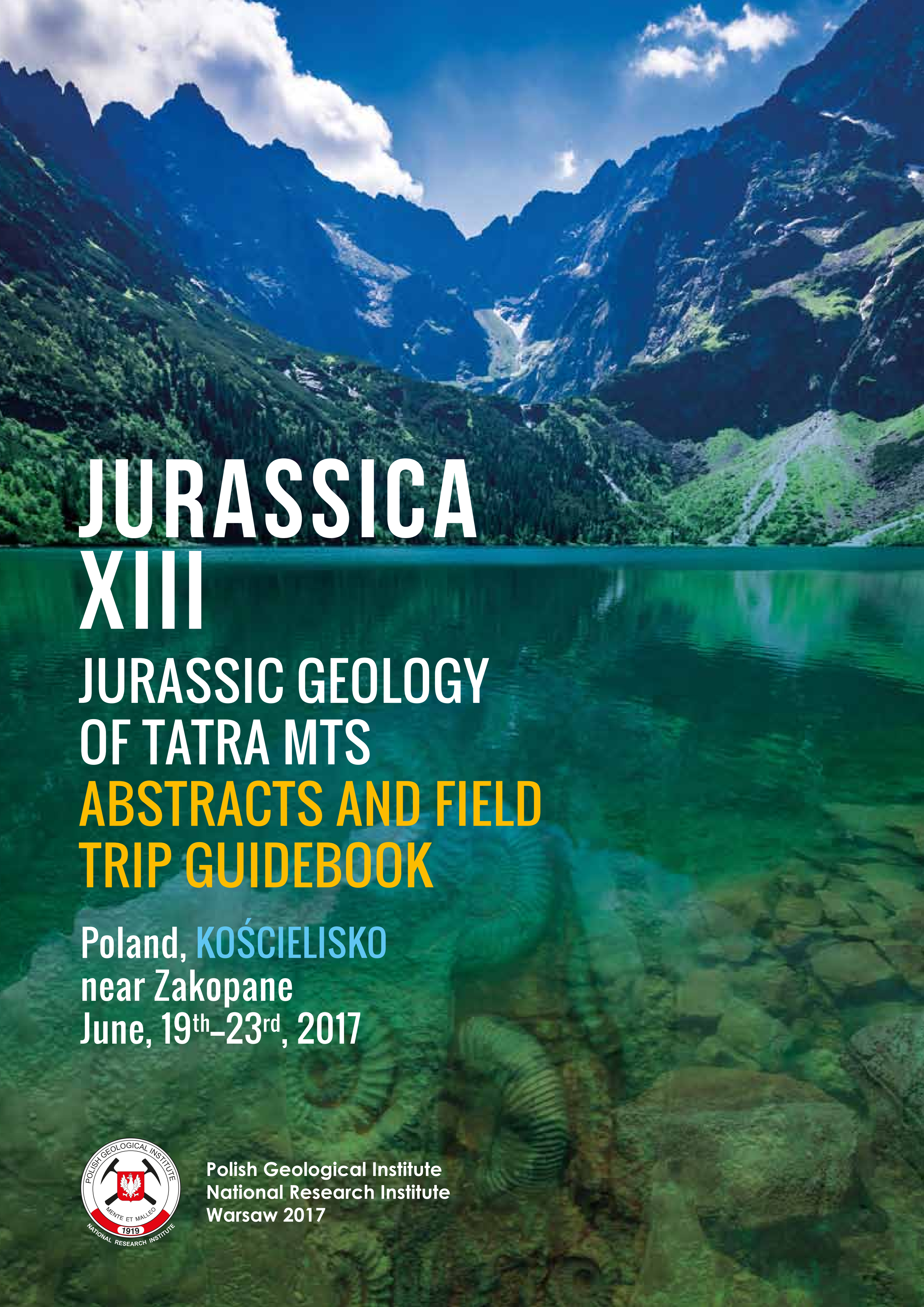

JURASSICA XIII

JURASSIC GEOLOGY OF TATRA MTS

ABSTRACTS AND FIELD TRIP GUIDEBOOK

Poland, KOŚCIELISKO
near Zakopane
June, 19th–23rd, 2017

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ABSTRACTS

MAGNETOSTRATIGRAPHY OF THE JURASSIC–CRETACEOUS BOUNDARY SECTION AT VELIKY KAMENETS (PIENINY KLIPPEN BELT, UKRAINE)

VLADIMIR BAKHMUTOV[1], JACEK GRABOWSKI[2], MICHAŁ KROBICKI[3, 4], DANIELA REHÁKOVÁ[5], PETR SCHNABL[6], HUBERT WIERZBOWSKI[1], ŠIMON KDÝR[6], KRISTÝNA ČÍŽKOVÁ[6]

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The Veliky Kamenets section (Pieniny Klippen Belt, Ukraine) is a unique locality which shows excellently exposed Lower Jurassic to lowermost Cretaceous sedimentary succession, The Toarcian–Berriasian part is precisely dated with dinoflagellates, calpionellids and ammonites (Reháková *et al.*, 2011). The succession at Veliky Kamenets ends up with a synsedimentary limestone breccia of the Walentowa Breccia Member of the Łysa Limestone Formation. It is underlaid by a basalt body precisely dated as Elliptica – Simplex chrons of the Middle and Late Berriasian. The dominant Bajocian to Middle Tithonian lithology comprises variegated types of Ammonitico Rosso facies while the Tithonian/Berriasian boundary interval is developed as pinkish calpionellid limestones. The rocks yielded very favourable properties for palaeomagnetic investigations (Lewandowski *et al.*, 2005). Therefore an attempt of integrated bio-, magneto- and chemostratigraphic approach has been performed to create a high resolution chronostratigraphic scheme for the Tithonian–Berriasian interval of the section.

Thermal demagnetisation was the only procedure for acquiring the data about palaeomagnetic polarities. The magnetostratigraphic interpretation was compared with newly studied calpionellid stratigraphy. Veliky Kamenets section yielded reliable magnetostratigraphic results within the studied 15 m thick succession, from Intermedia Subzone to lower part of Ferasini Subzone.

J/K boundary is defined as Parvula – Colomi/Alpina Subzonal boundary, which occurs in the middle of the normal polarity zone N2 – M19n2n. From the succession the N1 belongs to M20n1n, R1 – M19r, R2 – M19n1r, N3 – M19n1n, R3 – M18r, R4 – M18n and R4 – M17r. The uppermost normal polarity zone N5 in the Elliptica Subzone is probably remagnetized by overlying basalt.

Magnetic susceptibility (MS) decreases between Tithonian and Lower Berriasian which is typical for the Carpathian pelagic and hemipelagic sections. It is interpreted as an effect increasing carbonate sedimentation and dilution of detrital particles in carbonate matrix. MS increase at the top of the section might be related to alterations caused by the basalt intrusion.

Acknowledgements: The study is in accordance of research plan n. RVO67985939. The investigation was funded by GA CR project n. GAP210/16/09979. The Polish side is funded by project n. 61.2301.1501.00.0 of the PGI-NRI. D. Reháková was funded by APVV-14–0118.

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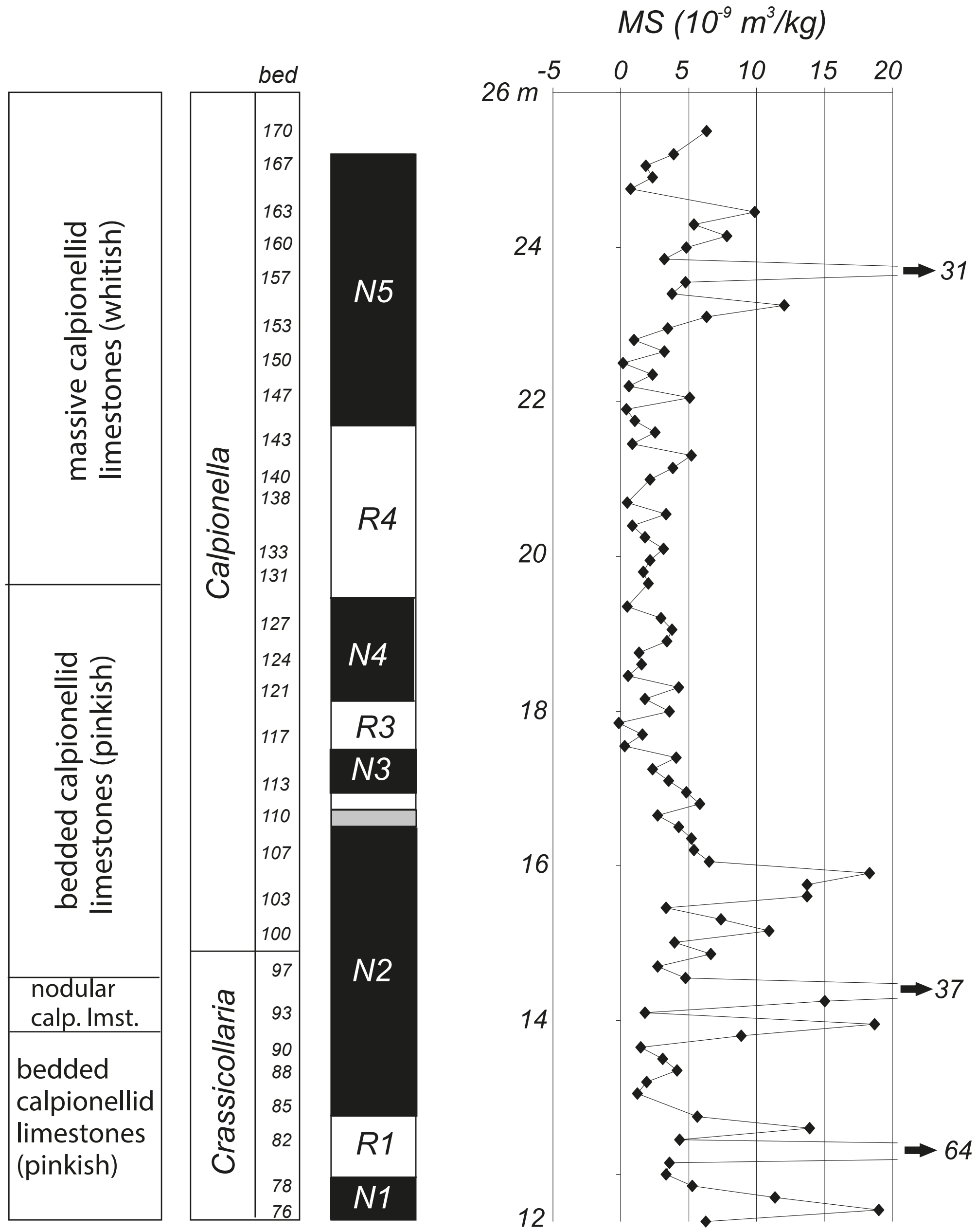

Fig. 1. Lithology, biostratigraphy, magnetostratigraphy and magnetic susceptibility (MS) from Veliky Kamenets section

PATHOGEN INFESTATION AS A CAUSE FOR MORTALITY EVENT OF LATE JURASSIC HORSESHOE CRABS AND THEIR EXCEPTIONAL PRESERVATION

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An aggressive epibiont infection covered the entire carapace of juvenile Late Jurassic horseshoe crabs from the Owadów-Brzezinki Quarry in Central Poland (Błażejowski, 2015; Błażejowski *et al.*, 2015; Kin, Błażejowski, 2014). Detailed examination of exceptionally preserved exoskeletons and surrounding sediment revealed the infestation of pathogens as the most probable cause for mass mortality. Associated biochemical factors facilitated excellent fossil preservation. Anoxic conditions resulting from algae blooms in restricted environments allowed for further fungal infestation evidenced by borings on exoskeleton's surface.

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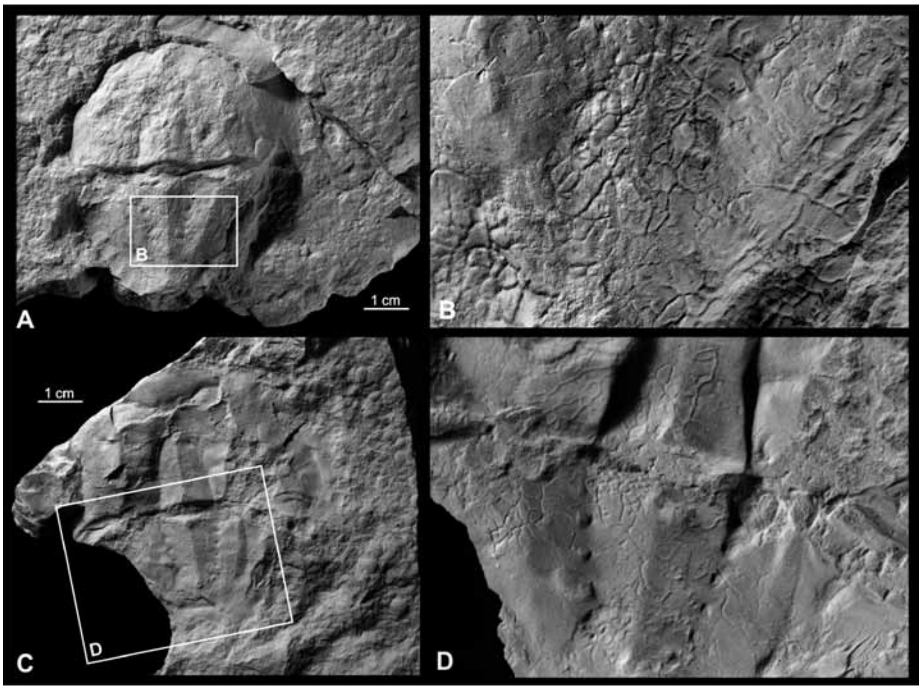

Fig. 1. Jurassic juvenile horseshoe crab showing severe damage caused by endolithic boring organisms Dorsal side. Owadów-Brzezinki Quarry, Kcynia Formation (Unit III), Upper Jurassic (Tithonian) (A–D)

PALAEOCLIMATIC AND PALAEOENVIRONMENTAL SIGNIFICANCE OF THE CLAY MINERALS FROM THE LOWER JURASSIC (AND RHAETIAN) IN KASZEWY 1 BOREHOLE (CENTRAL PART OF THE MID-POLISH TROUGH)

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The results of mineralogical research of the Rhaetian–Toarcian succession from the Kaszewy 1 full-cored borehole (almost 900 metres in thickness) and their preliminary interpretation are presented. Rhaetian–earliest Hettangian strata are of continental, alluvial-lacustrine origin. Next, in the Early Jurassic brackish-marine environments predominated. A set of nearly 300 mudrock samples was analysed at the Polish Geological Institute – National Research Institute laboratory by Wanda Narkiewicz (XRD of bulk sample and clay fraction). The bulk rock samples are mainly composed of phyllosilicates and quartz. Clay fraction mainly consists of illite (muscovite), kaolinite and chlorite, which are locally accompanied by the illite-smectite mixed-layers. Smectite, vermiculite, chlorite-vermiculite mixed-layers and serpentine appear only occasionally. Elemental geochemistry analyses were also performed.

Generally, the total burial depth and burial temperature of the uppermost Triassic–Lower Jurassic deposits in the epicontinental Polish Basin was mostly in the range of 1500–2500 m and 70–90°C respectively, indicating that the strata studied were rather insignificantly modified by burial diagenesis. The changes in clay mineral composition were mostly controlled by palaeoenvironmental factors, especially by weathering regime linked to the climatic conditions (Brański, 2010, 2011, 2012 and 2014). However, in the Kujavian segment of the Mid-Polish Trough burial depth was greater and the diagenesis impact was more significant. In Kaszewy, palaeotemperatures generally exceeded 100°C (T_{max} values reach 433–460°C) and burial depth of the Rhaetian–Toarcian succession is estimated at about 2500–4000 m. Such data imply significant illitisation and chloritisation of smectite. In Rhaetian, also the incipient illitisation of kaolinite cannot be excluded. Moreover, very high T_{max} values in some Rhaetian layers suggest that clay minerals might have been affected by hydrothermal fluids. On the other hand, almost all analysed samples correspond to massive mudrocks, which are very little permeable to fluid migrations and clay minerals in the section studied are mostly detrital. For this reason, clay minerals from Kaszewy (especially kaolinite) may be used – with caution, as palaeoenvironmental and palaeoclimatic proxy.

In Kaszewy section, average clay mineral composition suggest generally warm-temperate and moderately humid climate, without distinct seasonality. However, Rhaetian–Toarcian time is characterised by numerous long-term and short-term climatic fluctuations. We observe warm and wetter periods with stronger hydrolyse (kaolinite enriched) alternated with drier periods with less significant chemical weathering (kaolinite depleted). These results of clay mineral analyses are roughly consistent with the geochemical and palynological data. A fundamental shift in the mineral composition that indicates a basic climate change in the Rhaetian is less conspicuous, because of more significant diagenetic overprint in comparison with other sections. Importantly, some beds in the considered succession (especially in lower and uppermost Rhaetian, in lowermost Pliensbachian and in Lower Toarcian) are particularly rich in kaolinite indicating extreme chemical weathering in the aftermath of rapid warming and abundant rainfall. The secondary kaolinite episodes are also observed (*e.g.*, in Hettangian and in Upper Pliensbachian). In addition, abrupt and episodic shifts in the kaolinite-illite ratio and in the values of other weathering indices point to profound climate destabilisation and the sequence of catastrophic climatic reversals especially in the Late Rhaetian and at the Triassic–Jurassic boundary (*cf.*, Pieńkowski *et al.*, 2012, 2014; Brański, 2014). These kaolinite peaks are generally consistent with prominent negative excursions of carbon isotope curves known from the sections in Polish Basin and different parts of the world (Hesselbo, Pieńkowski, 2011; Pieńkowski *et al.*, 2012, 2014, and references therein).

However, other factors (beyond diagenesis) also controlled the mineralogy and geochemistry of Rhaetian–Toarcian deposits in Kaszewy and sometimes they cover palaeoclimatic signal to some extent. Generally, clay mineral composition was moderately altered by the effects of local tectonic movements, sea-level changes, erosion and recycling of ancient sediments or by hydraulic sorting during the transport and deposition. However, the influence of the erosion and recycling was periodically important and could strongly modify the climatic record. For example, in Early Toarcian a transient extreme erosion and run-off, caused by the main phase of global warming with very high rainfall have developed on the surrounding landmasses (Hesselbo, Pieńkowski, 2011). Unexpectedly, such super-greenhouse event may result in the temporary decrease of kaolinite content caused by fast removal of highly weathered zones and quick exposure of deeper, less weathered rocks with diverse mineralogy.

Acknowledgements: This paper is a part of the project financed from resources of the Polish National Science Centre, granted on the basis of decision no. DEC-

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MAGNETOSTRATIGRAPHY THROUGH THE J/K BOUNDARY OF KUROVICE SECTION (CZECH REPUBLIC)

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The Tithonian–Valanginian strata of the Kurovice section belongs to the Magura Group of Nappes within Carpathian Flysch Belt. Lithologically, the section comprises of Kurovice limestones and overlying Tlumačov marlstones in medium to thick beds. Fossil record consists of calpionellids, foraminifers, radiolarians, calcareous nannofossils, dinoflagellate cysts, aptychi, rhyncholites of nautiloids and rare belemnites. According to biostratigraphy, the Kurovice section covers strata from Early Tithonian Semiradiata Zone (*sensu* Reháková, 2000) to Berriasian Elliptica subzone, including acme *Calpionella alpina* that overlies the first occurrence of *Nannoconus wintereri*. Recent bed-by-bed study of the calpionellid distribution revealed that fossil record depends on the lithological character of strata. Precise identification of calpionellid zones (mainly in Berriasian) was problematic due to recrystallization of matrix and redeposition of Early and Late Tithonian microfossils into Berriasian deposits as a result of permanent enhanced water activity.

