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Foraminiferal and radiolarian biostratigraphy of the youngest (Late Albian through Late Cenomanian) sediments of the Tatra massif, Central Western Carpathians

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ABSTRACT:

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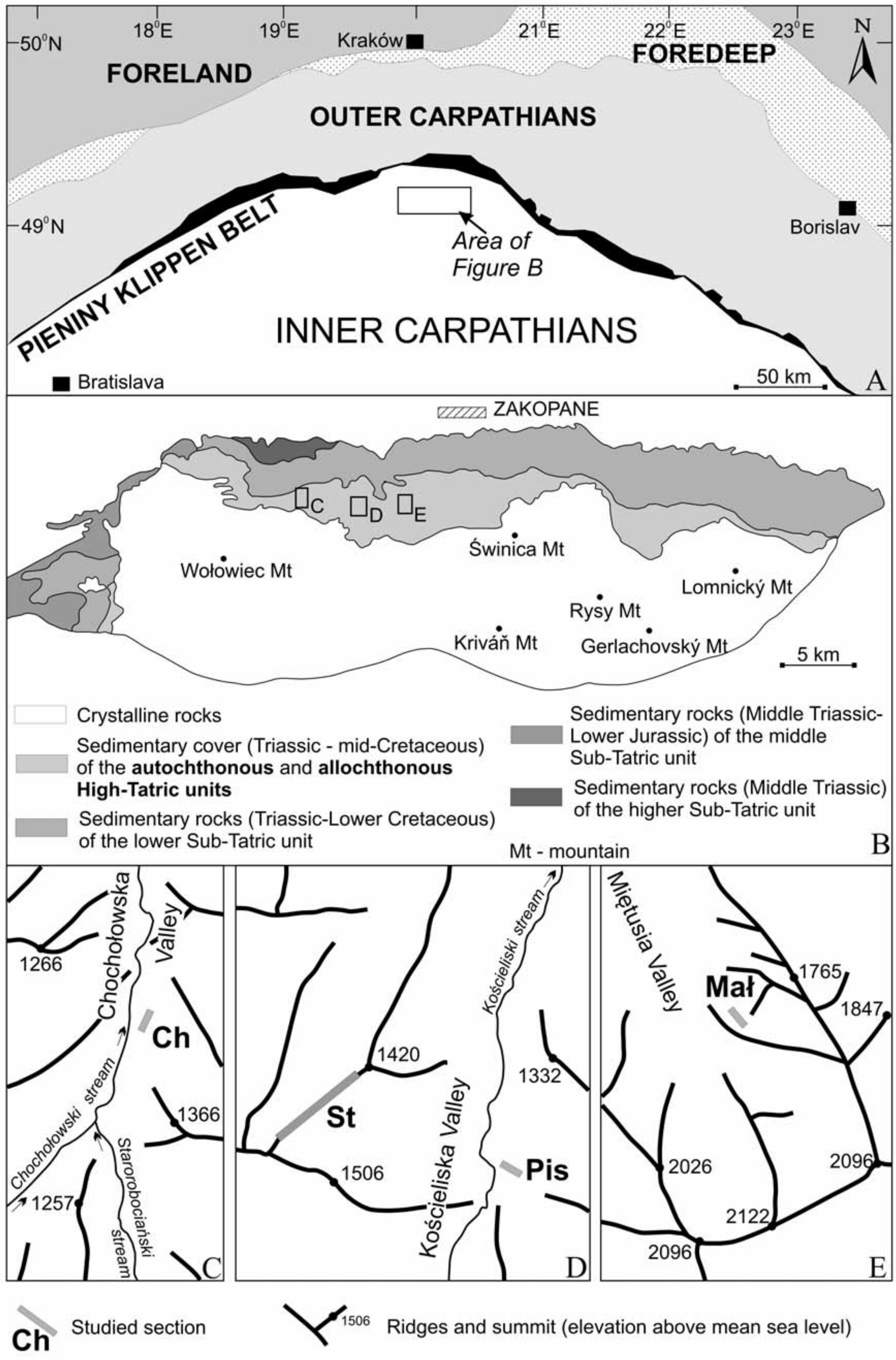
The foraminiferal and radiolarian biostratigraphy of selected sections of the Zabijak Formation, the youngest sediments of the Tatra massif (Central Western Carpathians), have been studied. Benthic foraminifers, mainly agglutinated species, occur abundantly and continuously throughout the studied succession, while planktic foraminifers are generally sparse. Five planktic and two benthic foraminiferal zones have been recognized. The marly part of the Zabijak Formation comprises the *Pseudothalmanninella ticinensis* (Upper Albian) through the *Rotalipora cushmani* (Upper Cenomanian) planktic foraminiferal zones, and the *Haplophragmoides nonioninoides* and *Bulbobaculites problematicus* benthic foraminiferal zones. The radiolarians were recognized exclusively in the Lower Cenomanian part of the formation.

Key words: Albian–Cenomanian; Tatra massif; Biostratigraphy; Foraminifera; Radiolaria.

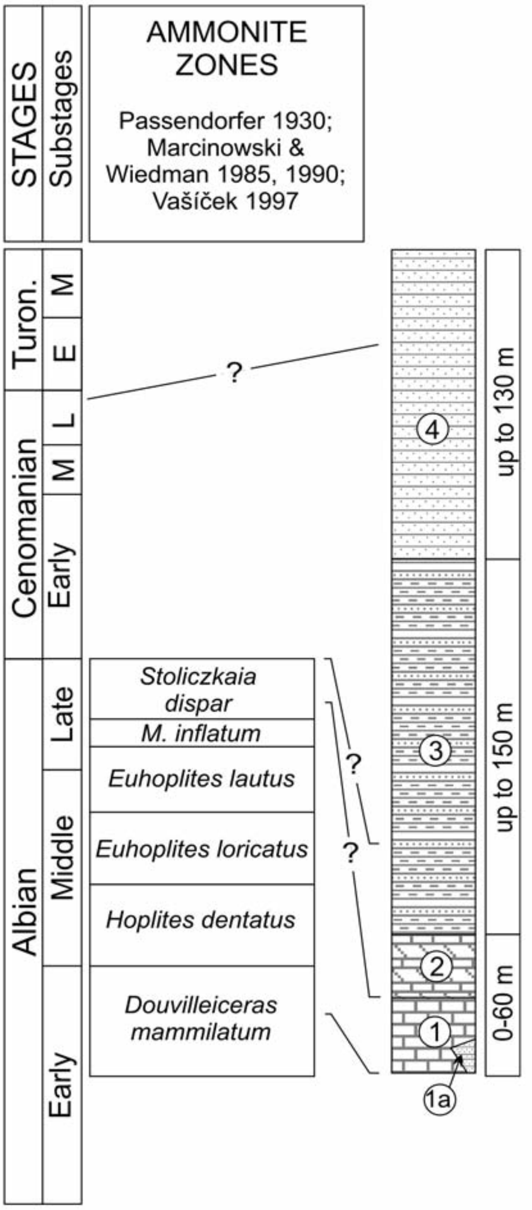
INTRODUCTION

The Tatra Mountains form the highest part of the Central Western Carpathians and are built of two main components: the Palaeozoic crystalline core; and the Mesozoic (Early Triassic–Late Cretaceous) sedimentary sequence, which belongs to several tectonic units, including the High-Tatric autochthonous cover and the overthrust High-Tatric and Sub-Tatric nappes (e.g. Andrusov 1965; Książkiewicz 1977; Froitzheim *et al*. 2008 and references therein; Text-fig. 1). The youngest part of the sedimentary sequence is referred to the Zabijak Formation (Krajewski 2003), dated roughly as Albian– ?Middle Turonian.

Although the biostratigraphy of the Zabijak Formation has been studied intensively, most of the published reports were devoted to its early–late Albian basinal unit, represented by the Żeleźniak Member and the underlying Raptawicka Limestone and Wysoka Turnia Limestone formations. The older reports referred primarily to ammonites. The first stratigraphical results were published by Uhlig (1897, 1908). Based on the ammonites *Puzosia planulata* (Sowerby) and *Stoliczkaia dispar* (d'Orbigny), he suggested Early ("upper Gault") and Late Cretaceous ages for these deposits. Subsequently, detailed biostratigraphic studies of glauconitic and phosphatic limestones in the lower part of the Zabijak Formation were carried out by


50°N
18°E
19°E
Kraków
21°E
22°E
23°E
N
FORELAND
FOREDEEP
OUTER CARPATHIANS
49°N
Borislav
Area of Figure B
PIENINY KLIPPEN BELT
INNER CARPATHIANS
Bratislava
50 km
A
ZAKOPANE
C
D
E
Świnica Mt
Wołowiec Mt
Lomnický Mt
Rysy Mt
Kriváň Mt
Gerlachovský Mt
5 km
Crystalline rocks
Sedimentary cover (Triassic - mid-Cretaceous) of the autochthonous and allochthonous High-Tatric units
Sedimentary rocks (Triassic-Lower Cretaceous) of the lower Sub-Tatric unit
Sedimentary rocks (Middle Triassic-Lower Jurassic) of the middle Sub-Tatric unit
Sedimentary rocks (Middle Triassic) of the higher Sub-Tatric unit
Mt - mountain
B
Chochołowska Valley
1266
Ch
1366
Chochołowski stream
Staroroboclański stream
1257
C
1420
St
1506
Kościeliski stream
1332
Kościeliska Valley
Pis
D
Miętusia Valley
1765
Mał
1847
2026
2096
2122
2096
E
Ch
Studied section
1506
Ridges and summit (elevation above mean sea level)

Passendorfer (1930). Within the autochthonous cover, he dated the Albian transgression as late Early Albian (*Douvilleiceras mammillatum* ammonite Zone). The transgression started later in the Giewont area, in the Middle Albian *Hoplites dentatus* ammonite Zone (Passendorfer 1930; Marcinowski and Wiedman 1985, 1990). The calcareous sedimentation lasted up to the early Late Albian *Mortoniceras inflatum* Zone (Text-fig. 2), as confirmed by a stratigraphically important inoceramid bivalve assemblage comprising *Actinoceramus concentricus* (Parkinson, 1819), *Actinoceramus sulcatus* (Parkinson, 1819) and *Inoceramus anglicus* Woods, 1911 (see Passendorfer 1930).



