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Revisiting the age of Jurassic coral bioherms in the Pieniny Klippen Belt (Western Carpathians) on the basis of benthic foraminifers

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Abstract: Coral bioherms of the Vršatec Limestone that formed massive, several tens of meters thick complexes during the Jurassic were important sources of carbonate production, with carbonate sediment exported to deeper parts of the Pieniny Klippen Basin (Western Carpathians). However, the age of these carbonate factories remains controversial. New analyses of benthic foraminiferal assemblages occurring in coral bioherms and peri-biohermal deposits of the Vršatec Limestone at five sites in the western Pieniny Klippen Belt (Vršatec-Castle, Vršatec-Javorníky, Malé Hradište, Malé Hradište-Kalvária, and Drieňová Hora) show that these sediments were deposited during the Bajocian and were lateral equivalents of crinoidal limestones and breccias, in contrast to previous studies suggesting that they were deposited during the Oxfordian. First, all sites are characterized by similar composition of foraminiferal assemblages on the basis of presence–absence data, although foraminiferal assemblages in biosparitic facies at Vršatec are dominated by miliolids whereas biomicritic facies at Malé Hradište are dominated by the spirillinid *Paalzowella*. The composition of foraminiferal assemblages does not differ between the lower and upper parts of the Vršatec Limestone. Second, foraminifer species that were assumed to appear for the first time in the Oxfordian already occur in the Middle Jurassic sediments of the northern Tethyan shelf. Third, the first and last appearances of foraminifers documented in other Tethyan regions are in accordance with stratigraphic analyses and ammonoid occurrences, demonstrating that bioherm-forming coral communities developed on the Czorzstyn Ridge during the Bajocian. Several species of foraminifers of the Vršatec Limestone appeared for the first time during the middle or late Aalenian (*Labalina occulta, Paalzowella feifeli)* and during the Bajocian (*Hungarillina lokutiense*, *Radiospirillina umbonata, Ophthalmidium caucasicum, O. terquemi, O. obscurum, Paalzowella turbinella, Cornuspira tubicomprimata*, *Nubecularia reicheli)* or appeared for the last time in the Bajocian (*Tethysiella pilleri*) or Early Bathonian (*Ophthalmidium caucasicum, O. obscurum*). The composition and diversity of communities with benthic foraminifers of the Vršatec Limestone is similar to the composition of foraminiferal communities on carbonate platform environments with corals of the French Jura and Burgundy during the Bajocian.

Keywords: Middle Jurassic, Bajocian, benthic foraminifers, coral reefs, Vršatec Limestone, Pieniny Klippen Belt, Western Carpathians, Slovakia.

Introduction

Coral bioherms and peri-biohermal deposits in the Carpathian realm were largely restricted to the western sector of the Czorsztyn Ridge in the Pieniny Klippen Basin (PKB) during the Jurassic, occurring in a 17 km long band in western Slovakia, extending from the Dolná Súča Klippe on the SW, through Krivoklát and Vršatec klippen till Mikušovce Klippe on the NE (Fig. 1; Mišík 1979; Morycowa & Mišík 2005). They form marked rocky cliffs and their thickness attains several tens of meters. The carbonate sediment produced in such environments during the Jurassic probably sourced deeper, offshore and basinal environments of the Pieniny Klippen Belt. However, the majority of the Jurassic sediments on the Czorsztyn Ridge were deposited on pelagic, sediment-starved seafloor at depths below the photic zone (Fig. 2), with depositonal conditions that were similar to those occurring on pelagic carbonate platforms during the Jurassic in the Eastern Alps, Southern Alps, Apennines, and Sicily (Santantonio 1993; Cobianchi & Picotti 2001; Marino and Santantonio 2010). The biohermal limestones with corals define the so-called Vršatec Limestone (Mišík 1979). Mišík (1979) and Morycowa & Mišík (2005) suggested that the Vršatec Limestone belongs to the Oxfordian stage on the basis of corals and bivalves. Owing to this assignment of coral limestones to the Oxfordian, Mišík (1979) distinguished two tectonic slices at the Vršatec klippen. He suggested that these two slices significantly differ in the development of Oxfordian deposits, the first one with shallow water-coral biohermal limestones deposited in photic environments, and the second one with strongly condensed, red micritic nodular or non-nodular limestones deposited in aphotic environments (Fig. 3). In contrast to Mišík (1979),

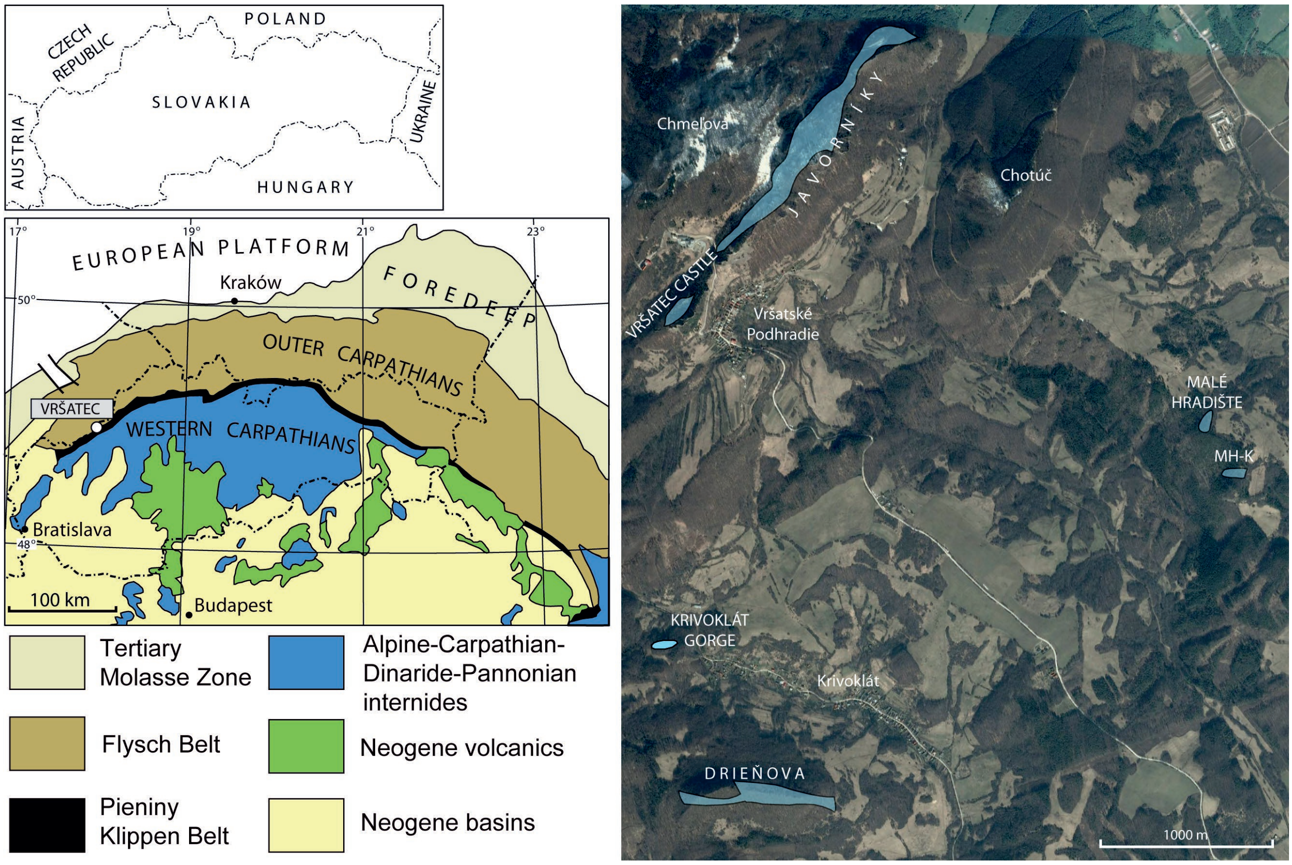

Fig. 1. Geographic maps showing the location of the Pieniny Klippen Belt in the Western Carpathians and the locations of five sites of outcrops for the Vršatec Limestone. A sixth site, the Krivoklat Gorge, was not sampled in this study and the occurrences near Mikušovce and Dolná Súča (also not included) are out of the satellite map.

Schlögl et al. (2006, 2009a, b) showed that the Vršatec Limestone belongs to the Bajocian on the basis of the stratigraphic superimposition criteria and ammonite occurrences. First, the Middle Jurassic crinoidal limestones overlie coral limestones at Vršatec-Javorníky Klippe, and coral limestones thus cannot belong to the Oxfordian. Second, Upper Bajocian–Lower Bathonian ammonite *Nannolytoceras tripartitum* occurs in a dyke penetrating through the Vršatec Limestone (Schlögl et al. 2006, 2009a). In addition, several other dykes with Bathonian–Callovian ammonites occur in the uppermost part of the Vršatec Limestone in the Vršatec-Castle Klippe (Schlögl et al. 2009b). Crinoidal limestones in the Czorsztyn Unit in the Polish and Slovakian parts of PKB (assigned to the Smolegowa and Krupianka formations) range from the upper Propinquans Zone of the Lower Bajocian to the lower Garantiana Zone of the Upper Bajocian on the basis of ammonites (e.g., Krobicki & Wierzbowski 2004; Wierzbowski et al. 2004). In the Czorsztyn Unit, these crinoidal limestones exhibit hiatuses both at their lower and upper boundaries.

Morycowa & Olszewska (2013) analyzed thin sections from the biohermal and peribiohermal facies of the Vršatec Limestone. They described benthic foraminifers of the genera *Rumanolina*, *Paalzowella, Redmondoides, Troglotella,* and, *Haghimashella* and the microencruster *Iberopora*. They argued that four foraminifer species and *Iberopora* appeared for the first time in the Oxfordian, indicating that the Vršatec Limestone is of Late Jurassic age, thus suggesting the initial biostratigraphic inference of Mišík (1979) may be correct. Here, using 120 new thin sections collected at five sites with the Vršatec Limestone, we revisit stratigraphic and paleogeographic distribution of 14 species of benthic foraminifers from the Vršatec Limestone, and assess overall genus-level composition of foraminiferal assemblages from several sites. We show that the first appearances of species that were supposed to be indicative of the Late Jurassic, as detected in other Tethyan regions, actually extend to the Bajocian. We document the presence of species that are alone or in combination diagnostic of the Middle Jurassic, clarify stratigraphic and geographic ranges of the identified species of benthic foraminifers, and discuss the stratigraphic position of the Vršatec Limestone and its general biotic composition.

Geological and stratigraphic setting

The Pieniny Klippen Basin (Western Carpathians) was represented by a depositional belt of mixed, carbonate–siliciclastic ramps with shallow-water and hemipelagic sedimentation.

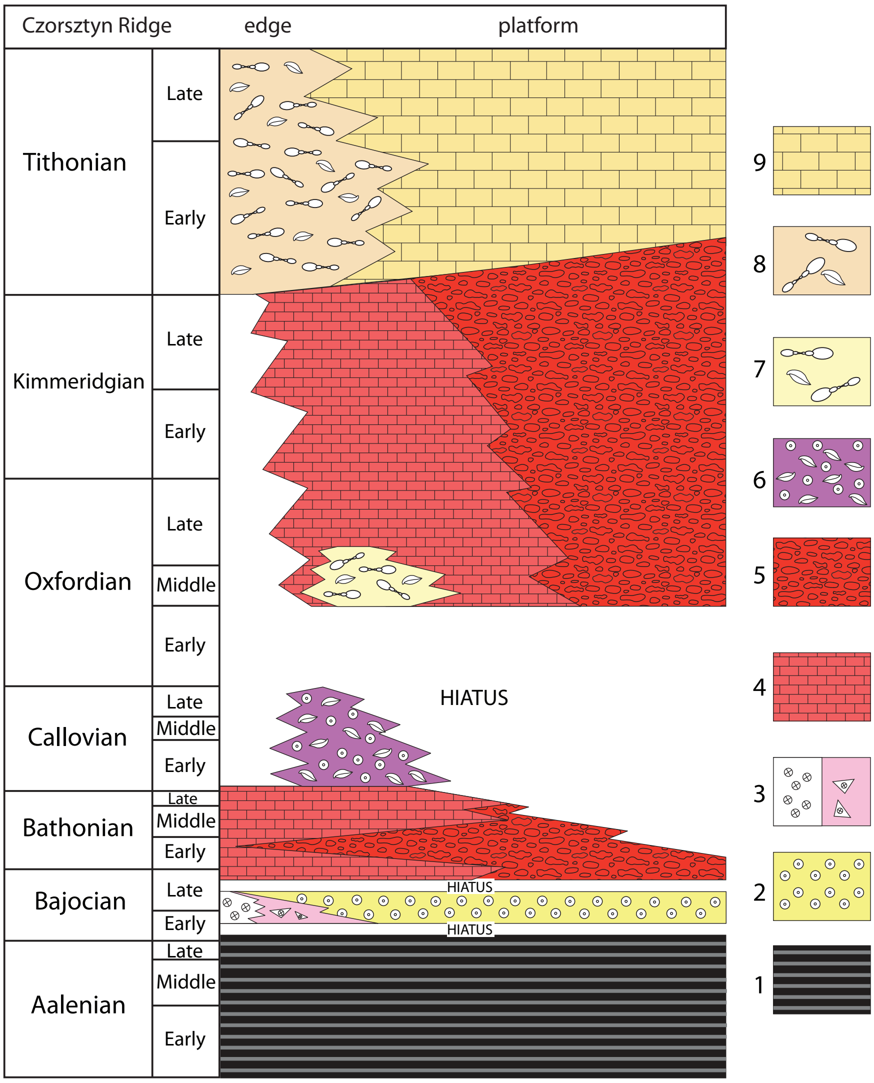

Fig. 2. The lithostratigraphic scheme of the Czorsztyn Ridge for the Middle and Upper Jurassic along an edge-platform gradient, with the Vršatec Limestone deposited in the shallowest parts of the Czorsztyn Ridge. The stage durations are proportional to durations in Ogg et al. (2016). 1 — Dark marly deposits, undivided Krempachy Marl Formation (lower part), and Skrzypny Shale Formation (upper part). 2 — White to red crinoidal limestones, Smolegova and Krupianka formations. 3 — Coral biohermal limestone and peri-biohermal limestone, Vršatec Limestone. 4 — Red non-nodular massive limestone, Bohunice Formation. 5 — Red nodular limestone, Czosztyn Limestone Formation. 6 — Crinoidal–brachiopod limestone, Štepnice Limestone Member. 7 — White-yellowish ammonite–brachiopod shell-beds, Kočkovce Limestone Member. 8 — White to red ammonite shell-beds, Rogoznik Coquina Member. 9 — Yellowish to reddish massive bioclastic limestone, Korowa Limestone Member.