To correlate the bio- and magnetostratigraphy over 500 specimens, collected during 2013, 2014 and spring-autumn 2016 fieldworks, were subjected to various rock-magnetic and palaeomagnetic measurements: mostly thermal demagnetization, occasionally also alternating field demagnetization, goethite elimination using preheating followed by alternating field demagnetization, acquisition of remanent magnetization and temperature dependence of magnetic susceptibility (kT). The results reveal in average very low remanent magnetization (NRM = 0.12 mA/m) and magnetic susceptibility (k = 15.5 SI×10^{-6}). Acquisition of isothermal remanent magnetization suggests presence of low (magnetite) and high (goethite or hematite) coercivity fractions. The kT measurements showed Morin transition of hematite in low temperatures.

Over 60 m profile includes both, normal and reversed (Fig. 1), magnetic polarities of characteristic remanent magnetization with slightly scattered mean direction: D = 206.5°, I = 48.3°, α_{95} = 4.1°, 141 samples (using dip of the strata 30–50°). The characteristic component is demagnetized in temperature range of 200–440°C and field range of 20–50 mT. The thermal demagnetization proved to be more convenient method as expected for limestones. The palaeolatitude (*ca.* 26°N) and counterclockwise rotation (*ca.* 155°) are in agreement with data obtained from the Brodno section with palaeolatitude *ca.* 24°N and *ca.* 124° counterclockwise rotation (Houša *et al.*, 1999).

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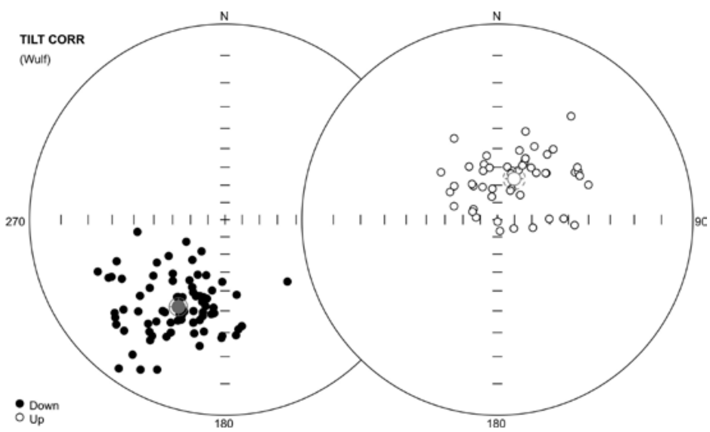

Fig. 1. Stereographic projection of mean directions (after tectonic correction)

Left – normal polarity directions; right – reversed polarity directions

FACIES DISTRIBUTION OF THE JURASSIC AND LOWERMOST CRETACEOUS FORMATIONS WITHIN THE PELSO AND THE TISZA UNITS (HUNGARY)

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Jurassic and Cretaceous successions (Császár, 1997) developed in two fundamentally different tectonic units namely in the Pelso and the Tisza Units separated by the Mid-Hungarian Tectonic Line (Fig. 1). The northwestern border of the Pelso Unit is formed by the Raba-Hurbanovo Line to the northwest of which the Kisalföld Basin is filled with thick Neogene succession. On both sides of the Austrian/Hungarian border the Rechnitz (Rohonc) window is the easternmost surface occurrence of the Penninicum. In these Jurassic – Lower Cretaceous successions a lower and an upper tectonic subunits are distinguished. According to Pahr (1980) in the lower one a 2000 m thick subunit is composed of phyllite, quartz-phyllite and greenschist. The higher subunit tectonically looks more complicated. Its rock types are as follows: phyllite, quartz-phyllite greenschist, calcphyllite and serpentinite.

Within the Pelso Unit close to the Mid-Hungarian tectonic line there is a smaller tectonic line called Gail Valley – Balaton Line running to the North-East as far as Tokaj Mts. This narrow tectonic unit is the direct continuation of the Southern Alps and Southern Karavanken (Császár, Gawlick, 2014). The other specialty of the unit is that the basalt body in the Bükk is correlated with the Vardar Zone which is a subunit of the Dinarida–Hellenida tectonic unit.

The major body of the Pelso Unit is the Transdanubian Range with younger Mesozoic successions in its axial part, which can be relatively well correlated with the Upper Austroalpine nappes (Tollmann, 1977; Császár *et al.*, 2014). The north-eastern part of the Transdanubian Range is called Gerecse Mts, in which the Jurassic and Cretaceous successions have great similarities with those of the Upper East-Alpine nappes (especially with those in the Northern Calcareous Alps). There is a gap between the Dachstein Limestone Fm. and the Pisznice Lms Fm. The latter one contains Hierlatz Limestone intercalation. From the Pliensbachian upwards the succession is similar to that of the Eastern Bakony, while in the Vértes Mts the Jurassic is highly lacunose. It is in connection with the large fault at the southwestern end of the Vértes Mts (Mór Trough).

The Jurassic and Lower Cretaceous of the Southern Bakony Mts have great similarities with both the Northern and Southern Karavanken. The Hettangian Kardosrét Limestone is oncoidic, and the Middle Jurassic Tölgyhát Limestone is replaced by the Bositra-bearing Eplény Limestone. The Jurassic and Lower Cretaceous of the Southern Bakony can be compared to the successions of the Tirolicum and the Juvavicum. The Upper Jurassic and Lower Cretaceous of the southwestern part of the Southern Bakony closely relate to both the Northern and Southern Karavanken (Mogyorósdomb Lms, Sümeg Marl and Tata Lms).

The Pre-Mesozoic position of the Tisza Unit is still under discussion. The majority of models agree that it derives from more northern positon than the Eastern Alps. It means that the Pelso and the Tisza Units fundamentally changed their geographic positions during the Late Jurassic, Cretaceous and Early Cenozoic times. The succession of the Gresten facies was replaced by the Mecsek Coal Fm, and then changed into marine type sedimentation. In the Early Cretaceous the Mecsekjános Basalt Formation was formed. Its special result is the Mecsek type coral reef or atoll in the Early Cretaceous. The Jurassic and Cretaceous of the Villány Zone are highly lacunose although they were formed during the late Early Cretaceous (basinal Bisse Marl and flysch type Boly Sandstone Fm).

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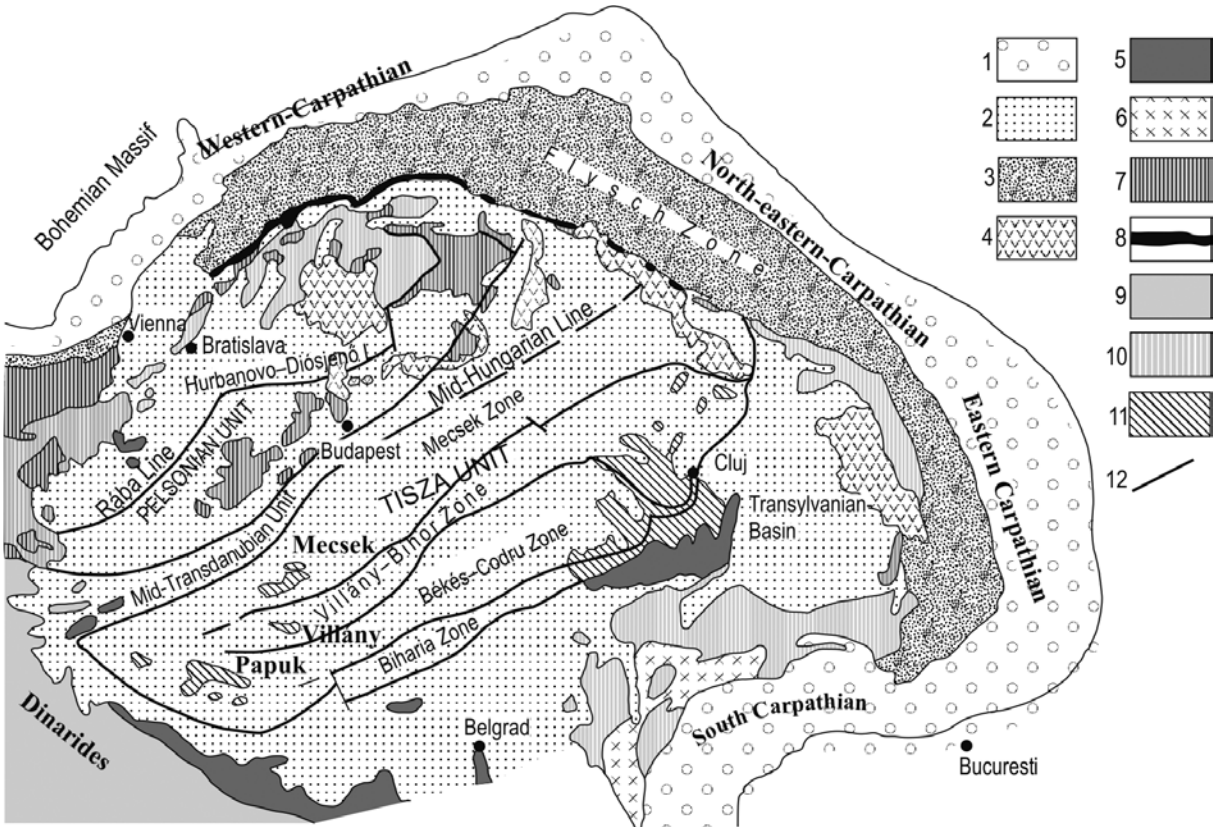

Fig. 1. Tectonic sketch map of the Pannonian Basin and surrounding areas

1. Foreland Molasse; 2. Internal Molasse of the Carpathian Basin; 3. Rhenodanubian and Carpathian Flysch; 4. Miocene volcanic arc on the surface; 5. Penninic, Vardar and Mures Ophiolite Belt; 6. Crystalline Massif in the Southern Carpathians; 7. Upper East-Alpine Belt and its equivalents; 8. Pieniny Klippen Belt; 9. Dinarides; 10. Lower and Middle East-Alpine units and their Carpathian equivalents; 11. Crystalline and Mesozoic formations of the Tisza Unit; 12. Major tectonic lines of the Tisza and Pelso Units

MAGNETOSTRATIGRAPHY OF JURASSIC–CRETACEOUS BOUNDARY SECTION AT ST BERTRAND'S SPRING, DROME, FRANCE

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Rock- and palaeomagnetic investigations at St Bertrand's Spring (Le Ravin de Font de St Bertrand, Drome, France) were carried out in order to determine the magnetostratigraphy and, by this, contribute to global definition of a Jurassic–Cretaceous (J–K) boundary. The composite St Bertrand limestone sequence (60 m thick) is part of the Vocontian trough succession. It is situated north of the hamlet of Les Combes, on the northern side of the Ravin de St Bertrand.

Samples indicate dia- to paramagnetic behaviour of magnetic susceptibility and weak remanent magnetization (Fig. 1). Two characteristic remanent components (normal: D = 329.1°, I = 54.8°, α_{95} = 7.1; and reversed: D = 135.3°, I = –58.8°, α_{95} = 9.2) were extracted from thermal demagnetization data. The results of palaeomagnetic measurements have been combined to give a magnetostratigraphic column and reveal the presence of three normal/reversed polarity sequences (Fig. 1). The base of Calpionella alpina zone and the first appearance of the calcareous nannofossil *Nannoconus wintereri* fall in a lowermost normal polarity zone which was identified as M19n. Comparison of the site's magnetozone pattern with the GPTS revealed that the uppermost reversed zone could be only M17r. Thus, the polarity sequences are interpreted as corresponding to magnetozones M19r-M17n (Elbra *et al.*, submitted), indicating that the St Bertrand rocks are of late Tithonian to mid Berriasian age. The Brodno subzone (M19n1r) was not detected.

Goethite and traces of hematite have been identified, but rock magnetic results prove magnetite to be the main magnetic mineral and the carrier of characteristic remanence components throughout the sequence.

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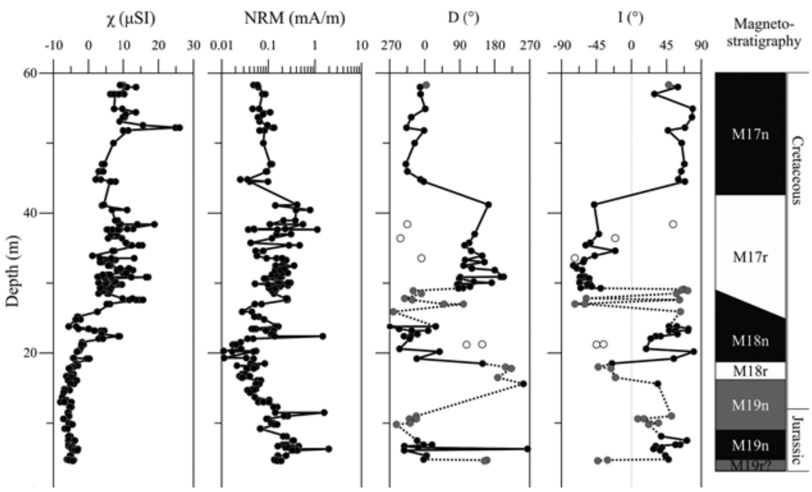

Fig. 1. Magnetic susceptibility (χ), natural remanent magnetization (NRM), declination (D), inclination (I), and magnetostratigraphy at St Bertrand's Spring

Open symbols indicate samples not used in magnetostratigraphic interpretation. Grey symbols represent samples with high MAD and/or which are from areas with unclear magnetostratigraphy

LITHOLOGY AND MICROFACIES OF THE JURASSIC–LOWER CRETACEOUS "BIANCONE" LIMESTONES, PIENINY LIMESTONE FORMATION

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Upper Berriasian–Lower Valanginian "biancone" limestones crops out above red nodular limestones of the Czorstyn Formation north of the Dlhá village, in the Krásna Hôrka Quarry near Tvrdošín town and north of the Medvedzie village (Orava area). They are light grey to greenish, bedded (10–35 cm) limestones with cherts and rare layers of marly shales. They are also characterized by conchoidal fractures. According to microstructure, the studied limestones represent biomicrite with calpionellids (wackestone with calpionellids, rarely wackestone/packstone). Allochems are for the most part directed irregularly. In lower part of the sequence, association of *Calpionellopsis oblonga* Cadisch, *Calpionellopsis simplex* (Colom), *Calpionella alpina* Lorenz, *Calpionella elliptica* Cadish, *Remaniella cadischiana* (Colom), *Remaniella colomi* Pop, *Remaniella duranddelgai* Pop, *Remaniella filipescui* Pop, *Remaniella* sp., *Lorenziella hungarica* Knauer et Nagy and *Lorenziella plicata* Remane indicating Calpionellopsis Zone, oblonga Subzone (Pop, 1994; Reháková, Michalík, 1997; Grün, Blau, 1997; Andreini *et al.*, 2007) can be identified. Within this zone, bad preserved loricas similar to *Praecalpionellites murgeanui* Pop occur. In upper part of the sequence *Calpionellites major* (Colom), *Tintinnopsella carpathica* (Murgenau et Filipescu), *Tintinnopsella longa* (Colom), *Tintinnopsella subacuta* (Colom), *Lorenziella hungatrica* Knauer et Nagy, rare *Calpionellopsis oblonga* Cadisch associated with remaniellids mentioned above representing Calpionellites Zone, major Subzone can be observed. In Berriasian – Valanginian calpionellid association (mainly within Calpionellopsis Zone), well-preserved redeposited *Crassicollaria brevis* Remane, *Crassicollaria colomi* Doben, *Crassicollaria intermedia* (Durand-Delga), *Crassicollaria massutiniana* (Colom), *Crassicollaria parvula* Remane representing Upper Tithonian Crassicollaria Zone occur. For this calpionellid association is characteristic that some of them are deformed. Other fossil remains are represented by calcareous dinoflagellates (*Cadosina semiradiata fusca* Wanner, *Shizosphaerella minutissima* (Colom) and others), *Globochaete alpina* Lombard, *Ostracoda* div. sp., benthic foraminifers (*Spirillina* sp., *Patellina* sp., *Lenticulina* sp.), fragments of echinoderms and aptychi, nannoconids, rare radiolarians, filaments and recrystallized biodetritus. In primary matrix and clasts (biomicrite with saccocomas/packstone with saccocomas), planktonic crinoids *Saccocoma* Agassiz can be observed. The presence of calcareous microfossils are documented by *Cyclagelosphaera brezae* Applegate, Bergen (1988), *Kokia* cf. *stellata* Perch-Nielsen, 1988, *Kokia curvata* Perch-Nielsen (1988), and *Rucinolithus wisei* Thierstein (1971). "Biancone" limestones are covered by dark grey bedded spotted marly limestones with cherts.

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INTEGRATION OF SEDIMENTOLOGICAL, GEOCHEMICAL STUDIES AND MAGNETIC SUSCEPTIBILITY OF THE UPPER AALENIAN AND LOWER BAJOCIAN BLACK SHALES FROM THE CIECHOCINEK IG 2 BOREHOLE (KUJAWY, POLAND)

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The Ciechocinek IG 2 borehole was drilled in the central part of the Mid-Polish Trough, a zone characterized by considerable subsidence compensated by sedimentation. It is also the zone of the largest thickness of the Middle Jurassic deposits. In this area, the Upper Aalenian section reaches 142.0 m, and the Lower Bajocian 104.0 m in thickness (Feldman-Olszewska, 2007). The entire interval has been documented by nearly continuous drill core, with a total length of 215.0 m.

The main purpose of the study was to analyse the relationship between the sedimentological characteristics of the rocks, to determine the amount of organic matter and the content of principal and trace elements, and to measure the magnetic susceptibility. The study included detailed investigation of fine-grained units, and the identification of their hydrocarbon potential and the possibility of more precise correlation of the individual sections between boreholes in the region.

The deposits represent a single transgressive-regressive cycle of Aalenian–Early Bajocian age, which commenced with deposition of Early Aalenian sediments within an estuary. They pass up into a coarsening-upward cycle that begins with black shales and culminates in shoreface sandstones. Most of the Upper Aalenian section consists of black clay shales that, in the lowermost Lower Bajocian, pass up into mudstones, heteroliths, and then fine- and medium-grained sandstones. Sedimentological studies have shown the presence of black shales, non-calcareous, without sedimentary structures, locally with pyrite, usually with spherical marly or marly-sideritic concretions; bioturbation is not observed. Less abundant are lenticular laminated or bedded clayey mudstones and mudstones. In these parts of the section, trace fossils of the genera *Planolites*, *Schaubcylindrichnus* and *Chondrites* are rarely present. Benthic fauna is represented by single bivalves, usually in the form of castings, and by benthic foraminifers. In the upper part of the section, wavy-bedded heteroliths and wavy-bedded, ripple-bedded, cross-bedded or massive sandstones appear. These sediments were deposited in offshore, transition, lower shoreface, and middle shoreface zones, respectively (Feldman-Olszewska, *op. cit.*).

For the entire core material, continuous magnetic susceptibility profiling was made.

To identify the type and maturity of organic matter and to determine the hydrocarbon potential in the investigated sediments for the fine-grained intervals (black shales, less clayey mudstones and mudstones) the organic carbon content was measured for 41 samples using the Rock-Eval analysis conducted at the Energy Security Program of the Polish Geological Institute – NRI by M. Janas and P. Karcz. The obtained TOC values range from 2.3 to 11.6%. Research performed by Grotek (2007) indicates that the organic matter (vitrinite – kerogen type III) is mostly terrestrial in origin.

Geochemical analysis of the main and trace elements was carried out for 24 shale samples. For 18 samples, complete analysis of the elements was performed at the ACKME Lab (Canada) by the ICP-MS method. Elemental analysis of six samples was performed at the Central Chemical Laboratory of PGI-NRI, using the XRF method. The ICP-MS method was used for selected trace elements (V, Ni, Cu, Mo, U, Th and rare earth elements). The resulting values of the U and Mo contents and Si/Al, K/Al, Ti/Al, Zr/Al, Ni/Co, U/(V+Ni), V/(V+Ni), V/Cr, U/Th ratios were used to analyze the degree of oxygenation of bottom waters. The results of geochemical analyses of principal and trace elements and TOC were compared with the magnetic susceptibility curve. Twenty-six thin sections of shales with different organic carbon contents were also analysed.

