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APTIAN AGE OF THE "SPOTTED LIMESTONE" (PIENINY LIMESTONE FORMATION) IN GRAJCAREK STREAM (PIENINY KLIPPEN BELT, POLAND)

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Abstract: Planktonic foraminifera, calcareous dinocysts and nannofossils have been identified in thin sections of the "spotted limestone", exposed in the Grajcarek Stream at Szlachtowa and assigned to the Pieniny Limestone Formation in the Magura Succession, Pieniny Klippen Belt (southern Poland). The new data indicate that the "spotted limestone" is older than was suggested in previous reports (Albian or Cenomanian?). The foraminiferal taxa belong mainly to the upper part of the Lower Aptian. The calcareous nannofossils may correspond to the Aptian NC6(?)–NC7 zones, whereas the assemblage of calcareous dinoflagellate cysts is less conclusive (Late Barremian–Aptian).

Key words: Cretaceous, biostratigraphy, microfacies, calcareous microfossils, Pieniny Klippen Belt, Poland.

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INTRODUCTION

In the Grajcarek tectonic unit (the Magura Succession, Pieniny Klippen Belt, Carpathians), the Trzy Korony Group (Tithonian–Albian) is only 3–6 m thick, and the Pieniny Limestone Formation in the lower part of this group reaches 2–6 m (Birkenmajer, 1977). The pelagic (cherty) limestones of the upper part of the Pieniny Limestone Formation are exposed in some outcrops, located on the right (northeastern) bank of the Grajcarek Stream (Birkenmajer, 1958, 1977, 1979; Golonka and Sikora, 1981; Obermajer, 1986). One of these outcrops is situated east of Jarmuta Hill (Birkenmajer, 1958, figs 106, 110; Birkenmajer in Birkenmajer *et al*., 1965; Birkenmajer, 1977, figs 7B, 10C). The same outcrop (M in Fig. 1A) was described as the "Malinowa profile" by Golonka and Sikora (1981). Another outcrop of a pelagic limestone is located at Szlachtowa, east of Szczawnica (S-t in Fig. 1B), 560 m southeast of the outcrop mentioned above and situated near the eastern slope of Jarmuta Hill. This outcrop, briefly described by Golonka and Sikora (1981), was the target of the present study. The aim of the paper is to determine the age of the limestone exposed in the Grajcarek Stream at Szlachtowa (Fig. 1B) by means of microfossils – mainly planktonic foraminifera – and the calcareous nannofossils found in the samples studied (thin sections).

HISTORY OF RESEARCH

According to Birkenmajer (1958), the age of the "cherty-calpionellid limestone" and "cherty limestone" (equivalent to the Pieniny Limestone Formation; Birkenmajer, 1977) is Upper Kimmeridgian–Barremian. The upper boundary of the formally designated Pieniny Limestone Formation was placed at the top of the Barremian (Birkenmajer, 1977, 2001; Obermajer, 1987). Nevertheless, Birkenmajer and Dudziak (1987b) reported nannofossil species indicating that in the Branisko and Pieniny successions the upper boundary of the formation may fall within the Upper Aptian. Birkenmajer and Dudziak (1987b) reported the following calcareous nannofossils from the top part of the Pieniny Limestone Formation in the Kapuśnica section: *Amphizygus brooksi* ssp. *nanus* Bukry, *Cyclagelosphaera deflandrei* (Manivit) Roth, *C. margereli* Noël, *Lithastrinus floralis* Stradner, *Micrantholithus hoschulzi* (Reinhardt) Thierstein, *Parhabdolithus embergeri* (Noël) Stradner, *Vagalapilla matalosa* (Stover) Thierstein and *Watznaueria* spp. The authors suggested the Late Aptian age of this assemblage (Birkenmajer and Dudziak, 1987a, p. 120), but indicated that because of the very poor state of preservation, the calcareous nannoplankton has relatively restricted significance for any more precise definition of the age of the deposits occurring close to the Lower/Upper Cretaceous boundary.

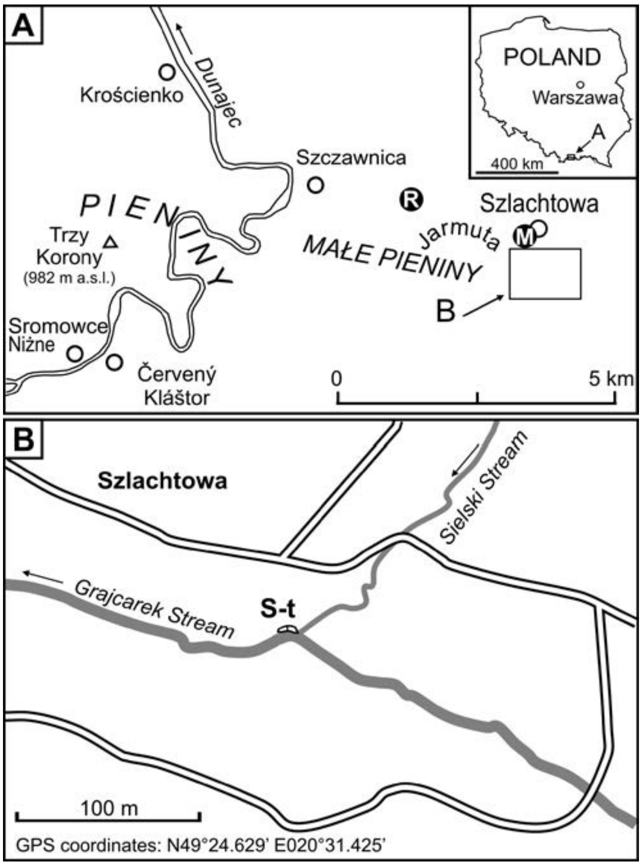

Fig. 1. Location of outcrop studied of the "spotted limestone" (Pieniny Limestone Formation) at Szlachtowa, in the Pieniny Klippen Belt (Carpathians, Poland). **A.** Schematic location map of outcrop studied and other exposures mentioned in the text, east of the Dunajec River: M – Malinowa section, R – Rzeźnia section. **B.** Detail location of outcrop (S-t) at bank of Grajcarek Stream**.**

According to Kasiński *et al*. (1981), the planktonic foraminifers recorded in the upper part of the Pieniny Limestone Formation are insignificant for stratigraphy because of the wide ranges of their occurrence and the frequently poor preservation. In the Magura Succession (Grajcarek Unit), the dinocysts extracted from the topmost beds of the Pieniny Limestone Formation exposed in the Rzeźnia outcrop (R in Fig. 1A) are diagnostic for the Barremian (E. Gedl, 2007).

However, Golonka and Sikora (1981) concluded that in most cases, the sedimentation of the cornstones (cherty limestones) lasted to the Albian and in some areas was completed in the Neocomian. In general, their cornstones correspond to the Pieniny Limestone Formation of Birkenmajer (1977) also in the so-called Hulina Succession (Golonka and Sikora, 1981), which may be correlated with the Magura Succession of Birkenmajer (1977). About 8 m of the cherty limestone was reported from the "profile of Szlachtowa", located in Grajcarek Stream (Golonka and Sikora, 1981, fig. 1B, profile 14). These authors found *Stomiosphaera wanneri* Borza and scarce *Pithonella ovalis* (Kaufmann) in the topmost limestone beds exposed in their Szlachtowa profile, but planktonic foraminifers were not recorded in the section. Golonka and Sikora (1981) postulated an Albian age for the upper part of the cherty limestones at Szlachtowa. However, *St. wanneri* was reported as occurring from the Valanginian up to the Upper Barremian (Borza, 1984a; Reháková, 2000), whereas *Pithonella ovalis* may be found also in the pre-Albian strata (see below).

According to Obermajer (1987), the Pieniny Limestone Formation is extremely thin (0.3 m) in the profile at the Szlachtowa sawmill and contains early Tithonian microfossils. Probably, the Szlachtowa sawmill profile of Obermajer (1987) referred to another limestone outcrop and not to the one reported earlier by Golonka and Sikora (1981), although both profiles have been indicated as being at the same site. P. Gedl (2008, fig. 24B) published a photograph of the "exposure of the Szlachtowa Formation (Grajcarek Succession) at Grajcarek-Jarmuta site". This photograph ("present view on the site") shows the limestone in the lower part of the klippe. Considering the opposite dip directions of the limestone on the photograph and on the redrawn (from Birkenmajer, 1979) geological interpretation, Figure 24A, B (P. Gedl, 2008) perhaps may represent two different sites. In any case, Figure 24B (P. Gedl, 2008) shows the pelagic limestone described in the present contribution.

According to Oszczypko *et al.* (2012), at the mouth of Sielski Stream (on the right bank of Grajcarek Stream) the radiolarites are overlain by "spotted limestones" up to 4 m thick. These limestones (Oszczypko *et al*., 2012, fig. 8G, p. 424) are capped by "a 5–10 cm layer of washed-away red shales of the Malinowa Fm., followed by the basal portion of the Jarmuta conglomerates". The lithostratigraphical position of the "spotted limestones" is indicated on page 434 of this paper (Oszczypko *et al*., 2012): "The uppermost part of the CKH is represented by radiolarites with intercalations of red shale (mouth of Sielski Stream, WP 370), which yielded a typically poor foraminiferal assemblage composed of *Bathysiphon* sp., *Nothia excelsa*, *Hedbergella planispira* and rare radiolarians, not younger than Turonian. The radiolarites are overlain by spotted limestones (sample WP 943), which yielded a rich nannoconid assemblage with *Nannoconus* aff. *minutus* Brönnimann of Hauterivian–Cenomanian range." Therefore, according to Oszczypko *et al*. (2012), their spotted limestones belong to the "Cenomanian Key Horizon" (CKH).

According to Scheibner and Scheibnerová (1969), in the Kysuca Succession (Pieniny Klippen Belt, Slovakia) the Brodno Member (Aptian–Albian) contains "bedded spotted cherty limestones" as intercalations in dark grey to black, silty shales. In the Rochovica section, Michalik *et al.* (1999, 2008) have reported a Barremian–Early Aptian age for the Vranie Member in the uppermost part of the Pieniny Limestone Formation. The Koňhora Formation (Lower Aptian) is followed by the Upper Aptian–Lower Albian Brodno Formation (13–16 m), consisting of well bedded bioturbated marly limestones, with intercalations of dark and red marls.

MATERIAL

The outcrop studied is located on the northern bank of the Grajcarek Stream, at the mouth of the Sielski Stream, south of Szlachtowa (Fig. 1; see also Golonka and Sikora, 1981, fig. 1B and Oszczypko *et al*., 2012, fig. 8G). The klippe, about 6 m high (Fig. 2A), is composed of light grey to grey brown and grey olive, bedded biomicrites (Fig. 2B), dipping 40–50^{o} to the north. The bed thickness is between 0.2 and 0.5 m. There are some chert lenses in the lower part of the outcrop (Fig. 2C). These cherts are dark grey, light brown and in places reddish in colour. The micritic limestones are spotted, especially in the upper part of the outcrop (Fig. 3A, B, E). The laminated limestone bed, 0.2 m thick, occurs in the upper part of the outcrop (Fig. 3D; sample S-t-10 in Fig. 2C), overlying a partly burrowed, olive grey, laminated limestone (Fig. 3C; sample S-t-9 in Fig. 2C). The topmost limestone bed (0.3 m) is tectonically deformed. The measured section is only about 3 m thick (Fig. 2C), because the upper part of the klippe is parallel to the limestone beds. The beds 2–11 were measured from the lowermost part of the outcrop (left side of the klippe in Fig. 2A) towards the strata situated in its northern part, close to the hammer (their numbers correspond to sample numbers). Position of the latter is shown in Figure 2C: a total of ten samples was collected.

The limestone described above is underlain by the radiolarite beds, gently dipping to the north. The red radiolarite is exposed in the Sielski Stream, a tributary of the Grajcarek Stream (Fig. 1C), to the northeast of the klippe shown in Fig. 2A. The limestone and radiolarite occur below the deposits of the Jarmuta Formation (*cf*. Oszczypko *et al*., 2012).

The "spotted limestone" belongs to the Trzy Korony Group of Birkenmajer (1977). The limestone is similar in lithology to the upper (informal) member of the Pieniny Limestone Formation (Birkenmajer, 1977, p. 97). The limestone at the Szlachtowa site is poor in chert intercalations and nodules; it does not contain any of the dark grey, dark green to black, silty shales characteristic for the Brodno Member (Birkenmajer, 1977). Moreover, the thickness of the Brodno Member attains 0.5–1 m only in the Magura Succession (Birkenmajer, 1977), whereas the "spotted limestone" at Szlachtowa is 3 m thick (4 m after Oszczypko *et al*., 2012). Considering the data mentioned above, and following both Golonka and Sikora (1981) and P. Gedl (2008), the "spotted limestone" from the Grajcarek Stream at Szlachtowa is assigned to the Pieniny Limestone Formation of the Trzy Korony Group.

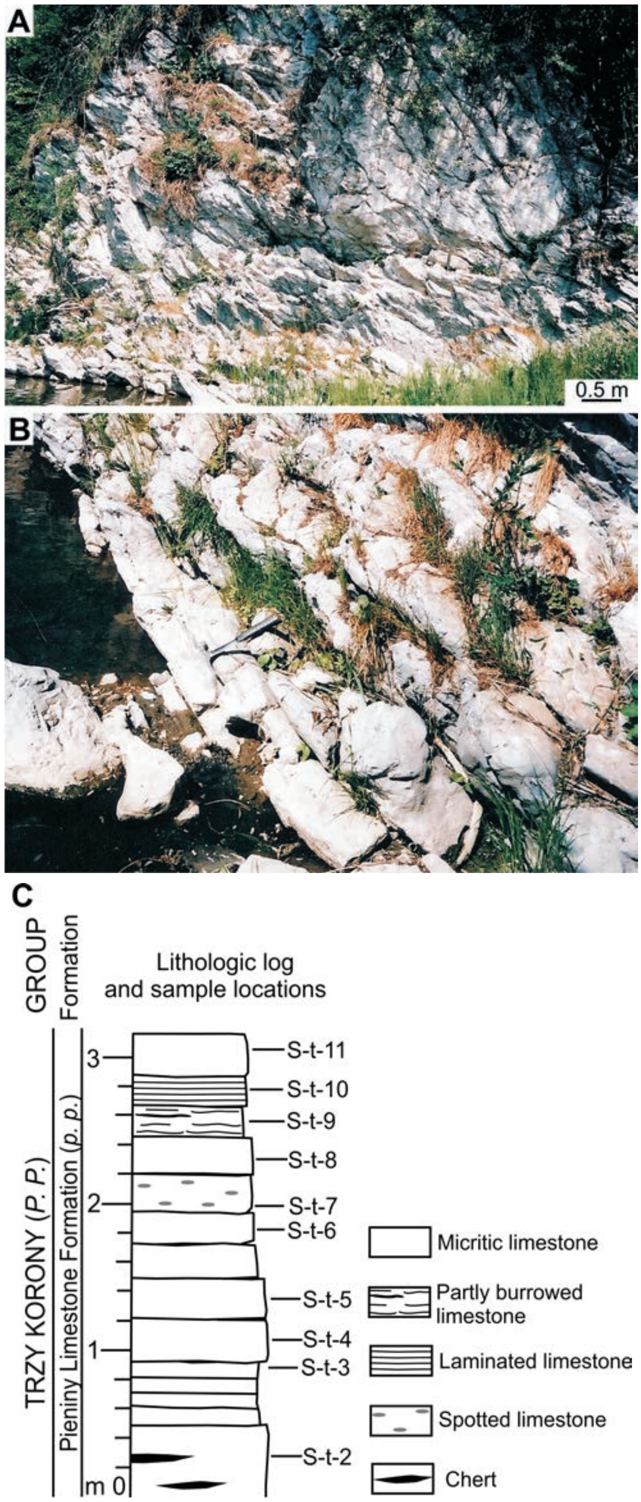

Fig. 2. Exposure of the "spotted limestone" (Pieniny Limestone Formation) at Szlachtowa. **A.** The "spotted limestone" at Szlachtowa in outcrop (S-t), located at northern bank of Grajcarek Stream (see Fig. 1B). The limestone beds, assigned to the Pieniny Limestone Formation, dip to the north (towards the right edge of the photograph). **B.** Close-up of limestone beds, exposed in lower part of outcrop. The hammer indicates limestone bed S-t-3, which was sampled (hammer length = 28 cm). **C**. Lithic log and sample positions.

