PALAEOENVIRONMENTAL INTERPRETATION OF CHAOTIC COMPLEXES OF THE MELIATA UNIT (WESTERN CARPATHIANS, SLOVAKIA): NEW DATA FROM BIOCHRONOLOGY, LITHOSTRATIGRAPHY AND GEOCHEMISTRY

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Keywords: *olistostromes; radiolarians; geochemistry; palaeoenvironmental; Triassic, Jurassic; Meliata Unit; Western Carpathians.*

ABSTRACT

The Meliata Unit (Meliaticum) is a remnant of the Tethyan oceanic suture occurring in the southern Western Carpathian zones. It includes the blueschist-facies Bôrka Nappe and low-grade syn-orogenic accretionary complexes, which are generally assigned to the Meliata Unit *s.s*. The Meliatic chaotic tectono-sedimentary units related to the closure of the Meliata Ocean include Jurassic mass-flow deposits and assorted types of tectonic mélanges. We studied several hitherto poorly known localities in southern Slovakia, which provided new information about the stratigraphy and geochemistry of the Triassic and Jurassic sedimentary formations. Litho-biostratigraphical data and component analysis reveal a dramatic change in depositional conditions likely occurring at the Triassic/Jurassic boundary, which was probably related to the onset of subduction. The trench-type Middle Jurassic sedimentation is characterised by the presence of mass-flow bodies inserted within turbiditic sequences of dark shales, sandstones, allodapic bioclastic limestones and Middle Jurassic radiolarites. Geochemical analyses indicate a mature continental provenance of the terrigenous clastic material, which was likely derived from the northern passive margin of the Meliata Ocean built by the later Central Carpathian (Austroalpine) units. Sliding blocks and breccia layers are composed of various platform and pelagic Middle-Upper Triassic carbonates, Middle Triassic and Upper Triassic radiolarites and occasionally also basalts. Subsequently, the olistostromes were tectonically reworked together with Middle Jurassic white radiolarites, crinoidal limestones and siliciclastic rocks to form heterogenous mélanges, which in part incorporated also oceanic basalts, serpentinized ultramafics and blueschist-facies metamorphic rocks exhumed from the subduction channel. Thereby, the sedimentary olistostromes and polygenous tectonic mélanges jointly form chaotic complexes that are characteristic of the Meliata Unit as a whole. With the closing of the Meliata Ocean in the Late Jurassic, the Meliata accretionary complexes were thrust over the foreland Austroalpine lower plate (Gemericum), while the suture zone underwent additional deformation stages that have even more complicated its structure.

INTRODUCTION

Collisional orogenic belts are characterized by the presence of at least one suture zone that marks the position of an ancient oceanic domain between two colliding continental plates. As such, suture zones typically include slivers of oceanic material such as ophiolite-bearing mélanges, deep-marine pelagic sediments, vestiges of subduction-related blueschist-facies metamorphism and accretionary complexes of syn-orogenic clastic deposits including chaotic mass-wasting bodies like olistostromes. The northernmost segment of European Alps, the Western Carpathians, bear two such suture zones. The northern one, known as the Pieniny Klippen Belt (PKB), is an extremely narrow but lengthy zone which separates the Tertiary accretionary wedge of the External Carpathian Flysch Belt from the Cretaceous stack of the Austroalpine basement thrust sheets and cover nappes of the Central Western Carpathians (CWC). The PKB is a kind of a shallow suture that is rich in chaotic syn-orogenic breccia bodies and huge olistoliths, but it does not include metaophiolites (serpentinites) or high-pressure rock formations. Nevertheless, it is believed to represent a suture after closure of the Liguria-Piemont branch of the Alpine Atlantic Ocean (e.g. Plašienka et al., 2020 and references therein).

In contrast, the supposed Meliata suture (Meliata Unit; Meliaticum, Meliatic) divides the CWC from the Internal Western Carpathian (IWC) units of the Adria and/or Dinaridic affinity (Transdanubian and Bükk, respectively). The Meliatic complexes are composed of several distinct elements differing in composition, tectono-metamorphic evolution and position in the accretionary wedge (Plašienka, 2018; Plašienka et al., 2019 and references therein). The main Meliatic constituents are: i) the blueschist-facies Bôrka Nappe representing the distal continental margin exhumed from the subduction channel during the Late Jurassic and subsequently thrust over the foreland lower CWC plate; ii) variable mélange complexes (see below); iii) relatively coherent Jurassic successions of deep-marine hemipelagic and distal flysch deposits with olistostrome bodies, which include Triassic carbonate blocks revealing the late mid-Anisian (Pelsonian) breakup of the Meliata Ocean (e.g. Kozur, 1991). Hence, the Meliata units are constituents of the Late Jurassic - Early Cretaceous Neotethyan orogenic belt formed in response of closing of the Neotethys Ocean (e.g. Missoni and Gawlick, 2011a; Gawlick and Missoni, 2019).

Mélange complexes represent a chaotic mixture of various sedimentary, volcanic, and metamorphic rocks resulting from complex tectonic, chiefly subduction/collision processes. The present study focuses on the Jurassic mélange and/or olistostrome complexes of the Meliata Unit, which record the subduction/accretionary processes connected with the opening, expansion, subduction and closure of the Triassic-Jurassic Meliata Ocean in the southern Western Carpathian zones. This paper examines small, yet significant occurrences of chaotic complexes of the Meliata Unit in the southern part of the Western Carpathians. New bio-lithostratigraphical and geochemical results from these locations are presented. Our aim is to extend understanding of the palaeoenvironmental factors and sedimentary conditions that preceded the Jurassic closure of the Meliata Ocean employing several research methods.

REGIONAL FRAMEWORK

The investigated area occurs in the Slovakian-Hungarian borderland belonging to the Slovak-Aggtelek Karst area, which represents a transitional zone between the CWC Austroalpine and IWC Tethyan Carpathians. The area is built up of four superposed major tectonic units. The Upper Austroalpine Gemer Superunit (Gemericum) (Fig. 1a) in the lowermost structural position is composed of Lower Paleozoic volcano-sedimentary complexes affected by low-grade Variscan and Alpine metamorphism that are covered by continental clastic and platform carbonate formations (Permian to Lower-Middle Triassic; e.g. Vozárová and Vozár, 1988). The Gemericum is overlain by the Meliatic suture complexes and by the Turnaicum and Silicicum cover nappe units (Mello et al., 1996; Plašienka, 2018; Fig. 1a). The very low-grade Turnaicum (Vozárová and Vozár, 1992) includes Pennsylvanian to Lower Triassic clastic formations, Lower Anisian platform carbonates and Upper Anisian to Norian deep-water pelagic limestones and shales, while presence of the Jurassic strata is uncertain. The Turnaicum rocks are in part imbricated with the underlying Meliatic elements to form a joint accretionary complex overriding the Gemericum (Lačný et al., 2016). With a pronounced structural and metamorphic unconformity (Reichwalder, 1982), the

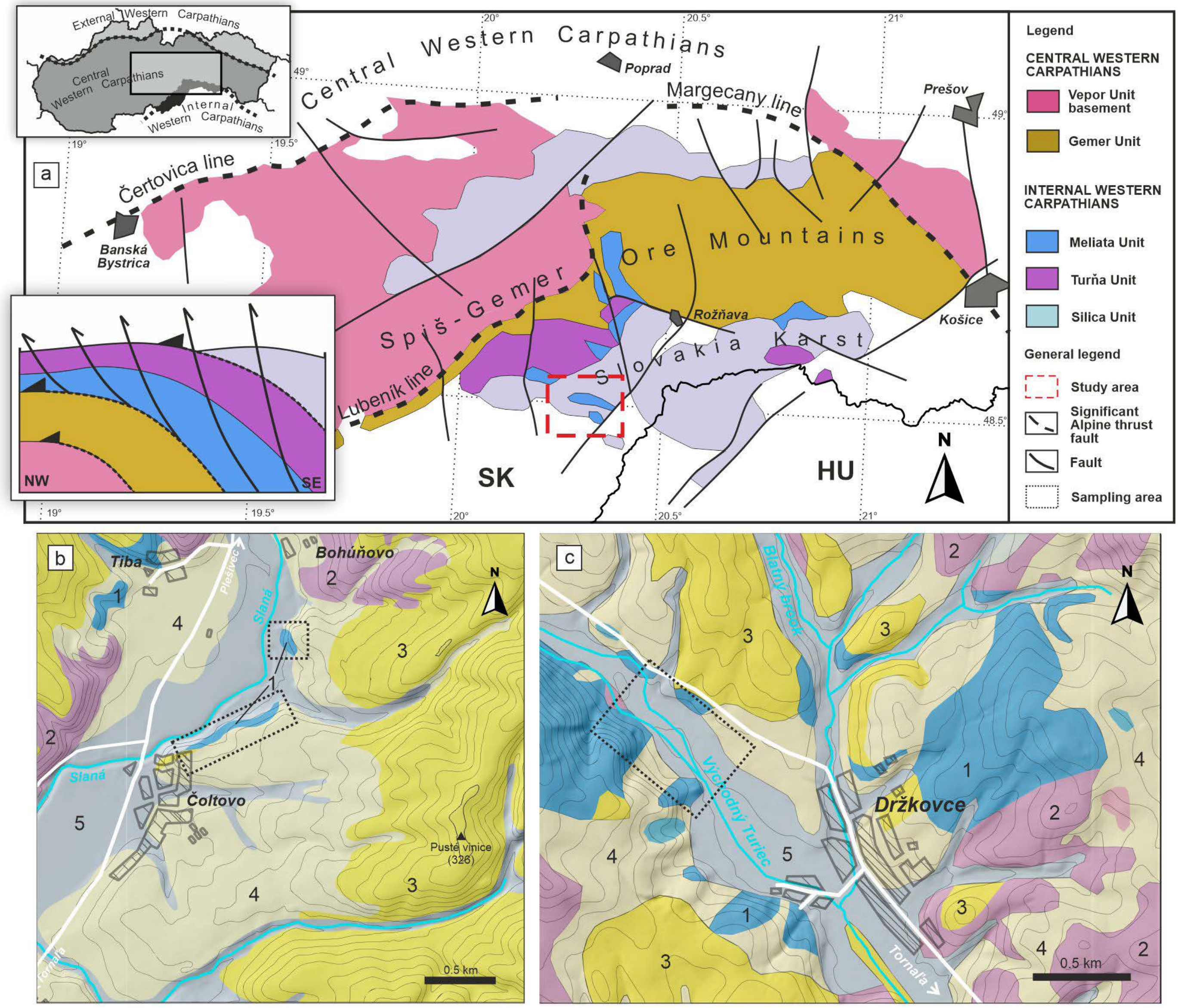

Fig. 1 - Structural and geological situation of investigated area: a) Tectonic sketch of the Central-Internal Carpathian zones; b) Schematic geological map of the Čoltovo and Bohúňovo locality (Mello et al., 1996); c) Schematic geological map of the Držkovce locality (Mello et al., 1996). 1 - dark Jurassic claystones with thin intercalations of sandstones, calcareous claystones, grey-green radiolarites, as well as Triassic olistostromes – Meliata Unit s.s; 2 - Predominantly Triassic carbonates - Silicicum; 3 - Miocene deposits; 4 - Quaternary eluvial and deluvial deposits; 5 - Quaternary fluvial deposits.

Meliatic-Turnaicum stack is overthrust by the Silica Nappe (Silicicum), which includes Permian evaporites as a detachment horizon, Lower Triassic clastic sediments, and Middle-Upper Triassic shelf deposits, predominantly thick platform carbonates (e.g. the Wetterstein and Dachstein formations), with a restricted presence of basinal formations (Bystrický, 1964; Mello, 1975). Comparatively thin, mostly basinal Jurassic strata, are locally preserved. The Jurassic sequence is terminated by probably lower Upper Jurassic pelagic deposits with terrigenous admixture and carbonate olistostromes with clasts of Middle Jurassic radiolarites (Sýkora and Ožvoldová, 1996; Rakús, 1996; Rakús and Sýkora, 2001). Although it is generally considered as not metamorphosed, structural incoherence of the Silicicum nappe system is indicated by varying (occasionally even fairly high) conodont colour alteration indices (CAI; cf. Gawlick et al., 2002, 2023; Havrila, 2011). The units of the IWC are largely covered by the Cenozoic overstepping formations (see Fig. 1b, c). These formations consist mainly of Oligocene-Lower Miocene organodetritic limestones, coarse-grained clastic rocks, breccias, and Middle Miocene volcanic rocks.

