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*BIOSTRATIGRAPHY*

# Foraminiferal Biozonation of the Early and Middle Jurassic in the Pieniny Klippen Belt (Carpathians)

by

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**Summary.** A new biozonation scheme here proposed is based on benthic foraminifers recovered from the Toarcian to Bajocian deposits in the Pieniny Klippen Belt, Carpathians (Poland and Slovakia). Four zones and two subzones are established and correlated to ammonite biostratigraphy. The marker species included here are those considered to be the most important for local and regional zonation. Some of them, such as *Lingulina* gr. *tenera* (Bornemann), *Falsopalmula tenuistriata* (Franke), *Lenticulina d'orbignyi* (Roemer), and *L. quenstedti* (Gümbel) are valuable for global correlation purposes.

**1. Introduction.** The biostratigraphy of the Middle Jurassic of the Pieniny Klippen Belt is based on ammonites (see [5, 28]). There is a need for use of other faunal groups for determining the age of rocks which lack ammonites. Benthic foraminifers were already employed for solving some biostratigraphic problems in the Jurassic of the Belt (see [9, 10, 11, 32]).

This study is an attempt to establish a regional biozonation based on the benthic foraminiferal record correlated with the ammonite dating of Myczyński [28].

Unfortunately, foraminifers are not the best marker group in the Jurassic. Nevertheless, some foraminiferal taxa from the Pieniny Klippen Belt appear to be limited to particular stratigraphic intervals. These marker species are used to create this biostratigraphic scheme.

Key words: Foraminifera, Jurassic, biostratigraphy, correlation

**2. Methods.** The biostratigraphic study is based on benthic foraminifers recovered from marly and clay outcrop samples. The samples collected were dried, weighed out (250 g), and then disintegrated in a solution of sodium. Disintegrated samples were sieved through 105 μm mesh sieve. Quantitative results of microfaunal analysis have been presented elsewhere [12, 42–47]. This study focuses on selected foraminiferal marker species which are briefly described and discussed in the taxonomic chapter of this paper (see Fig. 5). The figured specimens represent digitised SEM photographs edited in Corel Photo-Paint (TM), Version 5.0 software.

**3. Geological setting.** The study area is mainly confined to the Polish part of the Pieniny Klippen Belt, except for Litmanová outcrop located in Slovakia, close to the Polish border (Figs 1, 2). The Pieniny Klippen Belt represents the axial, heterogeneous, highly deformed tectonic zone of the Western Carpathians (Fig. 2). It consists of the Klippen successions, Outer Carpathians (Magura), and the Inner Carpathian (Manín) units incorporated in the Belt during its complex deformational history [5]. The deposits of the Klippen Belt were accumulated mainly in the Pieniny Klippen and Magura basins. Most of deposits are attributed to the Klippen successions which mainly correspond to separate tectonic units. These successions of facies represent different palaeobathymetric zones within the Klippen Basin represented, from the north to the south, by the Czorsztyn,

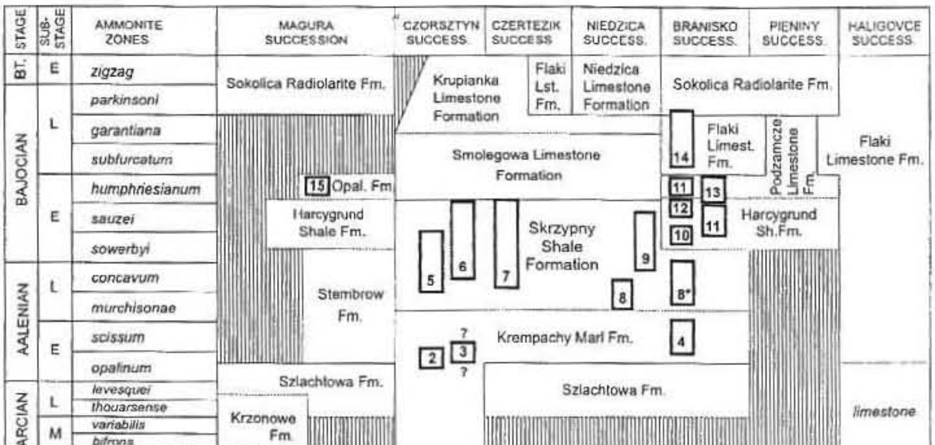


Fig. 1. Distribution and age of Early-Middle Jurassic rocks in the Pieniny Klippen Belt (adapted from Birkenmajer, [5] and modified)

Numbered bars represent analysed sections outcropped at: (1) Krzonowe; (2) Biała Woda — creek-bed; (3) Krempachy — south of Kramnica klippe (exact stratigraphic position uncertain); (4) Podubocze; (5) Krupianka; (6) Biała Woda near waterfall; (7) Litmanová; (8) Kapuśnica 'N' — Niedzica Succession; (8*) Kapuśnica 'B' — Branisko Succession; (9) Czajakowa Skała; (10) Żłobowe Potoczki; (11) Harcygrund; (12) Cisowiec; (13) Podzamcze; (14) Flaki; (15) Sztolnia creek.


Fig. 2. Distribution of studied outcrops in the Pieniny Klippen Belt (PKB). For labels see Fig. 1

Czertezik, Niedzica, Branisko, and Pieniny successions (Fig. 1). The southern slope of the basin are represented by the Nižna and Haligovce successions. The Magura Basin separated by the Czorsztyn Ridge was located to the north from the Klippen Basin. Both basins composed a part of the Western Tethys [6].

The Klippen and Magura successions include Triassic (partly), but mainly Jurassic and Cretaceous marine deposits. The Triassic sediments are known from the Haligovce Succession and from exotic rock fragments in Cretaceous conglomerates. In the Polish part of the Pieniny Klippen Belt, the Lower Jurassic rocks are known from exotic fragments (grey spotty limestones) in Cretaceous conglomerates [7]. The Klippen successions in Poland poorly record the uppermost Early Jurassic (Pliensbachian, Toarcian). The Aalenian and Bajocian are more complete. These epochs are characterized by basinal deposition of grey spotty marls and limestones (Fleckenmergel and Fleckenkalk facies) interrupted by dark-grey to black claystones, mudstones and marls. This "black shale" facies developed at the Aalenian/Bajocian regional anoxic event [44].