RESULTS

Microfacies and nannofacies

Golonka and Sikora (1981, fig. 15) presented their profile of Szlachtowa as containing about 8 m of cherty limestone described as "nannoconite microfacies", with the radiolarians, *Stomiosphaera wanneri* and rare *Pithonella ovalis*. The present study demonstrates that the limestone exposed at the northern bank of the Grajcarek Stream at Szlachtowa (Fig. 1C) is, in general, nannoplankton-rich biomicrite with radiolarians and/or planktonic foraminifera. Other microfacies components are uncommon; these are benthic foraminifers, phosphatic debris, echinoderm bioclasts and rare calcareous dinoflagellate cysts. Two micro-

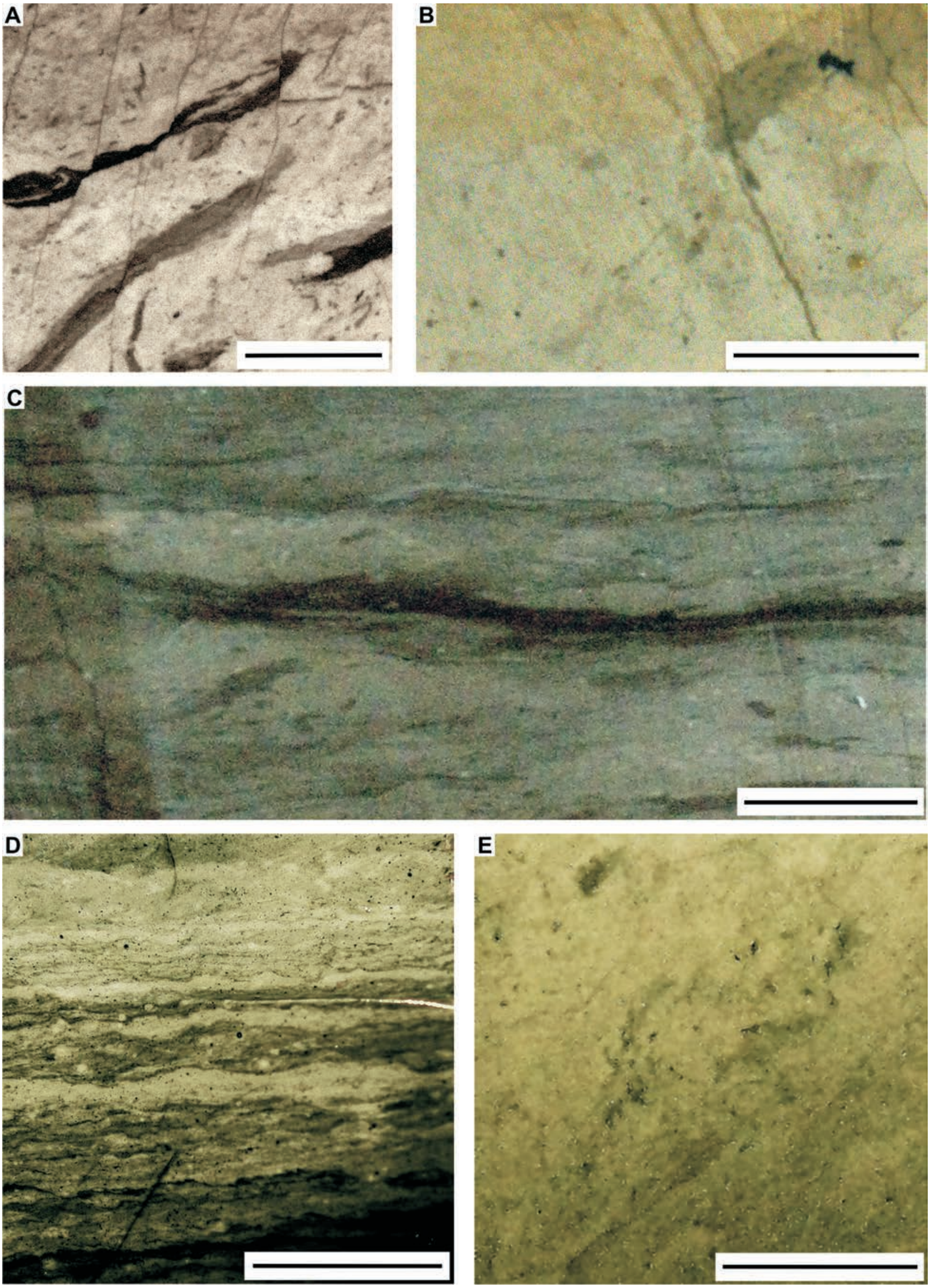

Fig. 3. Photographs of selected samples from the "spotted limestone" (Pieniny Limestone Formation), at Szlachtowa. Scale bars = 1 cm. **A.** Burrows preserved in spotted limestone (sample S-t-7). **B.** Burrowed light olive grey micritic limestone (sample S-t-8). **C.** Partly burrowed, olive grey laminated limestone (sample S-t-9). **D.** Greyish olive green laminated limestone (sample S-t-10). **E.** Burrowed light olive grey limestone (sample S-t-11).

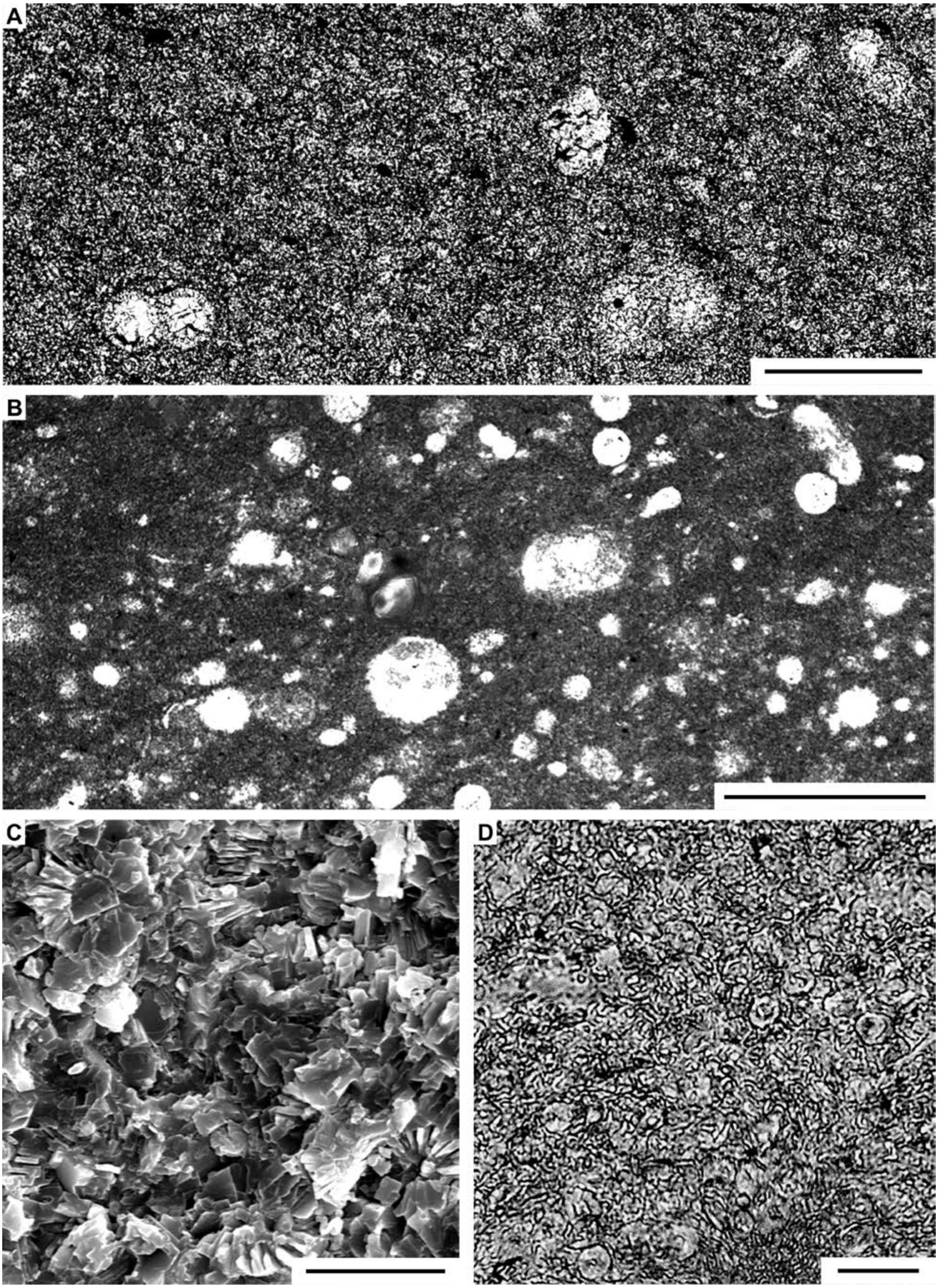

Fig. 4. Microfacies and nannofacies of the limestone beds studied in the "spotted limestone" (Pieniny Limestone Formation) at Szlachtowa. Scale bars in A = 100 µm, in B = 500 µm, in C, D = 10 µm. **A.** Foraminiferal microfacies, sample S-t-9. **B.** Radiolarian microfacies, sample S-t-4. **C.** Nannoconid nannofacies, sample S-t-11. **D.** Nannomicrite with frequent nannofossils, mainly circular and elliptical coccoliths, sample S-t-9.

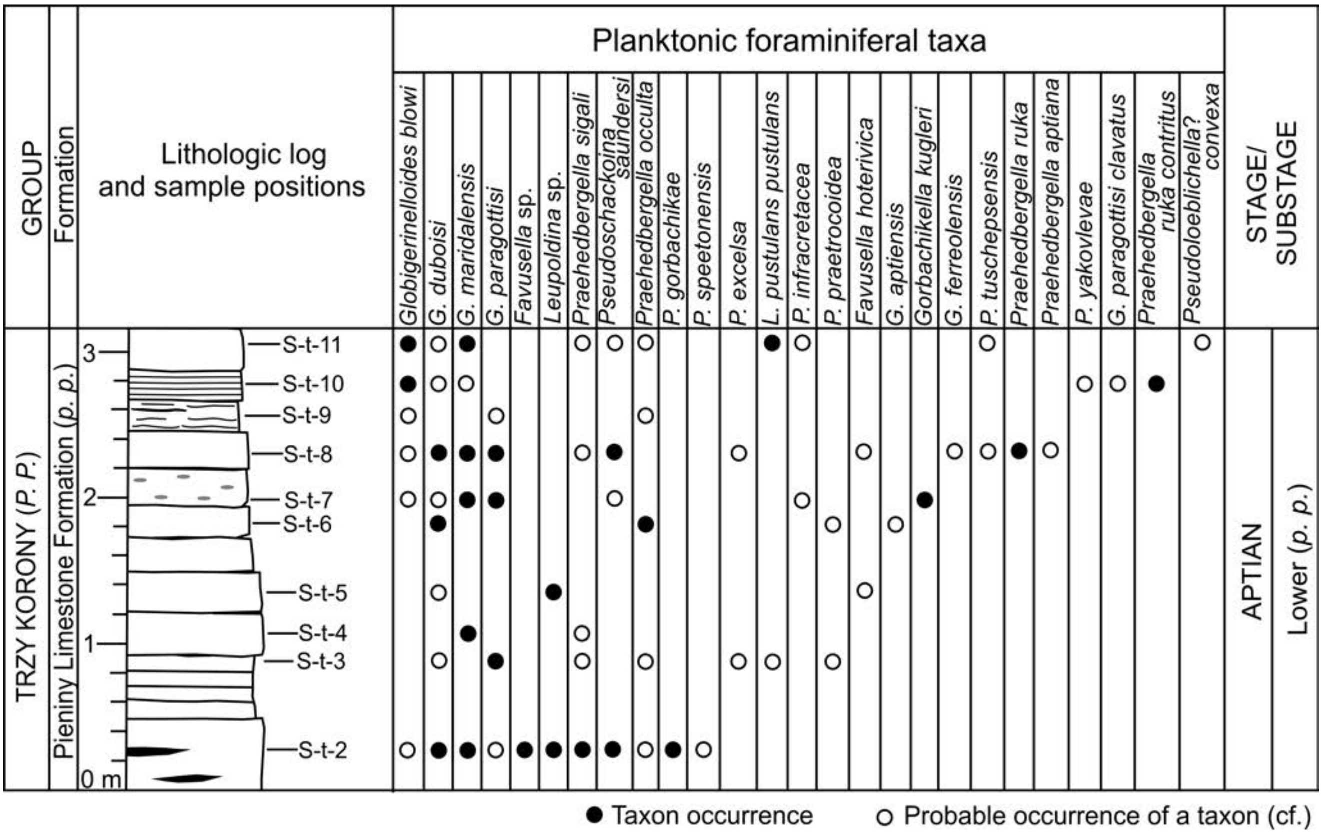

Fig. 5. Distribution of planktonic foraminiferal taxa identified in samples collected from the "spotted limestone" (Pieniny Limestone Formation) at Szlachtowa. See Fig. 2C for explanation of lithological symbols.