Subject of our research, the Meliaticum, exhibits a lithologically variable composition which is differing in scattered exposures all around the area (Fig. 1a). In general, three main partial units or complexes were distinguished by Lačný et al. (2016) and Plašienka et al. (2019). From bottom to top, these are: 1) the high pressure/low temperature (HP/LT) metamorphosed Bôrka Nappe overlying the Gemericum rocks; 2) ophiolite-bearing polygenous tectonic mélange composed f both HP/LT and unmetamorphosed fragments, and 3) the sedimentary complex with olistostrome bodies of the Meliata Unit *s.s.* However, these subunits are often jointly imbricated and thus their distinction in region with poor exposures is sometimes difficult.

The Bôrka Nappe (Leško and Varga, 1980; Mello et al., 1998) shows some close lithological relationships with the underlying Gemericum rocks (Mello et al., 1998; Plašienka et al., 2019; Potočný et al., 2020). The nappe is heavily tectonically dismembered due to a strong metamorphic overprint; its stratigraphy is only based on lithological similarities with analogous unmetamorphosed rock formations. Accordingly, the Bôrka sedimentary succession includes Paleozoic, Triassic and possibly Jurassic formations. The oldest metasedimentary member includes coarse-grained clastic, acid volcanoclastic and volcanic rocks of Permian age (Vozárová et al., 2012). The Early Triassic age is represented by fine-grained clastic sediments (Mello et al., 1998), followed by the most characteristic member of the Bôrka Nappe, the Middle Triassic pale massive marbles and dolostones in association with metabasites and various types of phyllites (Mello et al., 1998). The carbonate complex exhibits syn-sedimentary volcanism in the form of mixed carbonate-volcanoclastic rocks followed by basaltic lava flows associated with abyssal sediments. The volcanic rocks of mafic composition record a geochemical evolution from back-arc basalts (BABB) to enriched and normal mid-oceanic ridge basalts (E-MORB and N-MORB; Ivan, 2002a, b; Faryad et al., 2005). The Late Triassic-Jurassic period is represented by dark siliceous phyllites and distal turbidites. The conditions and age of the HP/LT metamorphism in the Bôrka Nappe were studied by numerous authors (Maluski et al., 1993; Dallmeyer et al., 1996, 2008; Faryad, 1995a, 1995b, 1999; Faryad and Henjes-Kunst, 1997; Mello et al., 1998; Faryad and Hoinkes, 1999; Árkai et al., 2003; Faryad et al., 2005; Vozárová et al., 2008; Putiš et al., 2011, 2014, 2015; Németh et al., 2012; Li et al., 2014; Nemec et al., 2020). The HP/LT metamorphic conditions reaching up to 1.55 GPa at 520 °C (Nemec et al., 2020) were achieved between ca 155 and 172 Ma based on the $^{40}Ar/^{39}Ar$ ages of phengitic micas (Maluski et al., 1993; Dallmeyer et al., 1996, 2008; Faryad and Henjes-Kunst, 1997). In many places, the blueschist-facies metamorphic associations are overprinted by the greenschist-facies isothermal decompression during exhumation from the subduction channel (e.g. Faryad, 1995a, 1995b, 1999; Dallmeyer et al., 2008). From a palaeogeographical perspective, the Bôrka Nappe is interpreted as a fragment of the subducted distal passive continental (Austroalpine-Gemericum) margin facing the Meliata Ocean.

The Meliata Unit *s.s.* represents a sedimentary unit of Jurassic deep-water deposits with olistostromes and olistoliths of various Triassic carbonates and Ladinian radiolarites, but with rarely occurring real oceanic material (Mock et al., 1998 and references therein). The relationships of ophiolite-poor and ophiolite-rich olistostromes and mélanges is not clear, usually they occur separately, but sometimes they are mixed together. The situation where the former underlie the latter, as it was documented in the Darnó Mts of northern Hungary (Dimitrijević et al., 2003; Kovács et al., 2010), cannot be confirmed in the territory of Slovakia, since structural situations mostly indicate the opposite arrangement.

The majority of Meliatic complexes is composed of assorted, tightly imbricated and dismembered mélanges. The polygenous mélanges contain variably sized blocks of basalts, serpentinites, blueschists, acid volcanic rocks, radiolarites of Middle-Late Triassic age, variegated Triassic shallow- and deep-water carbonates, as well as blocks derived from the Variscan, possibly Gemericum basement (gneisses and amphibolites affected by the blueschist-facies overprint – e.g. Faryad and Frank, 2011). All these are embedded in the Jurassic radiolarite-shaley-marly-sandy matrix, whereby the chaotic complexes show a partially sedimentary and partially tectonic origin. A distinct type is represented by a purely serpentinite mélange, formed by brecciated and serpentinized ultramafic rocks and basalts involved in a strongly sheared serpentinite matrix, which was identified as the Bretka Complex by Plašienka et al. (2019).

Biostratigraphical studies of the Meliaticum complexes/formations were primarily based on the conodont fauna (Kozur and Mostler, 1972; Kozur and Mock, 1973a, 1973b; Mock, 1975a, 1975b), subsequently, stratigraphy grounded in radiolarian fauna was also included. Dumitrică and Mello (1982) first determined the red radiolarites (Držkovce locality) as Middle Triassic (Illyrian - Fassanian/Ladinian). Later, at the Bohúňovo locality, red to white ribbon radiolarites were identified as Ladinian (Kozur et al., 1995), proving the affiliation of the rocks to the radiolarite-ophiolite sequence of the Meliaticum. For the red and variegated radiolarites from other localities, such as Meliata, Čoltovo and Jaklovce the age ranges of Anisian (Pelsonian) to Norian were proven (Dumitrică and Mello, 1982; Kozur, 1991; Putiš et al., 2019). These Triassic rocks form blocks or olistoliths in the Jurassic turbidites, olistostromes or mélanges. However, the Middle Jurassic radiolarites are often difficult to distinguish from older blocks. Dumitrică and Mello (1982) determined radiolarites from Bohúňovo as Callovian-Oxfordian in age, considering them as a part of the Silicicum reflecting the deepening of the sedimentation. Kozur et al. (1996) conducted a thorough study of radiolarians at the Meliata type locality. They determined that the grey radiolarites within grey to green turbidites and thin black siliceous shales are of Bajocian-Callovian age (probably also Early Oxfordian age).

METHODS

In this work, we focused on the southernmost occurrences of the Meliata Unit in the southern Slovakia, near the villages of Čoltovo, Bohúňovo and Držkovce. Geomorphologically, this area belongs to the CWC/IWC bordering area and the Rimava Basin. At the neighbouring Čoltovo (N 48.499944° E 20.381892°) and Bohúňovo (N 48.505877° E 20.386559°) localities, attention was paid to two old quarries. In Čoltovo, heavy machinery was used by our team to excavate a section (Fig. 2a, b, c). At the Držkovce locality, we studied an old quarry (N 48.548121° E 20.220547°) (Fig. 2g) and the surrounding county close to the village (Fig. 1c). All outcrops were precisely documented and sampled for further biostratigraphical, geochemical and microstructural analyses.

Samples were collected for the lithological and microfacies characteristics, but most importantly for the age determination by radiolarian fauna. Samples were also studied for foraminifera and calcareous nanoplankton, however, without any significant results. At Čoltovo, two sampling campaigns were carried out, first collection of samples from old outcrops (samples MBR) was later supplemented by samples from new excavator dug outs – 6 new sites (CLP1 - CLP6 from the NE to the SW) (Fig. 2b). From the new Čoltovo section, altogether 41 samples were collected from all rock types. From Bohúňovo, located to the north from Čoltovo, 12 samples were obtained. Additional 5 samples come from outcrops at Držkovce. Thin sections were made from all of the samples for further analysis and are stored at the Faculty of Natural Sciences, Comenius University in Bratislava. After the evaluation of samples and thin sections, 22 samples of predominantly radiolarites and siliceous shales were selected and processed using different methods for retrieving radiolarians. Material from the first sampling was dissolved in 5% HF for 48 hours. Second set of samples was processed using two methods, dissolving in 5% HF for 24 hours and in 10% HF for 24 hours. 8 samples yielded identifiable radiolarians. As thin sections show, radiolarians are abundant but very poorly preserved, most probably due to recrystallization and dissolution during diagenesis and further tectonic-metamorphic processes.

Geochemical analyses were performed on the selected siliciclastic sediments from the sedimentary succession at all three locations (Čoltovo, Bohúňovo and Držkovce). Samples from the Meliata Unit *s.s.* type locality near the village of Meliata were also included for comparison (MEL9, MEL16, MBR17). Standard whole-rock wet chemical analyses were used to determine the major, trace, and rare earth elements in the rocks. The samples were analysed using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-ES) and by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) carried out in the Bureau Veritas Mineral Laboratory in Vancouver, Canada and in the ALS geochemical laboratory in Rosia Montana, Romania. Contents of recalculated volatile-free major elements and trace elements contents are presented in Table 1.

RESULTS

Litho-biostratigraphy of the chaotic complexes

Čoltovo, Bohúňovo and Držkovce localities represent slightly different parts of a complicated sedimentary-olistostrome structure belonging to the Meliata Unit and will be described as follows.

Čoltovo locality

The Čoltovo locality starts 20 meters to the east from the new excavated dig outs (N 48.500299° E 20.383630°), with outcrops in red radiolarites and red siliceous siltstones, highly tectonized, slightly metamorphosed. The age of the radiolarites was dated to Late Triassic (early Late Carnian-Early Norian, sample MBR4-B; Fig. 2b).

The newly excavated section at the Čoltovo locality was divided into two distinct parts. The eastern part of the section (sample sets CLP1 to CLP3) is characterized by strongly eroded dark-coloured siliceous siltstones (Fig. 3a, b, c; Fig. 4a) with light grey to green fine-grained sandstones containing fragments and intercalations of various rocks tens of centimetres in diameter, represented by basic volcanoclastic/volcanic rocks and dark coarse-grained crinoidal limestones (Fig. 2e).

Crinoidal limestones vary in structure and composition. They pass from fine-grained to coarser portions with abundant crinoids. Based on thin sections examination, three lithofacies were appointed: 1) very fine calc-siltite (Fig. 3a, b, c, g; Fig. 4b) containing no allochems and rare tiny fragments of bivalve and brachiopod shells, together with agglutinated foraminifera; 2) crinoidal packstone with allochems often pyritized, pressed to each other with jigsaw boundaries, pressure seams and stylolites. The allochems are represented mainly by crinoidal ossicles. The rock also contains clasts of limestones, dolostones and clasts of basic to intermediate volcanic rocks; 3) the third lithofacies is clast-supported fine-grained conglomerate with crinoidal ossicles (Fig. 4c), fragments of bivalve and brachiopod shells. They contain fragments of sterile micritic limestones (locally peloidal limestones), siltstones to sandstones with dark clayey matrix, crystalline limestones and altered basic to intermediate volcanic rocks. Described crinoidal limestones contain nodosariid and lenticulinid foraminifera of unknown age, however the microfacies rules-out the Triassic age and, on the other hand, typical Cretaceous components are missing, thus pointing to the Jurassic age of the rock (possibly Early to Middle).

Siltstones (Fig. 4d) of the Triassic part of the Čoltovo excavations (Fig. 2c, e) also contain blocks of basalts (Fig. 4e) containing spherical voids (bubbles - amygdales) (Fig. 3e), empty or filled (partly or entirely) with calcite, chalcedony, chlorite and zeolites.

In contrast, the western part of the section (CLP4 - CLP6; Fig. 2a, b, f) is less eroded and more compact. Starting from the contact with previous part of the section, white silicified siltstones (Fig. 3c) incorporating basic volcanic material are exposed (Fig. 2f). Siltstones are deformed and strongly fractured, containing cherty layers with very poorly preserved radiolarians. White siltstones pass by a direct contact into red siliceous siltstones with radiolarians (Fig.2f). Red siltstones sporadically form loaf-like structures (Fig. 3h). Radiolarians from these layers are Middle Triassic (Late Anisian-earliest Ladinian) in age (sample CLP4.5A). Important component of the western part of the Čoltovo section are dark red, green and purple radiolarites (Fig. 3d; Fig. 4f) of Middle Triassic age (Late Anisian; sample CLP6.4). Red to white siliciclastic sediments and variegated radiolarites occur in association with basic volcanic rocks (Fig. 2g; Fig. 3f). In the white radiolarites, short "filaments" are preserved.