## 3. Lithostratigraphic units and localities

**3.1.** *Krzonowe Formation.* The Krzonowe Formation is included into the Durbaszka Group of the Magura Succession which exposes at Krzonowe south of Frydman, the only locality of this formation [5] (Figs 1, 2: loc. 1). The formation consists of yellow-grey, yellow-green or olive-green and rusty shales with intercalations of fine-grained micaceous, limonitic or sideritic sandstones, ferriginous oolitic-bioclastic limestone, and ostreid coquina (with oolitic matrix) [5, 12]. This facies resembles the "Minette-type ironstones" (see e.g. [41]). The Krzonowe Formation is underlain by dark-grey mudstones containing siderite concretions (lenses) and thin sandstones which represent the Szlachtowa Formation

[12]. The upper boundary of the Krzonowe Formation against the Szlachtowa Formation is either tectonic or sedimentary [12]. A Middle Aalenian age was suggested based on geological position of the formation above the "Aalenian flysch" [4]. Grypheids (bivalves) described by Pugaczewska [34] also supported the Aalenian age. New biostratigraphic data based on benthic foraminifera suggest an older age of the Krzonowe Formation [12]. This is based on the occurrence of *Lingulina* gr. *tenera* which ranges from Early Pliensbachian to Early Toarcian and partly overlaps with the range of bivalve *Bositra buchi* (Roemer): Toarcian-Oxfordian [23]. Thus, the co-occurrence of both marker taxa indicates Early Toarcian age of the lowermost part of the formation. Stratigraphic position of the upper part of the formation is uncertain because distribution of grypheids, as the only marker group, is strongly environmentally controlled.

*Krzonowe* (Magura Succession — Figs 1, 2: loc. 1). This is the only exposure of the formation located in the Krzonowe forest south of Frydman in the Polish Spisz area (see [5] — fig. 13; [12] — figs 1, 3–9, 22; tabs 1–4).

**3.2.** *Krempachy Marl Formation.* The Krempachy Marl Formation is characterised by thin-bedded grey to grey-bluish spotted marlstones and limestones. The thickness of this unit varies between 10 and 30 m. It occurs in the Czorsztyn, Czertezik, Niedzica and Branisko successions. The Czorsztyn, and Branisko successions have been studied. The age of the formation, in the Czorsztyn Succession based on ammonites, represents a stratigraphical interval from the Upper Pliensbachian to the Upper Aalenian [4, 5]. In the Branisko Succession, the formation represents the Lower Aalenian and the lowermost part of the Upper Aalenian (*Leioceras opalinum* to *Ludwigia murchisonae* zones) only [28].

*Krempachy* (Czorsztyn Succession — Figs 1, 2: loc. 3). This is the type section of the formation located on the right bank of the Białka River and south of the Kramnica Klippe ([4] — pl. 7, fig. 1; pl. 12, fig. 3; [5] — figs 7, 14A; [45] — figs 2A, 5). This outcrop is poorly exposed at present.

*Biała Woda* (Czorsztyn Succession — Figs 1, 2: loc. 2). The 1.5 m thick section of the formation crops out in the stream-bed (left bank) of the Biała Woda valley, to the east of the Smolegowa Skała klippe, 300 m below (downstream) the outcrop of the Skrzypny Shale Formation ([45] — figs 2 D, 6).

*Podubocze* (Branisko Succession — Figs 1, 2: loc. 4). It was exposed to the ESE of the Czorsztyn Castle, in a small valley ([45] — figs 2 B, 7; see [28] — figs 1, 11, 12; [5] — fig. 7 H: 14B). At present the locality is flooded by the artificial lake.

**3.3.** *Skrzypny Shale Formation.* This formation is represented by black and dark-grey claystones and mudstones often containing sideritic concretions [5, 44]. The upper part of the formation consists of a horizon of grey, strongly bioturbated mudstones with small phosphatic and larger phosphatic-sideritic concretions which are best developed in the Czorsztyn Succession [47]. This horizon with phosphatic concretions is documented within all successions, from the

Czorsztyn through Czertezik, Niedzica, to Branisko Succession. The mean thickness of the formation is approximately 10 m. The formation ranges in age from the *Ludwigia murchisonae* Zone to the *Otoites sauzei* Zone [4, 5, 28, 36].

*Biała Woda* (Czorsztyn Succession — Figs 1, 2: loc. 6). The locality is on the right side of the Biała Woda valley near a small waterfall, to the east of the Smolegowa Skała klippe, 300 m above (downstream) from the outcrop of the Krempachy Formation ([44] — figs 1, 3; [45] — figs 1, 2 D, 14, 15).

*Krupianka* (Czorsztyn Succession — Figs 1, 2: loc. 5). The outcrop is located on the left bank of the Krupianka stream beneath the klippes of Sołtysia Skałka ([44] — figs 1, 3; [45] — figs 1, 2 D, 12, 13a, b; see [4]).

*Czajakowa Skała* (Niedzica Succession — Figs 1, 2: loc. 9). The formation is outcropped at the SE side of the Homole Gorge, beneath the Czajakowa Skała klippe ([44] — figs 1, 3; [45] — figs 1, 2 D, 16, 17).

*Kapuśnica* (Niedzica and Branisko successions — Figs 1: loc. 8 , 8*; Fig. 2: loc. 8). The formation was exposed on the west side of the Dunajec River gorge (near the present water dam). The Niedzica Succession that includes deposits of the studied formation was exposed 250 m towards the north (upstream) from the dam, ca 40 m above the former Dunajec river-bed (so-called Kapuśnica "N" in [44] — figs 1, 3 and [45] — figs 1, 2 D, 18, 19; [5] — fig. 15 C). The Skrzypny Shale Formation of the Branisko Succession was outcropped closer to the present dam (ca 40–50 m towards the north) (so-called Kapuśnica "B" in [44] — figs 1, 3 and [45] — figs 1, 2 D, 18, 20; [5] — fig. 15 C). Both Kapuśnica localities are flooded by the artificial lake.

**3.3.** *Harcygrund Shale Formation.* This formation which occurs within the Branisko Succession has been studied here. It is characterised by dark-grey to black shaly marlstones, silty marls and shaly marly limestones. The shales often contain thin shells and imprints of the bivalve *Bositra buchi* (Roemer). The thickness of the formation ranges from 70 to 100 m. The lower boundary with the Skrzypny Shale Formation is undefined (tectonic), the upper one is usually tectonic. A few localities reveal a transitional contact with the overlying Podzamcze Limestone Formation [5]. The Early Bajocian age of the Harcygrund Shale Formation is based on ammonites [28]. The unit represents a biostratigraphical interval from the *Sonninia sowerbyi* Zone, through the *Otoites sauzei* Zone, to the lowest part of the *Stephanoceras humphriesianum* Zone (Fig. 1).