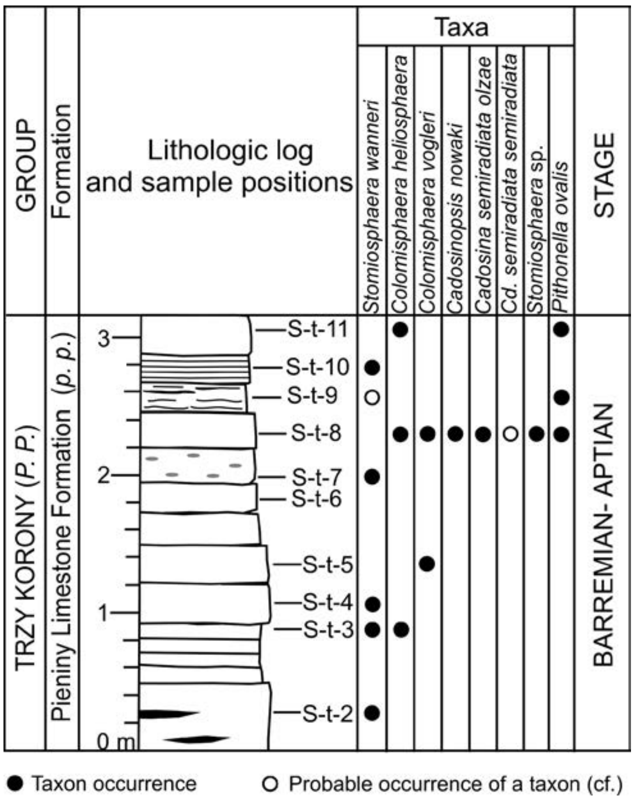

Fig. 6. Occurrence of calcareous dinoflagellate cysts in the "spotted limestone" (Pieniny Limestone Formation) at Szlachtowa. See Fig. 2C for explanation of lithological symbols.

facies types occur in the limestone studied: radiolarian MF (Fig. 4A) and foraminiferal MF (Fig. 4B). Radiolarians are the most frequent microfossils observed in thin sections, but are poorly preserved, only as calcitic moulds. The planktonic foraminifers are less common and usually are represented by small-sized specimens. The nannoconid-dominated nannofacies (Fig. 4C) is present in samples S-t-2 and S-t-11, whereas coccoliths are the main component of the nannofossil assemblages, occurring in samples S-t-3 to S-t-10 (Fig. 4D).

Planktonic foraminifera, calcareous dinoflagellate cysts and calcareous nannofossils

The distribution of planktonic foraminifers, identified in thin sections from the limestone exposed at Szlachtowa, is shown in Fig. 5.

The distribution of calcareous dinoflagellates is shown in Fig. 6. The following calcareous dinoflagellate cysts have been recorded in the samples collected from the lower part of the section (S-t-2 to S-t-7): *Stomiosphaera wanneri* Borza, 1969 (Fig. 7A), *Colomisphaera heliosphaera* (Vogler, 1941) and *C. vogleri* (Borza, 1969); see also Fig. 6. The sample S-t-8 contains a more diversified calcareous dinocyst assemblage with *Cadosinopsis nowaki* Borza, 1984b (Fig. 7B), *Cadosina semiradiata olzae* Nowak, 1966 (Fig. 7E), *Colomisphaera vogleri* (Borza, 1969) (Fig. 7C), *C. heliosphaera* (Vogler, 1941) (Fig. 7D), *Cadosina* sp. cf. *C. semiradiata semiradiata* Wanner, 1940 (Fig. 7G), *Pitho-*

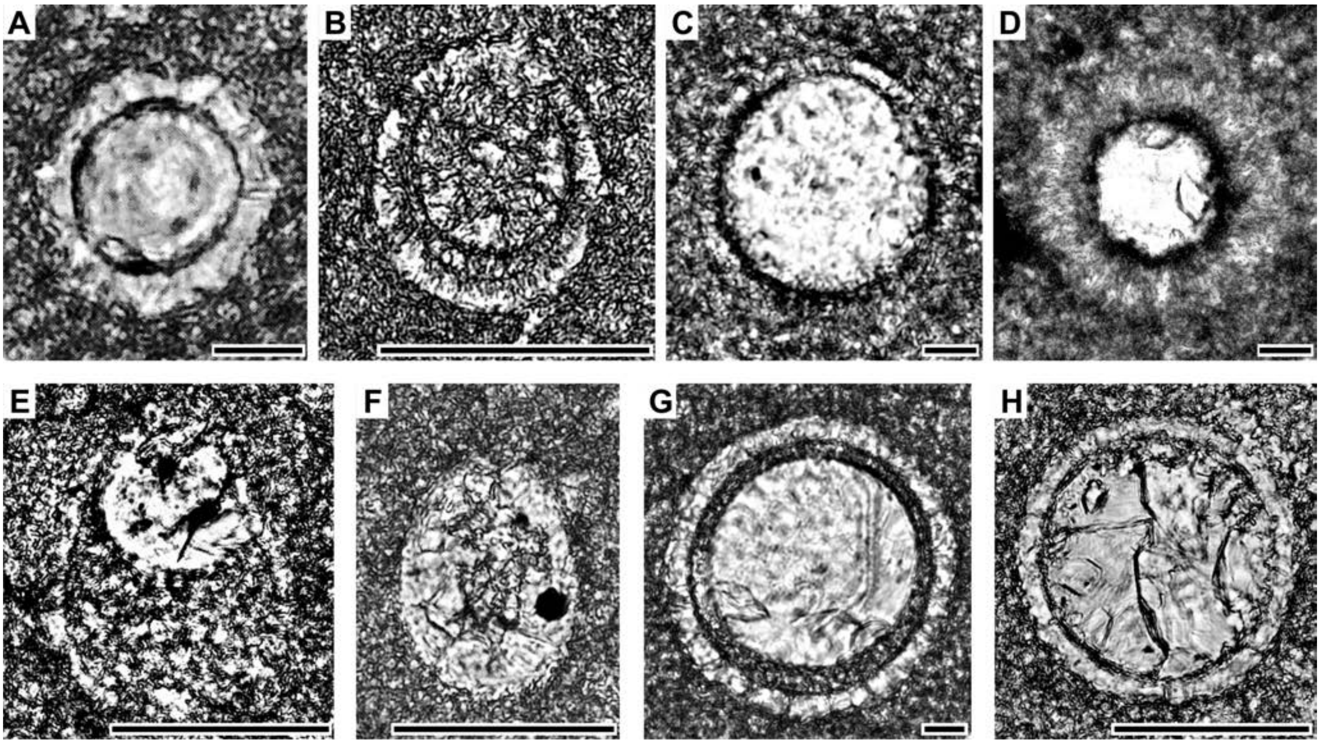

Fig. 7. Calcareous dinoflagellate cysts registered in samples (thin sections) from the "spotted limestone" (Pieniny Limestone Formation) at Szlachtowa. Scale bars in A, C, D, G = 10 μm, in B, E, F, H = 50 μm. **A.** *Stomiosphaera wanneri* Borza, 1969, sample S-t-2. **B.** *Cadosinopsis nowaki* Borza, 1984, sample S-t-8. **C.** *Colomisphaera vogleri* (Borza, 1969), sample S-t-8. **D.** *Colomisphaera heliosphaera* (Vogler, 1941), sample S-t-8. **E.** *Cadosina semiradiata olzae* Nowak, 1966, sample S-t-8. **F.** *Pithonella ovalis* (Kaufmann), longitudinal section, sample S-t-8. **G.** *Cadosina* sp. cf. *C. semiradiata semiradiata* Wanner, 1940, sample S-t-8. **H.** *Stomiosphaera* sp., sample S-t-8.

nella ovalis (Kaufmann) (Fig. 7F) and *Stomiosphaera* sp. (Fig. 7H).

Calcareous nannofossils were analysed in thin section under the microscope; moreover, samples S-t-2, S-t-10 and S-t-11 were studied with a scanning electron microscope. The distribution of calcareous nannofossils, identified in the samples studied, is shown in Figure 8; some taxa are illustrated in Figures 9 and 10.

INTERPRETATION AND DISCUSSION

Planktonic foraminifera

The taxa: *Globigerinelloides duboisi* (Chevalier, 1961), *G. maridalensis* (Bolli, 1959), *Praehedbergella occulta* (Longoria, 1974), *P. ruka* Banner, Copestake and White, 1993 and *Pseudoschackoina saundersi* (Bolli, 1959) are characteristic for the Aptian Stage, although *G. duboisi*, *H. occulta* and *H. ruka* first appear in the latest Barremian (according to Coccioni *et al*., 2007). Longoria (1984) has reported *G. maridalensis* from the upper Bedoulian and lower Gargasian in the tripartite subdivision of the Aptian (Fig. 11), but Coccioni *et al*. (2007) recorded this species occurring as early as the middle part of the Hedbergella excelsa Zone. Therefore, *G. maridalensis* is considered to range from the earliest Aptian to Late Aptian in the bipartite subdivision of this stage (Verga and Premoli Silva, 2003a). BouDagher-Fadel *et al.* (1997) reported this taxon from the Schackoina cabri Zone and from the (entire) Late Aptian. The species *Praehedbergella excelsa* (Longoria) was found to occur in the latest Barremian (Coccioni *et al*., 2007) and Lower Aptian (Longoria, 1974), whereas Aguado *et al*. (1999) have reported this taxon (*Blefuscuiana excelsa*) from the Lower Aptian up to the upper part of the L. cabri Zone. Huber and Leckie (2011) have extended the range of *Hedbergella excelsa* (= *P. excelsa*) almost to the Aptian–Albian boundary (Fig. 11). The taxa *Pseudoschackoina saundersi* (Bolli, 1959) and *Globigerinelloides paragottisi clavatus* Verga and Premoli Silva, 2005 occur in the Lower and Upper Aptian (Fig. 11).

The planktonic foraminiferal taxa identified from the "spotted limestone" exposed at Szlachtowa are correlative with the stratigraphical interval, comprising the upper part of the Lower Aptian (Fig. 5). Occurrences of *Pseudoschackoina saundersi* indicate that the foraminiferal assemblage is younger than the Praehedbergella excelsa Zone (Coccioni *et al*., 2007). However, the index taxon for the Leupoldina cabri Zone was not identified in the thin sections studied, although a single specimen of *G.* cf. *ferreolensis* may be assigned to the upper part of this biozone. According to Sliter (1999, p. 322), *L. cabri* may be "very rare and sporadic in distribution" in the Calera Limestone of northern California. This taxon also seems to be very scarce in the Rochovica section (Michalík *et al.*, 1999); one specimen of *L.* cf. *cabri* from the lower part of the Brodno Formation was figured (Michalík *et al*., 2008). The upper boundary of the stratigraphical range of the taxa identified from the "spotted limestone" at Szlachtowa is indicated by

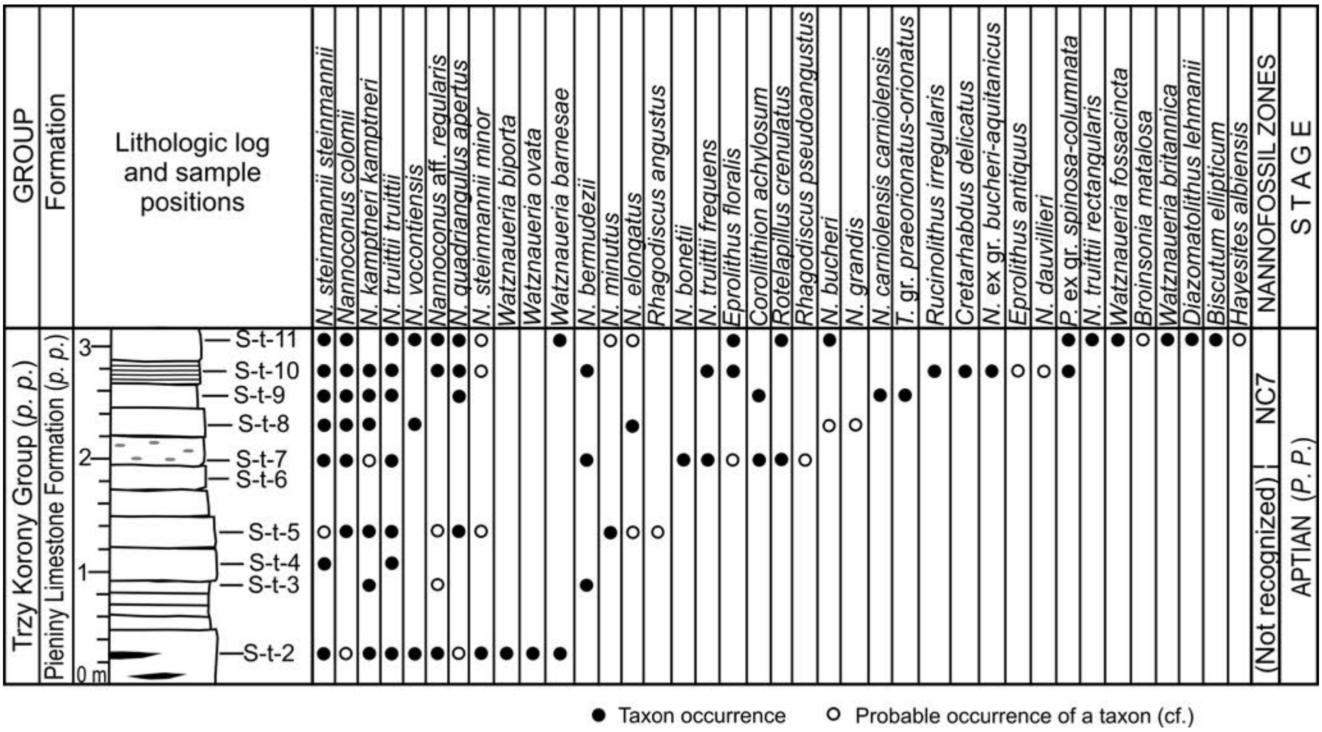

Fig. 8. Distribution of calcareous nannoplankton taxa in the “spotted limestone” (Pieniny Limestone Formation) at Szlachtowa. See Fig. 2C for explanation of lithological symbols.