Text-fig. 2. Local ammonite biostratigraphy for the Zabijak Formation; High-Tatric units in the Tatra Mts. Explanations to lithological column: 1 – glauconitic and phosphatic limestone; 1a – cliff breccias, intrabed gravelstones; 2 – marly limestones and highly calcareous marls, partly phosphatized; 3 – marly shales with very thin-bedded siltstones; 4 – sequence of marlstone/sandstone intervals with laminated siltstone horizons; maximum thickness of the successions after Krajewski (2003)

The age of the youngest sediments of the Zabijak Formation is poorly constrained. From the marls of the allochthonous units, Passendorfer (1930, 1983) reported the Late Albian ammonites *Stoliczkaia dispar* (d'Orbigny), *Halcoscaphites meriani* (Pictet and Campiche), and *Turrilites bergeri* Brongniart. He also noted the planktic foraminifers *Parathalmanninella appenninica* and *Parathalmanninella evoluta*, which indicate a Late Albian through Cenomanian age. In the Orava region of the Slovakian part of the Tatra massif, the same marls yielded the foraminifers *Parathalmanninella appenninica* and *Praeglobotruncana delrioensis* (see Kušik 1959). The Late Albian foraminifers *Ticinella* sp., *Globigerinelloides breggiensis* Gandolfi, *Pseudothalmanninella subticinensis* (Gandolfi), *Planomalina buxtorfi* (Gandolfi) and *Parathalmanninella appenninica* (Renz) were described from the upper part of the Zabijak Formation by Olszewska and Wieczorek (1995). From a still higher interval these authors reported a poorly preserved assemblage of *Dorothia* sp., *Gavelinella* sp., *Hedbergella* sp. and *Rotalipora* sp., with no precise age value.

So far, the youngest fossils reported from the Zabijak Formation are the planktic foraminifers *Praeglobotruncana helvetica* Bolli (= *Helvetoglobotruncana helvetica*) and *Globotruncana renzi* Gandolfi (= *Marginotruncana renzi*) mentioned by Čulova and Andrusov (1964). They indicate the Lower–Middle Turonian *H. helvetica* Zone (*sensu* Robaszynski and Caron 1995). Unfortunately, the authors did not give any details on the source locality or sample location.

The biostratigraphical data published so far suggest thus that an Albian through Middle Turonian age of the Zabijak Formation, albeit only its Albian age is well documented. The present paper provides firm foraminiferal and radiolarian dates for the upper part of the Zabijak Formation, represented by marls and fine-grained turbidites, with the aim of initiating a serious discussion concerning the age of the youngest deposits of the Tatra Mountains.

Text-fig. 1. Geological setting. A – Tatra Mountains against the background of a simplified geological map of the Western Carpathians and their foreland; B – Geological map of the Tatra Mountains (after Książkiewicz 1977; simplified). C-E – Location of the studied sections. C – Dolina Chochołowska valley: Ch – eastern slope of valley below Wyżnia Chochołowska Brama gorge; D – Dolina Kościeliska valley: St – Przełęcz Ku Stawku pass between Stoły Hill and Raptawicka Turnia Mt, Pis – Hala Pisana alp; E – Dolina Miętusia valley: Mał – Żleb Kobylarz gully below Małołączniak Mt.

GEOLOGICAL SETTING

The sedimentary rocks of the Tatra massif are composed of the High-Tatric and Sub-Tatric units (e.g., Świderski 1921; Rabowski 1925, 1931; Sokołowski 1959; Text-fig. 1B). The High-Tatric units consist of the para-autochthonous sedimentary cover of the crystalline core, and of the allochthonous units, comprising (from west to east) the Czerwone Wierchy, Giewont and Široka nappes. The High-Tatric units are composed of Lower Triassic through Upper Cretaceous, mainly calcareous deposits. The Sub-Tatric nappes, built of deposits of similar age, were uprooted from their original crystalline basement and thrust from the south over the High Tatric units during pre-'Senonian' times (Jurewicz 2005 and references therein).

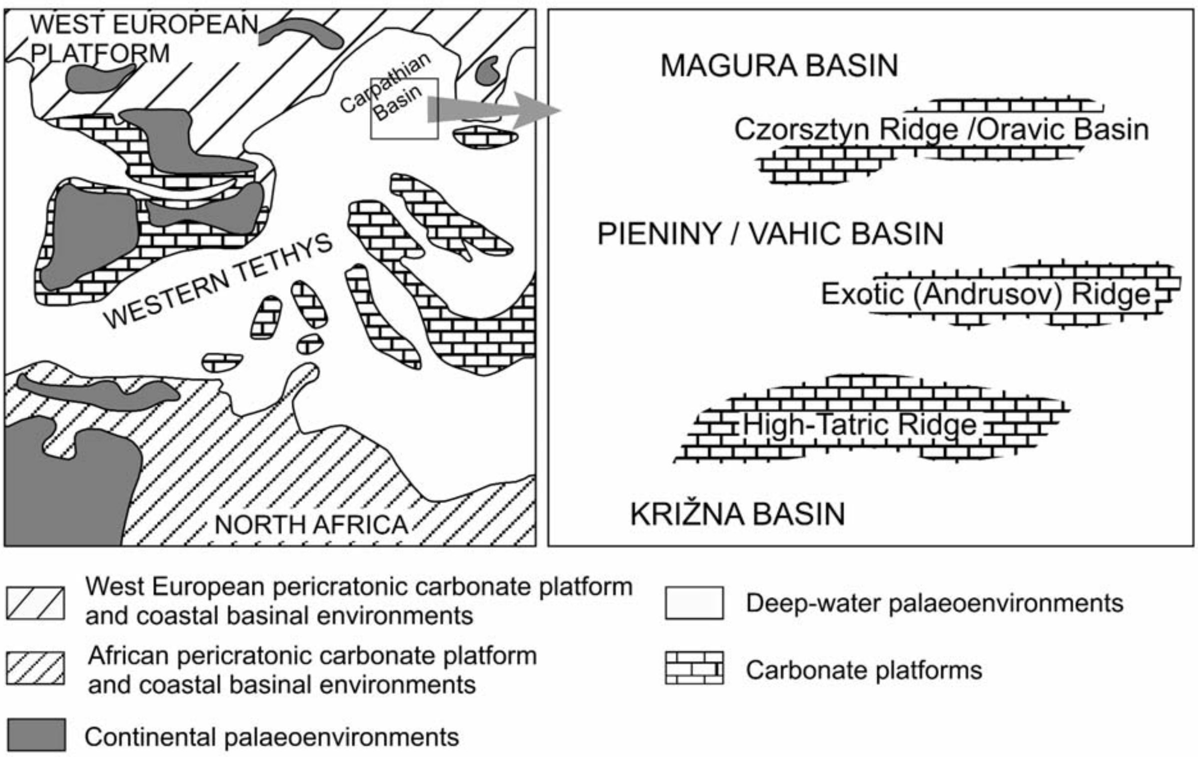
During the Mesozoic, the Tatras (Tatricum, Fatricum and Hronicum *sensu* Biely 1990), as a part of the Central Western Carpathian area, were situated in the Western Tethys domain, between the European and African plates (e.g., Ricou *et al*. 1996; Plašienka 1999; Text-fig. 3). The palaeomagnetic data (Grabowski 1997) from the pre-thrusting components in the Tatra massif indicate their proximity to the European plate at least in the post-Early Aptian/pre-Coniacian time span. Open marine conditions with pelagic and hemipelagic sedimention characterized the Tatras during the Early and mid-Cretaceous. The marine sedimentation lasted up to a stage of compressional deformations of the Central Carpathians (?Late Cenomanian–Turonian), which resulted in the folding and thrusting of the High- and Sub-Tatric nappes (Jurewicz 2005 and references therein).