Volcanic rocks at the Čoltovo section were described in detail by Kantor (1955), who pointed out their macroscopically significant variability and visible transitions. The observed macro- and microscopic structures (divergent, arborescent, vesicular textures) are unique within the context of the basic volcanic rocks of the Western Carpathians and indicate that the solidification process occurred at a remarkably fast rate (Kantor, 1955).

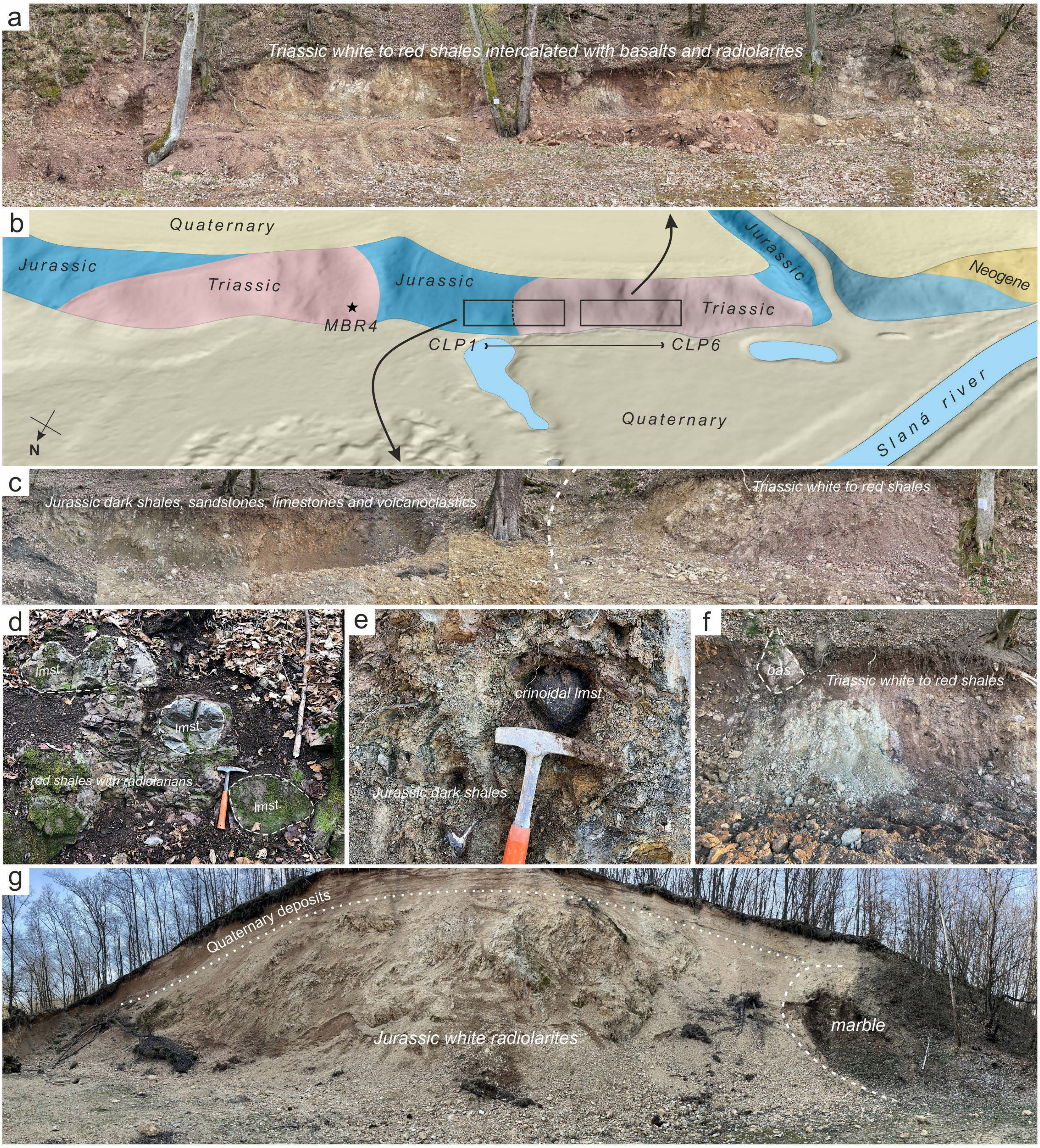

Fig. 2 - Outcrops of the mélange complexes: a - excavated Triassic formations at the Čoltovo locality; b - geological situation at the Čoltovo locality; c - contact of Triassic formations with Jurassic matrix at the Čoltovo locality; d - blocks of limestones in red shales at the Bohúňovo locality; e - heavily weathered dark Jurassic siltstones with blocks of dark crinoidal limestone at the Čoltovo locality; f - white and red shales with blocks of volcanics at the Čoltovo locality; g - strongly deformed Jurassic white radiolarites containing block of crystalline limestone at the Držkovce locality.

Table 1 - Whole-rock major and trace element analyses by inductively coupled plasma mass spectrometry (ICP-MS) and Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-ES) analyses.

Locality	Držkovce		Čoltovo						Bohúňovo	Meliata		
Sample	MBR1	MBR11-1	CLP6.4	CLP4.2B	CLP1.1	CLP5.6	CLP4.5A	MBR4-B	MBR2-C5	MBR17	MEL16	MEL9
Age	*MT*	*MJ*	*MT*	*N/A*	*N/A*	*N/A*	*MT*	*LT*	*MT*	*N/A*	*J*	*N/A*
SiO_2	89.30	95.55	79.26	87.00	89.60	72.40	78.20	75.90	54.00	82.60	86.50	71.40
Al_2O_3	3.41	1.78	9.10	2.91	2.81	12.30	8.61	3.80	7.79	6.90	2.39	0.74
Fe_2O_3	4.89	1.06	4.48	1.80	3.92	5.50	5.68	2.90	19.00	4.66	2.23	1.12
MgO	0.34	0.31	0.87	0.37	0.62	0.95	0.98	1.79	4.14	1.64	0.56	0.27
CaO	0.17	0.09	0.22	4.15	0.32	0.18	0.15	6.00	4.93	0.24	3.57	13.90
Na_2O	0.27	0.10	0.59	0.45	0.54	0.71	0.54	0.12	0.23	0.44	0.04	0.03
K_2O	0.70	0.40	2.42	0.55	0.23	3.58	2.03	0.83	0.79	1.10	0.90	0.24
TiO_2	0.14	0.07	0.43	0.12	0.12	0.56	0.40	0.17	0.39	0.35	0.10	0.03
P_2O_5	0.06	0.04	0.06	0.04	0.07	0.06	0.08	0.04	0.18	0.17	0.04	0.02
MnO	0.16	0.01	0.01	0.07	0.02	0.01	0.04	0.18	0.44	0.02	0.24	0.14
Cr_2O_3	0.002	0.003	0.009	0.002	0.003	0.010	0.006	0.004	0.006	0.005	0.002	<0.002
LOI	1.07	0.60	2.50	4.15	1.28	2.96	2.57	8.20	8.08	2.11	3.31	11.40
Total	100.52	100.00	99.93	101.61	99.53	99.24	99.31	99.96	99.99	100.25	99.89	99.30
Ba	123	45	163	48.6	23.5	220	167	52	101.5	129.5	99.9	20.5
Ni	19	20	28	8	17	16	44	24	128	43	7	2
Sc	4	2	11	4	3	16	10	6	8	8	3	2
Be	<dl	<1	2	<dl	<dl	<dl	<dl	1	<dl	<dl	<dl	<dl
Co	8	2.5	3.4	3	6	5	8	2.9	21	12	4	1
Cs	1.64	1.1	4.9	1.26	0.98	9.25	4.48	1.4	1.96	2.57	1.25	0.55
Ga	5.4	2.6	13.2	3.9	3.3	21.7	14.3	4.4	14.5	10.4	3.9	1.1
Hf	0.96	0.4	2.2	0.83	1.52	3.08	2.45	1	2.3	3.05	0.76	0.15
Nb	3.04	1.9	7.8	3.05	3.02	12.1	8.55	3.6	7.61	9.35	2.72	0.9
Rb	29.1	15.2	95.5	21.8	9.8	153.5	85.4	34	31.4	48	41.3	10.8
Sn	0.8	1	2	1.1	0.5	3.1	1.8	1	2	1.4	0.7	<0.5
Sr	16	11.1	46.7	42.6	24.6	36.7	36.4	41.1	42.9	18.4	45.8	140
Ta	0.2	0.1	0.6	0.1	0.2	0.8	0.6	0.2	0.4	0.7	0.2	<0.1
Th	2.25	1.2	6.5	2.3	3.71	8.04	5.67	3	4.69	6.42	2.02	0.63
U	0.55	0.4	1.6	0.73	1.12	2.88	1.24	0.6	2.78	0.93	0.38	0.21
V	43	23	70	16	47	88	62	23	221	55	15	5
W	0.9	1.3	1.9	1.3	0.5	3.7	1.4	0.7	1.9	1.4	0.6	0.6
Zr	42	18.1	83.4	29	55	123	95	35.2	108	116	30	7
Y	11.2	5.8	13.6	12.9	8.7	17.4	17.6	14	28.9	16.6	6.7	11.8
La	12	5	24.2	4	9.2	25.6	37.3	11.6	17.7	71.1	9.6	7.1
Ce	14.8	9.7	47.7	9	21.3	53.4	59.4	25.3	21.6	141.5	16.4	7.3
Pr	2.49	1.21	5.45	1.26	2.73	6.14	8.28	3.07	3.63	15.9	2.32	1.99
Nd	10.6	5.3	19.4	6.3	12.2	22.2	30.7	14.1	13.8	55.6	8.7	8.6
Sm	1.89	1.08	3.57	2.04	2.66	4.26	6.09	2.98	3.77	8.84	1.89	1.84
Eu	0.4	0.19	0.69	0.45	0.49	0.82	1.32	0.99	1.07	1.84	0.47	0.42
Gd	2.62	1.18	2.96	2.32	2.59	3.57	5.48	2.99	4.59	7.19	1.51	2.47
Tb	0.33	0.17	0.42	0.4	0.32	0.5	0.63	0.48	0.74	0.74	0.18	0.29
Dy	2.17	0.95	2.5	2.33	1.94	2.93	3.74	2.72	4.72	3.66	1.32	1.66
Ho	0.43	0.21	0.57	0.42	0.39	0.69	0.77	0.48	1.02	0.62	0.22	0.32
Er	1.41	0.43	1.84	1.24	0.94	2.16	2.24	1.29	3.14	1.63	0.7	0.8
Tm	0.17	0.07	0.23	0.15	0.15	0.33	0.31	0.16	0.42	0.21	0.07	0.1
Yb	1.18	0.39	1.64	1.05	0.9	2.1	2.06	0.97	2.91	1.68	0.61	0.61
Lu	0.16	0.06	0.27	0.14	0.13	0.4	0.26	0.16	0.39	0.25	0.07	0.07

LOI = Loss on ignition; < dl = below detection limit; MT = Middle Triassic; LT = Late Triassic; MJ = Middle Jurassic; J = Jurassic; N/A = No age available.