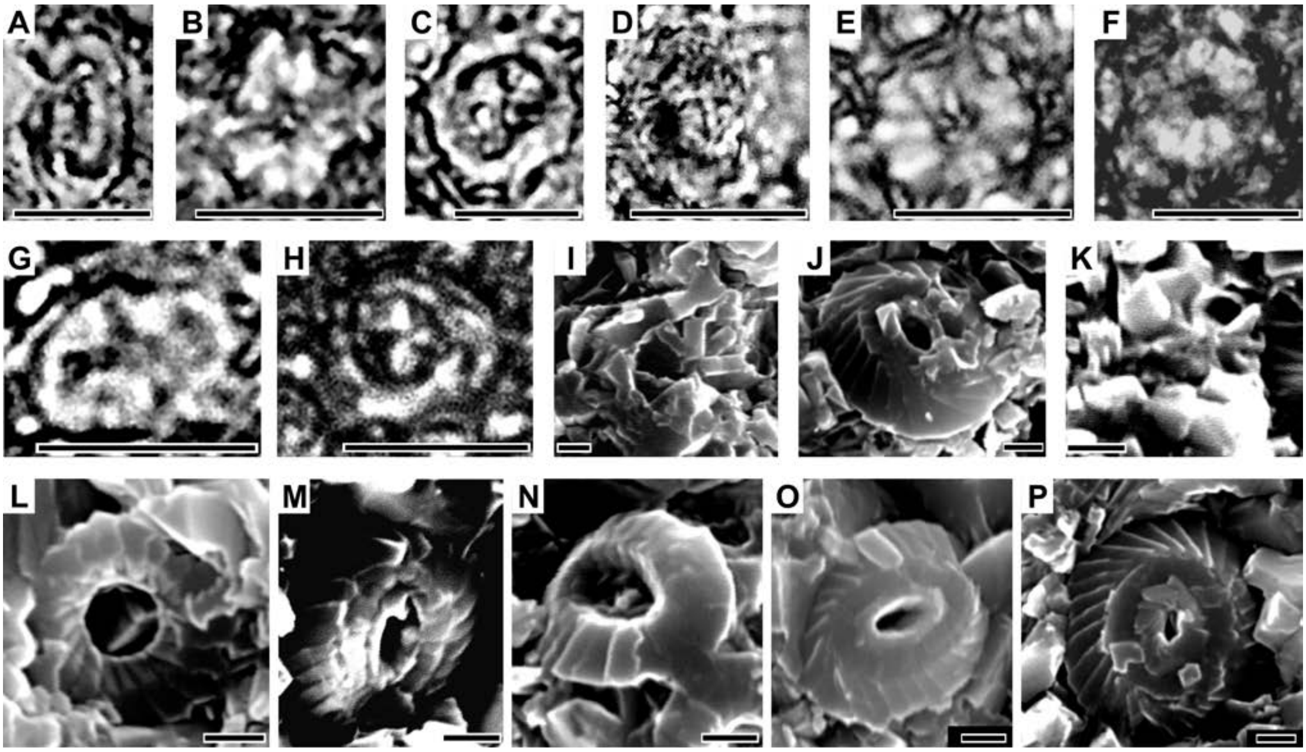

Fig. 9. Calcareous nannofossils found in samples from the “spotted limestone” (Pieniny Limestone Formation) at Szlachtowa. Scale bars in A–H (light micrographs) = 10 µm, in I–P (scanning electron micrographs) = 1 µm. **A.** *Rhagodiscus* cf. *angustus* (Stradner) Reinhardt, sample S-t-5. **B.** *Rucinolithus irregularis* Thierstein in Roth and Thierstein, sample S-t-10. **C.** *Corollithion achylosum* (Stover), sample S-t-7. **D.** *Broinsonia* cf. *matalosa* (Stover) Burnett, sample S-t-11. **E.** *Eprolithus floralis* (Stradner) Stover, sample S-t-10. **F.** *E.* cf. *antiquus* Perch-Nielsen, sample S-t-10. **G.** *Tranolithus* sp. ex gr. *T. praeorionatus-orionatus*, sample S-t-9. **H.** *Prediscosphaera* sp. ex gr. *P. spinosa-columnata*, sample S-t-11. **I.** *Rotelapillus crenulatus* (Stover), sample S-t-11. **J.** *Watznaueria britannica* (Stradner) Reinhardt, sample S-t-11. **K.** *Hayesites* cf. *albiensis* Manivit, sample S-t-11. **L.** *Diazomatolithus lehmanii* Noël, sample S-t-11. **M.** *Watznaueria ovata* Bukry, sample S-t-2. **N.** *Biscutum ellipticum* (Górka), sample S-t-11. **O.** *Watznaueria fossacincta* (Black) Bown, sample S-t-11. **P.** *Watznaueria barnesae* (Black) Perch-Nielsen, sample S-t-11.

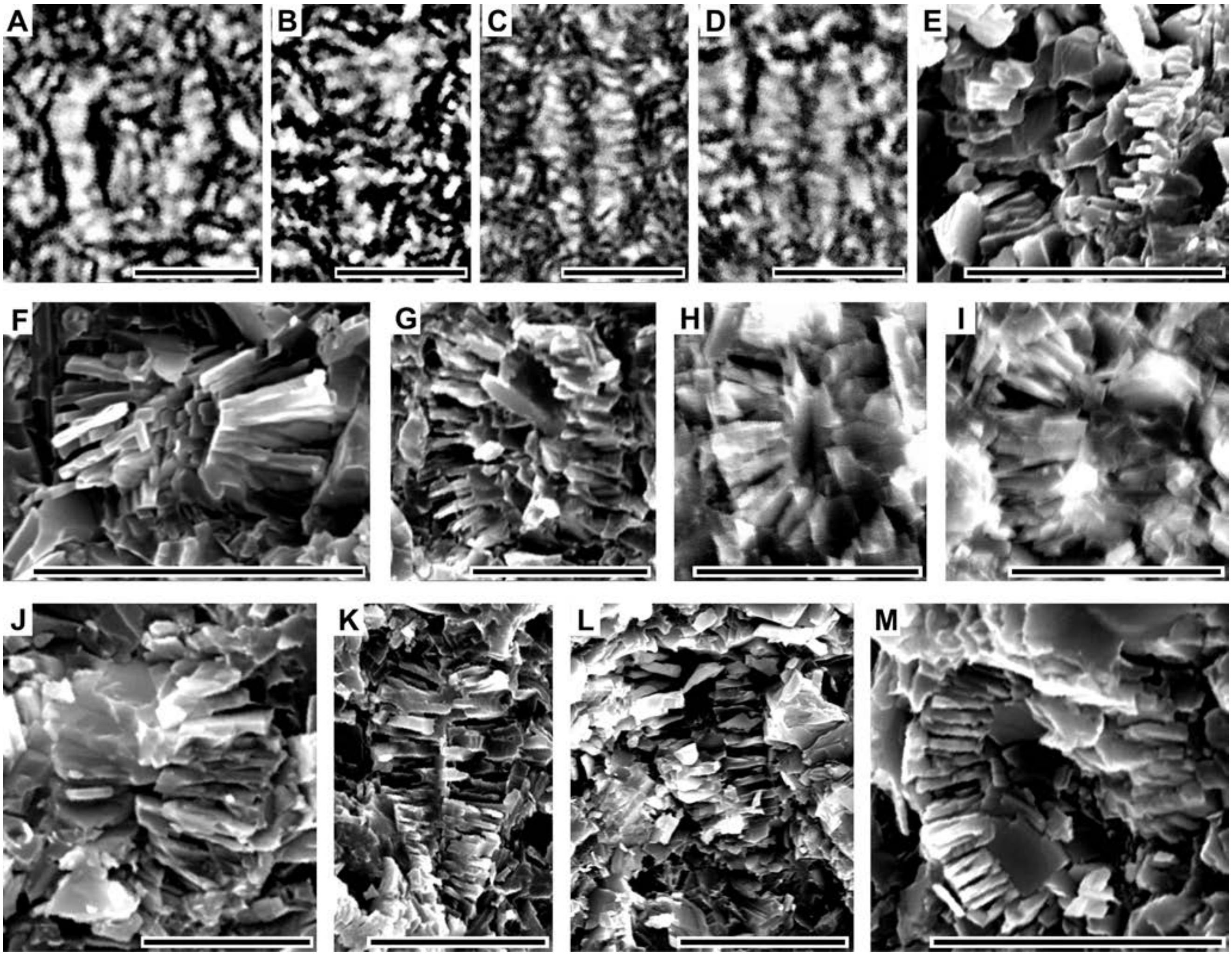

Fig. 10. Nannoconids from the “spotted limestone” (Pieniny Limestone Formation) at Szlachtowa (A–D: light microscope photographs, E–M: scanning microscope micrographs). Scale bars = 10 µm, except in J = 5 µm. **A.** *Nannoconus* sp. ex gr. *N. bucheri-aquitanicus,* sample S-t-10. **B.** *N.* cf. *dauvillieri* Deflandre, sample S-t-10. **C.** *N. colomii* Lapparent, sample S-t-8. **D.** *N. bermudezii* Brönnimann, sample S-t-7. **E.** *Nannoconus quadriangulus apertus* Deflandre, sample S-t-11. **F.** *N. truittii* subsp. *rectangularis* Deres and Achéritéguy, sample S-t-11. **G.** *N. bucheri* Brönnimann, sample S-t-11. **H.** *N. truittii* subsp. *frequens* Deres and Achéritéguy, sample S-t-10. **I**, **J.** *Nannoconus* sp. aff. *N. regularis* Deres and Achéritéguy: I – sample S-t-10, J – sample S-t-2. **K.** *N. steinmannii steinmannii* Kamptner, sample S-t-11. **L.** *N. kamptneri kamptneri* Brönnimann, sample S-t-2. **M.** *N. vocontiensis* Deres and Achéritéguy, sample S-t-11.

known occurrences of *Leupoldina pustulans, Pseudoloeblichella*? *convexa* and *Praehedbergella sigali.* These taxa disappeared about the Cabri/Ferreolensis zonal boundary (*P. sigali*) or within the Ferreolensis Zone (*L. pustulans pustulans* and *P.*? *convexa*) (Fig. 11). Therefore, the presence of *L. pustulans pustulans*, *P. sigali*, *P.* cf. *sigali*, *Pseudoloeblichella*? cf. *convexa* and *Gorbachikella kugleri* (Bolli) and the absence of typical specimens of *G. ferreolensis* (Fig. 5) narrow the range of the foraminiferal assemblage to the L. cabri Zone.

Calcareous dinoflagellate cysts

The taxon *Pithonella ovalis* (Kaufmann), earlier recorded by Golonka and Sikora (1981), was found in samples S-t-8 to S-t-11 (Fig. 6). The taxon was reported from the Middle and Upper Albian (Bonet, 1956; Reháková, 2000). According to Bignot and Lezaud (1964), the range of *P. ovalis* was Late Aptian–Maastrichtian (after Colom, 1955 and Bonet, 1956). Borza (1969, pl. 63, fig. 15) illustrated a specimen of *P. ovalis* from the Hauterivian–Barremian (Manin Succesion). However, in the text, Borza (1969, p. 69) mentioned the occurrence of very scarce specimens of this taxon in the Barremian–Aptian. This information was not taken into consideration in his later paper (Borza, 1984a; see also Dias-Brito, 2000). According to Keupp (1987, 1992), the stratigraphical distribution of *P. ovalis* ranges from the uppermost Aptian to the end of the Maastrichtian. According to Wendler *et al.* (2013), the range *of Pithonella ovalis* extends from the Upper Aptian to the K-Pg boundary. Weinkauf *et al.* (2013) recorded *Pithonella ovalis* in the Late Hauterivian deposits of the Frielingen section (Germany); however, the authors wrote (on page 256) that “the in-situ nature of the pithonelloid cysts cannot be considered unquestionable”. In the Szlachtowa

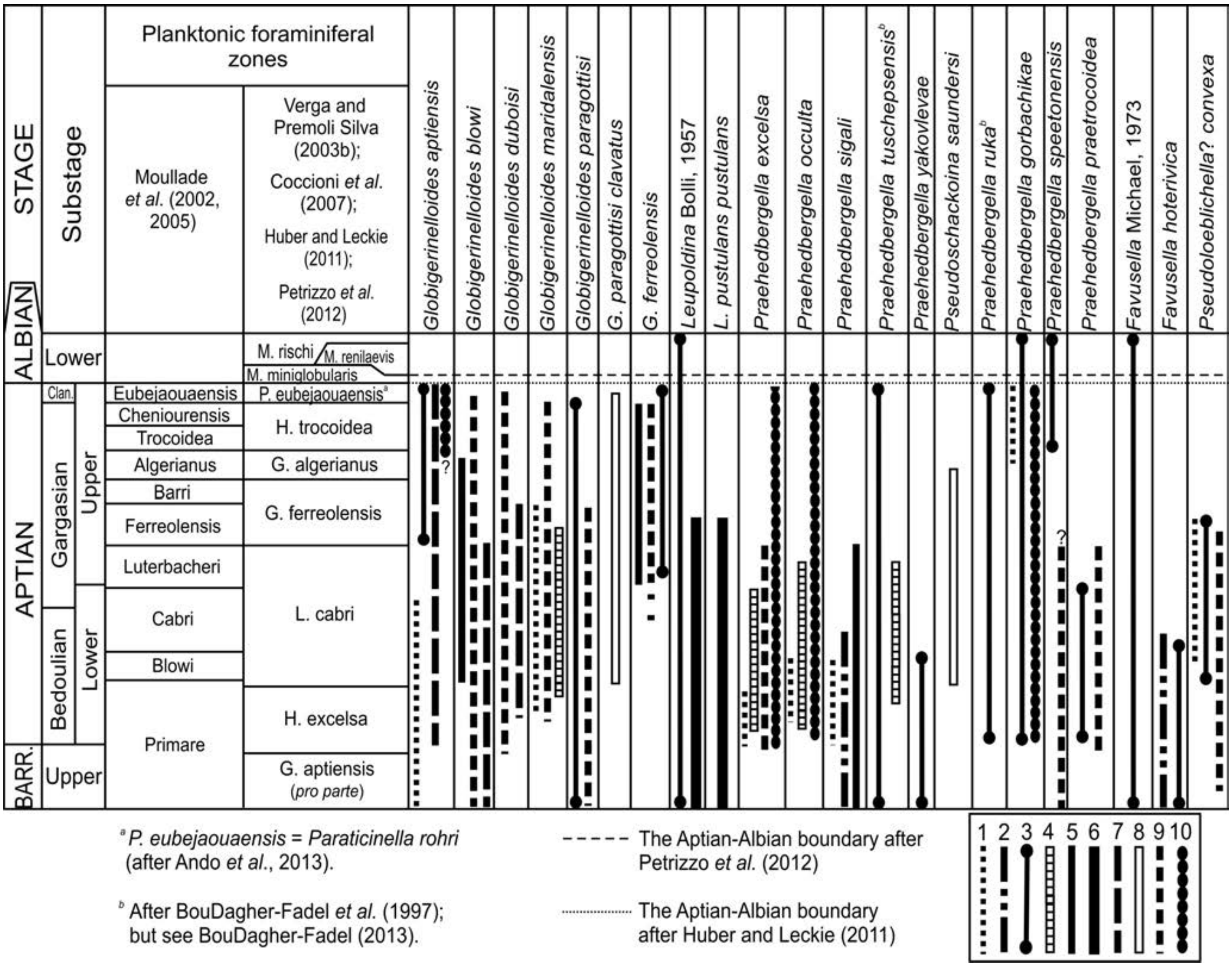

Fig. 11. Ranges of selected Early Cretaceous planktonic foraminifers, according to various authors: 1 – Longoria (1974, 1984); 2 – Caron (1985); 3 – BouDagher-Fadel *et al.* (1997, 1998) and BouDagher-Fadel (2013); 4 – Aguado *et al.* (1999); 5 – Moullade *et al.* (2002, 2005); 6 – Verga and Premoli Silva (2002); 7 – Verga and Premoli Silva (2003a, b); 8 – Verga and Premoli Silva (2005); 9 – Coccioni *et al.* (2007); 10 – Huber and Leckie (2011). The Leupoldina cabri Zone was considered to belong to Lower Aptian (Aguado *et al*., 1999), Lower and Upper Aptian (Verga and Premoli, 2003a, b, 2005; Coccioni *et al.*, 2007), Upper Aptian (Longoria, 1974; BouDagher-Fadel *et al*., 1997), to the Bedoulian and Gargasian (Moullade *et al.*, 2002, 2005) or entirely to the Gargasian Substage (Longoria, 1984; BouDagher Fadel *et al*., 1998).

section, *Pithonella ovalis* occurs only in the uppermost samples. The calcareous dinoflagellate assemblage from samples S-t-8 to S-t-11 does not contain *Stomiosphaera echinata* Nowak, 1968, the index species for the Echinata Zone (Late Valanginian–Early Aptian, according to Reháková, 2000). The absence of this taxon suggests that the stratigraphical position of the section studied may occur above the Echinata Zone, probably within the Cieszynica-Olzae Zone (Fig. 12, interpretation B). Nevertheless, the occurrence of *Stomiosphaera wanneri* Borza, 1969, and *Cadosinopsis nowaki* Borza, 1984b (in the sample S-t-8) is not in agreement with the interpretation mentioned above (Fig. 12). Therefore, an alternative stratigraphical model is shown embracing the Upper Barremian and Lower Aptian (Fig. 12, interpretation A). However, this alternative interpretation is based on the assumption that *S. echinata,* albeit very scarce (?), still should occur in the limestone studied.