Works on integrating all these research results are ongoing.

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PELAGIC HITCH-HIKERS OR SESSILE ISLANDERS? TRACES OF EPIZOANS, AND EVIDENCES OF COMMENSALISM ON JURASSIC CEPHALOPOD SHELLS

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Late Jurassic ammonites of the Transdanubian Central Range (Hungary) are generally preserved as internal moulds, but some carbonates, deposited on elevated highs, occasionally contain ammonites with permineralised shell preserved. These shells may contain rare epizoans, such as calcareous polycheta worms, occasionally pennular corals, and crinoids, and different type of trace fossils. Among the traces the following types can be distinguished: (1) microborings of algae and/or bryozoans; (2) grazing traces of molluscan radula (*Radulichnus*); (3) home scars left behind possibly by patellid gastropods (limpets); (4) regular echinoid grazing traces (*Gnathichnus*); (5) elongated pits of possibly acrothoracia balanids.

Some of the listed animals settled down on the already empty shells, while others where attaching during the lifetime of the cephalopod. Traces of encrustation and bioerosion can be found mainly on the body chamber of larger ammonite specimens.

Patellid home scars are specific – only aspidoceratid ammonites possess these types of traces. Some of these traces suggest that the epizoans punctured the ammonite shell, which was subsequently healed by the cephalopod animal.

The elongated and oriented pits were found only on the specimens of a single ammonite species, namely on the Kimmeridgian “*Aspidoceras*” *acanthicum* from Páskom Hill (Bakony Mountains). These traces may represent acrothoracica (burrowing barnacles) borings, which have never been documented on ammonites before. The evidence suggests, that the minute balanids were living together with the cephalopods; therefore these traces represent a new type of commensalism between the ammonites and the boring balanids.

The study of these epizoans and traces on ammonite shells give a new insight into complexity of the Late Jurassic sea-life, which can be characterized by previously unknown interactions, and also reveals the bioerosional significance of certain animals. Understanding the traces may contribute towards the better understanding of the palaeoenvironment, since different groups of animals require specific environmental conditions, which we have to take into account. The identification of trace makers shed light on the unknown aspects of the permanent Mesozoic evolution.

WHERE AND WHAT WAS THE TETHYS? – MYTHS, ASTONISHING AND CONFUSING MISUSAGE OF TERMS: BACK TO THE ROOTS AND OPEN QUESTIONS

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Abstract: The exact reconstruction of the Late Permian to Early Cretaceous geodynamic history and palaeogeography of the western Tethys realm is still a matter of controversial discussions. Younger and polyphase tectonic motions, *e.g.,* the still enigmatic "Mid-Cretaceous revolution", Late Cretaceous–Neogene closure of the Alpine Atlantic with the subsequent lateral tectonic extrusion, Neogene opening of the oceanic domains in the western Mediterranean with accompanying rotations produced the todays existing block puzzle in the Circum–Pannonian realm, where Tethys and Atlantic meet. Destruction of the Late Permian to Early Cretaceous palaeogeography is the main reason for opposing palaeogeographic reconstructions beside the lack of exact data related to the closure of the different oceans and therefore the Tethys question.

The Late Permian to Early Cretaceous geodynamic evolution of the Circum–Pannonian realm is one crucial area for the still controversial discussed palaeogeographic and palinspastic reconstructions of the northwestern part of the Tethyan realm. Main focus is the time frame before the "Mid-Cretaceous" revolution and the at that time newly arranged plate configuration and therefore the Tethys question. Due to the fact that this "Mid-Cretaceous" revolution and younger polyphase tectonic motions draw a veil over the older Mesozoic plate configuration several crucial and still topical questions remain, *e.g.*:

1. How many Triassic–Jurassic oceans (*e.g.,* Kure Ocean, Meliata-Hallstatt Ocean, Maliac Ocean, Vardar Ocean, Pindos/Mirdita Ocean, Palaeo-Tethys Ocean, Neo-Tethys Ocean) existed in the northwestern Tethyan realm? and where are the suture zones?
2. Are the Eastern Alps/Western Carpathians plus some Pannonian units (ALCAPA), the Southern Alps/Dinarides and the units in the Pannonian realm (*e.g.,* Transdanubian Range, Tisza) in Triassic times independent microplates between oceanic domains? or are they scattered by polyphase younger tectonic motions of one originally continental realm (northwestern part of Pangaea) representing different parts of the Triassic European shelf? Later, the Early Jurassic Pangaea-breakup resulted *e.g.,* in the opening of the Central Atlantic Ocean and its eastward continuation, the Alpine Atlantic, and the formation of a new plate between the Alpine Atlantic and the Tethys.

In the last century and in the frame of different opposing models about mountain building processes before the plate tectonics revolution the definition of the Tethys Ocean experienced numerous contrasting definitions (see Sengör, 1998). The most influential model for decades was the conception of Kober (1921) and Stille (*e.g.,* 1918, 1924, 1949): They invented the Tethys as a from the later Precambrian to Neogene lasting geosyncline involved in world-wide orogenies/orogenic phases of short duration (and more or less contemporaneous!). Related to our question, in those theories an older kimmerian (~Triassic/Jurassic boundary) and a younger kimmerian (~Jurassic/Cretaceous boundary) orogenic cycle were distinguished, but both "phases" were attributed as "alpine". Today we should strictly avoid these terms for the simple reason that these terms were invented not in alpinotype mountain ranges with a complete different meaning, although Kraus (1951) tried to transfer in details these "phases" to the Southern/Eastern Alps creating in fact a widespread confusion lasting until today. After invention of plate tectonics these models and also the related terms (phases) became practically obsolete, but are still nowadays used widespread. Especially the idea of orogenic phases, invented by Stille (1918) is still used commonly, but contradicts with plate tectonics: a concept of episodic orogeny is contradictory to the very premise of the plate tectonic theory.

Important is to understand, that the oceanic system which separates from Jurassic times onwards the *e.g.,* Eastern and Southern Alps, and the Western Carpathians from Europe (Ligurian-Piemont-Penninic-Vah Ocean) do not belong to the Tethyan oceanic realm: this oceanic system is the prolongation of the Central Atlantic Ocean to the east and was recently named Alpine Atlantic (Missoni, Gawlick, 2011) on base of Frisch (1980). The term Alpine Tethys, used in several palaeogeographic reconstructions for this Jurassic-Neogene ocean (*e.g.,* Stampfli, Kozur, 2006; Schmid *et al.*, 2008; Handy *et al.*, 2014, among many others), is a misleading interpretation of the original definition of the Tethys Ocean (Suess, 1901). Suess (1901) defined the Tethys Ocean as a Mesozoic ocean striking from east Asia to southern/southeastern Europe. Suess (1888, 1901) indubitable has seen the Tethys as a Triassic to Cenozoic oceanic system. Therefore his Tethys Ocean is different from the Jurassic "centrales Mittelmeer" of Neumayr (1885) with its larger extension to the west, which includes also the newly formed Alpine and Central Atlantic oceanic system. The wrong understanding of the Jurassic "centrales Mittelmeer" as Tethys reached the top in naming the Central Atlantic Ocean *e.g.,* as west/western Tethys or Atlantic Tethys (*e.g.,* Ricou, 1996).

Following in general the palaeogeographic Pangaea reconstruction of Carey (1958) the Tethys-problem became a paradoxon (for details: Sengör, 1985, 1998). The Tethys paradoxon was more or less elucidated with the model of Sengör (1984, 1985) who invented a northern Palaeo-Tethys (late Paleozoic – after genesis of Pangaea – to Early Cretaceous ocean) and a southern Neo-Tethys (Triassic to Neogene ocean) with the Cimmerian Continent(s) between. The Cimmerian Continent(s) consists most probably of several continental blocks in its western part with oceanic domains in between, and each of these continents experienced a slightly different geodynamic history, including the time of the orogenesis. For Asia this model in general is working perfectly (Sengör 1985, 1997, 2015; Ricou 1996), but for the Mediterranean area – the western end of Tethys – this model was not able to open the "Gordon's knot".

On base of the "suture zone" concept (Hsü, 1995 based on Suess, 1937) Sengör (since 1984) attributed in southeast Europe parts of the Middle Jurassic orogenesis to the Palaeo-Tethys suture zone, and therefore to the Cimmerides. As a result the Jurassic orogeny in the southern Calcareous Alps or Western Carpathians as well as in the Dinarides/Hellenides was also attributed to the Cimmerides. Later, following more or less this suture zone(s) of the "Cimmerides" in south-east Europe the model of *e.g.,* Stampfli, Borel (2004) needs several Triassic independent back-arc oceanic systems north of the Palaeo-Tethys (Kure, Meliata, Maliac, Pindos oceans). The position of the Neo-Tethys in this reconstruction is close to the position of the Ionian sea.

Sengör (since 1984) defined the super-orogenic complex that descended from Tethys as Tethysides: those orogens formed by the closure of the Palaeo-Tethys are defined as Cimmerides and those orogens formed by the closure of the Neo-Tethys are defined as Alpides. The timing of collision in both oceanic systems should be in parts overlapping. This definition of the Alpides found also a lot of followers, but for the Mediterranean realm it intensified the confusion and the misleading use of terms and definitions. But, to define in Asia young collisions (*e.g.,* collision of India with Asia) as belonging to the Alpides, is a wrong definition in respect to the oceanic realm closed. To avoid confusion, we have clear to distinguish mountain building processes A) related to the Tethys oceanic system or B) related to the Atlantic oceanic system. If we define the Alps as type-region for the Alpine orogen (Alpides) we have to realize that the Alpine orogen in the Mediterranean is related to the closure of the Alpine Atlantic as westward prolongation of the Central Atlantic and is therefore not part of the Tethysides. The evolution of the Alpine Atlantic is characterized by a graben stage since Late Hettangian, followed by an oceanic break-up in the late Early/Middle Jurassic, subduction since the Late Cretaceous, and Late Paleogene/Neogene collision.

In the eastern Mediterranean mountain belt (Tethysides) around the Circum–Pannonian realm striking to the southeast a Jurassic orogeny is preserved, and following questions remain: A) is this orogen part of the Cimmerides (= Palaeo-Tethys and/or related back-arc oceanic systems?) or B) an independent Neo-Tethys orogen as part of the Tethysides?

The Jurassic orogeny is characterized by Middle to early Late Jurassic ophiolite obduction (upper plate) and a westward/northwestward propagating nappe stack (from former distal shelf areas to proximal shelf areas) forming on the lower plate (*e.g.,* Adria/Apulia) a thin-skinned orogen. Important is to recognize, that only the western part of the ocean was closed in the Jurassic, the eastern part remain open until the ?Paleogene. The history of all mountain belts involved to the partial closure of this oceanic domain (Eastern Alps, Western Carpathians, units in the Pannonian realm, Dinarides, Hellenides) is characterized by a characteristic stacking pattern which mirrors a complete Wilson Cycle: a Late Permian to early Middle Triassic (Pelsonian) graben infilling, a Middle Triassic (late Pelsonian) to early Middle Jurassic passive margin evolution (with a late Pelsonian/Illyrian oceanic break-up) and a Middle to early Late Jurassic active margin evolution. Ophiolite obduction and crustal thickening resulted in mountain uplift and unroofing starting around the Jurassic/Cretaceous boundary. As a consequence, a Middle to early Late Jurassic orogenic event cannot belong to the Alpine orogeny for following reasons: A) age, B) (palaeo)geographic position, and C) different Wilson Cycle. This defines this ocean as a Triassic–Jurassic ocean: the Neo-Tethys Ocean. The Neo-Tethys Ocean in this definition is very close to the understanding of Suess´s Tethys between Cimmeria in the north and Gondwana in the south.

Consequently and logically the Middle-Late Jurassic orogen in the eastern Mediterranean belong to the Tethysides, but not to the Cimmerides, because the Cimmerides were formed by the closure of the Palaeo-Tethys north of the Cimmerian continent(s) and not by the closure of the Neo-Tethys south of the Cimmerian continent(s)! From this fact we have to deduce that the northern/northwestern Neo-Tethys margin is the southern/southeastern margin of Cimmeria! Further, we have to recognize, that subduction in Palaeo-Tethys started early, latest around the Permian/Triassic boundary.

Missoni, Gawlick (2011) invented for the Middle to early Late Jurassic orogeny along the western Neo-Tethys Ocean the term Neotethyan Belt. Position and eastern end of the Neotethyan Belt as well as the terminology of the oceanic systems in Turkey is under controversial discussion (see Sayit *et al.*, 2015 for discussion), but it should end somewhere east of the Anatolide/Tauride block. From here one oceanic domain (since Anisian) strikes in northwestward direction ending somewhere in the Alpine/Carpathian realm (this is the true Neo-Tethys!), and another one (since Late Triassic) strikes south of the Anatolide/Tauride block to the west (the southeastern Mediterranean = Ionian Ocean as remnant; but this ocean is independent from the Neo-Tethys, because it is younger = southern branch of Neo-Tethys: Sengör, 1985).

As a consequence of the palaeogeographic position of the Neo-Tethys, the suture of the Palaeo-Tethys must be in the north, and should have an latest Permian to Middle Triassic age. Due to these facts following questions arise: A) Is the northern/northwestern margin of the Neo-Tethys preserved? and if the answer is yes B) where? and C) what can be then the blueprints of a Palaeo-Tethys suture zone? According to practically all palaeogeographic reconstructions the northern/northwestern margin of the Neo-Tethys should be represented by the Western Carpathians and Eastern Alps, most probably with Tisza and Moesia as eastward prolongation. But, until now, no blueprints of a Triassic Palaeo-Tethys suture zone are recognized in that area. In contrast, some units interpreted as remnants of a Palaeo-Tethys suture zone are described from the southern Toscanides to Sicily and Crete. This creates a new Tethys paradoxon waiting to be solved: the Palaeo-Tethys would be now situated south of the Neo-Tethys (compare Stampfli, Kozur, 2006).

How to solve this paradoxon?

If a suture zone is eroded one powerful tool is component analysis of mass transport deposits in trench-like (mélanges) and foreland basins: Here components could be the only remnants of eroded hinterlands and therefore the proof of a single component may change plate tectonic and palaeogeographic reconstructions substantially. In addition, age dating of the matrix is essential. Another powerful tool is Tectonostratigraphy (Event-Stratigraphy, Sedimentology/Facies including exact age control, and tectonics combined). A detailed Mesozoic Tectonostratigraphy combined with basin evolution and component analysis contribute essentially in solving questions on the way to a better convincing palinspastic reconstruction for the Mesozoic not only of the Circum–Pannonian realm. The Circum–Pannonian mountain belts, where Palaeo-, Neo-Tethys and Atlantic meet, are important regions to contribute essentially in the reconstruction of the Earth history and how Plate Tectonics work. To conclude, very important is a clear and not misleading use of terms, based on historic definitions and views, for nowadays usage translated and adapted to the plate tectonic concept.

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LATE MIDDLE TO EARLY LATE JURASSIC OVERLOOKED HALLSTATT MÉLANGES (ZLATAR MÉLANGE) BETWEEN THE DRINA-IVANJICA UNIT IN THE EAST AND THE EAST BOSNIAN-DURMITOR MEGAUNIT TO THE WEST IN THE INNER DINARIDES (DINARIDIC OPHIOLITE BELT, SW SERBIA, ZLATAR MOUNTAIN):

ANALYSIS OF UNINVESTIGATED MYSTIC AND ENIGMATIC MÉLANGES AS A CRUCIAL TOOL FOR THE CORRELATION OF THE NOWADAYS BY POLYPHASE JURASSIC TO NEOGENE POLYPHASE TECTONIC MOTIONS (CONTRACTIONAL, EXTENSIONAL, STRIKE-SLIP) SCATTERED TECTONIC UNITS IN THE CIRCUM-PANNONIAN REALM (*E.G.*, EASTERN AND SOUTHERN ALPS, WESTERN CARPATHIANS, "PELSÖ-MEGAUNIT", TISZA, DINARIDES/ALBANIDES), THE PALAEOGEOGRAPHIC RECONSTRUCTION AND THE GEODYNAMIC EVOLUTION OF THE WESTERN NEO-TETHYS REALM – FRESH DATA PROVIDING NEW DEEP AND CONVINCING INSIGHTS FOR THE ENDLESS AND CONTROVERSIAL DISCUSSION "HOW MANY TETHYS OCEANS" IN THE WESTERN TETHYAN REALM EXISTED IN TRIASSIC–JURASSIC TIMES (*E.G.*, HALLSTATT-MELIATA, MALIAC, VARDAR/AXIOS, PINDOS, NEO-TETHYS, DINARIDIC OCEANS OR SIMPLY ONLY ONE NEO-TETHYS OCEAN IN THE SENSE OF THE TETHYS DEFINITION BY SUESS 1888, 1901, NOWADAYS COMMONLY WRONGLY USED AS SYNONYM FOR THE "CENTRALES MITTELMEER" OF NEUMAYR 1885)

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Abstract: In the Dinaridic Ophiolite Belt (SW Serbia) hemipelagic Triassic sediments (Hallstatt Limestone succession), which were deposited originally on the outer passive margin of the Neo-Tethys Ocean, occur only as components of different size (mm to square km) in mass transport deposits of Middle Jurassic to early Late Jurassic age, forming a sedimentary mélange. This late Middle to early Late Jurassic Hallstatt Mélange in the Inner Dinarides plays a crucial role for the reconstruction 1) of the Triassic–Jurassic passive margin configuration of the western Neo-Tethys Ocean, 2) of the Middle to Late Jurassic geodynamic history of the Dinarides, and 3) for the correlation of the tectonic units in the Circum–Pannonian realm.

Hallstatt Limestone successions in the western Tethyan realm are only known from the distal passive European (or Adria) margin facing the Neo-Tethys Ocean to the east (Fig. 1). Nowadays the sedimentary rocks of the outer shelf region (Hallstatt Zone) are found only in sedimentary mélanges, mainly occurring as far-travelled nappes, generally far away from the position the suture zone.

In the Zlatar Mountain and adjacent areas below the Middle to early Late Jurassic ophiolitic mélange and their overlying ophiolite sheets of the Dinaridic Ophiolite nappe occur mass transport deposits and slide blocks in a radiolaritic-argillaceous matrix. The components of the mass transport deposits and the slide blocks consist of Triassic to Early Jurassic carbonates and Middle Jurassic radiolarites, and the matrix are late Middle to early Late Jurassic radiolarites, siliceous claystones and siliceous marls. The slide blocks in the Zlatar (Hallstatt) Mélange reach several tens to hundred metres in size, occasionally even kilometres. Several olistoliths and blocks contain well-preserved parts of the Triassic sedimentary succession. Their stratigraphy and facies evolution allowed the reconstruction of complete sedimentary successions originating from a distal continental margin setting (Hallstatt facies zone), located originally east of the preserved facies belts of the Inner Dinarides. Sedimentary features, the litho- and microfacies of the Hallstatt Limestone sequences clearly indicates, that the whole Hallstatt Mélange area of the SW Serbia (Zlatar Mélange) represents a far-travelled nappe from the Triassic–Jurassic distal passive margin facing the Neo-Tethys Ocean to the east.

Deformation and accretion started in the Neo-Tethys Ocean with intra-oceanic thrusting in the late Early or early Middle Jurassic (Karamata, 2006). This thrusting process resulted in the obduction of the accreted ophiolites onto the outer shelf in Middle Jurassic time. The former Triassic to Early Jurassic passive continental margin of Adria with its huge Triassic carbonate platforms took a lower plate position in this developing thin-skinned orogen. Thrusting started in the continental slope to outer shelf region and successively propagated towards the inner shelf. In the middle to late Middle Jurassic contractional tectonics reached the outer parts of the shelf and affected the Hallstatt facies zone. Deep-water trench-like basins formed in sequence in front of advancing nappes resp. the obducted ophiolite sheets. The trench-like basins accumulated thick successions of gravitatively redeposited sediments deriving from the accreted older sedimentary sequences.