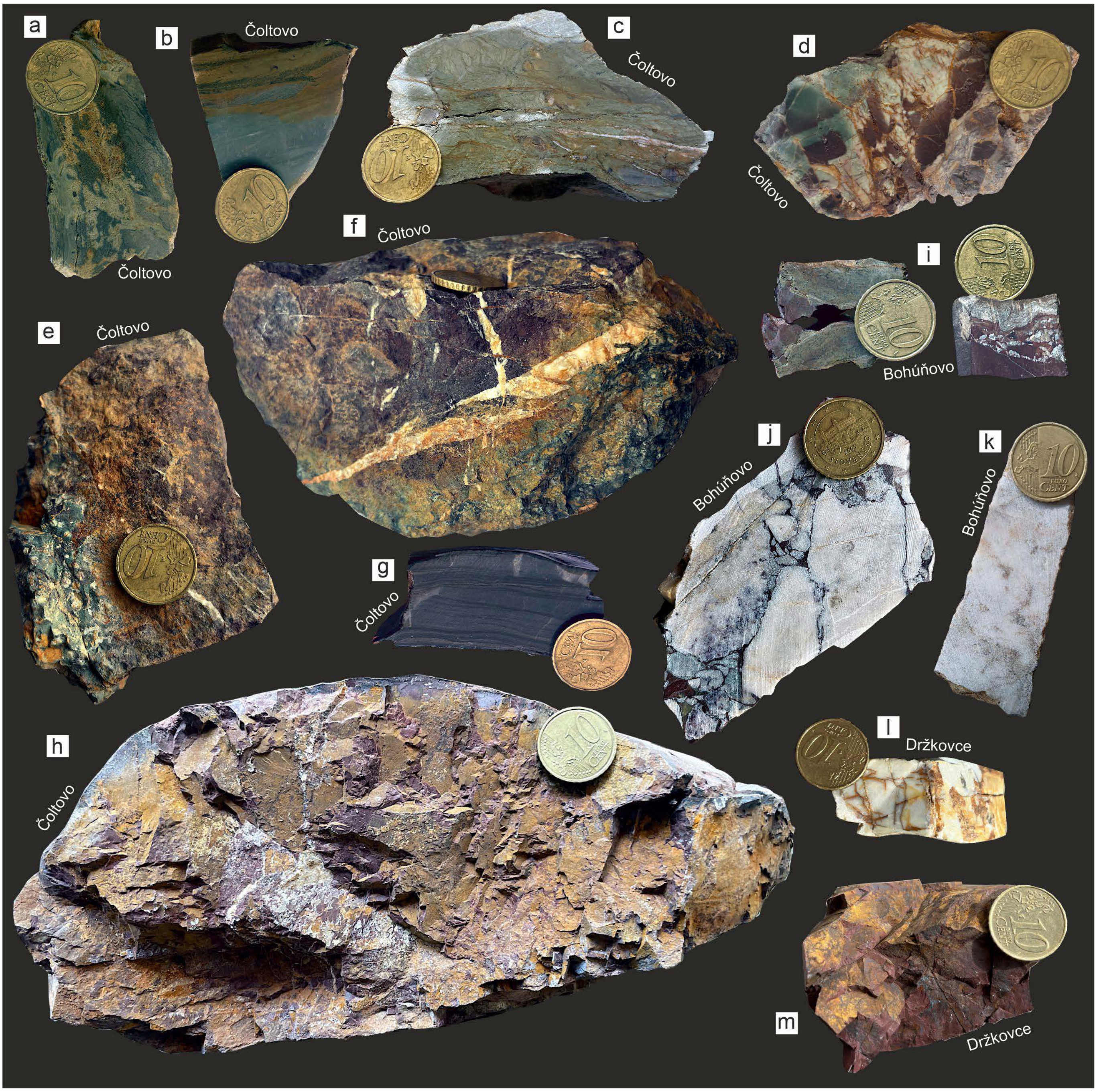

Fig. 3 - Macro samples of typical lithologies in the Meliata mélange; *Čoltovo locality*: a - dark spotted siltstone; b - calcareous siltstones; c - deformed calcareous siltstones; d - brittle deformed variegated radiolarite; e - amygdaloidal basalt; f - radiolarite with volcanic dyke; g - dark laminated siltstone; h - loaf-like radiolarite; *Bohúňovo locality*: i - blocks of Triassic radiolarites in red siltstones; j - clasts of limestones in red siltstones; k - light crystalline limestone; *Držkovce locality*: l - white Jurassic radiolarite; m - red Triassic radiolarite.

Bohúňovo locality

Situation at the Bohúňovo locality differs from the Čoltovo and Držkovce localities, however the lithological composition is more or less typical for the Meliata Unit, with large block of white marbles (Fig. 4g; Fig. 3k) outcropping at the old Bohúňovo quarry. South of the quarry a couple of poorly exposed outcrops occur, previously studied by Lačný et al. (2015). Here, red siliceous siltstones with limestone and radiolarite (Fig. 4h) blocks are present (Fig. 2d). Middle to possibly Late Triassic (Late Ladinian-earliest Carnian) radiolarian assemblage (sample MBR2-A1) was obtained from a radiolarite block. The siliceous matrix around the blocks (Fig. 3i, j) is partly deformed, locally strongly impregnated by opaque Fe-Mn minerals containing radiolarians of unknown age (sample MBR2). The red siltstones microscopically comprise fragments of red radiolarites with generally poorly preserved and partly deformed radiolarians. The matrix is greenish silicite, locally strongly impregnated by opaque Fe-Mn minerals. The second group of blocks is represented by brecciated limestones (Fig. 4i) with two types of clasts: 1) skeletal and sphinctozoan reef limestone containing voids in the sponges filled by radiaxial fibrous calcite, ostracods, gastropods and agglutinated foraminifera of the genus *Meandrospira* (Fig. 4m, n, o); 2) microbial, microoncoidal and micropeloidal limestones containing numerous determinable and indeterminable micritized allochems and agglutinated foraminifera (Fig. 4j, k, l, p, r, q, s).

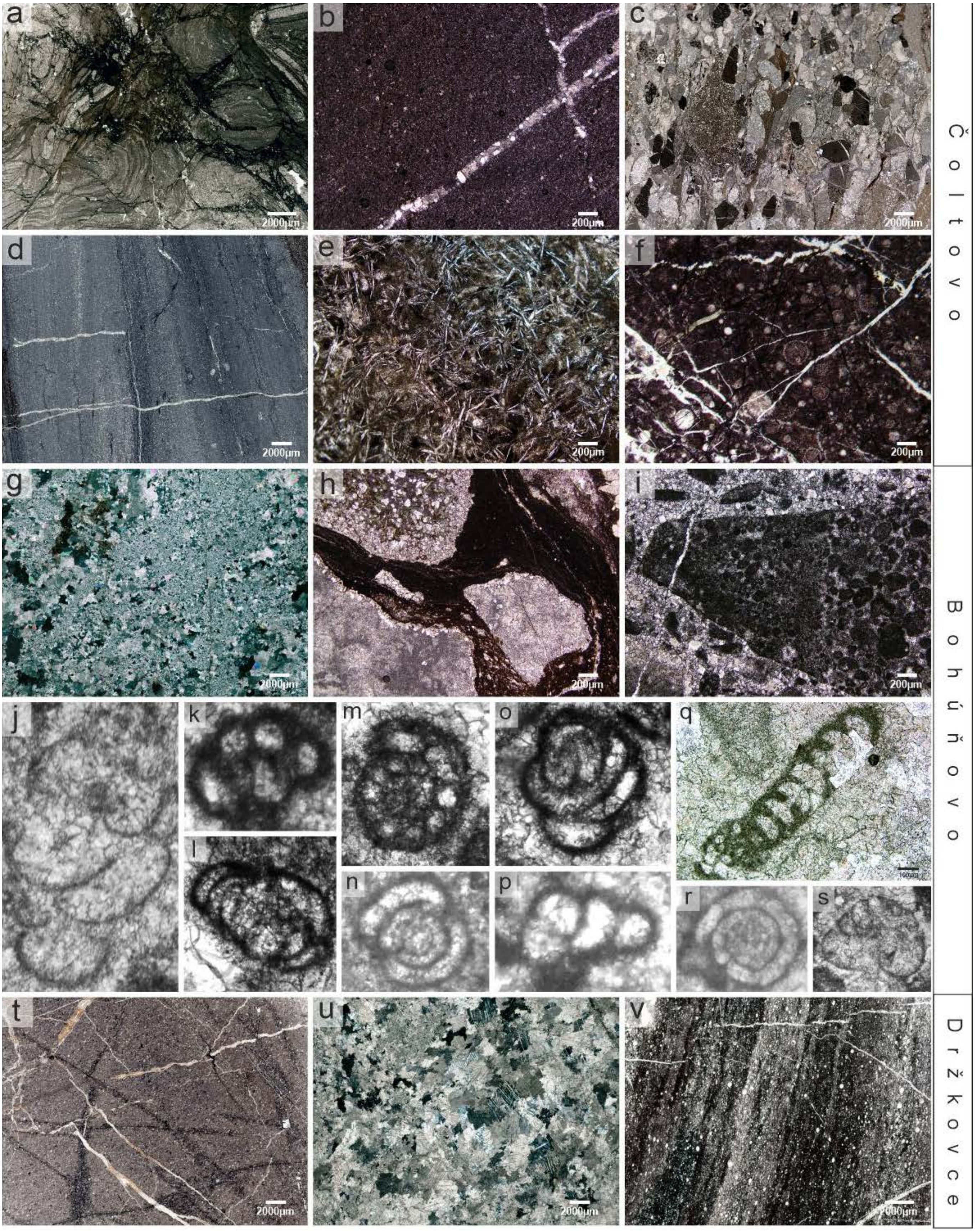

Fig. 4 - Microfacies: *Čoltovo locality*: a - dark Jurassic shales; b - black siltstone (fine-grained part of the crinoidal limestone formation); c - coarse-grained black crinoidal limestone; d - laminated Triassic siltstone; e - basalt block; f - strongly fractured radiolarite with matrix pervasively impregnated by opaque Fe-Mn minerals; *Bohúňovo locality*: g - white crystalline limestone; h - red shales surrounding limestone and radiolarites blocks; i - non-metamorphosed oligomictic brecciated limestone (likely Triassic) with fine-grained sparitic cement. The clasts are fine-grained microoncoidal limestones; j - *Diplotremina astrofimbriata* Kristan-Tollmann; k, l - unidentifiable benthic foraminifera; m, n - *Meandrospira dinarica* Kochansky-Devidé and Pantić; o, p - unidentifiable benthic foraminifera; q - *Endotebanella* sp. cf. *E. pentacamerata* Salaj; r - *Meandrospira dinarica* Kochansky-Devidé and Pantić; s - *Diplotremina astrofimbriata* Kristan-Tollmann. *Držkovce locality*: t - white Jurassic radiolarites at Držkovce quarry; u - white crystalline limestone; v - red Triassic radiolarite impregnated by opaque Fe-Mn minerals.

Držkovce locality

The Držkovce locality consists of two outcrops. One underneath the main road, in the Východný Turiec stream (N 48.549939° E 20.221539°), where red radiolarites of Middle-Triassic age appear (Late Anisian-earliest Ladinian, sample MBR1; Fig. 3m; Fig. 4t). Second part of the outcropping Meliata Unit at the Držkovce locality is an old quarry in white thin-layered strongly tectonized Middle Jurassic (Middle Bathonian to Late Bathonian-Early Callovian) radiolarites (samples MBR11-1 and MBR11-2; Fig. 3l; Fig. 4v) with a white recrystallized limestone block of probably Triassic age (Fig. 2g; Fig. 4u).

Radiolarian analyses

For taxonomy and age ranges of the Middle and Late Triassic radiolarian markers we refer mainly to Dumitrică et al. (1980), Kozur and Mostler (1994), Kozur (1996), Tekin (1999), Goričan et al. (2005), Bragin (2007, 2011), O'Dogherty et al. (2009a) and Stockar et al. (2012). The exact assignment of Triassic radiolarian faunas to zones was generally unattainable, due to a relatively poor preservation of the radiolarians, missing indicative radiolarian species and lack of other controlling, stratigraphically important fossils.

For the taxonomy and ranges of the Middle Jurassic radiolarians we used Baumgartner et al. (1995), Goričan (1994), O'Dogherty et al. (2009b, 2017), and we apply the Unitary Association Zones (UAZ95).

Čoltovo locality

Sample MBR4-B

The rock is a laminated red radiolarite highly tectonized, slightly metamorphosed with very poorly preserved radiolarians and occasional sponge spicules (Fig. 5). Whole parts of the rock are strongly silicified. The radiolarians are mostly spherical, commonly flattened and poorly sorted, as indicated by their variable size, however small forms prevail in the residuum. The best preserved radiolarians are impregnated by opaque Fe-Mn minerals. In the silicified parts, carbonate rhombohedra representing carbonate exsolutions described by Mišík (1993) occur. The rock is penetrated by veinlets filled with calcite and chalcedony.

Sample MBR4-B contains Triassic radiolarian fauna, such as genera *Triassocampe* and *Capnuchosphaera*. Occurring *Pachus multinodosus* is described from the early Late Carnian to the Early Norian (Tekin, 1999; Ishida et al., 2005; Bragin, 2007; Tekin et al., 2012). Sample MBR4-B includes *Capnuchosphaera triassica* appearing from the Early Carnian to Early Norian in the *Epigonolella abneptis* Conodont Zone (Tekin, 1999; Bragin, 2007). Based on the co-occurrence of these species and the genus *Triassocampe* (Early Anisian-Early Norian after O'Dogherty et al., 2009a) the early Late Carnian to Early Norian age of the sample is most probable (Fig. 5a-h).

