Mineralia Slovaca, Web ISSN 1338-3523, ISSN 0369-2086
53, 2 (2021), 115 – 130,

Biostratigraphy and palaeoecological evaluations based on trace fossils and calcareous nannofossils from the Middle Jurassic (Aalenian – Bajocian) bioturbated limestones from the Periklippen Zone of the Drietoma Unit (Myjava Upland, Slovakia)

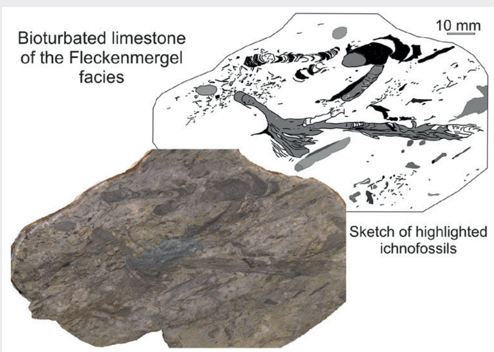
VLADIMÍR ŠIMO and SILVIA ANTOLÍKOVÁ

Earth Science Institute of the Slovak Academy of Sciences, Dúbravská cesta 9, 840 05 Bratislava, Slovakia;
geolsimo@savba.sk

Abstract: Intensively bioturbated hemipelagic limestone of the Fleckenmergel facies is regarded as an equivalent of the Allgäu Formation. Studied outcrops within the sequence of the bioturbated limestone are situated in the westernmost part of Periklippen Zone (respectively Klippen Zone). Mentioned Middle Jurassic bioturbated limestone belongs to the youngest of Fleckenmergel facies ever within the Western Carpathians. The association of trace fossils consists of *Chondrites*, *Lamellaeichnus*, *Nereites*, *Planolites*, *Teichichnus* and *Zoophycos*. Relatively well diversified trace fossil assemblage comprises various forms of deposit feeders, chemosymbiotic structures and vertically oriented open burrows situated on the bottom surface at various levels of substrate depths. Palaeoenvironmental conditions can be characterised by relatively well oxygenated substrate with sufficient of organic input. With the exception of a questionable vertically oriented trace fossil, it is a typical community of deep-water ichnofacies. Based on the study of calcareous nannofossils, the age of the layers was confirmed as the Middle Jurassic – Aalenian/Bajocian boundary. The age was determined by the first occurrence of species *Watznaueria fossacincta* and *Watznaueria manivitae.* The assemblage of the calcareous nannofossils is pointing out eutrophic conditions in the sedimentary area.

Key words: biostratigraphy, calcareous nannofossils, trace fossils, Middle Jurassic limestones, Drietoma Unit, Myjava Upland

Graphical abstract



Highlights

- The bioturbated dark-brown limestones of the Drietoma Unit Fleckenmergel facies from the area of Periklippen Zone were studied by biostratigraphy and palaeoecological research.
- The age of the bioturbated limestone was determined as the Middle Jurassic – the Aalenian / Bajocian boundary and the sedimentary environment can be characterized by relatively well-oxygenated substrate with sufficient organic input.

Introduction

The Periklippen Zone of the studied area is situated near to the westernmost part of the Pieniny Klippen Belt. Lower to Middle Jurassic dark-coloured significantly bioturbated limestone succession of the Periklippen Zone is characterized as an equivalent of the Allgäu Formation (e.g. Csibri, 2019). This succession belongs to the Drietoma Unit. (Hók et al., 2009). Biostratigraphical evaluations of the Middle Jurassic (Aalenian – Bajocian) sediments from the Myjava Upland are based on calcareous nannofossils. Moreover, the same age is also determined from previous geological mapping (Csibri, 2019; Potfaj et al., 2014). This study is focused on the one of the youngest bioturbated limestonesof "Fleckenmergel/Fleckenkalk" Middle Jurassic facies succession. Stratigraphic span of the "Fleckenmergel" lithofacies in the Central Western Carpathians is from upper Sinemurian to Bajocian (Wieczorek, 1995). Chronostratigraphic total span of the Allgäu Fm. which belongs to the area of the western part of the Tethys is ranged from Hettangian to late Middle Jurassic in the Northern Calcareous Alps (Gawlick et al., 2009; Wieczorek, 1995). This long-term Lower–Middle Jurassic deep-water Fleckenmergel facies of large western region of the Tethys is characterized by a relatively uniform community of trace fossils (e.g. Wieczorek, 1995; Šimo & Tomašových, 2013; Šimo & Reolid, 2021). Ichnological study from Middle Jurassic Fleckenmergel sequences from Periklippen Zone of Drietoma Unit has not been provided so far.

Geological settings

The study area is located in the Periklippen Zone which belongs to the Drietoma Unit, in the Myjava Upland (Fig. 1). However, some authors (Potfaj et al., 2014; Salaj et al., 1987; Salaj, 1990) classify this area to the Klippen Belt. Sampling has been provided on two outcrops (48°44’5.64”N, 17°30’57.55”E; 48°44’6.76”N, 17°31’16.44”E) located 4 km westward of the Podbranč Castle (Fig. 2). These poorly exposed outcrops are situated in grey, bioturbated dark-brown limestones of the equivalent of the Allgäu Formation of Aalenian to Bathian age (Csibri, 2019). An inverted superposition based on the geological section can be assumed (Csibri, 2019). The Drietoma Unit was described between the area of Drietoma and Bošáca villages by Began et al. (1966). The Drietoma Unit within the PKB is reached in the area between Myjava and Pruské (Mišík, 1997).The following description of Drietoma succession is described according to Csibri (2019). The northernmost part of the studied area of the Periklippen Zone is represented by exotic pebbles, medium to coarse-grained conglomerates, and calcareous sandstones of the Rašov Formation (Campanian – Maastrichtian). The southern part of the Periklippen Zone within the close surrounding studied area consists of rare quartz arenites occurrences (Carpathian Keuper) belonging to the Norian, lumachela limestone of Rhaetian age and dark grey shales (Hettangian – Sinemurian age). The main part of succession is built of organodetritic limestones and red crinoidal limestones (Pliensbachian); pale yellow limestones and cherty limestones, bioturbated limestones as an equivalent of the Allgäu Formation (Aalenian – Bathian); radiolarites, radiolarian limestones and black silicites (Callovian – Oxfordian); grey, bioturbated (expressly referred to as “spotted”), marly limestones (Tithonian – Hauterivian); exotic pebbles; hyaloclastic lavas (Aptian – Albian); conglomerates with exotic pebbles (Cenomanian). Samples of this study were collected from the part of bioturbated limestones within the Allgäu Formation (Aalenian – Bathian).

Methods

Sampling material was collected in the Škarítkovci settlement area. Samples come from grey bioturbated limestone of Aalenian – Bathian age. Samples for trace fossil study purposes were cut perpendicularly and horizontally to bedding planes. Cuts areas were polished and moistured by alcohol and scanned by an office scanner. Complicated tectonic situation of area and uncovered area surface allow collecting material just from two poor exposed outcrops. Sampling was focused on the bioturbated rocks.

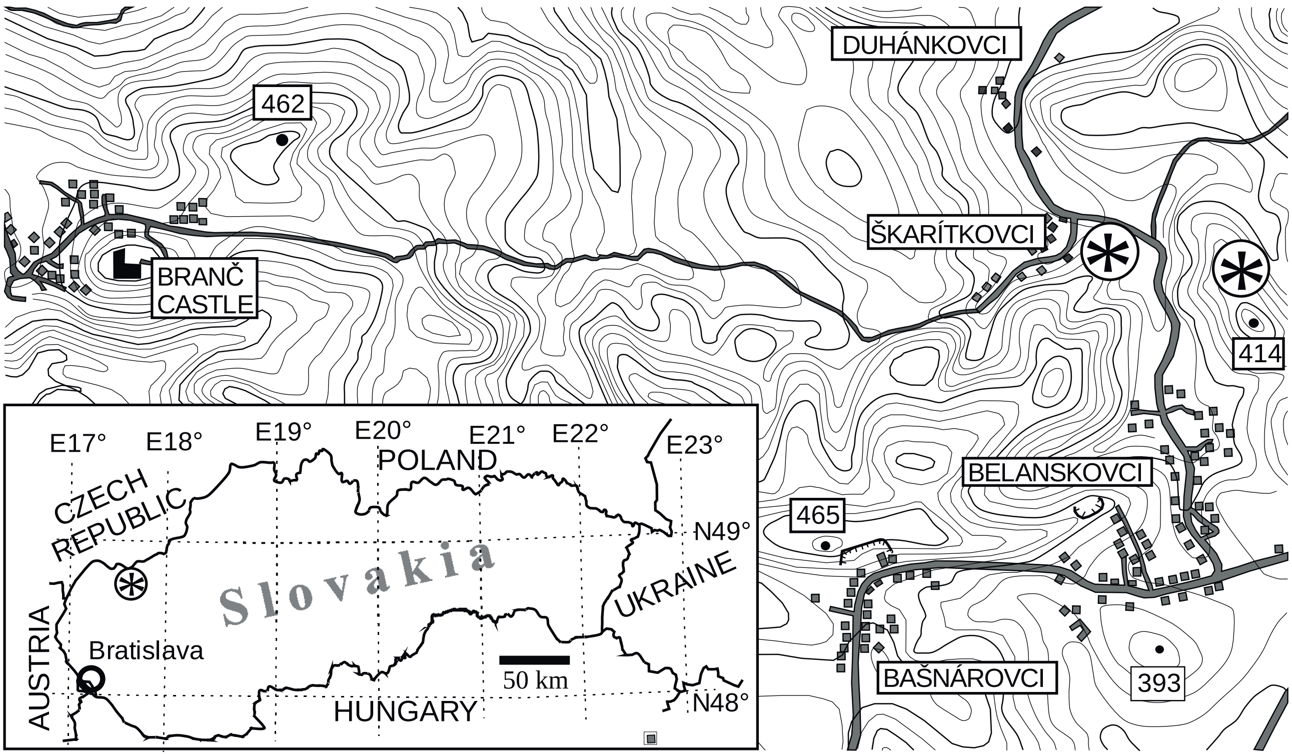


Fig. 1. Locations of outcrops – marked by * symbols.