The appearance of *Pithonella ovalis* (Kaufmann) in samples S-t-8 to S-t-11 supports the interpretation of the "spotted limestone" from the Szlachtowa outcrop as a normal stratigraphical succession. However, the Lower Aptian foraminiferal assemblage found in samples S-t-8 through S-t-10 requires an earlier occurrence of *Pithonella ovalis*, previously considered to appear in the Albian or Late Aptian–Albian (Fig. 12).

Calcareous nannofossils

The stratigraphical ranges of selected taxa according to various authors are presented in Figure 13.

The occurrence of *Corollithion achylosum* (Stover, 1966) (Fig. 9C) in samples S-t-7 and S-t-9 should indicate their age as being at least Late Aptian (Fig. 13). This taxon was reported by Birkenmajer and Dudziak (1987a) from the

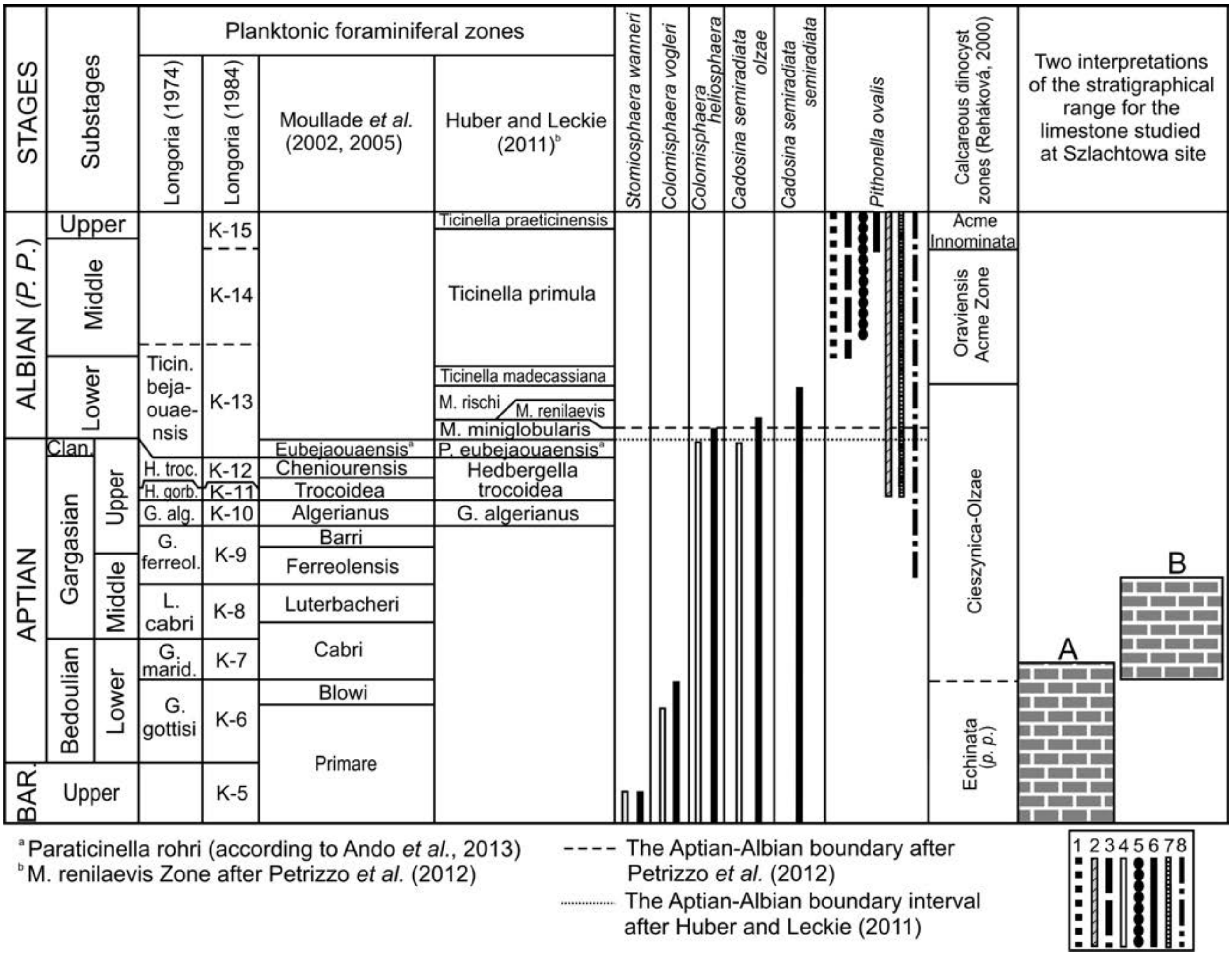

Fig. 12. Alternative interpretations of the stratigraphical position for the "spotted limestone" (Pieniny Limestone Formation) at Szlachtowa (this study) based solely on calcareous dinoflagellate cysts. Ranges of calcareous dinoflagellate taxa are shown after: 1 – Bonet (1956), 2 – Bignot and Lezaud (1964), 3 – Borza (1969), 4 – Borza (1984a), 5 – Dias-Brito (2000), 6 – Reháková (2000); 7 – Keupp (1987, 1992), 8 – Wendler *et al*. (2013). The Barremian–Albian zones after Reháková (2000); Clan. – Clansayesian; H. troc. – Hedbergella trocoidea Zone; H. gorb. – Hedbergella gorbachikae Zone; G. alg. – Globigerinelloides algerianus Zone; G. ferreol. – Globigerinelloides ferreolensis Zone; G. marid. – Globigerinelloides maridalensis Zone.

Wronine Formation of the late Early to Middle Albian age in the Grajcarek tectonic unit (near Czorsztyn). In Italy, *C. achylosum* was recorded as occurring in strata of latest Aptian to Late Albian age (Erba, 1988). The first occurrence (FO) of this taxon was reported from the Upper Aptian pelagic limestones in the Cismon core (Southern Alps, see Erba *et al*., 1999). The taxon *Eprolithus floralis* (Stradner) Stover, 1966, identified in samples S-t-10 and S-t-11, was reported from the Upper Aptian and Albian (Fig. 13). However, Bown *et al*. (1998) reported *E. floralis* also from the Lower Aptian (Fig. 14). Birkenmajer and Dudziak (1987b) recorded this taxon (as *Lithastrinus floralis*) from the uppermost part of the Pieniny Limestone Formation in the Branisko and Pieniny successions (Pieniny Klippen Belt).

The occurrence of *Hayesites* cf. *albiensis* Manivit (Fig. 9K) suggests the Late Aptian to Albian age of sample S-t-11, although the stratigraphical position of the FO of *H. albiensis* seems to be ambiguous (Figs 13 and 14). Occurrence of very scarce specimens of *Prediscosphaera* sp. ex gr. *P. spinosa-columnata* (Fig. 9H) indicates proximity to the NC8 Zone (Bralower *et al*.,1995 and Bown *et al*.,1998). Early forms of *P. columnata* have been recognized in the uppermost Aptian strata of SE France (Bown in Kennedy *et al*., 2000; see also Petrizzo *et al*., 2012, fig. 2). The specimen of *Tranolithus* sp. ex gr. *T. praeorionatus-orionatus* (Fig. 9G) suggests the latest Aptian age of sample S-t-9.

The occurrence of *Nannoconus* sp. aff. *N. regularis* Deres and Achéritéguy, 1980 (Fig. 10I, J) in samples S-t-2, S-t-10 and S-t-11 (Fig. 8) is consistent with the Aptian age of the limestones, exposed in the Szlachtowa outcrop. The figured specimens are slightly longer (higher) than the holotype of *N. regularis* (Deres and Achéritéguy, 1980). According to Erba (1988, 1989), the first appearance of *N. regularis* is latest Aptian in age (Figs 13, 14). The taxon *Nannoconus carniolensis carniolensis* Deflandre and Deflandre-Rigaud (described by Deflandre and Deflandre-Rigaud, 1967 as *N. carniolensis*), may indicate a Late Aptian age for

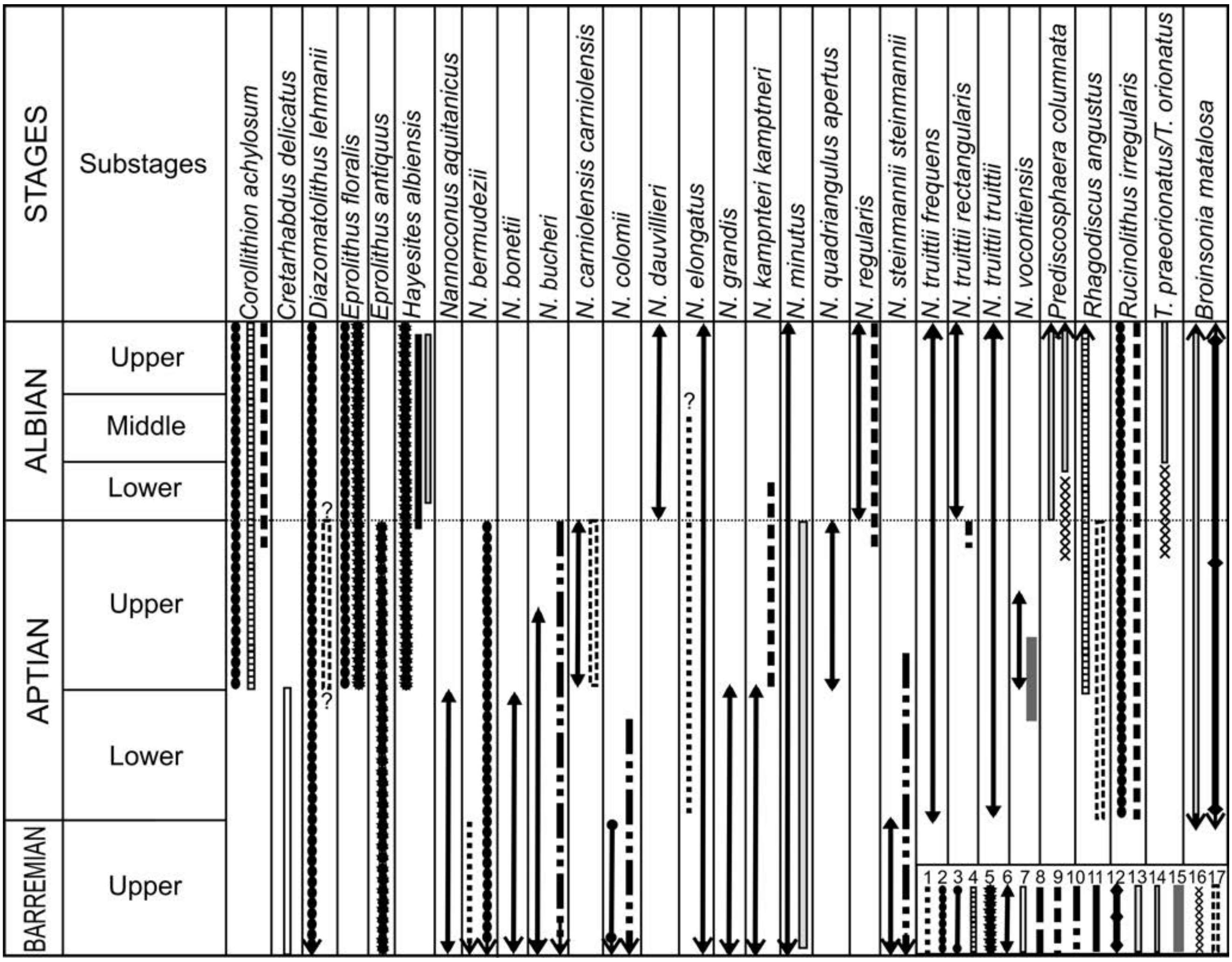

Fig. 13. Stratigraphical ranges of selected Cretaceous calcareous nannofossils, according to various authors: 1 – Brönnimann (1955); 2 – Thierstein (1973); 3 – Grün and Allemann (1975); 4 – Hill (1976); 5 – Perch-Nielsen (1979, 1985); 6 – Deres and Achéritéguy (1980); 7 – Covington and Wise (1987); 8 – Erba and Quadrio (1987); 9 – Erba (1988); 10 – Erba (1989); 11 – Bralower *et al*. (1989, 1993, 1994); 12 – Mutterlose (1992); 13 – Cobianchi *et al*. (1997); 14 – Bown *et al*. (1998); 15 – Bralower *et al*. (1999); 16 – Bown in Kennedy *et al*. (2000); 17 – Da Gama *et al*. (2009).

sample S-t-9 (Fig. 12), whereas *N.* cf. *dauvillieri* Deflandre and Deflandre-Rigaud (Fig. 10B) would suggest even an Albian age (according to Deres and Achéritéguy, 1980) for sample S-t-10. Sample S-t-11, at the top of the studied section, contains *Nannoconus truittii* subsp. *rectangularis* Deres and Achéritéguy, 1980 (Fig. 10F) assigned to the latest Aptian–Cenomanian (Deres and Achéritéguy, 1980; Erba, 1988). However, this subspecies was reported also from the Lower Aptian in Cuba (Pszczółkowski and Myczyński, 1999).

In summary, the nannofossil data are consistent, in general, with the Aptian age of the samples studied and corresponding limestone beds, probably assignable to the NC6(?) and NC7 zones (Fig. 14).

CONCLUSIONS

1. The planktonic foraminiferal taxa, identified in thin sections of the "spotted limestone" (Pieniny Limestone Formation of the Trzy Korony Group in the Magura Succession, Pieniny Klippen Belt), exposed in Grajcarek Stream at Szlachtowa, belong mainly to the upper part of the Lower Aptian.

2. The limited nannofossil data acquired during this study are consistent with an Aptian age for the samples and the corresponding limestone beds, probably referable to the upper interval of the NC6(?) Zone and to the NC7 Zone.

3. Two interpretations are possible for the age of the section studied, considering the calcareous dinoflagellate assemblage found in the "spotted limestone". The first interpretation (A in Fig. 12) assumes a Late Barremian–Early Aptian age for the limestones and the second one (B) supports a late Early Aptian to Late Aptian age for them. Correlation with the foraminiferal and nannofossil data favours the latter interpretation.

4. The previously published opinions concerning the Albian or Cenomanian(?) age of the "spotted limestone" at Szlachtowa cannot be confirmed with the results of this study.