Annulotriassocampe sp. cf. *A. sulovensis* (Kozur and Mock)
Capnuchosphaera sp. cf. *C. concava* De Wever
Capnuchosphaera sp. cf. *C. constricta* (Kozur and Mock)
Capnuchosphaera triassica De Wever
Pachus multinodosus Tekin
Triassocampe sp.

Age: Late Triassic (early Late Carnian-Early Norian for the presence of *Capnuchosphaera triassica, Pachus multinodosus* and *Triassocampe* sp.).

Sample CLP4.5A

The rock is a red very fine-grained siliceous siltstone with opaque Fe-Mn matrix. The radiolarians are mostly spherical, poorly sorted as indicated by their variable size; some are flattened. They are filled with chalcedony. Quartz and calcite veinlets cut the entire rock.

Specie *Triassocampe deweveri* is described as appearing in the Late Anisian-Early Ladinian (Bragin, 1991; Feng et al. 2001) nonetheless *T. scalaris* and *T. deweveri* commonly occur in the *Spongosilicarmiger italicus* Radiolarian Zone (Early Fassanian in Kozur and Mostler, 1994). Sample CLP4.5A also contains *Pseudostylosphaera longispinosa* ranging from Early Ladinian-Late Ladinian (already in the *S. italicus* Zone) up to the Early Carnian? (Tekin, 1999; Stockar et al., 2012) and in Thassanapak et al. (2011) as already Anisian to Early Ladinian. Sample includes *Paroertlispongus multispinosus* of Late Anisian-Early Ladinian/Late Fassanian age (Goričan et al., 2005), and Stockar et al. (2012) describe its FO in the *S. transitus* Zone (Late Anisian/Illyrian) up to the Early Ladinian (Early Fassanian, *Eoprotrachyceras curionii* Ammonoid Zone). Sample includes *Oertlispongus inaequispinosus* appearing from the Late Anisian/Middle-Late Illyrian (common from the middle of *Reitziites reitzi* Ammoinoid Zone) (Brack et al., 2005; Budai and Vörös, 2006) to Early Ladinian/Early Fassanian (*E. curionii* Zone) (Balini et al., 2010), then becomes rare up to the *Pterospongus priscus* Subzone of the *Muelleritortis cochleata* Radiolarian Zone (correlatable with the lower part of the *Protrachyceras archelaus* Ammonoid Zone) (Fig. 5i-z).

Archaeocenosphaera sp.
Archaeocenosphaera ? sp.
Archaeospongosphaera sp.
Eptingium sp.
Oertlispongus inaequispinosus Dumitrică, Kozur and Mostler
Paroertlispongus multispinosus Kozur and Mostler
Pentactinocarpus sp.
Pseudostylosphaera sp. cf. *P. compacta* (Nakaseko and Nishimura)
Pseudostylosphaera longispinosa Kozur and Mostler
Triassocampe deweveri (Nakaseko and Nishimura)
Triassocampe scalaris Dumitrică
Triassocampe sp.

Age: Middle Triassic (Late Anisian-earliest Ladinian based on the presence of *Paroertlispongus multispinosus* and *Oertlispongus inaequispinosus*).

Sample CLP6.4

The rock is strongly tectonized purple and green laminated radiolarite, locally pervasively impregnated by opaque Fe-Mn minerals. The radiolarians (mostly spherical) are poorly preserved, generally as phantoms, often flattened. Their size is variable, which indicates poorer sorting. The rest is obliterated by silicification. Locally, thin veinlets with opaque Fe-Mn minerals subparallel to lamination are present.

The radiolarian assemblage includes *Spongopallium contortum* appearing in the Middle Triassic (Dumitrica et al., 1980) and in Ito et al. (2000) it is referred to as a characteristic specie of the Anisian-Ladinian. *Triassospongosphaera multispinosa* also appears in the sample and its age range is recorded as Late Anisian to Ladinian (Bragin, 2011), in other publications as Late Anisian to Middle Carnian (Kozur et al., 1996; Kozur and Mostler, 1979, 1981; Stockar et al., 2012). Species *Canoptum inornatus* ranges from the Late Ladinian (*Muelleritortis cochleata* Zone) to the Early Carnian (*Tritortis kretaensis* Radiolarian Zone) (Tekin, 1999). This sample also contains genus *Parasepsagon* of Middle-Late Anisian age (O´Dogherty et al., 2009a) (Fig. 5aa-ai).

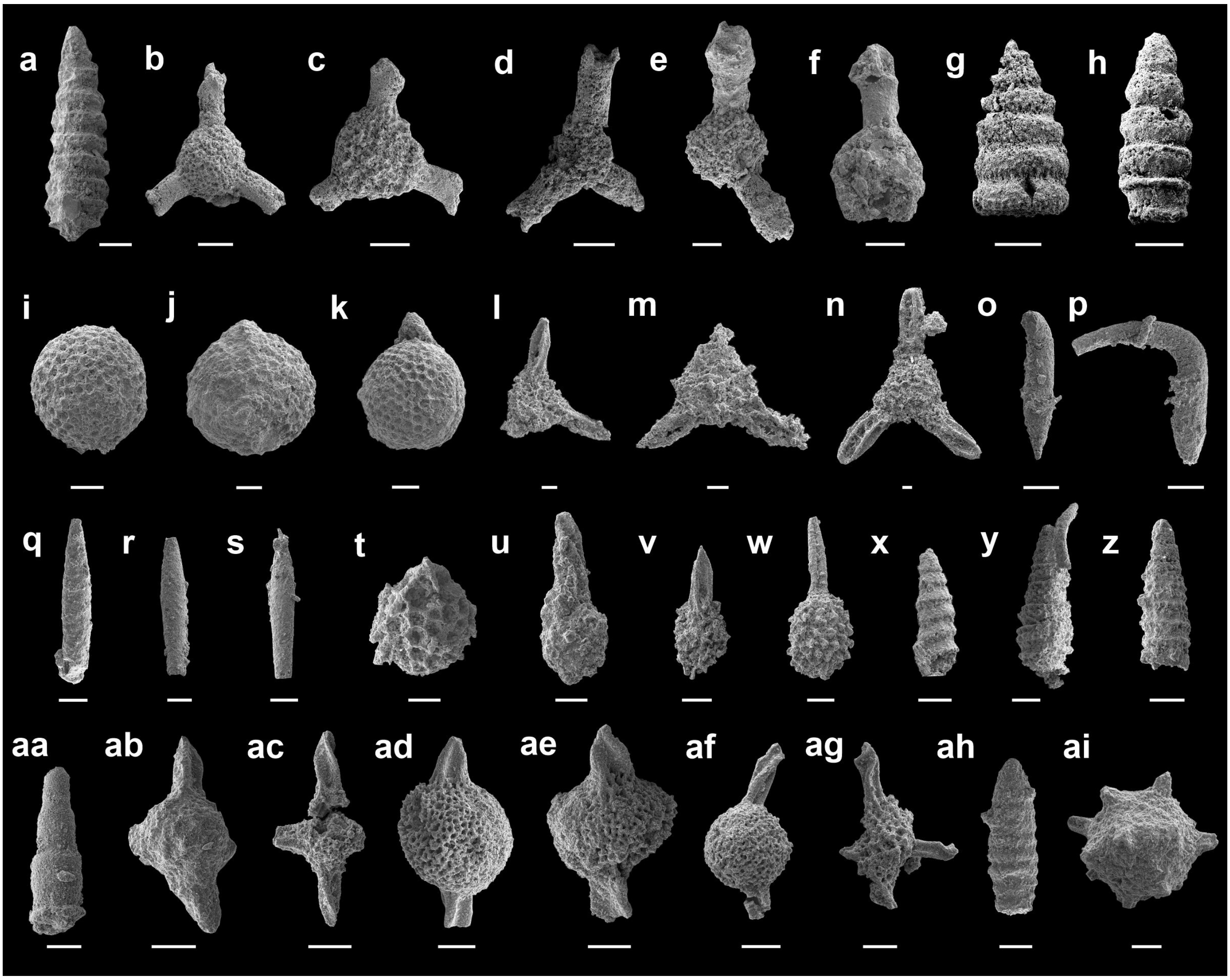

Fig. 5 - All scale bars represent 50 µm. Radiolarians from sample MBR4-B: a - *Annulotriassocampe* sp. cf. *A. sulovensis* (Kozur and Mock); b, c, d - *Capnuchosphaera* sp. cf. C. *concava* De Wever; e - *Capnuchosphaera* sp. cf. C. *constricta* (Kozur and Mock); f - *Capnuchosphaera* triassica De Wever; g - *Pachus multinodosus* Tekin; h - *Triassocampe* sp.
Radiolarians from sample CLP4.5A: i - *Archaeocenosphaera* sp.; j - *Archaeocenosphaera* ? sp.; k - *Archaeospongosphaera* sp.; l, m, n - *Eptingium* sp.; o, p - *Oertlispongus inaequispinosus* Dumitrică, Kozur and Mostler; q, r, s - *Paroertlispongus multispinosus* Kozur and Mostler; t - *Pentactinocarpus* sp.; u, v - *Pseudostylosphaera* sp. cf. *C. compacta* (Nakaseko and Nishimura); w - *Pseudostylosphaera longispinosa* Kozur and Mostler; x - *Triassocampe* sp.; y - *Triassocampe deweveri* (Nakaseko and Nishimura); z - *Triassocampe scalaris* Dumitrică.
Radiolarians from sample CLP6.4: aa - *Canoptum inornatus* Tekin; ab - Eptingiid sp.; ac - *Parasepsagon* sp.; ad, ae - *Spongopallium contortum* Dumitrică, Kozur and Mostler; af - *Spongopallium* sp. cf. *S. crassum* Tekin and Mostler; ag - *Tiborella* sp.; ah - *Triassocampe* sp.; ai - *Triassospongosphaera multispinosa* (Kozur and Mostler).

Canoptum inornatus Tekin
Eptingiid sp.
Parasepsagon sp.
Spongopallium contortum Dumitrică, Kozur and Mostler
Spongopallium sp. cf. *S. crassum* Tekin and Mostler
Tiborella sp.
Triassocampe sp.
*Triassospongosphaera multispinosa (*Kozur and Mostler)
Age: Middle Triassic (Late Anisian for the presence of *Triassospongosphaera multispinosa* and *Parasepsagon* sp.).

Bohúňovo locality
Sample MBR2-A1

Rock is a laminated red radiolarian-bearing shale with clasts of marbles. Rock has siliceous matrix strongly impregnated by opaque Fe-Mn minerals. The radiolarians are mostly sphaerical and poorly sorted, as indicated by their variable size. Their outer layers are visibly separated from the inner filling by thin opaque laminae. Radiolarite contains sponge spicules and bowl-like organic remnants (fish?). The rock is penetrated by chalcedonic veinlets.

Most important species in the sample is *Muelleritortis cochleata* belonging to the *M. cochleata* Zone (Late Ladinian) (Kozur and Mostler, 1994), appearing from the Late Ladinian to earliest Carnian (base of the *T. kretaensis* Zone) (Tekin, 1999) (Fig. 6a-h).
Archaeocenosphaera sp.
Eptingiid sp.
Muelleritortis cochleata (Nakaseko and Nishimura)
Pseudostylosphaera sp.
Triassocampe sp.
Tritortis sp.

