

# APTIAN FORAMINIFERAL STRATIGRAPHY AND *NANNOCONUS* ASSEMBLAGES FROM THE KOPKA SECTION (WESTERN TATRA MOUNTAINS, POLAND)

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Pszczołkowski, A., 2015. Aptian foraminiferal stratigraphy and *Nannoconus* assemblages from the Kopka section (Western Tatra Mountains, Poland). *Annales Societatis Geologorum Poloniae*, 85: 123–138.

**Abstract:** In the Kopka section (Dolina Kościeliska valley, Western Tatra Mountains), the upper part of the Kościeliska Marl Formation consists of biomicrites with marly interbeds. These deposits, 76 m thick, are assigned to the Praehedbergella excelsa and Leupoldina cabri zones, of Aptian age. The taxa identified belong mainly to the genera *Praehedbergella* Gorbachik and Moullade, 1973, *Globigerinelloides* Cushman and Ten Dam, 1948 (emended by Longoria 1974 and Verga and Premoli Silva, 2003a) and *Gorbachikella* Banner and Desai, 1988. Nineteen *Nannoconus* taxa were identified during an SEM study of 34 samples. The occurrence of *N. vocontiensis* in the higher part of the section allows the nannoconid assemblages in the upper part of the section to be distinguished from those in the lower part. Four *Nannoconus* assemblages were recognized in these limestones: (1) *Nannoconus bucheri*-*N. steinmannii*, (2) *N. truitti frequens*, (3) *N. vocontiensis* and (4) *N. aff. regularis*. The wide-canal *Nannoconus* specimens are more frequent than the narrow-canal ones in the limestones of earliest Aptian age (Praehedbergella excelsa Zone), but the wide-canal forms predominate consistently in the upper part of the section, still within the L. cabri Zone.

**Key words:** Aptian, planktonic foraminifers, *Nannoconus*, Kopka section, Western Tatra Mountains.

*Manuscript received 13 May 2014, accepted 15 November 2014*

## INTRODUCTION

Aptian nannoconid assemblages have not been the subject of detailed studies, not only in the Tatra Mountains (Fig 1A), but also across the entire Fatric Zliechov Basin. In the Pieniny Klippen Belt, the occurrence of nannoconids was taken into consideration only at the Rochovica section (Hálasová in: Michalík *et al.*, 2008). In the Western Tatra Mountains, Upper Barremian–Aptian limestones occur in the Kościeliska Marl Formation (Pszczołkowski, 2003); these limestones constitute a characteristic interval of calcareous deposition in the upper part of this lithostratigraphical unit. The aim of the present paper is to document a succession of Aptian nannoconid assemblages in the framework of planktonic foraminiferal biostratigraphy.

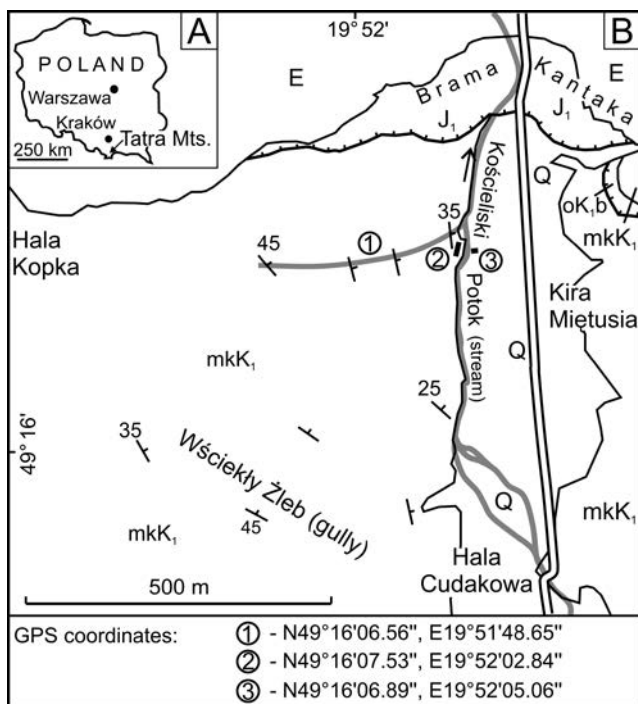
## PREVIOUS RESEARCH

The outcrops of the limestones studied are located in an unnamed gully, informally named the “Kopka gully” (Dolina Kościeliska valley, Western Tatra Mountains – Fig. 1B). They were shown on a geological map at a scale of 1 : 10000 (A2 Hruby Regiel sheet – Guzik *et al.*, 1958), as bands separated by marls, which are not exposed. According to K.

Guzik (in: Guzik *et al.*, 1958), the limestone beds are dipping to the north-east (47–50°) and continue south-eastwards towards the Kościeliski Potok stream. Lefeld (in: Lefeld *et al.*, 1985) assigned the limestones and marls to the Kościeliska Marl Formation. The type section of this formation was indicated on the “western and, partly eastern slopes of the Kościeliska Valley” (Lefeld in: Lefeld *et al.*, 1985, p. 77). According to this author, the youngest lithological units of the formation are ?Early Aptian in age and occur above the Muráň Limestone Member in the Belianske Tatra Mountains (Slovakia).

Kędzierski and Uchman (1997) concluded that the nannoplankton assemblage occurring in the Kościeliska Marl Formation is typical of the Tethyan realm and contains the Valanginian through early Aptian nannofossils. Their sample KS8 (Upper Berriasian–Lower Aptian) probably was collected from the strata exposed in the Kopka gully; samples KS9–KS17 may also be correlative to the Kopka section. The following *Nannoconus* taxa have been identified in the samples mentioned above: *N. bermudezii*, *N. colomii*, *N. globulus*, *N. minutus*, *N. steinmannii* and *Nannoconus* sp. (Kędzierski and Uchman, 1997).

Seven nannoconid assemblages have been recognized in the Kościeliska Marl Formation (Pszczołkowski, 2001).

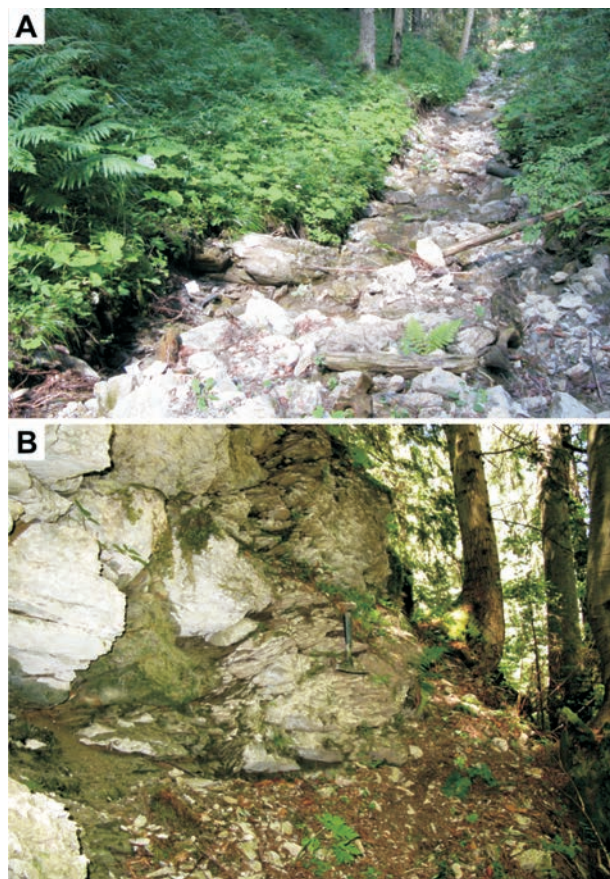


**Fig. 1.** Location of study area. **A.** Location of the Tatra Mountains in southern Poland. **B.** Map of the study area in the Kościeliska Valley (Western Tatra Mountains), after Guzik and Sokolowski (in: Guzik *et al.*, 1958) and Pszczółkowski (2003): oK<sub>1b</sub> – Osnica Formation (Berriasian); mkK<sub>1</sub> – Kościeliska Marl Formation (Berriasian–Aptian); J<sub>1</sub> – Lower Jurassic limestones of the Choč Nappe; E – Eocene conglomerates; Q – fluvial deposits (Holocene, mainly). Encircled numbers: 1 – Aptian limestones of the Kościeliska Marl Formation exposed in the gully located below the Polana Kopka glade on the left (western) bank of the Kościeliski Potok stream; 2 – Aptian limestones, exposed in the klippe close to the Kościeliski Potok stream; 3 – an outcrop of the Aptian limestone situated on the right (east) bank of the Kościeliski Potok stream. Barbed lines denote tectonic boundaries (overthrusts).

Two of them (assemblages 6 and 7) occur in the Upper Barremian–Aptian strata exposed in the Polana Kryta and Kira Miętusia sections. Pszczółkowski (2003) assigned the nannoconid-foraminiferal limestones (two informal units), occurring between the Polana Kopka glade and the Kościeliski Potok stream, to the Barremian–Lower Aptian. A preliminary investigation of the nannoconid assemblage revealed the presence of various taxa. However, a detailed study of these nannofossils was not performed at that time for the entire section.

