . | 1 |
| <i>Nodosaria</i> sp. | 3 | 1 | . | . | 1 | . | . | . |
| <i>Planularia</i> sp. | . | . | 1 | . | . | . | . | . |
| <i>Pleurostomella</i> sp. | 1 | 1 | . | 1 | . | . | 1 | 1 |
| <i>Quadriformina allomorphinoides</i> | . | 1 | . | . | . | . | . | . |
| <i>Quinqueloculina</i> sp. | . | . | 1 | . | . | . | . | . |
| <i>Ramulina</i> sp. | 1 | . | 1 | 1 | 1 | . | . | . |
| Planktonic: | | | | | | | | |
| <i>Favosella washitensis</i> | . | . | . | . | 1 | 1 | . | . |
| <i>Hedbergella delrioensis</i> | 2 | . | 1 | 1 | . | 1 | . | 1 |
| <i>Hedbergella praelibya</i> | 1 | . | 4 | 1 | 5 | 2 | 3 | . |
| <i>Hedbergella</i> sp. | 13 | 6 | 14 | 2 | 5 | 6 | 2 | 2 |
| <i>Globigerinelloides</i> sp. | 1 | 1 | 1 | . | . | . | . | . |
| <i>Parathalmaninella appenninica</i> | 1 | . | 1 | 1 | . | . | . | . |
| <i>Parathalmaninella balernaensis</i> | 1 | . | . | . | . | . | . | . |
| <i>Praeglobotruncana</i> cf. <i>delrioensis</i> | 1 | 1 | . | . | 1 | . | . | . |
| <i>Pseudothalmaninella</i> cf. <i>subticinensis</i> | . | . | . | 2 | 1 | . | . | . |
| <i>Pseudothalmaninella</i> cf. <i>ticinensis</i> | . | . | . | . | . | . | . | . |
| <i>Parathalmaninella/Pseudothalmaninella</i> | 4 | 4 | 6 | 4 | 1 | . | 2 | . |