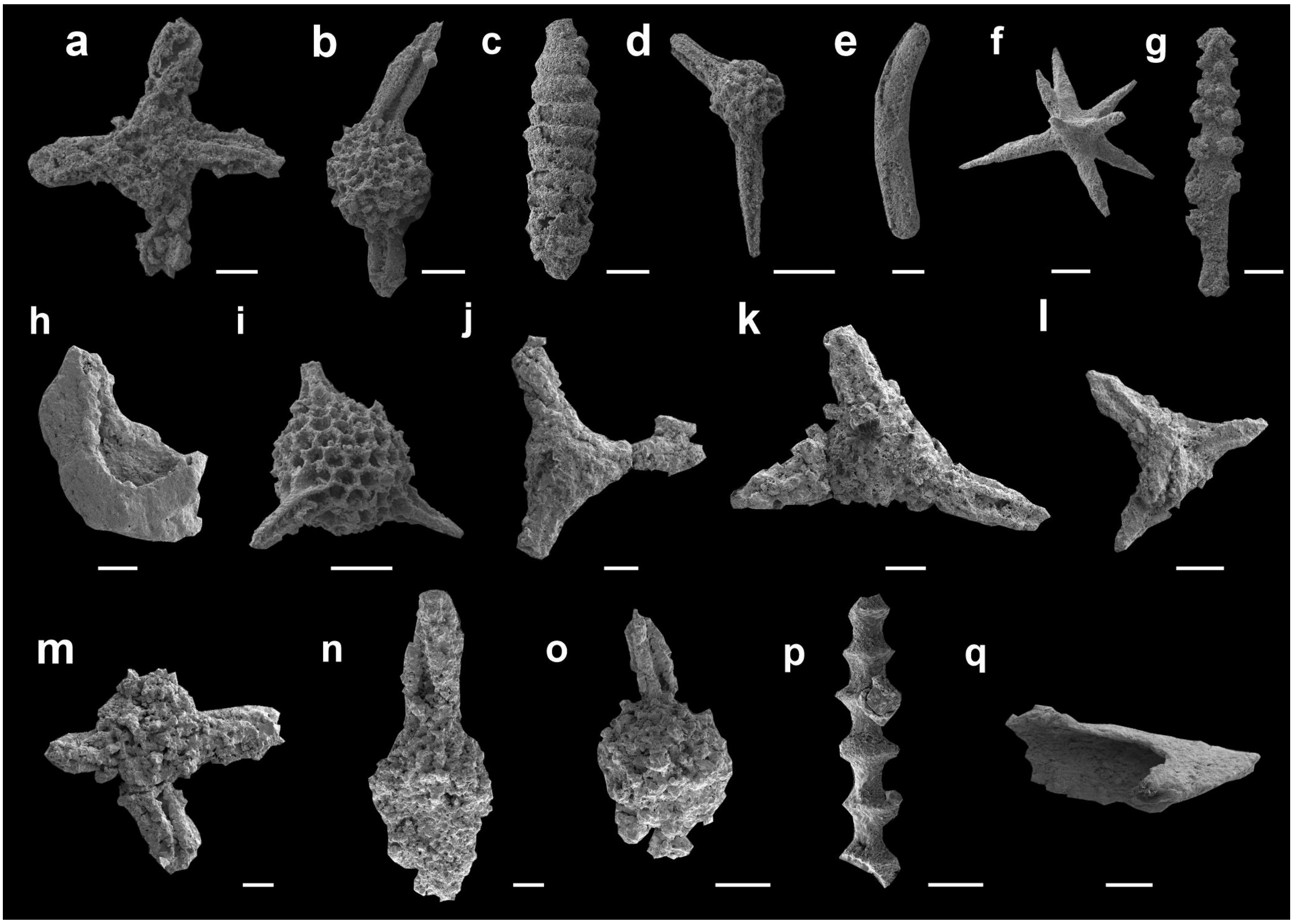

Fig. 6 - All scale bars represent 50 μm. Radiolarians from sample MBR2-A1: a - *Muelleritortis cochleata* (Nakaseko and Nishimura); b - *Pseudostylosphaera* sp.; c - *Triassocampe* sp.; d - *Tritortis* sp.; e - sponge spicule (monaxon); f - sponge spicule (triaxon); g - sponge spicule; h - fish remnants?
Radiolarians from sample MBR2-B: i, j - Eptingiid sp.; k - *Eptingium manfredi* Dumitrică; l - *Eptingium* sp.; m - *Muelleritortis* sp.; n, o - *Pseudostylosphaera* sp.; p - sponge spicule; q - fish remnants?

Age: Middle to possibly Late Triassic (Late Ladinian-earliest Carnian for the presence of *Muelleritortis cochleata*).

Sample MBR2-B

Rock is a laminated red radiolarite, containing sponge spicules, and it is microscopically identical with sample MBR2-A1.

This sample contained only few specimens of poorly preserved radiolarian fauna determinable on the genus level, except for the species *Eptingium manfredi*. *E. manfredi* is described as occurring in the Late Anisian/Illyrian to Early Ladinian/Fassanian (Dumitrică, 1978; Dumitrică et al., 1980; Kozur and Mostler, 1994; Kozur et al., 1996; Stockar et al., 2012). The age of the sample can also be indicated by the presence of the genus *Muelleritortis*, which occurs from the Ladinian to Early Carnian (O´Dogherty et al., 2009a) (Fig. 6i-h).

Eptingium manfredi Dumitrică
Eptingium sp.
Muelleritortis sp.
Pseudostylosphaera sp.

Age: Middle Triassic (Early Ladinian for the presence of *Eptingium manfredi* and *Muelleritortis* sp.).

Držkovce locality

Sample MBR1

The rock is a red laminated radiolarite with radiolarians not sorted by size in the laminae and strongly impregnated by opaque Fe-Mn minerals. The radiolarians (exclusively spherical, partly flattened) are relatively large and filled with microquartz, sponge spicules appear sporadically. The outer layers of radiolarians are well preserved, which is emphasized by Fe-Mn coatings.

Few radiolarians from this sample were determined generally on the genus level. Obtained *Paroertlispongus multispinosus* with a medially widened main spine is an advanced form and first appears in the Late Anisian/Illyrian in the *Tetraspinocyrtis laevis* Radiolarian Zone or *Spongosilicarmiger transitus* Radiolarian Zone ranging to the Early Ladinian/ Early Fassanian (*E. curionii* Ammonoid Zone) (Goričan et al., 2005; Stockar et al., 2012) (Fig. 7a-c).

Triassocampe sp.
Pseudostylosphaera sp.
Paroertlispongus multispinosus (Kozur and Mostler)

Age: Middle Triassic (Late Anisian-earliest Ladinian for the occurrence of *Paroertlispongus multispinosus*).

Sample MBR11-1

The rock is a white tectonized radiolarite. The radiolarians are small in size, mostly spherical and very poorly preserved. They are filled with chalcedony to microquartz. The rock contains sponge spicules, and it is penetrated by a dense network of chalcedonic veinlet, locally passing to coarser quartz and impregnated by opaque Fe-Mn minerals which also fill veinlets cutting the rock.

This sample contained relatively numerous radiolarians belonging to the genera *Eucyrtidiellum*, *Transhsuum* and *Williriedellum*. Middle-Late Jurassic species *Mizukidella kamoensis* belonging to the UA Zones 3-7 (Baumgartner et al., 1995), which has been extended to Middle-Late Oxfordian (Vukovski et al., 2023). *Zhamoidellum ventricosum* refers to the 8-11 UAZ (Baumgartner et al., 1995), however in Smuc and Goričan (2005) *Z. ventricosum* was identified also in a sample belonging to 6-7 UAZ, indicating a probable age range of this taxon to 6-11 UAZ. *Eoxitus dhimenaensis* of the 3-11 UAZ (Baumgartner et al., 1995) was also determined (Fig. 7d-t).

Archaeodictyomitra sp. cf. *A. exigua* Blome
Archaeodicytomitra sp.
Campanomitra sp.
Crococapsa sp.
Eucyrtidiellum sp.
Eoxitus dhimenaensis (Baumgartner)
Mizukidella kamoensis (Mizutani and Kido)
Paronaella sp.
Praewilliriedellum convexum (Yao)
Transhsuum sp.
Transhsuum ? sp.
Williriedellum ? sp.
Zhamoidellum ventricosum Dumitrică

Age: Middle-Late Jurassic (Middle Bathonian 6 UA Zone to Middle-Late Oxfordian 9 UA Zone for the presence of *Zhamoidellum ventricosum* and *Mizukidella kamoensis*).

Sample MBR11-2

Sample MBR11-2 is from the same set of beds as MBR11-1, collected few meters apart. The rock is a radiolarite, with very poorly preserved radiolarians which are obliterated by severe silicification. Sponge spicules are present too. The radiolarians which are mostly visible only as phantoms are generally spherical, well sorted, often flattened. Residuum was likewise full of spherical radiolarians, nevertheless strongly corroded and principally undeterminable. The rock is impregnated by opaque Fe-Mn minerals, which also fill veinlets cutting the rock. Other veinlets are filled with chalcedony, locally passing to coarser quartz.

This sample was poor in preserved radiolarian species. The range of *Striatojaponocapsa conexa* is referable from Late Bajocian to Late Bathonian-Early Callovian age belonging to the UA Zones 4-7 (Baumgartner et al., 1995) (Figg. 7u-x).

Hiscocapsa sp.
Striatojaponocapsa conexa (Matsuoka)
Transhsuum sp. cf. *T. brevicostatum* (Ožvoldová)
Zhamoidellum ventricosum Dumitrică

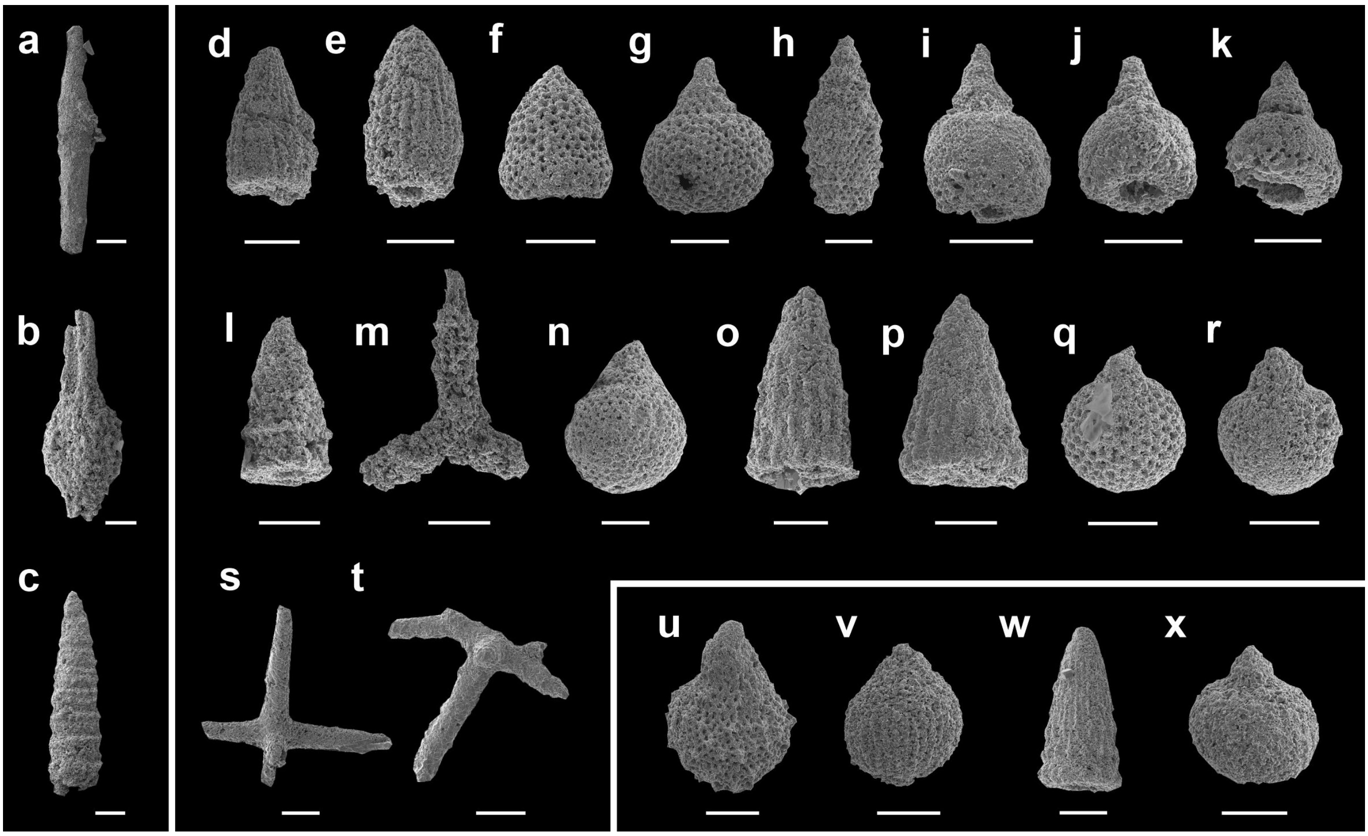

Fig. 7 - All scale bars represent 50 μm. Radiolarians from sample MBR1: a - *Paroertlispongus multispinosus* (Kozur and Mostler); b - *Pseudostylosphaera* sp., c - *Triassocampe* sp.
Radiolarians from sample MBR11-1: d - *Archaeodictyomitra* sp. cf. A. exigua Blome; e - *Archaeodictyomitra* sp.; f - *Campanomitra* sp.; g - *Crococapsa* sp.; h - *Eoxitus dhimenaensis* (Baumgartner); i, j, k - *Eucyrtidiellum* sp.; l - *Mizukidella kamoensis* (Mizutani and Kido); m - *Paronaella* sp.; n - *Praewilliriedellum convexum* (Yao); o - *Transhsuum* sp.; p - *Transhsuum* ? sp.; q - *Williriedellum* ? sp.; r - *Zhamoidellum ventricosum* Dumitrică; s, t - sponge spicule.
Radiolarians from sample MBR11-2: u - *Hiscocapsa* sp.; v - *Striatojaponocapsa conexa* (Matsuoka); w - *Transhsuum* sp. cf. T. *brevicostatum* (Ožvoldová); x – *Zhamoidellum ventricosum* Dumitrică.