The clasts and slides of the Hallstatt Mélange in the Zlatar Mountain (Zlatar Mélange) and adjacent areas derive from the outer shelf region and resemble the known situations in the Eastern Alps or the Albanides (Gawlick *et al.*, 2008). The Zlatar Mélange resembles the (Late) Bathonian to Early/Middle Oxfordian Sandlingalm Formation (Hallstatt Mélange) in the Northern Calcareous Alps (Gawlick *et al.*, 2007) and equivalents in the Inner Western Carpathians and several units in the Pannonian realm (Kovács *et al.*, 2014) or the Albanides (Gawlick *et al.*, 2014). Therefore, the Zlatar Mélange is an age equivalent to other Hallstatt Mélanges along the Neotethyan Belt and of Middle Jurassic to earliest Late Jurassic age (Missoni, Gawlick, 2011).

Hallstatt Mélanges are interpreted to be formed in front of advancing nappes in the outer shelf region due to ongoing ophiolite obduction in the late Middle Jurassic (Fig. 2). This is confirmed in the Inner Dinarides by the overlying ophiolitic mélange in the Zlatar Mountain. The Zlatar (Hallstatt) Mélange is overlain by the radiolaritic-ophiolitic mélange, which shows in the area of Sjenica to the south as well as in the Zlatibor Mountain to the north a Bathonian/Callovian to Oxfordian age range. Therefore, the Zlatar (Hallstatt) Mélange starts to form slightly later (Late Bathonian/Callovian) as the overlying ophiolitic mélange, which overthrust these mélange not earlier than in the (Middle/Late) Oxfordian. Also, the ophiolitic mélange is interpreted to be a primary sedimentary synorogenic radiolaritic trench-fill sequence that formed simultaneously with ophiolite nappe stack/emplacement and later ophiolite obduction/accretion (Gawlick *et al.*, 2016).

Hallstatt Mélange analysis in the Zlatar Mountain give clear evidence that:

- An relatively early stage of thrust propagation in front of the westward obducting Dinaridic ophiolites is represented by the erosional products of a nappe stack in the outer shelf region (Hallstatt Zone). In front of the Hallstatt nappes newly formed deep-water radiolaritic basins contain the erosional products of these nappes, preserved here in south-western Serbia below the Dinaridic Ophiolite nappe.
- The sedimentary Zlatar Mélange occur in a transported position below the west-directed obducted ophiolite mélange below the Dinaridic Ophiolite sheet (*e.g.*, Schmid *et al.*, 2008; Gawlick *et al.*, 2008), forming together a far-travelled nappe and mélange complex.
- The age of the Zlatar Mélange clearly indicates that the formation of deep-water trench-like basins in front of the obducted ophiolitic nappe pile started in Middle Jurassic times and not in the latest Jurassic as interpreted by Schmid *et al.* (2008).
- An autochthonous origin of a Triassic Ocean (Dinaridic or Pindos Ocean) between the Outer Dinarides and the Drina-Ivanjica Unit to the east as northward continuation of Pelagonia/Korabi units can be excluded (Stampfli, Kozur, 2006; Robertson *et al.*, 2009). This ocean would have existed in the lagoonal area of the Triassic carbonate platform in the Dinarides separating the open lagoon (Late Triassic lagoonal Dachstein Limestone) in two independent shelf areas without transition to an open-marine environment.
- The Zlatar (Hallstatt) Mélange nappe was thrust over the Drina-Ivanjica Unit to the west most probably in the Latest Jurassic times.

The situation of the Zlatar Mélange and the obducted ophiolite sheets in the Dinaridic Ophiolite Belt corresponds perfectly to the situation known further to the south in the Albanides and to the north in the Eastern Alps and Western Carpathians, where identical mélanges were formed in Middle to early Late Jurassic times. The Zlatar (Hallstatt) Mélange is therefore part of the Neotethys Belt in sense of Missoni, Gawlick (2011).

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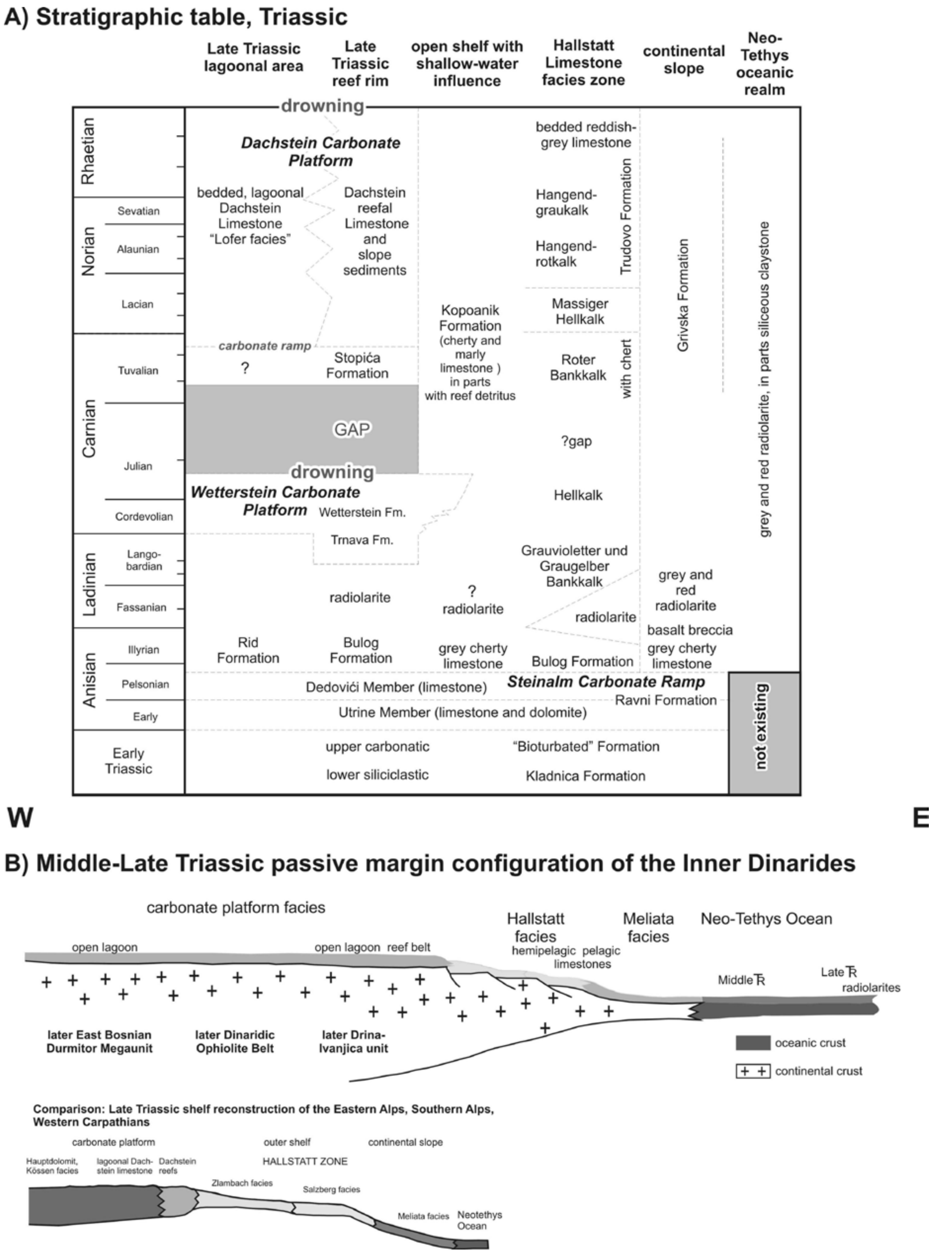

Fig. 1. A – Stratigraphic table for the Triassic of the Inner Dinarides

Early Triassic to early Middle Triassic after Dimitrijević (1997); Neo-Tethys oceanic realm continental slope after Gawlick et al. (2016); Hallstatt Limestone facies zone after Sudar (1986), Gawlick, Missoni (2015) and this study; open shelf with shallow-water influence after Sudar (1986), Schefer et al. (2010); Late Triassic reef rim and lagoonal area after Missoni et al. (2012), Sudar et al. (2013) and Dimitrijević (1997)

B – Middle to Late Triassic passive margin configuration of the Inner Dinarides

Middle to Late Triassic passive margin configuration after Gawlick et al. (2008), and comparison with the Late Triassic shelf configuration of the Eastern and Southern Alps and the Western Carpathians modified after Gawlick et al. (1999).
Generation of oceanic crust started in the Late Anisian in the Neo-Tethys realm. After Gawlick et al. [in press]

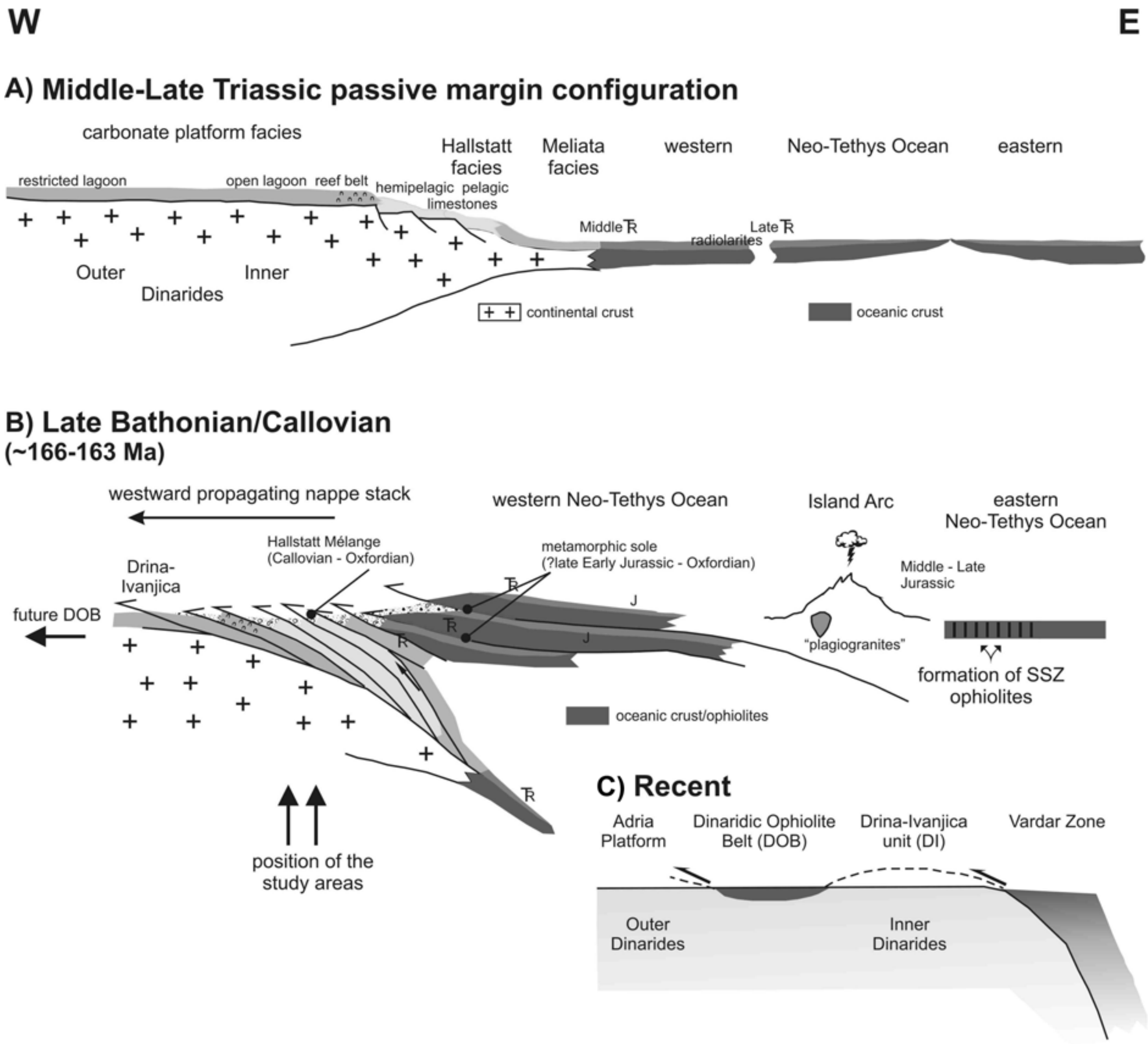

Fig. 2. Reconstruction of the Triassic shelf and provenance of the studied Triassic to Jurassic Hallstatt facies sequences (from Gawlick *et al.*, 2016, modified)

A – Middle to Late Triassic passive margin configuration (compare Fig. 1) Generation of oceanic crust started in the Late Anisian in the Neo-Tethys realm. The formation of an oceanic basin (Dinaridic Ocean) between the Outer (Triassic restricted lagoon) and Inner Dinarides (Triassic open lagoon, reef belt and transitional facies) is not possible due to the missing facies transitions from the lagoon to the open marine environment

B – Middle Jurassic (Late Bathonian–Callovian, ~166–163 Ma) westward directed ophiolite obduction, imbrication of the former passive margin forming a thin-skinned orogen (Neotethyan Belt: Missoni, Gawlick, 2011) and mélange formation. The Hallstatt Mélange is formed in front of the westward propagating ophiolite obduction. In Oxfordian times the Hallstatt Mélange will be overthrusted by the ophiolitic mélange and the overlying ophiolitic sheets

C – Recent position of the Dinaridic Ophiolite Belt with its sub-ophiolitic mélanges on the basis of Kober (1914) concerning the genesis and emplacement of the ophiolites and related radiolaritic-ophiolitic trench fills

EVOLUTIONARY PALAEOBIOGEOGRAPHY OF THE PROTOGLOBIGERINIDS (FORAMINIFERA) AT THE MIDDLE AND UPPER JURASSIC BOUNDARY

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Abstract: The influences of the late Callovian–early Oxfordian palaeoceonographic changes on the evolution and the distribution of the protoglobigerinids were studied based on the faunas from the Oxfordian of Jura Mountains (France), Bükk and Villány Mts (Hungary) and the review of the literature. Our new discoveries proved a fauna impoverishment which was different in the epicontinental and in the pelagic region of the Tethys. The so far most diverse Oxfordian protoglobigerinid associations were documented, consisting of *Conoglobigerina*? *avariformis* Kasimova forma sphaerica, *C.*? *avariformis* forma alta, *Globuligerina. bathoniana, G. oxfordiana* and *Haueslerina helvetojurassica*.

In the Middle Jurassic (mostly from the Bajocian), the aragonitic *Globigerina*-like forms occurred sometimes in large quantity, giving up to 90% of the foraminiferal fauna both in the epicontinental and in the pelagic region of the Tethys. In the Jurassic, based on isolated forms more than 40 species were established, but recently the generic classification is strongly debated. The majority of their records came from rock thin sections, which allow only very limited systematic assignments. There is no clear evidence that they all did have planktonic (holo-, mero or tycho) mode of life. Due to these facts, for this group we suggest the informal protoglobigerinids term (introduced by Gianotti, 1958).

During the Middle and Late Jurassic transition there are several gaps in deposition on epicontinental platforms as well as in the condensed Rosso Ammonitico facies formed on pelagic swells of the Mediterranean Tethys. This phenomenon is explained with the modification of the current patterns along the northern Tethys shelf was coupled with eustatic sea level change (late Callovian regression, latest Callovian–earliest Oxfordian maximum flooding), increasing seawater acidity and intense climate cooling, probably related to sea-floor spreading in the Atlantic. (*e.g.,* Norris, 1995; Dromart *et al.*, 2003; Cecca *et al.*, 2005). Due to the lack of the sediments and the dissolution of the aragonitic shells in cold and acidic water the protoglobigerinid record of this period is very poor (Görög, Wernli, 2003). It is especially true for the isolated forms, furthermore the majority of them are preserved as an internal moulds, not allowing the study of the most important taxonomic characters (aperture, suture, wall structure, surface ornamentation). In the last years we had several new discoveries of well-preserved, isolated protoglobigerinids from this period, significantly increasing the knowledge of this group. Thus our aim was to trace the influence of these events on the evolution and the palaeobiogeographic distribution pattern of protoglobigerinids.

The recent work is based on (1) our previous study from the Callovian of Villány Mts (Görög *et al.*, 2012); (2) our recent studies of the Oxfordian (from the Mariae Zone to the Transversarium Zone) of Bükk and Villány Mts (Hungary) and of the Southern Jura Mts (France); and (3) the review of the literature.

During the Callovian–Oxfordian period the area of Villány Mts (Tisia Unit) was a microcontinent detached from the European continent, with pelagic limestone sediments. From the Callovian of the Villány Mts two different rock types were studied: "filament"-rich rock of the Templom-hegy succession and iron oolitic limestone in the Rózsa-bánya quarry, where the Middle Oxfordian is represented by red nodular limestone. Internal limestone sediments of the neptunian dyke from Büdöskút, Bükk Mts deposited in deep pelagic basinal block dismembered earlier from the Adriatic margin (Velledits, Blau 2003; Haas *et al.*, 2013). From the typical epicontinental area the "Creniceras renggeri" marl and the Birmenstorf Member (marl with sponge bioherms) of the Southern Jura Mts were studied from Meyriat, Entremont, Platieres, Champfromier and Crotoney.

To study the presence and wall structure of the protoglobigerinids thin-section were made from all suitable rocks (40 samples). To extract the microfossils each samples of the limey samples were treated by glacial acetic acid, the argillaceous ones (5 samples) were soaked in a dilute solution of hydrogen peroxide. For the taxonomic classification SEM images were made.

From the Callovian, isolated protoglobigerinids with preserved shells are known only from six area of the Tethys: Mareta Beach Portugal (Stam, 1986), Czestochowa region, Poland (*e.g.,* Bielecka, Styk, 1981), Villány Mts, Hungary (Görög *et al.*, 2012); Bucegi Mts, Romania (Neagu, 1996); Crimea (*e.g.,* Hofman, 1958; Kuznetsova, Uspenskaya, 1980) and Kachchh Basin, W India (Alhussein, 2014). Besides the association of Villány Mts the others are monospecific or only two species were identified. It is true all other Callovian protoglobigerinid fauna, except the upper Callovian – early Oxfordian one from Poland described by Fuchs (1973) based on glauconitic moulds. The most frequently identified species are *G. oxfordiana*

(Grigelis), *Globuligerina bathoniana* (Pazdrowa) and *G. callitoviensis* (Kuznetsova); and after them *Conoglobigerina jurassica* (Hofman) and *C. meganomica* (Kuznetsova). In the two developments of the Villány Mts there are three common taxa (*G.* aff. *balakhmatovae* (Morozova), *G. dagestanica* (Morozova) and *G. oxfordiana*), the high spired *G. bathoniana* occurred in the proximal, while the large sized *C.*? *avariformis* Kasimova forma sphaerica Wernli, Görög in the distal facies. Compare the Callovian association to the Bathonian ones the main differences are that the very high spired *C. avarica* (Mozorova) morphogroup (*"C." biapertura* Wernli, Görög, *C. pupa* Wernli, Görög and *C. solaperta* Wernli, Görög) is missing; the large sized forms as *C.*? *avariformis* are subordinate as well as the tiny forms (~120 µm). Summarizing the disparity decreased in the Callovian. This tendency continued in the lower Oxfordian, 99% of the specimens were classified into only three species, namely *G. oxfordiana*, *Haueslerina helvetojurassica* (Haeusler) and *Compactogerina stellapolaris* (Grigelis). The relative homogenous fauna (consisting one or two species) reached much wider geographical distribution than ever before. Their fossil records are two times more than from the Callovian. The small sized (<150 µm) low spired forms more often occurred in mass (as ooze) in the pelagic carbonate facies, as in the recently studied sections of Bükk and Villány Mts. From these localities the majority of the specimens could be classified to *G. oxfordiana*. Our study on the Middle Oxfordian Birmenstorfer "Schichten" from Jura Mts yielded more divers association that the previous authors (*e.g.,* Haeusler, 1881; Stam, 1986) demonstrated. The relatively large sized (250–300 µm) *Conoglobigerina*? *avariformis* Kasimova forma sphaerica and *C.*? *avariformis* forma alta Wernli, Görög are the most frequent, besides them *G. oxfordiana* and *G. bathoniana* also occurred in the majority of the samples. The mid-high spired *C.*? *avariformis* forma sphaerica well-correspond to the *H. helvetojurassica* figured with drawings for example by Haeusler (1881) and Oesterle (1968). In some layers, small sized and low spired forms with extraumbilical aperture appeared in low quantity. These resemble specimens of *H. helvetojurassica* figured by Haeusler (1890) and Stam (1986). This is new morphotypes of the protoglobigerinids, could be the ancestor of the praehedbergellids. From the Oxfordian the *Compactogerina stellapolaris* were identified from internal moulds, so its presence is uncertain. Based on the review of the literature similar faunas with wide disparity (morphological variations) were described by Stam (1986) from the Birmenstorfen Schicten of Aargau, Switzerland and Samson *et al.* (1992) from Villers sur Mer Normandy, France.