This basin belonged to the southern edge of the NW European platform during the Early Jurassic and during the Aalenian (Segit et al. 2015). The PKB was located at 30–40 ºN during the Middle Jurassic and at 20–30 ºN during the Late Jurassic (Lewandowski et al. 2005). Although some degree of syntectonic differentiation into seamount-like elevations and deeper basins took place already during the Early Jurassic (Mišík et al. 1995), this belt became fully disconnected from the NW European platform and differentiated into shallower, pelagic carbonate platforms (Czorsztyn Ridge) and deeper basins (Kysuca Basin) during the earliest Bajocian (Birkenmajer 1977; Mišík 1979; Aubrecht 1997). The Bajocian–Early Oxfordian sedimentation was extremely sediment-starved and discontinuous on the Czorsztyn Ridge, disconnected from river-born sediment supply, and predominantly taking place at aphotic depths with very limited in situ carbonate production, with several minor and major stratigraphic hiatuses (Fig. 2; Aubrecht & Szulc 2006; Schlögl et al. 2009b).

The base of the Middle Jurassic is characterized by the deposition of hemipelagic dark marls and marlstones (Krempachy Marl, Skrzypne Marl, and Harcygrund Marl formations). The termination of this marly siliciclastic regime on the Czorsztyn Ridge is marked by a hardground with lag deposits on the base of crinoidal limestones of Bajocian age (Smolegowa and Krupianka formations, Fig. 2). Schlögl et al. (2006) suggested that coral biohermal limestones of the Vršatec Limestone developed on the shallowest portions of the Czorsztyn Ridge prior to the deposition of the crinoidal limestones or were time-equivalent with crinoidal limestones of the Smolegowa and Krupianka formations. This view differs from initial assignment of the Vršatec Limestone to the Oxfordian by Mišík (1979), indicating that crinoidal limestones underlie coral limestones (Fig. 3). The Vršatec Limestone is formed by coral biohermal framestones, bindstones, and rudstones. In addition to reef constructors, benthic communities are dominated by bivalve assemblages. Limestones with coral reefs are horizontally and/or laterally replaced by (i) breccias that accumulated at footwall margins of faulted blocks (with clasts of biohermal limestones) and by (ii) crinoidal limestones. After a hiatus (marked by hardground), these biohermal limestones are almost always overlain by crinoidal–spiculitic limestones (Fig. 4).

Crinoidal limestones locally alternate or pass upwards into stromatactis-rich limestones with frequent relicts of sponges (Aubrecht et al. 2002, 2009). The spiculitic limestones were deposited during the Bajocian in slope and basinal environments of the Czorsztyn Ridge (Flaki and Podzamcze formations, Birkenmajer 1977). The crinoidal limestones and their time-equivalents were deposited during the Early Bajocian (late Propinquans and Humphriesianum zones) and the early Late Bajocian (Niortense Zone and the early part of the Garantiana Zone). They are terminated by another spatially extensive hardground, with hiatus corresponding to the Late Bajocian upper Garantiana and lower Parkinsoni zones (Fig. 2; Wierzbowski et al. 2004; Schlögl et al. 2005). The hiatus between the crinoidal limestones and the overlying formations is present in all sections belonging to the former Czorsztyn Ridge. The higher parts of the Middle Jurassic successions are represented by condensed micritic to bioclastic nodular Ammonitico Rosso (Czorsztyn Formation) or non-nodular micritic or bioclastic limestones (Bohunice and Štepnica formations) on the top of the Czorsztyn Ridge and its slope (Mišík et al. 1994a; Aubrecht et al. 2009), and by radiolarites and radiolarian limestones in the adjacent basins (Czajakowa and Sokolica Radiolarite formations). The Callovian to Lower Oxfordian deposits are rarely preserved on the Czorsztyn Ridge and are mainly represented by a major stratigraphic hiatus (Schlögl et al. 2009b).

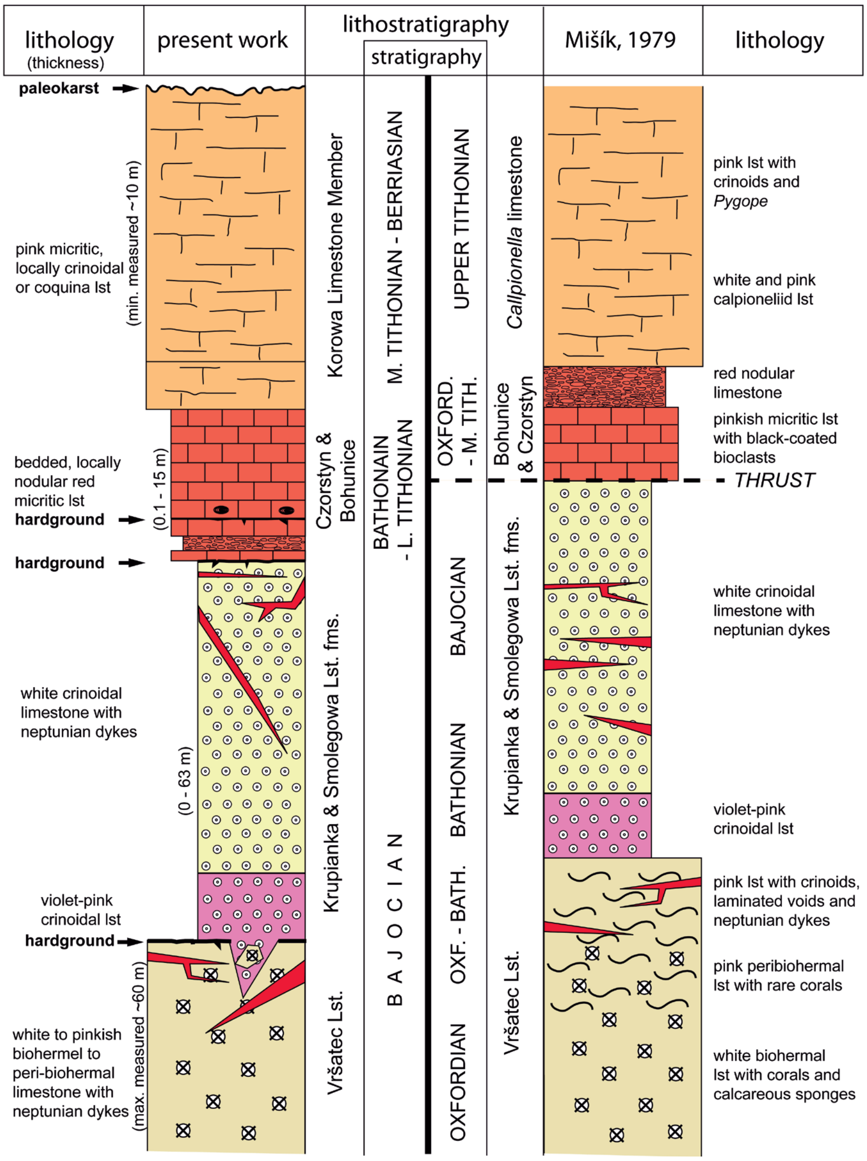

Fig. 3. The comparison of a lithostratigraphic succession at Vršatec–Javorníky interpreted in this study (left column) and by Mišík (1979) (right column). Mišík (1979) invoked the presence of two tectonic slices differing in the development of the Oxfordian deposits and in stratigraphical polarity, which were separated by a thrust on the top of crinoidal limestones (dashed line). However, in this study, we show that the klippe preserves a single Middle Jurassic–Lower Cretaceous succession. Note: Lst. Fm. — Limestone Formation

Material and methods

The studied sites with biohermal–peribiohermal limestones of the Vršatec Limestone are situated in the western Slovakia, Middle Váh Valley, between Vršatské Podhradie, Červený Kameň and Krivoklát villages (Fig. 1). Coral-dominated bioherms are otherwise absent in the rest of the Pieniny Klippen Belt. They include: (1) Vršatec Castle Klippe (VH, primarily with peri-biohermal facies with breccias, 49°03’55.57” N, 18°09’03.80” E), (2) Vršatec-Javorníky Klippe (VJ, mainly with massive biohermal facies, 49°04’10.24” N, 18°09’20.54” E); (3) Drieňová Hora Klippe (DRIE, 49°02’26.44” N, 18°09’23.19” E), (4) Malé Hradište Klippe (MH, 49°03’6.81” N, 18°11’31.24” E), and (5) an unnamed klippe between Malé Hradište Hill and Kalvária Hill (MH-K, 49°03’23.74” N, 18°11’39.03” E). The Vršatec Limestone also occurs at four other sites (Krivoklát Gorge, Mikušovce-quarry, Mikušovce-meadow, and Mikušovce-Mn-mine) that were not investigated in this study. The Middle Jurassic-Lower Cretaceous limestone successions at all localities belong to the Czorstyn Unit, and are capped by the Upper Cretaceous marls.

Benthic foraminifers were studied in a total of 120 thin sections prepared from samples collected from surface outcrops (88 thin sections from two Vršatec Klippen, 17 thin sections from from Malé Hradište Klippe and MH-K Klippe, and 4 thin sections from Drieňová Hora Klippe). To document differences between the lower and upper part of the formation, multiple thin sections were collected at locality 22 (Mišík 1979, locality VJ 22 in this paper) and in a transect between localities 24 and 40 (Mišík 1979, locality VJ 5 in this paper). The microfossils in these samples were documented by more than 3000 photographs. Zeiss microscope was used for micropaleontological study of the thin sections and microphotographs were taken with a Zeiss Axiocam 105 color digital camera. Thin-sections are stored at the Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University in Bratislava (archived under the reference title of this article). Some well-preserved specimens of *Cornuspira*, *Ophthalmidium*, and *Paalzowella* were determined to species level. All foraminifers that can be determined to genus level were counted in thin sections. To summarize differences in species abundances among the five sites and between the lower and upper part of the formation, the counts were pooled to site-level genus abundances and compared in barplots.

Results

Systematic paleontology

We use supraordinal classification of Foraminifera of Pawlowski et al. (2013). The genus and species-level determination follows Loeblich & Tappan (1988, 1992), Clerc (2005), and Rigaud et al. (2013, 2015a, b, 2018). The stratigraphic and paleogeographic distribution of agglutinated benthic foraminifers of the order Lituolida is relatively well-documented from the Jurassic deposits, especially on the basis of specimens extracted from sieved unlithified samples (e.g., Tyszka 1994; Smoleń 2012). However, biostratigraphic and paleogeographic importance of small-sized species with calcareous tests, belonging to the orders Miliolida, Spirillinida, and Involutinida that frequently occur in lithified carbonate deposits, remains poorly known. The representatives of the order Miliolida possess an imperforate wall formed by high-Mg calcite, with randomly oriented crystals refracting light in all directions and resulting in a porcelaneous appearance of the test. The representatives of the order Spirillinida generally possessed low-Mg calcite, hyaline tests. The representatives of order Involutinida have aragonitic tests.

Subphylum FORAMINIFERA d'Orbigny, 1826
Class TUBOTHALAMEA Pawlowski, Holzmann & Tyszka, 2013
Order MILIOLIDA Delage & Hérouard, 1896
Suborder Miliolina Delage & Hérouard, 1896
Superfamily Cornuspiroidea Schultze, 1854
Family Cornuspiridae Schultze, 1854
Subfamily Cornuspirinae Schultze, 1854
Genus *Cornuspira* Schultze, 1854

Cornuspira infraoolithica Terquem, 1870
(Fig. 5.22–23)

1870 *Cornuspira infraoolithica* n.sp. – Terquem: p. 243, pl. XXV, fig. 13.
2005 *Cornuspira infraoolithica* Terquem – Clerk: p. 36, pl. 3, fig. 1-4; pl. 14, fig. 6, 7.

Occurrences: Drieňová Hora Klippe (DRIE 01a), Malé Hradište Klippe (MH 01/1).

Description: A small biconcave species with a test diameter close to 250 µm, composed of a very small proloculus, followed by 7 to 9 planispiral whorls.