*Harcygrund Valley* (Figs 1, 2: loc. 11). This is the type section of the formation exposed on the left side of the lower part of the valley ([28] — p. 28–29, figs 1, 5, 6; [5] — figs 7H, 16A; [45] — figs 1, 2B, 22). A 8-m thick sequence of dark-grey marly limestones (maximum thickness of limestone bands: 30–40 cm, usually 10–20 cm) intercalated with dark-grey to black, often sandy marlstones is outcropped.

*Żłobowe Potoczki* (Figs 1, 2: loc. 10). Left tributary stream of the Niedziczanka Stream near Niedzica village ([45] — figs 1, 2B, 23); left bank of the middle part of the Żłobowe Potoczki, exposed 2 m above the stream; a two-meter thick section of dark-grey to black shaly marlstones; the whole complex tectonically contacts with vertical bands of green radiolarites (Czajakowa Radiolarite Fm.); shales rarely intercalated with thin bands of dark-grey marly limestones.

*Podzamcze — right bank of the Dunajec River* (Figs 1, 2: loc. 13). Near Niedzica, below the castle; 2–3-m thick complex of dark-grey and black shaly marlstones intercalated with thin (2–5 cm) bands of dark-grey spotty limestones (see [45] — figs 1, 2B, 24); dark-grey marls prevail over hard spotty limestones. This complex has been attributed to the Harcygrund Shale Formation [45]. Previously, the upper part of this outcrop (above grey-blue spotted limestones and marls of the Podzamcze Formation) was identified as the lowermost unit of the "Supra-Posidonia Beds" [28].

*Cisowiec* (Figs 1, 2: loc. 12). East side of the Krośnica-Kąty road cutting through the Długa Grapa near Flaki (see [24] — fig. 1b; [45] — figs 1, 2B, 25).

**3.4.** *Podzamcze Limestone Formation.* The formation consists of dark to light grey-blue spotted limestones intercalated with grey spotted marls. The mean thickness of the formation is about 40 m. A diverse ammonite-fauna of the *Stephanoceras humphriesianum* Zone indicates a Bajocian age [28]. Detailed description of this formation is presented elsewhere [42, 43].

*Harcygrund Valley* (Figs 1, 2: loc. 11). This formation was exposed below the type section of the the Harcygrund Shale Formation (on the left side of the lower part of the valley) (see [42] — fig. 4a; [45] — figs 1, 2B; [28] — figs 1, 5).

*Podzamcze — right bank of the Dunajec River* (Figs 1, 2: loc. 13). This was the type section of the formation exposed near Niedzica, below the castle (see [42] — fig. 4a, b; [45] — figs 1, 2B; [5] — figs 17, 18C; [28] — figs 1, 5, 8). Both localities are flooded by the artificial lake.

**3.5.** *Flaki Limestone Formation.* This formation includes, from the bottom: spotted grey spongolites intercalated with thin layers of marlstones; alternating grey to greenish pelitic to filament limestones and arenaceous crinoid marlstones; pink-green variegated arenaceous filament limestone; green sandy marlstones with abundant chamositic concretions; pelitic and filament limestones and marlstones. This 4-m thick sequence of the Flaki Limestone Formation is covered by 12-m of dark-grey to greenish spotty cherts of the Sokolica Radiolarite Formation ([45] — figs 32–33). The formation represents the upper part of the Middle Bajocian to the lower part of the Upper Bajocian in the Branisko Succession [5, 28].

*Flaki mountain near Sromowce* (Figs 1, 2: loc. 14. The type locality of the Flaki Limestone Formation is located in the road cutting, on the western side of the road Krośnica-Kąty ([45] — figs 1, 2B, 31–33; see [28] — figs 1, 11, 12; [5] — fig. 19B; [24] — figs 1, 2, 3B).

**3.6.** *Opaleniec Formation.* This formation is attributed to the Durbaszka Group of the Magura Succession. It is characterised by soft blue-grey to greenish spotty (fucoidal) marlstones with fine mica flakes and orange weathering coatings. The type locality at Sztolnia creek exhibits tectonic contacts with the Szlachtowa Formation and black mudstones of the Hulina Formation (Albian-Cenomanian). The Opaleniec Formation was previously attributed to the Lower Cretaceous "Wronine Beds". Further dating established its Middle Jurassic age [5, 8, 11, 32].

*Sztolnia Creek* (Figs 1, 2: loc. 15). The type section is located at the left bank of the Sztolnia Creek (middle course) below a small waterfall (see [5] — fig. 9 C; [8] — fig. 2a; [45] — figs 1, 2 C, 44).

## 4. Biostratigraphic zonation

### *Lingulina* gr. *tenera* Zone

*Definition.* This zone is based on the stratigraphical occurrence of *Lingulina* gr. *tenera* (Bornemann). The lower boundary is not defined due to lack of suitable sections in the Polish part of the Pieniny Klippen Belt. The upper boundary is based on the last occurrence of *L.* gr. *tenera* (Fig. 3).

*Range.* Early Toarcian (older age range not detected so far).

*Reference sections.* Krzonowe (lower part of the Krzonowe Formation) (Fig. 2).

*Remarks. L.* gr. *tenera* seems to be a good marker species due to its enhanced abundance per sample. Unfortunately, the lower age limit of this species is difficult to detect in the Pieniny Klippen Belt. It is very likely that *L.* gr. *tenera* appeared here in the earliest Early Jurassic.

### *Lenticulina d'orbignyi* Zone

*Definition.* This zone is based on the stratigraphical occurrence of *Lenticulina d'orbignyi* (Roemer). The lower boundary is not defined due to lack of suitable sections in the Pieniny Klippen Belt. It should be placed at the first occurrence of *L. d'orbignyi*. The upper boundary is based on the first occurrence of *Epistomina arcana* Antonova which is well defined in shallower facies (see Fig. 3). The last occurrence of *Lenticulina d'orbignyi* (Roemer) probably coincides with the first occurrence of *E. arcana* Antonova. *L. d'orbignyi* is a very characteristic but rare species, thus, its last occurrence is difficult to detect.

*Range.* (? Late Toarcian) Early Aalenian-Late Aalenian (? earliest Early Bajocian).

*Reference sections.* Biała Woda (Krempachy Marl Formation; lower part of the Skrzypny Shale Formation), Podubocze (Krempachy Marl Formation).

