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 laterally 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 Czorzętny 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, Cownspira tubicompriimata, Nubecularia reicheli) or appeared for the last time in the Bajocian (Tethysilla 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-biothermal deposits in the Carpathian realm were largely restricted to the western sector of the Czorzętny 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 Mikulovce 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 Czorzętny Ridge were deposited on pelagic, sediment-starved seafloor at depths below the photic zone (Fig. 2), with depositional 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),
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, Paalzowerella, 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.
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 °N during the Middle Jurassic and at 20–30 °N 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 biothermal framastites, 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 biothermal limestones) and by (ii) crinoidal limestones. After a hiatus (marked by hardground), these biothermal limestones are almost always overlain by crinoidal–spiculitic limestones (Fig. 4).

Crinoidal limestones locally alternate or pass upwards into stromatactis-rich limestones with frequent relics 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 Pro-
pinquans and Humphriesianum zones) and the early Late Bajocian (Niortense
Zone and the early part of the Garan-
tiana 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 lime-
stones and the overlying formations is
present in all sections belonging to
the former Czorsztyn Ridge. The higher
parts of the Middle Jurassic suc-
cessions are represented by condensed
micritic to bioclastic nodular Ammon-
itoico Rosso (Czorsztyn Formation)
or non-nodular micritic or bioclastic
limestones (Bohunice and Štepnica for-
mations) 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).

Material and methods

The studied sites with biohermal–
peribiohermal limestones of the Vrša-
tec Limestone are situated in the wes-
tern 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 bio-
hermal 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,
Mikušovec-quarry, Mikušovec-meadow, and
Mikušovec-Mn-mine) that were not investigated in this study.
The Middle Jurassic-Lower Cretaceous limestone successions
at all localities belong to the Czorsztyn 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 out-
crops (88 thin sections from two Vršatec Klippen, 17 thin sec-
tions 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

![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](image-url)
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 Pawłowski 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 Lituloida is relatively well-documented from the Jurassic deposits, especially on the basis of specimens extracted from sieved unlithified samples (e.g., Tyszka 1994; Smoleň 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 Spirillina generally possessed low-Mg calcite, hyaline tests. The representatives of order Involutinida have aragonitic tests.

**Subphylum FORAMINIFERA d’Orbigny, 1826**  
Class TUBOTHALAMEA Pawłowski, 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 – Clerc: p. 36, pl. 3, fig. 1-4; pl. 14, fig. 6, 7.

**Occurrences:** Dričňová Hora Klipe (DRIE 01a), Malé Hradište Klipe (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. 1, 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 Klipe (VH 5B/2, VH 5B/2B), Malé Hradište Klipe (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 deuterolocus 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 megaspheric 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 (Rieggraf 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 Aalenian, 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.

**Occurrences:** Vršatec Castle Klipe (VH 5B/2, VH 5B/2B), Malé Hradište Klipe (MH 01/1, MH 01/3a, MH 01/6a, MH 03/1a, MH 03/1c).
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, Gianetti & 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. 1-57, 6–16.

**Occurrences**: Vršatec Castle Klippe (VH 5B/1, VH 5B/2, 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 megaspherical 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–Toarcian of the 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 quinqueloculind 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 5/55), 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 platons.
Fig. 5. 1–6: *Vinelloidea bigoti* (Cushman); 1 — Malé Hradiště Klippe (MH 01/3a) ; 2–5 — Vršatec Castle Klippe (VH 5B/7, VH 5B/6, VH 5B/4) ; 6 — Malé Hradiště Klippe (MH 02/4a). 7–11: *Nabecularia reicheli* Rat; 7–9 — Vršatec Castle Klippe (VH 5B/4, VJ 22); 10, 11 — Vršatec–Javorníky Klippe (VJ 5-top of Ves Lms). 12–15: *Cornuspira tubicomprimata* Danitch; 12–15 — Malé Hradiště Klippe (MH 01/5). 16–21: *Cornuspira orbicula* (Terquem & Berthelin); 16 — Vršatec Castle Klippe (VH 5B/2b); 17–21 — Malé Hradiště Klippe (MH 01/1, MH 01/3a, MH 02/2b, MH 03/1a). 22, 23: *Cornuspira infrasoolithica* Terquem; 22 — Malé Hradiště 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: Vrsatec 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, Vrsatec-Javorniky 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 (Oktosum 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)