Summing up, the late Callovian–early Oxfordian palaeoceonographic changes had a negative impact on the diversity/disparity of the protoglobigerinids, which influenced stronger in the pelagic environment than in the epicontinental ones. Our new discoveries proved that this fauna impoverishment was not so strong that could have been thought on the basis of the fossil records. On the other hand the sea level high stand, the currents along the northern Tethys and the upwelling circulation making nutrient-rich surface waters at the submarine pelagic swells were favorable for the distribution of the opportunistic species as *G. oxfordiana*.

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CHEMO-, ISOTOPE- AND NANNOFOSSIL STRATIGRAPHY OF THE TITHONIAN/BERRIASIAN BOUNDARY IN THE LÓKÚT SECTION (TRANSDANUBIAN MTS, HUNGARY)

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Lókút section (Bakony Mts) represents a *ca.* 13 m thick succession of pelagic limestones, of Early Tithonian to Early Berriasian age and is precisely dated with calpionellids and magnetostratigraphy (Grabowski *et al.*, 2010). Lower Tithonian part of the section is calibrated with ammonites (Fözy *et al.*, 2011). Recently, carbon and oxygen isotope stratigraphy of the section has been presented by Price *et al.* (2016).

Nannofossil events, which include first occurrences of *Nannoconus kamptneri minor* and *N. steinmannii minor* in the topmost part M19n2n and lowermost part of M19n1r magnetozones respectively have been identified in the section. They are located *ca.* 2.0–2.5 m above the J/K boundary defined as Intermedia/Alpina subzonal boundary, situated in the lower half of magnetozone M19n2n. Proxies of terrigenous transport (Al, K, Rb, Th) suggest a significantly decreasing input and increasing carbonate productivity during the Lower Tithonian and the Berriasian. Slight oxygen depletion at the sea bottom (decrease of Th/U ratio), and large increase in concentrations of productive elements (P, Ba, Ni, Cu) is observed upsection. Nutrients supply via upwelling seems to be the most likely explanation. Deposition in the Lókút area was probably affected by long term climatic trends: aridization and warming. Decreasing $\delta^{13}C$ values of bulk rock samples throughout the Tithonian and the Berriasian are interpreted as a result of a global trend of accelerated carbonate productivity (*cf.*, Price *et al.*, 2016), and an effect of local factors such as increased upwelling intensity, and a possible change in the composition of carbonate mud.

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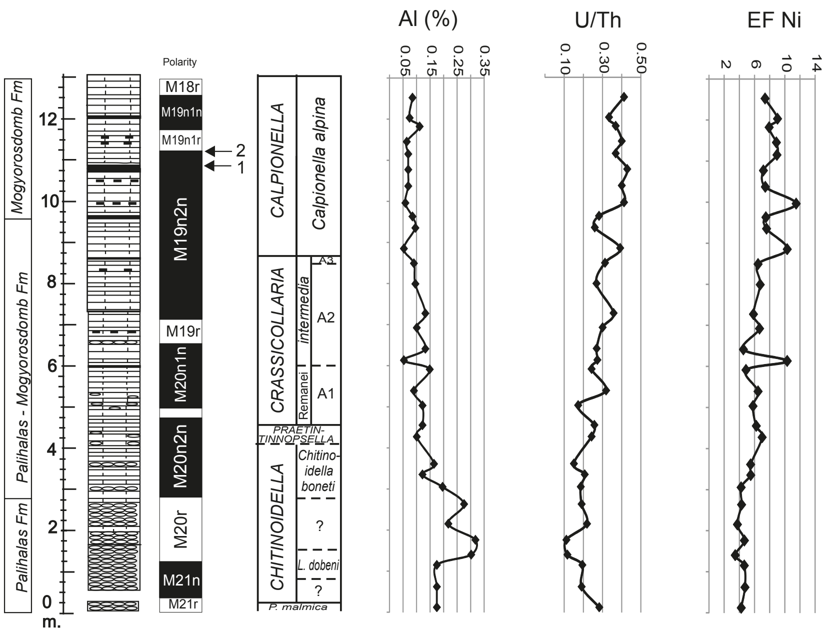

Fig. 1. Integrated stratigraphy of the Lókút section

Magnetostratigraphy and calpionellid stratigraphy after Grabowski *et al.*, 2010: proxies of lithogenic input (Al), redox (U/Th), palaeoproductivity (EF Ni) and first occurrences of *Nannoconus kamptneri minor* (1) and *N. steinmannii minor* (2)

TITHONIAN–BERRIASIAN MAGNETIC STRATIGRAPHY, GAMMA RAY SPECTROMETRY, ANISOTROPY OF MAGNETIC SUSCEPTIBILITY (AMS) STUDIES AND GEOCHEMICAL ANALYSES IN THE NORTHERN CALCAREOUS ALPS (LEUBE QUARRY, SALZBURG AREA, AUSTRIA) – FIRST RESULTS

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The latest Jurassic to Early Cretaceous Leube section in the central Northern Calcareous Alps comprises a series of the Tithonian to Valanginian hemipelagic limestones and marls of more than 200 m thickness dated by means of calpionellids and ammonites (Krische *et al.*, 2013; Bujtor *et al.*, 2013). First results of palaeomagnetic investigations confirmed presence of primary magnetization (Grabowski *et al.*, 2016). Reversed and normal magnetozones can be documented in the upper part of Oberalm Formation (Late Tithonian to Middle Berriasian) and in the Schrambach Formation (Late Berriasian to Late Valanginian). The red condensed horizon of the marly Gutratberg Member, which marks the transition between the Oberalm and Schrambach formations is situated in the lower part of a more than 30 m thick interval of normal magnetization (most probably M16n), in the lower part of the Upper Berriasian (Fig. 1).

Magnetic susceptibility (MS) correlates with K and Th content and is interpreted to mirror fluctuations in the content of fine-grained siliciclastics. A significant increase of siliciclastic input and fluctuations can be recognized in the upper part of the Oberalm Fm. *s. str.* whereas the older (lower Berriasian) part of the Oberalm succession shows lower and rather stable values. This trend is also confirmed by the lithological and lithofacies trend and the geochemical analyses of the sedimentary succession. Also around the Jurassic/Cretaceous boundary MS as well as K and Th content is rather low. This part of the succession is characterized by fine- to medium-grained allodapic layers from the Plassen Carbonate Platform to the south and mass transport deposits with Permian cm-sized claystone clasts. It contains only small amounts of paramagnetic minerals, but elevated U/Th ratios.

Well constrained anisotropy of the magnetic susceptibility (AMS) reveals a well-defined foliation within a bedding plane and NW–SE trending magnetic lineation. (Fig. 2). The magnetic fabric is typical for weakly deformed sedimentary rocks. The results indicate compression and thrusting direction from SW towards NE.

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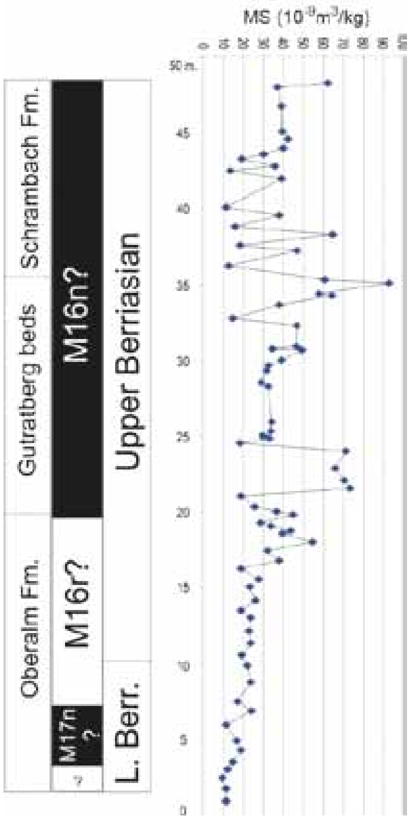

Fig. 1. Magnetic susceptibility (MS) record and magnetic polarity at the Oberalm/Schrambach Formation boundary

Black – normal polarity; white – reversed polarity

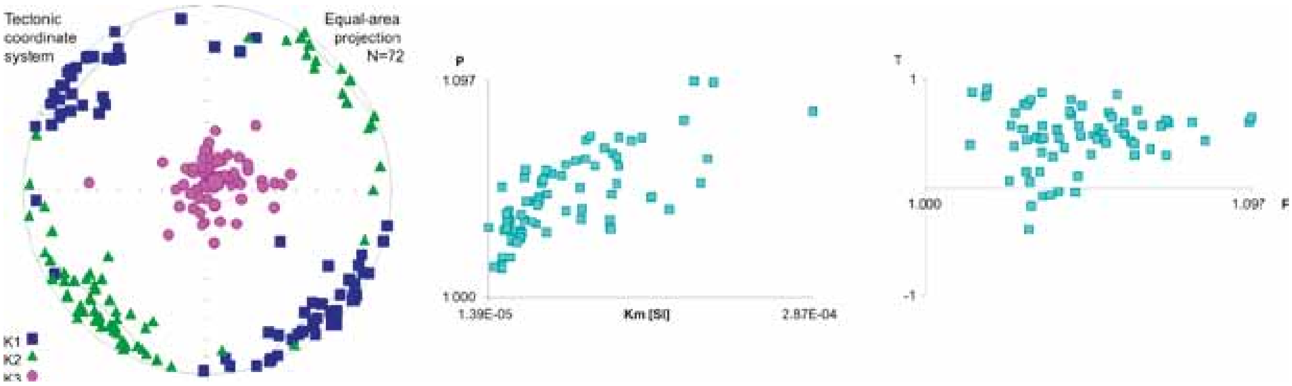

Fig. 2. Anisotropy of the magnetic susceptibility (AMS)

K1 (K2, K3) – maximum (intermediate, minimum) susceptibility axes (stereographic projection in bedding coordinates); Km – mean volume susceptibility; P – degree of anisotropy; T – shape parameter of the AMS ellipsoid

BASIN EVOLUTION DURING THE LATE JURASSIC TO EARLY CRETACEOUS IN THE BAKONY MOUNTAINS, HUNGARY

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During the early stage of the Alpine plate tectonic cycle, the Transdanubian Range Unit was situated between the South Alpine and Austroalpine realms (Schmid *et al.*, 1991; Haas *et al.*, 1995; Csontos, Vörös, 2004). After continental rifting of Pangea, the opening of the western basin of the Neotethys Ocean initiated in this region in the Middle Triassic. Later on, in connection with the opening of the Atlantic Ocean a new oceanic basin opened from the Early Jurassic onwards – the Penninic Ocean ("Alpine Tethys"). As a result of this process the Adriatic Spur (*i.e.*, the Austroalpine, South Alpine and Transdanubian Rage domains) separated from the European Plate. Closure of the Neotethys Ocean began in the Middle Jurassic and led to onset of the obduction of the oceanic basement onto the continental margins during the latest Jurassic to Early Cetaceous. In this period the Adriatic Spur was located between the expanding Penninic Ocean and the compressing margin of the Neotethys Ocean (Csontos, Vörös, 2004). During the latest Jurassic to earliest Cretaceous (Late Tithonian to Berriasian) a pelagic basin existed in the area of the Transdanubian Range which was in direct connection with the Alpine Tethys. Bathyal conditions may have prevailed in the western part of this basin located closer to the Alpine Tethys and it got gradually shallower eastward. Subduction derived imbrication of the Neotethys margin and obduction of the oceanic basement led to development of a foreland basin (Gerecse Basin) and a related forebulge in the eastern part of the Transdanubian Range unit during the Early Cretaceous (Tari, 1994; Fodor *et al.*, 2013). Manifested in the form of a submarine high, the forebulge separated the western Bakony Basin form the eastern Gerecse Basin during the early part of the Early Cretaceous (Berriasian to Barremian interval). Pelagic biogenic siliceous and carbonate sediments prevailed in the former basin whereas siliciclastic deposition was dominant in the latter one.

For interpretation of the latest Jurassic to earliest Cretaceous evolution of the Bakony Basin the results of detailed study of two key-sections can be used. The succession of the western part of the basin is represented by the type section of the Mogyorósdomb Formation in Sümeg (Haas *et al.*, 1985) whereas successions representing its eastern part are exposed in the vicinity of Lókút (Grabowski *et al.*, 2010). Although the basic lithological features are similar in the two sections, there are remarkable differences in the microbiofacies. Biomicrite packstones with large amount of Calpionellids and Globochaete, and usually only very few Radiolarians occur at Lókút. In contrast at Sümeg along with the afore-mentioned components, large amount of Radiolarians appear in many layers (Haas *et al.*, 1994). This difference probably reflects different paleogeographic setting of the two sections. The western part of the Bakony Basin was located probably in the neghbourhood of the westernmost part of the Trento Plateau (Vörös, Galácz, 1998) and through the deep marine Lombard Basin it was in direct connection with the Ligurian part of the Alpine Tethys (Winterer, Bosellini, 1981) (Fig. 1). In the Sümeg section cyclic alternation of Radiolarian-rich and Calpionellid-rich pelagites was observed (Haas *et al.*, 2004). This probably reflects periodic changes in the fertility of the near-surface water: the Radiolarian-rich intervals indicate eutrophic conditions while the Calpionellids-rich beds may have been formed under oligotrophic conditions. The observed eccentricity controlled ~100 ky cycles (Haas *et al.*, 2004) probably reflect changes in the upwelling and near-surface current pattern. Lack or scarcity of Radiolarian-rich beds in the Lókút area suggests depletion of the limiting nutrients and consequently decreasing fertility eastward.

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BIODIVERSITY OF THE LATE JURASSIC (EARLY OXFORDIAN) BRYOZOAN BIOTA OF THE SOUTHERN POLAND – THEIR EVOLUTION AND BIOGEOGRAPHY IN COMPARISON WITH THE EQUIVALENT FAUNAS OF THE ANGLO-NORMANDIAN BASIN

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The open shelf Early Oxfordian sponge biohermal facies exposed on the NE margin of the Holy Cross Mts (Cmielów area) represent a rich fossiliferous carbonate buildups colonized successively by many different benthic groups of organisms.

The rich bryozoans fauna of the Early Oxfordian bryozoans (*Cordatum* chron) from Ćmielów (Holy Cross Mts), which pre-dates the Bałtów assemblage is the most diverse known from the Oxfordian.

A wide range of colony-forms occurs at Ćmielów such as round-shaped, massive cerioporids, plate like bereniciform uniserial or multiserial colonies, narrow delicate branched idmoneiform, fungiform and encrusting sheet-like colony forms abound on the shelly, hard substrate, which form the dominant element. Eight species belonging to eight genera have been distinguished: *Oncousoecia* sp., *Radicipora radiciformis*, *Idmonea* sp. ?*Reptomultisparsa* sp., ?*Mecynoecia* sp. *Ceriocava corymbosa*, ?*Theonea chlatrata* and *Apsendesia cristata*, as well as the numerous bereniciform colonies.

Ćmielów assemblage is a good example, where rich accompanying fauna forms a successful habitat islands for the encrusting communities that settled simultanously as a host animals or after depth representing a benthic island model (Fig. 1).

Elevated parts of sea bottom were occupied since the Early Oxfordian by the sponge bioherm and than successively colonized by the coral reefs, among which the bryozoans play important role. Undoubtedly, the bryozoans assemblage from Cmielów is the richest assemblage from the Early Jurassic recognized from Poland and its contains many different morphotypes dominated by encrusting and plate-like colonies, together with rich associated biota represented by molluscs, brachiopods, ammonites, crinoids and echinoids. Cmielów assemblage is a good example where the rich accompanying fauna formed a habitat islands for the encrusting communities that either lived at the same time as a host animals or colonized their shells after death representing a benthic island model. This fauna is strongly bounded with the evolution of the bryozoans in the Late Jurassic – a time where the biodiversity decreased considerably in comparison with the Mid-Jurassic. The newly documented Early Oxfordian fauna have to be referred to the specimens from the Late Callovian–Early Oxfordian of the Oxford Clay Formation, as well as its Normandy equivant in aspects of their evolution, biogeography and palaeoecology of the Jurassic ecosystem, globally. The bryozoans of the Mid- and Late Jurassic, have been intensely studied from the southern part of England at the end of the XIXth century and also more recently from France (Normandy and Saone–Rhone basins) as well as from the Swabian Basin of Germany.

In the context of biodiversity a considerable attention should be paid to the Early Oxfordian Ćmielów bryozoans biota from the NE margin of the Holy Cross Mts, which significantly could enlarge our knowledge on the Late Jurassic cyclostome.

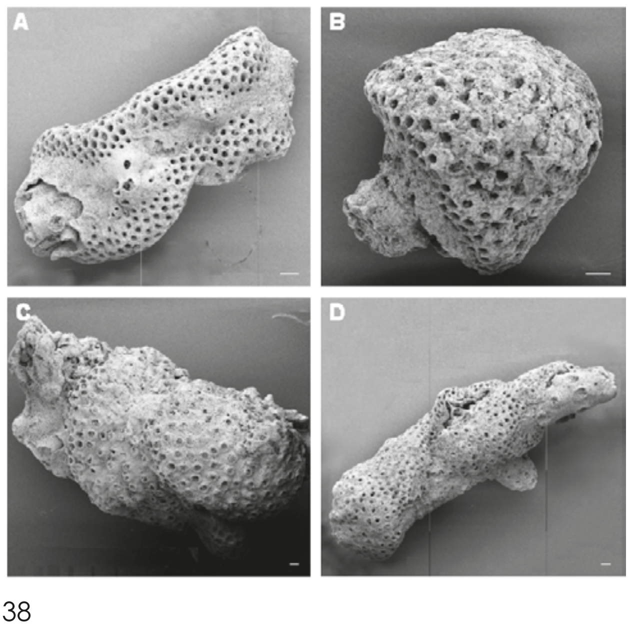

Fig. 1. Bryozoan colonies settled on the hard substrata of the other bryozoans representing benthic island model (scale bar 0.1 mm, Ćmielów area, NE margin of the Holy Cross Mts. Early Oxfordian)

MAGNETIC SUSCEPTIBILITY, CARBONATE CONTENT AND ELEMENTAL GEOCHEMISTRY OF UPPER KIMMERIDGIAN–LOWER TITHONIAN LIMESTONES FROM THE DŁUGA VALLEY, KRÍŽNA NAPPE OF THE TATRA MOUNTAINS, POLAND

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Upper Kimmeridgian–Lower Tithonian pelagic deposits were studied on the northern slope of the Długa Valley, which is a tributary valley of the Chochołowska Valley in the Western Tatra Mts. Deep-water limestones, 26 m thick, are represented by red, partly nodular limestones of the Czorsztyn Limestone Formation and grey, locally red, platy limestones of the Jasenina Formation (Fig. 1). This kind of sedimentation coincides with the recovery of carbonate production after Upper Bathonian–lower Upper Kimmeridgian radiolarite sedimentation (Jach *et al.*, 2012, 2014). This change is manifested by increase of carbonate content (from 46 to 74 wt.% $CaCO_3$, average content 50% wt) and occurrence of *Saccocoma* dominated microfacies which higher up in the section is succeeded by *Saccocoma-Globochaete* microfacies. The described microfacies succession refers to a broad phenomenon recorded in the Western Tethys.