Distribution: *Cornuspira infraoolithica* was described by Terquem (1870) from the Upper Bajocian (Parkinsoni Zone) of Moselle (France), by Terquem & Berthelin (1875) from the Pliensbachian (Margaritatus Zone) of France, and by Burbach (1886) from Pliensbachian of Gotha (Central Germany). Clerc (2005) described this species from the Upper Aalenian–Upper Bathonian deposits of the French Jura.

Stratigraphic range: Pliensbachian–Upper Bathonian.

Cornuspira orbicula (Terquem & Berthelin, 1875)
(Fig. 5.16–21)

1875 *Cornuspira orbicula* n. sp. – Terquem & Berthelin: p. 17, pl. I, fig. 12a-c.
2005 *Cornuspira orbicula* (Terquem & Berthelin) – Clerc: p. 37, pl. 3, fig. 5-19; pl. 14, fig. 1-5; pl. 32, fig. 1, 2.

Occurrences: Vršatec Castle Klippe (VH 5B/2, VH 5B/2B), Malé Hradište Klippe (MH 01/1, MH 01/3a, MH 01/6a, MH 03/1a, MH 03/1c).

Description: A slightly biconcave medium-sized species with a test diameter close to 380 µm, composed of a spherical proloculus and a low tubular deuteroloculus followed by 5 to 6 planispiral whorls. This species is characterized by a high morphological variation.

Discussion: Copestake & Johnson (2014) accepted that *Cornuspira liasina* appears to be microspheric form of the species while Terquem & Berthelin's (1875) *Spirillina orbiculare* seems to be its megalospheric equivalent.

Distribution: It is one of the most common representatives of the genus *Cornuspira* in the Middle Jurassic. This species was described as *Spirillina orbicula* by Terquem & Berthelin (1875) from the Upper Pliensbachian (Margaritatus Zone) of Essey-les-Nancy, France. In the first half of the 20th century, it was reported from Lower and/or Middle Jurassic outcrops: Lower Jurassic (Lias α, β, ζ) of the Swabian Alb (Issler 1908; Franke 1936), Lower and Middle Jurassic of NW Germany (Bartenstein & Brand 1937) and Callovian of NW Germany (Lutze 1960). Antonova (1959) described this species from the Lower Aalenian of the Laba River region (NW Caucasus). Trifonova (1961) described this species from the Pliensbachian and Toarcian of the villages of Sarantsi and Zimevitsa, Sofia district (Bulgaria). *C. orbicula* is also known from the Lower Toarcian of SW Germany (Riegraf 1985), and from the Aalenian–Lower Oxfordian (Wernli 1970) and Aalenian–Callovian (Clerc 2005) of the French Jura.

Stratigraphic range: Lower Jurassic to Callovian, common in the Upper Aaalenian, Upper Bajocian and Bathonian.

Cornuspira tubicomprimata Danitch, 1971
(Fig. 5.12–15)

1971 *Cornuspira tubicomprimata* sp. nov. – Danitch: p. 97, tabl. XVII, fig. 2 a, b.
2005 *Cornuspira tubicomprimata* Danitch – Clerc: p. 40, pl. 3, fig. 21-27; pl. 14, fig. 10, 11.

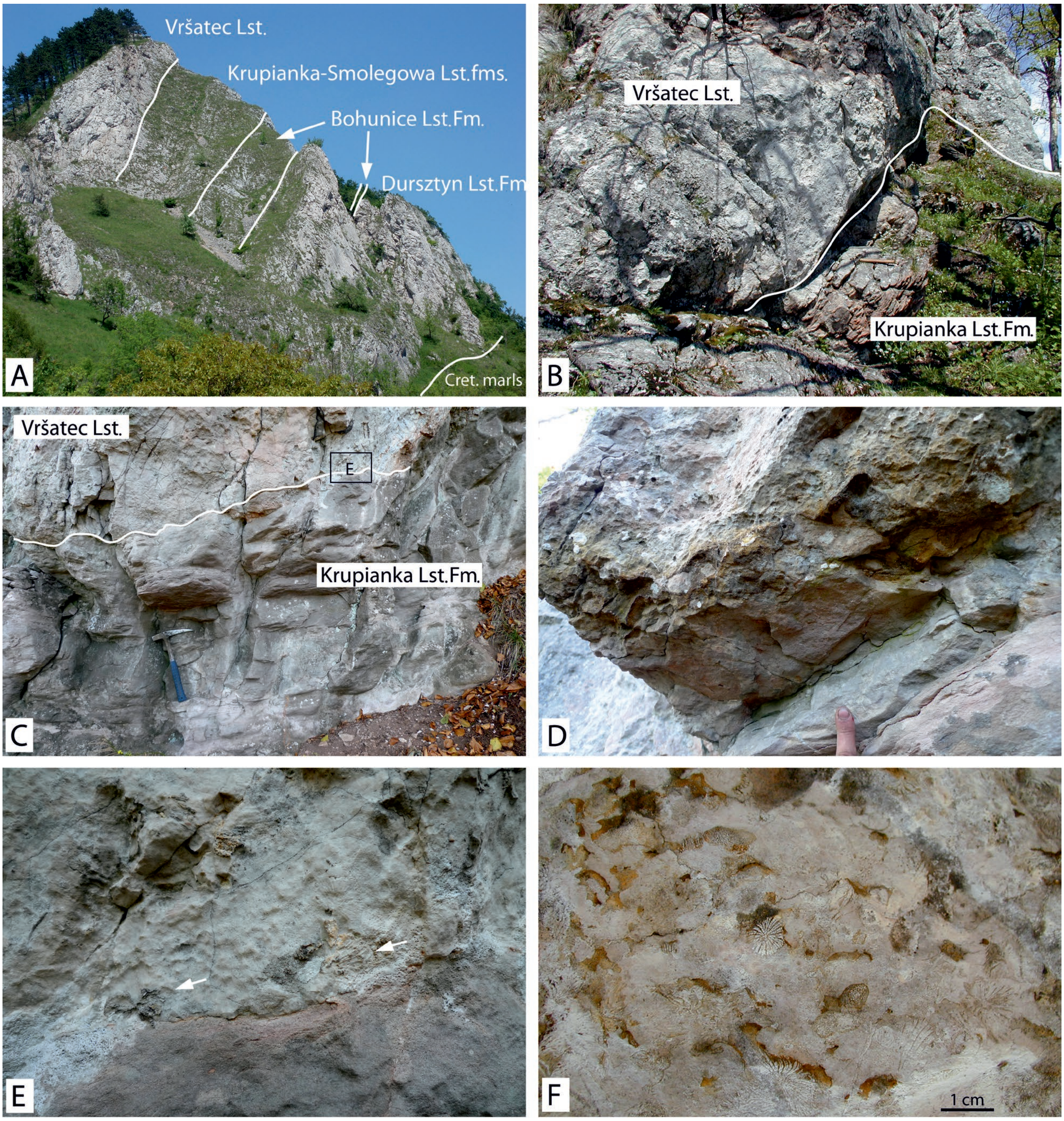

Fig. 4. A — Lithostratigraphic division at Vršatec-Javorníky klippe. **B, C, E** — Irregular upper surface of coral limestone on the boundary between the Vršatec Limestone and crinoidal limestones at Vršatec–Javorníky klippe. E — Close-up of C, showing the cross-section of the hardground boundary between light gray coral limestones (Vršatec Limestone , large corals marked by arrows) and red crinoidal limestones. **D, F** — Close-ups of the hardground on the top of the Vršatec Limestone. F — Close-up of D, showing the hardground surface with Fe-stained corals.

Occurrences: Vršatec Castle Klippe (VH 100), Malé Hradište Klippe (MH 01/6a).

Description: This species is characterized by a large proloculus, by a relatively flat test due to slow growth of tube thickness during ontogeny, and by a relatively thick wall (up to 10 µm).

Distribution: *Cornuspira tubicomprimata* was described by Danitch (1971) from the Upper Bajocian–Lower Bathonian sediments of region between Dniester and Prut rivers, Moldavia. According to Clerc (2005), *C. intervacare* described by Azbel (1988) from the Middle-Upper Oxfordian of Manguychlak (Kazakhstan) belongs to *C. tubicomprimata*. *C. tubicomprimata* also occurs in the Upper Bajocian of the French Jura (Clerc 2005).

Stratigraphic range: Upper Bajocian–Upper Oxfordian, more frequent in the Upper Bajocian.

Genus *Meandrovoluta* Fugagnoli & Rettori in Fugagnoli, Giannetti & Rettori, 2003

Meandrovoluta asiagoensis Fugagnoli & Rettori, 2003
(Fig. 6.1–6)

1966 *Glomospira* sp. – Radoičić: pl. 92, fig. 2; pl. 111, fig. 2; pl. 124, fig. 1–2.
2003 *Meandrovoluta asiagoensis* gen. et sp. nov. – Fugagnoli & Rettori: p. 45, pl. 1, figs. 1-12; pl. 2, figs. 1-5?, 6-16.

Occurrences: Vršatec Castle Klippe (VH 5B/1, VH 5B/2, VH 5B/4, VH 5B/5a, VH 5B/5b, VH 5B/6, VH II/2, VH 6), Drieňová Hora Klippe (DRIE 01, DRIE 02), Malé Hradište Klippe (MH 01/6a, MH 03).

Description: This species shows a high morphological variation. The coiling is zig-zag-shaped in the early stage and slightly undulated (meander-like) in the later ontogenetic stage. A globular proloculus is followed by an undivided second chamber. The second chamber is mostly irregularly coiled, with 3 to 5 coils. Most of the sections are identical to the megalospheric forms of *M. asiagoensis* (e.g., figs. 1a, 2, 3, 5, 6–16 on pl. 2 in Fugagnoli et al. 2003) characterized by the small size, by an increase of the zig-zag-shape part, and by a reduction of the disc-like or fanlike second stage.

Distribution: A genus *Meandrovoluta* (type-species *Meandrovoluta asiagoensis*) was originally described from the Sinemurian?–Domerian interval of the Calcari Grigi Formation of the Trento Platform (Southern Alps; Fugagnoli et al. 2003). Abundant foraminifers similar to glomospirinids occur in the Lower Jurassic limestone successions at many locations of the Tethyan region. All these glomospirinid foraminifers occurring in the Lower Jurassic of the Tethyan region were typically assigned to the genus *Glomospira* Rzehak, 1885 with a finely agglutinated wall (e.g., Radoičić 1966). However, *Meandrovoluta* differs from *Glomospira* in having a porcelaneous wall. Fugagnoli and Rettori (in Fugagnoli et al. 2003) placed *Meandrovoluta* in the family Cornuspiridae Schultze (order Miliolida) that is characterized by porcelaneous tests. Cai et al. (2006) described three new species: *Glomospira wölongensis, Glomospira tingriensis* and *Glomospirella minuscula* from the Niehnieh Hsiungla Formation of Tingri and Nyalam regions of southern Tibet, China. We assume that the species *Glomospira wölongensis* (pl. I, figs. 1–10 in Cai et al. 2006) and *Glomospirella minuscula* (pl. I, figs. 11–18 in Cai et al. 2006) represent junior synonyms of *Meandrovoluta asiagoensis*, because of the small size, very thin wall, the mode of coiling of the second chamber, and the poorly developed second disc-like stage. Based on ammonites, the age of the formation is Bajocian to Callovian (Dhital 2015), but the ammonites come from other sections, not from those studied by Cai et al. (2006). Therefore, the last occurrence date of this species on the basis of its distribution in the Niehnieh Hsiungla Formation is poorly constrained. *M. asiagoensis* was reported from the Sinemurian–Toarcian of the Karst Dinarides, Croatia (Velić 2007), the Upper Sinemurian–Upper Toarcian of Latium–Abruzzi carbonate platform, Central Italy (Chiocchini et al. 2008), and the Upper Sinemurian–Lower Pliensbachain of the Podpec Limestone of External Dinarides, Slovenia (Gale 2014).

Stratigraphic range: Sinemurian–Toarcian, Middle Jurassic.

Superfamily Milioloidea Ehrenberg, 1839
Family Spiroloculinidae Wiesner, 1920
Genus *Labalina* Azbel, 1988

Labalina occulta (Antonova, 1958)
(Fig. 7.1–4)

1958 *Spirophthalmidium occultum* sp. n. – Antonova: p. 52, tabl. II, fig. 5a, b, 6.
2005 *Labalina occulta* (Antonova) – Clerc: p. 78, pl. 11, fig. 10-22; pl. 26, fig. 4-15.

Occurrences: Vršatec Castle Klippe (VH 5B/3, VH 5B/4), Malé Hradište Klippe (MH 01/1, MH 03).

Description: The longitudinal sections have an oval contour. The length of the tests is around 200 µm. The tests are characterized by well-rounded evolute arrangement of the chambers and by a thin wall. In transverse sections, the specimens are mainly oval and stretched, with well-visible coiling in a quinqueloculinid arrangement, followed by a sigmoidal arrangement and a lobed contour. The number of chambers varies between 9 and 12.

Distribution: Antonova (1958) described this species as *Paleomiliolina occulta* from the Bajocian of the Psebai district, NW Caucasus, and from the Bajocian of the Laba River area, NW Caucasus (Antonova 1959). Danitch (1971) reported this species from the Upper Bajocian–Middle Bathonian of the region between Dniester and Prout rivers, Moldavia. Clerc (2005) found it in the Middle Aalenian to Upper Bathonian of the French Jura.