Lithostratigraphy

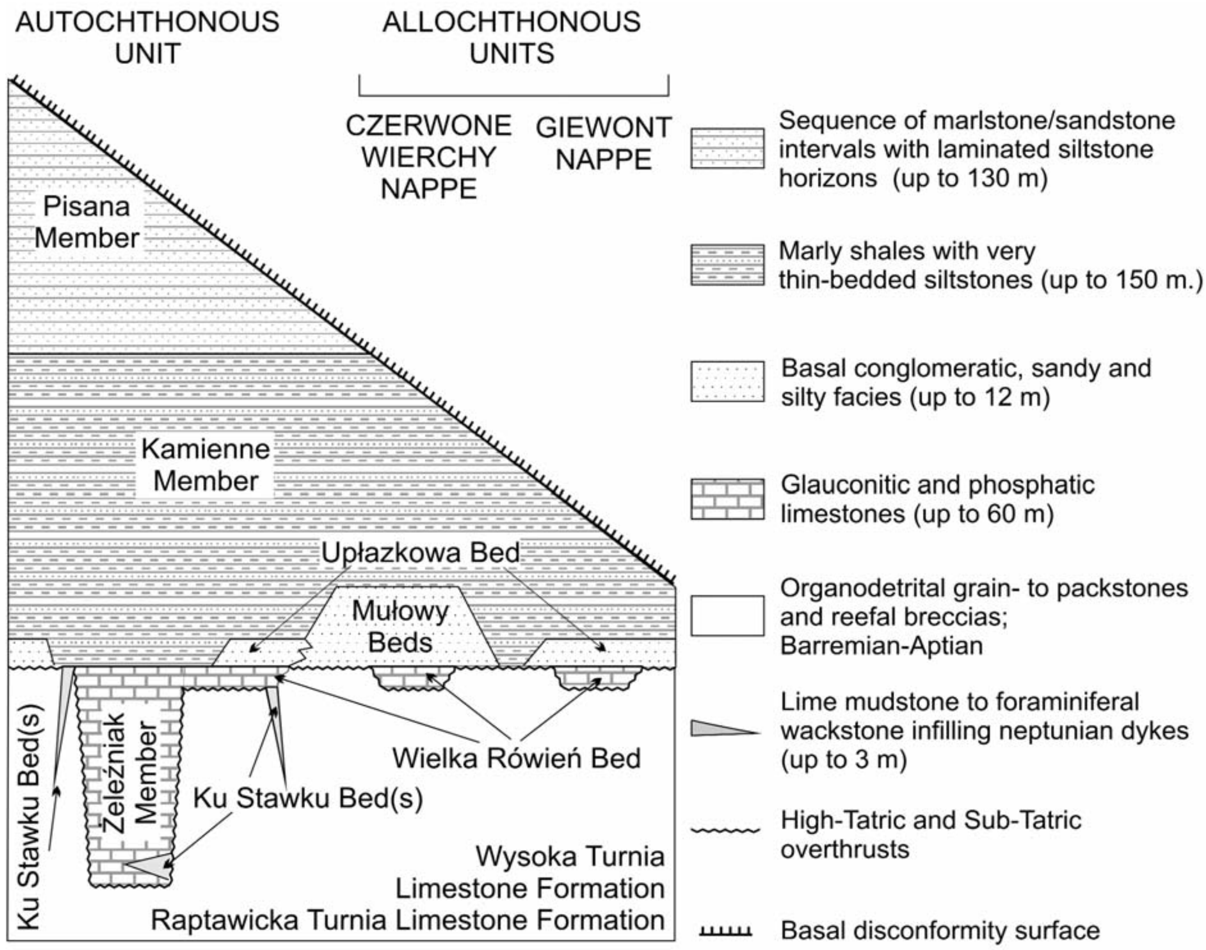
The youngest deposits of the High-Tatric units occur both within the sedimentary cover and in the allochthonous units. In the Polish part of the Tatra Massif, these deposits belong to the Zabijak Formation (Krajewski 1985, 2003), whereas in the Slovakian part they are referred to the Porúbka Formation (Nemčok *et al*. 1995).

The Zabijak Formation lies transgressively on the Valanginian–Lower Aptian rocks or is in tectonic contact with the older sedimentary basement (Passendorfer 1930; Kotański 1959; Lefeld 1968, 1973, 1979). Its complete succession is composed of (Passendorfer 1930; Rabowski 1959; Kotański 1961; Bac-Moszaszwili *et al*. 1979) (from bottom upwards):

(1) Glauconitic and phosphoritic limestones (0–60 m thick); the glauconitic limestones contain an abundant invertebrate fauna and phosphatic concretions



Tex-fig. 3. Late Albian–Cenomanian palaeogeographic reconstruction showing the studied area in the Western Tethys domain and the Carpathian Basin (after Ricou *et al*. 1996; Golonka *et al*. 2000; Birkenmajer 1979; Jurewicz 2005; simplified)



Text-fig. 4. Lithostratigraphic division of the Zabijak Formation (Albian–?Lower Turonian); High-Tatric units in the Tatra Mts (after Krajewski 2003)

(Passendorfer 1930), belonging to the Żeleźniak Member and Ku Stawku Beds (the latter unit as neptunean dikes; Text-fig. 4). The glauconitic limestones are replaced by limestones rich in phosphates with hardgrounds, stromatolites, oncolites and phosphatic pisolites (Niegodzisz 1965; Krajewski 1981a–c, 2003). Exotic crystalline pebbles (Passendorfer 1930) and intraclasts (Rabowski 1959) have been found in the glauconitic limestones.

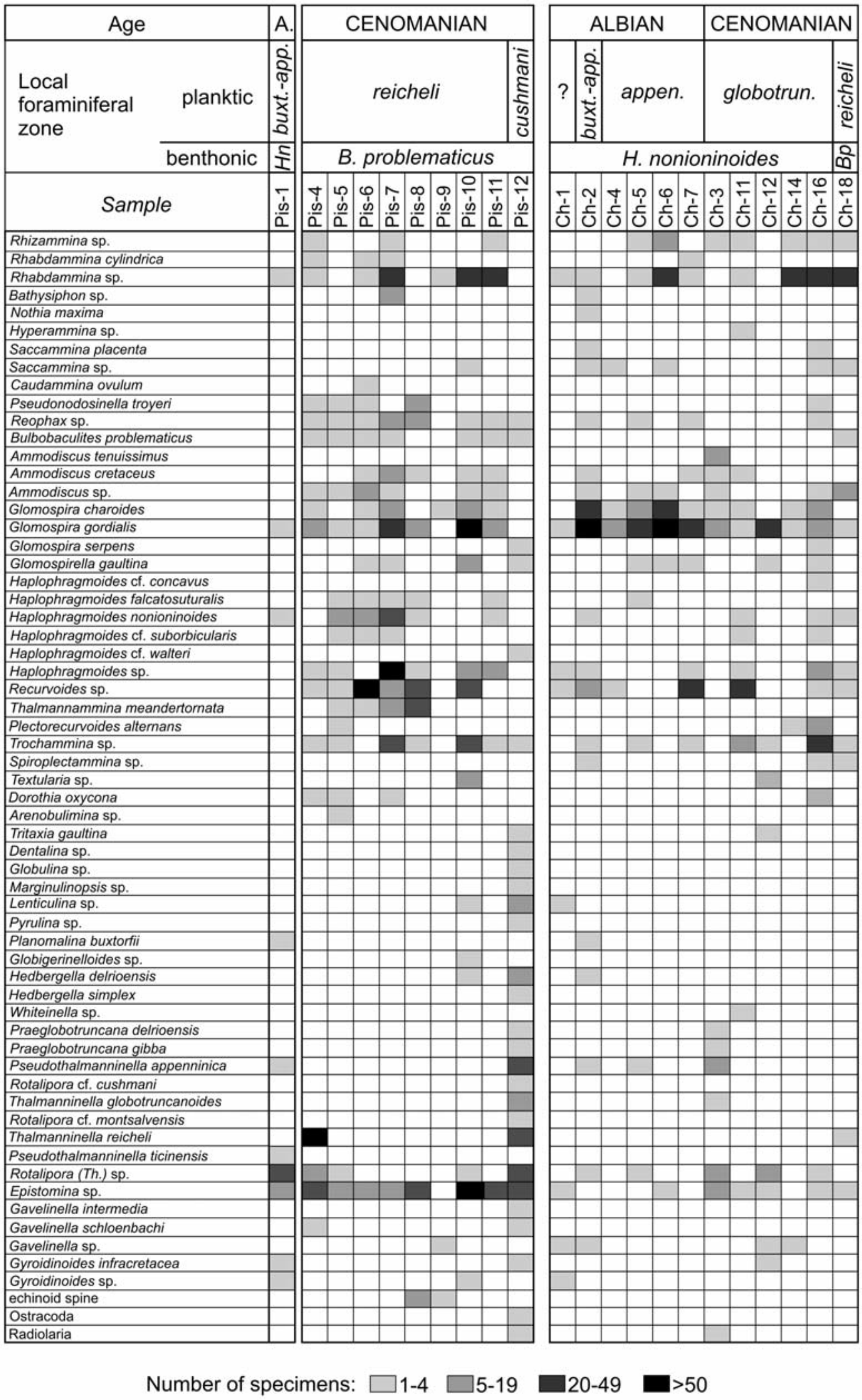
(2) Marly shales intercalated with very thin-bedded siltstones (up to 150 m thick); these are pelagic deposits, intercalated with hemipelagites and turbidites (Kamienne Member; Text-fig. 4). Dark-grey marly shales with fine-grained grey mudstones predominate (Krajewski 2003).