Magnetic susceptibility (MS) curve reveals only minor variations. Some trends as well as indistinct minimum (1.13×10^{-8} m^3/kg in the upper part of Jasenina Fm.) and maximum (4.69×10^{-8} m^3/kg in the lowermost part of Jasenina Fm.) are visible. Generally, the values are low in the Upper Kimmeridgian red nodular limestones, then they slightly increase in the uppermost Kimmeridgian towards the boundary of Czorsztyn and Jasenina Formations. Then they successively decrease in the Lower Tithonian platy limestones. Weak negative correlation of MS vs $CaCO_3$ may suggest higher carbonate production with decreasing detrital input. MS reveals only moderate correlation with lithogenic elements (Al, K, Ti, K, Rb and Th), which probably results from a small number of geochemical data.

Sediments are generally well-oxygenated with relatively high Th/U rato: between 9.0 in the lowermost part of Czorsztyn Formation and 3.4 in the upper part of Jasenina Fm. Palaeoproductivity proxies (P/Al, Cd/Al and Si/Al) reveal a slight increase in the top of the section, in the Lower Tithonian Malmica Zone.

The studied data require normalization to sedimentation rate which was calculated by using the available biostatigraphic data. If lithogenic elements are normalized to sedimentation rate, there appears to be a maximum input of Al, K, Ti, Th at the lowermost Tithonian (Pulla Zone).

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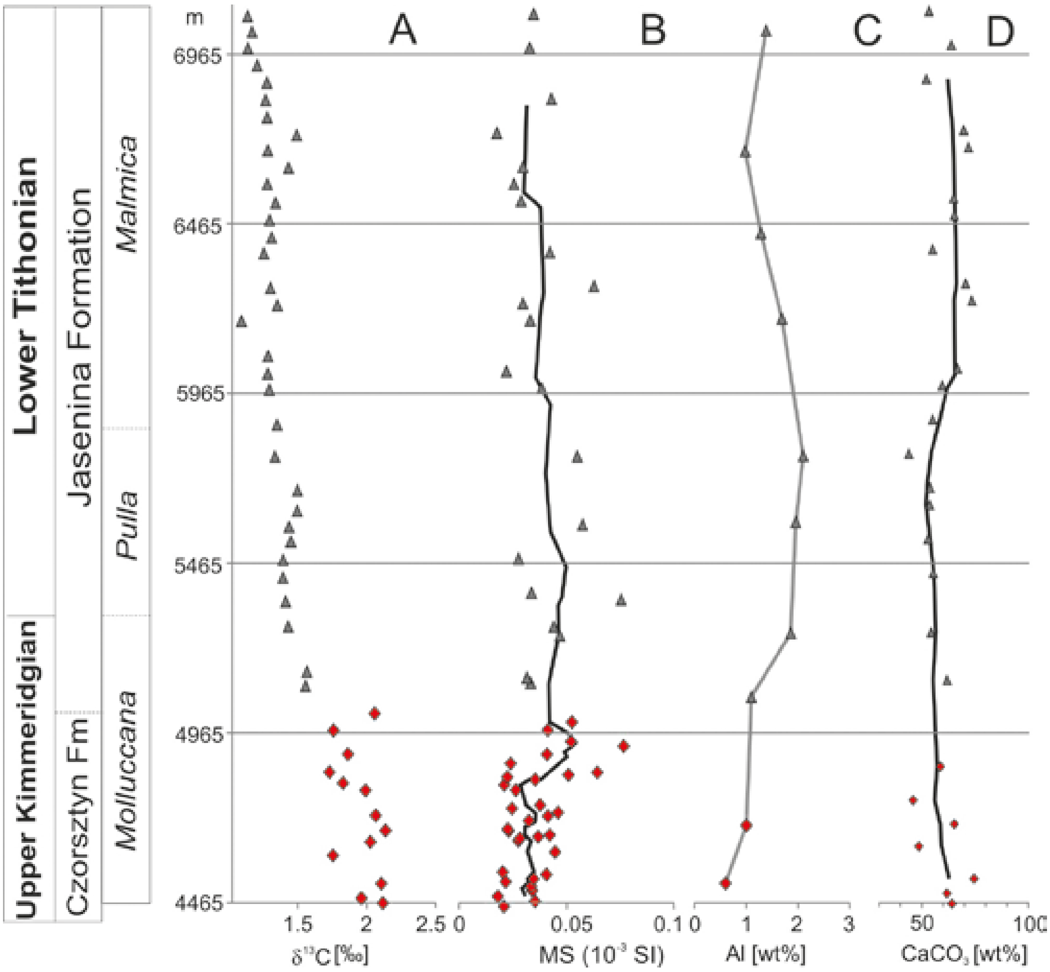

Fig. 1. Długa Valley section in the Western Tatra Mts (litho-, bio- and chronostratigraphy after Jach *et al.*, 2014)

A – carbon isotope measurements (after Jach *et al.*, 2014); B – measurements of magnetic susceptibility (MS) using SM-30 device; C – aluminium content; D – $CaCO_3$ content (after Jach *et al.*, 2014).
Thick black lines represent the five point moving average curve for MS (B) and $CaCO_3$ data (D).
Red symbols: Czorsztyn Limestone Formation; grey symbols: Jasenina Formation

CARBONATE-CLASTIC SEDIMENTS OF THE DUDZINIEC FORMATION (LOWER JURASSIC) IN THE KOŚCIELISKA VALLEY (HIGH-TATRIC SERIES, TATRA MOUNTAINS, POLAND)

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Abstract: Sediments of the Dudziniec Formation outcropping in the Kościeliska Valley (autochthonous unit, High-Tatric series, Tatra Mountains) are represented by a range of mixed carbonate-clastic deposits. Seven lithofacies have been distinguished based on lithology, sedimentary structures, colour and composition of intra- and extraclasts, with sandstones and crinoidal limestones as end members of a continuous spectrum of facies. The main factors governing the development and distribution of facies were the synsedimentary tectonic activity and distance from source areas. In terms of these factors influencing the deposition, the described Early Jurassic phenomena strongly resemble the Middle Jurassic development in the High-Tatric area.

The High-Tatric sedimentary succession of the Tatra Mountains is exposed in three tectonic units: Kominy Tylkowe, Czerwone Wierchy and Giewont (*e.g.*, Kotański, 1961). The Kominy Tylkowe Unit (also referred to as the autochthonous unit) rests directly on the crystalline basement. The unit embraces also the so-called parautochthonous folds, in which the sediments have been tectonically moved on minor distances, but palaeogeographically represent the same region. The Czerwone Wierchy and Giewont units (also called allochthonous or foldic) have been detached from their basement and transported northwards over the autochthonous unit as High-Tatric nappes during the Late Cretaceous (*e.g.*, Jurewicz, 2005). The High-Tatric Jurassic sediments are organized into lithostratigraphic units (Lefeld *et al.*, 1985): the Dudziniec Formation (Sinemurian–Bajocian – sandy-crinoidal deposits), the Smolegowa Formation (Bajocian – white crinoidal limestones), the Krupianka Formation (Bathonian – red crinoidal limestones, nodular limestones and ferruginous limestones) and the Raptawicka Turnia Formation (Callovian–Hauterivian – wavy bedded, nodular and massive limestones).

Carbonate-clastic sediments of the Dudziniec Formation were studied in detail in the upper part of the Kościeliska Valley. The following lithofacies were distinguished: sandstones, pebbly sandstones, sandy limestones, sandy-pebbly limestones, sandy crinoidal limestones, crinoidal limestones and crinoidal sandstones (Jezierska *et al.*, 2016). All the lithofacies have a mixed carbonate-clastic character, however, with distinctly different proportions of particular elements. Variety in the amount and character of clastic admixture reflect changes of sedimentary conditions during the deposition. Sedimentation of sandy facies took place in a shallow-water, high-energy environment, close to uplifted and eroded areas, whereas the crinoidal facies were deposited further from the land. The main factors controlling the sedimentation and the distribution of facies were: synsedimentary tectonic activity and the distance from source areas (with sandy facies representing periods of block faulting and tectonic instability, and crinoidal facies corresponding to episodes of deposition in relatively stable conditions). Comparison of the results with earlier works, which were focused on the Chochołowska Valley area (Wójcik, 1981), allows to conclude, that the regions located in the eastern part of the autochthonous unit (Kościeliska Valley area), represent shallower and a more proximal part of the basin, than the regions located on the west (Chochołowska Valley area). The presented detailed studies of the Lower Jurassic deposits of the Kościeliska Valley area contribute to the identification of environmental conditions and processes controlling sedimentation of the Dudziniec Formation in the whole High-Tatric domain. They also add new information to the general model proposed by Wójcik (1981).

Considering the development of the High-Tatric Lower and Middle Jurassic, and the processes influencing the deposition, the Dudziniec Formation and the Middle Jurassic formations reveal many similarities. All the discussed formations either occur as discontinuous lenticular bodies (Łuczyński, 2002), or their record is obscured by visible internal breaks in deposition (Jezierska, Łuczyński, 2016). In contrast to the Dudziniec Formation, the Smolegowa and the Krupianka formations occur in the whole High-Tatric area (Giewont, Czerwone Wierchy and autochthonous units). All the formations are in whole or partly developed as crinoidal facies, differing in the content of crinoidal debris and the amount of clastic admixture. In the crinoidal limestones of the Dudziniec and Smolegowa formations, the crinoidal material constitutes over 80% of rock volume and forms almost pure encrinites. The Krupianka Formation (Bathonian) is also partly developed as crinoidal limestones, with the content of crinoidal material ranging between 30 and 80% (Łuczyński, 2002), and a relatively abundant clastic admixture. Another important issue concerns the differentiation of bottom morphology during the Early and the Middle Jurassic. A significant part of Jurassic deposits of the Kominy Tylkowe Unit reveals pronounced lithofacies variation along the E–W line, with generally deeper facies on the west. Both the Early and Middle Jurassic of the High-Tatric series are also associated with the development of neptunian dykes (Łuczyński, 2001; Jezierska *et al.*, 2016).

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MAGNETOSTRATIGRAPHY OF JURASSIC–CRETACEOUS BOUNDARY SECTION AT BEAUME (BELVEDERE), VOCONTIAN BASIN, FRANCE – PRELIMINARY RESULTS

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The Belvedere section is situated close to Haute Beaume (Drome, France), in Vocontian Basin. The studied part is composed of 25 metres long well-bedded and massive limestone (36 beds), which continue at least additional 10 meters. The age of the sequence is considered to be Upper Tithonian to Lower Berriasian.

Magnetostratigraphic and micropalaeontological methods were applied. Thermal demagnetization showed the best results for magnetostratigraphy. Pilot measurements on 21 specimens indicates the presence of two normal and two reversed polarity intervals (Fig. 1). The ammonite biostratigraphy was studied up to bed number 75. The preliminary results on the distribution of the age-diagnostic ammonite taxa show that the Belvedere section spans most of the *B. jacobi* Zone *auctorum* (Frau *et al.*, 2016). The calpionellid found prove Intermedia, Colomi, Alpina and Ferasini subzones (Crassicollaria and Calpionella zones), which help to interpret the magnetostratigraphic column. According to the calpionellid biostratigraphy, the basal normal polarity zone (N1) corresponds to M19n. Moreover, the first occurrence of the calcareous nannofossil *Nannoconus wintereri* was recorded in this interval. One sample with reversed polarity lies in the upper part of N1 (marked with empty circle in Fig. 1), which may correspond to the Brodno subzone. However, one sample is statistically not enough. The second and third magnetozones (R1 and N2) we attribute to magnetozones M18r and M18n, respectively. The last magnetozone (R2) in the section is interpreted as M17r. The boundary between the last two zones (N2/R2) is gradual.

Magnetic susceptibility rises in the upper part, which might have been caused by a change in terrigenous input.

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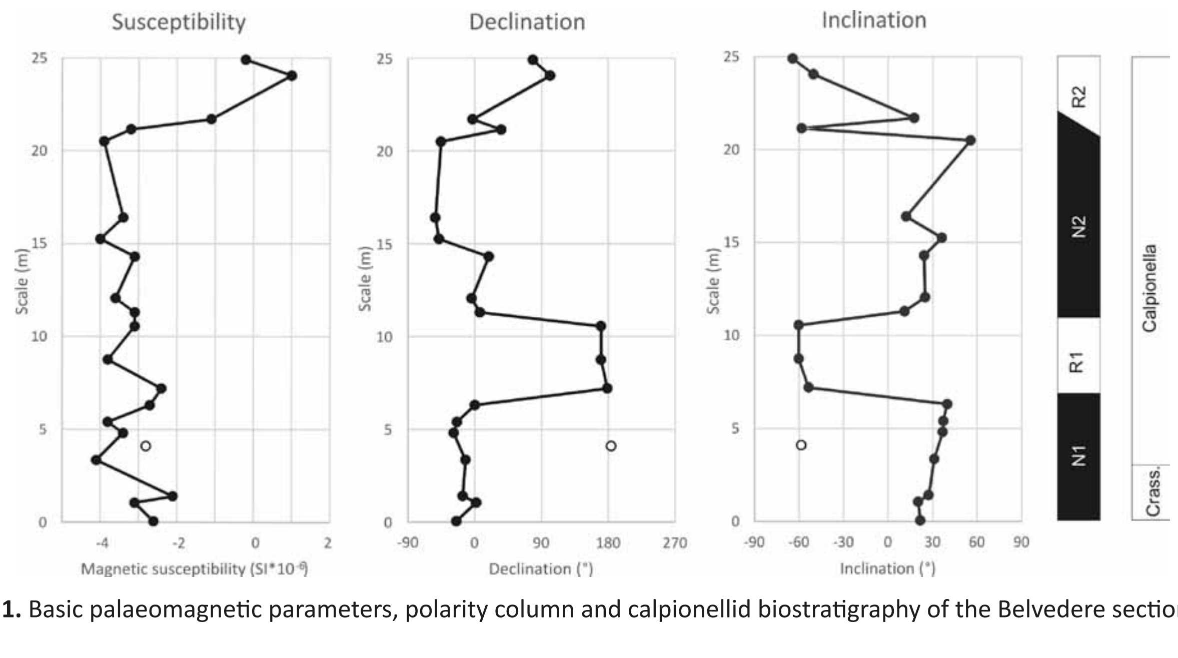

Fig. 1. Basic palaeomagnetic parameters, polarity column and calpionellid biostratigraphy of the Belvedere section

TOARCIAN AMMONITE CHRONOSTRATIGRAPHY OF THE TŰZKÖVES RAVINE SECTIONS (BAKONYCSERNYE, HUNGARY)

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Tűzköves Ravine close to Bakonycsernye (NE Bakony Mts, Transdanubian Central Range) is one of the classic sites of early and middle Jurassic ammonites in the Mediterranean Province. Numerous works dealt with its immensely rich cephalopod fauna (*e.g.*, Prinz, 1904; Géczy, 1966, 1967a), recently a new Aalenian–early Bajocian ammonite assemblage and stratigraphy were presented by Galácz *et al.* (2016). However, information on Middle–Late Toarcian ammonites, especially on the Hammatoceratidae and Erycitinae remained limited in the previous works. During the last ten years hundreds of Toarcian ammonoids were collected bed by bed from three newly excavated sections. The assemblage is rich in previously unrecorded index fossils and these taxa allowed completing the Toarcian biostratigraphy offered by the above mentioned authors (Kovács *et al.*, *unpublished study*).

In the classic work of Prinz (1904) the Jurassic strata of the Tűzköves Ravine were divided into three ages: Middle Lias, Upper Lias, and Lower Dogger. Later, based on precise collecting method, a detailed Mediterranean ammonite biostratigraphy was presented by Géczy (1967b) for the Tűzköves sections with four Toarcian chronozones (Harpoceras falciferum, Mercaticeras mercati, Phymatoceras erbaense, Dumortieria levesquei). In the 1960s the Geological Institute of Hungary carried out a collection of Jurassic rocks from a new section in the ravine, and the sequence was described on the basis of Géczy's zonation (M. mercati was replaced by the Hildoceras bifrons Zone) (Konda, 1989), this scheme was still used in the geological summary of the Transdanubian Range by Császár *et al.* (2012). The revision of the Pliensbachian–Toarcian boundary by Galácz *et al.* (2008) completed the former stratigraphic arrangement with the basal Toarcian Dactylioceras tenuicostatum Zone.

The new excavations studied by the author revealed thicker Toarcian fossil-rich layers with several hitherto unrecorded hildoceratid zonal and subzonal index taxa. Despite the condensation, six Middle–Upper Toarcian ammonite zones and eight subzones became distinguishable. The biostratigraphic achievement on the one hand, and the Lower–Middle Toarcian diagnostic taxa recorded in earlier papers on the other enable us to present a detailed, integrated ammonite chronostratigraphy that is based on contemporary syntheses (Elmi *et al.*, 1997, page 2003) with some amendments (Table 1). The scheme corresponds to that was summarized for the Middle–Upper Toarcian sequences of the Gerecse Mts by the author (Kovács, 2011). The results prove that the Toarcian sedimentation in the Bakony and the Gerecse Mts are closely affiliated, and the recent Toarcian ammonite chronostratigraphy can be used in point of the whole Transdanubian Central Range.

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Table 1. Toarcian chronozones and subchronozones of sequences of the Tűzköves Ravine

Géczy (1967b), Galácz et al. (2008)			Present paper		
Substage	Zone	Subzone	Subzone	Zone	Substage
Upper	Dumortieria levesquei			Pleydellia aalensis	Upper
				Dumortieria meneghinii	
	Phymatoceras erbaense			Geczyceras speciosum	
			Pseudogrammoceras fallaciosum	Grammoceras thouarsense	
			Grammoceras striatulum		
			Pseudogrammoceras bingmanni		
			Merlaites alticarinatus	Merlaites gradatus	Middle
			Pseudogrammoceras subregale		
			Merlaites clausus		
Lower	Mercaticeras mercati	Hildoceras semipolitum	Hildoceras bifrons	Hildoceras bifrons	
		Hildoceras sublevisoni	Hildoceras sublevisoni		
	Harpoceras falciferum		Harpoceras falciferum	Harpoceras serpentinum	Lower
			Harpoceras serpentinum		
	Dactylioceras tenuicostatum		Orthodactylites semicelatum	Dactylioceras tenuicostatum	
		Paltarpites paltus	Paltarpites paltus		

EARLY/MIDDLE JURASSIC (TOARCIAN/AALENIAN) POLYCHELID CRUSTACEAN REMAIN IN THE TAURIDA FLYSCH FORMATION (BAKHCHYSARAI REGION, CRIMEA, UKRAINE)

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Polychelidan lobsters (Decapoda, Polychelida) are weird lobster-like creatures with four to five pairs of claws. They are the coelacanths of the decapod crustaceans. Indeed, extant species, all ascribed to a single family (Polychelidae), which are distributed worldwide in deep-water environments (Galil, 2000; Ahyong, Galil, 2006; Ahyong, Chan, 2008; Ahyong, 2009; Chan *et al.*, 2011; Artüz *et al.*, 2014). As coelacanths, they seem to be the relics of a group that was once more diverse morphologically and inhabited more diverse environments (Ahyong, 2009; Audo *et al.*, 2014a, b, c; Bravi *et al.*, 2014). Also as for coelacanths, fossil polychelidans were discovered before their extant relatives (Heller, 1863). Compared to fossil polychelidan lobsters, extant species have strongly reduced eyes, and they are adapted to deep-water environments, and consequently sometimes referred to as "deep-sea blind lobsters" (Dall'Occo, Tavares, 2004; Bezerra, Bezerra Ribeiro, 2015; Farias *et al.*, 2015) and all of them are restricted to outer slope or abyssal depth (Ahyong, 2009). On average, adult polychelids are most frequently discovered on the sea-bottom from 500 to 1500 m (maximum up to 5124 m; Galil, 2000).