## GEOLOGICAL SETTING AND LOCATION OF THE STUDIED SECTION

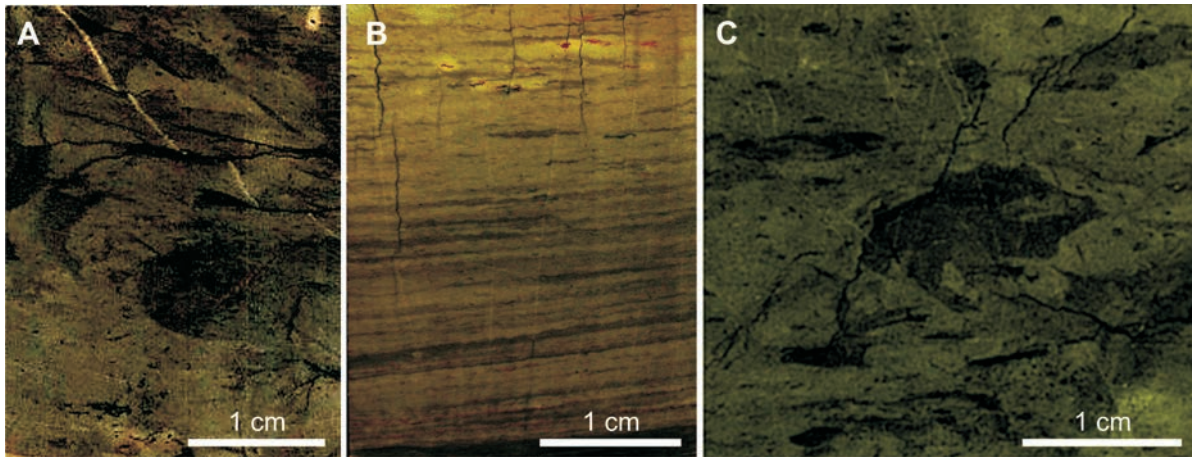
The Kościeliska Marl Formation terminates the Lower Sub-Tatric Succession in the Western Tatra Mountains (Lefeld, in Lefeld *et al.*, 1985). Its age was defined as latest Berriasian–?Early Aptian (Lefeld, in Lefeld *et al.*, 1985), on the basis of ammonites and calpionellids (Vigiliev, 1914; Lefeld, 1974). According to Kędzierski and Uchman (1997), the formation contains Valanginian through early Aptian



**Fig. 2.** Exposures of the strata studied. **A.** The Aptian limestones of the Kościeliska Marl Formation exposed in the gully located below the Polana Kopka glade on the left (western) bank of the Kościeliski Potok stream. **B.** The Aptian limestones of the Kościeliska Marl Formation exposed in the klippe (2 in Fig. 1B).

nannofossils. However, one sample (KS28) yielded calcareous nannoplankton from the Aptian–Albian boundary. Calpionellids and planktonic foraminifers (identified in thin sections) document the Middle Berriasian to Early Aptian age of the Kościeliska Marl Formation (Pszczółkowski, 2003). The Aptian Leupoldina cabri Zone was found to represent the youngest foraminiferal biozone recognized in the Kościeliska Marl Formation in the Western Tatra Mountains (Pszczółkowski, 2003).

The present contribution focuses on the nannoconid-foraminiferal limestones, occurring in the upper part of the Kościeliska Marl Formation (Pszczółkowski, 2003). The section studied is located on the western slope of the Dolina Kościeliska valley, 180 m south of the Brama Kantaka (Fig. 1B). The main part of the section (segment 1 – Fig. 1B) is exposed in the unnamed gully, for the purposes of the present contribution informally named the “Kopka gully”, situated between the Kościeliski Potok stream and the Polana Kopka glade (Fig. 2A). The strata exposed in the gully, together with the limestones occurring close to the Kościeliski Potok (segments 1–3 in Fig. 1B) are designated the “Kopka section”. Samples KA-1 through KA-40 were collected in the Kopka gully (segment 1), whereas samples KA-41 to KA-45 come from the klippe above the Kościeliski Potok (segment 2 – Figs 1B, 2B). The topmost part of the Kopka sec-



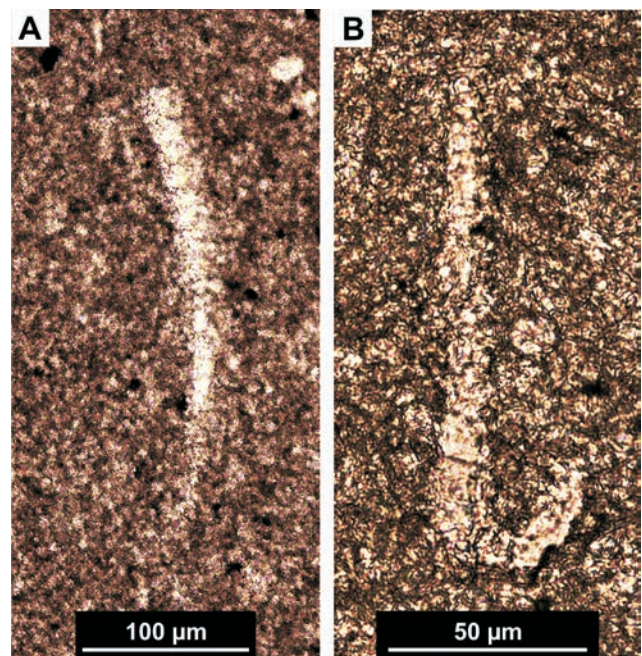
**Fig. 3.** Polished fragments of selected Aptian limestone samples from the Kopka section in the Dolina Kościeliska valley (Western Tatra Mountains). Rock colours after Goddard *et al.* (1975). **A.** Sample KA-6, burrowed limestone (colour: olive grey – 5 Y 3/2). **B.** Sample KA-18, limestone with lamination preserved (colour: olive grey – 5 Y 4/1). **C.** Sample KA-46, burrowed limestone (colour: olive grey – 5 Y 3/2).

tion (samples KA-46 and KA-47) occurs on the eastern bank of the Kościeliski Potok (segment 3 – Fig. 1B).

## DESCRIPTION OF THE KOPKA SECTION

The total thickness of the strata occurring in the Kopka section is 76 m. The limestones dip to the north-east (30–50°); the oldest strata are exposed in the western part of the gully, below the Polana Kopka glade, whereas the youngest beds occur downslope, close to the Kościeliski Potok (Fig. 1B). A good outcrop of the deposits studied is located in the klippe. The top beds occur on the eastern bank of the Kościeliski Potok (segment 3 in Fig. 1B). The limestones are not exposed continuously; the outcrops are separated by gaps that probably are underlain by shaly marls. The largest gap occurs in the upper part of the section, between segments 1 and 2 (Fig. 1B). Fifty samples have been collected from the whole section.

The nannoconid-foraminiferal limestones are thin-bedded to thick-bedded, yellow-brownish in colour on weathered surfaces. On fresh surfaces, the limestones (about 88% of the samples studied) are greyish olive (10 Y 4/2) or olive grey (5 Y 3/2 and 5 Y 4/1), according to the chart of Goddard *et al.* (1975). Only sample KA-1 is olive black (5 Y 2/1), whereas sample KA-10 is dusky yellowish brown (10 YR 2/2). The limestones are mainly biomicrites, locally with zoospores of *Globochaete alpina* (foraminiferal-globochaete microfacies) and bioclasts of Echinodermata, mainly crinoids. Benthic foraminifers are infrequent in the studied samples. In some beds, bioclasts and intraclasts are common to abundant. The limestones are commonly spotted, because of burrowing activity (Fig. 3A, C; see also Uchman, 1997 and Kędzierski and Uchman, 1997, fig. 5B). Lamination is preserved in a few beds, only (Fig. 3B). Ammonites are very rare in the limestones investigated (Pszczółkowski, 2003). Juvenile (uncoiled) ammonites occur sometimes in thin sections (Fig. 4A, B). In general, ammonites, although present in scree material of the Koście-



**Fig. 4.** Juvenile heteromorph ammonites (*Ancyloceratina* Wiedmann, 1966, emended Vermeulen, 2005) found in thin sections. **A.** Specimen from thin section (sample) KA-3. **B.** Specimen from thin section (sample) KA-24.

liska Marl Formation (Vigilieff, 1914; Lefeld, 1974), so far could not be used effectively in the biostratigraphical subdivision of this unit, mainly because of only rare occurrences of them in the exposed limestone beds.

## PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY

New data on the planktonic foraminifera identified in thin sections indicate that the entire section is Aptian in age (Figs 5, 6). However, the zonal assignment of samples