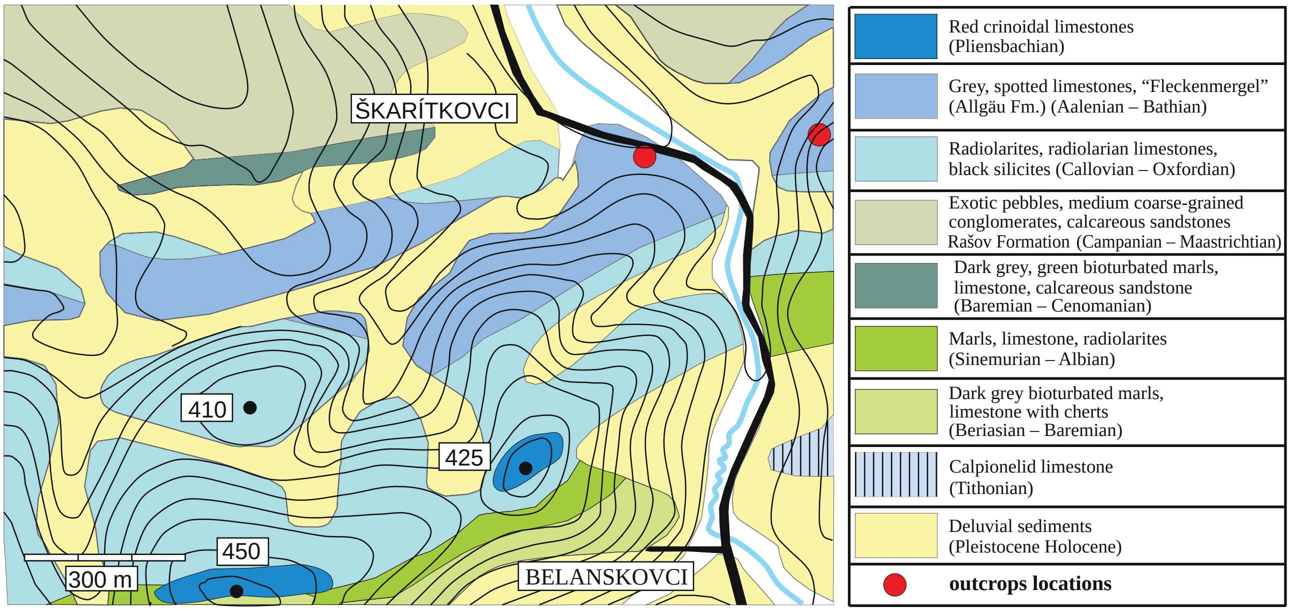


Fig. 2. Geological composition of the Periklippen Zone. The geological map was compiled from maps of Csibri (2019) and Potfaj et al. (2014). Numbers on the tops of hills are altitudes in meters.

The samples for calcareous nannofossils were prepared using the decantation method (Bown & Young, 1998) and applying the methodology of Svobodová (2012).

The smear slides were studied under the light microscope ZEISS AXIO SCOPE AI, at 1 000x magnification and nannofossil species were documented by digital camera AXIOCAM 105 COLOR. The determination of species was performed on the basis of Bown et al. (1998) and Young et al. (2017). Biostratigraphic correlation was carried out according to biostratigraphic synthesis NJT Zones by Mattioli & Erba (1999) and NJ Zones according to Bown and Cooper (1998). Statistical evaluation was carried out in the CorelDRAW® Graphics Suite X3 program. Preservation of calcareous nannofossils was determined as M (moderate – mechanical damage and etching of the specimens are weak) to P (poor; severe dissolution, fragmentation and/or overgrowth, the specific identification of specimens is difficult).The abundance of the calcareous nannofossil was L – low – (1 – 5 specimens per 1 field of view).

Overview to the Lower – Middle Jurassic studies of calcareous nannofossils from Fleckenmergel facies

Study overview of calcareous nannofossils is focused on Fleckenmergel type of lithofacies from the Central Western Carpathians and the Pieniny Klippen Belt. Calcareous nannofossils were studied occasionally from the Lower and Middle Jurassic sediments from the Western Carpathians. Gašpariková (Began & Gašpariková, 1979; Gašpariková, 1982), using zoning by Barnard & Hay (1974) and Prins (1969).

The overviews is based on the study of the bioturbated marls and dark shales of the Czorsztýn Unit from the Vršatec locality, from the Veľká Fatra Mts. and from the locality Skladaná skala, where Gašpariková determined two Lower Jurassic zones – *Crepidolithus crassus* (Pliensbachian) and *Podorhabdus cylindralithus* (Pliensbachian – Toarcian). She has found a few diversified and recrystallized nannoassemblages, often difficult to determine. While Noël (1965) described in Toarcian samples "massive coccoliths", Gašpariková did not find them.

Within the regional research of the Veľká Fatra Mts. the Mesozoic sediments of the Siprun sequence were investigated in localities of Trlenská dolina valley, Malinô Brdo and Ľubochnianska dolina valley. Samples from the Trlenská dolina valley came from the Allgäu layers (Fleckenmergel). Discovered calcareous nannofossils rank to the *Podorhabdus cylindralithus* Zone (Pliensbachian – Toarcian). Comparable assemblage was also detected on the Malinô Brdo locality and from the Šiprúň series of the Krížna Nappe.

In the present time, the *Podorhabdus cylindralithus* is basionym of *Axopodorhabdus cylindratus*. According to Bown & Cooper (1998) its first occurrence from Toarcian and Bajocian is characterized by Nannoplankton Zones NJ4a to NJ7.

Antolíková & Józsa (2017, 2018) examined calcareous nannoplankton of the Lower – Middle Jurassic age from the Skrzypny and Szlachtowa Formations from Litmanová and Kamienka localities, the Pieniny Klippen Belt. There are determined Aalen – Bajocian Nannoplankton Zones NJ8/NJ9.

ERA	PERIOD	EPOCH	STAGE	LITHOLOGY – DRIETOMA UNIT
MESOZOIC	CRETACEOUS		CENOMANIAN	“exotic” pebbles, conglomerates with “exotic” pebbles
		LOWER	ALBIAN	hyaloclastic lavas
			APTIAN	
			BARREMIAN	grey, bioturbated and marly organodetritic (aptychus) limestones
			HAUTERIVIAN	
			VALANGINIAN	pale, pelitic limestones of “biancone” facie
			BERRIASIAN	
		MALM	TITHONIAN	red crinoidal limestones with a transition to red nodular limestones
			KIMMERIDGIAN	
			OXFORDIAN	red and green radiolarites, radiolarian limestones, black silicities
	JURASSIC	DOGER	CALLOVIAN	
			BATHONIAN	bioturbated limestones 2. pale, yellow-brown bioturbated limestones, calcified limestones 1. gray bioturbated limestones
			BAJOCIAN	
			AALENIAN	
		LIAS	TOARCIAN	
			PLIENSBACHIAN	red crinoidal limestones light gray, sandy silstones and shales
			SINEMURIAN	
			HETTANGIAN	
	TRIASSIC	UPPER	RHAETIAN	organodetritic limestones, with brachiopoda
			NORIAN	light gray and pinkish quartzites and dolomites

Fig. 3. Lithological and stratigraphic table of the Drietoma Unit, according to Csibri (2019).

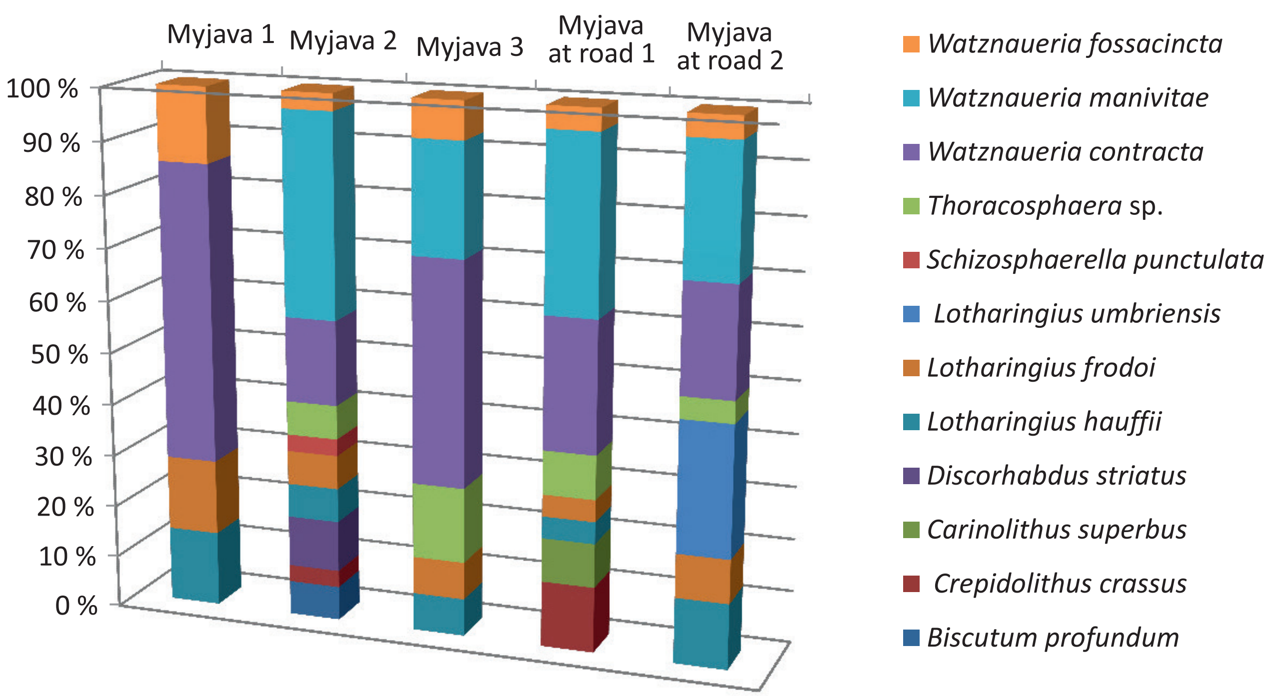


Fig. 4. Percentage evaluation of all found nannofossils (localization of samples M1–M3: 48°44'6.76" N, 17°31'16.44" E; M PC: 48°44'5.64" N, 17°30'57.55" E).

Results

Calcareous nannofossils

Assemblages of calcareous nannofossils from the studied samples were quantitatively and qualitatively poor. In the study samples twelve specieswere detected only. The least species were represented in the sample M1 and M3. The other samples were richer in species.

Two genera *Lotharingius* (on average 22 %) (*L. frodoi*, *L. haufii*, *L. umbriensis*) and *Watznaueria* (on average 63 %) (*W. manivitae*, *W. contracta*, *W. fassacincta*) were dominant in the calcareous nannofossil assemble. The percentage of *W. contracta* varies in the sample from 16 to 57 %, and *W. manivitae* from 21 to 39 %. Species *Lotharingius frodoi* is morphotype of *L. hauffii* according to Fraquas & Young (2011), but in our paper we distinguish both species individually. The genus *Watznaueria* is represented by *W. contracta* and *W. manivitae*. *Watznaueria contracta* and *Lotharingius contractus* are basionyms. *Lotharingius contractus* has been renamed as *Watznaueria contracta*. Therefore, in this paper we use the name *W. contracta* (Suchéras-Marx et al., 2015). Rare species *Crepidolithus crassus*, *Discorhabdus striatus* and *Schizosphaerella punctulata* were found in the samples also (Fig. 5).