(3) Sequence of marlstone/sandstone intervals with laminated siltstone horizons (up to 130 m thick) (the Pisana Member, Krajewski 2003; Text-fig. 4). Trace fossil assemblages have been determined from these deposits (Bac-Moszaszwili *et al*. 1979; Uchman 1997).

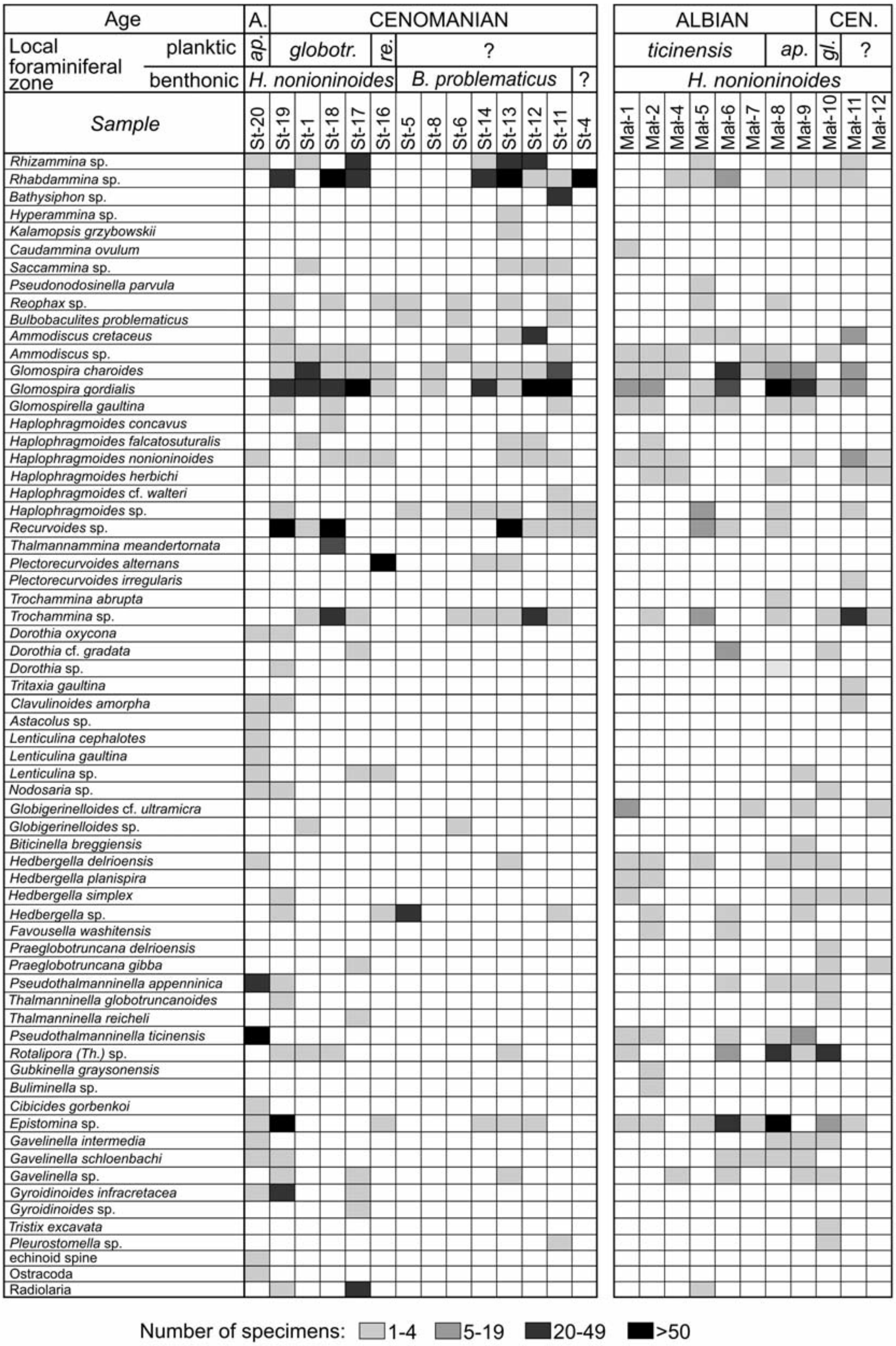
Studied sections

Forty-seven samples have been collected from four sections (Text-fig. 1). Three sections, located in the Dolina Chochołowska valley, on the Ku Stawku pass (between Stoły Hill and Raptawicka Turnia Mt), and in the Dolina Kościeliska valley (Hala Pisana alp), represent the autochthonous unit. The section in the Dolina Miętusia valley (Żleb Kobylarz gully) belongs to the allochthonous unit (Czerwone Wierchy nappe).

Dolina Chochołowska valley (Text-fig. 1C): Pale green marly shales, with subordinate fine-grained muddy intercalations are exposed in the right bank of the old channel of the Chochołowski Potok stream (ca 1020 m a.s.l.), between the Wyżnia and Niżnia Chochołowska Brama gorges. Twelve samples were taken from a 20 m thick succession of the Kamienne Member. The contact with underlying deposits is not exposed.



Text-fig. 5. Occurrence of foraminifera and radiolarians in the Hala Pisana alp and Dolina Chochołowska valley sections *versus* biostratigraphy; benthonic (agglutinated) foraminiferal zones after Geroch and Nowak (1984): *Bp* – *Bulbobaculites problematicus* Zone, *Hn* – *Haplophragmoides nonioninoides* Zone



Text-fig. 6. Occurrence of foraminifera and radiolarians in the Przełęcz Ku Stawku pass and Żleb Kobylarz gully sections *versus* biostratigraphy; benthonic (agglutinated)foraminiferal zones after Geroch and Nowak (1984); *ap. – Parathalmanninella appenninica* Zone, *gl. – Thalmanninella globotruncanoides* Zone, *re. – Thalmanninella reicheli* Zone

Przełęcz Ku Stawku Pass (Text-fig. 1D): Grey, pale green to grey and dark grey marly shales, intercalated with thin-bedded siltstones and fine-grained sandstones (the Kamienne Member) are exposed on the Pass (1380–1530 m a.s.l.), between Raptawicka Turnia Mt and Stoły Hill, on the left side of the Dolina Kościeliska valley. The silt and sand content increases upsection (transition to the Pisana Member). The Kamienne Member is in a normal tectonic position. These deposits lie on the glauconitic and phosphatic limestones of the Żeleźniak Member (Krajewski 2003) or on Barremian–Aptian limestones in Urgonian facies (Lefeld 1968). The lowest part of the studied deposits is more calcareous, represented by red pelagites with abundant planktic foraminifera. Fourteen samples taken from a 90 m thick succession contain foraminiferal and radiolarian assemblages.

Hala Pisana alp (Text-fig. 1D): The Kamienne Member is represented by pale grey, olive and dark grey marly shales, breaking down to platy shales. Within the shales, there are very rare intercalations of thin-bedded calcareous siltstones. The total thickness of the exposed succession is 40 m. Ten samples were taken from the section located in the west tributary of the Potok Kościeliski stream, cutting the Hala Pisana alp (1020–1050 m a.s.l.).

Żleb Kobylarz gully (Text-fig. 1E): The section is located in the Żleb Kobylarz Gully (1450–1510 m a.s.l.), near the tourist route leading to Małołączniak Mt. White Urgonian limestones at the base of the section are overlain transgressively by the Kamienne Member, composed of dark, black, grey and olive-grey marly shales. Ten samples were taken from the 40 m thick continuous succession. Two samples (Mał-11, 12) were taken from a loose block at the base of the section wall.

MATERIAL AND METHODS

Samples of about 750 g were dried and disaggregated in a sodium sulphate solution. The material was then washed through sieves with mesh diameters of 0.63 µm and 1500 µm. All microfauna was picked and mounted onto cardboard microscope slides. In addition, 20 samples were studied in thin section, in order to observe the relationship of the microfaunas to lithology and bioturbation. The photographs were taken under the scanning electron microscope in the Electronic Microscopy Laboratory in the Zoology Department of the Jagiellonian University.

The material is housed in the Institute of Geography, Pedagogical University of Cracow (collection No 08T).

FORAMINIFERAL ASSEMBLAGES

The foraminiferal material comprises predominantly agglutinated foraminifers with varying admixtures of calcareous benthic and planktic forms. A total of 78 species-level taxa were recognised, 43 of which are agglutinated, 18 calcareous benthics, and 17 planktic (Text-figs 5, 6).