How polychelidans ended up restricted to such deep environments? It is difficult to say because most fossils have well-developed eyes and often come from environments in the euphotic zone (up to 200 m in very clear waters).

To provide new elements on this subject, we reinvestigated *Palaeopolycheles crymensis* Levitsky, 1974, a species which was in a taxonomic limbo. We discovered that this Jurassic species possessed many traits in common with the extant species, such as reduced eyes, and is undoubtedly ascribe to the Polychelidae. We therefore investigated its palaeoenvironment to know if it lived in deep water as extant species. *Palaeopolycheles crymensis* is known by a single specimen preserved in a sideritic nodule from Yaman ravine near Prokhladnoe village (Bakhchysarai region, Crimea, Ukraine). This locality is also known for its stratotype section of the Taurida Flysch Formation (*sensu* Oszczypko *et al.*, in press) of Late Triassic–Early Jurassic age (Muratov, 1960; Muratov *et al.*, 1984). The age of the outcrop what estimated as Toarcian–Aalenian based upon the occurrences of *Dactylioceras* sp. and *Acrocoelites* (*Toarcibelus*) *quenstedti* (Oppel, 1856) which is now considered to span from the lower Toarcian to the Aalenian (Doyle, 1991). Recent micropalaeontological studies based on foraminiferal assemblages and calcareous nannoplankton (Oszczypko *et al.*, in press) generally confirm Early Jurassic age (Toarcian–Aalenian) of the uppermost part of flysch-type sequence in this region (Nikishin *et al.*, 2015).

The holotype of *T. crymensis* is preserved within a sideritic concretion which was compressed by diagenesis. Only one part of the nodule is known, which offers a view of the inner side of the carapace, pleon and telson. In the Taurida Flysch Formation sideritic concretions, such as that preserving *T. crymensis* holotype, are typical for dark grey, fine to very fine, thin- to medium-bedded turbiditic sandstones with shaly and mudstone intercalations and rare thick sandstone beds. In this case we have typical, deep-sea flysch-type deposits which very well documented syn-orogenic character of the Jurassic Crimean trough regime during sedimentation of turbidites with polychelidean remain.

From a taphonomical point of view, crustacean decapods need very special conditions, including limited post-mortem transport, relatively rapid burial and lack of bioturbation in the sediment (Plotnick, 1986; Plotnick *et al.*, 1988; Müller *et al.*, 2000). It is therefore possible that this specimen was autochthonous or parautochthonous of the environment where it fossilized. Sediments deposited on low-energy conditions (Schäfer, 1951) and mainly from suspension are preferable for decapods conservation. Rapid burial is necessary against short time which is needed for decomposition and disintegration of crustacean bodies and which are limited to few days (example given for shrimps with residence time inferior to 9 days – Bishop, 1986; Plotnick, 1986). Therefore studied crustacean presumably was buried very rapid and then coated by sideritic concretion which occurred in fine-grained silty mud originated as turbiditic suspension cloud which was not enough to destruction of this polychelid remain but protected it against destructive effects.

In short, our reinvestigations show that *P. crymensis* is an exceptional case of preservation within deep-sea turbidites, that Polychelidae had already evolved and conquered deep-water environments in the Early/Middle Jurassic.

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PLIENSBACHIAN *LITHIOTIS*-FACIES IN MOROCCAN HIGH ATLAS – PRELIMINARY PALAEOENVIRONMENTAL REPORT

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Recovery of marine reef fauna after Triassic/Jurassic mass extinction event was mainly marked by *Lithiotis*-type bivalves buildups occurrences. The so-called *Lithiotis*-facies (*sensu* Fraser *et al.*, 2004) is represented by world-wide Pliensbachian-Early Toarcian limestones with large bivalves dominated by *Lithiotis*, *Cochlearites*, *Gervileioperna*, *Litioperna*, *Mytiloperna* and/or *Opisoma* genus. After this biological crisis, when coral reefs decreased and almost collapsed, such type of bivalves occupied shallow-marine/lagoon-type environments and recovered organic buildups (mounds/reefs/biostromes) in numerous places of Tethyan-Panthalassa margins during this time (Krobicki, Golonka, 2009). Their world-wide distribution indicates palaeogeographic/geodynamic regimes during break-up of Pangea in Pliensbachian-Early Toarcian times. The Moroccan High Atlas Mountains are one of the classical site of *Lithiotis*-type bivalves-bearing buildups which occur in numerous localities (*e.g.*, Jebel Azourki – Assemsouk section, Ouaouizerth area near Beni Mellal, Todra gorge, Er-Rachidia region – Dar-el Hamra and Aït-Athmane) (Lee, 1983; Fraser *et al.*, 2004; Krobicki *et al.*, 2008; Wilmsen, Neuweiler, 2008).

One of the spectacular place where such buildup we studied is Assemsouk section in Jebel Azourki range. Perfectly crop out section of the Pliensbachian carbonate-clastic deposits is represented by record of regression manifested by continuous transition from shallow-water full marine limestones with corals trough calcareous-marly deposits (most probably lagoon-type) with numerous bivalves of *Lithiotis*-facies, up to nearshore clastic-carbonate deposits, often with good recorded cross-bedding structures and with abundant remains of plants which most probably represent lagoonal-paralic environments (Fig. 1). In the middle part of the section *Opisoma*-bearing beds occur and in the topmost part huge (up to 0.5 m long) shells of *Cochlearites* are in life position and represent monospecific autochthonous association.

In Beni Mellal region one of the best place of *Lithiotis*-facies limestones crop out along road near Ouaouizerth village. Continuous section (over 200 meters in thickness) is mainly built by well-bedded different kinds of limestones (*e.g.*, oncolitic/oolitic, biodetritic, laminated) intercalated by multicolored marls. Bivalves-rich beds constitute at least eight horizons, where they occur both in vertical, autochthonous life position, and in horizontal orientation as parautochthonous accumulations. In a few places lens-shape biostromes full of *Lithiotis*-type bivalves occur. They are dominated by *Litioperna* specimens in lower and upper parts of the section and a few *Gervileioperna* and *Opisoma* which occur in the middle part of it. Another fossils are represented by gastropods, solitary corals and echinoderm fragments and algae remains which occur locally. Several omission surfaces presumable indicate emersion events during sedimentation of these beds. Such sedimentological and palaeoecological features indicate supratidal and/or peritidal environments for different parts of sequence.

In Todra gorge vicinity and Er-Rachidia region *Lithiotis*-facies are a parts of wide carbonate platform(s) which is(are) the eastern margin of long belt of carbonate Pleinsbachian system (Aganane Formation = Lithiotid Limestone Formation – *sensu* Wilmsen, Neuweiler, 2008), which was facial equivalent of more deep-marine facies (Ouchbis Formation) surrounded this platform(s) from northern side.

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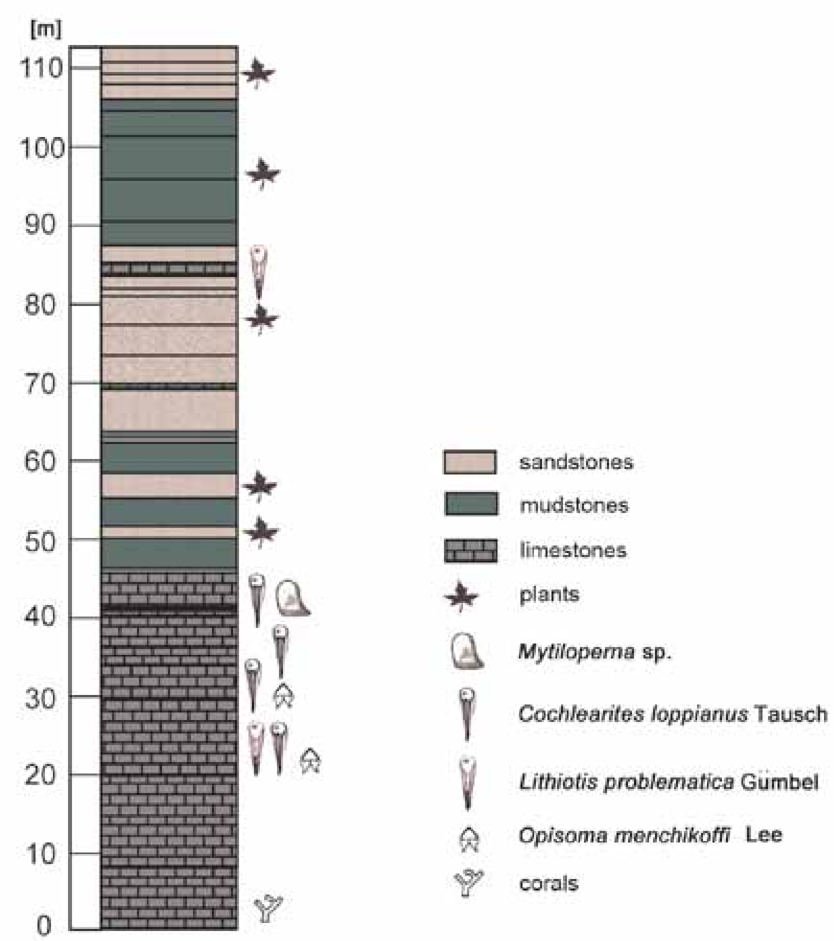

Fig. 1. Assemsouk section (Jebel Azourki, High Atlas, Morocco) record of regressive type of carbonate-clastic sedimentation with *Lithiotis*-facies bivalves

RECORD OF TRIASSIC/JURASSIC BOUNDARY ENVIRONMENTAL CHANGE IN WEST CARPATHIAN SECTIONS

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During Late Triassic, terrigene Carpathian Keuper deposits were followed by Rhaetian limnic/lacustrine mudstones and quartz sands of the Tomanová Fm with iron ores, dinosaur footprints, fern macroflora and diverse palynomorph associations in the Western Carpathian part of the northern Tethyan shelf. Sandstone and shale mineralogy, chemical and quantitative mineral analyses detected felsic sources (Lintnerová *et al.*, 2013). Clay fraction (>30% of the rock: 30–46% in claystone; 20–41% in sandstone), quartz and mica indicate weathering of granites; kaolinite originated by acid leaching in humid and warm climate. Detrital kaolinite decreases upwards (6–41%) being substituted by illite. Acidity increased due to OM decomposition in wetland conditions. Local increase of residual OM (from 0.1–1.5% to 2.5–8.12% of C_{org}) indicates water table rise, increased production and input of plant debris. OM is derived mostly from land plants, probably mixed with limnic OM as indicate the $^{13}C_{org}$ isotope (–27 to –25‰ V-PDB). High (pelo)siderite content (39%) with Fe^{2+} and other redox-sensitive elements indicates temporary reduction and acidification of the mud ore; negative $^{13}C_{sid}$ isotope ratio (–12 to –17‰ PDB) suggests change of pH and dissolved iron oxide by the "biogene" CO_2. Chamosite distribution reveals mobilization of iron (>5 and ≤16% in siderite free samples) during diagenesis. Fe oxides (goethite, lepidocrockite) represent weathering products of these Fe^{2+} minerals. High kaolinite marks start of humidification. C isotope data of OM from the Tomanová Fm are comparable with these from marginal/proximal marine zones, characterized by mixed terrigeneous and marine/limnic OM composition.

Kaolinite content in marine carbonates of the Rhaetian Fatra Fm from an adjacent shallow Zliechov Basin is low (< 10%), being reduced by diagenesis and transformation to chlorite and I/S. Benthic fauna from bioclastic limestones comprises bivalves, brachiopods, corals and foraminifers (Michalík *et al.*, 2013); its diversity decreases upwards. The palynofacies is dominated by terrestrial components, dinoflagellates and by high amount of phytoclasts. Plankton record has been recently supplemented by finding of calcareous nannoplankton remnants (Holcová and Michalík, 2016). Besides calcispheres and spherical nannoliths also monospecific assemblages of small (2.5–4 µm) circular coccoliths with small central opening were recorded. Coccoliths are very rare, usually 2–5 coccoliths were recorded per 100 fields of view of microscope.

Well-exposed 137 m thick uppermost Triassic sequence of the Fatra Formation in the Kardolina section near Tatranská Kotlina (Belanské Tatry Mts) offers a possibility to examine complete carbonate rock record interrupted by levels enriched in quartz grain debris. They enable to distinguish seven 400 ka orbital eccentricity cycles (with subordinated 100 ky cyclicity) expressed in short-timed influence of monsoonal rain precipitations, transporting quartz grains and other terrigene fragments into marine carbonate sedimentary system. One million of years before the Triassic–Jurassic boundary, increase of both content and size of quartz grains indicating growing humidity accelerated in favour of shorter periodical changes. Overturn of the sedimentary regime resulted in a change of rock composition, as well as in impoverishment (and finally, an extinction) of benthic faunas. The Atlantic MORB activity connected with CO_2 production caused rapid sea water acidification reflected in the abrupt decrease of carbonate content, and increase of volcanic ash fall (Ruhl *et al.*, 2011) indicated by increase of rock magnetic susceptibility: these phenomena are well-observable in the top part of the section. The distortion of top part of the Rhaetian carbonate sequence by submarine slumping, described from many sections in a wide area of Europe (Lindström *et al.*, 2015) indicates seismic instability connected with rifting of the Atlantic.

Non-carbonate basal members of the lowermost Jurassic Kopieniec Fm follows above the upper boundary of the Fatra Fm (Michalík *et al.*, 2007). The contact is sharp, stressed by a sudden termination of carbonates and by slump phenomena. The major $\delta^{13}C_{org}$ excursion within the T/J boundary interval documents perturbation of the global C cycle due to MORB volcanism. Two smaller negative $\delta^{13}C_{org}$ excursions correspond to OM content variations, decreasing carbonate content, as well as to changes in clay mineralogy. Palynomorphs are characterised by a sporomorphs increase caused by the major climatic change (Michalík *et al.*, 2010).

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Fig. 1. Lower part of the Kardolina section exposing transgressive contact of the Fatra Fm with underlying Carpathian Keuper deposits

SEDIMENTOLOGY, BIOSTRATIGRAPHY AND GEOCHEMISTRY OF MIDDLE JURASSIC STRATA IN THE STRÁŽOVCE SECTION (STRÁŽOVSKÉ VRCHY MTS), KRÍŽNA NAPPE OF THE CENTRAL CARPATHIANS, SLOVAKIA

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Basinal Zliechov Upper Triassic to Lower Barremian sequence of the Krížna Nappe has been exposed in 1975 by 3.5 km long escarpment below the Strážovce Hill in the Strážovské vrchy Mts between Zliechov and Čičmany (Borza *et al.*, 1980; Michalík, 1985). Cretaceous ammonite stratigraphy was studied by Vašíček *et al.* (1983, 1984), microbiostratigraphy of the J/K boundary by Michalík *et al.* (1990). Later on, the Cretaceous part of the section has been examined by Lintnerová (in Michalík *et al.*, 1995), dealing with stable C and O isotopes. Méres and Michalík (2006) analysed REE in the Jurassic basinal sequence, Grabowski *et al.* (2009) studying magnetic rock properties concluded remagnetisaton during Turonian thrust of the Krížna Nappe.

Claystone/dolomite sequence of the terrigenous Carpathian Keuper is covered by 35 m thick marine carbonates of Rhaetian Fatra Formation. Hettangian Kopieniec Formation (up to 70 m thick) consists of shallow marine argillites. Sinemurian–Pliensbachian Janovky Formation is formed by 50 m of bedded hemipelagic limestones with typical bioturbation (“spotted” limestones of the “Fleckenkalk – Fazies” of Alpine authors).

Lower Jurassic sequence terminates by several metres thick red marlstones with Toarcian belemnites and ammonites compared with the Adnet Formation. It is covered by 6–7 m thick limestone formation (called as the “ash gray siliceous limestone” by Mišík, 1964, or the “Bositra-crinoidal limestone” by Jach, 2007) with cherts, juvenile bivalves, globochaetes, crinoid ossicles and calcified radiolarians (Borza *et al.*, 1980; Michalík, 1985).

Middle Jurassic siliceous carbonates of the Ždiar Formation starts with layer deformed by sumarine slump (Fig. 1) containing subrounded (0.5–20 cm) clasts of limestone and silicite. Well-bedded sequence of brown-red silicitic limestone layers (4–24 cm; Fig. 2) separated by thin marly interbeds is 45–50 m thick. The rock is crowded by radiolarians (mostly calcified, but sometimes filled by fibrous chalcedony or quartz), and sponge spiculae sometimes arranged in laminae. Tiny calcite rhomboeders and irregular aggregates occur in the matrix, pyrite is less frequent.

The Ždiar Fm is covered by the Jasenina Formation, built of dark grey (reddish in the lowermost part) argillitic limestones and marls with quartz grains, white mica and chlorite, calcified radiolarians, sponge spicules, thin shelled bivalve shells, crinoid fragments, small aptychi and belemnites. Calpionellid rests in upper part indicate the Late Tithonian Crassicollaria Zone. In the Geological map of the Malé Karpaty Mts, the term was wrongly interpreted by Polák (2011), who used the name of the Jasenina Fm for all Upper Jurassic sediments. In contrary with shallower red nodular limestone facies, the latter formation represents axial part of the Zliechov Basin. Jach *et al.* (2014) parallelized the Jasenina Formation with the Pieniny Limestone Formation. However, the latter formation belongs to Upper Tithonian–Lower Cretaceous planktogenic “biancône” limestone facies represented here by the Osnica Formation, and higher up by the Mráznica Formation (Borza *et al.*, 1980; Vašíček *et al.*, 1983, 1984; Michalík *et al.*, 1990).

Content of principal elements in the pelagic Ždiar Fm is characteristic of low stable amount of Al_2O_3 (<5 hm %), variable contents of SiO_2 (20–50 hm %) and of CaO (25–40 hm %). Such a trend was produced by mixing of two principal constituents of marine sediments: (1) organogenic SiO_2 (radiolarians) and (2) chemogenic?/organogenic? $CaCO_3$. The absence or low important presentation of siliclastic material correlates with very low K_2O and Al_2O_3 contents. The distribution of REE in the Ždiar Fm was controlled by composition of sea water and by changing representation of organogenic $CaCO_3$ and SiO_2. These sediments inherited an expressive negative Ce/Ce^* ratio of the sea water, indicating considerable depth of the water column. Typical decrease of the ΣREE with increasing content of $CaCO_3$ is related to diluting effect of $CaCO_3$. Calmy environment is expressed by almost ideally parallel PAAS pictures of normallized REE.

The Zliechov Basin was situated on sialic crust fragment of the northern Tethyan shelf affected by tension (Michalík, 1993, 1994). Resulting subsidence of intrabasinal depressions was gradual, Triassic changes observed are rather attributable to global climatic variations (Michalík *et al.*, 2007, 2013). However, the Jurassic sequence records sudden deepening from hemipelagic Lower Jurassic limestones through condensed Adnet Limestone, and Aalenian silicitic limestones to eupelagic Ždiar Formation. The latter sediments were deposited on a bottom of an extensional ("pull-apart") basin with thinned crust, close below the CCD (Michalík, 2007).

Lefeld (1975) suggested Oxfordian–Kimmeridgian age of the Jurassic siliceous formations, supposing that underlying Bajocian–Callovian strata have been removed (dissolved) during Mid Jurassic collapse of the Zliechov Basin. Mišík (1964) interpreted Toarcian–Aalenian complex of the "Adnet" red limestone and marls and "Borišov ash-grey limestone" in the Veľká Fatra Mts as submarine slumped strata. Thin collapse breccia on the base of the Ždiar Formation in the Strážovce section (Borza *et al.*, 1980; Michalík, 1985) dates this slumping as pre-Callovian. Similarly, Michalík and Vlčko (2011) interpreted huge Pleš Breccia of the Tatric area as the collapse breccia after post-Toarcian sudden deepenenig.