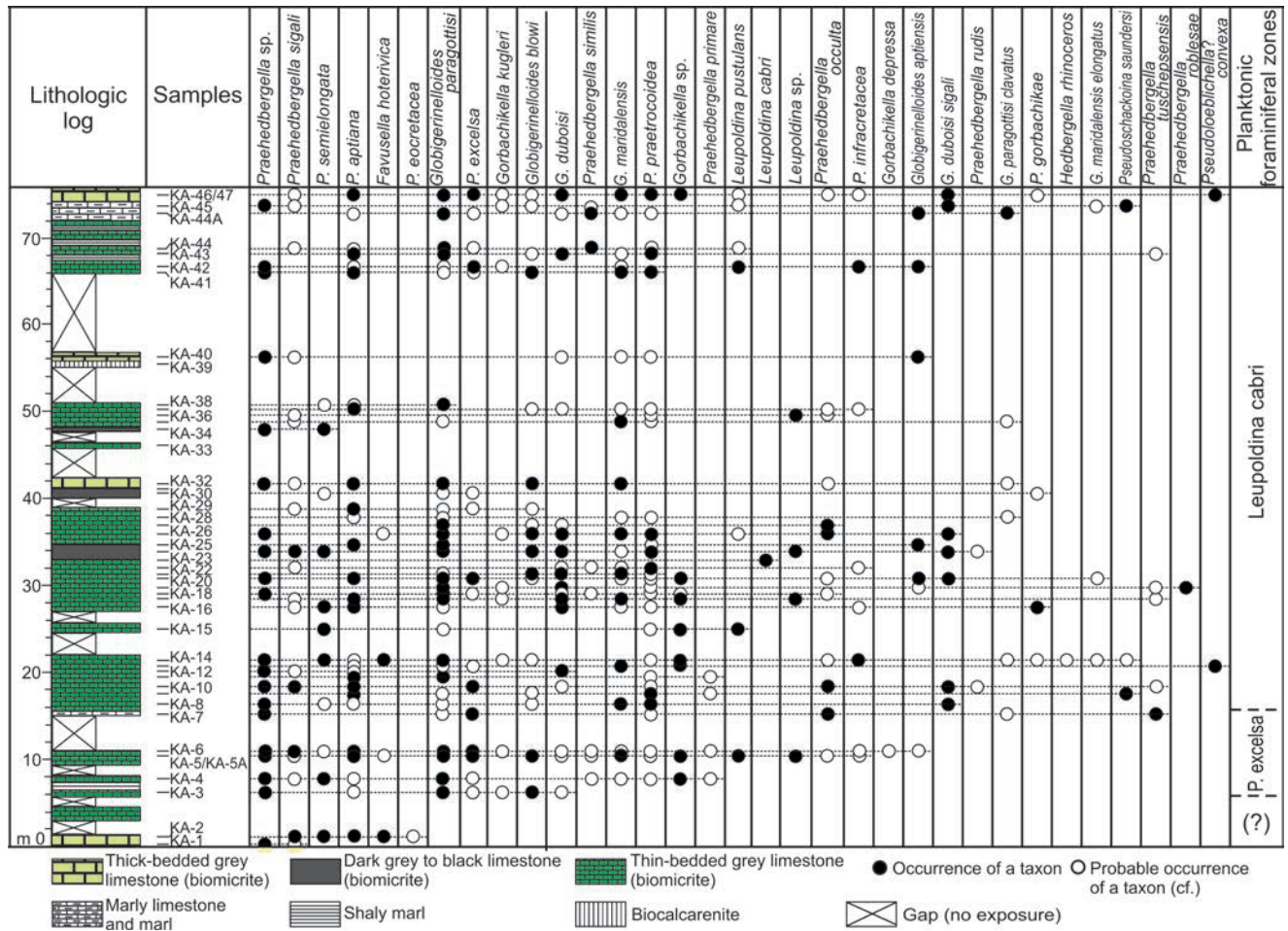


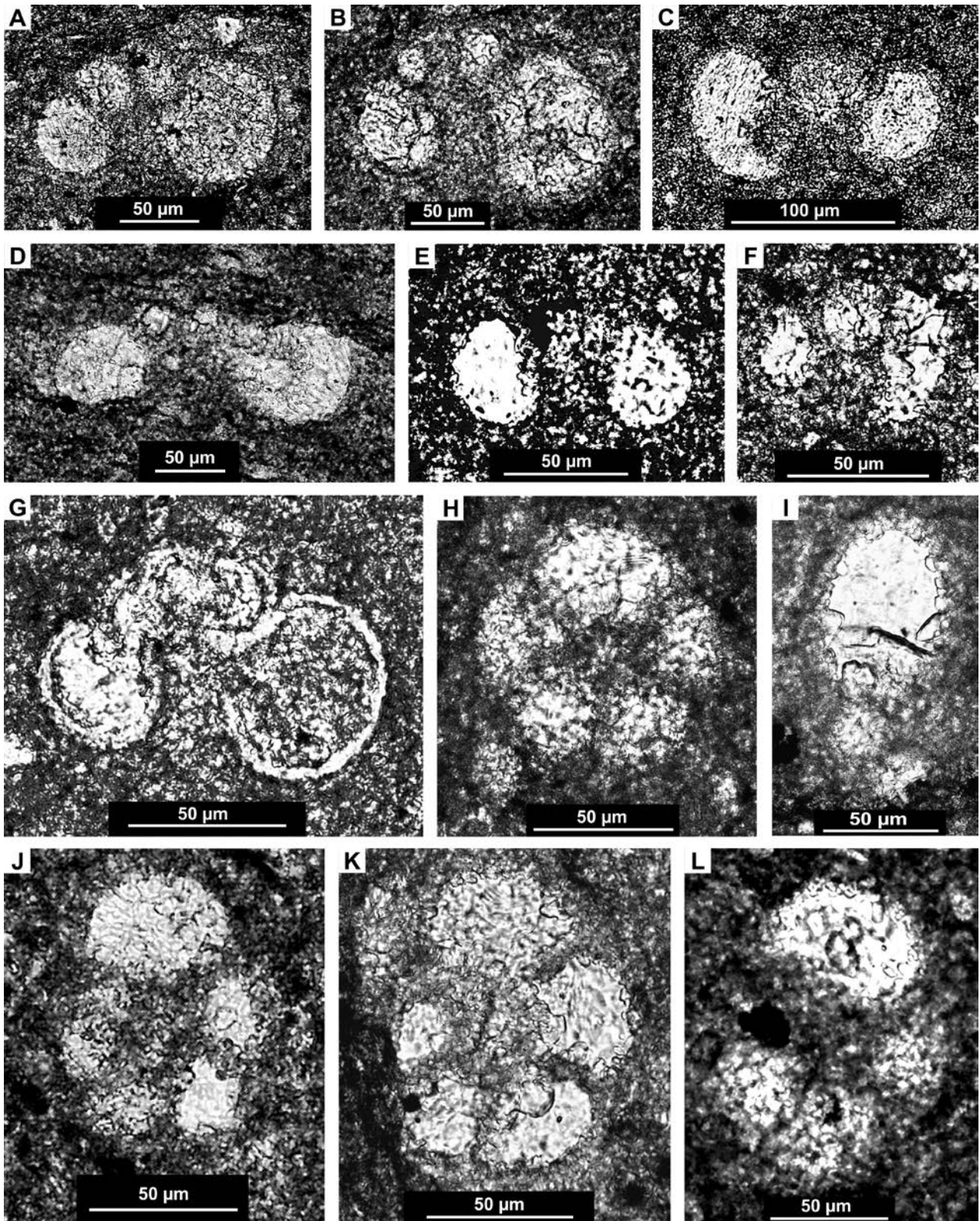
Fig. 5. Distribution of planktonic foraminiferal taxa identified in thin sections from samples collected in the Kopka section (upper part of the Kościeliska Marl Formation), Dolina Kościeliska valley, Western Tatra Mountains.

Stage	Substage	Ammonite zones Reboulet <i>et al.</i> (2011)	Planktonic foraminiferal zonation			Kopka section, Western Tatra Mts (this paper)			
			Moullade <i>et al.</i> (2002)	Coccioni and Premoli Silva (1994)	Coccioni <i>et al.</i> (2007)	Zones	Foraminiferal events		
Aptian	Upper	Epicheloniceras martini	cabri	L. cabri	L. cabri	L. cabri	? ↑ <i>Gl. aptiensis trans. terreolensis</i> ↓ <i>P. semielongata</i>		
		Dufrenoyia furcata							
	Lower	Deshayesites deshayesi		G. blowi				H. excelsa	P. excelsa
		Deshayesites forbesi							
		Deshayesites ogranlensis							
Barremian	U.	Imerites giraudi		G. aptiensis		↑ <i>H. cf. rhinoceros</i> ↑ <i>Gl. duboisi sigali</i> ↑ <i>Gl. maridalensis</i> ↑ <i>P. excelsa</i>			

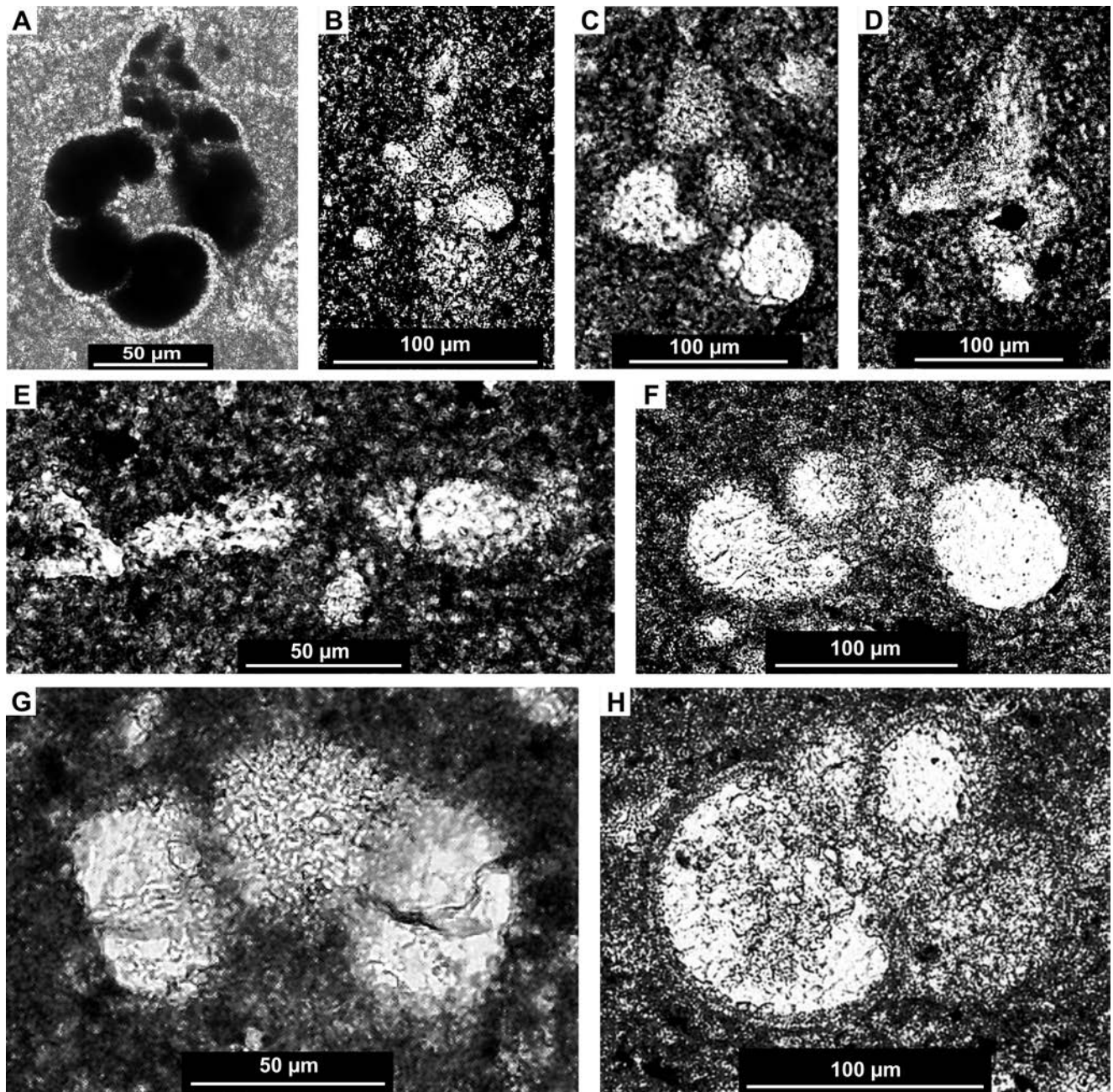
Fig. 6. Stratigraphical range of the limestones, exposed in the Kopka section (upper part of the Kościeliska Marl Formation). U. – Upper.