Stratigraphic range: Middle Aalenian–Upper Bathonian.

Superfamily Nubecularioidea Jones, 1875
Family Nubeculariidae Jones, 1875
Subfamily Nubeculariinae Jones, 1875
Genus *Nubecularia* Defrance, 1825

Nubecularia reicheli Rat, 1966
(Fig. 5.7–11)

1966 *Nubecularia reicheli* n. sp. – Rat: p. 80, fig. 2; pl. 1, fig. 1-9.
2005 *Nubecularia reicheli* Rat – Clerc: p. 52, pl. 17, fig. 7-9; pl. 18, fig. 1-6.

Occurrences: Vršatec Castle Klippe (VH 5B/1, VH 5B/2, VH 5B/3, VH 5B/4, VH 5B/5a, VH 5B/5b, VH 5B/6, VH 5B/7, VH 5B/8, VH II/1, VH II/2a, VH II/2b, VH II/4, VH Bos Lms/B, VJ 22, VH 100m, and samples from "*Bositra* dyke" (VH-Bositra B). Vršatec-Javorníky Klippe (VJ 5/2c, VJ 5/top), Drieňová Hora Klippe (DRIE 01), Malé Hradište Klippe (MH 01/1, MH 01/6a, MH 01/7, MH 02/1, MH 02/2b, MH 02/4a, MH 02/5, MH 03, MH 03/1a, MH 03/1c, MH 01/new, MH 02/new, MH 03/new, MH GPS).

Description: Encrusting porcelaneous species, characterized by thick crusts consisting of several layers and forming millimetric platoons.

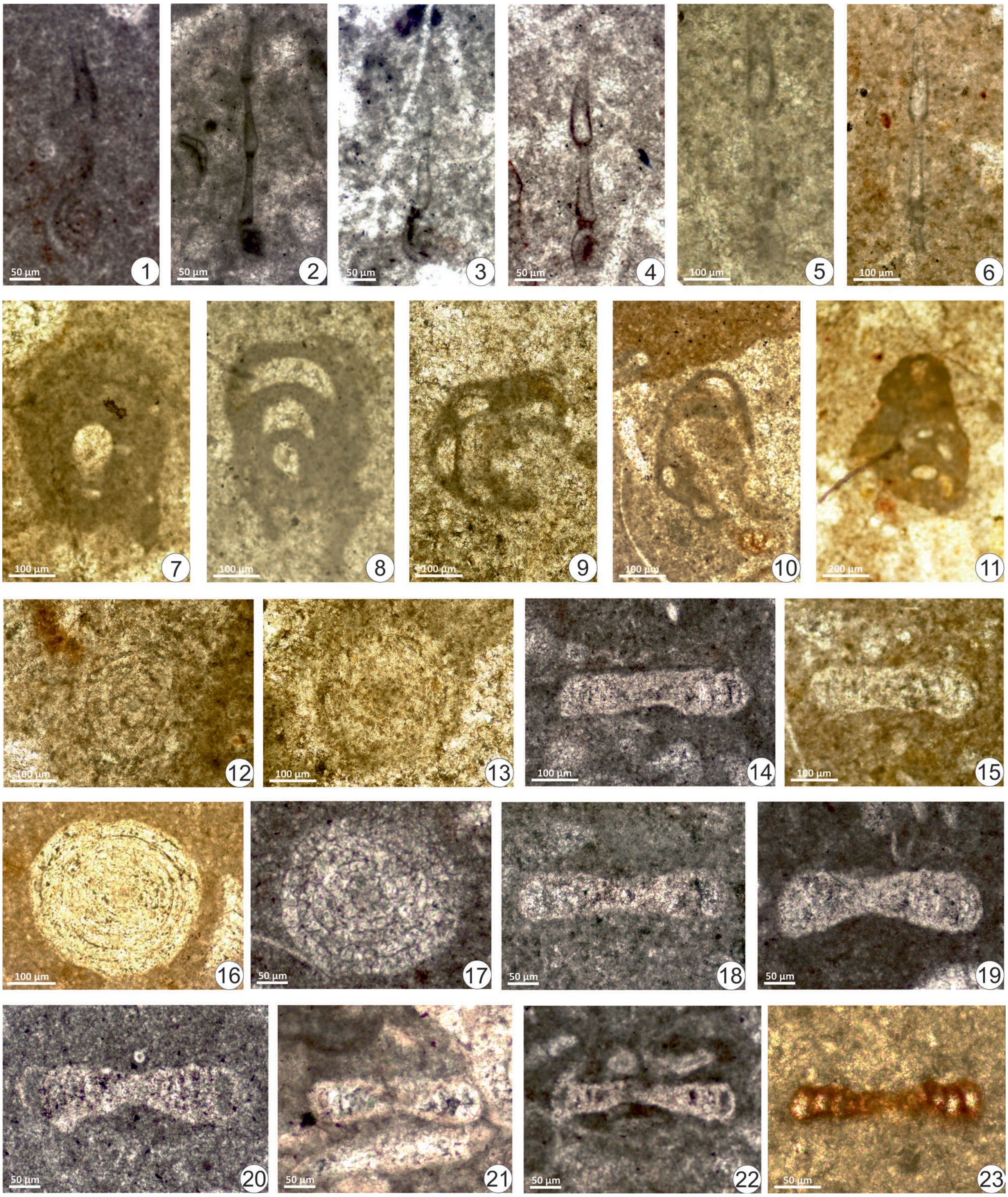

Fig. 5. 1–6: *Vinelloidea bigoti* (Cushman); 1 — Malé Hradište Klippe (MH 01/3a) ; 2–5 — Vršatec Castle Klippe (VH 5B/7, VH 5B/6, VH 5B/4) ; 6 — Malé Hradište Klippe (MH 02/4a). **7–11:** *Nubecularia reicheli* Rat; 7–9 — Vršatec Castle Klippe (VH 5B/4, VJ 22); 10, 11 — Vršatec–Javorníky Klippe (VJ 5-top of Vrs Lms). **12–15:** *Cornuspira tubicomprimata* Danitch; 12–15 — Malé Hradište Klippe (MH 01/5). **16–21:** *Cornuspira orbicula* (Terquem & Berthelin); 16 — Vršatec Castle Klippe (VH 5B/2b); 17–21 — Malé Hradište Klippe (MH 01/1, MH 01/3a, MH 02/2b, MH 03/1a). **22, 23:** *Cornuspira infraoolithica* Terquem; 22 — Malé Hradište Klippe (MH 01/1); 23 — Drieňová Hora Klippe (DRIE 01a).

Distribution: This species was described by Rat (1966) from the Bajocian of Burgundy (NE France), and by Wernli (1970) and Clerc (2005) from the Lower Bajocian to the Middle Callovian and the Upper Bajocian to the Lower Callovian of the French Jura, respectively.

Stratigraphic range: Lower Bajocian–Middle Callovian.

Subfamily Nubeculinellinae Avnimelech & Reiss, 1954
Genus *Vinelloidea* Canu, 1913

Vinelloidea bigoti (Cushman, 1930)
(Fig. 5.1–6)

1930 *Nubeculinella bigoti* n. sp. – Cushman: p. 134, pl. IV, fig. 2, 3.
2005 *Nubeculinella* aff. *bigoti* Cushman – Clerc: p. 47, pl. 15, fig. 1, 2, 5-8.

Occurrences: Vršatec Castle Klippe (VH 5B/1, VH 5B/2, VH 5B/3, VH 5B/4, VH 5B/5a, VH 5B/7, VH II/1, VH II/2b, VH 100m, Vršatec-Javorníky Klippe (VJ 5/2c), Malé Hradište Klippe (MH 01/1, MH 02/4a, MH 02/5, MH 03, MH 03/1a).

Description: The subsphaerical proloculus is followed by a narrow, tube-like chamber, up to five chambers in the initial whorl are visible and up to four chambers in the uncoiled, linear portion of the test. The wall is calcareous, built by high-Mg calcite.

Remarks: Canu (1913) assigned the genus *Vinelloidea* (type species *V. crussolensis*) to bryozoans. Cushman (1930) introduced the genus *Nubeculinella* from the Jurassic of Auberville (Calvados, France), with type species *Nubeculinella bigoti*. Voigt (1973) showed that the genus *Vinelloidea* Canu represents an adherent foraminifer, and is a senior synonym of the genus *Nubeculinella* Cushman. Loeblich & Tappan (1988) retained the genus name *Vinelloidea* Canu and refigured the type material of *V. crussolensis* Canu (Voigt 1973), designating it as a lectotype. Copestake & Johnson (2014) suggested that illustrations of *Vinelloidea crussolensis* in Loeblich & Tappan (1988) and *Nubeculinella bigoti* in Loeblich & Tappan (1988) do not warrant species discrimination and thus synonymized the two species. We follow this suggestion and use the genus name *Vinelloidea* on the basis of the priority rule.

Distribution: The species was first described by Cushman (1930) as *Nubeculinella bigoti* from the Oxfordian (*Cardioceras cordatum* Zone) of Auberville (Calvados, France). Widespread in the Tethyan region, it was found by Paalzow (1932) in the Middle Oxfordian (Transversarium Zone) of NE Swabian Alb, S Germany, by Gordon (1961, 1965) in the Oxfordian–Kimmeridgian of Dorset (S. England), by Antonova (1959) in the Aalenian–Lower Bajocian of the Laba River region, Russia, by Adams (1962) in the Lower Jurassic to Kimmeridgian of England, by Danitch (1971) in the Upper Oxfordian–Lower Kimmeridgian of the region between Dniester and Prut rivers, Moldavia. The species was described from the Toarcian–Oxfordian of the French Jura, France by Clerc (2005) and from the Lower Jurassic (Obtusum to Jamesoni zones) of Llanbedr (Mochras Farm) Borehole, North Wales, UK by Copestake & Johnson (2014).

Stratigraphic range: Sinemurian to Kimmeridgian.

Family Ophthalmidiidae Wiesner, 1920
Genus *Ophthalmidium* Kubler & Zwingli, 1870

Ophthalmidium caucasicum (Antonova, 1958)
(Fig. 7.15–19)

1958 *Spirophthalmidium caucasicum* sp. n. – Antonova: p. 51, tabl. II, fig. 1-4.
2005 *Ophthalmidium caucasicum* (Antonova) – Clerc: p. 55, pl. 4, fig. 3-8; pl. 20, fig. 1-10; pl. 32, fig. 3, 4.

Occurrences: Malé Hradište Klippe (MH 01/new, MH 03/new).

Description: A rather large species (up to 440 µm) characterized by a fully evolute test with a rounded peripheral margin, the wall is fine, markedly thin (not exceeding 10 µm).

Distribution: The species was first described by Antonova (1958) as *Spirophthalmidium caucasicum* from the Bajocian of the Psebai district, NW Caucasus. Antonova (1959) documented this species also from the Bajocian of the Laba River area (NW Caucasus) and Danitch (1971) from the Upper Bajocian–Lower Bathonian of the region between Dniester and Prut rivers, Moldavia. It was described by Clerc (2005) from the Bajocian–Lower Bathonian of the French Jura.

Stratigraphic range: Bajocian–Lower Bathonian.

Ophthalmidium obscurum (Ivanova & Danitch, 1971)
(Fig. 7.20–29)

1971 *Spirophthalmidium obscurum* sp. n. – Ivanova & Danitch *in* Danitch: p. 126, tabl. XXVIII, fig. 1a, b, 2a, b, 3, 4.
2005 *Ophthalmidium obscurum* (Ivanova & Danitch) – Clerc: p. 69, p. 7, fig. 8-14; pl. 22, fig. 6-10.

Occurrences: Vršatec Castle Klippe (VH 5B/1, VH 5B/2, VH 5B/3, VH 5B/4, VH 5B/6, VH 5B/7, VH 5B/8, VH II 2b, VH II 4, VH 100m, and samples from „*Bositra* dyke“ (VH-Bositra A). Vršatec-Javorníky Klippe (VJ 5t, VJ22), Malé Hradište Klippe (MH 01/1, MH 02/2b, MH 03/1a).

Description: A medium-sized species (up to 340 µm) characterized by an involute coiled test, oval shape, and a wall thick up to 18 µm.

Distribution: The species was first described by Danitch (1971) from the Upper Bajocian–Lower Bathonian of the region between Dniester and Prout rivers (Moldavia). Wernli (1970) described the species from the Upper Bajocian of the French Jura and Clerc (2005) from the Upper Bajocian–Lower Bathonian of the French Jura.

Stratigraphic range: Upper Bajocian to Lower Bathonian.

Ophthalmidium terquemi Pazdrowa, 1958
(Fig. 7.5–14)

1958 *Ophthalmidium carinatum* n. subsp. *terquemi* – Pazdrowa: p. 152, tabl. I, fig. 1-9; tabl. II, fig. 11; tabl. III, fig. 1-8; tabl. V, fig. 7; tabl. VI, fig. 1-3; tabl. VII, fig. 5-7.
2005 *Ophthalmidium terquemi* Pazdrowa – Clerc: p. 71, pl. 7, fig. 17-21; pl. 8, fig. 1-17; pl. 9, fig. 1-3; pl. 23, fig. 2-9; pl. 33, fig. 1, 2.