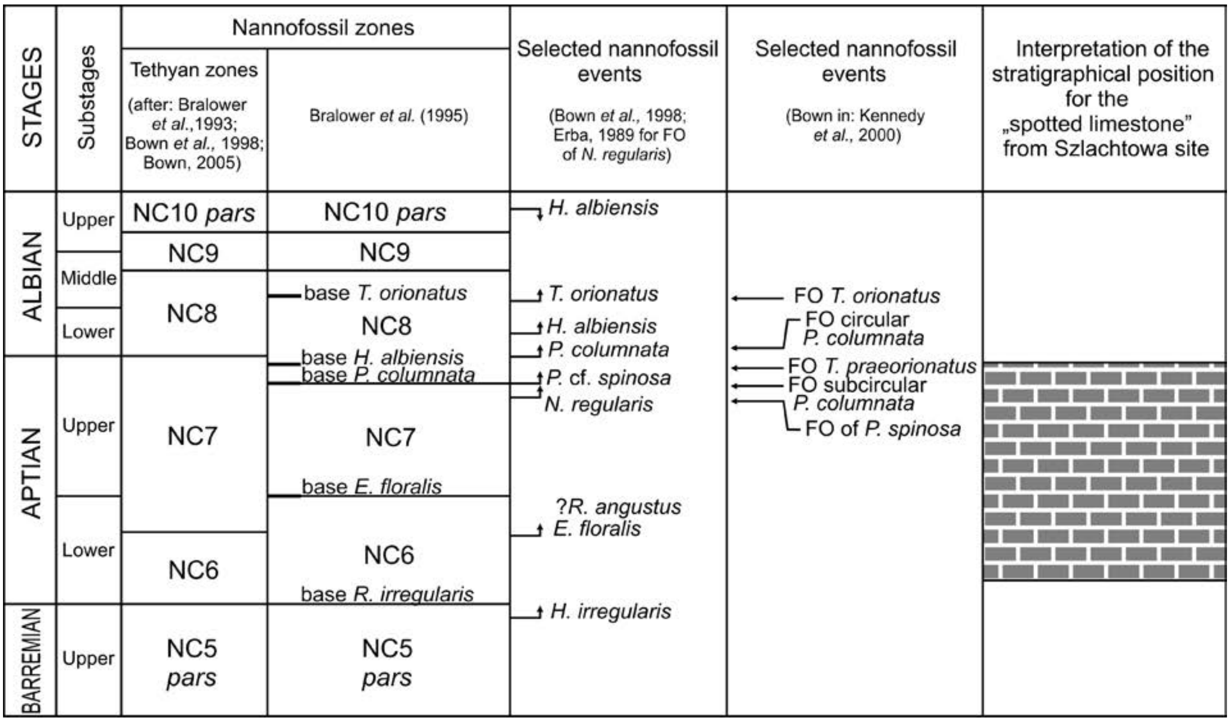

Fig. 14. Interpretation of the stratigraphical position of the "spotted limestone" (Pieniny Limestone Formation) at the Szlachtowa site based on the nannofossils.

TAXONOMIC NOTES ON PLANKTONIC FORAMINIFERA

General remarks

Sliter (1989, p. 1) observed that identifications of planktonic foraminifers based on two-dimensional, rather than three-dimensional views, are not equally precise and "... not all species recognizable from isolated specimens are morphologically distinctive in thin section". Some morphological structures, especially the wall surface and perforations (BouDagher-Fadel *et al*., 1997), usually are not discernible in thin section. Nevertheless, in Northern California (USA), Cretaceous planktonic foraminifers studied in thin sections served to establish a high-resolution biostratigraphy (Sliter, 1999). The recognition of taxa was achieved in axial section (side view) or in transverse section (Sliter, 1989, 1999; Longoria and Monreal, 2009).

Selected taxonomy

The short descriptions of taxa identified in the samples studied (thin sections) refer only to the specimens figured. The synonymy for each taxon contains the original publication, in which the taxon was created, and mainly recent papers. Full synonymy is given in the following papers: Longoria (1974), Coccioni and Premoli Silva (1994), BouDagher-Fadel *et al*. (1997), Moullade *et al*. (2002) and Verga and Premoli Silva (2002, 2003a, b, 2005).

Family FAVUSELLIDAE Longoria, 1974

Genus *Favusella* Michael, 1973

Type species: *Globigerina washitensis* Carsey, 1926.

Favusella sp. cf. *F. hoterivica* (Subbotina, 1953)
Fig. 15D, E

Remarks: One of the specimens figured (Fig. 15E) is an axial section of a small test, similar to early Aptian *F. hoterivica* from the northwestern Caucasus (BouDagher-Fadel *et al*., 1997, pl. 4.1, fig. 15), which is, however, larger.

Favusella sp.
Fig. 15F

Remarks: The shape of an axial section (102 µm at its maximum diameter) is similar to the specimen of *Favusella washitensis* (Carsey, 1926) from the Albian strata of northern Mexico (Longoria and Gamper, 1977, pl. 3, fig. 14), but the wall microstructure and surface of the chambers of the figured shell cannot be evaluated. According to Gorbachik and Kuznetsova (1983), *Favusella washitensis* ranges from the uppermost Aptian to the Lower Cenomanian (see also BouDagher-Fadel, 2013), although BouDagher-Fadel *et al*. (1997) extended the distribution of *F. washitensis* to Upper Aptian–Lower Cenomanian. Caron (1985) and Longoria and Gamper (1977) noted the occurrence of this taxon only in the Albian and Lower Cenomanian.

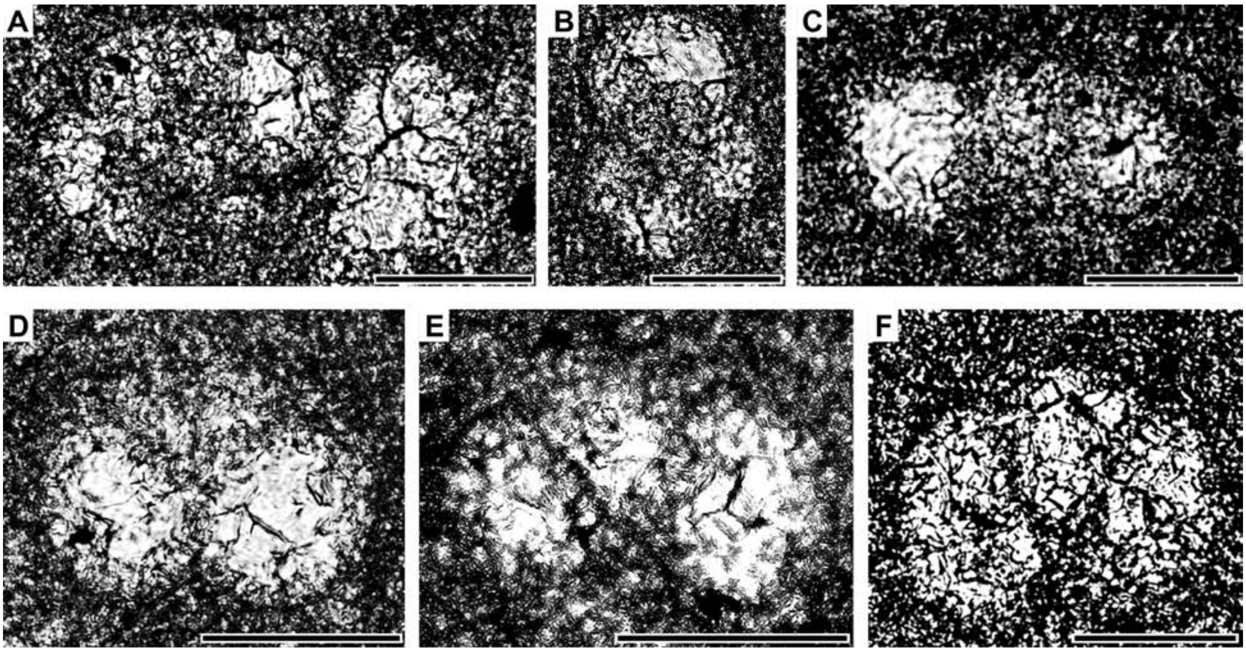

Fig. 15. *Praehedbergella*, *Gorbachikella, Pseudoloeblichella*? and *Favusella* from the "spotted limestone" (Pieniny Limestone Formation) at Szlachtowa. Scale bars = 50 μm. **A.** *Praehedbergella* cf. *praetrocoidea* (Kretchmar and Gorbachik), axial section, sample S-t-3. **B.** *Gorbachikella kugleri* (Bolli), transverse section (umbilical side), sample S-t-7. **C.** *Pseudoloeblichella*? cf. *convexa* (Longoria), axial section, sample S-t-11. **D.** *Favusella* sp. cf. *F. hoterivica* (Subbotina), peripheral section, sample S-t-8. **E.** *Favusella* sp. cf. *F. hoterivica* (Subbotina), axial section, sample S-t-5. **F.** *Favusella* sp., axial section, sample S-t-2.

Family SCHACKOINIDAE Pokorný, 1958

Genus *Globigerinelloides* Cushman and Ten Dam, 1948, emended Longoria (1974), emended Verga and Premoli Silva (2003a)

Type species: *Globigerinelloides algerianus* Cushman and Ten Dam, 1948.

Globigerinelloides blowi (Bolli, 1959)
Fig. 16F

*1959 *Planomalina blowi* sp. nov. – Bolli, p. 260, pl. 20, fig. 2a, b.
1994 *Globigerinelloides blowi* (Bolli) – Coccioni and Premoli Silva, p. 680, fig. 14.1–6.
1997 *Blowiella blowi* (Bolli) *sensu stricto* – BouDagher-Fadel, Banner and Whittaker, p. 179, pl. 10.1, figs 1–4, fig. 10.1.
2003a *Globigerinelloides blowi* (Bolli) – Verga and Premoli Silva, p. 329–331, figs 9.8–14, 10.1–12.

Description: The specimen figured is a transverse section of a test 123 μm at its maximum diameter, planispiral, semiinvolute, with 5.5 globular chambers in the final whorl increasing gradually in size. The penultimate chamber is larger than the ultimate one. The umbilical area is wide.
Remarks: The specimen resembles *G. blowi* figured by Verga and Premoli Silva (2003a, fig. 9.10a) from Cismon (Italy). According to Moullade *et al*. (2002), in SE France this species appears in the upper Bedoulian. However, Coccioni and Premoli Silva (1994) and Verga and Premoli Silva (2003a) have reported *G. blowi* from the upper Barremian to the upper Aptian (Fig. 11).

Globigerinelloides duboisi (Chevalier, 1961)
Fig. 16D

*1961 *Globigerinella duboisi* sp. nov. – Chevalier, p. 33, pl. 1, figs 14–17.
1988 *Blowiella duboisi* (Chevalier) – Banner and Desai, p. 172, pl. 8, figs 10–12.
1997 *Blowiella duboisi* (Chevalier) – BouDagher-Fadel, Banner and Whittaker, p. 179–180; pl. 10.1, figs 5–8, 10.1.
2003a *Globigerinelloides duboisi* (Chevalier) – Verga and Premoli Silva, p. 331, figs 5.1–13, 6.1–6.

Description: A transverse section of a small planispiral test (maximum diameter = 110 μm), with 4.5 chambers in the last whorl. The chambers increase rapidly in size, the ultimate one being the largest. The equatorial periphery is lobate (cross-shaped); the umbilicus is medium-sized and shallow.
Remarks: The specimen is similar to two individuals of *G. duboisi* illustrated by Verga and Premoli Silva (2003a, figs 5.9a, 5.11a), from DSDP Leg 79 and Cismon (Italy).

Globigerinelloides cf. *duboisi* (Chevalier, 1961)
Fig. 16E

Remark: The axial section of a small specimen exhibits features characteristic for *G. duboisi*, being similar to the tests figured by Verga and Premoli Silva (2003a, figs 5.2b, 5.5b).

Globigerinelloides maridalensis (Bolli, 1959)
Fig. 16A–C

*1959 *Planomalina maridalensis* sp. nov. – Bolli, p. 261, pl. 20, figs 4–6.
1974 *Globigerinelloides maridalensis* (Bolli) – Longoria, p. 86–88, pl. 9, figs 4–7, 10–13.
partim 1988 *Blowiella maridalensis* (Bolli) – Banner and Desai, p. 172, pl. 9, figs 2–3 [*non* fig. 1 – *vide* Verga and Premoli Silva, 2003a.]
1994 *Globigerinelloides maridalensis* (Bolli) – Coccioni and Premoli Silva, p. 682, fig. 14.11–14.