KA-1 and KA-2 is not clear; their foraminiferal assemblage consists of the following taxa (Fig. 5): *Praehedbergella sigali* (Moullade, 1966) – Fig. 7A, *P. semielongata* (Longoria, 1974) (Fig. 7D), *P. aptiana* (Bartenstein, 1965) (Fig. 7J, K), *P. cf. eocretacea* (Neagu, 1975), *Praehedbergella*

sp. and *Favusella hoterivica* (Subbotina, 1953) (Fig. 8G). Lack of *Praehedbergella excelsa* (Longoria, 1974) and *Globigerinelloides blowi* (Bolli, 1959) indicates that this assemblage may represent an older zone, that is, the G. aptiensis Zone in the scheme of Coccioni *et al.* (2007). However,



**Fig. 7.** Planktonic foraminifera (*Praehedbergella* spp.) from the Lower Aptian limestones exposed in the Kopka section (Dolina Kościeliska valley, Western Tatra Mountains). **A.** *Praehedbergella sigali* (Moullade, 1966), axial section, sample KA-2. **B.** *Praehedbergella excelsa* (Longoria, 1974), axial section, sample KA-5A. **C.** *Praehedbergella occulta* (Longoria, 1974), axial section, sample KA-10. **D, I.** *Praehedbergella semielongata* (Longoria, 1974), samples: KA-2 (D) and KA-4 (I). **E.** *Praehedbergella praetrocoidea* (Kretchmar and Gorbachik, 1986, in: Gorbachik, 1986), axial section, sample KA-24. **F.** *Praehedbergella* sp. cf. *P. praetrocoidea* (Kretchmar and Gorbachik), axial section, sample KA-5. **G.** *Praehedbergella* sp. cf. *P. rudis* (Banner, Copestake and White, 1993), axial section, sample KA-10. **H.** *Praehedbergella gorbachikae* (Longoria, 1974), transverse section, sample KA-16. **J, K.** *Praehedbergella aptiana* (Bartenstein, 1965), transverse sections, sample KA-2. **L.** *Praehedbergella* cf. *tuschepsensis* (Antonova, 1964), transverse section, sample KA-43.

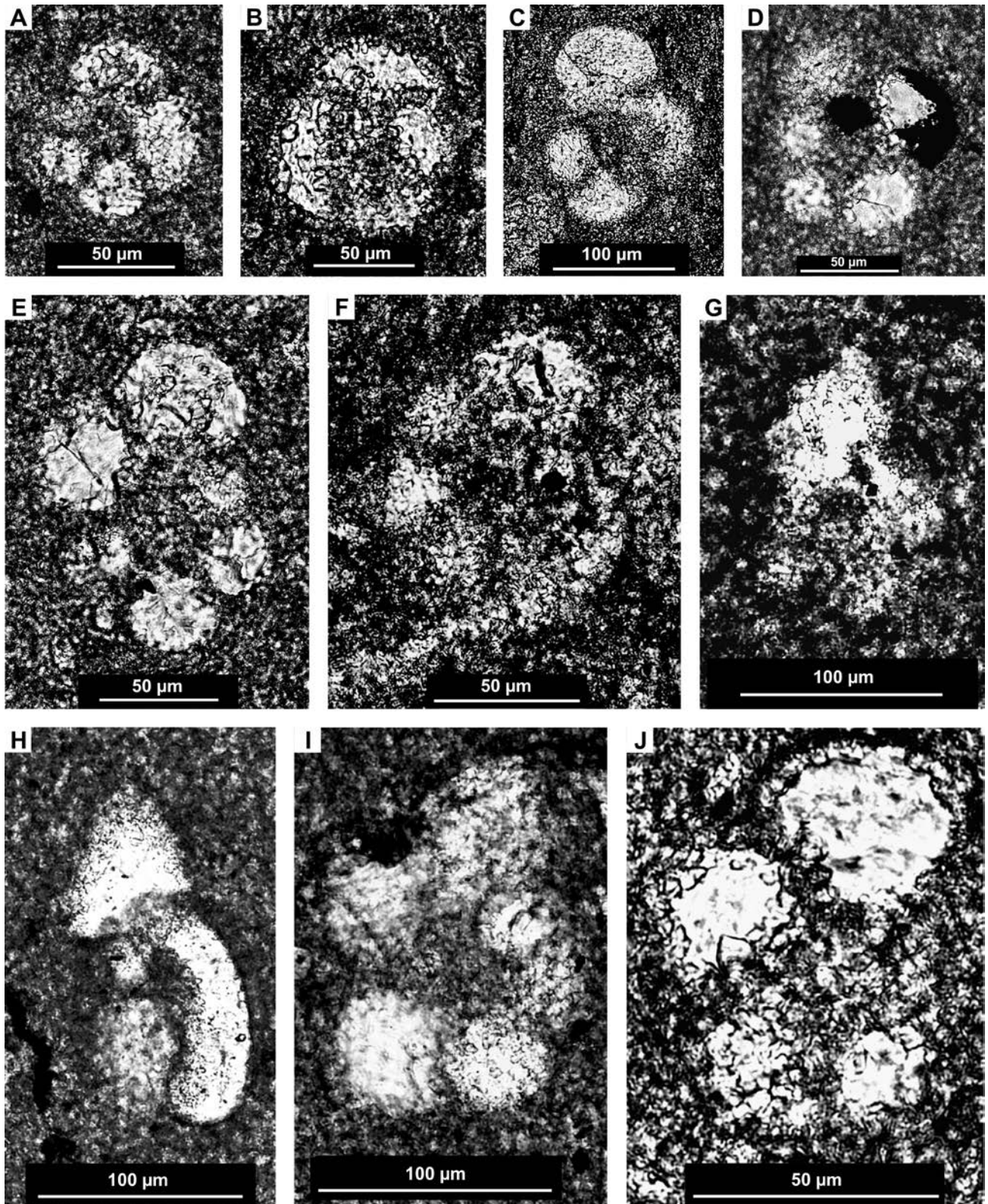


**Fig. 8.** *Hedbergella*, *Leupoldina*, *Pseudoloeblichella?*, *Favusella* and *Gorbachikella* from the Aptian limestones exposed in the Kopka section (Dolina Kościeliska valley, Western Tatra Mountains). **A.** *Hedbergella* cf. *rhinoceros* Coccioni and Cocon, 1988, transverse section, sample KA-14. **B, C.** *Leupoldina pustulans* (Bolli, 1957), samples: KA-5 (B) and KA-42 (C). **D.** *Leupoldina cabri* (Sigal, 1952), transverse section, sample KA-23. **E.** *Leupoldina* sp., axial section, sample KA-5A. **F.** *Pseudoloeblichella?* *convexa* (Longoria, 1974), axial section, sample KA-46. **G.** *Favusella hoterivica* (Subbotina, 1953), axial section, sample KA-2. **H.** *Gorbachikella* cf. *kugleri* (Bolli, 1959), oblique section, sample KA-46.

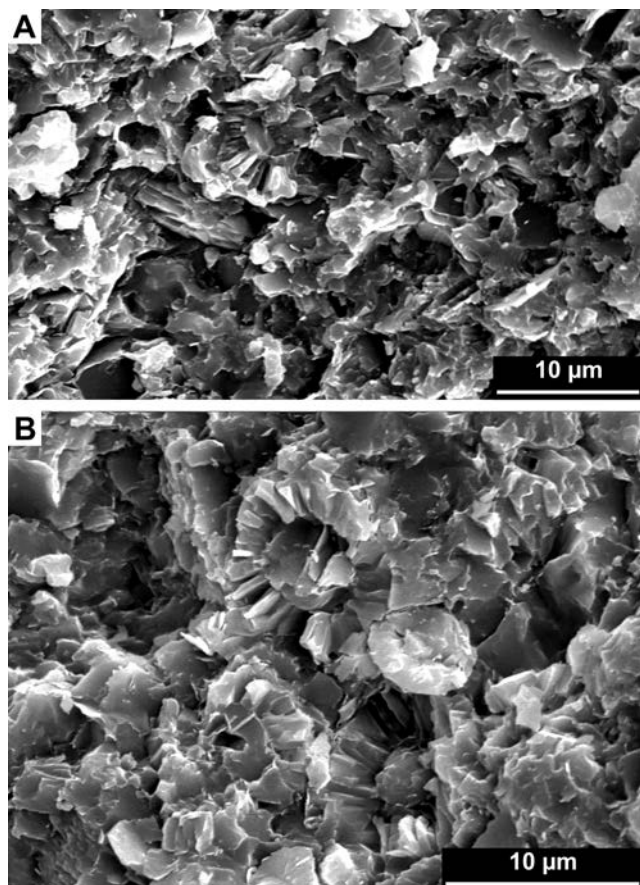
the species *Globigerinelloides aptiensis* was not observed in samples (thin sections) KA-1 and 2. Therefore, the corresponding limestone beds in the basal part of the section cannot be assigned to any existing foraminiferal zone. These beds are provisionally included in the lowermost Aptian strata (Fig. 6).