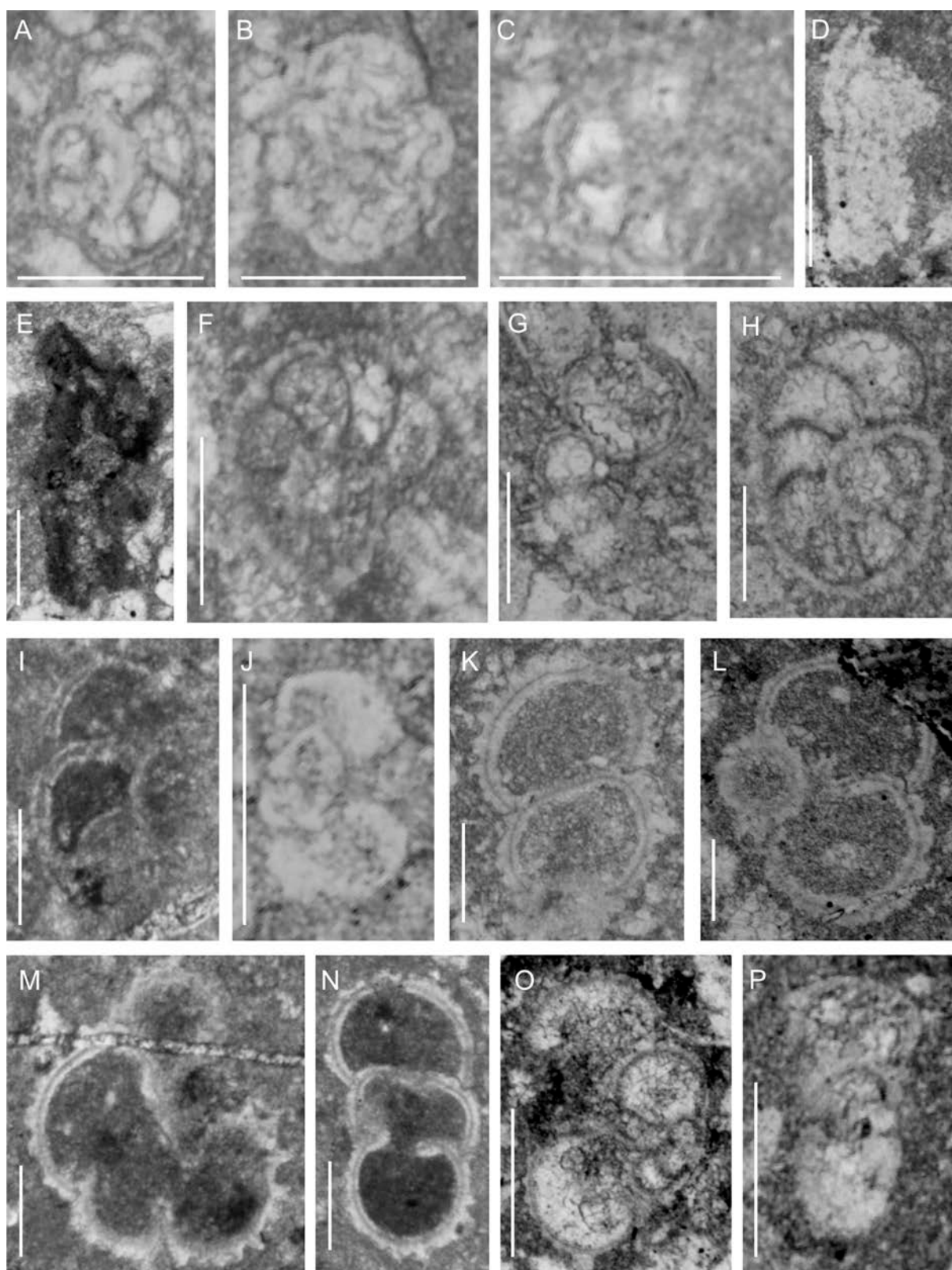


Plate I. Planktonic foraminifera from the Upper Albian limestone of the Želežniak Member, Tatra Mountains, Inner Carpathians: A, B. *Parathalmanninella appenninica* (Renz), A – sample Žel-1d, B – sample Žel-1c; C. *Parathalmanninella balernaensis* (Gandolfi), sample Žel-1a; D, E. *Parathalmanninella* sp. umbilico-convex, sample Žel-1b; F. *Pseudothalmanninella* cf. *ticinensis* (Gandolfi), sample Žel-1d; G, H. *Pseudothalmanninella* cf. *subticinensis* (Gandolfi), sample Žel-1e; I. *Parathalmanninella*/*Pseudothalmanninella* sp., sample Žel-1f; J. *Praeglobotruncana* cf. *delrioensis* Plummer, sample Žel-1a; K, L. *Favusella washitensis* Carsey, K – sample Žel-1h, L – sample Žel-1e; M, N. *Hedbergella praelibya* Petrizzo and Huber, sample Žel-1f; O. *Hedbergella* cf. *delrioensis* (Carsey), sample Žel-1c; P. *Globigerinelloides* sp., sample Žel-1c. Scale bar: 100 μ m.