*Remarks.* The zone is an equivalent of the 'Zone I' of Sepfontaine [37] and the *Lenticulina d'orbignyi* Zone described by Gradstein [20] from the Grand Banks. Gradstein [20] reports, following Bartenstein and Brand [3], Simon and Bartenstein [38], and Brouwer [14], that this species becomes extinct at the Toarcian/Aalenian boundary. Recent reports extend range of this species up to the lower part of the Late Bajocian [13, 15]. The lower limit of *L. d'orbignyi* is placed either in the Middle Toarcian or at the top of the Early Toarcian (Penn *et al.*, 1980; Copestake and Johnson, 1989; Brand and Ohmert, 1992) [13, 15, 33].

### *Falsopalmula tenuistriata* Subzone

*Definition.* This subzone is based on the stratigraphical occurrence of *Falsopalmula tenuistriata* Franke [18]. The lower boundary is not defined due to lack of suitable sections in the Pieniny Klippen Belt. It ought to be placed at the first occurrence of *L. d'orbignyi*. The upper boundary is defined at the first appearance of *Trochammina globoconica* (Fig. 3).

*Range.* ? Late Toarcian-Early Aalenian.

*Reference sections.* Biała Woda, Podubocze (Krempachy Marl Formation) (Figs 1, 2: loc. 2 & 4).

*Remarks. Pyramidulina columnaris* Franke [18] is also a characteristic species. The foraminiferal assemblage within this zone is abundant in *Spirillina* spp. It may be a biofacial equivalent of the Late Toarcian-Early Aalenian *Spirillina* Unit (Assemblage I) of Monaco et al. [27] from the Apennines.

### *Trochammina globoconica* Subzone

*Definition.* The subzone is based on the stratigraphical occurrence of *Trochammina globoconica* Tyszka et Kaminski [47] (= *Conotrochammina* sp. A — [44] Chapter 4.2). The lower boundary is defined at the first appearance of *Trochammina globoconica*. The upper boundary is defined by the upper boundary of *Lenticulina d'orbignyi* Zone (the first occurrence of *E. arcana* Antonova) (Fig. 3).

*Range.* Late Aalenian-(? earliest Early Bajocian).

*Reference sections.* Kapuśnica near Niedzica Castle (Skrzypny Shale Formation) (Figs 1, 2: loc. 8).

*Remarks.* The species *Verneuilinella pieninica* Tyszka et Kaminski [47] (= *Gravellina* sp. — [44] Chapter 4.2) is characteristic for this unit.

### *Epistomina arcana* Zone

*Definition.* This subzone is based on the stratigraphical occurrence of *Epistomina arcana* Antonova. The lower boundary is based on the first occurrence of *Epistomina arcana* Antonova which is common within shallower facies. The last occurrence of *Lenticulina d'orbignyi* (Roemer) probably coincides with the first occurrence of *E. arcana* Antonova in deeper facies (Fig. 3).

*Range.* ? The middle part of the Early Bajocian.

*Reference sections.* Biała Woda, Krupianka, Litmanová (Skrzypny Shale Formation), Żłobowe Potoczki, Harcygrund Valley, Cisowiec (Harcygrund Shale Formation) (Figs 1, 2).

*Remarks.* The assemblage abounds in epistominids. The species *E. semiornata* (Schwager), and *E. coronata* Terquem are especially characteristic for this unit within the Skrzypny Shale Formation. *Miliammina gerochi* Tyszka also cooccurs in this biozone. Its distribution is confined to the lower part of Harcygrund Shale Formation [46].

### *Lenticulina quenstedti* Zone

*Definition.* This zone is based on the stratigraphical occurrence of *Lenticulina quenstedti* (Gümbel). The lower boundary is based on the first occurrence of *Lenticulina quenstedti* in the studied material (Fig. 3). The top is not established due to the lack of lithologies suitable for microfaunal analysis.

*Range.* The ?latest Early-Late Bajocian (*S. humphriesianum* Zone and overlying ammonite biozones).

*Reference sections.* Podzamcze, Harcygrund Valley (Podzamcze Formation), Sztolnia creek (Opaleniec Formation), Flaki (Flaki Formation) (Figs 1, 2).

*Remarks. Lenticulina quenstedti* has been found in the *S. humphriesianum* Zone and the overlying beds (Podzamcze, Opaleniec, Flaki). Birkenmajer and Pazdro [9] also reported *L. quenstedti* from the Lower Aalenian Szlachtowa Formation.

**5. Discussion.** The proposed biozonation has revealed some limitations. Not every biostratigraphic boundary is well defined that results from the specific nature of geologic record in the Pieniny Klippen: most of outcrops show tectonic contacts between lithostratigraphic units. The Lower-Middle Jurassic rocks are usually strongly dispersed and poorly exposed. Nevertheless, this foraminiferal biozonation has already shown its applicability for solving some local biostratigraphic problems. For instance: a new age determination for the Krzonowe Formation was proposed; the age of the Opaleniec Formation was confirmed; the Skrzypny Shale Formation and Harcygrund Shale Formation were divided into well-dated informal units (lower and upper parts). It is very likely that further research on the Lower and Middle Jurassic strata in the Carpathians will give an opportunity to test it at a regional scale.

In general, Jurassic foraminifers are of limited biostratigraphic value. They often show long-ranges and/or random and patchy distribution. These features make them inadequate for global correlations. Consequently, there is no global foraminiferal biozonation. Only local or regional zonations have been presented so far (Figs 3, 4; see [15, 20, 37, 39]). The marker species used in this study are those considered to be the most important for local and regional zonation. Some of these species, such as *Lingulina* gr. *tenera* (Bornemann), *Falsopalmula tenuistriata* (Franke), *Lenticulina d'orbignyi* (Roemer) and *L. quenstedti* (Gümbel), are valuable for global correlation purposes. They roughly show similar biostratigraphic ranges in Europe and, sometimes, even outside of it (North America, Australia).