Biostratigrafic evaluation

The biostratigraphic age of the study layers is determined as an Aalenian/Bajocian boundary, Nannoplankton Zones NJ8/NJ9 according Bown & Cooper (1998) and Zone NJT9/NNJT10a according Mattioli & Erba (1999),

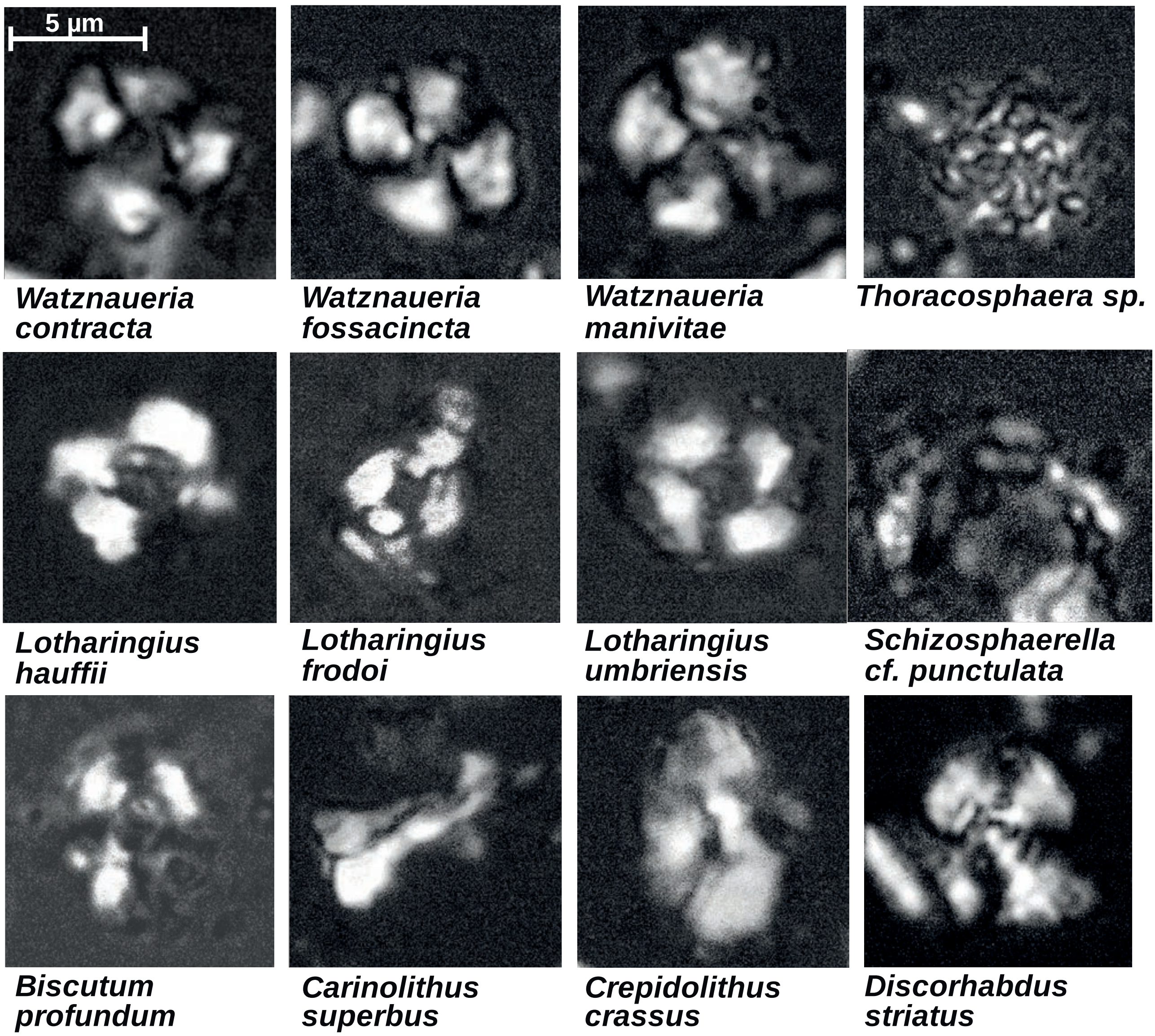


Fig. 5. Calcareous nannofossils association of Aalenian – Bajocian age from studied localities.

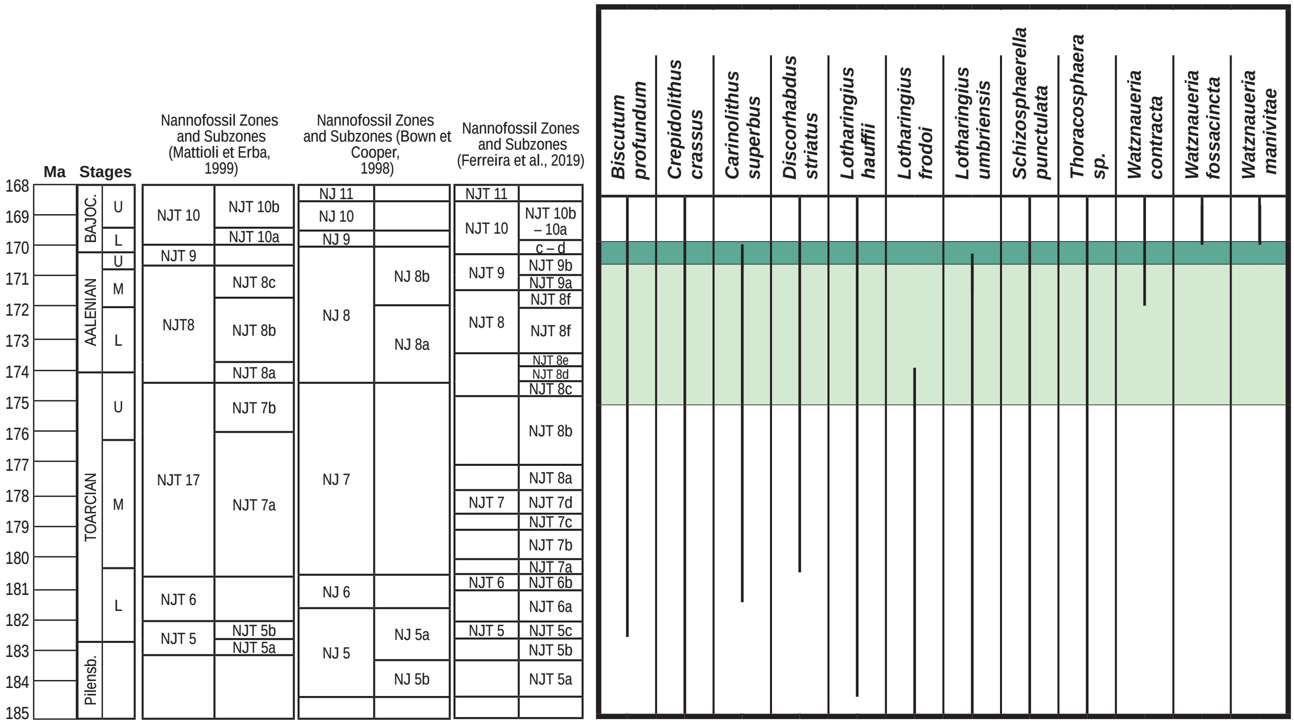


Fig. 6. Nannofossil zones of Aalenian – lower Bajocian age based on calcareous nannofossils from studied localities of the Periklippen Zone of the Drietoma unit.

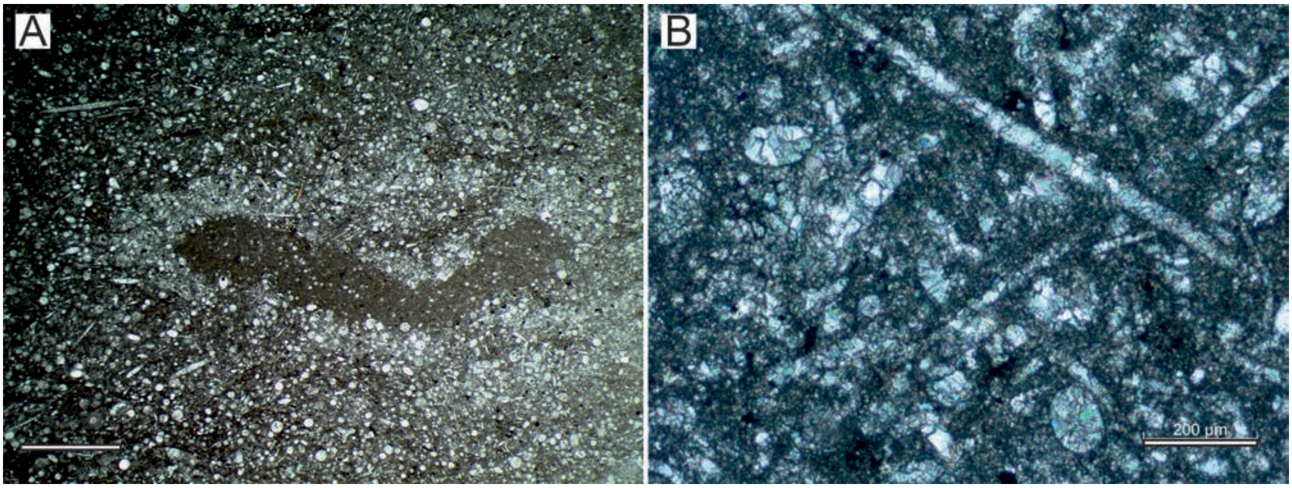


Fig. 7. Thin sections under transmitted light (A) and under plane-polarized light (B). A – Bioturbated packstone. A burrow with dark infill is enveloped by bioclastic material consisted of radiolarians and sponge spicules (*Nereites* isp.). Scale is 1 mm long. B – Packstone consisted of radiolarians and sponge spicules under plane-polarized light.

based on first occurrence of *Watznaueria fossacincta* and *Watznaueria manivitae* (Fig. 6).

The co-occurrence of the genera *Lotharingius* and *Watznaueria* is typical for the boundary Aalenian/Bajocian (Cobianchi et al., 1992; Mattioli & Erba, 1999; Mailliot et al., 2006).

Aalenian calcareous nannofossils are represented by species of the genus *Lotharingius*. (Fraguas & Young, 2011). *L. hauffi* has its last occurrence in the lower Bajocian. Other found species were *Biscutum profundum* (NJ5-NJ10, Toarcian – Bajocian), *Crepidolithus crassus* (NJ3-NJ17b, Sinemurian – Tithonian), *Carinolithus superbus* (NJ6-10, Toarcian – Bajocian), *Discorhabdus striatus* (NJ7-NJ15a, Toarcian – Oxfordian), *Schizosphaerella punctulata* (NJ1-NJ15, Hettangian – Kimmeridgian). The assemblage was complemented by species of *Thoracosphaera* sp. and *Watznaueria* sp.

Trace fossils

Trace fossils

Chondrites von Sternberg, 1833

Chondrites cf. *intricatus*

Description: *Chondrites* has been determined on the base of occurrence of tiny spots clusters and tiny well contrasted dark burrows of diameters bellow 0.5 mm. Branched root-like burrows are visible occasionally (Fig. 8).

Remarks: *Chondrites* is characterized as a chemosymbiotic trace fossil. This structure for sulphide transport is situated in low oxygen sediment (Bromley, 1996). It occupies the lower part of bottom sediment. Overall morphology of *Chondrites* has been studied by Fu (1991). New complex morphology insights and ethological interpretations of *Chondrites* show that it is extremotolerant ichnotaxon, which obviously occurs in organic rich sedimentary successions (Baucon et al., 2020).

Lamellaeichnus Šimo and Tomašových, 2013

Lamellaeichnus imbricatus Šimo and Tomašových, 2013

Description: *L. imbricatus* presents burrows composed of basal burrow and convex-shaped lamellae which obliquely run upward. Diameter of basal burrow attains 8 mm. Cross sections views of *Lamellaeichnus* burrows are displayed as around or elliptical basal burrows. Crescent-shaped (most often one) convex lamella on cross section and on oblique sections more convex lamellae (Fig. 8) are visible above the basal burrows. Vertical longitudinal sections show horizontal burrow from which the lamellae run upward. Horizontal longitudinal sections through the basal burrow display occasionally branched simple burrow. If the section is oriented above the basal burrow through lamellae, row of crescentsare visible. Remarks: This trace fossil is defined as a structure of vagile deposit feeder (Šimo & Tomašových, 2013). Occurrence of *Lamellaeichnus imbricatus* is typical in Lower Jurassic Fleckenmergel sequences of the Western Tethys (Šimo & Reolid, 2021).

Nereites MacLeay in Murchison, 1839

Nereites isp.

Description: *Nereites* isp. was determined from clusters of sectioned dark ellipsoid burrows with pale wall. Occasionally longitudinal sections of slightly arched burrows with pale wall are visible. Sectioned burrows are most often elliptical in shape. Diameters of black infill of burrows without pale wall attain 0.4–2.6 mm. Diameters of burrows with walls attains 1.4 to 5.6 mm (Fig. 9).