The overlying limestones, from sample KA-3 up to samples KA-46/47 at the top of the section, are correlated with the *P. excelsa* and *Leupoldina cabri* zones (Figs 5, 6).

The index taxon for the former zone – *P. excelsa* (Fig. 7B) – was registered in samples KA-5 and KA-6 (Fig. 5); *P. semielongata* (Fig. 7I) is also present in this zone. The boundary of the *P. excelsa* and *L. cabri* zones is shown below sample KA-8, but there is a gap in the section, which does not permit precise indication of this zonal boundary (Fig. 5). New data allowed the author to assign the upper part of the section (between samples KA-8 and KA-46/47) to the *L. cabri* Zone. This part of the section was previously



**Fig. 9.** *Globigerinelloides* spp. and *Pseudoschackoina saundersi* from the Aptian limestones exposed in the Kopka section (Dolina Kościeliska valley, Western Tatra Mountains). **A.** *Globigerinelloides paragottisi* Verga and Premoli Silva, 2003a, transverse section, sample KA-3. **B.** *Globigerinelloides maridalensis* (Bolli, 1959), transverse section, sample KA-8. **C.** *Globigerinelloides duboisi* (Chevalier, 1961), transverse section, sample KA-12. **D.** *Globigerinelloides blowi* (Bolli, 1959), transverse section, sample KA-5A. **E.** *Globigerinelloides aptiensis* Longoria, 1974, transverse section, sample KA-20. **F.** *Globigerinelloides aptiensis* trans. *ferreolensis*, transverse section, sample KA-40. **G.** *Globigerinelloides duboisi sigali* Longoria, 1974, transverse section, sample KA-45. **H.** *Globigerinelloides* cf. *maridalensis elongatus* Verga and Premoli Silva, 2005, oblique section, sample KA-20. **I.** *Pseudoschackoina saundersi* (Bolli, 1959), transverse section, sample KA-45. **J.** *Globigerinelloides paragottisi clavatus* Verga and Premoli Silva, 2005, transverse section, sample KA-44A.



**Fig. 10.** The Aptian *Nannoconus*-bearing limestones of the Kopka section, Dolina Kościeliska valley (Western Tatra Mountains). **A.** Pure nannoconid limestone, sample KA-10. **B.** *Nannoconus*-dominated limestone with occasional coccoliths, sample KA-24.

correlated with the uppermost interval of the B. *blowi* (= *G. blowi*) Zone (Pszczółkowski, 2003). The change partly results from different concepts of the Blowli and Cabri zones in the schemes used by various authors (Fig. 6), but also is due to the scarcity of the index taxon for the latter biozone in the limestones studied. Indeed, the specimens of *Leupoldina cabri* (Sigal, 1952) are rare in the thin sections analysed (Fig. 8D). Other occurrences of the genus *Leupoldina*, i.e. *L. pustulans* (Bolli, 1959) (Fig. 8B, C) and *Leupoldina* sp. (Fig. 8E), have been recorded in the Excelsa and Cabri zones (Fig. 5). Nevertheless, the L. cabri Zone is also documented by *Globigerinelloides duboisi sigali* Longoria, 1974 (Fig. 9G), *G. paragottisi clavatus* Verga and Premoli Silva, 2005 (Fig. 9J), *G. cf. paragottisi clavatus* and *G. cf. maridalensis elongatus* Verga and Premoli Silva, 2005 (Fig. 9H; see also Fig. 5). According to Coccioni *et al.* (2007), these taxa appear in the lowermost part of the L. cabri Zone. Moreover, the species *Pseudoschackoina saundersi* (Bolli, 1959) (Fig. 9I), identified in thin section (sample) KA-45, is known from the base of the L. cabri Zone to the G. algerianus Zone (Verga and Premoli Silva, 2005). Also the presence of specimens identified as *G. aptiensis* trans. *ferreolensis* (Fig. 9F) is consistent with the foraminiferal assem-

blage occurring in the L. cabri Zone (*cf.* Verga and Premoli Silva, 2003b).

In the Kopka section, the taxa identified belong mainly to the genera *Praehedbergella* Gorbachik and Moullade, 1973 (Fig. 7A–L), *Globigerinelloides* Cushman and Ten Dam, 1948, emended Longoria, 1974, emended Verga and Premoli Silva, 2003a (Fig. 9A–H, J) and *Gorbachikella* Banner and Desai, 1988 (Fig. 8H). The taxa *Globigerinelloides paragottisi* (Fig. 9A), *G. maridalensis* (Fig. 9B), *G. duboisi* (Fig. 9C) and *G. blowi* (Fig. 9D) are quite common in the samples (thin sections) studied, whereas *G. aptiensis* (Fig. 9E, F) and *G. cf. aptiensis* were found in seven samples. Other genera, *Favusella* Michael, 1973 (Fig. 8G), *Leupoldina* Bolli, 1957, emended Banner and Desai, 1988, emended Verga and Premoli Silva, 2002 (Fig. 8B–E), *Hedbergella* Brönnimann and Brown, 1958, emended Huber and Leckie, 2011 and *Pseudoschackoina* Verga and Premoli Silva, 2005 (Fig. 9I), are less frequent in the thin sections studied.

The species *Hedbergella cf. rhinoceros* Coccioni and Cocon, 1988 (Fig. 8A), found in thin section KA-14, has 6.5 chambers only (instead of 7 to 9) and may be an early representative of the species *H. rhinoceros* or, alternatively, a new taxon(?) from the *H. rhinoceros* group. The taxon *H. rhinoceros* was reported from the Late Aptian *Globigerinelloides algerianus* Zone to the Early Albian *Hedbergella planispira* Zone (Coccioni and Cocon, 1988) and also from the *H. trocoidea* Zone (Apennines, Italy – Coccioni *et al.*, 1990). The Early Aptian age of the uppermost interval of the L. cabri Zone in the Kopka section seems to be supported by the lack of foraminiferal taxa considered to appear in the Upper Aptian (or Middle Aptian – see Kuhnt *et al.*, 2011). According to Moullade *et al.* (2005), in SE France the range of *P. luterbacheri* (Longoria, 1974) starts approximately at the Bedoulian–Gargasian boundary (= Lower–Middle Aptian boundary according to Kuhnt *et al.*, 2011). This taxon, however, was not observed in the samples studied from the Kopka section (Fig. 5).

The taxa *Praehedbergella occulta* (Longoria, 1974) (Fig. 7C) and *P. cf. occulta* (Longoria) are frequent in samples belonging to the L. cabri Zone (Fig. 5). The stratigraphical range of *P. occulta* comprises the whole Aptian Stage (BouDagher-Fadel *et al.*, 1997). Even more frequent are the taxa *P. praetrocoidea* (Kretschmar and Gorbachik, in: Gorbachik, 1986) – Fig. 7E, and *P. cf. praetrocoidea* (Fig. 7F), whereas *Praehedbergella* sp. *cf. P. rudis* (Banner, Copestake and White, 1993) (Fig. 7G) was found in the lower part of the L. cabri Zone, only (Fig. 5). The foraminifer *Praehedbergella gorbachikae* (Longoria, 1974) (Fig. 7H) was identified in the sample KA-16 (Fig. 5); its appearance in the lower part of the L. cabri Zone is consistent with the wide range of this taxon (Aptian–Lower Albian according to BouDagher-Fadel *et al.*, 1997 and BouDagher-Fadel, 2013). The species *Praehedbergella cf. tuschepsensis* (Antonova, 1964) (Fig. 7L) is uncommon in the Kopka section (Fig. 5), while *Pseudoloeblichella? convexa* (Longoria, 1974) (Fig. 8F) was found in samples KA-14 and KA-46, only. In contrast, the taxa *Gorbachikella cf. kugleri* (Bolli, 1959) (Fig. 8H) and *Gorbachikella* sp. are common in the Excelsa and Cabri zones.