**6. Taxonomic descriptions.** Following abbreviations are used (next to sample labels) to express frequency of identified marker species: (s) — single (1–3

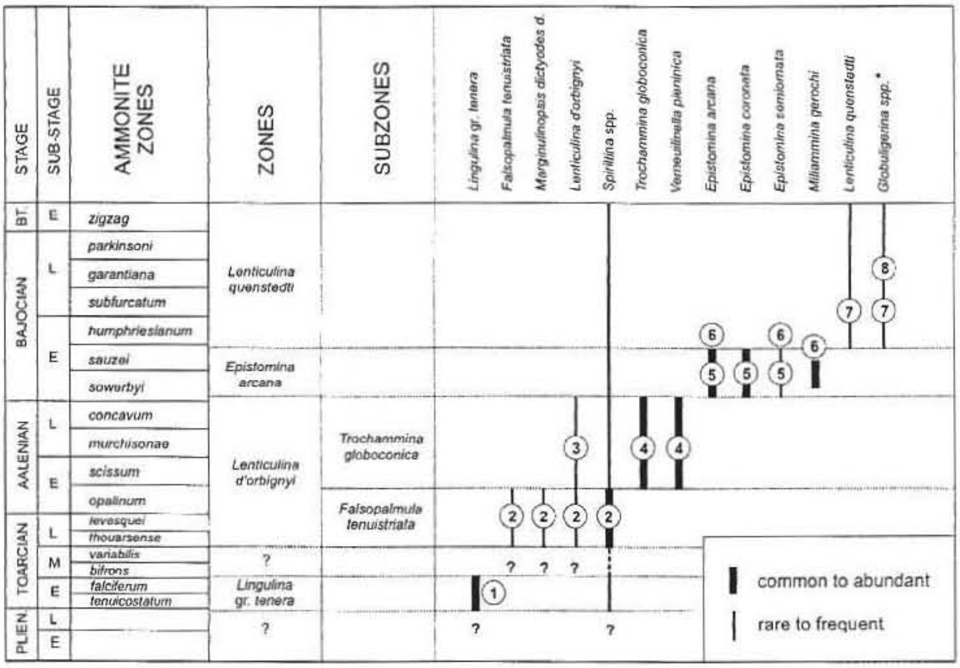


Fig. 3. Ranges of selected foraminiferal taxa and proposed biozonation based on foraminifera correlated with ammonite zonation (from [28])

Lithostratigraphical units where foraminiferal taxa were recognised: 1 — Krzonowe Formation (Magura Succession); 2 — Krempachy Marl Formation (Czorsztyn and Branisko successions); 3 — lower part of the Skrzypny Shale Formation (Czorsztyn Succession), and 4 — (Niedzica and Branisko successions); 5 — upper part of the Skrzypny Shale Formation (Czorsztyn Succession) and the Harcygrund Formation (Branisko Succession); 6 — Harcygrund Shale Formation (Branisko Succession); 7 — Podzamcze Limestone Formation; 8 — Flaki Limestone Formation (Branisko Succession). (*) planktonic foraminifera, identified in thin sections

specimens); (f) — frequent (4–10 specimens); (c) — common (11–50 specimens); (a) — abundant (50–200 specimens).

### *Trochammina globoconica* Tyszka et Kaminski, 1995
(Fig. 5: *1 a-c*)

1994 *Conotrochammina* sp. A — Tyszka [44]: pl. 3, figs 1–3
1995 *Trochammina globoconica* Tyszka et Kaminski [47]: figs 14–15, plate 3, figs 8–10
1998 *Trochammina globoconica* Tyszka et Kaminski — Mišík and Soták [26]: plate V, fig. D

*Description.* Test trochospiral, high conical with rounded non-tapered periphery, slightly lobate at spiral side; 4–5 chambers per whorl, reduced to 3–4 in the final whorl; sutures depressed; wall finely agglutinated; aperture single, umbilical, resembling a clover-like opening. Some specimens are squashed by compaction, appearing low conical in shape [47].

*Material.* Skrzypny Shale Formation (Niedzica Succession) — KPN-5 (a), KPN-2 (a).

| STAGE | SUB-STAGE | AMMONITE ZONES | Sepfontaine 1971 Prealps [37] | Gradstein 1977 Grand Banks [20] | Stam 1986 Grand Banks [39] | Copestake & Johnson 1989 Great Britain [15] | Pieniny Klippen Belt (this study) Ecozones | Zones | Subzones |
|---|---|---|---|---|---|---|---|---|---|
| BATHON. | | | **Zone IV** | *Globigerina bathoniana* | *Reinholdella spp.* | | | | |
| | E | *zigzag* | | | | | | | |
| BAJOCIAN | L | *parkinsoni* | | | | | **P-2** | | |
| | | *garantiana* | **Zone III** | *Garantella spp.* | *Garantella spp.* | | | *Lenticulina quenstedti* | |
| | | *subfurcatum* | | | | | **P-1** | | |
| | E | *humphriesianum* | | | | | | | |
| | | *sauzei* | **Zone II** | | | | **S-2** | *Epistomina arcana* | |
| | | *sowerbyi* | | | | | | | |
| AALENIAN | L | *concavum* | | | | | | | |
| | | *murchisonae* | | | | JF-16 | **S-1** | | *Trochammina globoconica* |
| | E | *scissum* | **Zone I** | | | | | *Lenticulina d'orbignyi* | |
| | | *opalinum* | | *Lenticulina d'orbignyi* | *Lenticulina d'orbignyi* | | | | |
| TOARCIAN | L | *levesquei* | | | | | **K-1** | | *Falsopalmula tenuistriata* |
| | | *thouarsense* | | | | | | | |
| | M | *variabilis* | (*L. d'orbignyi*) | | | JF-15 | | ? | |
| | | *bifrons* | | | | | | | |
| | E | *falciferum* | | | | | | *Lingulina gr. tenera* | |
| | | *tenuicostatum* | | | | JF-12 | | | |
| PLIEN. | L | | | | | JF-11 | | ? | |
| | E | | | | | JF-10 | | | |

Fig. 4. Correlation of proposed biozonation and ecozonation for the Aalenian-Bajocian of the Pieniny Klippen Belt of Poland [45] with known foraminiferal zonations

*Stratigraphic range:* Upper Aalenian. This species is only known from the Pieniny Klippen Belt. Mišík and Soták [26] report this species from the Callovian-Oxfordian limestones of the Czorsztyn Succession (the Pieniny Klippen Belt, Slovakia).

*Verneuilinella pieninica* Tyszka et Kaminski, 1995
(Fig. 5: *2a, b*)

1994 *Gravellina* sp. — Tyszka [44]: plate III, figs 13–15
1995 *Verneuilinella pieninica* Tyszka and Kaminski [47]: p. 287, figs 16–17; plate 2, figs 13 15

*Description.* Test trochospiral, highly conical with a quadriserial arrangement (4 chambers per whorl); sutures flush or slightly depressed; wall finely agglutinated; interiomarginal aperture located close to the axis of coiling (usually not visible).

*Material:* Skrzypny Shale Formation (Niedzica Succession) — KPN-5 (a), KPN-2 (a).