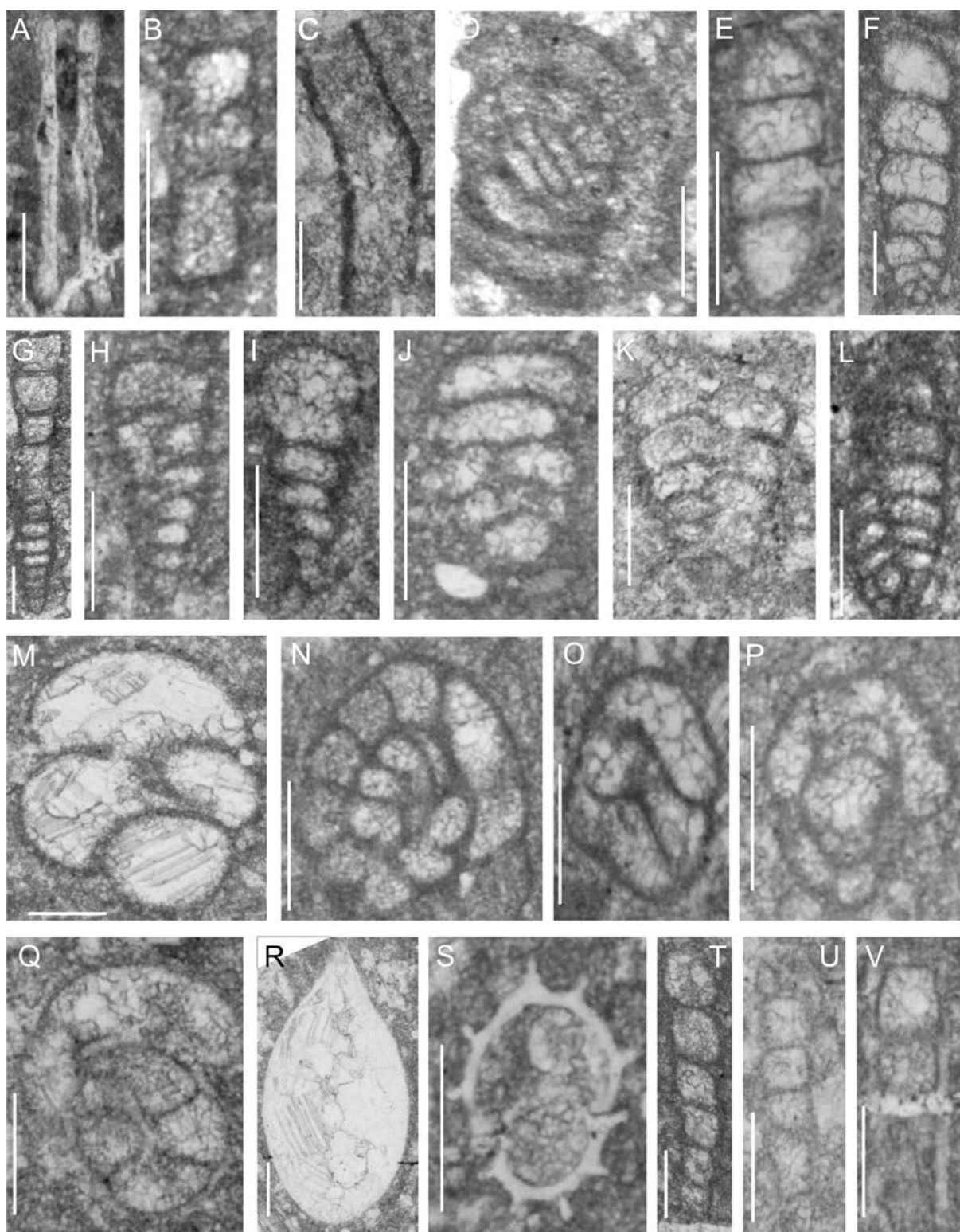


Plate II. Benthic foraminifera from the Upper Albian limestone of the Želežniak Member, Tatra Mountains, Inner Carpathians: A. *Psammosiphonella cylindrica* (Glaessner), sample Žel-1d; B. *Rhabdammina* cf. *linearis* Brady, sample Žel-1b; C. *Rhizammina* sp., sample Žel-1a; D. *Glomospira gordialis* (Jones & Parker), sample Žel-1h; E. *Pseudonodosinella troyeri* (Tappan), sample Žel-1d; F. *Ammobaculites irregularis* Gümbel, sample Žel-1d; G. *?Gerochammina stanislavii* (Neagu), sample Žel-1c; H, I. *Eobigerina variabilis* (Vašíček), H – sample Žel-1h, I – sample Žel-1a; J. *?Tritaxia* sp., sample Žel-1h; K. *?Dorothisia gradata* (Berthelin), sample Žel-1a; L. *Verneulinoides neocomiensis* Mjatluk, sample Žel-1c; M. *Trochammina* sp., sample Žel-1d; N. *Thalmannammina meandertornata* Neagu & Todorjescu, sample Žel-1h; O, P. *Plectorecurvoides alternans* Noth, O – sample Žel-1c, P – sample Žel-1b; Q. *Recurvoides imperfectus* (Hanzlikova), sample Žel-1h; R. *Lagenella* sp., sample Žel-1b; S. *Nodosaria* sp., sample Žel-1d; T. *Laevidentalina* sp., sample Žel-1c; U. *Dentalina* sp., sample Žel-1a; V. *Nodosaria* sp., sample Žel-1a; Scale bar: 100 μm.