Remarks: It is characterized as a horizontally oriented deposit feeder structure. Modern form of *Nereites* has been described from the central South China Sea on the transition zone between oxic and anoxic conditions (Wetzel, 2002). Morphology of *Nereites* represents central tunnel (dark infill) with thick lobed mantle (Uchman, 1995; Knaust, 2017).

Planolites Nicholson, 1873

Planolites isp.

Description: Simple (not branched, not walled) horizontally oriented burrows. Maximal diameters of *Planolites* attain 7 mm. It is elliptic or round on the section. Active homogenous infill of *Planolites* is darker colored on the pale background of sediment (Fig. 8).

Remarks: *Planolites* is structure of active deposit feeder (Fillion & Pickerill, 1990). This trace is designated as a cross-facies and stratigraphically ubiquitous for its simple morphology.

Skolithos Haldeman, 1840

?Skolithos isp.

Description: Vertically oriented burrows of diameters 1 to 2.5 mm. Passive bright detritic infill contrasts with surrounding sediment (Fig. 8).

Remarks: *Skolithos* ichnofacies marked shallow water with relatively high energy environment. However, occurrence of *Skolithos* isp. Within deep water trace fossil association cannot indicate such shallow water environment. *Skolithos* ichnosystematic revisions have been provided by Alpert (1974) and Schlirf & Uchman (2005). Described vertical burrows can be attributed to dwelling structure of suspension-feeding organisms or predators (Knaust, 2017).

Teichichnus Seilacher, 1955

Teichichnus longummurus Šimo and Reolid, 2021

Description: Cross-sections of *Teichichnus longummurus* are presented as a sub-vertically oriented chain of well recognizable spreite structure with basal causative burrows. Basal causative burrows of *T. longummurus* have diameters between 2 and 2.5 mm. Lengths of spreite structure on cross sections views including basal burrow are from 14 to 29 mm (Figs. 8 and 10). Longitudinal section contains long fine strings of lamellae. Branching of the trace occurs commonly.

Remarks: Morphology of *Teichichnus* ichnospecies dominated by horizontal or obliquely oriented lamellae which are stacked vertically on the top of each other (Knaust, 2017). *Teichichnus longummurus* protrusive lamellae are arranged in inclined position to basal burrow. Protrusive spreite is typical in cross section of *Teichichnus longummurus*. The most similar to *Teichichnus longummurus* ichnospecies is *Teichichnus duplex* (Schlirf & Bromley, 2007). Its ethology can be characterized as deposit feeder.

Zoophycos Massalongo, 1855

Zoophycos isp.

Description: Parallel dark spreite lines were determined as *Zoophycos* isp. Spreite structures are not easy to distinguish inside of lines. Widths of *Zoophycos* isp. spreite lines on perpendicular sections ranged between 2.2 to 5.2 mm (Fig. 10). Morphology of *Zoophycos* was changing during time from simple whorl forms to forms combining whorls and long tongue like structures (Olivero, 2003; Zhang et al., 2015).

Remarks: *Zoophycos* is interpreted as a morphologically variable structure. It is built per collecting, keeping and food gardening. *Zoophycos* contains storage organic material from bottom surface which is processing during cycles of organic matter input. Several ethological manners (deposit feeding was not confirmed) of *Zoophycos* and combination of repetitive reworking of the structure in deep part of bottom substrate in anoxic to low oxygen conditions has been proven (Belghouthi et al., 2020; Löwemark et al., 2004; Löwemark, 2015).

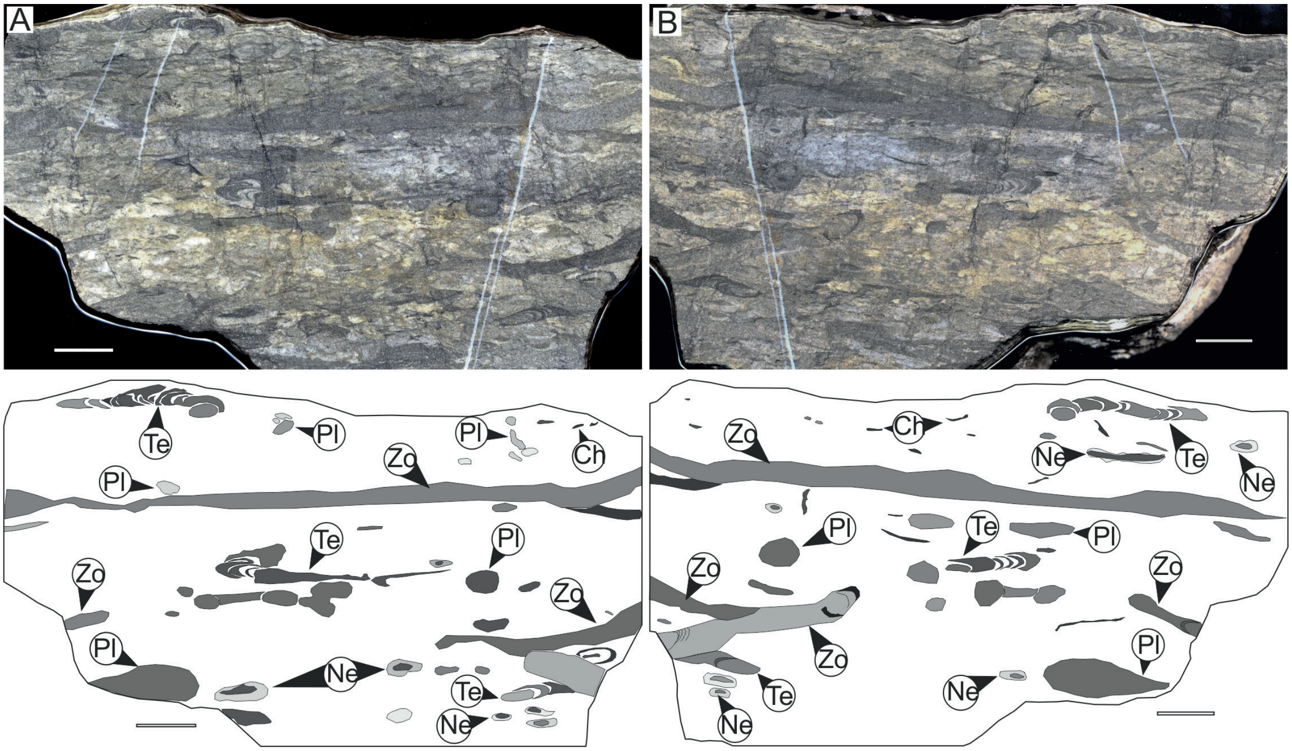


Fig. 8. Perpendicular cut of sample. View of opposite sides are approximately distant by cut and surface polishing up to 6 mm. Ch – *Chondrites* cf. *intricatus*, Ne – *Nereites* isp., Te – *Teichichnus longummurus*, Pl – *Planolites* isp., Zo – *Zoophycos* isp. Scale 10 mm. The Škarítkovci settlement. Scale 10 mm.

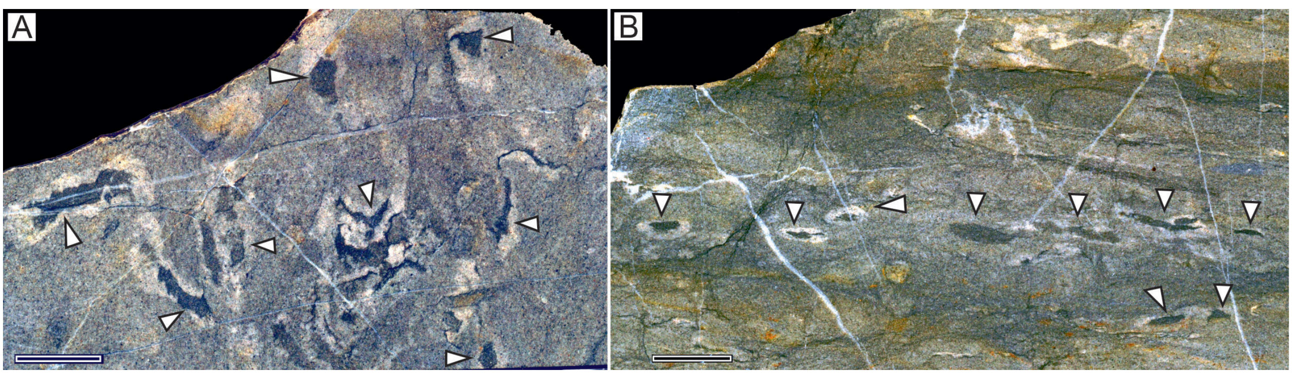


Fig. 9. Detailed view on *Nereites* isp. ichnofabric. A – Horizontal section on bedding plane. *Nereites* isp. is meandering. Central faecal string is enveloped by pale sediment. B – Perpendicular section on bedding plane. *Nereites* isp. of the Škarítkovci settlement. Scale 10 mm.

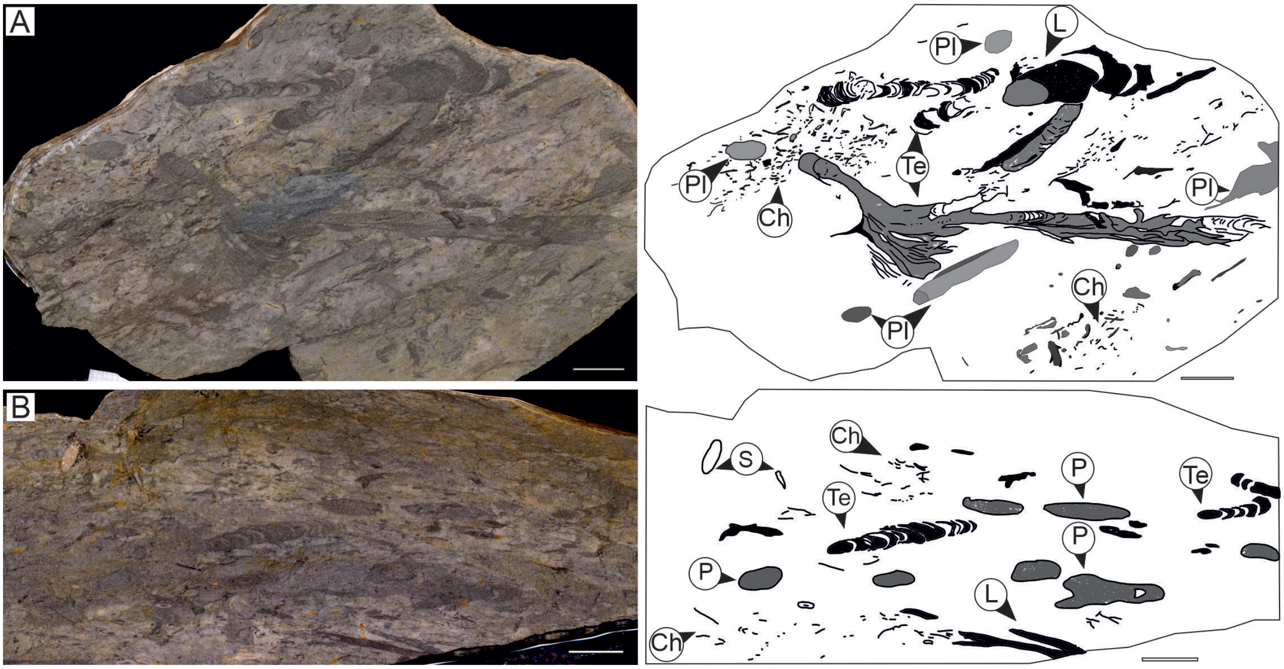


Fig. 10. Opposite views of vertically sectioned sample. Ch – *Chondrites* cf. *intricatus*, L – *Lamellaeichnus*, Pl – *Planolites* isp., S – *Skolithos* isp., Te – *Teichichnus longummurus*, Zo – *Zoophycos* isp. Scale 10 mm. The Škarítkovci settlement.