Age: Middle Jurassic (Middle Bathonian 6 UA Zone to Late Bathonian-Early Callovian 7 UA Zone for the presence of *Striatojaponocapsa conexa* and *Zhamoidellum ventricosum*).

GEOCHEMISTRY

Geochemical analyses were performed on various types of pelagic sedimentary rocks collected at Čoltovo, Bohúňovo, Meliata and Držkovce localities (Fig. 1). Additionally, three samples (MEL9, MEL16 and MBR17) from the Meliata type locality were encompassed, in order to extend the geochemical data, and for comparison. The occurring lithologies are: 1) dark red radiolarites, 2) red shales with layers of carbonate breccias, and 3) red to white siliceous siltstones in association with basic volcanic rocks and variegated radiolarites.

Generally, chemical components of cherts can be divided into three main groups according to their origin in siliceous deposits (Matsumoto and Ijima, 1983): 1) biogenic silica, originating from siliceous skeletal detritus, 2) components of terrigenous origin, predominately related to clay minerals (SiO_2, TiO_2, Al_2O_3, FeO, MgO, Na_2O, K_2O, Cr, Rb, Zr), and 3) components predominantly derived from marine water (Fe_2O_3, MnO, Cu, Ni, V, Zn). The Si/Si + Al + Fe + Ca ratios between 0.7-1.0 indicate a high content of biogenic silica in our samples (Rangin et al., 1981; Ruiz-Ortiz et al., 1989). The calculated values of the Fe_2O_3/TiO_2, $Al_2O_3/(Al_2O_3 + Fe_2O_3)$, $100xFe_2O_3/SiO_2$, $100xAl_2O_3/SiO_2$, $Fe_2O_3/100\text{-}SiO_2$ and $Al_2O_3/100\text{-}SiO_2$ ratios were plotted into discrimination diagrams about the provenance after Roser and Korsch (1988) and Murray (1994), and depositional environment after Dhannoun and Al-Dlemi (2013) and Mortazavi et al. (2013). Majority of the samples fall within the fields of the pelagic environment affected by terrigenous input from the marginal continental area (Fig. 8a, b), and a shallow water environment (Fig. 8d). In the provenance discrimination diagram according to Murray (1994; Fig. 8c), most of the samples plot in the fields of mature quartzose, i.e. continental terrigenous provenance. All the samples fall in the mentioned fields, however, the sample MBR2-C5 from the Bohúňovo locality is the only one that falls into completely different fields regarding provenance and palaeoenvironment. It corresponds to the deeper-water environment in the vicinity of a mid-ocean ridge with a mafic igneous provenance.

DISCUSSION

Tectonostratigraphic history of the Meliata Superunit

Relying on the existing information about the Meliata Unit and newly achieved litho-biostratigraphical and geochemical data, we discuss the possible processes which preceded Jurassic closure of the Meliata Ocean. Our data describe the depositional environment of the investigated rocks in the Neotethyan Meliata Ocean/Basin from the Middle Triassic up to the Middle Jurassic. The Triassic pre-subduction history and palaeoenvironmental conditions of the Meliata Unit

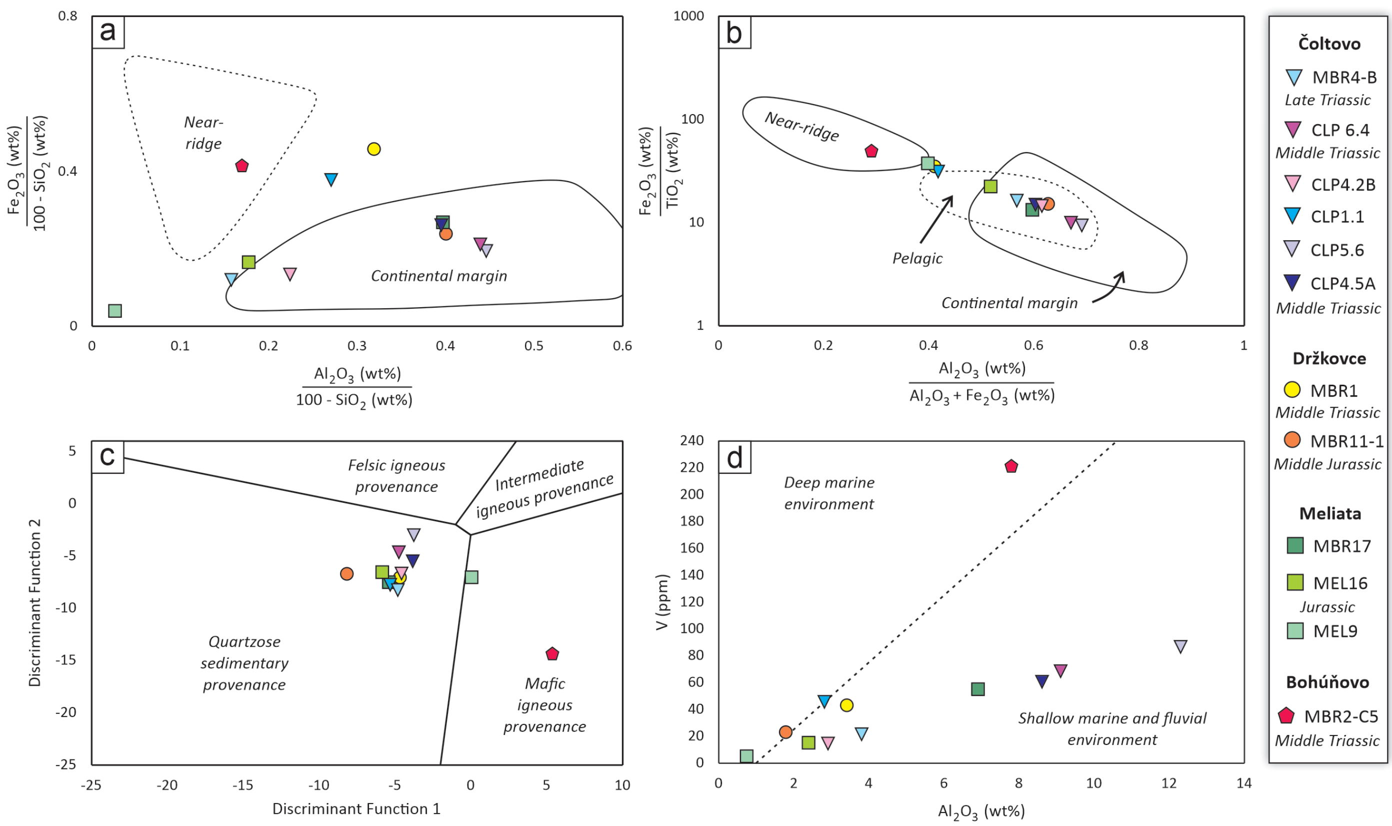

Fig. 8 - Palaeoenvironment diagrams of the Meliata samples based on the geochemistry: a - Diagram of Fe_2O_3/Al_2O_3 ratio normalized on $100\text{-}SiO_2$ (Murray, 1994). Majority of the samples indicating vicinity of the continental margin; b - Fe_2O_3/TiO_2 vs. $Al_2O_3/Al_2O_3+Fe_2O_3$ diagram (Murray, 1994) showing bundling of samples in the field indicating vicinity of the continental margin and pelagic environment; c - Provenance discrimination diagram for shales (Roser and Korsch, 1988) showing mature continental provenance of the samples; d - V vs Al_2O_3 discrimination diagram indicating vicinity to shallow marine environment (Dhannoun and Al-Dlemi, 2013; Mortazavi et al., 2013).

are closely connected with later subducted lower plate margin of the CWC (blueschist-facies Bôrka Nappe) (see Fig. 10 in Plašienka, 2018).

The formation of the Meliata Ocean was preceded by a continental rifting process, which began during the Permian. Rifting is documented by the sedimentation of mainly coarse-grained clastic sediments associated with acid volcanic rocks of the lowermost part of the Bôrka Nappe (Mello et al., 1998). These are followed by the Early Anisian ramp and platform limestones, which were suddenly, during the Pelsonian, substituted by deep-marine pelagic sedimentation (Fig. 9). This event was recognized at numerous localities (e.g. Kozur, 1991; Mock et al., 1998) and is interpreted as the breakup phase and opening of the Meliata Ocean. As a result, the future Austroalpine units, including the peripheral Gemericum, formed the northern passive margin. The nature of the possible southern margin is not clear, since ambiguous views consider the Meliata Ocean either as the back-arc basin developed inboard the European Plate due to northward subduction of Paleotethys (e.g. Stampfli and Borel, 2002), or as a north-western gulf of the large-scale Neotethyan oceanic realm (e.g. Schmid et al., 2008). Since the Late Anisian, the Meliatic sedimentary environments embraced the distal passive margin and adjacent parts of the ocean floor (Gawlick and Missoni, 2019 and references therein).

Based on the studied Čoltovo, Bohúňovo and Držkovce localities, the story of the Meliata Ocean started on a continental slope and rise with deposition of Middle Triassic red and green siliceous rocks, shales and limestones that are presently associated with mafic volcanic rocks. The Middle Triassic age of these formations was proved by radiolarian fauna and associated with carbonate/volcanic formations in the Bôrka Nappe, which were determined by U-Pb LA-ICP-MS zircon dating as 243-249 Ma (Putiš et al., 2019; Potočný et al., 2022). Middle-Upper Triassic sedimentary formations exposed in the Čoltovo section are composed of silty and fine-grained radiolarian-bearing siliceous shales and radiolarites. Geochemical analyses reveal terrigenous provenance of the mature, quartz-dominated siliciclastic material, most probably derived from the northern (Austroalpine) passive margin. This material was transported from the margin to the oceanic slope or rise. Relatively shallow marine environment suggested by the results from the geochemistry (Fig. 8d), and also by the presence of sponge spicules (Triassic sponges inhabited generally shallow marine environments), possibly indicates relative closeness to the continental margin, but not necessarily depositional environment. The variegated, mostly red Middle Triassic radiolarites form isolated, tectonically inserted blocks within the shaly-silty matrix.