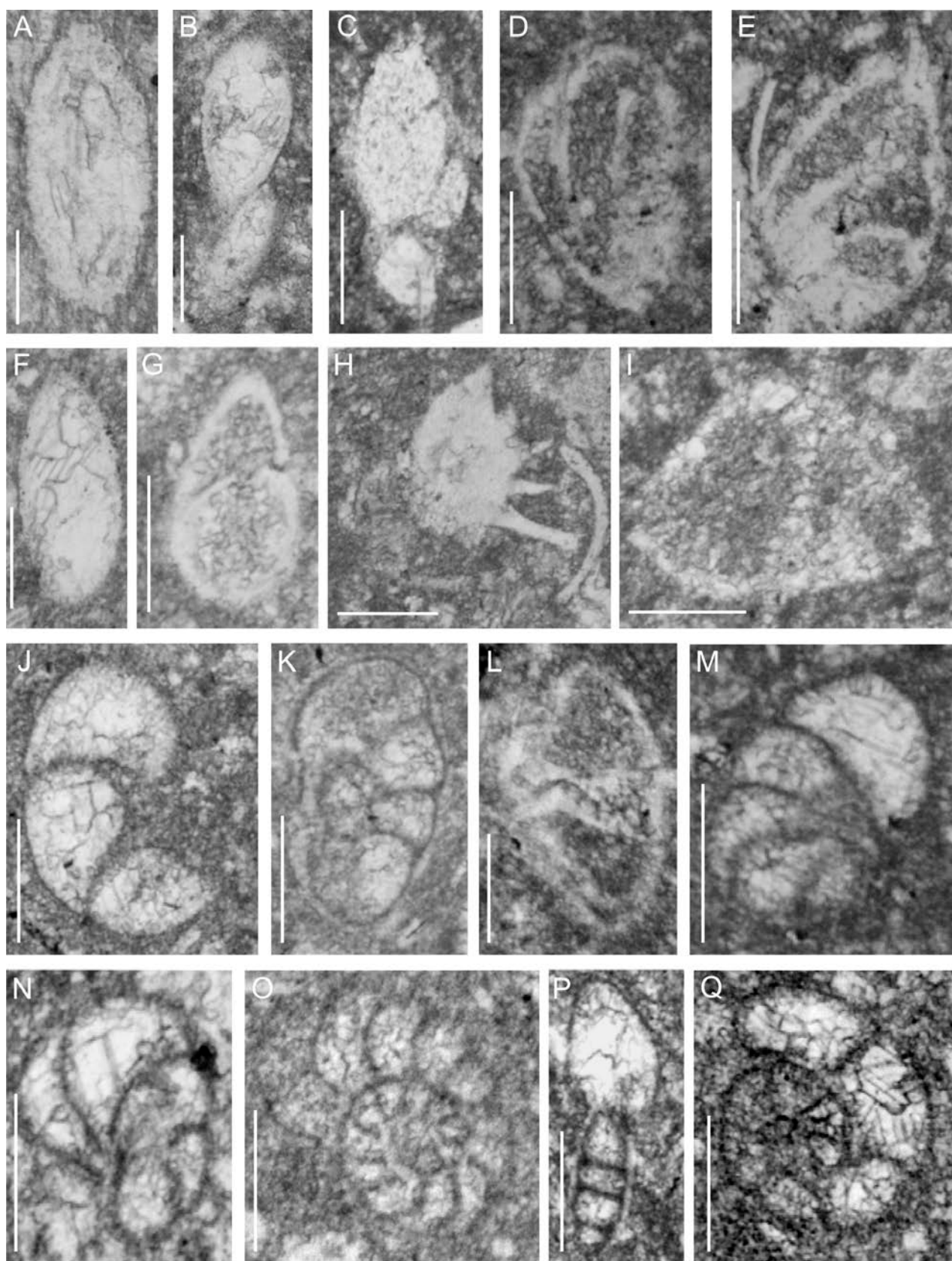


Plate III. Benthic foraminifera from the Upper Albian limestones of the Želežniak Member, Tatra Mountains, Inner Carpathians: A. *Quinqueloculina* sp., sample Žel-1c; B. *Pleurostomella* sp., sample Žel-1b; C. ?*Pleurostomella* sp., sample Žel-1d; D. ?*Lagena* sp., sample Žel-1a; E. *Planularia* sp., sample Žel-1c; F. ?*Astacolus* sp., sample Žel-1c; G. *Lenticulina* sp., sample Žel-1b; H. *Epistommina* sp., sample Žel-1c; I. *Gyroidinoides* sp., sample Žel-1d; J. *Quadrиморфina allomorphinoides* (Reuss), sample Žel-1b; K. *Berthelina* sp., sample Žel-1b; L. *Cibicides* sp., sample Žel-1c; M–Q – gavelinids, N, P – sample Žel-1a, M, O, Q – sample Žel-1d. Scale bar: 100 μ m.

Tubular forms are rare, represented by *Psammosiphonella cylindrica* (Glaessner) (Plate II: A), *Rhabdammina* cf. *linearis* Brady (Plate II: B), and *Rhizammina* sp. (Plate II: C).

The calcareous benthic foraminifers comprise numerous gavelinids (Plate III: J–Q) and forms from genera *Cibicides* (Plate III: L), *Gyroidinoides* (Plate III: I), and *Epistommina* (Plate III: H). Lagenids are less frequent, including genera *Lagena* (Plate II: R), *Nodosaria* (Plate II: S, V), *Laevidentalina* (Plate II: T), *Dentalina* (Plate II: U), *Pleurostomella* (Plate III: B, C), *Lenticulina* (Plate III: G), ?*Astacolus* (Plate III: F), and ?*Planularia* (Plate III: E). Only single specimen of miliolid group (*Quinqueloculina* sp.) has been found in the echinoderm-foraminiferal limestone (Plate III: A).