Palaeoecology and benthic palaeoenvironment

Genus *Watznaueria* seems to be ubiquitous and dominant during mid-Jurassic – Late Cretaceous, especially within the low and middle palaeolatitudes (Street & Bown, 2000; Lees et al., 2004, 2005). The presence of *Watznaueria* species signifies eutrophic and pelagic conditions (Suchéras-Marx et al., 2015). According to various authors, living conditions of this species are different, e.g. *Watznaueria fossacincta*/*Watznaueria barnesiae* signifies maximum stress of palaeoenvironmental conditions, seasonal blooms, and peaks of eutrophy (Lees et al., 2004). Anomalously low-diversity assemblage dominated by *Watznaueriaceae* is result of high trophic conditions which excluded bridge normal open-ocean taxa (Lees at al., 2005). According Roth & Krumbach (1986), Perch-Nielsen (1985), *Watznaueria* indicated low palaeofertility and/or pelagic palaeoenvironments.

Genus *Lotharingius* can survive indifferent conditions. Critical conditions during the Early Toarcian anoxic event, the biomineralization crisis, the high atmospheric pCO_2, and ocean acidification led to the crisis and extinguishment of nannofossils. Then *Lotharingius* began to develop and therefore the sizes increased. Based on Fraguas & Young (2011) calcareous nannofossils palaeoecological evaluation the study layers show eutrophic, pelagic water conditions. Two species *Crepidolithus crassus* and *Schizosphaerella punctulata* prefer deep-water conditions. However, these species occur in the samples less frequently.

Fine grained bioturbated marly and carbonate organodetritic substrate was consisted of radiolarians, sponge spicules and macroscopic fragments of shells. Microscopic views contain features of tiny bioturbation. Minute burrows are infilled by dark matrix and their walls have different pale color composed of radiolarian and sponge spicules and other bioclasts (Fig. 7A). Macroscopic trace fossils comprise rare vertically oriented trace fossils (?*Skolithos* isp.) and these trace fossils are regarded to permanent dwelling structures. Dominated part of trace fossil association is deeper situated and below from vertically oriented trace fossils (?*Skolithos* isp.). This association consists of deposit feeders trace fossils (*Lamellaeichnus*, *Nereites*, *Planolites*, *Teichichnus*, *Zoophycos*). Occurrence of *Zoophycos* isp. indicates seasonal cyclic sedimentological conditions presented by higher and slow rate of sedimentation with seasonal input of organic matter. Assemblage of *L. imbricatus*, *Planolites* isp. and *Teichichnus* isp. can be regarded to shallow part of bottom bioturbation below mixed layer. The deeper part of sediment was occupied by *Nereites* isp. This ichnofossil was situated within substrate of redox conditions. *Chondrites* cf. *intricatus*is structure of chemosymbiotic producer, occupied probably the deepest level of substrate on the redox potential boundary.

Described association of trace fossils is little different from the Lower Jurassic Fleckenmergel association from the Fatricum Unit. *Nereites* isp. andvertical burrows (?*Skolithos* isp.) are missing in the Lower Jurassic Fleckenmergel facies of the Fatricum Unit. *Nereites* isp.

has been reported from Lower Toarcian succession of eastern part of the External Subbetic Zone (Rodríguez-Tovar & Uchman, 2010). Thus, *Nereites* isp. is not considered as an exotic exceptional foreign element of the Fleckenmergel facies. Rarely occurred vertically oriented shafts, ?*Skolithos* isp. are not typical in Fleckenmergel facies and fragments of vertically oriented burrows can be interpreted as causative burrows of another trace fossils, for example *Zoophycos* isp.

Discussion

In this locality, in the Myjava Upland, in the Lower Jurassic "Fleckenmergel" facies, the calcareous nannofossils have been studied for the first time.

The biostratigraphical age of this "Fleckenmergel" facies according to Csibri (2019) was determined as Toarcian – Bathonian. The results of our study confirm the age determined by Potfaj et al. (2014), as Aalenian/Bajocian boundary, Nannoplankton Zone NJT9/NNJT10a *sensu* Mattioli & Erba (1999).

The assemblage of calcareous nannofossils was quantitatively and qualitatively poor. Determining species of calcareous nannofossils were formed within two majority groups – genera *Lotharingius* and *Watznaueria*. The co-occurrence of species of *Lotharingius* and *Watznaueria* is typical for the lower/middle Jurassic.

Genus *Watznaueria* began to develop in Upper Aalenian and its occurrence continued in Lower Bajocian. New species were developed: *W. contracta*, *W. britannica*, *W. manivitae*. *Watznaueria* species according to Cobianchi et al. (1992), De Kænel et al. (1996), Mattioli (1996), Mattioli & Erba (1999) probably evolved from *Lotharingius*. The onset of species was caused secondly by a change in the nutritional condition of the environment within changing geographical conditions (Sucheras-Marx et al., 2015).

The genus *Lotharingius* began to develop on the Pliensbachian/Toarcian boundary when alongside *L. hauffii* the *L. barozii* and *L. sigillatus* have been developed. The occurrence of the species *L. hauffii* continued to the Bajocian. *L. umbriensis* has its last occurrence on the Aalenian/Bajocian boundary.

There are several theories about this majority species representation. The majority occurrence of this genus may be due to diagenetic dissolution or evolutionary changes.

1. Over 40 % occurrence of *Watznaueria* in the Lower Cretaceous assemblage indicated replacement of existing species with new ones as a result of palaeoecological changes (Thierstein, 1981; Roth & Bowdler, 1981; Roth & Krumbach, 1986; Thierstein & Roth, 1991). Also, the major part of the here determined nannofossils consist of two genera, not just of the genus *Watznaueria*. Therefore, this assemblage is probably impoverished of diagenetic dissolution (Tiraboschi & Erba, 2010).
2. However, other authors consider that the major representation of genera *Watznaueria* and *Lotharingius* in the Lower and Middle Jurrasic is due to evolutionary development (Pittet & Mattioli, 2002; Lees et al., 2004; Olivier et al., 2004; Tremolada et al., 2006).

This theory is acceptable in the Lower/Middle Jurassic conditions. The species of the genus *Watznaueria* could be gradually replacing the species of the genus *Lotharingius*.

The occurrence of the genus *Lotharingius* on the Aalenia/Bajocian boundary and in Bajocian is interesting. According to some authors (Cobianchi et al., 1992; Mattioli & Erba, 1999; Mailliot et al., 2006), the last occurrence of the most *Lotharingius* species is in the lower/middle Aalenian, but according to other authors their occurrence continues to Bajocian. Probably it is a disconnected occurrence. A similar assemblage of calcareous nannofossils have been found in the Ravin du Bès section (Bas Auran, Subalpine Basin, SE France) by Tiraboschi & Erba (2010), in the middle-Jurassic formations at the Murtinheira section at Cabo Mondego (Portugal; Pavia & Enay, 1997) and in the Subbetic Basin in Spain (Aguado et al., 2017) as well.

The assemblage of calcareous nannofossils from Zones NJT9 to NJT10 – has been described in the Subbetic Basin in Spain. Based on the composition of the assemblage, it was determined that the main factors influenced the Early Bajocian calcareous nannofossils were trophic level (nutrient availability) and nutricline depth. Palaeoecological conditions were characterized as eutrophic, based on a number increase of specimens of the *Watznaueria* family. The occurrence of *Crepidolithus crassus* may suggest a deterioration of environmental conditions in the lower photic zone. It was caused by a change in nutritional conditions, turbidity, and stratification of the water column.

According to Aguado et al. (2017), the Aalenian/Bajocian boundary, characterized by weak and/or deep nutricline with nutrients rather uniformly spread throughout the photic zone, concomitant with mesotrophic conditions and increasing productivity, is suggested. Later Lower Bajocian is characterized by fertilization of the surface waters, while in Lower Bajocian the fertilization by upwelling occurred during the eutrophication episode (Aguado et al., 2017).

According to Suchéras-Marx et al. (2012) and their investigation in the Cabo Mondego area in Portugal, the Upper Aalenian-Lower Bajocian period is significant in terms of sedimentation of calcareous nannofossils. Studies show that calcareous nannofossil fluxes increase markedly in this time, coinciding with a 0.75 ‰ a positive shift in carbon isotope compositions of bulk carbonate in the study area of Cabo Mondego (Portugal). In particular, the *Watznaueria* species shows that its average proportion in rocks is 2 to 20 %. The diversification of *Watznaueria* throughout the Bajocian caused a major increase in the flux of pelagic carbonate to the deep ocean. However, it was also important in the global biogeochemistry of that time oceans.

Trace fossil assemblage of the Fleckenmergel/ Fleckenkalk lithofacies

The Central Western Carpathians and the Pieniny Klippen Belt Lower Jurassic successions which contain deep-water hemipelagic bioturbated limestonesand marlstones ("Fleckenmergel" lithofacies) are traditionally regarded to be an equivalent of the Allgäu Formation (e.g. Mišík, 1959, 1964; Mišík & Rakús, 1964; Rakús, 1963, 1964) of the Northern Alps (e.g. Gawlick, 2009; Jacobshagen, 1965). Trace fossils assemblage of lower to middle Jurassic in the "Fleckenmergel" lithofacies of the Western Tethys is consisting of few ichnogenera. The most frequented ichnogenera for wide region from the Subbetic to the Western Carpathians and Alps are: *Chondrites*, *Planolites*, *Teichichnus*, *Zoophycos* (e.g. Wieczorek, 1995; Jacobshagen, 1964; Rodríguez-Tovar & Uchman, 2010). However, *Zoophycos* is typical for upper Sinemurian – Bajocian successions of western Tethys. Its occurrence is usual for the Central Western Carpathians, the Pieniny Klippen Belt and the Northern Alps regions. While, occurrences of *Zoophycos* in the southern parts of western Tethys is noted from pelagic sediments of Toarcian – Aalenian age only (Reolid et al., 2018; Sandoval et al., 2012). *Lamellaeichnus imbricatus* and *Teichichnus longummurus* occur both widely in the Subbetic and the Central Western Carpathians and the Pieniny Klippen Belt regions in the Lower Jurassic Fleckenmergel lithofacies (Šimo & Tomašových, 2013; Reolid et al., 2020; Šimo & Reolid, 2021). *Nereites* isp. has also been referred from the Subbetic (Rodríguez-Tovar & Uchman, 2010). Bioturbation absence and trace fossil assemblage decrease have been noted from the Early Toarcian Oceanic Anoxic Event in the Subbetic (Rodríguez-Tovar & Uchman, 2010) and also in the Central Western Carpathians of the Fatric Unit (Müller et al., 2020).