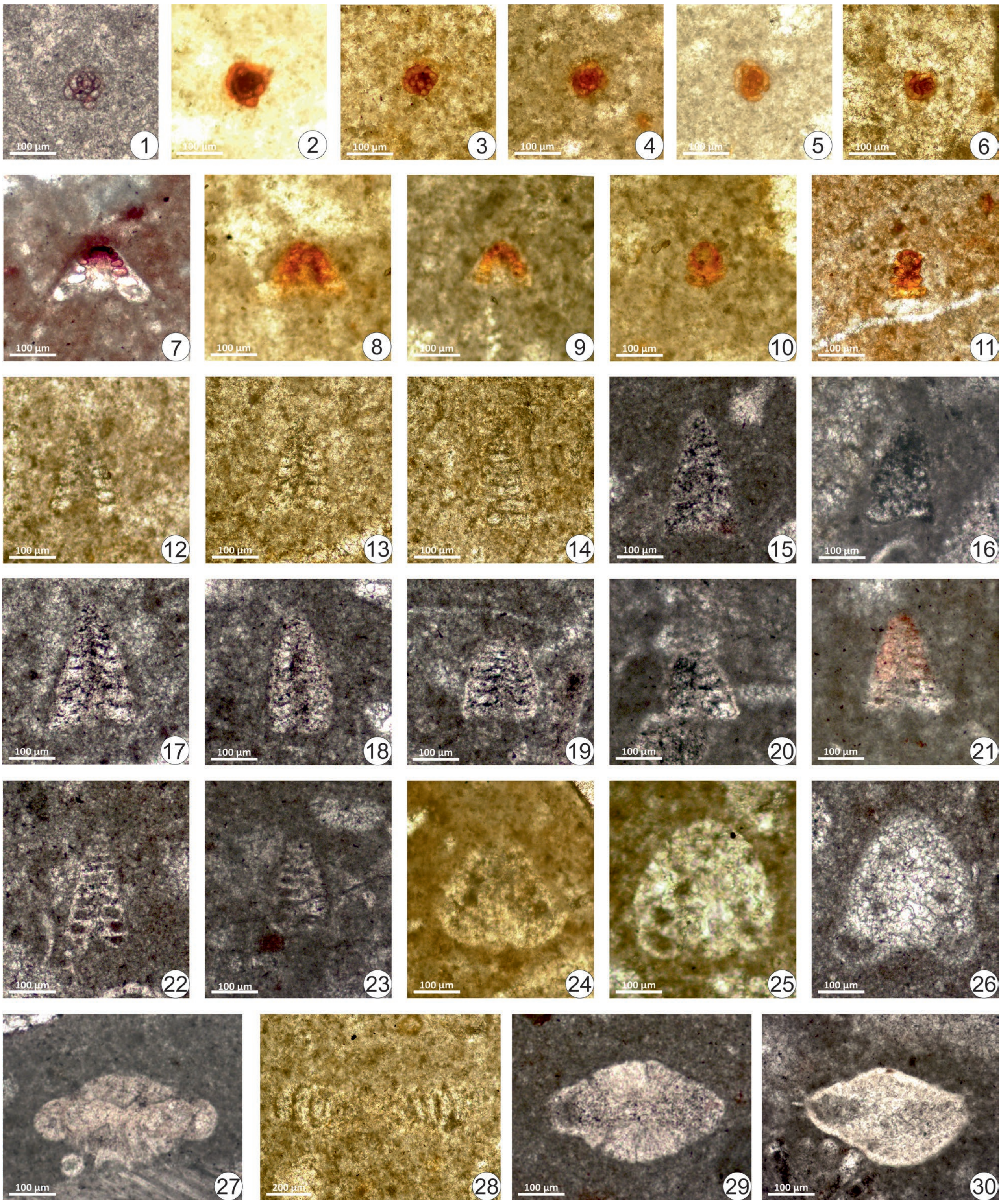

Fig. 6. 1–6: *Meandrovoluta asiagoensis* Fugagnoli & Rettori; 1–4 — Vršatec Castle Klippe (VH 5B/2, VH 5B/5b, VH 6); 5, 6 — Malé Hradište Klippe (MH 03). **7–11:** *Hungarillina lokutiense* Blau & Wernli; 7–10 — Vršatec Castle Klippe (VH 5B/2b, VH 5B/5b); 11 — Malé Hradište Klippe (MH 03). **12–21:** *Tethysiella pilleri* (Blau); 12–20 — Malé Hradište Klippe (MH 01/6a, MH 03/1a, MH 03/1c, MH 03/new); 21 — Vršatec Castle Klippe (VH 5B/5b). **22, 23:** *Kristantollmanna* cf. *altissima* (Pirini); 22, 23 — Malé Hradište Klippe (MH 01/6a). **24–26:** *Trocholina turris* Frentzen; 24–26 — Malé Hradište Klippe (MH 01/3, MH 01/7, MH 03/1c). **27–30:** *Radiospirillina umbonata* Blau & Wernli; 27–29 — Malé Hradište Klippe (MH 01/3a, MH 03/1a); 30 — Vršatec Castle Klippe (VH 5B/2).

Occurrences: Vršatec-Javorníky Klippe (VJ 10base), Drieňová Hora Klippe (DRIE 01), Malé Hradište Klippe (MH 01/6b, MH 02/2b, MH 03, MH 03/1a).

Description: Relatively large species (up to 500 µm) characterized by an involute to semi-involute coiled test and with a relatively thick wall (12 and 30 µm) for the last chamber and the inner wall of the chambers is thicker at the base and at the collar level.

Distribution: The species *Ophthalmidium terquemi* Pazdrowa was described by Pazdrowa (1958) as a new subspecies of *Ophthalmidium carinatum* Kubler & Zwingli from the Bajocian of Czestochowa (Poland). This taxon was distinguished as *Ophthalmidium carinatum terquemi* Pazdrowa from the Bajocian–Middle Bathonian of Czestochowa, Poland (Pazdrowa 1959; Pazdro 1972), and as *Ophthalmidium terquemi* from the Upper Bajocian–Lower Callovian of the Swabian Alb (Blank 1990). It was found in the Bajocian–Lower Bathonian of the French Jura and Burgundy by Piuz (2004) and in the Bajocian–Lower Callovian of the French Jura by Clerc (2005).

Stratigraphic range: Bajocian–Lower Callovian.

Order SPIRILLINIDA Gorbatchik & Mantsurova, 1980
Suborder Spirillinina Hohenegger & Piller, 1975
Family Spirillinidae Reuss & Fritsch, 1861
Subfamily Neotrocholininae Rigaud, Schlagintweit & Bucur, 2018
Genus Hungarillina Blau & Wernli, 1999

Rigaud et al. (2018) comprehensively revised this genus, with synonymy lists and new taxonomic, phylogenetic, and stratigraphic schemes, and assigned it to the subfamily Neotrocholininae.

Hungarillina lokutiense Blau & Wernli, 1999
(Fig. 6.7–11)

1999 *Hungarillina lokutiense* n. gen., n. sp. – Blau & Wernli, p. 539, pl. I, figs. 1-17.
2018 *Hungarillina lokutiense* Blau & Wernli – Rigaud, Schlagintweit & Bucur, figs. 2F-G.

Occurrences: Vršatec Castle Klippe (VH 5B/2, VH 5B/5b), Malé Hradište Klippe (MH 03).

Description: Relatively high trochospirally coiled test with completely filled umbilical cavity displays the characteristic "bell shape" of the type-species.

Distribution: Blau & Wernli (1999) described their new genus *Hungarillina* with three new species: *H. lokutiense, H. media* and *H. pedunculata* from the Middle Jurassic pebbles in the Upper Bajocian megabreccia near Lokut (Transdanubian Central Range, Hungary). Velledits & Blau (2003) described this species from protoglobigerinid wackestones and packstones from neptunian dykes in the Büdöskút Limestone, Bükk Mountains (NE Hungary). Therefore, the stratigraphic range of this species can extend beyond the Bajocian stage. This species was also found by Piuz (2004) in the Lower Bajocian of the French Jura and in Burgundy (SE France). Schlagintweit & Moshammer (2015) described this species from a fissure (filled by peloidal packstones and grainstones) in the Vils Limestone (Außerfern in Tyrol, Austria). Its Bajocian age was inferred on the basis of *H. lokutiense*.

Discussion: The microfacies with protoglobigerinids and spirillinids, containing *Hungarillina lokutiense* and *Radiospirillina umbonata*, was assigned by Velledits & Blau (2003) to the Bathonian?–Callovian?.

Stratigraphic range: Bajocian (this paper), Bathonian?–Callovian? (Velledits & Blau 2003).

Genus Radiospirillina Blau & Wernli, 1999

Rigaud et al. (2018) assigned this genus to subfamily Neotrocholininae.

Radiospirillina umbonata Blau & Wernli, 1999
(Fig. 6.27–30)

1999 *Radiospirillina umbonata* n. gen., n. sp. – Blau & Wernli: p. 541, pl. II, figs. 3, 5, 7-8.
2018 *Radiospirillina umbonata* Blau & Wernli – Rigaud, Schlagintweit & Bucur: fig. 4A.

Occurrences: Vršatec Castle Klippe (VH 5B/1, VH 5B/2, VH 5B/5a), Malé Hradište Klippe (MH 03/1a, MH 03).

Description: Sublenticular test, formed by a globular proloculus followed by subplanispirally to low trochospirally enrolled, undivided second tubular chamber.

Distribution: The genus *Radiospirillina*, with the type species *Radiospirillina umbonata*, was described as a new genus and a new species by Blau & Wernli (1999) from the Middle Jurassic pebbles in the Upper Bajocian megabreccia near Lokut (Transdanubian Central Range, Hungary). Velledits & Blau (2003) described this species from neptunian dykes in the Büdöskút limestone, Bükk Mountains (NE Hungary). Piuz (2004) reported the same species from the Bajocian echinodermic shelf in the French Jura and in Burgundy (SE France). A specimen illustrated by Mišík et al. (1994b, pl. 2, fig. 6) and determined as *Trocholina* sp., found in a dyke penetrating through Bajocian pink crinoidal limestones (formerly supposed to be of Bathonian-Callovian age) from the Krasín Klippe near Dolná Suča also belongs to *Radiospirillina umbonata.*

Stratigraphic range: Bajocian, Bathonian?–Callovian? (Velledits & Blau 2003).

Genus Tethysiella Blau, 1987a

Tethysiella pilleri (Blau, 1987a)
(Fig. 6.12–21)

1987a *Praepatellina pilleri* n. gen. n. sp. – Blau: p. 508, pl. 3, figs. 9-11, 13-15.
1991 *Tethysiella pilleri* (Blau, 1987a) – Blau & Haas: p. 21, figs. 7 S-T.

Occurrences: Vršatec Castle Klippe (VH 5B/2, VH 5B/5b), Vršatec-Javorníky Klippe (VJ 5/2c), Malé Hradište Klippe (MH 01/3a, MH 03, MH 03/1a, MH 03/1c).