5. DISCUSSION

5.1. Biostratigraphy

Planktonic foraminiferal assemblages comprise a few stratigraphically important species, which define a position of the studied limestone succession. The occurrence of *Parathalmanninella appenninica* occurring together with *P. balernaensis*, *Pseudothalmanninella* cf. *ticinensis* and *P.* cf. *subticinensis* is typical of the *P. appenninica* Zone. As the interval zone, its base is defined as the first occurrence (FO) of the zonal marker, and the upper boundary is placed in the FO of *Thalmanninella globotruncanoides*. Based on the correlation of the foraminiferal zonation with other biozonations and chronostratigraphy (Gale et al., 2011), the *P. appenninica* Zone, as the taxon commonly used in the zonations of the Tethyan successions (Caron, 1985; Båk, 1992; Robaszynski & Caron, 1995; Hart et al., 1996; Båk M. & Båk K., 1999; Båk & Oszczyko, 2000; Neagu, 2005) corresponds to the Upper Albian, calibrated by cycle stratigraphy studies in numerical age model as 100–98 Ma (Gale et al., 2011; Ogg & Hinnov, 2012).

The presented foraminiferal data, related to the youngest part of the Tatric carbonate platform are in agreement with the biostratigraphic results coming from the overlying marly strata, which have been studied in this area in other sections (Båk K. & Båk M., 2013). The micropalaeontological material occurring in the overlying marls is more abundant. As a consequence of this, more diversified planktonic foraminiferal assemblages have been determined in the marls, including among others *Planomalina buxtorfii* (Gandolfi), one of several keeled taxa. This species has not been found in the studied limestones. According to the foraminiferal

zonations from the pelagic and hemipelagic succession in Hautes Alps (Gale et al., 2011), which was used in the interregional correlations of the Middle–Upper Albian successions (Ogg & Hinnov, 2012), the FAD and the LAD data of *P. buxtorfii* are within the *P. appenninica* Zone, in its upper part. It may suggest that sedimentation of the youngest limestone succession on the Tatric Ridge terminated in the lower part of the *P. appenninica* Zone.

Besides the planktonic taxa, the foraminiferal assemblages from the studied limestones contain agglutinated forms including numerous specimens of *Plectorecurvoides alternans* (Noth), an index species in benthic zonations of the Carpathian sediments (Geroch & Nowak, 1984; Neagu et al., 1992; Båk et al., 1995; Neagu, 1990; Olszewska, 1997). The stratigraphic range of this zone is much wider than the *P. appenninica* Zone. Its base was reported within the *Biticinella breggiensis* Zone, correlated with the Middle Albian, and the top – in the *Rotalipora reicheli* Zone, corresponded to the Middle Cenomanian (Båk, 2000). In the Carpathians, its frequent occurrence, which is characteristic for the studied succession, was documented from the Upper Albian–Lower Cenomanian substages (Olszewska, 1997; Neagu, 1990; Melinte-Dobrinescu et al., 2015).

5.2. Palaeoecology based on foraminiferal morphogroups

Palaeoecological interpretation of benthic foraminiferal assemblages by means of morphogroup analysis is commonly used in environmental interpretation of the sea floor (Nagy, 1992; Kender et al., 2008; Reolid et al., 2008; Cetean et al., 2011; Setoyama et al., 2011; Båk et al., 2014; Melinte-Dobrinescu et al., 2015). The morphogroup concept use the idea that species with the same test shape have the same life-style and feeding strategies, and in this way, distribution and abundance of morphogroups can reflect changes in selected environmental parameters (Jones & Charnock, 1985; Kaminski et al., 1995; Kaminski & Gradstein, 2005; Murray et al., 2011).

The agglutinated and calcareous foraminifera from the limestones studied are treated separately, and are arranged in separate morphogroup sets.

5.2.1. Agglutinated foraminiferal morphogroups

The agglutinated assemblages are dominated by elongated tapered and subcylindrical forms including *Pseudonodosinella*, *Reophax*, *Ammobaculites*, *Eobigerina*, *Gerochammina*, *Verneuulinodes*,