*Stratigraphic range:* Upper Aalenian — this species is only known from the Pieniny Klippen Belt.

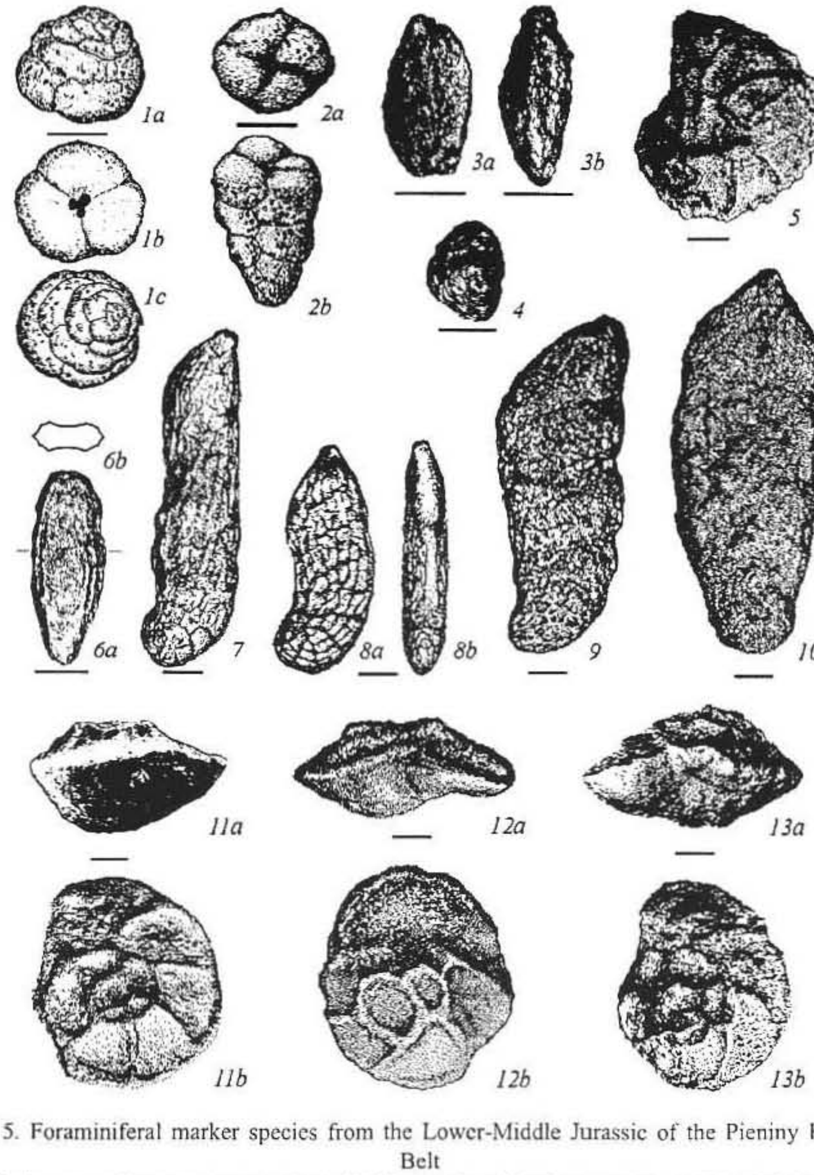


Fig. 5. Foraminiferal marker species from the Lower-Middle Jurassic of the Pieniny Klippen Belt

1 — *Trochammina globoconica*, Tyszka et Kaminski, holotype: (a) peripheral, (b) umbilical, and (c) spiral views, sample KPN-5, Skrzypny Shale Formation; 2 — *Verneuilinella pieninica*, Tyszka et Kaminski, holotype: (a) umbilical, (b) peripheral views, sample KPN-2, Skrzypny Shale Formation (figures 1 and 2 reprinted from [47]; 3–4 — *Miliammina gerochi* Tyszka, paratypes: (3a-b) peripheral views, sample ZPH-2, Harcygrund Shale Formation; (4) apertural view, sample ZPH-1; 5 — *Lenticulina quenstedti* (Gümbel), spiral view, sample FF-11, Flaki Lmst. Formation; 6 — *Lingulina* gr. *tenera* (Bornemann): (a) peripheral view, (b) cross-section, sample L-2, Krzonowe Formation; 7–8 — *Lenticulina d'orbignyi* (Roemer): (7) spiral view, sample PDK-10, Krempachy Marl Formation: (8a) spiral view, (8b) peripheral view, sample BS-10, Skrzypny Shale Formation; 9 — *Marginulinopsis dictyodes dictyodes* (Deecke), spiral view, sample PDK-10, Krempachy Marl Formation; 10 — *Falsopalmula tenuistriata* (Franke), spiral view, sample PDK-10, Krempachy Marl Formation; 11 — *Epistomina arcana* Antonova (11a) peripheral and (11b) spiral views, sample BS-1; 12 — *E. coronata* Terquem: (12a) peripheral view, sample XS-2, and (12b) spiral view, sample XS-2; 13 — *E. semiornata* (Schwager): (13a) peripheral and (13b) spiral views, sample XS-3, (11–13) Skrzypny Shale Formation. *Scale bar represents 100 μm*

*Miliammina gerochi* Tyszka, 1997
(Fig. 5: *3a, b, 4*)

1995 *Miliammina* sp. — Tyszka [45]: pl. 11, figs 3–6
1997 *Miliammina gerochi* Tyszka [46]: p. 360–363, figs 4A-D, 5A-F

*Description*: Test free, small, elongate, triangular to trapezoidal in apertural view; periphery rounded; quinqueloculine arrangement with chambers added 144° apart; sutures indistinct, sometimes slightly depressed; wall smooth, thin, finely agglutinated; aperture forms a single, rounded to ovate, opening with a delicate lip.

*Material*. Harcygrund Shale Formation: samples ZPH-1 (a), ZPH-2 (a), ZPH-5 (a), HAH-9 (c); HAH-10 (a).

*Stratigraphic range*. Lower Bajocian of the Pieniny Klippen Belt [46].

*Falsopalmula tenuistriata* (Franke, 1936)
(Fig. 5: *10*)

1936 *Flabellina tenuistriata* Franke [18]: p. 93, pl. 9, fig. 17
1989 *Palmula tenuistriata* (Franke) — Copestake and Johnson [15]: p. 183, pl. 6.2.5, fig. 18

*Description*. Test free with small initial coiled portion followed by chevron-shaped (flabelline) portion with 4–5 chambers; poorly preserved subreticulate ornament with very fine pattern; slightly raised sutures.