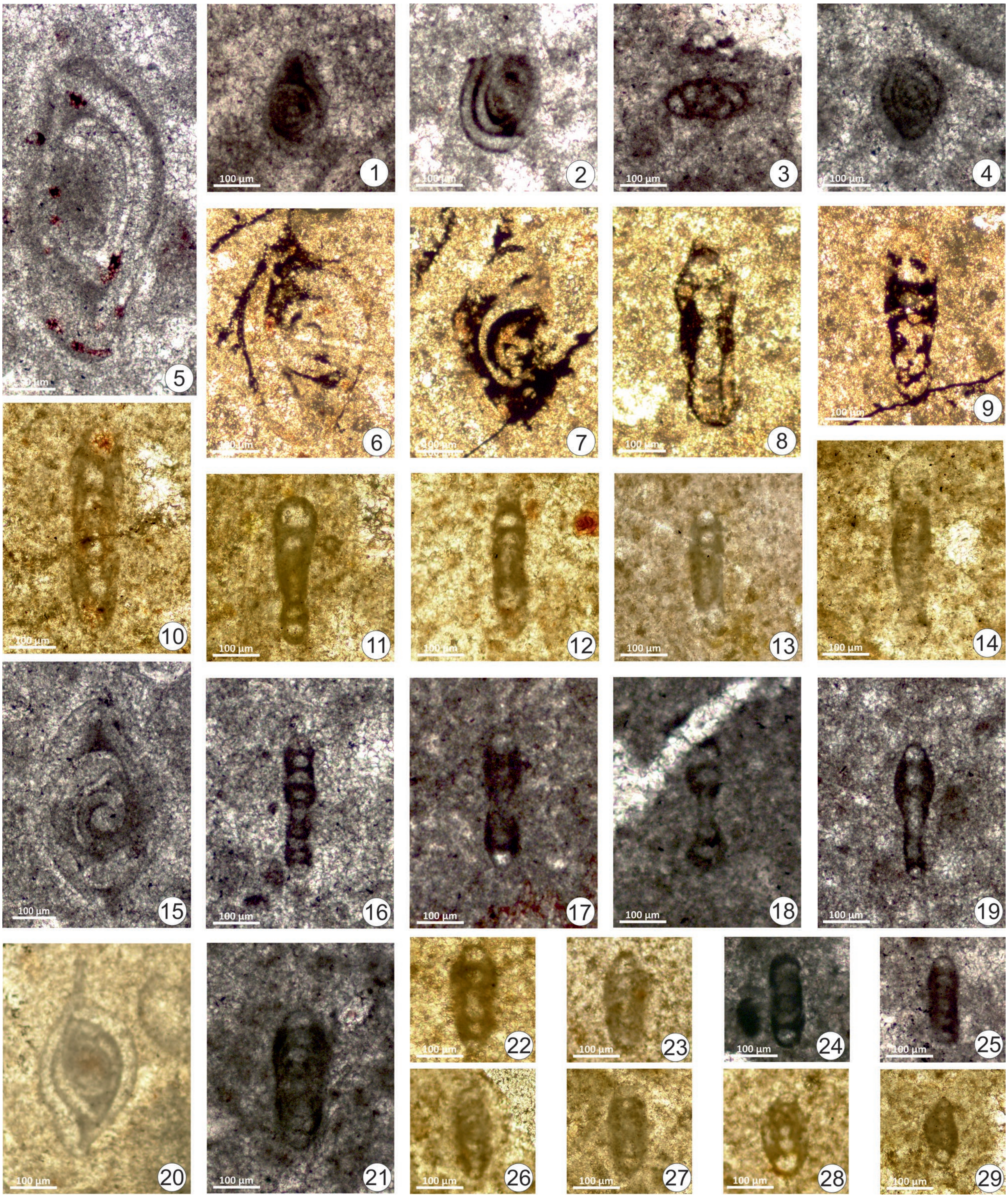

Fig. 7. 1–4: *Labalina occulta* (Antonova); 1–3 — Vršatec Castle Klippe (VH 5B/4); 4 — Malé Hradište Klippe (MH 02). **5–14***: Ophthalmidium terquemi* Pazdrowa; 5 — Malé Hradište Klippe (MH 03); 6–9 — Vršatec-Javorníky Klippe (VJ XB base); 10–14 — Malé Hradište Klippe (MH 01/6b, MH 02/2b, MH 03). **15–19:** *Ophthalmidium caucasicum* (Antonova); 15–19 — Malé Hradište Klippe (MH 01/new, MH 03/new). **20–29:** *Ophthalmidium obscurum* (Ivanova & Danitch); 20 — Vršatec Castle Klippe (VH 100m); 21–23 — Malé Hradište Klippe (MH 01/3a, MH 03); 24, 25 — Vršatec Castle Klippe (VH-AT, VH 5B/4); 26–29 — Malé Hradište Klippe. (MH 03).

Description: Trochospirally coiled test consists of two chambers, proloculus and a very high trochospiral deuteroloculus tube, and possessing an empty umbilicus.

Distribution: *Tethysiella pilleri* was described as *Praepatellina pilleri* by Blau (1987a) from the red fissure fillings in the Oberrhät Limestone (Lavanter Breccie, Lienzer Dolomiten, Austria, East-Tyrol). The fissure fillings are of the Early Jurassic age. Blau & Haas (1991) found this species in red fissure fillings in the Lower Jurassic limestones from Transdanubian Central Range (Hungary). They changed the genus name of this species, characterized by a very high trochospiral deuteroloculus tube and an empty umbilicus, to *Tethysiella* Blau, 1987a (*Praepatellina* Blau, 1987a is a junior homonym of *Tethysiella*). The species was reported also from the Bajocian of the French Jura and Burgundy, SE France (Piuz 2004, 2008).

A specimen illustrated by Mišík et al. (1994b, pl. 2, fig. 5) and determined as *Trocholina* sp., found in a dyke penetrating through Bajocian pink crinoidal limestones (formerly assigned to Bathonian–Callovian) from the Krasín Klippe near Dolná Súča also belongs to *Tethysiella pilleri.*

Stratigraphic range: Lower Jurassic–Bajocian.

Family Placentulinidae Kasimova, Poroshina & Geodakchan, 1980
Subfamily Ashbrookiinae Loeblich & Tappan, 1984
Genus *Paalzowella* Cushman, 1933

Paalzowella turbinella (Gümbel, 1862)
(Fig. 8.1, 2)

1862 *Rotalina turbinella* n. sp. – Gümbel: p. 230, taf. IV. fig. 10a-b.
2015 *Paalzowella*? sp. aff. *turbinella* (Gümbel) – Schlagintweit & Moshammer: p. 211, text-figs. 3 pars, 4a-f.

Occurrences: Vršatec-Javorníky Klippe (VJ 5/2a, V11ts), Malé Hradište Klippe (MH 01/1, MH 01/3a)

Description: We assign the trochospirally coiled specimens of the genus *Paalzowella* whith convex umbilical side displaying a central flattened part and giving rise to a boat-like outline of the test in axial sections to *P. turbinella* (in accordance with the diagnostic trait of the species).

Distribution: Gümbel (1862) introduced the new species *Rotalina turbinella* from the Middle Oxfordian at Streitberg (Franconian Alb). A specimen illustrated by Mišík et al. (1994b, pl. 2, fig. 7) and determined as *Schakoinella* cf. *spinata* Blau, found in a dyke penetrating through Bajocian pink crinoidal limestones (formerly supposed to be of Bathonian–Callovian age) from the Krasín Klippe near Dolná Súča also belongs to *Paalzowella turbinella*. The species was described from the Bathonian of the Mecsek Mountains (South Hungary) by Görög (1995). Schlagintweit & Moshammer (2015) found the species in a fissure filling in the Vils Limestone (Eastern Alps) of Bajocian age (age determination on the basis of presence of *H. lokutiense*). Morycowa & Olszewska (2013) described this species from the Vršatec Limestone.

Stratigraphic range: Bajocian–Middle Oxfordian.

Paalzowella feifeli (Paalzow, 1932)
(Fig. 8.3–23)

1932 *Trocholina feifeli* nov. spec. – Paalzow: p. 140, taf. XI, fig. 6, 7.
1932 *Trocholina elevata* nov. spec. – Paalzow: p. 140, taf. XI, fig. 4.
1932 *Trocholina transversarii* nov. spec. – Paalzow: p. 141, taf. XI, fig. 8, 9, 10.
2004 *Paalzowella feifeli* (Paalzow) – Piuz: PI. 4, figs 1-12, fig. 13-18, *P. feifeli* ? formes carénées, fig. 15, 17, 18, *P. feifeli* aff. *elevata* (Paalzow)

Occurrences: Vršatec Castle Klippe (VH 5B/5b), Vršatec-Javorníky Klippe (VJ 5/1, VJ 5/A), Malé Hradište Klippe (MH 01/1, MH 01/3a, MH 01/6a, MH 01/7, MH 02/1, MH 02/2b, MH 03, MH 03/1a, MH 03/1c, MH 01/new, MH 03/new, MH GPS).

Description: Trochospirally coiled in a low cone test (Fig. 8.3–6 — *Paalzowella feifeli feifeli*) or in a high cone test (Fig. 8.7–15 — *Paalzowella feifeli elevata*), numerous chambers arranged in 5 to 12 whorls, periphery of the chambers ornamented by carinae with elevated flangelike keel. In the studied material we also found sections with a strongly curved central part on the convex umbilical side and with very long and strongly flangelike keels (Fig. 8.16–23, determined here as *Paalzowella* sp.).

Distribution: Paalzow (1932) described three new species of the genus *Trocholina* Paalzow, 1922: *Trocholina feifeli, T. elevata* and *T. transversarii* from the Middle Oxfordian of the Franconian Alb (Lower Schwammergel, Streitberg). As noted by Schlagintweit & Moshammer (2015), most species and subspecies of the genus *Paalzowella* (type species *Paalzowella turbinella* (Gümbel, 1862)) were described from the Middle to Upper Jurassic on the basis of isolated specimens: by Seibold & Seibold (1960) (Oxfordian–Lower Kimmeridgian of South Germany); Lutze (1960) (Lower Oxfordian of Northwestern Germany); Bielecka (1960) (Oxfordian of Chrzanow, Southern Poland); Bastien & Sigal (1962) (Upper Oxfordian of Trept, Isere); Oesterle (1968) (Oxfordian of the Swiss Jura Mountain); Winter (1970) (Lower Kimmeridgian of Franke, Germany); Stam (1986) (Lower Callovian–Upper Oxfordian of Portugal), Schmalzriedt (1991) (Oxfordian–Lower Kimmeridgian of Swabian Alb, SW Germany), Canales et al. (1993) (Upper Aalenian–Lower Bajocian of the Southwest sector of the Basque-Cantabrian basin, Spain), Görög (1995) (Bathonian of the Mecsek Mountains, South Hungary), Görög et al. (2012) (Callovian of the Villány Mountains, southern Hungary), and others. Piuz (2004) documented this species in thin sections from the Bajocian of the French Jura and Burgundy (SE France). Although Morycowa & Olszewska (2013) argued that the presence of *Paalzowella turbinella* and *Rumanolina feifeli* (here assigned to the genus *Paalzowella)* supported the Late Jurassic age of the Vršatec Limestone, these species clearly originated earlier and are not diagnostic of the Late Jurassic.

Stratigraphic range: Upper Aalenian–Lower Kimmeridgian.

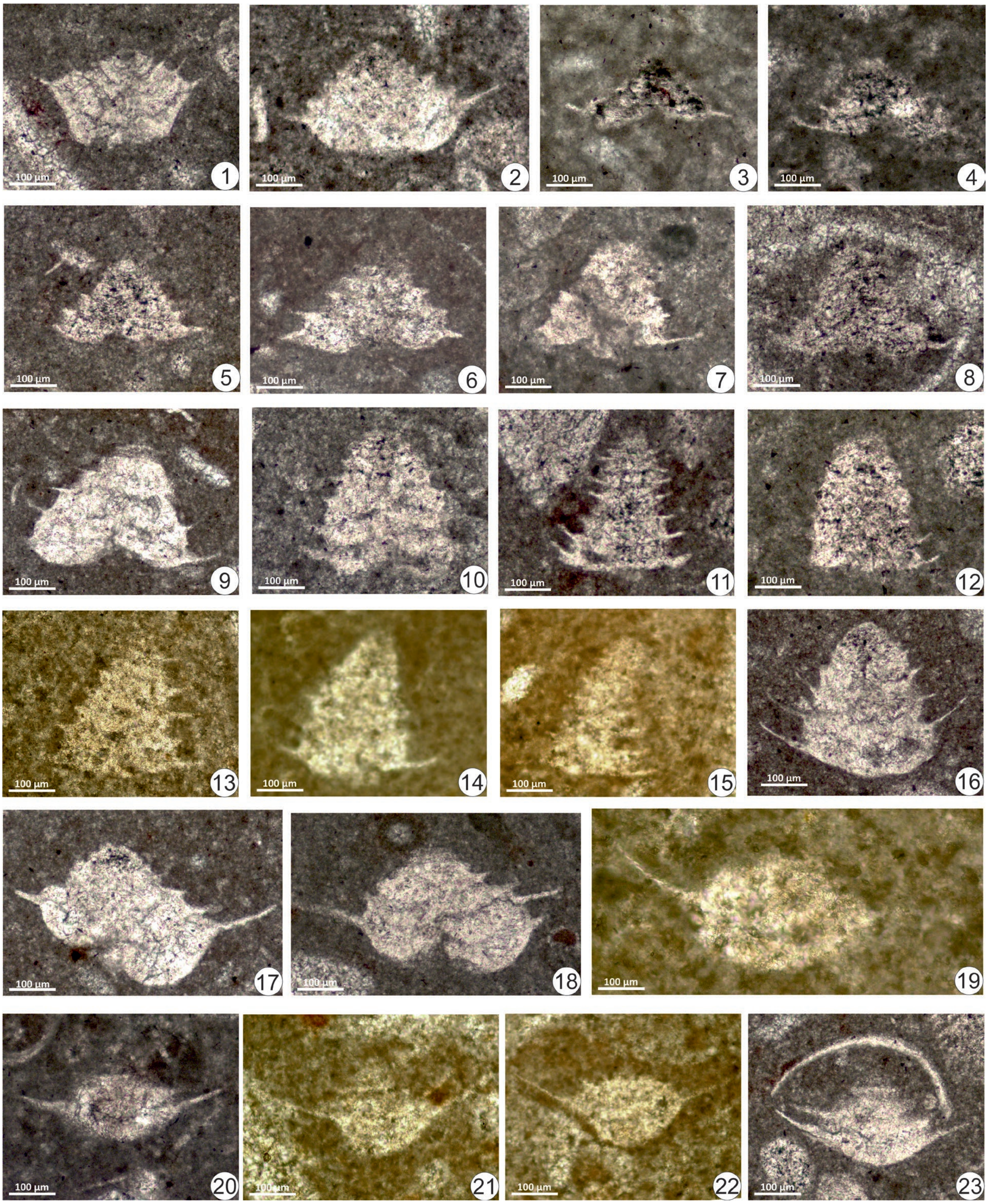

Fig. 8. 1–2: *Paalzowella turbinella* (Gümbel); 1–2 — Malé Hradište Klippe (MH 01/3a, MH 03/new). **3–23:** *Paalzowella feifeli* Paalzow; 3–5 — Vršatec Castle Klippe (VH 5B/5b) ; 6–23 — Malé Hradište Klippe (MH 01, MH 01/1, MH 01/3a, MH 01/6a, MH 03, MH 03/1a, MH 01/new).

Class FORAMINIFERA INCERTAE SEDIS
Order INVOLUTINIDA Hohenegger & Piller, 1977
Family Trocholinidae Kristan-Tollmann, 1963, emend. Rigaud et al., 2013
Subfamily Lamelliconinae Zaninetti et al., 1987, emend. Rigaud et al., 2013
Genus *Kristantollmanna* Rigaud, Blau, Martini & Rettori, 2013

Kristantollmanna cf. *altissima* (Pirini, 1966)
(Fig. 6.22, 23)

1966 *Turrispirillina altissima* n. sp. – Pirini: p. 95, taf. 3, fig. 1-3, ?4-5.
1987a *Turrispirillina* (?) *altissima* Pirini – Blau: S. 505, taf. 4, fig. 10-13.