Marsonella and *Dorothia*. They comprise 62.5% of the total number of assemblages among the agglutinated taxa (Fig. 2). Elongated, uniserial forms (*Reophax*, *Pseudonodosinella*) as detritivore and bacterial scavengers (Nagy, 1992; Tyszk, 1994) may live as deep infauna that was documented on the basis of observations of their modern counter-parts (Mackensen & Douglas, 1989; Hunt & Corliss, 1993; Kaminski *et al.*, 1995). *Reophax* may live both in shallow-water (lagoonal) environments (Hughes, 2000), through the mid to outer shelves (e.g. Olóriz *et al.*, 2006; Reolid *et al.*, 2008), up to deep-water settings (Schafer *et al.*, 1981). *Pseudonodosinella* is typical of bathyal-abyssal environments (Geroch & Kaminski, 1995). Similar ecologic features are related to occurrence of other elongated uniserial forms from genera *Ammobaculites* and *Bulbobaculites* possessing initial coiled phase (Barnard *et al.*, 1981; Nagy, 1992; Tyszk, 1994; Hughes, 2004). These taxa are less tolerant for low oxygen content in the sediments. In mid-Cretaceous pelagic/hemipelagic facies, their numerous occurrence is related to red coloured, oxygenated marls (Bak, 2000; Melinte-Dobrinescu *et al.*, 2015). However, they can also tolerate reduced salinity and oxygen by reducing of uncoiled portion of the test, reducing size and dimensions of grains, which were agglutinated into the test (Barnard *et al.*, 1981; Jenkins, 2000; Hughes, 2004; Reolid *et al.*, 2008). Elongated subcylindrical taxa, which are represented in the sediments studied by *Eobigerina*, *Gerochammina*, *Marsonella* and *Dorothia* were interpreted as deep infaunal forms (e.g. Nagy, 1992; Tyszk, 1994; Bak, 2004; Cetean *et al.*, 2011; Löb & Mutterlose, 2012; Reolid *et al.*, 2012; Nikitenko *et al.*, 2013).

The elongated forms are associated in the limestones with plano-convex trochospiral (*Trochammina*) and rounded trochospiral/ streptospiral (*Recurvoides* and *Thalmanammina*) taxa, which consists of 33.3% of the total number of agglutinated tests. Flattened planispiral/streptospiral taxa (*Ammodiscus*, *Glomospira* and *Repmanina*) are very rare, not exceeding 5% (Fig. 2). All mentioned above morphogroups are interpreted as epifauna with various feeding strategies, as active or passive herbivores, detritivores and omnivores, similarly as was suggested by Jones & Charnock (1985), Nagy (1992), Tyszk (1994), Bornmalm *et al.*, (1997), Jenkins (2000), Kaminski & Gradstein (2005), Reolid *et al.*, (2008). They may live in environments with various concentration of organic carbon, at both well and poorly oxygenated bottom water (Jenkins, 2000), however, they may be frequent at sea floor with low oxygen content in sediment-water interface (Jenkins, 2000 or as opportunists in stress environments (Bak, 2000; 2007).