*Material*. Krempachy Marl Formation Formation — PDK-3 (s), PDK-10 (s), PDK-15 (s), PDK-17 (s).

*Stratigraphic range*. Upper Aalenian. This species is an excellent marker in Europe for Late Toarcian and Aalenian; however, no post-Toarcian records are known from Britain [15]. Bartenstein [2] suggests only Toarcian age for this species.

*Lingulina* gr. *tenera* (Bornemann)
(Fig. 5: *6 a, b*)

1936 *Frondicularia tenera* (Bornemann) — Franke [18]: p. 64, pl. 6, fig. 18
1937 *Frondicularia tenera tenera* (Bornemann) — Bartenstein and Brand [3]: p. 156, pl. 1 A, figs 11, 19; pl. 2A, figs 10a-c; pl. 2B, figs 18a, b; pl. 3, Figs 25, 26; pl. 5, figs 67a, b
1957 *Geinitzina tenera* (Bornemann) subsp. *tenera* (Bornemann) — Nørvang [30]: p. 336–338, figs 18–23
1957 *Geinitzina tenera* (Bornemann) subsp. *tenuistriata* (Nørvang) — Nørvang [30], p. 334–335, figs 13, 16, 17, 24
1972 *Geinitzina tenera* (Bornemann) — Norling [29], p. 96–99, fig. 51 A-G, table 21
1989 *Lingulina tenera tenera* Bornemann — Copestake and Johnson [15]: p. 179, pl. 6.2.4, fig. 9
1989 *Lingulina tenera tenuistriata* Bornemann — Copestake and Johnson [15]: p. 179, pl. 6.2.4, fig. 10
1993 *Paralingulina tenera* (Bornemann) — Herrero [22]: p. 104–111, pl. 9, figs 2–14
1996 *Lingulina tenera* (Bornemann) — Birkenmajer and Tyszka [12]: fig. 22 (5–6)

*Description.* Test with distinct median sulcus between longitudinal ribs (see Fig. 5: *6b*); periphery keeled, usually with additional finer striation close to periphery; sutures flush; chambers broader than high, early chambers gradually more wide, the last one or two chambers slightly narrower; aperture terminal preserved as an elongate slit in the plane of compression.

*Remarks.* In this study, this taxon is regarded as a single species represented by different morphologic varieties. Most of specimens resemble *L. tenera* subsp. *tenera* and *L. tenera* subsp. *tenuistriata* described by Nørvang [30]. Scandinavian *L. tenera* subsp. *pupa* (Nørvang) shows more rounded cross-section that differs from our distinctly compressed tests. *L. tenera tenuistriata* (Nørvang) identified by Copestake and Johnson [15] also resembles the studied material. There is also a problem of generic position of this taxon. Gerke [19] classifies *L. tenera* to *Paralingulina* (nom. nov. pro *Neogeinitzina* Brotzen) which differs from *Lingulina* d'Orbigny in having prominent longitudinal costae and less overlapping chambers ([25] after [19]). Both traits seem to be insufficient for generic level recognition, thus, a broader definition of the genus *Lingulina* is preferred.

*Material.* Krzonowe Formation — samples: L-2 (a), L-4 (a), L-5 (a), L-7 (c), L-8 (c), L-9 (s),

*Distribution.* Hettangian-Early Toarcian according to most of the above references. *L. tenera tenuistriata* (Nørvang) from Britain ranges from Rhaetian to Late Toarcian [15].

*Lenticulina d'orbignyi* (Roemer)
(Fig. 5: *7, 8a, b*)

1936 *Cristellaria (Lenticulina) d'orbignyi* (Roemer) — Franke [18]: p. 118; pl. 12, fig. 4
1971 *Lenticulina dorbignyi* (Roemer) — Wernli [48]: p. 320; pl. III, Figs 4, 9; pl. X, fig. 2
1986 *Lenticulina d'orbignyi* (Roemer) — Stam [39]: p. 123; pl. 6, figs 1, 2
1992 *Lenticulina d'orbignyi* (Roemer) — Brand and Ohmert [13]: p. 15–16; pl. 1, figs 1–6
1994 *Lenticulina d'orbignyi* (Roemer) — Tyszka [44]: plate IV, figs 15–16

*Description.* Test lenticular, often uncoiled in final stage (5–6 last chambers); reticulate ornament covers whole test.

*Remarks.* This species is traditionally attributed to the genus *Lenticulina*. Loeblich and Tappan's (1988) taxonomic approach suggests to include this species into *Marginulinopsis*, because most of identified specimens are uncoiled (Fig. 5: *7, 8a, b*). Only single, usually smaller, specimens exhibit typical lenticular shape. It is likely that these coiled, lenticular forms represent an earlier stage in ontogenesis. The present author believes that this view may be right for the studied material but it is hardly applicable to all descriptions of this taxon. Nevertheless, the forms figured and described by Wernli [48], Stam [39], and Brand and Ohmert [13] also show a tendency to uncoiling and *Marginulinopsis*-like shape.

*Material.* Krempachy Marl Formation: sample PDK-10 (s); BK-1 (s); Skrzypny Shale Formation: sample BS-10 (s).

*Stratigraphic range.* Total range — Early Toarcian to Early Bajocian, however disappearing in West Germany, France and Switzerland at the top of the Aalenian [13, 15]; Middle-Late Toarcian of the Umbria-Marche Basin (central Italy) [27], Aalenian of Portugal and Grand Banks [39], also known from the Late Toarcian of Canada and NW Australia [15].

*Lenticulina quenstedti* (Gümbel)
(Fig. 5: *5*)

1965 *Lenticulina (Lenticulina) quenstedti* (Gümbel) — Hanzlíková [21]: p. 73, pl. 4, figs 8, 11, 13; pl. 5, fig. 2
1971 *Lenticulina quenstedti* (Roemer) forma A — Wernli [48]: pp. 322–323, plate IV, figs 23, 27; Plate X, Fig. 1
1972 *Lenticulina quenstedti* (Gümbel) — Norling [29]: p. 69
1979 *Lenticulina quenstedti* (Gümbel) — Pazdro [31]: p. 114–115, pl. I, fig. 9
1989 *Lenticulina quenstedti* (Gümbel) — Riegraf and Luterbacher [35]: p. 1032–1033, pl. 3, fig. 29–35
1986 *Lenticulina quenstedti* (Gümbel) — Stam [39]: p. 123, pl. 5, figs 9–11

*Description.* Test free, planispiral, without tendency to uncoiling; sutures slightly curved, distinctly raised as sutural ribs converging at umbilical area in form of a circular rib or a set of circular ribs; periphery sharp with a marginal keel, more evident around initial part.