Continuous spreading of the Meliata Ocean resulted in the subduction process starting at the Triassic-Jurassic boundary as deduced from the crystallization of metamorphic monazites in the Bôrka Nappe (Potočný et al., 2023). The Early Jurassic age is possibly indicated by the presence of black crinoidal limestones and by pelagic clastic deposits without any fossil evidence. Their age is assumed only on the basis of the position, overlying the Triassic sequences of the Bôrka Nappe (Mello et al., 1998). The gradual closing and shortening of the oceanic realm led to the processes that produced the most characteristic feature of the Meliata Unit *s.s.*, the Jurassic olistostrome formations. They are represented by Middle Jurassic turbiditic siliciclastic sediments interlayered with cherty sequences, containing olistoliths/blocks of the Middle to Upper Triassic carbonates, radiolarites (Fig. 9) (Kozur

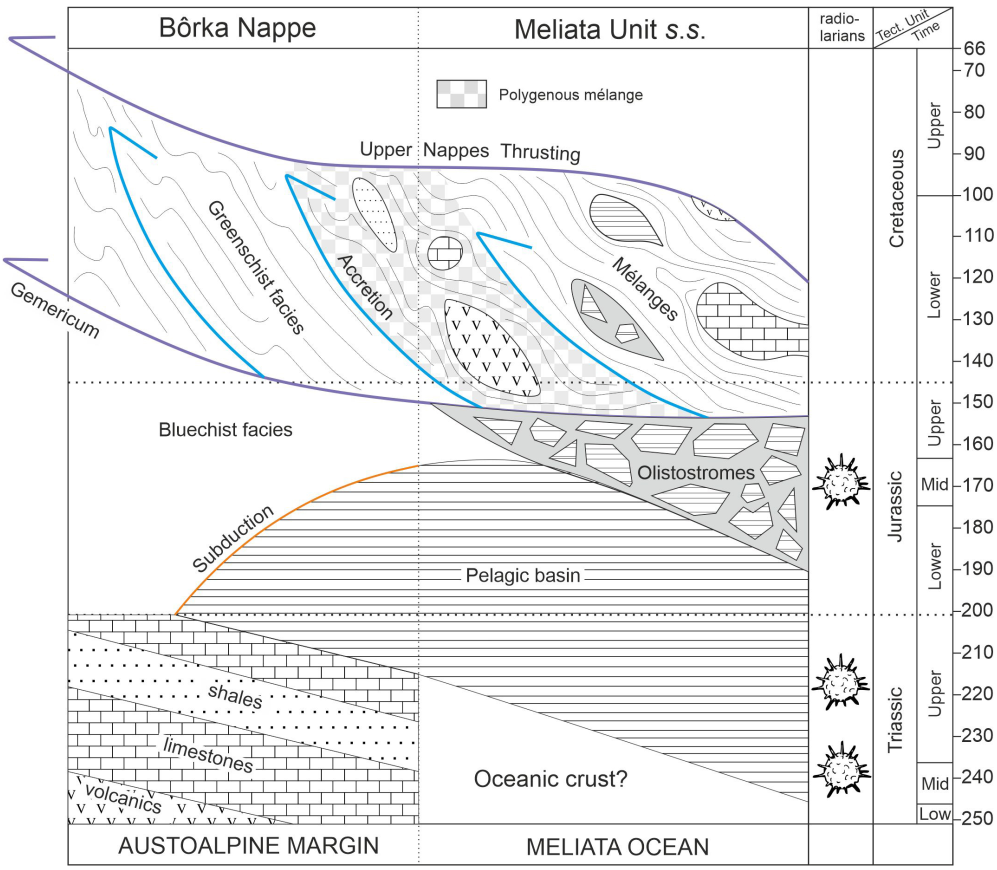

Fig. 9 - Triassic to Cretaceous tectonostratigraphic evolution of the Meliata Unit.

et al., 1996) and N-MORB basalts (Putiš et al., 2019). The rocks exposed in the Držkovce quarry represent the cherty sequence with Middle Jurassic radiolarians in a direct contact with a large olistolith of Triassic carbonate/marble (Fig. 2g). The Jurassic part of the Čoltovo section consists of dark siliceous shales, silicified siltstones and turbiditic sandstones with a few layers and loose blocks of allodapic crinoidal limestones and possibly Triassic volcanic rocks.

Ocean closure and subduction were continuing, the peak of blueschist metamorphic conditions of the continental and inferred oceanic crust was constrained between 160-150 Ma ($^{40}Ar/^{39}Ar$) and 155-152 Ma (K-Ar) in the Bôrka Nappe (Dallmeyer et al., 1996, 2005; Maluski et al., 1993; Faryad and Henjes-Kunst, 1997). Subduction of the Meliata Ocean was followed by exhumation and formation of the accretionary wedge between ca. 150-130 Ma (Li et al., 2014; Vozárová et al., 2014; Putiš et al., 2015; Potočný et al., 2023) and by its subsequent thrusting above the Gemericum. Ensuing tectonic processes associated with stacking of the underlying Gemericum and Veporicum resulted in the collapse of the accretionary complex with later compressional or transpressional reworking. The transformation of the accretionary wedge into mélanges has been caused by these post-subduction processes. The matrix of the olistostromes was partially eliminated by the later thrusting of the Meliata Unit, where the dark silty sediments could have possibly served as detachment horizons lubricating the thrust planes. The fact that different localities may represent different thrust sheets is also supported by their differences in composition, the presence of ophiolites (Bretka, Dobšiná, Jaklovce locality – Putiš et al., 2015; Plašienka et al., 2019) and tectonization.

Although some authors interpreted the Čoltovo locality as an olistostrome with transition to normal stratigraphic succession (Mello and Gaál, 1984; Gaál, 1987), our data prefer a mélange origin as a result of the Jurassic subduction, detachment of oceanic pelagic sediments, tectonic mixing with oceanic volcanics and slices of Jurassic sedimentary formations and final incorporation into an accretionary wedge that was thrust over the former passive margin of the lower Austroalpine - Gemericum foreland.

Correlation of the western Tethyan ophiolite-bearing mélanges

The term mélange was introduced more than a century ago and was repeatedly used in various meanings since. In the recent literature, the term mélange is applied in different connotations referring to their origin and tectonic settings (see Festa et al., 2010, 2012, 2019 and Gawlick and Missoni, 2019 for the reviews). According to the most frequent usage, a mélange is characterized by a disorganized block-in-matrix structure developed by deformation processes like shearing and mixing of various, partially exotic components and commonly (but not always) also ophiolitic material. Mélanges should form mappable bodies that have tectonic contacts with surrounding complexes (e.g. Hsü, 1968, 1974). As such, mélanges are predominantly formed in convergent tectonic settings and are particularly related to the oceanic suture zones and/or obducted ophiolite complexes. However, the term mélange is often used in a broader sense, including the chaotic sedimentary bodies formed by the mass-transport depositional mechanisms. Unlike the mélanges *s.s.*, individual slide blocks (olistoliths), debris flows, olistostromes and scarp breccias may be represented in various active tectonic settings, including the rifting-related extensional/transtensional and syn-orogenic shortening/thrusting situations (e.g. Plašienka, 2012). Provided that the sedimentary mass-flow bodies are subsequently pervasively sheared, their distinction from purely tectonic mélanges is difficult or impossible. As argued for instance by Raymond (1984), Festa et al. (2012) or Gawlick and Missoni (2019), mélanges and broken formations may represent variable transitional elements between the sedimentary mass-transport deposits and tectonic mélange end members. Accordingly, the term mélange should be used in a descriptive, non-genetic sense. Structural types of the chaotic complexes are controlled by factors like the degree of lithification, the clasts to matrix ratio and competence contrasts, tectonic setting, kinematic and P-T conditions of deformation etc. As a result, the chaotic sedimentary body may be buried within a thrust stack or accreted below an accretionary wedge, pervasively sheared and mixed with extraneous components, or imbricated and intermixed with ophiolitic mélanges in suture zones. Hence, the mass-transport sedimentary body, which was generated by the same contractional tectonic processes, which finally caused its burial and pervasive deformation, may be designated as the sedimentary mélange, although this term does not comply with the original definition (Gawlick and Missoni, 2019).

We designate the Meliatic chaotic block-in-matrix rock units as polygenous mélanges to accentuate their polyphase structural evolution and polygenetic composition of components derived from the footwall (blueschist-facies metamorphic rocks exhumed from the subduction channel) and hanging wall complexes (very low-grade deep-marine metasediments with exotic blocks representing the accretionary complex). These are associated with ophiolitic breccias as witnesses of the incorporated oceanic basement rocks. Such complexes document the along-strike differences in the sedimentary and structural evolution of the Meliata suture zone from the rifting/spreading, through the subduction/accretion up to the collision/suturing processes.

A comprehensive review of sedimentary mélanges occurring in the Alpine-Carpathian-Dinaridic, i.e. western Tethyan regions was provided by Gawlick and Missoni (2019). Designated as constituents of the Tethyan Belt (Missoni and Gawlick, 2011a), mélange units of similar composition, age and position occur from the Hellenides and Albanides (e.g. Gawlick et al., 2008; Bortolotti et al., 2013), through Dinarides (Chiari et al., 2011; Gawlick et al., 2009, 2016, 2017, 2020; Djerić et al., 2024), Northern Calcareous Alps (Frisch and Gawlick, 2003; Missoni and Gawlick, 2011a, b; Gawlick and Missoni, 2015; O'Dogherty et al., 2017; Drvoderic et al., 2023) up to the Rudabánya-Bükk region of the Internal Western Carpathians (NE Hungary; see Dimitrijević et al., 2003; Kövér et al., 2009, 2018; Kovács et al., 2010; Kiss et al., 2012; Haas et al., 2013).

The Western Carpathian mélange complexes in SE Slovakia, which are an integral and characteristic constituent of the Meliatic Superunit, share many common attributes with other Tethyan mélanges. At the same time, they exhibit several important differences pointing to the along-strike diversities in tectonic evolution of the Tethyan orogenic belt. According to Gawlick and Missoni (2019), the most important common features are: 1) the Middle-Late Triassic passive margin palaeogeographic setting of the mélange components derived from the shelf and continental slope facies zones; 2) correlative tectonostratigraphy and identical event succession from the late Middle Anisian rifting and breakup of the Neotethys Ocean, through the Middle-Late Triassic passive margin stage, Early-Middle Jurassic subduction, ophiolite obduction and mélange formation, and the Late Jurassic closing of the Triassic oceanic domains and deposition of shallow-water carbonate platforms sealing the nappe structures. On the other hand, the Meliatic units include some elements that are not known from other parts of the Neotethyan Belt, and vice-versa lack some others which are characteristically present there (see also Plašienka et al., 2019): 1) comparatively large blueschist-facies Bôrka Nappe witnessing incorporation of the distal passive margin into and its subsequent exhumation from the subduction channel; 2) the absence of obducted Jurassic ophiolite nappes and lack of supra-subduction ophiolite complexes which are typical of the western Vardar ophiolite nappes in the Inner Dinarides; 3) no signs of presence of the Late Jurassic platform limestones sealing the thrust structures in the Alps and Dinarides, instead thrusting continued during the latest Jurassic and Early Cretaceous. Moreover, the exact correlation of the Carpathian, Alpine and Dinaridic Tethyan mélange units is largely suppressed by their intermittent occurrences in the area extensively covered by the overstepping Cenozoic and particularly Neogene complexes related to the Pannonian Basin system. Considering these differences, Plašienka (2018) proposed a collisional, not obductional model of closure of the Neotethyan Meliata Ocean.

CONCLUSIONS

Čoltovo, Bohúňovo and Držkovce localities represent mélange structure with olistostrome bodies. Based on the lithology, microfacial analysis and biochronology, the history the Meliata complexes spans between the Middle Triassic and the Middle Jurassic. The most characteristic rock complexes included in chaotic formations are:

- Middle Triassic - limestones, terrigenous siltstones and variegated radiolarites
- Late Triassic - red radiolarites, siltstones and basic volcanic rocks
- Early Jurassic - possibly black crinoidal limestones and dark clastic pelagic sediments (without biostratigraphical evidence)
- Middle Jurassic - olistostromes with cherty intercalation and blocks of Triassic rocks

Geochemical analyses were performed on the Triassic sediments. Mature fine-grained terrigenous siliciclastic material was derived from continental sources and deposited on a continental slope, where they intercalated the radiolarian-bearing shales. On the other hand, a sample from Bohúňovo shows a mafic igneous provenance and a deep-water environment near the mid-oceanic ridge.

Studied localities of the Meliata Unit record gradual spreading and deepening of the Meliata Ocean which was the NW branch of the Neotethys realm. First phase of sedimentation is represented by distal terrigenous clastic sediments and radiolarites with significant volcanic and tectonic activity during the Middle-Upper Triassic. The second, Jurassic phase, points to the formation of olistostromes in connection to the subduction process. The Meliatic accretionary wedge is fragmented into allochthonous blocks or sheets, comprising the Tethyan Meliatic Basin and the northern continental margin – the Bôrka Nappe. These complexes were incorporated into subduction-accretion mélanges.

The complex tectonic structure of the CWC, which originated during the Cretaceous period, is characterised by a north-vergent thrust structure that nucleated at the Meliata suture.

ACKNOWLEDGEMENTS

The research was supported by projects of the Slovak Research and Development Agency (APVV-17-0170; APVV-21-0281), Grant Agency for Science, Slovakia (VEGA 1/0435/21; 2/0012/24) and National Science Centre of Poland, (project 2021/43/B/ST10/02312). We are thankful also to two anonymous reviewers, editor-in chief Marco Chiari and executive editor Alessandra Montanini for constructive remarks and suggestions that substantially improved the scientific level of the earlier versions of the manuscript. Special thanks go to the second reviewer Špela Goričan, not only for valuable review and important comments, but also for her support and advice regarding the taxonomy and stratigraphy of radiolarians.

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Received, December 1, 2023
Accepted, December 27, 2024