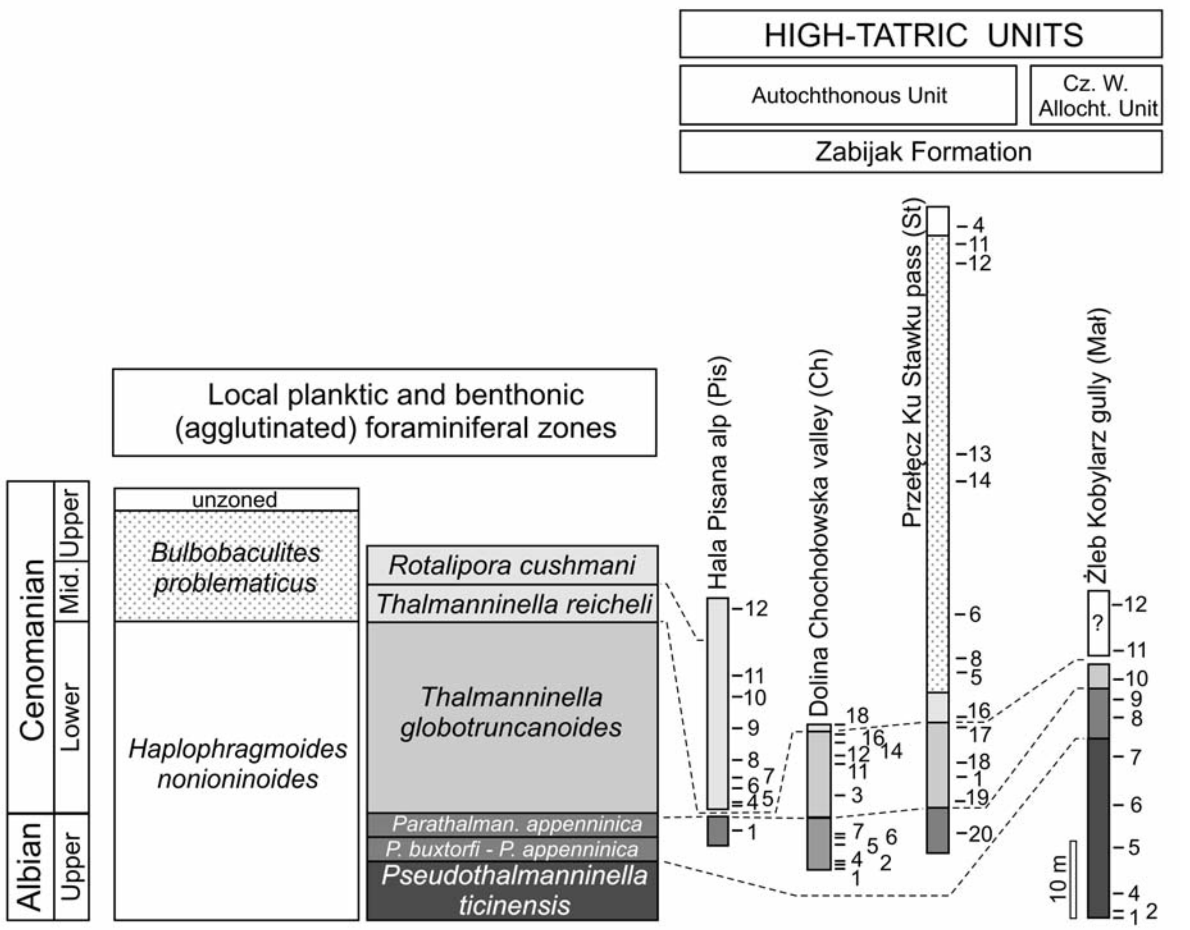
The agglutinated foraminifers are dominated by siliceous-walled forms, with *Glomospira* (Pl. 1, Figs E, G, H), *Ammodiscus* (Pl. 1, Fig. F), *Recurvoides, Trochammina* (Pl. 1, Figs O, P) and tubular forms (Pl. 1, Figs A–C) such as *Rhizammina* and *Rhabdammina* among the main genera. Stratigraphically important is the presence of *Haplo-phragmoides nonioninoides* (Reuss) (Pl. 1, Figs R–T), *H*. cf. *walteri* (Grzybowski) (Pl. 1, Figs W–Y), *Plectorecurvoides alternans* Noth (Pl. 2, Figs C–F), and *Bulbobaculites problematicus* (Neagu) (Pl. 2, Figs C–F). The content of agglutinated foraminifers increases significantly upsection.

Calcareous benthic foraminifers are dominated by *Epistomina* (Pl. 2, Figs V, W), *Gavelinella* (Pl. 2, Figs T, U) and *Gyroidinoides* (Pl. 2, Figs O–R), with epistominids being the most dominant forms. The benthic forms represent up to 25% of the whole assemblages.

Phosphatised planktic foraminifera are generally poorly-preserved. They form a significant part of the microfossil assemblages in the lower part of the succession. They are dominated by *Pseudothalmanninella subticinensis* (Gandolfi) and *Pt. ticinensis* (Gandolfi) (Pl. 3, Figs H, I), with rare *Planomalina buxtorfii* (Gandolfi). The planktic foraminifera are also rich in the middle part of the Kamienne Member, where rotaliporids, with abundant *Parathalmanninella appenninica* (Renz) (Pl. 3, Figs J–L), dominate, composing almost 100% of the microfaunal assemblage. These deposits also contain other stratigraphically siginificant planktic forms such as *Thalmanninella globotruncanoides* (Sigal) (Pl. 3, Fig. M) and *Th. reicheli* (Mornod) (Pl. 3, Fig. N–P). The highest part of the Kamienne Member yielded *Rotalipora cushmani* (Morrow) (Pl. 3, Fig. R).

FORAMINIFERAL STRATIGRAPHY

Seven biostratigraphical zones are distinguished based on the succession of planktic (mainly) and ag-



Text-fig. 7. Local planktic and benthic (agglutinated) foraminiferal zones with correlation of the Upper Albian–Cenomanian sections studied. Numbers to the right of the section columns relate to sample numbers

glutinated benthic foraminifera (Text-fig. 7). The local planktic biozonation is compared with the chronostratigraphic standard and integrated microfossil zonation for the Western Tethys area of Robaszynski and Caron (1995).

Pseudothalmanninella ticinensis interval range Zone

Definition: Its lower boundary is marked by the FO (first occurrence) of *Ps. ticinensis* (Gandolfi), and its upper boundary by the FO of *Planomalina buxtorfii* (Gandolfi) and *Parathalmanninella appenninica* (Renz).
Remarks: This zone was recognised only within the allochthonous succession of the Czerwone Wierchy Unit. Planktic foraminifera are rare, represented by single age-diagnostic rotaliporids and *Hedbergella* spp. Relatively abundant *Globigerinelloides bentonensis* (Morrow) was found in sample Mał-1. The zone is characterised by relatively common benthic agglutinated taxa: *Glomospira* spp., *Glomospirella gaultina* (Berthelin) and *Ammodiscus* spp. A more diverse agglutinated assemblage was recognised in sample Mał-5, with frequent *Recurvoides*, *Haplophragmoides* and trochaminids.
Age: Early Late Albian, as proposed by Robaszynski and Caron (1995).

Planomalina buxtorfii – Parathalmanninella appenninica concurrent range Zone

Definition: An interval with the co-occurrence of both eponymous taxa.
Remarks: The zone was recognised in the Hala Pisana alp and in the Dolina Chochołowska valley sections. Planktic foraminifers dominate in the assemblage from the Hala Pisana alp section, comprising the index species and *Pseudothalmanninella ticinensis*. The calcareous benthic forms (mainly belonging to th genus *Epistomina*) are poorly-preserved..

Age: Late Late Albian, according to Robaszynski and Caron (1995).

***Parathalmanninella appenninica* interval Zone**

Definition: The lower boundary of the zone is defined by the LO (last occurrence) of *Planomalina buxtorfi* (Gandolfi), and its upper boundary by the FO of *Thalmanninella globotruncanoides* (Sigal).
Remarks: The zone was recognised in the Dolina Chochołowska valley and Żleb Kobylarz gully sections. The assemblage from the Żleb Kobylarz gully section is dominated by planktic and calcareous benthic forms, and is also characterised by diverse agglutinated forms. The Dolina Chochołowska valley section yielded much less diverse benthos, dominated by ammodiscids (56–78%), with subordinate very rare planktic forms and calcareous benthos.
Age: The latest Albian, according to Hardenbol *et al*. (1998) and Caron (1985).

***Thalmanninella globotruncanoides* interval range Zone**

Definition: Its lower boundary is defined by the FO of *Th. globotruncanoides*, and its upper boundary by the FO of *Thalmanninella reicheli* (Mornod).
Remarks: This zone was recognized in the Dolina Chochołowska valley, Ku Stawku pass and Żleb Kobylarz gully sections. In all three sections, the zone is dominated by agglutinated benthos, primarily *Glomospira gordialis* (Jones and Parker), *G. charoides* (Jones and Parker), and other ammodiscids. Several samples are characterised by frequent *Haplophragmoides nonioninoides* (Reuss), *Plectorecurvoides alternans* Noth, *Recurvoides* spp., *Thalmannamina meandertornata* Neagu and Tocorjescu and trochaminids. The astrorhizid content increases in the upper part of this zone. Planktic foraminifers are rare, their content varying from 0 to 52%. Besides the index species, *Parathalmanninella appenninica*, *Praeglobotruncana delrioensis* (Plummer), *Praeglobotruncana gibba* Klaus, *Globigerinelloides bentonensis* (Morrow), ?*Whiteinella* sp. and hedbergellids occur in these deposits.
Age: Early Cenomanian. The FO of *Thalmanninella globotruncanoides* is a marker for the base of Cenomanian (Kennedy *et al*. 2004).