These well distinguishable Fleckenmergel/ Fleckenkalk trace fossils, contrasting on homogenized background, are attractive to study which can reveal migration of elements during processes of rock diagenesis within bioturbated parts of sediment (Reolid & Reolid, 2020). This ichnoassociation with exception of *Nereites* isp. is comparable with Pliensbachian and Toarcian Fleckenmergel lithofacies from Fatricum Unit. However, *Nereites* isp. occurs in the Sinemurian – lower Pliensbachian Fleckenmergel succession of the Pieniny Klippen Belt of the Perechinska Formation (Šimo & Reolid, 2021). *Nereites* has been mentioned from the lower Toarcian Fleckenmergel sedimentary succession in the Betic Cordillera of Spain (Rodríguez-Tovar & Uchman, 2010). Therefore, occurrence of *Nereites* in the mentioned sedimentary successions of Lower up to Middle Jurassic Fleckenmergel lithofacies is relatively rare, but not exceptional.

Conclusions

Based on the study of calcareous nannofossils, the zones of the Upper Aalenian/ Bajocian, Zones NJT9/ NNJT10a were found. Predominantly occurrence of the genera *Watznaueria* and *Lotharingius*, indicated eutrophic and pelagic palaeoecological conditions. The high rate of sediment bioturbation and relatively diversified deposit feeder assemblage allow assuming that the environment of the shallowest bottom substrate was well oxygenated. Vertically oriented burrows (?*Skolithos* isp.) passively filed by pale sediment were situated in the upper part of the bottom substrate. These rare questionable findings can be interpreted as fragments of *Zoophycos* isp. J-shaped causative burrows. Trace fossils of substrate feeders (*Lamellaeichnus imbricatus*, *Planolites* isp., *Teichichnus longummurus*, *Zoophycos* isp.) occupied consolidated deeper part of bottom sediment. The lowermost occupied part of bottom sediment contained *Nereites* isp. and *Chondrites* cf. *intricatus*.

Acknowledgements

This work was supported by projects **APVV-20-0079,** and **APVV-17-0555 and VEGA 2/0013/20.** Special thanks are devoted to reviewers, Katarína Žecová and Radek Mikuláš for their constructive comments.

Appendix – List of calcareous nannofossils

Axopodorhabdus cylindratus (Noël, 1965) Wind and Wise in Wise and Wind, 1977

Biscutum profundum de Kaenel & Bergen, 1993

Carinolithus superbus (Deflandre in Deflandre & Fert, 1954) Prins in Grün et al., 1974

Crepidolithus crassus (Deflandre in Deflandre & Fert, 1954) Noël, 1965

Discorhabdus striatus Moshkovitz & Ehrlich, 1976

Lotharingius barozii Noël, 1973

Lotharingius frodoi Mattioli, 1996

Lotharingius hauffii Grün and Zweili in Grün et al., 1974

Lotharingius umbriensis Mattioli, 1996

Lotharingius sigillatus (Stradner, 1961) Prins in Grün et al., 1974

Podorhabdus cylindratus Noël, 1965 = *Axopodorhabdus cylindratus*

Schizosphaerella punctulata Deflandre & Dangeard, 1938

Watznaueria barnesiae (Black in Black & Barnes, 1959) Perch-Nielsen, 1968

Watznaueria britannica (Stradner, 1963) Reinhardt, 1964

Watznaueria contracta (Bown & Cooper, 1989) Cobianchi et al., 1992

Watznaueria fossacincta (Black, 1971) Bown in Bown & Cooper, 1989

Watznaueria manivitae Bukry, 1973

References

Aguado, R., O'Dogherty, L. & Sandoval, J., 2017: Calcareous nannofossil assemblage turnover in response to the early Bajocian (middle Jurassic) palaeoenvironmental changes in the Subbetic Basin. *Palaeogeogr. Palaeoclimatol. Palaeoecol., 472, 128–145*.

Alpert, S. P., 1974: Systematic review of the genus *Skolithos. J. Paleont., 48, 4, 661–669*.

Antolíková, S. & Józsa, Š., 2017: New paleoenvironmental and biostratigraphic data from the Aalenian Skrzypny Formation Litmanová area based on foraminifera and calcareous nannofossils. In: Zbor. abstraktov a exkurzný sprievodca Otvoreného geologického kongresu Vysoké Tatry 2017. *Bratislava, Slovenská geologická spoločnosť, s. 105. ISBN 978-80-972667-7-6. ISSN 2453–9732*.

Antolíková, S. & Józsa, Š., 2018: Aalenian-Bajocian calcareous nannoplankton and benthic foraminifera from the Skrzypny and Szlachtowa Formations from Litmanová and Kamienka, Pieniny Klippen Belt, Slovakia: age and paleoenvironment. In: *19th Czech-Slovak-Polish Palaeontological Conference & MIKRO 2018 workshop Abstract Book. Plzeň, West Bohemian Museum in Pilsen, 5.* ISBN 978-80-7247-145-4.

Barnard, T. & Hay, W. W., 1974: On Jurassic Coccoliths: A tentative zonation of the Jurassic of Southern England and Northern France. *Eclogae geol. Helv., 67, 3, 563–585*.

Baucon, A., Berdnarz, M., Dufour, S., Felletti, F., Malgesini, G., Carvalho, C. N., Niklas, K. J., Wehhrmann, A., Batstone, R., Bernardini, F., Briguglio, A., Cabella, R., Cavalazzi, B., Ferretti, A., Zanzerl, H. & Mcilroy, D., 2020: Ethology of the trace fossil *Chondrites*: Form, function and environment. *Earth Sci. Rev., 202, 102–989.* DOI: 10.1016/j.earscirev.2019.102989.

Began, A. & Gašpariková, V., 1979: Príspevok ku stratigrafii jury czorsztýnskej sukcesie. *Geol. Práce, Spr., 73, 71–74.*

Began, A., Borza, K. & Salaj, J., 1966: Remarks to the occurrence of the Manín Series westward from Trenčín. *Geol. Práce, Spr., 40, 168–170* (in Slovak with German summary).

Belghouthi, F., Wetzel, A., Zouari, H. & Jeddi, R. S., 2020: *Zoophycos* in storm-affected environments: a case study from lower Maastrichtian deposits of the Mateur-Beja area (Northern Tunisia). *Ichnos, 27, 2, 200–220.* DOI: 10.1080/10420940.2020.1730360.

Bown, P. R. & Cooper, M. K. E., 1998: Jurassic. In: Bown, P. R. (ed.): Calcareous Nannofossil Biostratigraphy. *British Micropalaeont. Soc. Publ. Ser., 34–85.*

Bown, P. R., Rutledge, D. C., Crux, J. A. & Gallagher, L. T., 1998: Early Cretaceous. In: Bown, P. R. (ed.): Calcareous Nannofossil Biostratigraphy. *British Micropalaeont. Soc. Publ. Ser., 86–131.*

Bown, P. R. & Young, J. R., 1998: Techniques. In: Bown, P. R. (ed.): Calcareous nannofossil biostratigraphy. *London, Chapman & Hall, 16–28.*

Bromley, R. G., 1996: Trace Fossils – Biology, taphonomy and applications. Sec. ed. *London, Chapman & Hall, 361 p.*

Cobianchi, M. A., Erba, E. & Pirini-Radrizzani, C., 1992: Evolutionary trends of calcareous nannofossil genera *Lotharingius* and *Watznaueria* during the Early and Middle Jurassic. *Mem. Soc. Geol. Padova, 43, 19–25.*

Csibri, T., 2019: Geological structure and tectonic development of Pieniny Klippen Belt in the Podbranč-Myjava segment. Rigorous thesis. *Bratislava, Comenius University, Fac. Natur. Sci., p.70*

De Kænel, E., Bergen, J. A. & Perch-Nielsen, K., 1996: Jurassic calcareous nannofossil biostratigraphy of western Europe. Compilation of recent studies and calibration of bioevents. *Bull. Soc. géol. France, 167, 15–28.*

Ferreira, J., Mattioli, E., Sucherás-Marx, B., Giraud, F., Duarte, L. V., Pittet, B., Suan, G., Hassler, A. & Spangenberg, J. E., 2019: Western Tethys Early and Middle Jurassic calcareous nannofossil biostratigraphy. *Earth Sci. Rev., 197,* https://doi.org/10.1016/j.earscirev.2019.102908.

Fillion, D. & Pickerill, R. K., 1990: Ichnology of the Upper Cambrian? To Lower Ordovician Bell Island and Wabana groups of eastern Newfoundland, Canada. *Palaeontogr. Canad., 7, p. 119.*

Fraguas, A. & Young, J. R., 2011: Evolution of the coccolith genus Lotharingius during the Late Pliensbachian–Early Toarcian interval in Asturias (N. Spain). Consequences of the Early Toarcian environmental perturbations. *Geobios, 44, 361–375.*

Fu, S., 1991: Funktion, Verhalten und Einteilung fucoider und lophocteniider Lebensspuren. *Cour. Forsch.-Inst. Senckenberg, 135, 1–79.*

Gašpariková, V., 1982: Liassic calcareous nannoflora from Klippen belt (Czorsztyn Unit). *Západ. Karpaty, Sér. Paleont., 8, 159–170.*

Gawlick, H. J., Missoni, S., Schlagintweit, F., Suzuki, H., Frisch, W., Krystyn, L., Blau, J. & Lein, R., 2009: Jurassic tectonostratigraphy of the Austroalpine domain. *J. Alpine Geol., 50, 1–152.*

Hók, J., Pešková, I. & Potfaj, M., 2009: Litostratigrafická náplň a tektonická pozícia drietomskej jednotky (západný úsek bradlového pásma). *Miner. Slov., 41, 3, 313–320.*

Jacobshagen, V., 1965: Die Allgäu-Schichten (Jura – Fleckenmergel) zwischen Wettersteingebirge und Rhein. *Jb. Geol. Bundesanst., 108, 1–114.*

Knaust, D., 2017: Atlas of Trace Fossils in Well Core: Appearance, Taxonomy and Interpretation. *Springer.*

Lees, J. A., Bown, P. R. & Mattioli, E., 2005: Problems with proxies? Cautionary tales of calcareous nannofossil palaeoenvironmental indicators. *Micropaleontology, 51, 333–343.*

Lees, J. A., Bown, P. R., Young, J. R. & Riding, J. B., 2004: Evidence for annual records of phytoplankton productivity in the Kimmeridge Clay Formation coccolith stone bands (Upper Jurassic, Dorset, UK). *Mar. Micropaleont.*, 52, 29–49.