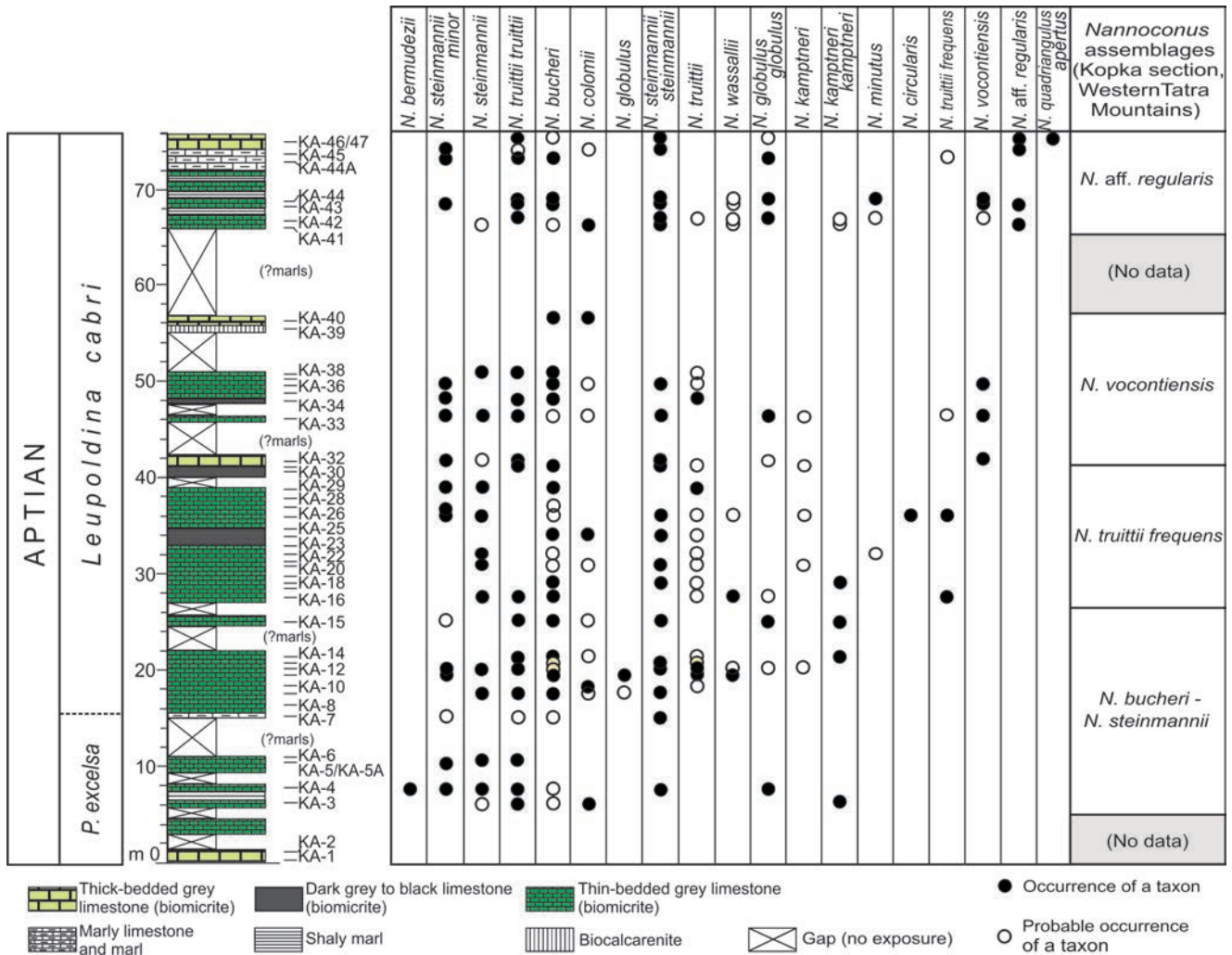


Fig. 11. Distribution of *Nannoconus* taxa identified in Aptian limestones of the Kościeliska Marl Formation (upper part), in the Kopka section (Dolina Kościeliska valley, Western Tatra Mountains).

**NANNOCONUS ASSEMBLAGES**

Thirty-four samples from the Kopka section were investigated for occurrences of *Nannoconus* taxa under the scanning electron microscope; the results are shown in Fig. 11 and Table 1. Nannoconids were not observed in samples KA-1 and KA-2. In samples KA-5, KA-6 and KA-7, calcareous nannofossils are scarce, whereas samples KA-9 and KA-10 contain frequent nannoconids (Fig. 10A). Abundant nanoconids occur in sample KA-24, while coccoliths are rather scarce (Fig. 10B). In all samples studied, 19 taxa belonging to the genus *Nannoconus* Kamptner were identified (Fig. 11). The taxa: *Nannoconus bucheri* Brönnimann, 1955 (Fig. 12A), *N. colomii* de Lapparent (Fig. 13F), *N. truittii* Brönnimann, 1955, *N. truittii* Brönnimann *truittii* Deres and Achéritéguy, 1980 (Fig. 12B), *N. steinmannii* Kamptner and *N. steinmannii* Kamptner *steinmannii* Deres and Achéritéguy, 1980 (Fig. 13D) are common in the samples analysed.

In general, in the samples studied, the wide-canal specimens of *Nannoconus* predominate over the narrow-canal ones (Tab. 1). In sample KA-11, both forms are equally abundant; in samples KA-20 and KA-22 the narrow-canal

forms (N) are more abundant than the wide-canal ones (W). There are long specimens assigned to the taxon *N. ex gr. steinmannii-bermudezii* in these samples. In samples KA-24 to KA-46, the wide-canal forms predominate (except for sample KA-32). The species *Nannoconus colomii* occurs up to sample KA-41, and probably in sample KA-45 (Tab. 1), that is, in the upper part of the L. cabri Zone (Figs 5, 6). For comparison, it is pertinent to mention that *N. colomii* have not been recorded above the lowermost Aptian in the sections of northern and central Italy (Erba, 1989). Earlier, Deres and Achéritéguy (1980) terminated the range of this taxon in the Barremian. However, *N. colomii* disappeared at the G. ferreolensis/G. algerianus zonal boundary (Upper Aptian) in western Cuba (Pszczółkowski *et al.*, 2013). With regard to the taxon *N. steinmannii steinmannii*, Bralower *et al.* (1994) correlated the upper boundary of its range (at the DSDP and ODP sites) with the topmost interval of the G. blowi Zone in the upper part of the Lower Aptian. However, in the Italian sections, Erba (1989) reported the last appearance datum (LAD) of *N. steinmannii* from the G. ferreolensis Zone; this discovery is in better agreement with the data from the Kopka section in the Western Tatra Mountains.

Table 1

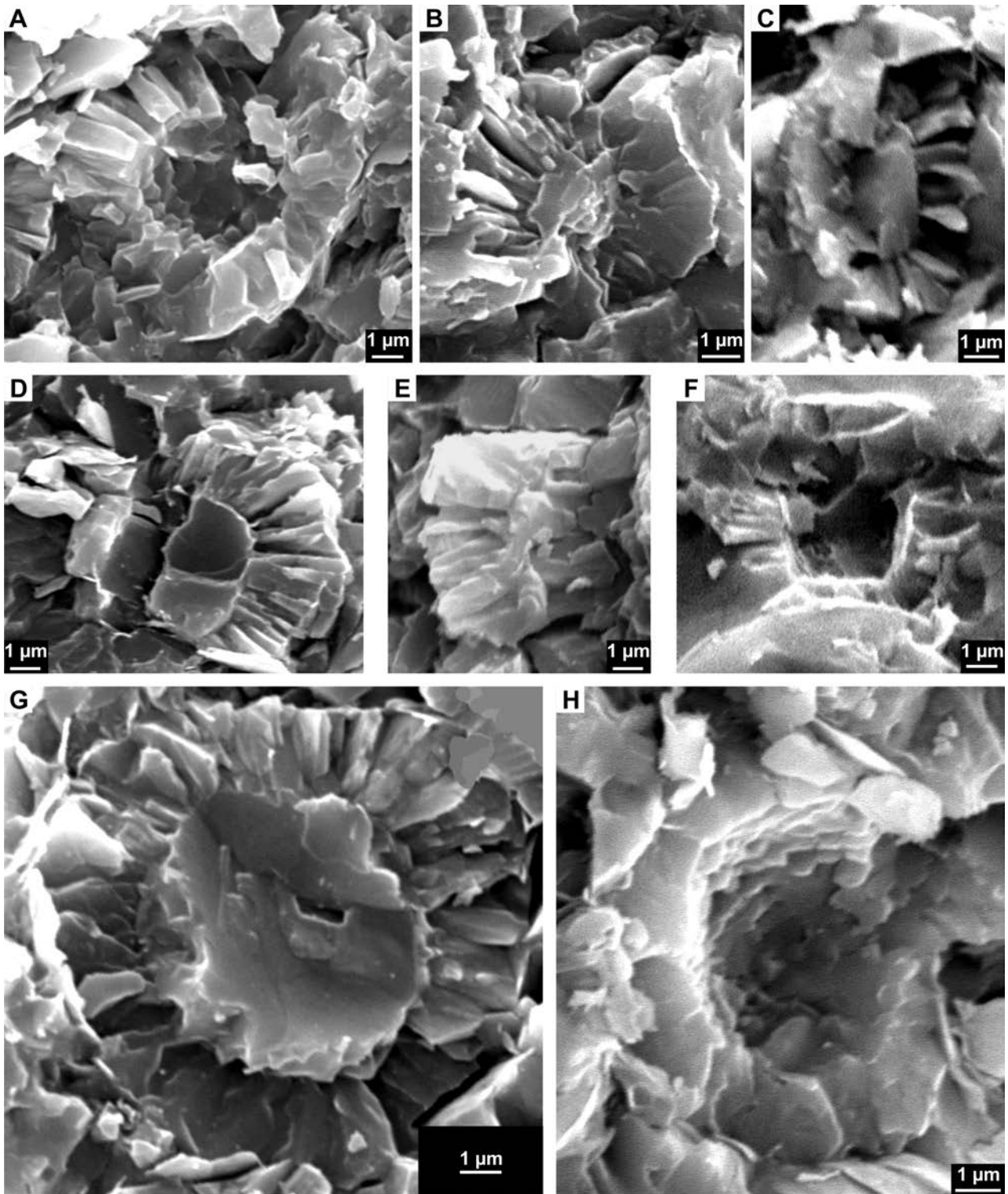
Occurrence of calcareous nannofossils and N/W ratio for *Nannoconus* assemblages in samples of the Aptian limestones from the Kopka section in the Dolina Kościeliska valley (Western Tatra Mountains)