***Thalmanninella reicheli* interval range Zone**

Definition: The lower boundary is defined by the FO of *Th. reicheli*, and its upper boundary by the FO of *Rotalipora cushmani* (Morrow).
Remarks: This zone has been recognised the Dolina Chochołowska valley, Hala Pisana alp and Ku Stawku pass sections. Planktic foraminifers, represented by *Parathalmanninella appenninica* (Renz), *Thalmanninella reicheli*, *Th. globotruncanoides*, *Rotalipora montsalvensis* Mornod, *Praeglobotrunca delrioensis*, *Pr. gibba*, *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan) and *H. simplex* (Morrow), are abundant in only a few samples. The relatively diverse benthic forms are are dominated by agglutinated taxa. The abundance of *Recurvoides* spp., *Plectorecurvoides alternans* Noth and *Thalmannammina* spp. increases significantly upward. The succession of the Hala Pisana alp section is characterised by calcareous foraminifers, with a high content of epistominids (up to 30%).
Age: Middle–Late Cenomanian (the FO of *Thalmanninella reicheli* was proposed as a potential marker of the base of the middle Cenomanian substage, see Tröger and Kennedy 1996).

***Rotalipora cushmani* taxon range Zone**

Definition: The zone is defined by the range of its index taxon.
Remarks: The zone was recognised in the Hala Pisana alp section. The zone is characterised by taxonomically diverse rotaliporids, represented by *Rotalipora cushmani* (Mornod), *Parathalmanninella appenninica* (Renz), *Thalmanninella reicheli*, *Th. globotruncanoides*, *Rotalipora montsalvensis*, *Praeglobotrunca delrioensis*, *P. gibba*, *Hedbergella delrioensis*, *H. planispira* and *H. simplex*. The relatively diverse benthic foraminifers are dominated by calcareous forms, with numerous specimens of epistominids.
Age: Late Middle–Late Cenomanian (Robaszynski and Caron 1995). The LO of *Rotalipora cushmani* is diachronous in various environments, mainly due to expansion of the oxygen minimum zone in the water column during the OAE2 (e.g., Desmares *et al*. 2007; Oba *et al*. 2011).

***Bulbobaculites problematicus* interval range Zone**

Definition: The lower boundary of the zone is defined by the FO of *Bulbobaculites problematicus* (Neagu), and its upper boundary by the FO of *Uvigerinammina* ex gr. *jankoi* Majzon.
Remarks: This is the zone of *B. problematicus* of Geroch and Nowak (1984). It has been recognised in the Dolina Chochołowska valley, Hala Pisana alp and Ku Stawku pass sections. Its lower part is time-equvalent to the *Thalmanninella reicheli* Zone. Above the LO of

Th. reicheli (Mornod), the foraminiferal assemblage is dominated by agglutinated foraminiferal genera: *Glomospira*, *Ammodiscus*, *Haplophragmoides*, *Trochammina*, *Recurvoides* and tubular forms. In the upper part of the zone the index taxon is rare. Planktic foraminifers are scarce and poorly-preserved above the LO of *Th. reicheli*. Calcareous benthos, except for single specimens of *Epistomina* and *Gavelinella*, is rare throughout the zone.
Age: Middle–Late Cenomanian.

DISCUSSION ON AGGLUTINATED FORAMINIFERAL STRATIGRAPHY

In the absence of age-diagnostic planktic taxa, the succession of selected deep-water agglutinated foraminifers appear biostratigraphically applicable. Among potentially useful forms are: *Haplophragmoides nonioninoides* (Reuss), *Plectorecurvoides alternans* Noth, *Bulbobaculites problematicus* (Neagu) and *Haplophragmoides* cf. *walteri* (Grzybowski).

H. nonioninoides ranges from the Upper Albian through to Middle Cenomanian, and is considered a zonal indicator of the Upper Albian. The species possesses a wide bathymetric distribution, ranging from outer shelf through lower bathyal environments (e.g., Geroch 1959; Hanzliková 1966). According to Geroch and Nowak (1984), and Neagu (1990), the FO of *H. nonioninoides* coincides with the base of the Albian, ranging through middle/late Cenomanian in the Outer Carpathians. This is the nominate taxon of Geroch and Nowak's "*H. nonioninoides* Zone" (1984), a partial range zone, of early–middle Albian age. In the same area, Olszewska (1997) reports *H. nonioninoides* from the Barremian through the late Albian. She defines the "*H. nonioninoides* Zone" as an early Albian acme zone.

In the studied sections, *H. nonioninoides* was found sporadically in the lower Upper Albian part of the succession, where the impoverished agglutinated assemblage consists of thin-walled, fine-grained and stratigraphically long-ranging forms (*Ammodiscus* spp., *Glomospira* spp, *Rhizammina* sp.). The occurrence of *H. nonioninoides* increases in the Lower-Middle Cenomanian deposits, where more typical organically cemented "flysch-type" agglutinated species appear and the benthic foraminiferal assemblage shows greater taxonomic diversity.

The FO of *Plectorecurvoides alternans* Noth was reported from the Lower Cenomanian *Th. globotruncanoides* Zone, where it is quite rare. It becomes more abundant in the succeeding Middle Cenomanian *Th. reicheli* Zone. In the Carpathians, this taxon is used as a zonal marker of the eponymous zone (Geroch and Nowak 1984; Neagu 1990; Olszewska 1997; Bąk 2000). Its FO was precisely defined in the Pieniny Klippen Belt sections (pelagic sediments) within the *Biticinella breggiensis* planktic foraminiferal Zone, corresponding to the Middle Albian (Bąk 2000). *P. alternans* was described exclusively from deep-water environments of the Western Tethys; Carpathians, Alps (Noth 1952) and the Morocco Numidian Flysch (Morgiel and Olszewska 1981). It seems that upper–middle bathyal depths were its upper depth limit. Thus, its apparent absence from the Upper Albian deposits of the Tatra sections may suggest a shallower depth of the basin floor during this time.

Another stratigraphically important species is *Bulbobaculites problematicus* (Neagu), which was found in the Tatra sections in the Middle Cenomanian *Th. reicheli* Zone. Its FO datum is still unclear. Neagu (1990) reported this species from the lower Albian of the flysch Eastern Carpathians in Romania. Olszewska (1997), in her composite zonation for the Polish Outer Carpathians, reports its oldest occurrences in the uppermost Albian (together with *Planomalina buxtorfi* and *Rotalipora appenninica*). In the North and the South Atlantic and their marginal basins, the species appears first much later, namely directly above the anoxic deposits of the Cenomanian–Turonian boundary event, which was attributed, at least in part, to a first occurrence of red, oxic sedimentary environments in these areas (Kuhnt and Kaminski 1990). In the Pieniny Klippen Belt, *B. problematicus* appears (independent of facies) near the base of the Middle Cenomanian *Th. reicheli* Zone (Bąk 2000).

Thus, the FO of *B. problematicus* near the base of *Th. reicheli* in the Tatra sections, is in full agreement with observations from the Pieniny Klippen Belt area (Bąk 2000). Its rare occurrence in the studied deposits seems to be linked with poorly-oxygenated bottom water.

In the upper part of the Zabijak Formation, above the *Th. reicheli* Zone, occurs *Haplophragmoides* cf. *walteri.* Its small morphotypes, characterised by six chambers in the last whorl, a circular outline, and distinctly depressed sutures, were found in sample St-11 (Ku Stawku pass section) within a diverse agglutinated foraminiferal assemblage. *Haplophragmoides walteri*, common in the Paleogene, was reported as *H.* cf. *walteri* from the Upper Cretaceous (Hemleben and Troester 1984; Kuhnt and Kaminski 1989, 1990) of the North Atlantic and the Western Tethys (southern Spain, Umbrian Appenines). In the Carpathians, it appears first in the uppermost Cenomanian or lowermost Turonian (Bąk 2000, 2007a, b; Bąk *et al*. 2005). The presence of *H*. cf. *walteri* in the Zabijak Formation may thus suggest a Cenomanian–Turonian boundary interval for this part of the succession. It must be admitted, however, that noneof the truly Turonian benthic foraminifers (e.g., *Uvigerinammina jankoi*) has been found here.

RADIOLARIAN ASSEMBLAGES

Radiolarians are rather scarce in the studied sediments. However, well preserved specimens have been found in several Upper Albian and Cenomanian samples. The assemblage includes spumellarians belonging to *?Archaeocenosphaera mellifera* O'Dogherty and *Mallanites triquetrus* (Squinabol), and nassellarians such as *Stichomitra communis* Squinabol, *Dictyomitra montisserei* (Squinabol) and *Holocryptocanium tuberculatum* Dumitrica. These taxa were described from analogous sediments in the Pieniny Klippen Belt (Bąk 1993, 1996, 1999), the Polish Outer Carpathians (eg. Bąk 2004) and Apennines (Bąk 2011) but in those areas they form part of a more diverse assemblage.