Löwemark, L., Lin, I. T., Wang, CH. H., Huh, CH. A., Wei, K. Y. & Chen, CH. W., 2004: Ethology of the *Zoophycos* – Producer: Arguments against the Gardening Model from $\delta^{13}C_{org}$ Evidences of the Spreiten Material. *TAO, 15, 4, 713–725.*

Löwemark, L., 2015: Testing Ethological Hypotheses of the Trace Fossil Zoophycos Based on Quaternary Material from the Greenland and Norwegian Seas. *Palaeogeogr. Palaeoclimatol. Palaeoecol., 425, 1–13.*

Mailliot, S., Mattioli, E., Guex, J. & Pittet, B., 2006: The Early Toarcian Anoxic Crisis, a synchronous event in the Western Tethys? An approach by Quantitative Biochronology (Unitary Associations), applied on calcareous nannofossils. *Palaeogeogr. Palaeoclimatol. Palaeoecol., 240, 562–586.*

Mattioli, E., 1996: New calcareous nannofossil species from the Early Jurassic of Tethys *Riv. ital. Paleont. Stratigr., 102, 397–412.*

Mattioli, E. & Erba, E., 1999: Synthesis of calcareous nannofossil events in Tethyan Lower and Middle Jurassic successions. *Riv. ital. Paleont. Stratigr., 105, 373–376.*

Mišík, M., 1959: Lithologishes Profil durch die Schichtenfolge des höheren Lias ("Fleckenmergel") des Gebirges Belanské Tatry. *Geol. Sbor. Slov. Akad. Vied, 10, 183–187 (in Slovak).*

Mišík, M., 1964: Lithofazielles Studium des Lias der Grossen Fatra und Westteils der Niederen Tatra. *Sbor. geol. Vied, Západ. Karpaty, 7–89.*

Mišík, M. & Rakús, M., 1964: Bemerkungen zu räumlichen Beziehungen des Lias und zur Paläogeographie des Mesozoikum in der Grossen Fatra. *Zbor. geol. Vied, Západ. Karpaty, 1, 159–199.*

Mišík, M., 1997: The Slovak part of the Pieniny Klippen Belt after the pioneering works of D. Andrusov. *Geol. Carpath., 48, 209–220.*

Müller, T., Karancz, S., Mattioli, E., Milovský, R., Pálfy, J., Schlögl, J., Segit, T., Šimo, V. & Tomašových, A., 2020: Assessing anoxia, recovery and carbonate production setback in a hemipelagic Tethyan basin during the Toarcian Oceanic Anoxic Event (Western Carpathians).*Global Planet. Change.*

Noël, D., 1965: Sur les coccolithes du Jurassique Européen et d´Afrique du Nord. Essai de classification des coccolithes fossiles. *Ed. Cent. Natl. Rech*. Sci*., Paris, 1–209.*

Olivero, D., 2003: Early Jurassic to Late Cretaceous evolution of *Zoophycos* inthe French Subalpine Basin (southeastern France). *Palaeogeogr. Palaeoclimatol. Palaeoecol., 192, 59–78.*

Oliver, N., Pittet, B. & Mattoli, E., 2004. Palaeoenvironmental control on sponge-microbialite reefs and contemporaneous deep-shelf marl-limestone deposition (Late Oxfordian, southern Germany). *Palaeogeogr. Palaeoclimatol. Palaeoecol., 212, 233–263.*

Pavia, G. & Enay, R., 1997: Definition of the Aalenian–Bajocian Stage boundary. *Episodes, 20, 1, 16–22.*

Perch-Nielsen, K., 1985: Mesozoic calcareous nannofossils. In: Bolli, H. M., Saunders, J. B. & Perch-Nielsen, K. (eds.): Plankton Stratigraphy. *Cambridge, Cambridge Univ. Press, 329–426.*

Pittet, B. & Mattioli, E., 2002: The carbonate signal and calcareous nannofossil distribution in an Upper Jurassic section (Balingen-Tieringen, Late Oxfordian, southern Germany). *Palaeogeogr. Palaeoclimatol. Palaeoecol., 179, 71–96.*

Potfaj, M., Teťák, F., Havrila, M., Pešková, I., Olšavský, M. & Vlačiky, M., 2014: Geologická mapa Bielych Karpát (južná časť) a Myjavskej pahorkatiny. (Regionálna geologická mapa M 1 : 50 000 spracovaná digitálne na nedeformovanom topografickom podklade.) *Bratislava, Št. Geol. Úst. D. Štúra.*

Prins, B., 1969: Evolution and Stratigraphy of Coccolithinids from the Lower and Middle Lias. Proc. I. Conf. Plank. *Microfossils, Genéve, 1967, 2, 547–558.*

Rakús, M., 1963: Distribution of the Toarcian lithofacies in the central zone of the West Carpathians. *Geol. Sbor. Slov. Akad. Vied, 14, 19–27.*

Rakús, M., 1964: Paläontologische studien im Lias der Grossen Fatra und Westteils der Niederen Tatra. *Sbor. geol. Vied, Západ. Karpaty, 94–154.*

Reolid, M., Molina, J. M., Nieto, L. M. & Rodríguez-Tovar, F. J., 2018: The Toarcian Oceanic Anoxic Event in the South Iberian Palaeomargin. *Springer Briefs Earth Sci., 122 pp.* DOI:10.1007/978-3-319-67211-3.

Reolid, M., Iwańczuk, J., Mattioli, E. & Abad, I., 2020: Integration of gamma ray spectrometry, magnetic susceptibility and calcareous nannofossils for interpreting environmental perturbations: An example from the Jenkyns Event (lower Toarcian) from South Iberian Palaeomargin (Median Subbetic, SE Spain). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* DOI:10-1016/j.palaeo.2020.110031.

Reolid, M. & Reolid, J., 2020: Geochemical compositional mapping of Lower Jurassic trace fossils: Palaeoenvironmental significance and methodological implications. *Palaeogeogr. Palaeoclimatol. Palaeoecol., 538, 109–456.*

Rodríguez-Tovar, F. J. & Uchman, A., 2010: Ichnofabric evidence for the lack of bottom anoxia during the Lower Toarcian oceanic anoxic event in the Fuente de la Vidriera Section, Betic Cordillera, Spain. *Palaios, 25, 576–587.*

Roth, P. H. & Bowdler, J. L., 1981: Middle Cretaceous calcareous nannoplankton biogeography and oceanography of the Atlantic Ocean. *SEPM, Spec. Publ., 32, 517–546.*

Roth, P. H. & Krumbach, K. R., 1986: Middle Cretaceous calcareous nannofossil biogeography and preservation in the Atlantic and Indian Oceans: implications for paleoceanography. *Mar. Micropaleont., 10, 1, 235–266.*

Salaj, J. (ed.), 1987: Vysvetlivky ku geologickej mape Myjavskej pahorkatiny, Brezovských a Čachtických Karpát 1 : 50 000. *Bratislava, Geol. Úst. D. Štúra, 1–181.*

Salaj, J., 1990: Geologická stavba bradlovej a pribradlovej zóny stredného Považia a litologická klasifikácia kriedových sedimentov novovymedzených sekvencii. *Miner. Slov., 22, 2, 155–174.*

Sandoval, J., Bill, M., Aguado, R., O'Dogherty, L., Rivas, P., Morad, A. & Guex, J., 2012: The Toarcian in the Subbetic basin (southern Spain): Bio-events (ammonite and calcareous nannofossils) and carbon-isotope stratigraphy. *Palaeogeogr. Palaeoclimatol. Palaeoecol., 342, 40–63.* DOI: 10.1016/j.palaeo.2012.04.028.

Schlirf, M. & Uchman, A., 2005: Revision of the ichnogenus *Sabellarifex* Richter, 1921 and its relationship to

Skolithos Haldeman, 1840 and *Polykladichnus* Fürsich, 1981. *J. System. Palaeont., 3, 2, 115–131.* DOI: 10.1017/S1477201905001550.

Schlirf, M. & Bromley, R., 2007: *Teichichnusduplex* n. isp., new trace fossil from the Cambrian and the Triassic. *Beringeria, 37, 133–141.*

Street, C. & Bown, P. R., 2000: Palaeobiogeography of Early Cretaceous (Berriasian-Barremian) calcareous nannoplankton. *Mar. Micropaleont., 39, 265–291.*

Suchéras-Marx, B., Guihou, A., Giraud, F., Lécuyer, C., Allemand, P., Pittet, B. & Mattioli, E., 2012: Impact of the Middle Jurassic diversification of *Watznaueria* (coccolith-bearing algae) on the carbon cycle and $\delta^{13}C$ of bulk marine carbonates. *Glob. Planet. Change, 86–87, 92–100.*

Suchéras-Marx, B., Mattioli, E., Giraud, F. & Escarguel, G., 2015: Paleoenvironmental and paleobiological origins of coccolithophorid genus *Watznaueria* emergence during the Late Aalenian-Early Bajocian. *Paleobiology, 41, 3, 415–435.* DOI: 10.1017/pab.2015.8.

Svobodová, A., 2012: Upper Turonian and Lower Coniacian calcareous nannoplankton stratigraphy in the borehole V 800 Střeleč, Bohemian Cretaceous Basin. *Diploma Thesis. Praque, Charles Univ., 95p.*

Šimo, V. & Tomášových, A., 2013: Trace-fossil assemblages with a new ichnogenus in “spotted” (Fleckenmergel–Fleckenkalk) deposits: A signature of oxygen-limited benthic communities. *Geol. Carpath., 64, 5, 355–374.*

Šimo, V. & Reloid, M., 2021: Palaeogeographic homogeneity of trace fossil assemblages in Lower Jurassic spotted marls and limestones: comparison of the Western Carpathians and the Betic Cordillera. *Geol. Soc. London, Spec. Publ.* DOI: https://doi.org/10.1144/SP514-2020-110.

Tiraboschi, D. & Erba, E., 2010: Calcareous nannofossil biostratigraphy (Upper Bajocian–Lower Bathonian) of the Ravin du Bès section (Bas Auran, Subalpine Basin, SE France): Evolutionary trends of *Watznaueria* barnesiae and new findings of “Rucinolithus” morphotypes. *Geobios, 43, 1, 59–76.*

Thierstein, H. R. & Roth, P. H., 1991: Stable isotopic and carbonate cyclicity in Lower Cretaceous deep-sea sediments: dominance of diagenetic effects. *Mar. Geol., 97, 1–34.*

Thierstein, H. R., 1981: Late Cretaceous nannoplankton and the change at the Cretaceous-Tertiary boundary. *SEPM Spec. Publ., 32, 355–394.*

Tremolada, F., Bornemann, A., Timothy, J., Bralower, T. J., Koeberl, C. & Van De Schootbrugge, B., 2006: Paleoceanographic changes across the Jurassic/Cretaceous boundary: The calcareous phytoplankton response. *Earth Planet. Sci. Lett., 241, 361–371.*

Uchman, A., 1995: Taxonomy and palaeoecology of flysch trace fossils: The Marnoso-aranacea Formation and associated facies (Miocene, Northern Apennines, Italy). *Beringeria, 15, 1–115.*

Wieczorek, J., 1995. Trace fossils from Fleckenmergel facies (Jurassic) of the Tatra Mts. *Geobios, Mem. Spec., 18, 425–431.* DOI:10.1016/S0016-6995(95)80188-X.

Wetzel, A., 2002: Modern *Nereites* in the South China Sea – ecological association with redox conditions in the sediment. *Palaios, 17, 507–515.*

Young, J. R., Bown, P. R. & Lees, J. A., 2017: Nannotax3 website. International Nannoplankton Association. Accessed 21 Apr. 2017. URL: http://www.mikrotax.org/Nannotax3.

Zhang, L.-J., Fan, R.-Y. & Gong, Y.-M., 2015: *Zoophycos* Macroevolution since 541 Ma. *Sci. Reports, 5, 1, 14954.*

Biostratigrafia a paleoekologické vyhodnotenie fosílnych stôp a vápnitého nanoplanktónu zo strednojurského (álen – bajok) bioturbovaného vápenca pribradlovej zóny drietomskej jednotky (Myjavská pahorkatina)

Pribradlová zóna skúmanej oblasti sa nachádza v najzápadnejšej časti pieninského bradlového pásma (obr. 1, 2). Spodnojurská až strednojurská sedimentárna sukcesia pribradlovej zóny tmavých bioturbovaných vápencov sa označuje ako ekvivalent algäuského súvrstvia (napr. Csibri, 2019). Fácia „fleckenmergel“ sa považuje za sukcesiu drietomskej jednotky (obr. 3).

Pôvodne sa však toto územie označovalo ako posidóniové vrstvy a boli súčasťou bradlového pásma (Potfaj et al., 2014; Salaj et al., 1987; Salaj, 1990).