Occurrences: Drieňová Hora Klippe (DRIE 01, DRIE 06), Malé Hradište Klippe (MH 03).

Description: High conical test consisting of globular proloculus followed by a trochospirally enrolled, undivided tubular chamber, characterised by reduced lamellae on both sides of the test.

Distribution: The species was described by Pirini (1966) as *Turrispirillina altissima* from the Lower Jurassic limestones of Montemerano-Grosseto (Central Italy). Blau (1987a) described the species from the red fissure fillings in the Oberrhät Limestone (Lavanter Breccie, Lienzer Dolomiten, Austria). The fissure fillings were deposited during the Early Jurassic.

Stratigraphic range: Lower Jurassic, Bajocian (this paper).

Genus *Trocholina* Paalzow, 1922

Trocholina turris Frentzen, 1941
(Fig. 6.24, 25)

1941 *Trocholina turris* n. sp. – Frentzen: p. 306, taf. 1, fig. 13 a-c.
1999 *Trocholina turris* Frentzen – Böhm: p. 181, pl. 18, figs. 1-3.

Occurrences: Malé Hradište Klippe (MH 01/3, MH 01/7, MH 03/1c).

Description: Conical test characterised by a high trochospiral coiling of the deuteroloculus, the number of whorls is 7 to 10.

Distribution: The species was described by Frentzen (1941) from the Lower Jurassic of SW Germany. It is known mainly from the European epicontinental Lower Jurassic but also from the Upper Triassic. Kristan-Tollmann (1990) described this species from the Rhaetian of Central Papua New Guinea and Senowbari-Daryan et al. (2010) from the Rhaetian of the Nayband Formation (Central Iran). Blau (1987b) reported *T. turris* from red fissure fillings in the Oberrhät Limestone (Lavanter Breccie, Lienzer Dolomiten, Austria). Blau & Haas (1991) described this species from red fissure infillings (Lower Jurassic from Transdanubian Central Range, Hungary). Böhm et al. (1999) depicted this species from the Hettangian–Sinemurian of Adnet (Salzburg, Austria). Velledits & Blau (2003) reported *T. turris* from crinoidal wackestones–packstones in neptunian dykes in the Büdöskút Olistolith, Bükk Mountains (NE Hungary). According to Velledits & Blau (2003), the age of these crinoidal wackestones–packstones can range from Hettangian to Sinemurian. However, their record of the species is based on a single specimen only.

Stratigraphic range: Norian?, Rhaetian–Lower Jurassic, Bajocian (this paper).

Discussion

Macrobenthic assemblages

Coral assemblages of the Vršatec Limestone were described by Morycowa & Mišík (2005). We re-assessed the composition of the coral assemblages on the basis of new and extensive sampling (Schlögl et al. 2014). The most abundant genera are represented by *Isastrea, Periseris, Thecosmilia, Cladophyllia, Dendraraea,* and *Thamnasteria*. Such coral assemblage is typical of the Lower Bajocian reefs of France, Luxembourg and Switzerland (Lathuilière 2000a, b). Five of these genera are also common in the Oxfordian, especially at higher-latitude reefs, but they are represented by morphologically similar but different species in the Bajocian and in the Oxfordian. The genus *Periseris* does not occur in the Upper Jurassic. Morycowa & Mišík (2005) described the genus *Atelophyllia* on the basis of two fragments. We confirm the identification of this genus, which was known from the Lower Bajocian of France only. The findings of *Dendraraea dendroidea* are also consistent with the Bajocian age (Lathuilière & Gill 1998). The Bajocian age also explains the absence of some coral taxa that are generally very abundant in Oxfordian reefs. Coral reefs were widespread on the epicontinental shelves on the northern margin of the Tethys Ocean during the Oxfordian (Insalaco et al. 1997; Leinfelder et al. 2002; Martin-Garin et al. 2012). They formed also extensive deposits on shallow platform margins in the Tethys Ocean, today exposed in the Southern Alps, Slovenia, Croatia, Albania, and Montenegro (Turnšek et al. 1981; Bosellini et al. 1981; Winterer & Bosellini 1981; Sartorio 1989). However, Oxfordian deposits in the Penninic Ocean mark the maximum relative sea level rise, recorded by maximum condensation on shallow elevations and by maximum extent of deposition of radiolarites in troughs. Oxfordian coral reefs were not recorded from pelagic platforms in the Penninic Ocean. In this light, their presence in the Oxfordian and their absence on pelagic carbonate platforms during time intervals with shallower conditions during the Middle and latest Jurassic was enigmatic. Our study thus explains this paradox by showing that coral reefs were formed in the Pieniny Klippen Belt during the Bajocian and not during the Oxfordian.

Bivalves are mostly represented by internal molds; recrystallized shells with preserved external surface are rare. They are frequent in coral framestones, floatstones and rudstones at Vršatec-Javorníky (locality 22 in Mišík 1979), including *Chlamys (Chlamys) textoria*, *Camptonectes (Camptonectes)* sp., *Spondylopecten (Spondylopecten) cardinatus, Plagiostoma premutabilis, Pseudolimea* cf. *duplicata*, „*Placunopsis*“ sp., *Liostrea* sp., *Actinostreon gregareum*, and *Pinna* sp.

Spondylopecten (Spondylopecten) cardinatus is typical of coral-reef habitats. Corals themselves are occasionally bioeroded by bivalves. The ichnofossil *Gastrochaenolites* found in corals most probably refers to the bivalve taxon *Lithophaga*. Kochanová (1979) described 15 bivalve taxa from the Vršatec Limestone. She distinguished several species of the genus *Chlamys*, but they all belong to *Chlamys (C.) textoria* that is characterized by high intraspecific morphologic variation (Johnson 1984). With the exception of *Chlamys (C.)* cf. *subtextoria* (Kochanová 1979), individuals of the genus *Chlamys* found in the Vršatec Limestone belong to coarsely-ribbed and intermediate morphotypes of *Chlamys (C.) textoria* of Johnson (1984). Such morphotypes inhabited coral and sponge reefs in other geographic regions (Johnson 1984). Mass occurrences of large-sized valves of *Oxytoma* (*Oxytoma*) *inaequivalvis* directly on corals or between the coral colonies were documented at Drieňová Hora Klippe. This bivalve association is highly similar to that described in the Bajocian of the southern French Jura (Lathuilière 1982).

Coral framestones and floatstones contain brachiopod assemblages primarily formed by small-sized rhynchonellids (Siblík 1979). They resemble *Parvirhynchia*-dominated assemblages that are typical of Bajocian coral reefs (Almeras & Lathuilière 1984). Red crinoidal limestones of the Krupianka Formation, immediately overlying coral bioherms at Vršatec-Javorníky Klippe, about 1 m above the top of the Vršatec Limestone, contain brachiopod assemblages with *Capillirhynchia jaccardi*, *Morrisithyris phillipsiana*, *Acanthothiris spinosa*, *Antiptychina haasi, Monsardithyris ventricosa*, and *Striirhynchia subechinata*. Peribiohermal limestones, formed by breccias with clasts of crinoidal and biohermal limestones and radiaxial cements, probably formed on the margin of bioherms (after the shutdown of coral production), contain fissures filled with shell concentrations with *Bositra buchi* and with abundant brachiopods at Vršatec -Castle. They also contain ammonite *Nannolytoceras tripartitum,* the stratigraphic range of the species is from the Upper Bajocian Parkinsoni Zone to Lower Bathonian Progracilis Zone. Brachiopods are represented by *Ferrithyris antiplecta, Antiptychina bivallata, Monsardithyris uniplicata, Caucasella rectecostata,* and *Parvirhynchia mutans*. A similar assemblage occurs in the uppermost parts of crinoidal limestones at Slavnické Podhorie (Pevný 1969; Aubrecht et al. 2002) and at Babiná (Mišík et al. 1994a), indicating that the fissure was filled not later than during the Late Bajocian.

In addition to abundant crinoids, biohermal and especially peribiohermal limestones contain at some levels also gastropods, decapods, echinoids, and holothurians. Cidaroid spines can be also locally abundant, forming peculiar crinoidal–cidaroid-rich limestones at Mikušovce. Ammonites and nautiloids are extremely rare, always fragmented and very poorly preserved.

Stratigraphic distribution of foraminiferal assemblages

The micropaleontological analysis of thin sections of biohermal and peribiohermal Vršatec Limestone show that assemblages of benthic foraminifers in the Vršatec Limestone consist of 32 genera (Table 1), with three species of *Cornuspira*, three species of *Ophthalmidium* and two species of *Paalzowella*. They contain taxa of the class Tubothalamea (orders Miliolida and Spirillinida), Globothalamea (orders Robertinida, Rotaliida and Textulariida), as well as Incertae sedis orders Lagenida and Involutinida. In accordance with Morycowa & Olszewska (2013), we document the presence of *Paalzowella feifeli* and *Paalzowella turbinella.* Morycowa & Olszewska (2013) also described *Rumanolina seiboldi*, *Rumanolina elevata, Troglotella incrustans*, and *Haghimashella* cf. *arcuata*. However, the specimens documented on their figs. 4.4 and 4.5 do not belong to the genus *Rumanolina* introduced by Neagu & Cirnaru (2001) because they do not show a diagnostic trait of the genus, i.e., acute to flap-like keels that should be developed along the arched sutures. In addition,

Table 1: The list of genera of the Vršatec Limestone determined at four sites, with total number of specimens and total number of thin sections with at least one specimen.

	Vršatec-Castle	Vršatec-Javorníky	Malé Hradište	Drieňová Hora	Vršatec-Castle	Vršatec-Javorníky	Malé Hradište	Drieňová Hora
	Number of specimens				Number of thin sections			
Cornuspira	7	16	58	3	3	7	10	1
Meandrovoluta	4	18	7	6	2	7	3	2
Labalina	0	7	7	0	0	2	2	0
Nubecularia	21	46	55	2	7	13	16	1
Vinelloidea	12	24	15	0	3	9	5	0
Ophthalmidium	18	41	71	0	7	12	15	0
Hungarillina	0	3	0	0	0	1	0	0
Radiospirillina	0	7	7	0	0	3	3	0
Tethysiella	0	9	13	0	0	4	4	0
Paalzowella	2	7	86	0	1	3	14	0
Kristantollmanna	0	0	0	4	0	0	0	2
Trocholina	2	0	30	1	1	0	9	1
Frondicularia	1	0	0	0	0	0	0	0
Lingulina	0	3	1	0	0	2	1	0
Nodosaria	9	19	19	5	3	8	5	2
Lenticulina	12	12	14	2	3	4	6	1
Astacolis	0	3	0	0	0	1	0	0
Marginulina	0	0	0	0	0	0	0	0
Reinholdella	7	21	4	7	3	9	2	2
Epistomina	0	1	0	0	0	1	0	0
Ammobaculites	2	17	1	4	1	7	1	2
Callorbis	0	0	1	0	0	0	1	0
Trochammina	11	29	10	9	3	9	3	3
Duotaxis	5	18	1	0	1	4	1	0
Verneulinoides	0	6	5	7	0	3	2	3
Reophax	1	0	0	1	1	0	0	1
Mesoendothyra	2	13	3	0	1	6	2	0
Redmondoides	0	2	0	0	0	1	0	0
Bigenerina	3	2	5	1	3	1	1	1
Textularia	6	24	6	6	3	9	2	2
Troglotella	0	1	0	0	0	1	0	0
Earlandia	3	1	1	0	3	1	1	0

the description of the genus *Rumanolina* is based on few isolated specimens and both *R. seiboldi* and *R. elevata* are probably restricted to the Valanginian. The specimens determined as *Spirillina* sp. (figs. 4.4 and 4.10 in Morycowa & Olszewska 2013) probably belong to the genus *Cornuspira* because they also do not possess the diagnostic trait of *Spirillina*, i.e., globular proloculus followed by a gradually enlarging enrolled undivided tubular second chamber. The specimen determined as ?*Rumanolina* sp. shown in fig. 4.8 probably belongs to *Trocholina* (*T. ultraspirata* Blau, 1987a) that occurs in the Lower Jurassic (Rigaud et al. 2013).

After our revision, it seems that several species of foraminifers of the Vršatec Limestone appeared in the Tethyan Realm for the first time during the Bajocian (*Hungarillina lokutiense, Radiospirillina umbonata, Ophthalmidium caucasicum, O. terquemi, O. obscurum, Paalzowella turbinella, Cornuspira tubicomprimata, Nubecularia reicheli),* or do not stratigraphically extend into the Bathonian (*Tethysiella pilleri*). Although communities with benthic foraminifers with calcareous tests (porcelaneous high-Mg calcite miliolids and mono- or polycrystalline low-Mg calcite spirillinids) are usually not used as stratigraphic markers in the Jurassic successions, their composition and co-occurrence patterns allow an accurate dating of the Vršatec Limestone. Therefore, in contrast to Morycowa & Olszewska (2013), we argue that assemblages with benthic foraminifers rather indicate that biohermal and peribiohermal limestones of the Vršatec Limestone developed during the Bajocian. This stratigraphic inference is in accordance with stratigraphic data on ammonites that occur in dykes within the Vršatec Limestone at Vršatec-Castle (*Nannolytoceras tripartitum*) (Schlögl et al. 2009a). The co-occurrence of *Hungarillina lokutiense* (first occurrence (FO) Bajocian), *Radiospirillina umbonata* (FO Bajocian), *Ophthalmidium caucasicum* (FO Bajocian), *Ophthalmidium terquemi* (FO Bajocian), *Paalzowella turbinella* (FO Bajocian), *Cornuspira tubicomprimata* (FO Upper Bajocian), *Ophthalmidium obscurum* (FO Upper Bajocian), and *Tethysiella pilleri* (last occurrence (LO) Bajocian) fully substantiates their Bajocian age (Fig. 9).