Sample	Calcareous nannofossils	<i>Nannoconus</i> (N/W – semi-quantitative estimation)	
KA-1/2	None	-	-
KA-3	Frequent	0.14	N<W
KA-4	Frequent	1.08	N>W
KA-5	Very scarce	>1	N>W
KA-6	<i>Nannoconus</i> spp. (scarce specimens)	0.49	N<W
KA-7	Rare, poorly preserved	4	N>W
KA-9	Frequent <i>Nannoconus</i> specimens, coccoliths infrequent and poorly preserved	0.19	N<W
KA-10	Frequent <i>Nannoconus</i> specimens, coccoliths infrequent	0.27	N<W
KA-11	Frequent <i>Nannoconus</i> specimens, coccoliths infrequent	1	N=W
KA-12	Frequent <i>Nannoconus</i> specimens, coccoliths very scarce	0.8	N<W
KA-13	Frequent <i>Nannoconus</i> specimens, coccoliths very scarce	1	N=W
KA-14	Frequent <i>Nannoconus</i> specimens, coccoliths very scarce	0.64	N<W
KA-15	Abundant <i>Nannoconus</i> specimens	0.6	N<W
KA-16	Infrequent, poorly preserved	0.12	N<W
KA-18	Infrequent, poorly preserved	0.33	N<W
KA-20	Frequent <i>Nannoconus</i> specimens, mainly	1.8	N>W
KA-22	Frequent <i>Nannoconus</i> specimens and less frequent coccoliths	3.2	N>W
KA-24	Frequent <i>Nannoconus</i> specimens and less frequent coccoliths	0.23	N<W
KA-26	Abundant <i>Nannoconus</i> , very scarce coccoliths	0.6	N<W
KA-27	Frequent <i>Nannoconus</i> specimens and scarce coccoliths	0.72	N<W
KA-29	Frequent <i>Nannoconus</i> specimens and scarce coccoliths	0.6	N<W
KA-31	Infrequent, poorly preserved	0.5	N<W
KA-32	Frequent <i>Nannoconus</i> specimens; coccoliths scarce, sometimes partly dissolved	1.1	N>W
KA-33	Frequent <i>Nannoconus</i> specimens, coccoliths very scarce	0.9	N<W
KA-34	Infrequent, poorly preserved	0.54	N<W
KA-36	Frequent <i>Nannoconus</i> specimens, coccoliths very scarce	0.5	N<W
KA-38	Frequent <i>Nannoconus</i> specimens, coccoliths scarce	0.4	N<W
KA-40	Infrequent <i>Nannoconus</i> specimens, only	0.79	N<W
KA-41	Frequent <i>Nannoconus</i> specimens, coccoliths very scarce	0.75	N<W
KA-42	Frequent <i>Nannoconus</i> specimens, coccoliths scarce	0.33	N<W
KA-43	Frequent <i>Nannoconus</i> specimens, coccoliths scarce, poorly preserved	0.43	N<W
KA-44	Frequent <i>Nannoconus</i> specimens, coccoliths very scarce	0.56	N<W
KA-44A	Abundant <i>Nannoconus</i> specimens	0.27	N<W
KA-45	Infrequent, poorly preserved	0.64	N<W
KA-46	Frequent <i>Nannoconus</i> specimens, poorly preserved	0.47	N<W

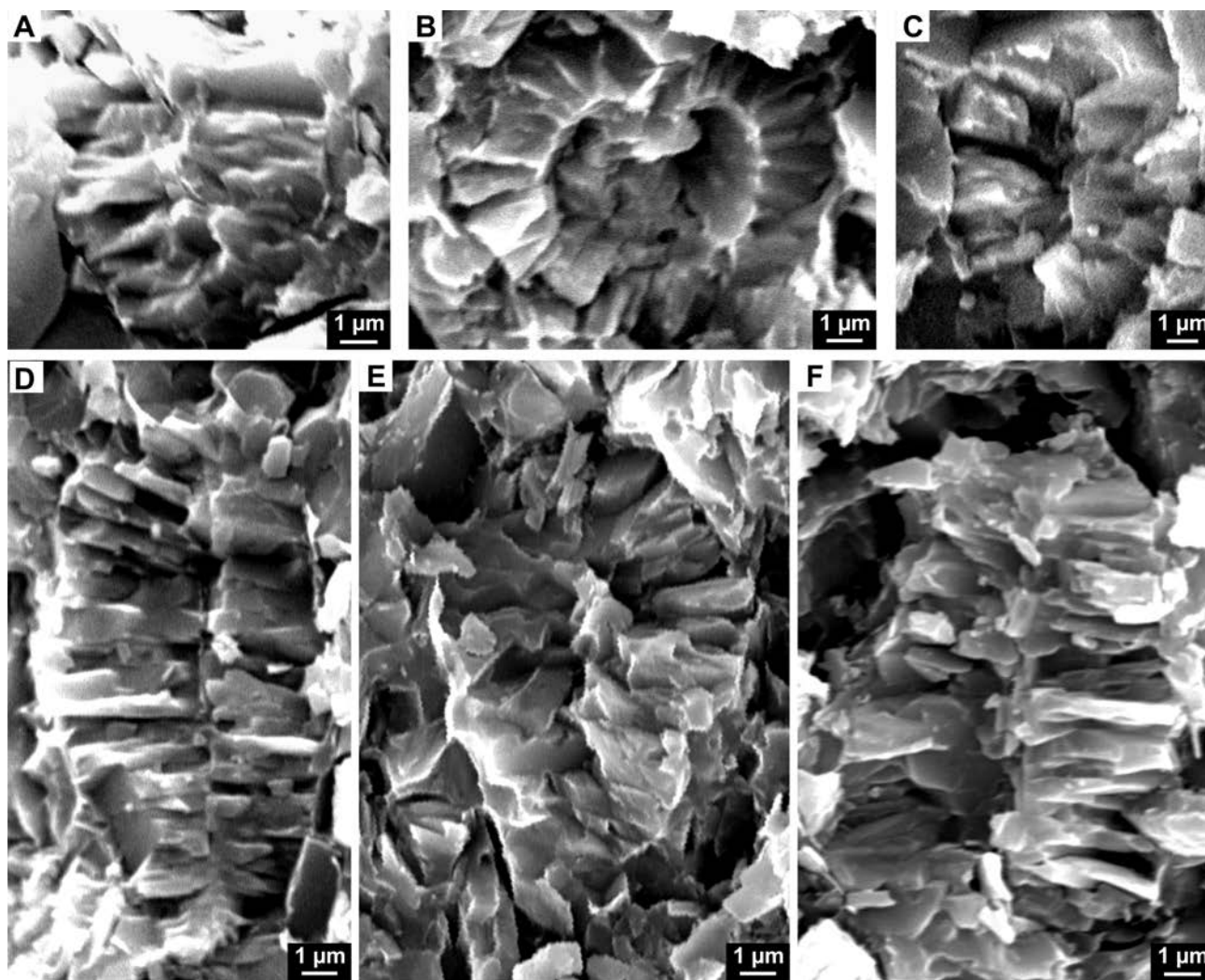
N – narrow-canal forms of *Nannoconus* Kamptner, 1931; W – wide-canal forms of this genus.

Above sample KA-2, the whole section may be subdivided into four *Nannoconus* assemblages: (1) *N. bucheri*-*N. steinmannii*, (2) *N. truittii frequens*, (3) *N. vocontiensis* and (4) *N. aff. regularis* (Fig. 11). Assemblage (1) occurs in the lower part of the section and comprises 13 taxa, with *N. steinmannii minor* (Fig. 13A), *N. steinmannii steinmannii*, *N. truittii truittii* and *N. bucheri* being the most numerous. This assemblage is named *N. bucheri*-*N. steinmannii* because these species are very frequent and also in order to refer to the *N. bucheri* Zone distinguished by Deres and Achéritéguy (1980) in the Lower Aptian. Assemblage (2)

includes 15 taxa, the following being the most common: *N. bucheri*, *N. truittii truittii* and *N. steinmannii steinmannii* (Fig. 11). However, in this assemblage *N. truittii frequens* (Fig. 12C) makes its first appearance; therefore, this sub-species is the most characteristic taxon. The taxon *N. truittii frequens* was described from the Lower Aptian–Turonian (Deres and Achéritéguy, 1980). In the Kopka section, this taxon also appears in the Lower Aptian strata (Figs 6, 11). Also one specimen of *Nannoconus circularis* (Fig. 12H) was found in assemblage (2).



**Fig. 12.** Scanning electron micrographs of selected *Nannoconus* specimens from Aptian limestones in the Kopka section (Dolina Kościeliska valley, Western Tatra Mountains). **A.** *Nannoconus bucheri* Brönnimann, 1955, longitudinal section, sample KA-9. **B.** *N. truittii truittii* Brönnimann, 1955, oblique section, sample KA-9. **C.** *N. truittii* Brönnimann *frequens* Deres and Achéritéguy, 1980, oblique longitudinal section, sample KA-26. **D.** *N. vocontiensis* Deres and Achéritéguy, 1980, longitudinal section, sample KA-32. **E.** *N. cf. minutus* Brönnimann, 1955, longitudinal section, sample KA-42. **F.** *N. quadriangulus apertus* Deflandre and Deflandre-Rigaud, 1962, longitudinal section, sample KA-46. **G.** *N. wassallii* Brönnimann, 1955, oblique transverse section, sample KA-11. **H.** *N. circularis* Deres and Achéritéguy, 1980, oblique section, sample KA-26.