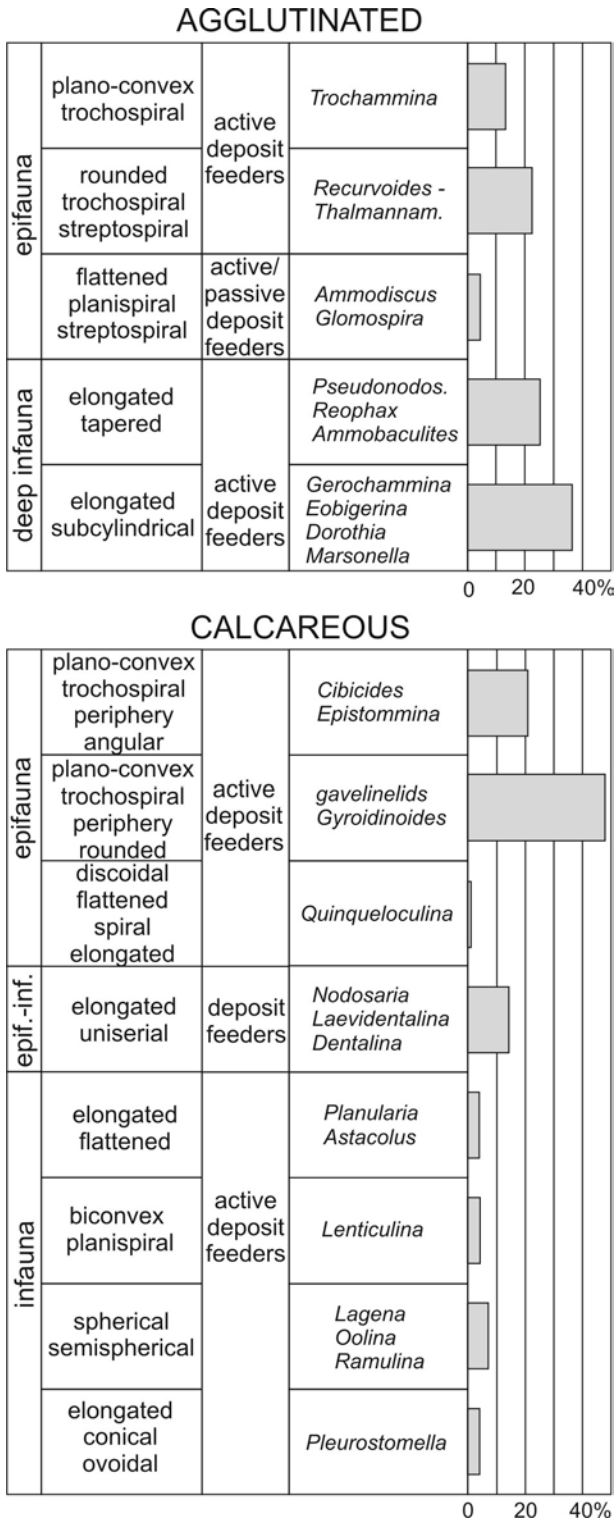


Figure 2. Percentage content of foraminiferal morphogroups according to test morphology and feeding strategies, calculated separately for agglutinated and calcareous assemblages; the Upper Albian limestone, Tatra Mountains, Inner Carpathians.

5.2.2. Calcareous benthic foraminiferal morphogroups

The calcareous benthic assemblages are dominated by plano-convex trochospiral forms with rounded periphery, including mainly gavelinellids,

which are associated with *Gyroidinoides* (48% of the total number of the calcareous tests; Fig. 2). They are interpreted as epifaunal active deposit feeders, which favored life conditions especially on calcareous sediment (Hradecka, 1993), under well oxygenated bottom water conditions (Kaiho, 1994, 1999). Gavelinellids are typical of shelf environments (Gawor-Biedowa, 1972; Peryt, 1983; Hradecka, 1993; Speijer & Van der Zwaan, 1996; Tyszk, 2006). *Gyroidinoides* that occurs subordinately in the sediments studied is not sensitive to changes in oxygen and nutrient contents, occurring both in oligotrophic, well-oxygenated and mesotrophic environments (Dubicka & Peryt, 2012a, 2012b).

Other planoconvex trochospiral forms, characterized by angular periphery of the tests are the second group in the calcareous benthos (20%; Fig. 2), interpreted to be epifaunal grazing herbivores. *Epistommina* and *Cibicides*, included to this group are forms typical of outer shelf environment (Samson, 2001; Olóriz et al., 2006).

A single miliolid specimen from genus *Quinqueloculina*, found in the studied material belongs to the group, which occurs generally in intertidal zone and inner shelf of the modern environments (Bandy & Arnal, 1957), however, some of them may occur in deeper shelf (Jorissen, 1987). They are tolerant to a wide range of environmental conditions (Murray, 1991).

All three morphogroups of the calcareous benthos, described above are interpreted as epifauna. Epifaunal taxa but also adapted to shallow infaunal habitats are characterized by elongated uniserial tests, containing *Nodosaria*, *Laevidentalina*, *Dentalina* and *Ramulina* in the sediments studied. Their shallow infaunal position in the sediment and feeding strategy as deposit-feeders to grazing omnivores and/or bacterial scavengers were suggested among others by Koutsoukos et al., (1990) and Tyszk (1994).

Elongated and sphaerical/semisphaerical forms with flattened, biconvex and conical test morphology are characteristic of infaunal taxa, which comprise about 20% of total content of the calcareous benthos. However, part of them, discoidal flattened and biconvex forms including *Planularia*, *Astacolus* and *Lenticulina* may live also as epifauna in open marine outer shelves (e.g. Bernhard, 1986; Tyszk, 1994; Olóriz et al., 2003, 2006; Löb & Mutterlose, 2012).

5.2.3. Interpretation

Foraminiferal assemblages in modern deep-water environments are controlled by organic carbon flux to the sea floor and the oxygen concentration in the bottom waters and the uppermost part of the

sediment (e.g. Hunt & Corliss, 1993; Jorissen, 1987; Jorissen et al., 1995; Kaminski et al., 1995; Kaiho, 1994, 1999; Gooday & Rathburn, 1999; de Rijk et al., 2000; Gooday et al., 2000; Wollenburg & Kuhnt, 2000; Szarek et al., 2007; Murray et al., 2011). Water depth could be another factor affecting the benthic foraminiferal assemblages. The presented above composition of agglutinated and calcareous morphogroups points to lack of distinct dominance of life style and feeding strategy of the particular species.