The comparison between the lower and upper parts of the Vršatec Limestone at Vršatec-Javorníky indicates that the overall composition remained similar, being dominated by *Nubecularia* and *Ophthalmidium* (Fig. 10), and no major stratigraphic turnover is thus apparent within the Vršatec Limestone. Dykes of crinoidal limestones penetrate into coral limestones and bedded crinoidal limestones directly overlie coral limestones at Vršatec-Javorníky. At Vršatec-Castle, the thickness of crinoidal limestones is locally extremely thin, reduced to 2.5 m or even zero, and the Bohunice Formation locally directly overlies peribiohermal facies (with breccias) on the top of the Vršatec Limestone. The upper boundary of the Vršatec Limestone is pre-dating the termination of crinoidal limestones at some sites or temporally coincides with the termination of crinoidal limestones of the Krupianka and Smolegowa formations. Thus the deposition of the Vršatec Limestone clearly terminated prior to the middle Garantiana Zone (Late Bajocian) as suggested by maximum stratigraphical extent of the crinoidal limestones on the Czorsztyn Ridge. However, the termination of coral reefs probably occurred earlier. First, the boundary between the coral limestones and crinoidal limestones is consistently characterized by a hardground surface, indicating a major hiatus in deposition. Second, the presence of several tens of meters of crinoidal limestones (which consistently terminated their deposition during the early Garantiana Zone in the Pieniny Klippen Belt, Wierzbowski et al. 2004) that overlie coral limestones at Vršatec-Javorníky indicate that the coral-reef production stopped prior to the Garantiana Zone. We note that formation of coral reefs largely terminated at the end of the Humphriesianum zone in western Europe (Durlet et al. 2001).

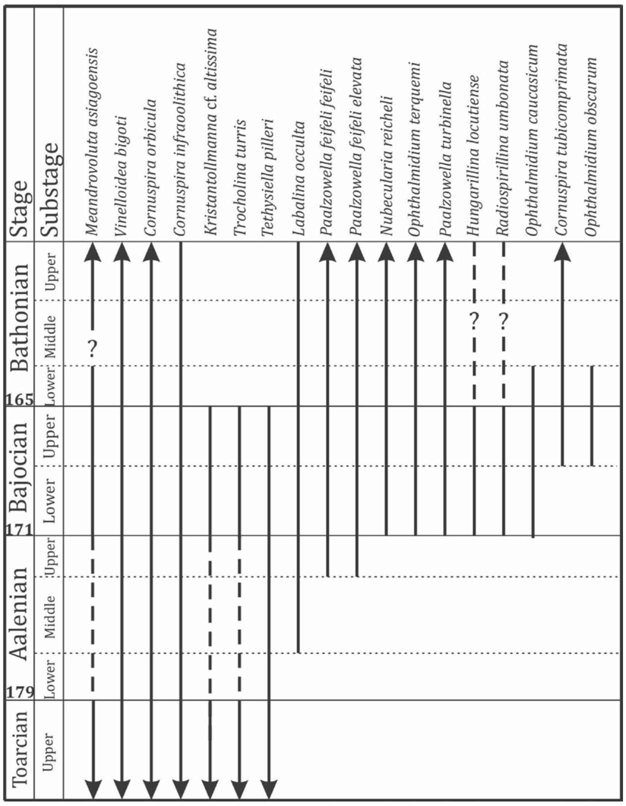

Fig. 9. Stratigraphic ranges of foraminifer species described in this study overlap in the Bajocian stage. The upper stratigraphical extent of *K.* cf. *altissima* and *T. turris* are based on the Bajocian age of the Vršatec Limestone as documented in this paper.

Paleogeographic comparison of foraminifer communities

The foraminifer assemblages of the Vršatec Limestone are dominated by calcareous miliolid, spirillinid, and involutinid species. Differences in the composition of assemblages between the two Vršatec sites (with dominance of miliolids) on one hand and Malé Hradište on the other hand (dominated by *Paalzowella*) indicate some degree of environmental heterogeneity among sites (Fig. 11). Similar types of assemblages

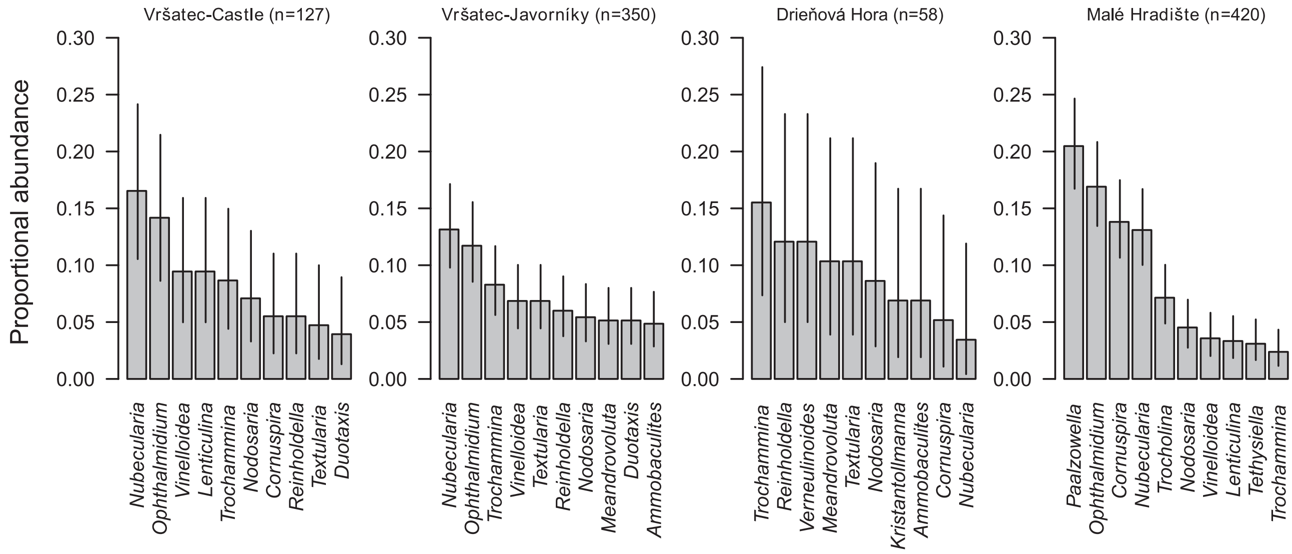

Fig. 10. Barplots summarizing proportional abundances of ten most common genera of foraminifers (with 95 % binomial confidence intervals) of the Vršatec Limestone at four sites show that the assemblage at Malé Hradište is dominated by *Paalzowella* where the Vršatec klippen are dominated by the miliolids *Nubecularia*, *Ophthalmidium,* and *Vinelloidea*. The assemblage at Drieňová Hora is dominated by the agglutinated genus *Trochammina* but the sample size is small.

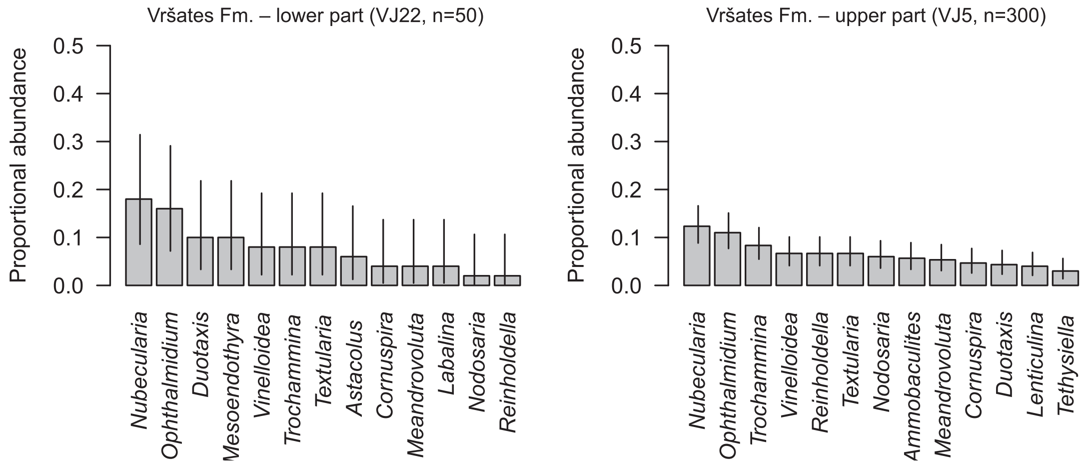

Fig. 11. Barplots summarizing proportional abundances of 13 most common genera (with 95 % binomial confidence intervals) of foraminifers at two sections at Vršatec–Javorníky shows no marked taxonomic differences between the lower and upper part of the Vršatec Limestone.

are known from few regions of the Tethyan realm. Assemblages dominated by spirillinids (*Paalzowella, Tethysiella, Radiospirillina, Hungarillina*) and involutinids were described from the pelagic carbonate platforms of the Eastern Alps and Transdanubian Central Range. Calcareous benthic foraminifers were described by Blau (1987a, b) from the Lower Jurassic dykes penetrating the Rhaetian Oberrhät Limestone and breccia infills (Lavanter Breccie, Lienzer Dolomiten, Austria). He described two new genera, 14 new species and two new subspecies. Blau & Wernli (1999) described new genera and new species from thin sections of the Middle Jurassic pebbles in the Upper Bajocian megabreccia near Lokut (Transdanubian Central Range, Hungary), including: *Hungarillina (H. lokutiense*, *H. media*, *H. pedunculata*), *Radiospirillina (Radiospirillina umbonata*), and *Spirilliconus (S. corinnae*). Velledits & Blau (2003) reported some of the species (*Hungarillina lokutiense, Radiospirillina umbonata, Spirillina* sp.) from neptunian dykes filled with *Bositra*-protoglobigerinid–spirillinid wackestones–packstones in the Büdöskút Limestone, Bükk Mountains (NE Hungary). Their age ranges are very poorly constrained between Toarcian and Oxfordian. Schlagintweit & Moshammer (2015) found a small-sized spirillinid-involutinid assemblage in the fissures of the Vils Limestone (Eastern Alps). An overall Middle Jurassic age (Bajocian?) was indicated by *Hungarillina lokutiensis*.

Assemblages dominated by encrusting miliolids (*Nubecularia, Vinelloidea*), mobile miliolids (*Ophthalmidium*), and spirillinids (*Paalzowella, Tethysiella, Radiospirillina, Hungarillina*) characterized carbonate platforms with corals from the French Jura and Burgundy (and Subalpine Basin) (Piuz 2004; Clerc 2005). Shallow-platform assemblages in coral habitats were dominated by spirillinids, *Paalzowella*, *Tethysiella,* low-energy deep-platform assemblages were dominated by miliolids (*Labalina*, *Ophthalmidium*, *Cornuspira),* nodosariids*,* and by agglutinated foraminifers, and high-energy crinoidal and shelly assemblages were dominated by *Nubecularia* and *Lenticulina.* Some miliolids such as *Ophthalmidium* have a broad environmental distribution not limited to a single substrate or depth. It inhabited coral-free pelagic carbonate platforms (Böhm et al. 1999) as well as coral and crinoidal environments on carbonate platforms (Piuz 2004). Some species of *Nubecularia* participate in the cortex of oncoids on shallow carbonate platforms (Rat 1966), some others formed large oncoids in aphotic environments of pelagic carbonate platforms (Gradziński et al. 2004), and consortia with microbes in deep-shelf environments with sponges (Reolid 2011). However, diversity of foraminifer assemblages in these oncoidal assemblages tends to be smaller than diversity of assemblages from the Vršatec Limestone. The co-occurrence of different morphogroups and the relatively high genus diversity show close similarity to those foraminifer assemblages inhabiting carbonate platforms of Burgundy and French Jura during the Bajocian.

Conclusions

The research integrating field data, micro- and macropaleontological taxonomic analyses and paleoecological analyses of coral bioherms and peri-biohermal deposits of the Vršatec Limestone shows significant evidence for their Bajocian age (proposed previously on the base of ammonites from the dykes infillings and brachiopod and coral associations), in contrast to previous studies suggesting an Oxfordian age. In this light, the Vršatec klippen consist of one single, continuous Middle Jurassic–Lower Cretaceous succession, rather than representing two tectonic slices with different depositional histories. The benthic foraminifer assemblages of coral limestones contain several species that have either their first or last appearance during the Bajocian. This study thus shows that analyses based on the distribution of benthic foraminifers in thin-sections represent a powerful tool for the biostratigraphic dating, especially if biostratigraphically important groups such as ammonites are absent. The composition and diversity of the benthic foraminifers of the Vršatec Limestone is similar to the Bajocian carbonate-platform environments with corals of the French Jura and Burgundy.

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