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: Vrsatec 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). Vrsatec-Javorniky 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 Hradiště Klippe (MH 03). 7–11: *Hungarillina lokutiense* Blau & Wernli; 7–10 — Vršatec Castle Klippe (VH 5B/2b, VH 5B/5b); 11 — Malé Hradiště Klippe (MH 03). 12–21: *Tethysella pilleri* (Blau); 12–20 — Malé Hradiště 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 Hradiště Klippe (MH 01/6a). 24–26: *Trocholina turris* Frentzen; 24–26 — Malé Hradiště Klippe (MH 01/3, MH 01/7, MH 03/1c). 27–30: *Radiospirillina umbonata* Blau & Wernli; 27–29 — Malé Hradiště Klippe (MH 01/3a, MH 03/1a); 30 — Vršatec Castle Klippe (VH 5B/2).
**Occurences**: Vršatec-Javorníky Klippe (VJ 10b, VJ 11), Malé Hradište Klippe (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 Częstochowa (Poland). This taxon was distinguished as *Ophthalmidium carinatum* Pazdrowa from the Bajocian–Middle Bathonian of Częstochowa, Poland (Pazdrowa 1959; Pazdro 1972), and as *Ophthalmidium terquemi* Pazdrowa from the Bajocian–Middle Bathonian of Częstochowa, 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 Spirillina Hohenegger & Piller, 1975
Family Spirillidae 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.

**Occurences**: Vršatec Castle Klippe (VH 5B/1, VH 5B/2, VH 5B/5a), Malé Hradište Klippe (MH 03/1a, 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 a fissure (filled by peloidal packstones and grainstones) in the Vills Limestone (Außerfern in Tyrol, Austria). Its Bajocian age was inferred on the basis of *H. lokutiense*.

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

**Stratigraphic range**: Bajocian–Lower Callovian?

**Genus Radiospirillina** Blau & Wernli, 1999

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

**Radiospirillina umbonata** Blau & Wernli, 1999

(Fig. 6.27–30)

2018 *Radiospirillina umbonata* Blau & Wernli – Rigaud, Schlagintweit & Bucur: fig. 4A.

**Occurences**: 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 neptunian dykes in the Bündöskút limestone 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 Krasin Klippe near Dolná Súča also belongs to *Radiospirillina umbonata*.

**Stratigraphic range**: Bajocian, Bathonian–Callovian?

**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.

**Occurences**: 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 deuto-
loculus tube, and possessing an empty umbilicus.

Distribution: Tethysiella pilleri was described as Praepatellina pilleri by Blau (1878a) from the red fissure fillings in the Oberhüt Limestone (Lavanter Breccie, Lienzer Dolomiten, Austria, East-Tyroil). 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 deuterolocus tube and an empty umbilicus, to Tethysiella Blau, 1878a (Praepatellina Blau, 1878a is a junior homonym of Tethysiella). The species was also reported from the Bajocian of the French Jura and Burgundy, SE France (Piaz 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 Krásín Klippe near Dolná Súča also belongs to Tethysiella pilleri.

Stratigraphic range: Lower Jurassic–Bajocian.

Family Placenticulidae Kasimova, Poroshina & Godakchan, 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 Castle Klippe (VJ 5B/5b), Vršatec-Javorníky Klippe (VJ 5/1, VJ 5/3A, 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. Piaz (2004) documented this species in thin sections from the Bajocian of the French Jura and Burgundy (SE France). Although Morczywa & 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 & Pillir, 1977
Family Trocholinidae Kristan-Tollmann, 1963, emend. Rigaud et al., 2013
Subfamily Lamelliconinae Zaninetti et al., 1987, emend. Rigaud et al., 2013
Genus Kristantollmannia Rigaud, Blau, Martini & Rettori, 2013

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

1966 *Turrispirillina altissima* n. sp. – Pirini: p. 95, taf. 3, fig. 1-3, 74-5.
1987a *Turrispirillina (?) altissima* Pirini – Blau: S. 505, taf. 4, fig. 10-13.

**Occurences:** Dričňová 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 Oberhät 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.