A comparison of the morphogroup composition with the TROX ecological model by Jorissen et al., (1995) explaining benthic foraminiferal microhabitat preferences, shows the mesotrophic environment with deep position of the redox-front in the sediments studied. High level of bioturbation visible in thin sections of the rocks caused that organic matter was transported to deeper sediment layers, where it provided the nutritional conditions to agglutinated and calcareous infaunal forms. A relatively high proportion of infaunal foraminifers within the agglutinated assemblages could be indicative of enhanced input of nutrients to the basin floor. The origin of the nutrients was most probably related to high primary productivity. A confirmation of such phenomena is an occurrence of highly phosphatized sediments at the top of the studied succession. According to Krajewski (1981; 1984), the phosphate pizolites and phosphate cementation of grains occurring directly above the echinoderm-foraminiferal limestone developed in microenvironments rich in organic matter.

Concluding, the well-oxygenated bottom water conditions with an enhanced rate of organic matter flux from surface plankton production characterized the sea floor of elevated block of the Tatic area during the Late Alban.

5.3. Palaeobathymetry

Sedimentary features of the limestone studied, *i.e.* homogenous texture of the rocks consisting mostly of micritic grains with calcareous biogenic particles of similar dimensions (up to 500 µm in diameter; 50–200 µm on average), and a lack of lamination are suggestive of very slow sedimentation, related rather to “flat” surface of the shelf than to an inclined area (slope). From sedimentological point of view, the lack of tempestites in the limestone studied suggests that the sea floor was located below storm-driven wave base.

Comparison of foraminiferal morphogroups may help in reconstruction of palaeobathymetry of marine sedimentary basins (Kaminski & Gradstein, 2005; Murray et al., 2011; Setoyama et al., 2011).

Tubular agglutinated taxa are practically absent in the studied assemblages, what is characteristic feature of modern marginal and shelf environments (Murray et al., 2011). It is also known from various Mesozoic shelf-derived carbonate sediments (e.g. Krajewski & Olszewska, 2007; Dubicka & Peryt, 2012b; Olóriz et al., 2003; Reolid et al., 2008, 2013). Lack of forms with quinqueloculine coiling (excluding a single specimen of *Quinqueloculine* sp., most probably reworked) shows that the sea floor was significantly below depths, which are characteristic of marshes and lagoons (Murray et al., 2011). Modest amounts of multilocular, trochospiral agglutinated taxa (*Trochammina*) suggest deeper parts of the shelves, even below the neritic depths for the studied environment (Murray et al., 2011). Dominance of epifaunal forms among the calcareous benthic foraminifers is typical of shelves, both in their internal and external parts (Reolid et al., 2008). In turn, a high abundance (53%) of agglutinated taxa vs calcareous benthic forms, and enhanced content of agglutinated taxa with streptospiral coiling (*Recurvoides*, *Thalmanammina*, *Plectorecurvoides*), is typical of bathyal depths (Kaminski & Gradstein, 2005 and references therein). However, the range of abundance of the latter morphogroup is wider. They are also present in elevated amounts on the outer shelf-upper bathyal depths (Setoyama et al., 2011).

Taking into account the presented data, it can be assumed that deposition of the echinoderm-foraminiferal limestone within the elevated block of the demised Tatric platform was located in the outer shelf depths during the Late Albian.

6. CONCLUSIONS

The succession of echinoderm-foraminiferal limestone that is covered by hardground with phosphatic stromatolites represents the youngest part of the Lower Cretaceous carbonate platform of the Tatricum in the Inner Western Carpathians. The demise of this platform, which begun on the Tatric Ridge since the Early Aptian (Masse & Uchman, 1997), finally terminated within the elevated blocks (like that containing the sediments studied) during the *Parathalmaninella appenninica* Chron (in its older part), correlated with the Late Albian.

The composition of foraminiferal assemblages from these limestone suggests that the sea floor of such fragments of the platform was located on the outer shelf depths during that time. It shows on significant immersion of this platform since the Early Albian, when it was partly submerged (Krajewski, 2003). The main reason of

these bathymetric changes was probably eustatic change during the Albian, when the sea level rose by ~50 m culminating during the *P. appenninica* Chron (Grotzsch et al., 1993; Haq, 2014). The tectonic processes, which took place during the Early–Middle Albian (Lefeld, 1968; Masse & Uchman, 1997), expressed by development of neptunian dykes (Krajewski, 2003), could be other important factor in the immersion of this area.

The sea floor on the elevated block of the demised platform was characterized by well-oxygenated bottom water conditions with an enhanced rate of primary organic matter flux.

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