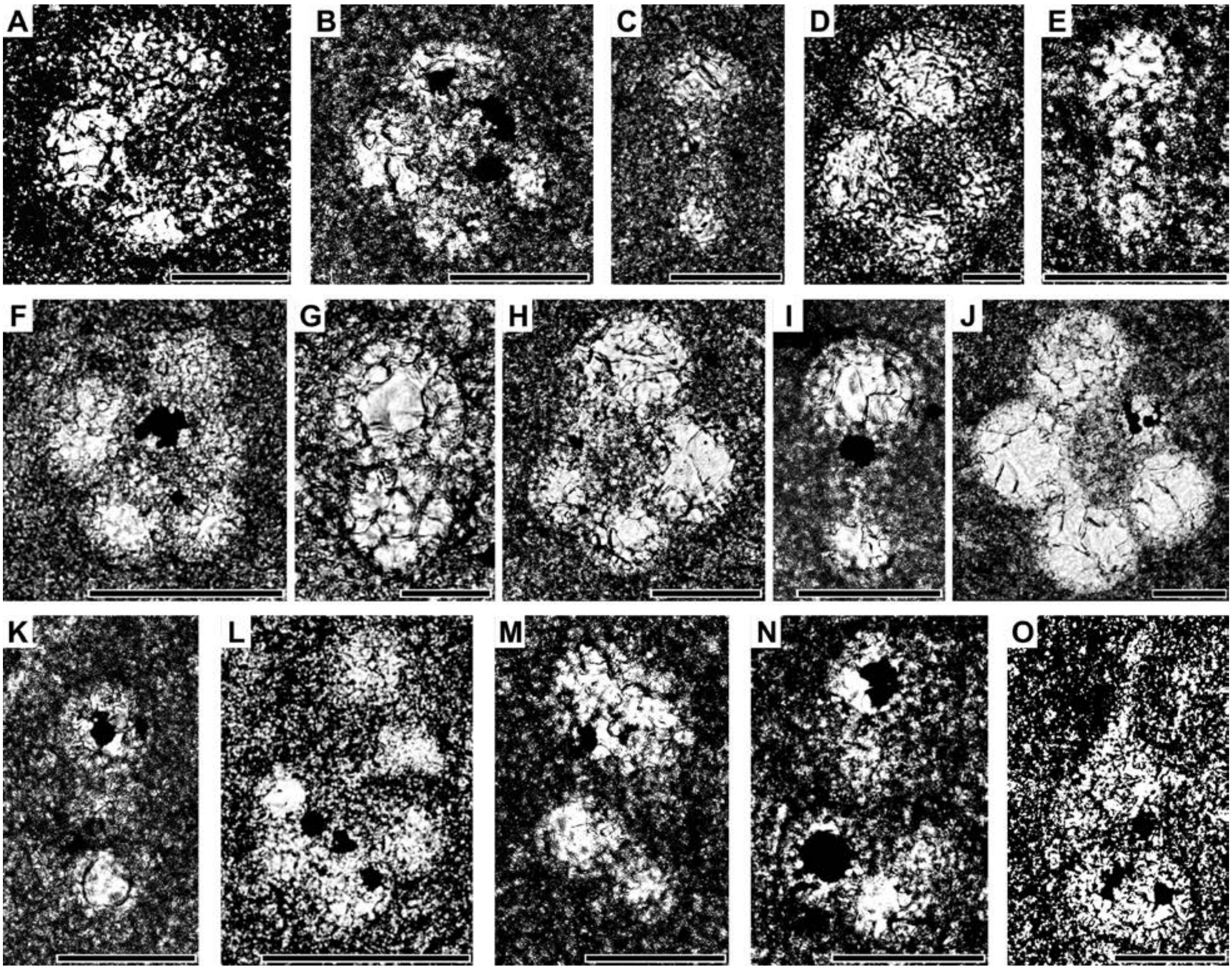

Fig. 16. *Globigerinelloides* and *Leupoldina* from the "spotted limestone" (Pieniny Limestone Formation) at Szlachtowa. Scale bars in A–C, E, H–K, M–O = 50 μm, in D = 25 μm, in F, L = 100 μm, in G = 20 μm. **A**, **B.** *Globigerinelloides maridalensis* (Bolli), transverse sections, sample S-t-2. **C.** *Globigerinelloides maridalensis* (Bolli), axial section, sample S-t-8. **D.** *Globigerinelloides duboisi* (Chevalier), transverse section, sample S-t-2. **E.** *Globigerinelloides* cf. *duboisi* (Chevalier), axial section, sample S-t-2. **F.** *Globigerinelloides blowi* (Bolli), transverse section, sample S-t-11. **G.** *Globigerinelloides* cf. *blowi* (Bolli), axial section, sample S-t-9. **H.** *Globigerinelloides paragottisi* Verga and Premoli Silva, transverse section, sample S-t-8. **I.** *Globigerinelloides paragottisi* Verga and Premoli Silva, axial section, sample S-t-8. **J.** *Globigerinelloides* sp. ex gr. *G. paragottisi-blowi,* transverse section, sample S-t-11. **K.** *Globigerinelloides* cf. *aptiensis* Longoria, axial section, sample S-t-6. **L.** *Globigerinelloides* cf. *ferreolensis* (Moullade), transverse section, sample S-t-8. **M.** *Globigerinelloides* cf. *paragottisi clavatus* Verga and Premoli Silva, transverse section, sample S-t-10. **N.** *Leupoldina pustulans pustulans* (Bolli), transverse section, sample S-t-11. **O.** *Leupoldina* cf. *pustulans pustulans* (Bolli), oblique section, sample S-t-3.

2003a *Globigerinelloides maridalensis* (Bolli) – Verga and Premoli Silva, p. 331–332, figs 8.1–14, 9.1–7.

Description: Transverse (Fig. 16A, B) and axial (Fig. 16C) sections of three small specimens (maximum diameters are 105 μm, 87 μm and 99 μm, respectively). Both transverse sections show tests consisting of 5 chambers in the outer whorl. The subglobular to elongate chambers increase gradually in size as added; the final chamber of crescentic shape is broader than high. Sutures are radial, straight; the umbilical area is rather wide, being better recognizable in the specimen shown in Fig. 16A. The specimen cut in axial section is slender, with the ultimate (?) chamber compressed.
Remarks: The larger specimen (Fig. 16A) is similar to the holotype (Bolli, 1959, pl. 20, fig. 6a) and also to the test shown by Verga and Premoli Silva (2003a, fig. 8.10a). The other transverse section (Fig. 16B) is similar to *G. maridalensis* from Cismon and Lesches en Diois (Verga and Premoli Silva, 2003a, fig. 8.3a, 6a). However, it is smaller than the tests illustrated by the authors cited. The axial section is similar to the test from Cismon (Verga and Premoli Silva, 2003a, fig. 8.2a).

Globigerinelloides paragottisi Verga and Premoli Silva, 2003
Fig. 16H, I

1961 *Globigerinella duboisi* Chevalier, p. 32, pl. 1, fig. 18 (see also Verga and Premoli Silva, 2003a).
1974 *Globigerinelloides gottisi* (Chevalier) – Longoria, p. 85, pl. 7, figs 10–13.
1988 *Blowiella gottisi* (Chevalier) – Banner and Desai, p. 172, pl. 8, figs 13–15.
1994 *Globigerinelloides gottisi* (Chevalier) – Coccioni and Premoli Silva, p. 681, fig. 14.7– 10.
1997 *Blowiella gottisi* (Chevalier) – BouDagher-Fadel, Banner and Whittaker, p. 180, pl. 10.1, figs 9–12, 10.1.
*2003a *Globigerinelloides paragottisi* sp. nov. – Verga and Premoli Silva, p. 332–333, figs 6.7–14, 7.1–13.

Description: Two specimens, cut in a transverse (Fig. 16H) and axial (Fig. 16I) sections. The transverse section of a small-sized planispiral specimen, 123 μm at its maximum diameter, with five globular to subglobular chambers in the last whorl. The equatorial

periphery is moderately lobate, the sutures straight and radial; and the umbilical area wide. The aperture is poorly preserved as a low arch. The axial section shows a planispiral mode of coiling and a globular shape of the chambers.
Remarks: As observed by Verga and Premoli Silva (2003a), the species *G. paragottisi* comprises most of the specimens, previously identified as *G. gottisi.* The transverse section from Szlachtowa is similar to the tests illustrated by Verga and Premoli Silva (2003a, figs 6.8a, 7.5a) and also by Michalík *et al*. (2008, fig. 9.6). The axial section (Fig. 16I) and the tests shown in Verga and Premoli Silva (2003a, figs 7. 6b, 12b) are alike.

Globigerinelloides cf. *aptiensis* Longoria, 1974
Fig. 16K

Remarks: The specimen figured is an axial section of a small-sized planispiral test, 89 µm at its maximum diameter. It is similar to the tests illustrated by Verga and Premoli Silva (2003b, figs 6.2b, 6.4c). BouDagher-Fadel *et al*. (1997) have assigned the species *Globigerinelloides aptiensis* to the genus *Alanlordella* BouDagher-Fadel, 1995.

Globigerinelloides cf. *ferreolensis* (Moullade, 1961)
Fig. 16L

Remarks: The figured transverse section consists of 7 chambers that are similar to the test of *G. ferreolensis* from Lesches en Diois (SE France, Verga and Premoli Silva, 2003b, fig. 7.7a) and also to the specimen illustrated by Premoli Silva and Sliter (1986, pl. 1.6). However, the specimen from Szlachtowa is smaller (attaininig 140 µm at its maximum diameter) and more evolute; it may belong to primitive representatives of this taxon (*cf.* Banner and Desai, 1988, pl. 9, figs 7, 8). The holotype (Moullade, 1961, pl. 1, figs 1–5) has 8 chambers in the last whorl and is less evolute than the specimen of *G.* cf. *ferreolensis* from Szlachtowa.

Globigerinelloides cf. *paragottisi clavatus* Verga and Premoli Silva, 2005
Fig. 16M

Remarks: The specimen is a transverse section of a small-sized test, about 106 µm at its maximum diameter. Although three chambers of the last whorl are only preserved, the specimen is broadly similar to the tests figured by Verga and Premoli Silva (2005, figs 5.2a, 3a).

Globigerinelloides sp. ex gr. *G. paragottisi* Verga and Premoli Silva, 2003a-*G. blowi* (Bolli, 1959)
Fig. 16J

Remarks. The figured specimen, 204 µm at its maximum diameter, shows some features characteristic for both species of *Globigerinelloides*. This specimen is broadly similar to *G. paragottisi* from Lesches en Diois (Verga and Premoli Silva, 2003a, fig. 6.14a), having, however, more spherical chambers than the test from SE France.

Genus *Leupoldina* Bolli, 1957, emended Banner and Desai, 1988, emended Verga and Premoli Silva, 2002

Type species: *Leupoldina protuberans* Bolli, 1957.

Leupoldina pustulans pustulans (Bolli, 1957)
Fig. 16N

Description: A traverse section of a small specimen, 103 µm at its maximum diameter, composed of four chambers. The first three chambers are subglobular; the last chamber is pyriform, with a single spherical ampulla. Sutures radial, rather depressed.
Remarks: The figured section is broadly similar to the specimen illustrated by Verga and Premoli Silva (2002, fig. 4.2a).

Leupoldina cf. *pustulans pustulans* (Bolli, 1957)
Fig. 16O

Description: The oblique section of a small test (132 µm at its maximum diameter) displays three chambers in the last whorl. The ultimate chamber have two prolongations, once probably terminated by ampullae, poorly preserved or partly broken off (?). Two chambers are subglobular, similar to "*Blowiella*-like" early whorls (*cf.* Banner and Desai, 1988, pl. 10, figs 1 and 2, regarded as *L. pustulans pustulans* by Verga and Premoli Silva, 2002, p. 203).

Family PRAEHEDBERGELLIDAE Banner and Desai, 1988
Genus *Gorbachikella* Banner and Desai, 1988

Type species: *Globigerina kugleri* Bolli, 1959.

Gorbachikella kugleri (Bolli, 1959)
Fig. 15B

- *1959 *Globigerina kugleri* sp. nov. – Bolli, pp. 270–271, pl. 23, figs 3–5.
- 1974 *Caucasella hoterivica* (Subbotina) – Longoria, pp. 49–50, pl. 11, figs 9–11, 14–16 [see also Banner and Desai, 1988; BouDagher-Fadel *et al.*, 1997.]
- 1988 *Gorbachikella kugleri* (Bolli) – Banner and Desai, p. 151, pl. 2, fig. 2.
- 1995 *Gorbachikella kugleri* (Bolli) – BouDagher-Fadel, Banner, Bown, Simmons and Gorbachik, p. 188, pl. 2, figs 1–5.
- 1997 *Gorbachikella kugleri* (Bolli) – BouDagher-Fadel, Banner and Whittaker, p. 87, pl. 6.1, figs 1–6, pl. 6.2, figs 1–6.

Description: A transverse section of a small test (umbilical side), 104 µm at its maximum diameter, composed of 4 chambers. Equatorial periphery lobate; the chambers are subglobular, the ultimate chamber is distinctly larger. The umbilicus is relatively broad; the partly preserved aperture is semicircular and intraumbilical.
Remarks: The specimen figured is broadly similar to the paratype of *Globigerina kugleri* (Bolli, 1959, pl. 23, fig. 4) and also to *Gorbachikella kugleri* from Early Barremian of Tunisia (BouDagher-Fadel *et al*., 1995, pl. 2, fig. 2a). However, it is smaller than both of the compared tests. This taxon was reported from the Hauterivian–Early Aptian (BouDagher-Fadel *et al*., 1997).

Genus *Praehedbergella* Gorbachik and Moullade, 1973

Type species: *Globigerina tuschepsensis* (Antonova, 1964).

Praehedbergella gorbachikae (Longoria, 1974)
Fig. 17E

- *1974 *Hedbergella gorbachikae* sp. nov. – Longoria, pp. 56–58, pl. 15, figs 1–16.
- 1977 *Hedbergella gorbachikae* Longoria – Longoria and Gamper, p. 203, pl. 2, figs 7–12.
- 1988 *Blefuscuiana gorbachikae* (Longoria) – Banner and Desai, pp. 160, 162, pl. 5, figs 8–12.
- 1997 *Blefuscuiana gorbachikae* (Longoria) – BouDagher-Fadel, Banner and Whittaker, p. 127, pl. 8.6, figs 1–6, fig. 8.1.
- 1999 *Blefuscuiana gorbachikae* (Longoria) – Aguado, Castro, Company and de Gea, fig. 3, fig. 6.1, 2.