The low frequency of radiolarians in the Tatric sediments could be interpreted here as reflecting a dilution effect, caused by higher detrital input in the Tatra Basin than in the pelagic environment of the Pieniny Klippen Belt and the Umbria-Marche basins. Confirmation of this is a positive correlation between the content of radiolarian specimens and tubular astrorhizids in the studied samples. As a general rule, the astrorhizids reach an acme in environments affected by frequent bottom currents (e.g., Kaminski and Gradstein 2005; Szarek *et al*. 2009). The radiolaria occur here in the samples where the frequency of astrorhizids decreases, indicating a trend towards an increase in pelagic sedimentation. Another cause might be a water column insufficiently saturated with respect to silica, and a low rate of pelletization. Such circumstances create a higher probability of dissolution of radiolarian skeletons (cf. Bąk 2011).

The recognised radiolarian species are consistent with the age assignment based on foraminiferal assemblages. *Dictyomitra montisserei* (Pl. 3, Fig. X) and *Holocryptocanium tuberculatum* (Pl. 3, Fig. T) recognised in sample St-17 indicate that these deposits are not older than Early Cenomanian. The total range of *D. montisserei* is Albian–Cenomanian (O'Dogherty 1994), while the lower limit of *H. tuberculatum* reported by Dumitrica (1970) and Pessagno (1977) is Early Cenomanian. *Mallanites triquetrus* (Pl. 3, Fig. S) from sample Ch-3 also indicates an Early Cenomanian age based on its range calculated on Unitary Associations (UA; O'Dogherty 1994). ?*Archaeocenosphaera mellifera* (Pl. 3, Figs U–W) from sample Pis-12 was a rather long-lived species, indicating the Albian–Turonian time-interval (UA 10–21 of O'Dogherty 1994).

CONCLUSIONS

The oldest marly sediments of the Zabijak Formation occur in the allochthonous units (Żleb Kobylarz gully section), and correspond to the *Pseudothalmanninella ticinensis* Zone (Upper Albian). Marly sedimentation within the autochthonous area of the Tatra massif started later, in the *Planomalina buxtorfii* – *Parathalmanninella appenninica* Zone, in the latest Late Albian.

The youngest planktic foraminiferal zone documented is the Middle–Upper Cenomanian *Rotalipora cushmani* Zone.

The uppermost part of the studied succession within the autochthonous unit is represented by the *Bulbobaculites problematicus* Zone, which corresponds to the Middle–Upper Cenomanian, and ranges possibly up to the Cenomanian–Turonian boundary. The Early Turonian planktic and/or benthonic foraminifers were not found.

Radiolarians from the studied sediments are well documented in the lower and middle part of the Zabijak Formation, corresponding to the Lower Cenomanian.

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PLATE 1

Late Albian–Cenomanian agglutinated foraminifera from the Tatra Mts.

A – *Rhabdammina cylindrica* Glaessner (Pis-4);
B – *Rhizammina* sp. (Ch-16);
C – *Hyperammina* sp. (Ch-11);
D – *Saccammina* sp. (Ch-16);
E – *Glomospira serpens* Grzybowski (Ch-16);
F – *Ammodiscus cretaceus* Reuss (Pis-10);
G – *Glomospira gordialis* (Jones and Parker) (Mał-1);
H – *Glomospira charoides* (Jones and Parker) (Mał-2);
I – *Pseudonodosinella parvula* (Tappan) (Mał-5);
J – *Pseudonodosinella troyeri* (Tappan) (Ch-16);
K–N – *Bulbobaculites problematicus* (Neagu), Pis-5 (K), St-6 (L), Pis-10 (M), Pis-11 (N);
O, P – *Trochammina* sp., Mał-5 (S), Mał-11 (T);
R–T – *Haplophragmoides nonioninoides* (Reuss), Pis-5 (B–F, I);
U, V – *Haplophragmoides herbichi* (Neagu), Mał-12 (U), Mał-8 (V);
W–Y – *Haplophragmoides* cf. *walteri* (Grzybowski), Pis-12 (W), St-11 (Y, Z)

Scale bars represent 100 μm

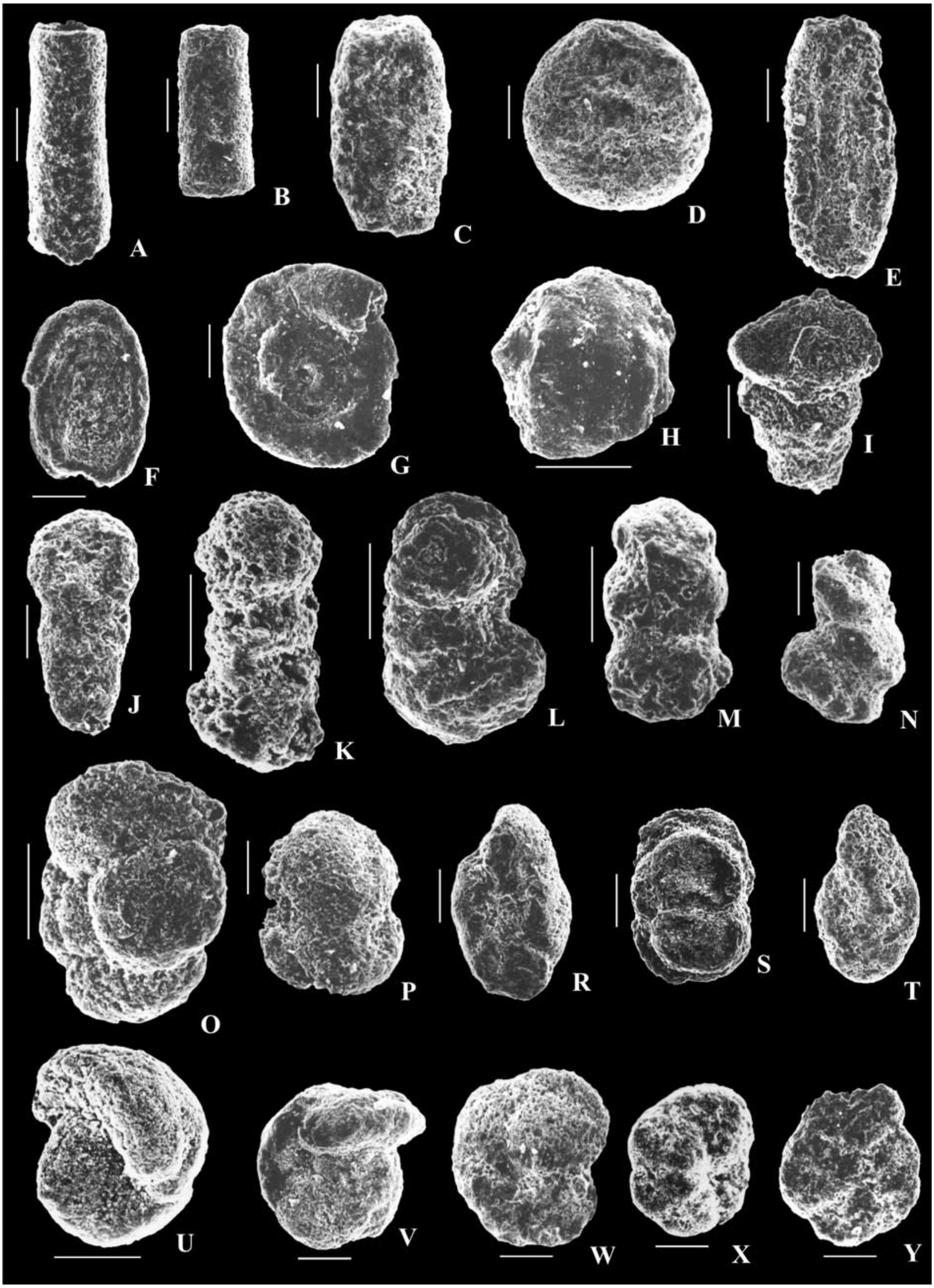
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PLATE 2

Late Albian–Cenomanian agglutinated and calcareous benthic foraminifera from the Tatra Mts.