Cieľom tejto štúdie bolo biostratigrafické a paleoekologické vyhodnotenie spodno- až strednojurských tmavých vápencov („fleckenmerglov“) z oblasti Myjavskej pahorkatiny na základe fosílnych stôp a vápnitého nanoplanktónu s cieľom spresniť doterajšie poznatky.

Biostratigrafické vyhodnotenie vzoriek v tejto práci je založené na strednojurských druhoch vápnitého nanoplanktónu (obr. 4, 5). Toto štúdium je doplnené aj o opis spoločenstva fosílnych stôp a jeho paleoekologickú charakteristiku sedimentárneho prostredia. Študovaný úsek je najmladšou sukcesiou fácie typu „fleckenmergel“ v rámci alpsko-karpatského regiónu (Gawlick et al., 2009; Wieczorek, 1995). V tomto dlhotrvajúcom vývoji hlbokovodnej fácie „fleckenmergel“ (sinemúr – bajok) sa vyskytuje pomerne chudobné uniformné spoločenstvo fosílnych stôp (Wieczorek, 1995; Šimo a Tomašových, 2013; Šimo a Reolid, 2021). Táto práca prináša dosiaľ jediné ichnologické vyhodnotenie strednojurských bioturbovaných vápencov z pribradlovej zóny drietomskej jednotky.

Vzorky boli odobraté z dvoch odkryvov, lokalizovaných 4 km západne od hradu Podbranč, v blízkosti usadlosti Škarítkovci.

Predchádzajúce štúdium vápnitých nanofosílií v spodno- až strednojurských sedimentoch v Západných Karpatoch

Spodno- až strednojurský vápnitý nanoplanktón nie je v jurských sedimentoch Západných Karpát podrobne preskúmaný. Štúdium spodno- až strednojurských vápnitých nanofosílií sa realizovalo z tmavých fľakatých vápencov typu „fleckenmergel" z pieninského bradlového pásma.

Na lokalite Vršatec, z Malej Fatry v čorštynskej jednotke a na lokalite Skladaná skala určila Gašpariková (Gašpariková in Began a Gašpariková, 1979; Gašpariková, 1982) dve spodnojurské zóny *Crepidolithus crassus* (pliensbach) a *Podorhabdus cylindralithus* (pliensbach – toark) podľa zonácií v prácach Barnard a Hay (1974) a Prins (1969).

V mezozoických sedimentoch šiprunskej sekvencie Malej Fatry výskum prebiehal na lokalitách Trlenská, Malinô Brdo a Ľubochňa. Nájdené spoločenstvo vápnitých nanofosílií bolo charakteristické pre zónu *Podorhabdus cylindralithus* (pliensbach – toark).

V súčasnosti sa názov druhu *Podorhabdus cylindralithus* považuje za bazionymum druhu *Axopodorhabdus cylindratus*. Podľa Bowna a Coopera (1998) je rozpätie výskytu tohto druhu od toarku po bajok, nanoplanktónové zóny NJ 4a až NJ 7.

V spodno- až strednojurských sedimentoch z lokalít Litmanová a Kamienka zo súvrství Skrzypny a Szlachtowa určila Antolíková (Antolíková in Antolíková a Józsa, 2017, 2018) vápnité nanospoločenstvo zón NJ8/NJ9, hranica álen/bajok.

Vápnité nanofosílie

Spoločenstvo vápnitých nanofosílií bolo pomerne chudobné, našlo sa len dvanásť druhov. Najviac sa vyskytovali druhy rodu *Watznaueria* (*W. manivitae*, *W. contracta, W. fassacincta*), ktorého priemerné zastúpenie v spoločenstve bolo 63 %. Druhým najviac rozšíreným rodom bol *Lotharingius* (*L. frodoi*, *L. haufii*, *L. umbriensis*), ktorého priemerné zastúpenie v spoločenstve bolo 22 %.

V spoločenstve sa najviac vyskytoval druh *W. contracta*, ktorého prítomnosť vo vzorkách varírovala od 16 do 57 %, a druh *W. manivitae*, ktorý mal vo vzorkách 21 až 39 % zastúpenie.

Na základe zisteného spoločenstva vápnitých nanofosílií bola určená hranica álen/bajok. Nanoplanktónové zóny NJ8/NJ9 sú vymedzené podľa práce Bowna a Coopera (1998) a zóna NJT9/NNJT10a podľa práce autorov Mattioli a Erba (1999) na základe prvého výskytu druhov *Watznaueria fossacincta* a *Watznaueria manivitae* (obr. 6).

Spoločný výskyt rodov *Lotharingius* a *Watznaueria* je typický pre hranicu álen/bajok (Cobianchi et al., 1992; Mattioli a Erba, 1999; Mailliot et al., 2006). Álenský vápnitý nanoplanktón je charakterizovaný najmä druhmi rodu *Lotharingius* (Fraguas a Young, 2011), zatiaľ čo posledný výskyt *L. hauffi* je až v spodnom bajoku. Ďalšie nájdené druhy sú *Biscutum profundum* (NJ5-NJ10, toark – bajok), *Crepidolithus crassus* (NJ3 – NJ17b, sinemúr – titón), *Carinolithus superbus* (NJ6 – 10, toark – bajok), *Discorhabdus striatus* (NJ7 – NJ15a, toark – oxford), *Schizosphaerella punctulata* (NJ1 – NJ15, hetanž – kimeridž). Navyše, spoločenstvo nanoplanktónu obsahuje aj druhy *Thoracosphaera* sp. a *Watznaueria* sp.

Vápnité nanofosílie – paleoekológia

Druh *Watznaueria* vyzerá všadeprítomný počas strednej jury až neskorej kriedy, najmä v stredných a nižších zemepisných šírkach (Street a Bown, 2000; Lees et al., 2004, 2005). Prítomnosť druhov rodu *Watznaueria* signalizuje eutrofické a pelagické podmienky (Suchéras-Marx et al., 2015). Podľa rôznych autorov sú životné podmienky tohto druhu odlišné, napr. *Watznaueria fossacincta/Watznaueria barnesiae* signalizuje maximálny stres z paleoenvironmentálnych podmienok, sezónnych rozkvetov a vrcholov eutrofie (Lees et al., 2004). Anomálne nízka diverzita s dominanciou *Watznaueriaceae* je výsledkom vysokých trofických podmienok, ktoré vylučujú premosťovanie bežných taxónov otvoreného oceánu (Lees et al., 2005).

Podľa Rotha a Krumbacha (1986) a Percha-Nielsena (1985) *Watznaueria* naznačuje nízku paleofertilitu a/alebo pelagické paleoenvironmentálne prostredie.

Rod *Lotharingius* môže prežiť v rôznych podmienkach. Kritické podmienky počas ranej toarkskej anoxickej udalosti, biomineralizačná kríza, vysoký atmosférický pCO_2 a okyslenie oceánov viedli ku kríze a likvidácii nanofosílií. Potom sa *Lotharingius* začal rozvíjať, a preto sa veľkosť zväčšovala (Fraguas a Young, 2011).

Na základe paleoekologického hodnotenia vápnitého nanoplanktónu zo skúmaných vzoriek sa ukazujú eutrofické pelagické podmienky. Dva druhy, *Crepidolithus crassus* a *Schizosphaerella punctulata*, uprednostňovali hlbokomorské podmienky. Tieto druhy sa však vo vzorkách vyskytujú zriedkavo.

Fosílne stopy

Jemný bioturbovaný slienito-vápnitý substrát bol tvorený organodetritom spikúl hubiek a fragmentmi schránok lastúrnikov. Na mikroskopickej úrovni je evidentné biologické prepracovanie mikroklastov (obr. 7A).

Spoločenstvo fosílnych stôp bolo zastúpené druhmi: *Chondrites* cf. *intricatus*, *Lamellaeichnus imbricatus*, *Nereites* isp., *Planolites* isp., ?*Skolithos* isp., *Teichichnus longummurus* a *Zoophycos* isp.

Nereites isp. má tmavú jemnozrnnú výplň horizontálnej, nepravidelne meandrujúcej chodby a svetlú stenu zloženú z rádiolárií a spikúl hubiek (obr. 7B). Vertikálne orientované chodby fosílnych stôp (?*Skolithos* isp.) sa vyskytujú zriedkavo. Najväčšie množstvo fosílnych stôp tvoria štruktúry po aktívnych požieračoch substrátu: *Lamellaeichnus imbricatus*, *Nereites* isp., *Planolites* isp., *Teichichnus* longummurus a *Zoophycos* isp. (obr. 8, 9, 10). *Chondrites* cf. *intricatus*, štruktúra chemosymbiotického pôvodu sesílneho organizmu, bola situovaná na rozhraní oxidačno-redukčného prostredia. Tieto chemosymbionty zrejme okupovali najhlbšiu obývateľnú časť substrátu. Stopa *Nereites* isp. zo spodnojursko-strednojurských sukcesií fácií „fleckenmergel“ nie je z Vnútorných Západných Karpát evidovaná a otázny je aj jej výskyt z bradlového pásma (Šimo a Reolid, 2021). *Nereites* isp. je evidovaný zo spodnotoarkskej sukcesie fleckenmerglovej fácie z betickej kordiléry (Rodríguez-Tovar a Uchman, 2010), preto výskyt tejto stopy je v týchto fáciách relatívne vzácny, ale nie výnimočný. Takto významne bioturbovaný sediment bez náznakov primárnych sedimentárnych štruktúr s etologicky diverzifikovaným spoločenstvom fosílnych stôp indikuje relatívne dobre prekysličené hlbokomorské prostredie dna.

Záver

Študované územie Myjavskej pahorkatiny patrí do pribradlovej zóny pieninského bradlového pásma. Biostratigrafický a paleoekologický výskum sa realizoval zo spodno- až strednojurských tmavých bioturbovaných vápencov (charakterizovaných ako ekvivalent algäuského súvrstvia, označovaných aj ako litofácia typu „fleckenmergel“) na základe fosílnych stôp a vápnitých nanofosílií.

Výsledky**:**

1. Na základe zisteného spoločenstva vápnitých nanofosílií boli určené nanoplanktónové zóny NJT9/NNJT10a, ktoré zodpovedajú veku vrchný álen/bajok.
2. Spoločenstvo fosílnych stôp reprezentovali druhy: *Chondrites* cf. *intricatus*, *Lamellaeichnus imbricatus*, *Nereites* isp., *Planolites* isp., *Skolithos* isp., *Teichichnus* longummurus a *Zoophycos* isp.
3. Na základe dominantného výskytu druhov vápnitých nanofosílií *Watznaueria* a *Lotharingius* boli určené paleoekologické podmienky sedimentačného priestoru ako eutrofické a pelagické.
4. Vysoká miera bioturbácie sedimentu a relatívne diverzifikované spoločenstvo pôvodcov fosílnych stôp umožňuje predpokladať, že prostredie najplytšieho dna bolo dobre okysličené. V hornej časti sedimentov dna sa nachádzali vertikálne orientované nory (*?Skolithos* isp.) vyplnené bledým sedimentom. Tieto nálezy možno interpretovať ako fragment rodu *Zoophycos* isp., pričom chodby mali tvar písmena J. Druhy *Lamellaeichnus imbricatus*, *Planolites* isp., *Teichichnus* longummurus a *Zoophycos* isp. žili v spevnenej hlbšej časti dnového sedimentu. Najspodnejšia časť sedimentu bola obývaná druhmi *Nereites* isp. a *Chondrites* cf. *intricatus*.

Doručené / Received: 31. 8. 2021
Prijaté na publikovanie / Accepted: 15. 12. 2021