*Material.* Rare to frequent; the Podzamcze Limestone Formation (Branisko Succession) — samples H-5 (s), P-5 (f); Flaki Limestone Formation (Branisko Succession) — samples FF-6 (s), FF-8 (s), FF-9 (s); Opaleniec Formation (Magura Succession) — samples SO-1 (s), SO-8 (f), SO-9 (f).

*Stratigraphic range.* Concavum Zone; Malm in the Jura Mountains [48]; Late Bathonian-Early Oxfordian of Sweden and Bajocian-Kimmeridgian of Europe [29]; Late Aalenian-earliest Kimmeridgian of Portugal and Late Bajocian-Kimmeridgian of Grand Banks [39]; Bajocian-Early Aptian according to Riegraf and Luterbacher [35] who include Cretaceous *Lenticulina ouachensis* (Sigal) into synonimy.

*Marginulinopsis dictyodes dictyodes* (Deecke)
(Fig. 5: *9*)

1884 *Cristellaria dictyodes* Deecke — [16]: p. 48, Taf. 2, Figs 9, 9a
1992 *Lenticulina (Astacolus) dictyodes dictyodes* (Deecke) — Brand and Ohmert [13]: p. 18–19, pl. 2, figs 12–18; pl. 6, figs 61–66, 73

*Description.* Test free, early stage planispiral, late stage uncoiling; sutures slightly curved, periphery lobate, rounded; surface ornamented, reticulate, with fine hexagonal to irregular mosaic pattern forming small depressions and reticulate, irregular ribs; aperture terminal.

*Material.* Aalenian; Krempachy Marl Formation — samples: PDK-10 (s); PDK-15 (s); PDK-18 (s).

*Stratigraphic range.* Late Aalenian-Bajocian in Germany [13].

*Epistomina arcana* Antonova, 1958
(Fig. 5: *11a, b*)

1958 *Epistomina arcana* Antonova — [1]: p. 72, pl. V, figs 7, 9, 10
1994 *Epistomina arcana* Antonova — Tyszka: [44] pl. IV, figs 5–7

*Description.* Test asymmetrically biconvex with distinctly more convex umbilical (ventral) side; spiral (dorsal) side with strongly raised sutures; distinct peripheral rim; smooth umbilical side; apertures not visible.

*Remarks.* This species differs from *E. coronata* Terquem in having distinctly more convex umbilical side and peripheral rim. Pazdro [31] includes *E. arcana* into synonymy of *E. coronata.*

*Material.* Skrzypny Shale Formation — samples XS-5 (c), XS-4 (c), BS-2 (a), BS-1 (a), XS-3 (a), XS-2 (c); CZS-1 (s), CZS-3 (s), CZS-5 (f), CZS-9 (f), CZS-10 (f); LS-3 (s), LS-5 (s), LS-10 (f), LS-12 (f) (LS samples from Litmanová), Harcygrund Shale Formation — sample HAH-10 (s)

*Stratigraphic range.* Uppermost part of the Late Aalenian — Early Bajocian (this study); Bajocian of the Russian Platform and NW-Caucasus [1].

*Epistomina coronata* Terquem, 1883
(Fig. 5: *12a, b*)

1883 *Epistomina coronata* Terquem [40]: p. 378, plate 43, fig. 9
1969 *Epistomina coronata* Terquem — Pazdro [31]: 54–55, plate IV, figs 3, 4; plate XII, figs 5, 7; plate XI, fig. 1
1994 *Epistomina coronata* Terquem — Tyszka: [44] pl. IV, figs 3–4

*Description.* Test more or less symmetrically biconvex, distinctly convex spiral (dorsal) side with strongly raised sutures, especially in older part of tests, indistinct peripheral rim; umbilical (ventral) side smooth, distinct radial sutures.

*Remarks.* The studied specimens differ from *E. parastelligera* (Hofker) in strongly raised sutures and from *E. arcana* Antonova in more equally biconvex shape, distinctly convex spiral side, and indistinct peripheral (marginal) rim.

*Material.* Upper part of the Skrzypny Shale Formation — samples XS-5 (c), XS-4 (c), BS-2 (c), BS-1 (c), XS-3 (c), XS-2 (c); LS-2 (s), LS-3 (s), LS-10 (f), LS-12 (f), LS-14 (s), LS-15 (s) (LS samples from Litmanová), Harcydgrund Shale Formation — sample CH-3 (f).

*Stratigraphic range.* Uppermost part of the Late Aalenian — Early Bajocian (this study); Kouiavian and Bathonian (Late Bajocian-Bathonian) of the Częstochowa region and of the Polish Lowland [31].

*Epistomina semiornata* (Schwager, 1867)
(Fig. 5: *13a, b*)

1867 *Rotalia semiornata* Schwager — in Ellis and Messina [17]
1969 *Reinholdella* cf. *semiornata* (Schwager) — Pazdro [31]: p. 74–75, text-fig. 16
1994 *Epistomina semiornata* Schwager — Tyszka [44]: pl. IV, figs 3–4

*Description.* Test biconvex, spiral side with raised sutures which are distinctly arched backwards, umbilical side smooth, clear but indistinct peripheral rim.

*Remarks.* This species differs from *E. coronata* in lower raised sutures between older chambers, and from *E. arcana* in symmetrically biconvex test and less distinct peripheral rim.

*Material.* Skrzypny Shale Formation — samples XS-5 (s), XS-4 (s), BS-2 (f), BS-1 (s), XS-3 (s), XS-2 (s); LS-5 (s), LS-15 (s), LS-20 (s) (LS samples from Litmanová); Harcydgrund Shale Formation — sample HAH-9 (s)

*Stratigraphic range.* Uppermost part of the Late Aalenian — Early Bajocian (this study); Aalenian-Bajocian of the Pieniny Klippen Belt [31]; Early Bajocian of Württenberg (type area). The specimen figured by Pazdro's [31] comes from the Skrzypny Shale Formation (Mały Rogoźnik stream, west of Szaflary). ?*Reinholdella semiornata* (Schwager) was also listed in the same formation outcropped at Stus near Falsztyn and at the Sołtysia Klippe [10]. The latter represents the Krupianka locality in the present study (Fig. 2).

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