A, B – *Haplophragmoides* sp., Ch-11 (A), Pis-7 (B);
C–F – *Plectorecurvoides alternans* Noth, Ch-16 (C), St-16 (D–F);
G – *Marsonella gradata* Berthelin (St-17);
H – *Arenobulimina* sp., Pis-5;
I – *Clavulinoides amorpha* (Cushman), Mał-11; J – *Nodosaria* sp.;
K, L – *Lenticulina gaultina* (Berthelin), St-20 (K), Mał-9 (L);
M – *Astacolus* sp., St-20;
N – *Cibicides gorbenkoi* Akimez, St-20;
O–R – *Gyroidinoides infracretacea* (Morozova), Pis-12;
S – *Buliminella* sp., Mał-2;
T – *Gavelinella schloenbachi* Reuss, Mał-8;
U – *Gavelinella intermedia* (Berthelin), Mał-8;
V, W – *Epistomina* sp. Ch-3 (V), St-20 (W)

Scale bars represent 100 µm

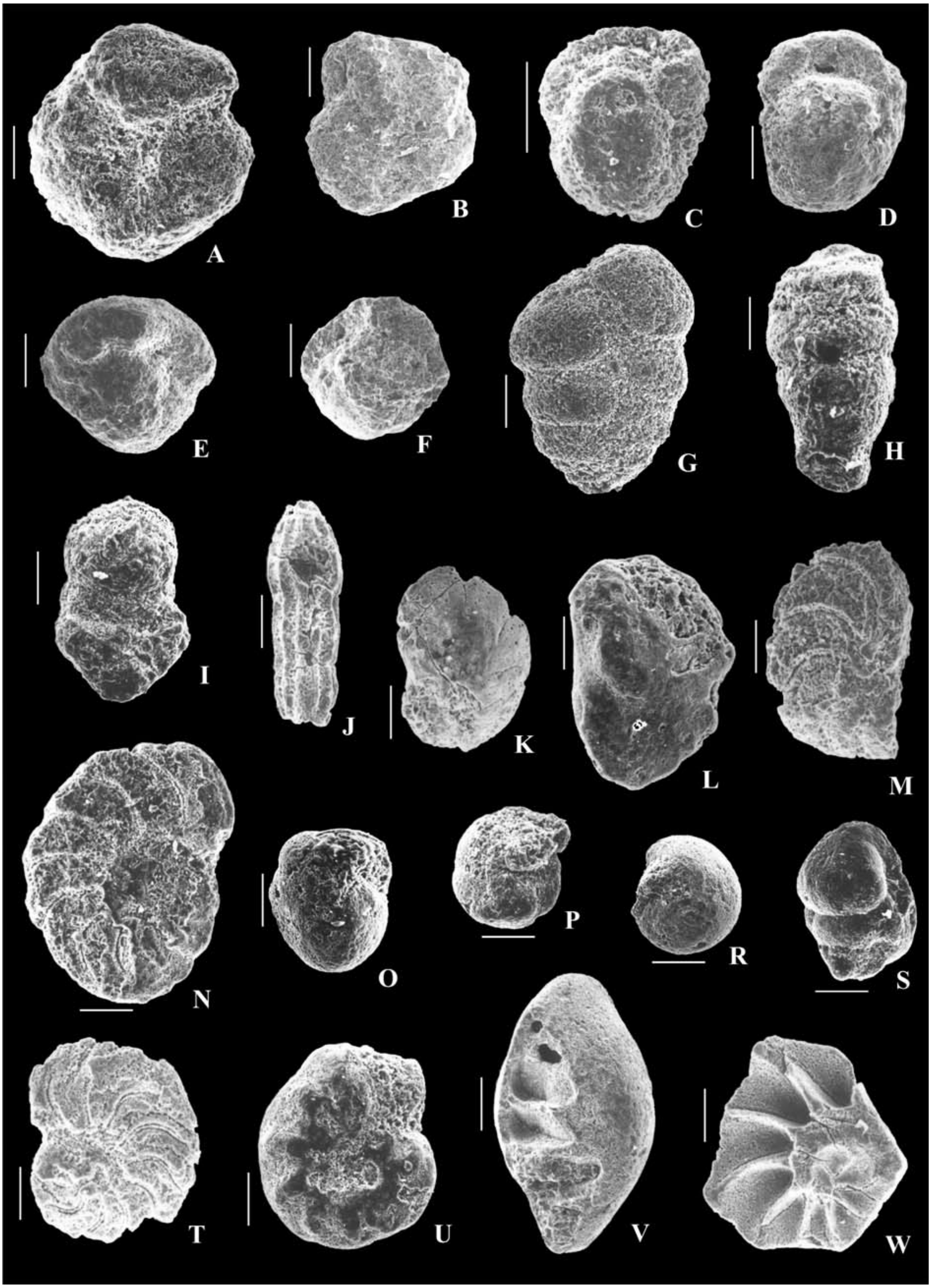
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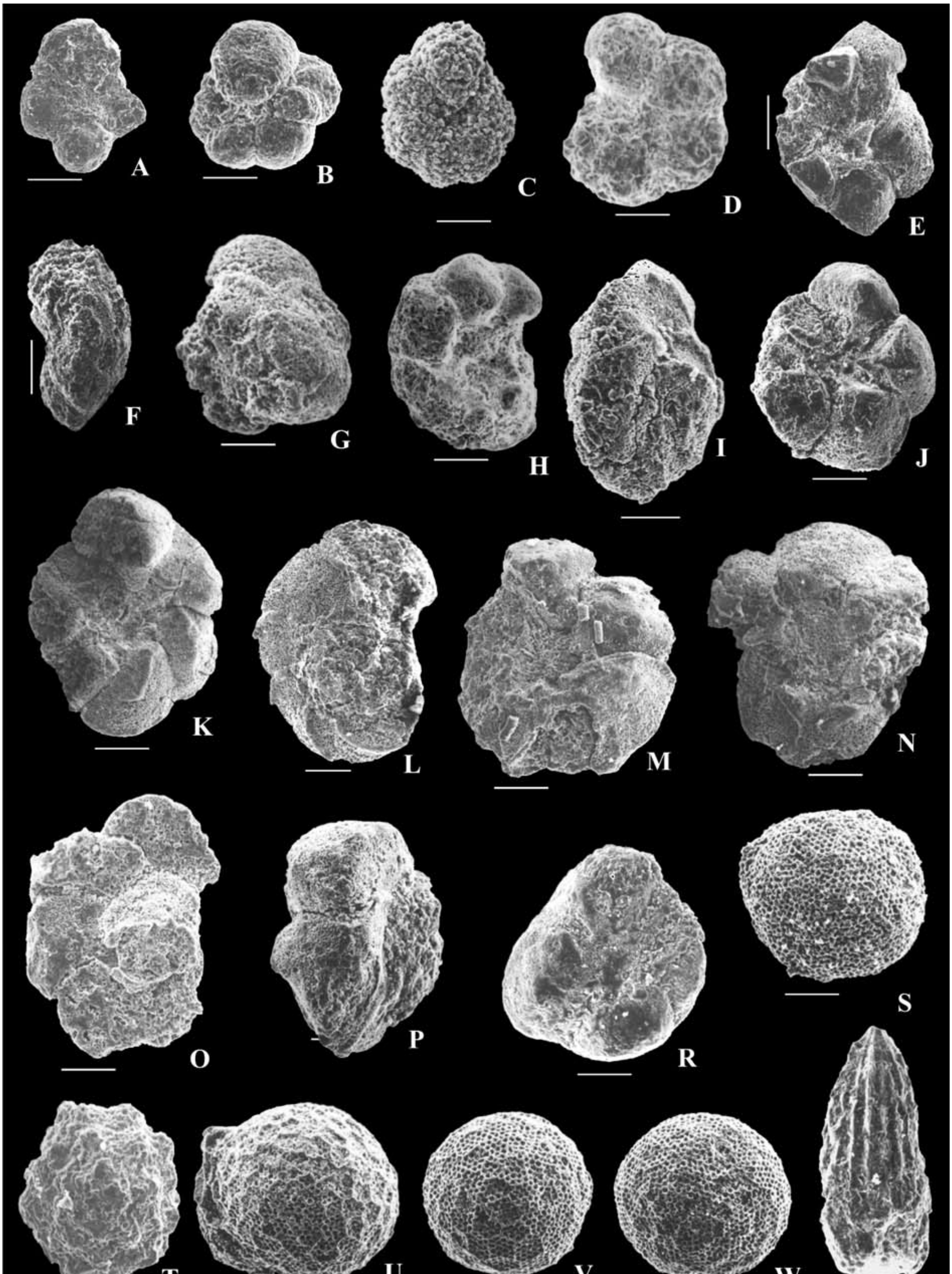
PLATE 3

Late Albian–Cenomanian planktic foraminifera and radiolaria from the Tatra Mts.

A – *Hedbergella simplex* (Morrow), Mał-10;
B – *Hedbergella delrioensis* (Carsey), Mał-1;
C – *Globigerinelloides* cf. *ultramicra* (Subbotina), Mał-1;
D – *Praeglobotruncana delrioensis* (Plummer), Pis-12;
E–G – *Praeglobotruncana stephani* (Gandolfi), St-16;
H, I – *Pseudothalmanninella ticinensis* (Gandolfi), Mał-8 (K), St-20 (L);
J–L – *Parathalmanninella appenninica* (Renz), Pis-12 (J), St-19 (K), St-19 (L);
M – *Thalmanninella globotruncanoides*, Ch-3;
N–P – *Thalmanninella reicheli* Mornod, Pis-12 (N, P), St-16 (O).
R – *Rotalipora* cf. *cushmani* (Morrow), Pis-12;
S – *Mallanites triquetrus* (Squinabol), Ch-3;
T – *Holocryptocanium tuberculatum* Dumitrica, St-17;
U–W – *?Archaeocenosphaera mellifera* O'Dogherty, Pis-12;
X – *Dictyomitra montisserei* (Squinabol), St-17

Scale bars represent 100 μm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