**Fig. 13.** Scanning electron micrographs of selected *Nannoconus* specimens from Aptian limestones in the Kopka section (Dolina Kościeliska valley, Western Tatra Mountains). **A.** *Nannoconus steinmannii* Kamptner *minor* Deres and Achéritéguy, 1980, longitudinal section, sample KA-43. **B.** *N. globulus globulus* Brönnimann, 1955, longitudinal section, sample KA-42. **C.** *N. aff. regularis* Deres and Achéritéguy, 1980, longitudinal section, sample KA-46. **D.** *N. steinmannii steinmannii* Kamptner, 1931, longitudinal section, sample KA-44. **E.** *Nannoconus kamptneri kamptneri* Brönnimann, 1955, oblique longitudinal section, sample KA-18. **F.** *N. colomii* de Lapparent, 1931, longitudinal section, sample KA-10.

Assemblage (3) is named *N. vocontiensis*, because this taxon (Fig. 12D) appears at its base in sample KA-32 (Fig. 11). The presence of *Nannoconus* cf. *vocontiensis* in the limestones studied, although in one sample only, was mentioned previously (Pszczółkowski, 2003). Now it is possible to evaluate the significance of appearance of *N. vocontiensis* in the Kopka section. Deres and Achéritéguy (1980) restricted the stratigraphical range of this taxon to the lower part of the Upper Aptian (“base de l’Aptien supérieur”). The first appearance of this taxon (FAD) permits the *Nannoconus* assemblages occurring in the upper part of the Kopka section to be distinguished from those recognized in the lower part. Assemblage (3) still contains numerous specimens belonging to the taxa: *N. steinmannii minor*, *N. steinmannii steinmannii*, *N. truittii truittii* and *N. bucheri* (Fig. 11).

The highest assemblage (4) is characterized by the occurrence of *N. aff. regularis* (Fig. 13C), *N. vocontiensis* in

its lower part and *N. quadriangulus apertus* (Fig. 12F) in the uppermost samples (KA-46/47). Assemblage (4) also contains *N. steinmannii minor* (Fig. 13A), *N. truittii truittii*, *N. bucheri*, *N. colomii*, *N. steinmannii steinmannii* (Fig. 13D), *N. cf. wassallii*, *N. globulus globulus* (Fig. 13B), *N. minutus* and *N. cf. minutus* (Fig. 12E). According to Deflandre and Deflandre-Rigaud (1967), *N. quadriangulus apertus* occurs in the Gargasian; Deres and Achéritéguy (1980) showed this taxon as occurring in the Upper Aptian. The specimens assigned herein to *N. aff. regularis* are smaller than those included in the taxon *N. regularis* by Deres and Achéritéguy (1980). The stratigraphical range of *N. regularis* was reported to be Albian–Santonian (Deres and Achéritéguy, 1980), but Erba (1988, 1989) found this species in the uppermost Aptian, too. In the Italian sections, *N. regularis* Zone was correlated with part of the latest Aptian foraminiferal Ticinella bejaouaensis Zone (Erba, 1988). Probably, *N. aff. regularis* is an earlier representative of this

“slightly conical” and “almost isometric” *Nannoconus* species (Deres and Achéritéguy, 1980). The *N. aff. regularis* assemblage may occur in the Upper Aptian part of the L. cabri Zone (*sensu* Leckie *et al.*, 2002; Coccioni *et al.*, 2007) or at the Lower-Upper Aptian boundary (after Ogg *et al.*, 2012).

### PROBABLE “NANNOCONID CRISIS” AND CHANGE IN THE RATIO OF NARROW/WIDE-CANAL SPECIMENS IN THE SECTION STUDIED

In the Kopka section, calcareous nannofossils are present in almost all samples studied, except for KA-1 and KA-2. However, in samples KA-5 to KA-7, calcareous nannofossils are scarce to rare (Tab. 1). The corresponding beds belong to the upper part of the P. excelsa Zone (Fig. 5). This part of the section comprises limestones and marls, about 5.7 m thick; however, the marls are not exposed there. The limestone sample KA-5 contains very scarce nannoconids (*N. steinmannii minor* and *N. sp. ex gr. N. steinmannii-colonii*, only). This part of the section may correspond to the “nannoconid crisis” (Erba, 1994), documented in the Cismon section in Italy (Méhay *et al.*, 2009; Erba *et al.*, 2010) and southeast France (Moullade *et al.*, 1998; Herrle and Mutterlose, 2003). Erba *et al.* (1999) correlated the beginning of the “nannoconid crisis” with the lower boundary of the modified L. cabri Zone, below the “Selli Level” (oceanic anoxic subevent 1a – Erba, 1994) and above magnetozone CM0 (see also Channell *et al.*, 2000). The “nannoconid crisis” was shown to occur in the upper interval of the NC6 nannofossil Zone, and in the L. cabri Zone, directly above magnetozone CM0 (Erba, 2004; Erba *et al.*, 2010). Slightly earlier (in magnetozone M0 – earliest Aptian), the wide-canal nannoconids became more abundant than the narrow-canal forms (Erba, 2004). The “nannoconid crisis” occurred during the collapse of calcification of planktonic and benthic calcareous organisms, in conditions of CO<sub>2</sub> excess in the ocean-atmosphere system (Weissert and Erba, 2004; Erba *et al.*, 2010).

In the Kopka section, the nannofossils became more frequent in sample KA-9, with *Nannoconus* predominating over the coccoliths. In the younger limestones of the section (L. cabri Zone), calcareous nannofossils are present, but often poorly preserved (Tab. 1). The wide-canal specimens predominated over the narrow-canal ones in the lowermost part of the section (sample KA-3), but only above sample KA-32 the wide-canal forms predominate consistently (in each sample) over the narrow-canal nannoconids (Tab. 1). This change is linked with the *N. vocontiensis* assemblage, and continues in the *N. aff. regularis* one (Fig. 11). Between sample KA-9 and the top of the section, the nannoconids have recovered, although some layers poor in calcareous nannofossils (Tab. 1) still occur among the beds with frequent *Nannoconus*.

Busson and Noël (1991) compared nannoconids with calcareous dinoflagellates. Erba (1994, 2004) proposed that narrow-canal nannoconids lived in the lower photic zone and the wide-canal nannoconids inhabited the intermediate

photic zone, whereas the coccolithophorids thrived in the upper photic zone. Replacement of the narrow-canal-dominated *Nannoconus* assemblage by the wide-canal forms was interpreted “as a response of calcareous nannoplankton to a rise of the nutricline accompanying a weakening of the thermocline” (Erba, 2004, p. 91).

In the Zliechov Basin, hemipelagic limestones of the Mráznička Formation pass into the marls and limestones of the Kościeliska Marl Formation towards the deeper part of the sedimentary basin (Michalík, 2007). The common occurrence of foraminiferal – or foraminiferal-*Globochaete* – microfacies in the Aptian nannoconid-dominated limestones indicates meso- to oligotrophic conditions (*cf.* Coccioni *et al.*, 1992) in the deeper areas of the Zliechov Basin. A significant proportion of limestones in the upper part of the Kościeliska Marl Formation may be interpreted as a result of a lowered sea level during the Early Aptian (Haq *et al.*, 1987; Herrle and Mutterlose, 2003). According to Reháková (2000) and Michalík *et al.* (2008), the Koňhora Event (and formation) in the Kysuca Succession (Pieniny Klippen Belt) corresponded to the Lower Aptian (short term) sea level fall. According to Michalík *et al.* (2008), the Koňhora Event correlates with the “Selli Event” (Erba, 1994).

### CONCLUSIONS

1. In the Kopka section (Dolina Kościeliska valley, Western Tatra Mountains), the upper part of the Kościeliska Marl Formation consists of biomicrites with marly interbeds. These deposits, 76 m thick, are assigned mainly to the Praehedbergella excelsa and Leupoldina cabri zones of Aptian age, on the basis of planktonic foraminifers identified in thin sections.

2. Although the specimens of the index taxon are rarely observed in the thin section, the presence of the L. cabri Zone is documented also with the occurrence of the following foraminifers: *Globigerinelloides duboisi sigali*, *G. cf. paragottisi clavatus*, *G. cf. maridalensis elongatus* and *H. cf. rhinoceros*. The specimens identified as *Globigerinelloides aptiensis* trans. *ferreolensis* occur in the uppermost part of the Kopka section.

3. Nineteen *Nannoconus* taxa were identified in 34 samples studied. The most frequent specimens belong to the taxa: *N. bucheri*, *N. truittii truittii* and *N. steinmannii steinmannii*. The entire section is subdivided into four *Nannoconus* assemblages: (1) *N. bucheri-N. steinmannii*, (2) *N. truittii frequens*, (3) *N. vocontiensis* and (4) *N. aff. regularis*. The presence of *Nannoconus vocontiensis* distinguishes the nannoconid assemblages of the upper part of the section from those occurring in the lower part.

4. In samples KA-5 to KA-7, calcareous nannofossils are scarce to rare. This part of the section may correspond to the worldwide “nannoconid crisis” (Erba, 1994).

5. The wide-canal specimens predominated over the narrow-canal ones in the lowermost part of the section (sample KA-3), but the wide-canal forms predominate consistently over the narrow-canal nannoconids only in the upper part of the section within the L. cabri Zone.

### Acknowledgments

I thank Ryszard Orłowski for valuable technical help during the SEM study of the limestone samples. The Ministry of Environment permitted collection of the samples in the study area of the Western Tatra Mountains. I express my gratitude also to the Director of the Tatra National Park in Zakopane for permission to work in the nature reserves of the Polish part of the Tatra Mountains. I also thank Eva Halásová and Mariusz Kędzierski for their helpful reviews. I am grateful to Przemysław Gedl for help and constructive editorial remarks and to Frank Simpson for his English language editorial work.

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