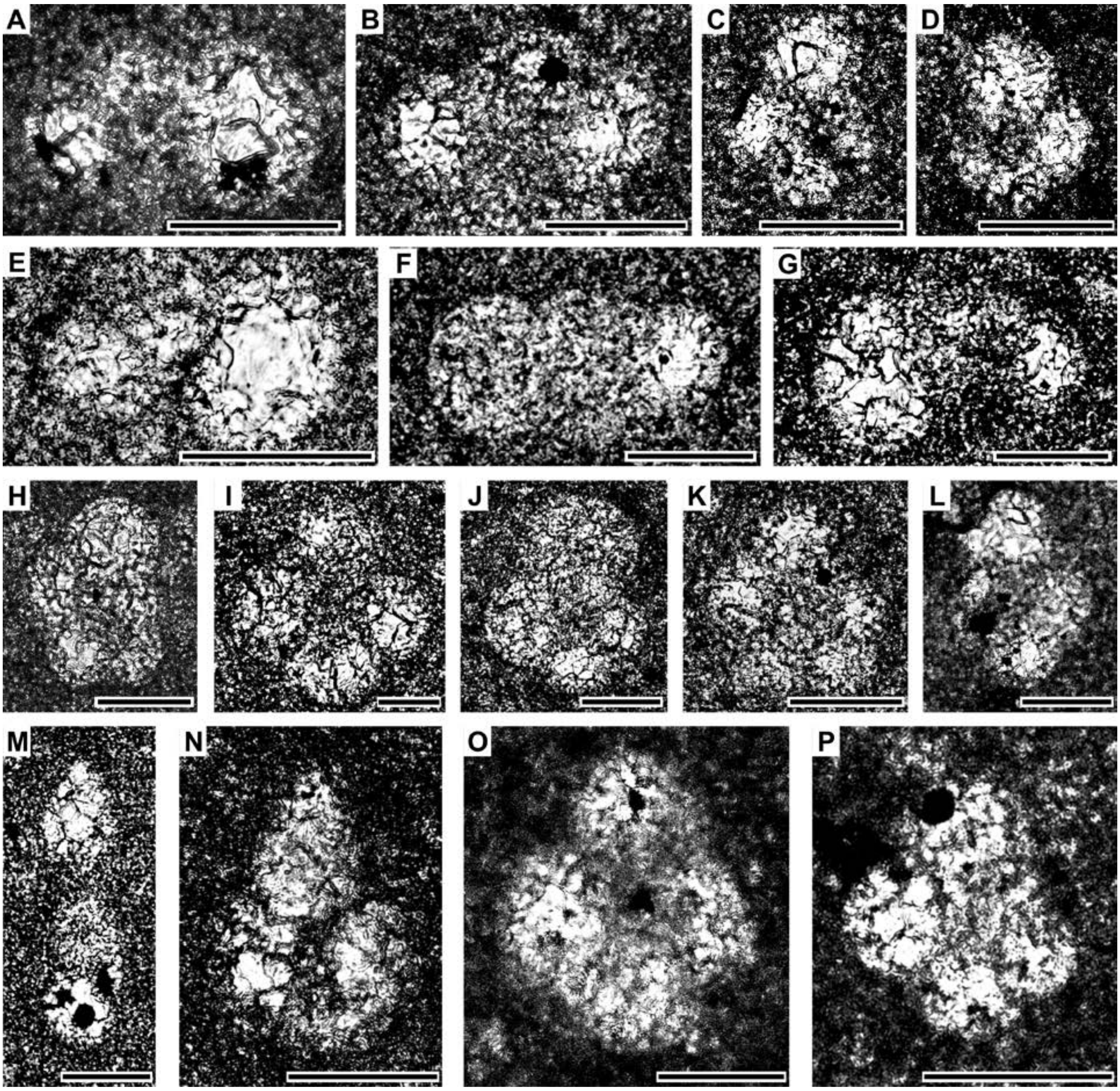

Fig. 17. *Praehedbergella* and *Pseudoschackoina* from the “spotted limestone” (Pieniny Limestone Formation) at Szlachtowa. Scale bars = 50 µm, except in I = 25 µm. **A.** *Praehedbergella ruka contritus* Banner, Copestake and White, axial section, sample S-t-10. **B.** *Praehedbergella* cf. *excelsa* (Longoria), axial section, sample S-t-8. **C.** *Praehedbergella* cf. *yakovlevae* BouDagher-Fadel, Banner and Whittaker, axial section, sample S-t-10. **D.** *Praehedbergella ruka contritus* Banner, Copestake and White, transverse section (umbilical side), sample S-t-10. **E.** *Praehedbergella gorbachikae* (Longoria), axial section, sample S-t-2. **F.** *Praehedbergella occulta* (Longoria), axial section, sample S-t-6. **G.** *Praehedbergella* cf. *sigali* (Moullade, 1966), axial section, sample S-t-3. **H.** *Praehedbergella* sp. ex gr. *P. daminiae-infracretacea*, transverse section, sample S-t-10. **I.** *Praehedbergella sigali* (Moullade), transverse section (umbilical side), sample S-t-2. **J.** *Praehedbergella* cf. *tuschepsensis* (Antonova), transverse section (spiral side), sample S-t-8. **K.** *Praehedbergella* cf. *speetonensis* Banner and Desai, transverse section, sample S-t-2. **L**, **M.** *Pseudoschackoina saundersi* (Bolli): L – transverse section, sample S-t-2; M – axial section, sample S-t-8. **N.** *Pseudoschackoina* cf. *saundersi* (Bolli), transverse section, sample S-t-11. **O.** *Praehedbergella ruka* Banner, Copestake and White, transverse section, sample S-t-8. **P.** *Praehedbergella* cf. *ruka* Banner, Copestake and White, transverse section, sample S-t-8.

2011 *Hedbergella gorbachikae* Longoria – Huber and Leckie, pp. 66–67, figs 5.3a–c, 5.5.

Description: The axial section of a very small test, 85 µm at its maximum diameter, consisting of globular (to ovoid) chambers in the last whorl. The test is plano-convex, with the spiral side flattened. Umbilical side convex; the ultimate chamber protruding into the umbilical area (umbilicus almost covered by the ultimate chamber).

Remarks: The specimen is similar to holotype (Longoria, 1974, pl. 15, fig. 12) and paratype (Longoria, 1974, pl. 15, fig. 10) of *H. gorbachikae* from Mexico being, however, much smaller. According to Longoria (1974), in Mexico this taxon ranges from the upper part of G. algerianus Zone to the top of T. bejaouaensis Zone. Longoria and Gamper (1977) have extended its range up to the lowermost Ticinella ticinensis Zone (Albian). Huber and Leckie (2011) reported occurrence of *H. gorbachikae* also from the lower

Aptian G. blowi Zone in of the Atlantic deep-sea sections. Coccioni *et al*. (2007) have found this taxon as early as the base of the H. excelsa Zone (latest Barremian).

Praehedbergella occulta (Longoria, 1974)
Fig. 17F

*1974 *Hedbergella occulta* sp. nov. – Longoria, pp. 63–64, pl. 11, figs 1–3, 7, 8; pl. 19, figs 1–3, 17, 18; pl. 20, figs 5–9, 17, 18; pl. 27, fig. 15.
1988 *Blefuscuiana occulta* (Longoria) – Banner and Desai, p. 162, pl. 6, figs 8–12.
2011 *Hedbergella occulta* Longoria – Huber and Leckie, p. 70, fig. 11.1–6.

Description: The specimen figured is an axial section, 110 µm in maximum diameter. It has globular to subglobular chambers, which are characteristic for this species (Longoria, 1974); the test is coiled in a very low trochospire. Umbilicus is broad and deep.
Remarks: This specimen is similar to Longoria's paratypes (Longoria, 1974, pl. 11, fig. 3 and pl. 20, fig. 7), being however smaller.

Praehedbergella ruka contritus Banner, Copestake and White, 1993
Fig. 17A, D

*1993 *Praehedbergella ruka contritus* subsp. nov. – Banner, Copestake and White, p. 6, pl. 1, figs 3a–c, 4a–b.
1997 *Praehedbergella ruka contritus* Banner, Copestake and White – BouDagher-Fadel, Banner and Whittaker, pp. 107–108, pl. 7.2, figs 10–12, fig. 7.1.

Description: The axial (Fig. 17A) and transverse (Fig. 17D) sections of two specimens; the transverse section of a very small specimen (70 µm at its maximum diameter) shows four chambers in the last whorl of the test. The chambers enlarge rather rapidly; the umbilicus is small.
Remarks; The transverse section figured closely resembles the ventral view of the holotype (re-illustrated by BouDagher-Fadel *et al*., 1997, pl. 7.2, fig. 12), which is about 120 µm in diameter. BouDagher-Fadel (2013) considers *P. contritus* to be a separate species.

Praehedbergella ruka Banner, Copestake and White, 1993
Fig. 17O

*1993 *Praehedbergella ruka s. s*. sp. nov. – Banner, Copestake and White, p. 6, pl. 1, figs 2a–c.
1997 *Praehedbergella ruka s. s*. Banner, Copestake and White, 1993, *sensu stricto* – BouDagher-Fadel, Banner and Whittaker, p. 107, pl. 7.2, figs 7–9, fig. 7.1.

Description: A transverse section of a small specimen (120 µm in maximum diameter), consisting of four chambers in the final whorl, which increase gradually with growth. The umbilicus is small; the aperture is a narrow slit.
Remarks: The figured specimen is similar to the holotype of *P. ruka s. s*. (Banner, Copestake and White, 1993, pl. 1, fig. 2a; see also BouDagher-Fadel *et al*., 1997, pl. 7.2, fig. 9).

Praehedbergella cf. *ruka* Banner, Copestake and White, 1993
Fig. 17P

Remarks: The shape of a small specimen (70 µm in maximum diameter) is similar to the holotype of *P. ruka papillata* (Banner, Copestake and White, 1993, pl. 1, fig. 5a; see also BouDagher-Fadel *et al*., 1997, pl. 7.3, fig. 3), but perforation cones cannot be observed in the case of the figured section (umbilical view) from Szlachtowa outcrop (sample S-t-8). BouDagher-Fadel (2013) considers this taxon to be a separate species (*P. papillata*).

Praehedbergella sigali (Moullade, 1966)
Fig. 17I

*1966 *Hedbergella* (*Hedbergella*) *sigali* sp. nov. – Moullade, p. 87–88, pl. 7, figs 20–25.
1974 *Hedbergella sigali* Moullade – Longoria, p. 68, pl. 21, figs 6–8, pl. 22, figs 1–13, pl. 24, figs 4–6.
1989 *Hedbergella sigali* Moullade – Sliter, p. 15, pl. 1, figs 2–4.
1993 *Praehedbergella sigali* (Moullade) *compacta* – Banner, Copestake and White, p. 8, pl. 2, fig. 3a–c.
1994 *Hedbergella sigali* Moullade – Coccioni and Premoli Silva, p. 677, fig. 12: 13–21.
1997 *Praehedbergella sigali* (Moullade) *sensu stricto* – BouDagher-Fadel, Banner and Whittaker, p. 108, pl. 7.3, figs 4–8, pl. 7.4, figs 1–4, fig. 7.1.
1997 *Praehedbergella sigali* (Moullade) *compacta* Banner, Copestake and White – BouDagher-Fadel, Banner and Whittaker, p. 109, pl. 7.3, figs 9-12, fig. 7.1.
1999 *Praehedbergella sigali* (Moullade) – Aguado, Castro, Company and de Gea, fig. 5.5–8.

Description: The specimen figured, 83 µm at its maximum diameter, was cut in transverse section (umbilical view). The test consists of four chambers in the final whorl. The penultimate chamber is significantly larger than the antepenultimate one. The umbilicus is moderately narrow; the aperture hardly visible and slit-like.
Remarks: The figured transverse section is broadly similar to the test illustrated by Longoria (1974, pl. 21, fig. 6) from the Aptian L. cabri Zone, and also to *P. sigali* from the early Barremian (BouDagher-Fadel *et al*., 1997, pl. 7.3, fig. 4). According to Moullade *et al*. (2002), this species reveals a wide range of variation in shape and increasing rate of chambers.

Praehedbergella cf. *sigali* (Moullade, 1966)
Fig. 17G

Description: The axial section of a small specimen (125 µm at its maximum diameter) shows subglobular to reniform chambers of the last whorl and a moderately narrow umbilicus. The trochospire is slightly convex. The thickness of the chamber wall is about 4 µm.
Remarks: The figured specimen is similar to the test from SE France, illustrated by Moullade *et al*. (2008, pl. 6.2).

Pseudoloeblichella? cf. *convexa* (Longoria, 1974)
Fig. 15C

Remarks: The axial section of the specimen figured is broadly similar to the holotype of *Loeblichella convexa* (Longoria, 1974, pl. 1, fig. 12) from the Leupoldina cabri Zone (lower part of the Upper Aptian). BouDagher-Fadel *et al*. (1997) included this species in the genus *Blefuscuiana,* but Coccioni *et al*. (2007) used the informal generic name "*Pseudoloeblichella*".

Praehedbergella cf. *excelsa* (Longoria, 1974)
Fig. 17B

Remarks: The figured axial section of a small specimen, about 100 µm at its maximum diameter, is similar to the paratype of *Hedbergella excelsa* illustrated by Longoria (1974, pl. 18, fig. 9) and also to the specimen shown by Petrizzo *et al.* (2012, pl. 2.8b).

Praehedbergella cf. *praetrocoidea* (Kretchmar and Gorbachik in Gorbachik, 1986)
Fig. 15A

Remarks: The axial section figured is broadly similar to the tests illustrated by: Moullade *et al*. (2005, pl. 5, fig. 2), Sliter (1999, pl. 1, fig. 10) and by BouDagher-Fadel *et al*. (1998, pl. 2, figs 2, 4). The specimen figured differs from *Hedbergella trocoidea* (Gandolfi) (*cf.* Longoria, 1974, pl. 17, figs 2, 6) in its broader umbilicus.

Praehedbergella cf. *speetonensis* Banner and Desai, 1988
Fig. 17K

Remarks: The transverse section of a small specimen (93 µm at its maximum diameter) is similar to the Late Aptian *Blefuscuiana speetonensis* figured by BouDagher-Fadel *et al*. (1997, pl. 8.11, fig. 10), although the latter test is larger.

Praehedbergella cf. *tuschepsensis* (Antonova, 1964)
Fig. 17J

Remarks: The overall shape of the specimen is similar to the holotype of *P. tuschepsensis*, figured by BouDagher-Fadel *et al*. (1997, pl. 7.1, fig. 5), and even more to the holotype of *P. tuschepsensis* (Antonova) *perforare* Banner, Copestake and White (BouDagher-Fadel *et al*., 1997, pl. 7.1, fig. 10). It is not possible to identify fully the subspecies of *P. tuschepsensis*, because perforation cones cannot be observed on the chambers of the transverse section figured. BouDagher-Fadel (2013) considers *P. tuschepsensis perforare* and *P. tuschepsensis grigelisi* to be separate species.

Praehedbergella cf. *yakovlevae* BouDagher-Fadel, Banner and Whittaker, 1997
Fig. 17C

Remarks: The transverse section of a small specimen (67 µm at its maximum diameter) is similar to the holotype of *P. yakovlevae* (BouDagher-Fadel *et al*., 1997, pl. 7.4, fig. 8), which, however, has a larger test (about 180 µm).

Praehedbergella sp. ex gr. *P. daminiae* Banner, Copestake and White (1993)-*P. infracretacea* (Glaessner, 1937)
Fig. 17H

Remarks: A small specimen (transverse section), similar to the holotype of *Blefuscuiana daminiae* Banner, Copestake and White (1993, pl. 3, fig. 6c), but also to *B. infracretacea* (Glaessner), figured in that paper (pl. 4, fig. 2a). It seems that distinction of *P. daminiae* from *P. infracretacea* is rather difficult in the case of a small test (in thin section). According to BouDagher-Fadel *et al*. (1997), the range of *B. daminiae* is Late Barremian to Early Aptian, whereas *B. infracretacea* (= *P. infracretacea*) is known from Early Aptian to Early Albian.

Genus *Pseudoschackoina* Verga and Premoli Silva, 2005

Type species: *Planomalina saundersi* Bolli, 1959.

Pseudoschackoina saundersi (Bolli, 1959)
Fig. 17L, M

*1959 *Planomalina saundersi* sp. nov. – Bolli, p. 262, pl. 20, figs 10, 11 [*non* fig. 9 according to Verga and Premoli Silva, 2005.]

1974 *non Globigerinelloides saundersi* (Bolli) – Longoria, p. 88, pl. 3, figs 2, 6–12; pl. 9, figs 8, 9 [see also Verga and Premoli Silva, 2005.]

1974 *Globigerinelloides cepedai* (Obregón de la Parra) – Longoria, p. 83, pl. 7, figs 1–5, pl. 9, figs 1–3 [see also Verga and Premoli Silva, 2005.]

2005 *Pseudoschackoina saundersi* (Bolli, 1959) – Verga and Premoli Silva, pp. 257–258, figs 5.13–15, 6.1–14.

Description: Two specimens are figured: a transverse section of a small test (maximum diameter 110 µm; Fig. 17L) and an axial section of a larger test, about 170 µm at its maximum diameter (Fig. 17M). The transverse section displays an evolute test with 6 chambers in the last whorl. The four early chambers are subglobular, whereas the penultimate one is subtriangular, radially elongate and pointed at the outer end. The ultimate chamber is trapezoidal in shape; a broken tubulospine is partly preserved at its base. The umbilical area is rather wide; the aperture is a low equatorial slit. The axial section (Fig. 17M) has two spherical to subspherical chambers and the ultimate one radially elongate and pointed.
Remarks: The axial section is similar to the specimen illustrated by Verga and Premoli Silva (2005, fig. 6.2b), and the transverse section broadly resembles the paratype from Trinidad, which, however, has only 5 chambers (Bolli, 1959, pl. 20, fig. 11).

Pseudoschackoina cf. *saundersi* (Bolli, 1959)
Fig. 17N

Remarks: This transverse section is broadly similar to the test shown by Verga and Premoli Silva (2005, fig. 5.14a), and also to *G. cepedai* from the upper part of Leupoldina cabri Zone (Longoria, 1974, pl. 7, fig. 4).

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