**Occurences:** 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 Oberhät 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 Morycow & 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. Morycow & 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 dendroidae* 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, Pseudolimnea cf. duplicata, „Placunopsis” sp., Liostra 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 (Lathuiliére 1982).

Coral framestones and floatstones contain brachiopod assemblages primarily formed by small-sized rhychonellids (Siblík 1979). They resemble *Parvirhynchia*-dominated assemblages that are typical of Bajocian coral reefs (Almeras & Lathuiliére 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 philippiana*, *Acanthothiris spinosa*, *Antipitychina haasi*, *Monsardithyris ventricosa*, and *Striirhynchia subechinata*. Perbiohermal 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 *Namnolytoceras triparsatum*, the stratigraphic range of the species is from the Upper Bajocian Parkinsoni Zone to Lower Bathonian Progradil Zone. Brachiopods are represented by *Ferrithyris antiplecta*, *Antipitychina 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 perbiohermal 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 perbiohermal 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 *Opalthalidium* and two species of *Paalzowella*. They contain taxa of the class Tubothalamene (orders Miliolida and Spirillinida), Globothalamene (orders Robertinida, Rotaliida and Textulariida), as well as Incertae sedis orders Lagenida and Involutinida. In accordance with Myrowcya & Olszewska (2013), we document the presence of *Paalzowella feifeli* and *Paalzowella turbinella*. Myrowcya & 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,
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 species 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 species determined as *?Rumanolina* sp. shown in fig. 4.8 probably belongs to *Trocolina* (*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 tubicompribata*, *Nabecularia reicheli*), or do not stratigraphically extend into the Bathonian (*Tethysiella pilieri*). 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 biothermal and peribiothermal 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 (*Namnolytoceras tripartitum*; Schlögl et al. 2009a). The co-occurrence of *Hungarillina lokutiense* (first occurrence (FO) Bajocian), *Radiospirillina umbonata* (FO Bajocian), *Ophthalmidium caucasicum* (FO Bajocian), *O. terquemi*, *O. obscurum*, *Paalzowella turbinella*, *Cornuspira tubicompribata* (FO Upper Bajocian), *Ophthalmidium obscurum* (FO Upper Bajocian), and *Tethysiella pilieri* (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 *Nabecularia* and *Ophthalmidium* (Fig. 10), and no major stratigraphic turnover is thus apparent within the Vršatec Limestone. Dykes of cnoidal limestones penetrate into coral limestones and bedded cnoidal limestones directly overlie coral limestones at Vršatec-Javorníky. At Vršatec-Castle, the thickness of cnoidal limestones is locally extremely thin, reduced to 2.5 m or even zero, and the Bohunice Formation locally directly overlies peribiothermal facies (with breccias) on the top of the Vršatec Limestone. The upper boundary of the Vršatec Limestone is pre-dating the termination of cnoidal limestones at some sites or temporally coincides with the termination of cnoidal 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 cnoidal limestones on the Czorsztyn Ridge. However, the termination of coral reefs probably occurred earlier. First, the boundary between the coral limestones and cnoidal limestones is consistently characterized by a hardground surface, indicating a major hiatus in deposition. Second, the presence of several tens of meters of cnoidal 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).

**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 Hradiště on the other hand (dominated by *Paalzowella*) indicate some degree of environmental heterogeneity among sites (Fig. 11). Similar types of assemblages...
are known from few regions of the Tethyan realm. Assemblages dominated by spirillinids \((Paalzowella, \text{Tethysiella, Radio­spirillina, Hungarillina})\) 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 Bositra­protoglobigerinid–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 spirillinds (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 spirillinds, Paalzowella, Tethysiella, low-energy deep-platform assemblages were dominated by miliolids (Labalina, Ophthalmidium, Cornuspira), nodosarids, 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 oncocids on shallow carbonate platforms (Rat 1966), some others formed large oncoids in aphotic environments of Nubecularia particpate in the cortex 2004). Some species of coral and crinoidal environments on carbonate platforms (Piuz 2004). Others formed large oncoids in aphotic environments of 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 oncocids 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-shell environments with sponges (Reolid 2011). However, diversity of foraminifer assemblages in these oncocid 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 from the French Jura during the Bajocian.

Conclusions

The research integrating field data, micro- and macro-paleontological 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 benthi 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 benthi 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 benthi 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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