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Fig. 1. Slump deformation of basal layer of the Ždiar Formation, Strážovce section

Fig. 2. Detailed view of radiolarian limestone sequence of the Ždiar Formation, Strážovce section

SEISMIC CHARACTERISTICS OF THE OXFORDIAN CARBONATE BUILDUPS IN THE NIDA TROUGH

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The Nida Trough belongs to SE part of the Szczecin–Łódź–Miechów Synclinorium that developed along the SW flank of the Mid-Polish Swell formed during the Late Cretaceous–Paleogene inversion of the Mid-Polish Trough. In a wider regional context, Nida Trough together with its prolongation towards the SE *i.e.*, towards the Carpathian Foredeep and the Carpathians, could be regarded as a transition zone between the epicontinental Mid-Polish Trough and the Tethyan basins. During the Late Jurassic both the transition zone and the northern Tethyan shelf were areas of a wide-spread carbonate sedimentation with diversity of depositional systems including, inter alia, microbial-sponge facies associated with a wide variety of carbonate buildup deposits (Matyszkiewicz, 1999; Gutowski *et al.*, 2007). In the Oxfordian, the Nida Trough was located mainly within the carbonate open shelf and, progressively from NE, towards the end of the Oxfordian and the beginning of the Early Kimmeridgian, within the shallow-water carbonate platform (Matyja, 2009; Złonkiewicz, 2009).

The study area covers SE part of the Nida Trough (Pińczów area) where relatively dense coverage of 2D seismic data has been acquired. Reinterpretation of this seismic data proved presence of a large Oxfordian carbonate buildups. Main objective of this research was to seismically describe these organic buildups, identify their seismic signatures and classify seismic reflection configuration patterns to exactly analyze their internal structure and, as a consequence, their development. Essential part of the seismic stratigraphic interpretation was precise well-to-seismic tie, based on high-resolution synthetic seismograms calculated for key calibration wells. Detailed well-to-seismic correlation and 1D seismic stratigraphic analysis allowed for identifying stratigraphic position of the carbonate buildups on interpreted seismic profiles. Horizon correlation and further interpretation was supported by seismic attribute analysis which is an effective geophysical tool that allows for visual enhancement or quantification of desired geological features from seismic data (Chopra, Marfurt, 2007). Seismic attributes have been already used for recognition of the Oxfordian organic buildups within the Carpathian foreland (Misiarz, 2003; Gliniak *et al.*, 2005).

Analyzed different seismic attributes such as reflection strength, instantaneous phase, cosine of instantaneous phase, instantaneous frequency, apparent polarity etc. together with seismic facies classification provided precise information on external extent and internal depositional architecture of the Oxfordian organic buildups. Interpretation of seismic data was verified using seismic stratigraphic modelling techniques based on ray-tracing approach.

Acknowledgements: San Leon Energy and PGNiG S.A. kindly provided access to the seismic data used for this research.

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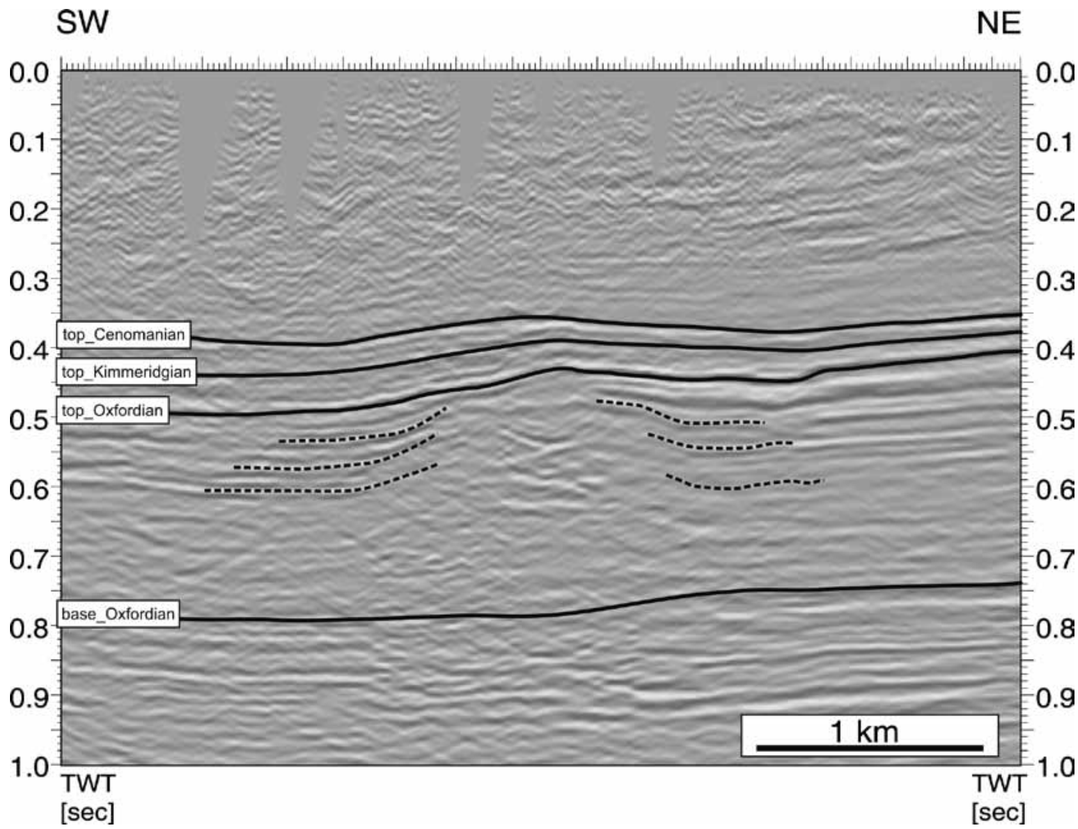

Fig. 1. Seismic image of the organic buildup within the Oxfordian carbonate succession near Pińczów

HIGH RESOLUTION STRATIGRAPHY ACROSS THE JURASSIC–CRETACEOUS BOUNDARY IN THE KUROVICE QUARRY, OUTER WESTERN CARPATHIANS, CZECH REPUBLIC

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Mutual calcareous nannofossil and calpionellid correlation is investigated in the marine sequences at the locality of Kurovice, Czech Republic. The section was chosen for the multidisciplinary research of the Jurassic-Cretaceous (J–K) boundary. Tithonian–Valanginian strata, Kurovice Limestone and Tlumačov Marl respectively, are represented by whitish grey allodapic limestones intercalated with marlstones and belong to the Magura Group of Nappes, Carpathian Flysch. Reháková (in Eliáš *et al.*, 1996) mentioned here calpionellid zones ranging from the Late Tithonian Crassicollaria to Late Berriasian Calpionellopsis Zone. However, J–K boundary was not strictly confirmed due to tectonic reduction. Recent bed-by-bed study confirmed more or less the calpionellid distribution pattern as it was presented in the paper mentioned above, but J–K boundary and the onset of further calpionellid subzones is now more precised. The aim of this study is to compare the distribution of calcareous nannofossils and calpionellids with focus on biostratigraphic and palaeoenvironmental interpretations and data correlate with magnetostratigraphy.

Calcareous nannofossils were investigated in smear slides in the fraction of 1–30 µm separated by decantation method using 7% solution of H_2O_2. Calpionellids were studied in thin-sections. Jurassic NJT and Cretaceous NJK nannofossil zones were applied by Casellato (2010).

Nannofossil and calpionellid record depends evidently on the lithological character of strata. Majority of calpionellid loricas are deformed and lorica´s colars are often damaged. Calcareous nannofossils are usually poorly preserved. Dominance of Ellipsagelosphaeraceae (90%) may furnish proof of strong etching and secondary post mortem modification of nannofloras. Other placoliths are rare, fragmented and usually cannot be identified. This phenomena may affect the final stratigraphic and other interpretations.

- Calcarenites yield extremely poor nannofossils. In the finely ground detritus scarce fragments (1–3 specimens per 10 fields of view of the microscope) are present, exclusivelly Ellipsagelosphaeraceae: *Watznaueria barnesiae* forms here almost 80%, *Cyclagelosphaera margerelii* reaches up to 11%. Calpionellids are also not frequent and many of them are resedimented.
- Homogeneous limestones in thin sections are characterized by dominance of sponge spicules and radiolarians and by rare calpionellids. This deposits contain poorly preserved nannofossils with abundance ±1 up to 10 specimens per 1 field of view of the microscope. Assemblages are represented by high numbers of genera *Watznaueria* and *Cyclagelosphaera* accompanied by rare *Conusphaera mexicana mexicana* and *C. mexicana minor*, *Polycostella beckmanii, Zeugrhabdotus cooperi,* and fragments of outer rims of genera *Retacapsa*, *Helenea*, etc. Specimens of *W. barnesiae* reach up to 70% and *C. margerelii* up to 13%.
- Marlstone intercalations provide relative abundant nannofossils while calpionellids are seldom in them. Nannofossil assemblages (10–20 up to ±50 specimens per 1 field of view of the microscope) are more diversified. Even though specimens of *W. barnesiae* still quantitatively prevail, the number of other *Watznaueria* and *Cyclagelosphaera* species increases. Specimens of genera *Conusphaera, Nannoconus, Polycostella, Retacapsa, Helenea, Diazomatolithus*, *Zeugrhabdotus* occur frequently.

Preliminary calpionellid and nannofossil stratigraphic data:

- The Late Tithonian wackstones contain calpionellid associations typical for the Remanei, Intermedia and Parvula subzones of the Crassicollaria zone.
- Increased abundance of sphaerical species of *Calpionella alpina* Lorenz was observed along the J-K boundary interval. Overlying limestones contain microfossils of Ferasini and Elliptica subzones of the standard Calpionella zone.
- *Conusphaera mexicana mexicana, C. mexicana minor* and *Conusphaera* sp. (“willowy” tapering nannoliths) occur in small numbers across the whole section.
- Presence of *Polycostella beckmannii* and *Conusphaera mexicana mexicana* in the lowermost part of section indicates NJT 15b zone.
- Nannoconids are found scarcely especially in the underlying strata of the acme of *Calpionella alpina*. First small specimens of genus *Nannoconus*, *N. puer* were recorded in association with *Helenea chiastia* and pentaliths, zone NJT 16b.
- Nannofossil first (FO) and last (LO) occurrence succession bellow the acme of *C. alpina,* from the underlie to overlie: *Nannoconus puer* (NJT 16b), FO *N. globulus minor* (NJT 17a), FO *Watznaueria cynthae*, LO *Polycostella beckmannii,* and FO *N. wintereri* (NJT 17b).

– Acme of *Calpionella alpina.*
– Nannofossil record above the acme of *C. alpina*, from the underlie to overlie: FO *Nannoconus globulus globulus*, FOs *Nannoconus kamptneri kamptneri* and *Speetonia colligata* (NKT).
  Other observations:
– Occasionally, reworked nannofossil specimens from the older Jurassic strata, *Parhabdolithus marthae* (?Upper Hettangian–Lower Sinemurian) and *Parhabdolithus robustus* (Sinemurian–Lower Pliensbachian) were found.
– Along the whole sequences studied calcareous dinoglagellate cysts typical rather for Early Tithonian were observed; also Late Tithonian crassicollarians and much elongated and bigger forms of *Calpionella alpina* were identified during the Berriasian part of sequence.
– Tethyan realm confirms not only presence of calpionellids, but also the occurrence of nannofossil genera *Conusphaera, Polycostella, Helenea* and *Nannoconus,* and in the Berriasian also *Speetonia colligata*.

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A REMARKABLE GASTROPOD FAUNULA FROM THE TOARCIAN OF THE TOTES GEBIRGE (NORTHERN CALCAREOUS ALPS, AUSTRIA)

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Gastropods are usually uncommon fossils in deeper-water sediments of the peri-Mediterranean Jurassic. The most diverse assemblages have been known from some peculiar rocks such as the Hierlatz Limestone or submarine fissure infillings and are largely confined to the Sinemurian–Pliensbachian and to the Middle Jurassic in age. Toarcian faunas are especially scarce and much less diverse than older Lower Jurassic ones. Apparently no gastropods of this age have been documented from the Northern Calcareous Alps so far.

Untiring work done by enthusiastic private collectors in the last decades resulted in the discovery of dozens of Jurassic fossil localities in the SW part of the Totes Gebirge. Toarcian rocks were encountered, however, only at two exposures. Red bioclastic limestone cropping out at the Klaushöfl area to the NNE of the village Bad Mitterndorf has yielded, besides abundant ammonites and scarce bivalves, a few specimens of normal-sized *Eucyclus*? sp., as well as relatively well-preserved microscopic gastropod remains hardly attributable to genera as a rule. The faunula consists of some twenty taxa, thus is considered as one of the most diverse Toarcian gastropod assemblages of the peri-Mediterranean region. Shells of a hitherto undescribed, presumably holoplanktonic form reminiscent of heteropods are very common. Its presence appears to provide further evidence of the considerable diversity of Jurassic holoplanktonic Gastropoda. Of other major groups recorded, representatives of Trochoidea (Eucycloidea), Cerithimorpha and Heterobranchia are the most frequent. Slit-bearing Vetigastropoda, a diverse group in older Lower Jurassic faunas are confined to rare Scissurelloids.

EVALUATING GEOCHEMISTRY OF OUTER-SHELF TEREBRATULID BRACHIOPODS IN SEDIMENT-STARVED ENVIRONMENTS

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Use of calcite $\delta^{18}O$ and Mg/Ca ratio in deep-shelf to bathyal brachiopod shells in assessing past variations in Mesozoic seawater temperature and other environmental conditions remains poorly constrained in the absence of other methods due to vital effects and unknown variations in seawater density and salinity. When interpreting seasonality in temperature or productivity of the Jurassic bottom environments in the Pieniny Klippen Belt on the basis of brachiopod geochemistry, it can be useful to assess geochemistry of brachiopods (that typically inhabited relatively deep-water environments below the photic zone) living in similar types of environments. Here, to assess whether intra-shell variation in $\delta^{18}O$ and Mg/Ca ratio of relatively deep-water brachiopods can detect seasonal fluctuations in temperature, we assess geochemical composition of the extant brachiopod *Laqueus erythraeus*. This species inhabited sediment-starved island shelves (potential analogues of the Jurassic pelagic carbonate platforms) off the Southern California Bight over the past few thousand years, and locally formed dense biostromes. We analysed $\delta^{18}O$ and Mg/Ca ratio in one shell of the terebratulid brachiopod *Laqueus erythraeus* collected alive at 116 m water depth and in multiple dead shells of this species dated by radiocarbon-calibrated amino acid racemization. At 116 m, annual temperature range ranges between 9–11°C, although at times of El Nino events in 1982–1983, 1986–1987, and 1992–1993, maximum monthly temperature attained 13°C. We find that $\delta^{18}O$ measured along a growth profile of a shell precipitated in oxygen isotopic equilibrium with ambient seawater, and maxima in Mg/Ca ratio coincide with minima in $\delta^{18}O$, suggesting that fluctuations in Mg/Ca ratio trace temperature fluctuations, as observed also in other brachiopod species. Preliminary observations of Holocene shells show that Mg/Ca ratios show centennial-scale fluctuations but on average remain remarkably constant, with minima and maxima staying within intra-shell seasonal variations captured by extant specimens collected in the 20th century.

ICHNOLOGICAL RECORD IN JURASSIC PELAGIC SEDIMENTS OF THE FATRICUM DOMAIN IN THE TATRA MOUNTAINS, SOUTHERN POLAND AND NORTHERN SLOVAKIA

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Jurassic deposits of the Krížna Nappe (Fatricum domain) in the Tatra Mountains (southern Poland and northern Slovakia) show gradual deepening from nearshore to deep sea environment below CCD, which is which is related opening of the Western Tethys. Three pelagic units have been analysed: the spotted limestones and marls of the *Fleckenmergel* facies (~110 m thick, lower Sinemurian – lower Pliensbachian in the Western Tatra Mts; 270 m thick, late Sinemurian–Bajocian in the Belianske Tatras and Kopy Sołtysie), spotted and green radiolarites (~14 m thick; upper Bathonian–middle Oxfordian), variegated and red radiolarites (~15 m thick; middle Oxfordian–Lower Kimmeridgian) and red nodular limestones (~7 m thick; lower Kimmeridgian–lower Tithonian). These units display decrease in sedimentation rate from Early Jurassic to Late Jurassic (from ~1.2 to ~0.4 cm/kyr; approximate estimation of compacted sediments).

Deposits of the *Fleckenmergel* facies are characterized by relatively abundant and moderately diverse trace fossils observed in cross section as variable dark spots visible in lighter, totally bioturbated background. *Planolites*, and *Thalassinoides, Chondrites* and *Trichichnus* are common. *Palaeophycus* and *Zoophycos*, *Teichichnus, Taenidium* and *Phycosiphon* are relatively rare.

The radiolaritic limestones and radiolarites contain less diverse and less abundant trace fossils. *Chondrites*, *Planolites*, scarce *Thalassinoides* and *Trichichnus* and rare *Zoophycos* are present. Even less diverse an less abundant trace fossils occur in the Oxfordian radiolarites. *Planolites* and *Chondrites* are rarely seen only in some beds.

The red nodular limestones contain common *Chondrites*, *Planolites* and rarely *Zoophycos* and *Thalassinoides*, mainly in the nodules. Primary lamination is rarely visible in some horizons.

All the deposits studied are almost totally bioturbated. These sediments display distinct decrease in abundance and diversity of trace fossils in time, accordingly to decreasing sedimentation rate and increasing depth of deposition. The trend in changes of ichnological features cannot be explained by oxygen deficiency in pore waters, because the deposits are lighter and colour up the stratigraphic column and contain less and less organic carbon. The trend is caused rather by decrease in trophic level. Less and less organic matter was buried with decreasing sedimentation rate and increasing distance from the shelf. In more eutrophic conditions (*Fleckenmergel* facies), organisms penetrated deeply in the sediment, where distinct and relatively diverse trace fossils were produced. In oligotrophic conditions (Oxfordian –lowermost upper Kimmeridgian radiolarites), the organic matter was concentrated in the soupy sediment near the sediment-water interface, where preservation of distinct trace fossils was impossible. Only in some beds, organisms penetrated deeper and produced trace fossils. Thus, diversity and abundance of trace fossils can be used and a proxy of trophic level in pelagic sediments.

The outline general trend is not linear. In some horizons, it disturbed by increase in clastic fines, which coincides with higher content of food in the sediment. Fluctuations in supply of clastic grains were probably influenced by consequences of eustatic/climatic changes.

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LOWER KIMMERIDGIAN OF THE WIELUŃ UPLAND AND ITS BORDERS: LITHOSTRATIGRAPHY, AMMONITE STRATIGRAPHY (UPPER PLANULA/PLATYNOTA TO DIVISUM ZONES), PALAEOGEOGRAPHY AND CLIMATE-CONTROLLED CYCLES

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Abstract: The Early Kimmeridgian of the Wieluń Upland after decline of the deep-neritic sponge megafacies deposits during the late Planula Chron was characterized by development of the flat biostromal limestones, micritic limestones and marls of the Prusicko Fm. These deposits originated in the moderately deep marine environment between shallow-marine carbonate platforms from the north and the south. Towards north-west the open-marine carbonate and marly deposits of the open-marine facies (Burzenin Fm.) occurred. This palaeogeographical pattern was controlled by synsedimentary tectonics. The detailed biostratigraphical classification of the deposits studied from the Platynota to Divisum ammonite zone interval, and their lithological character enable recognition of the primary sedimentary cyclicity by comparison with the well dated short eccentricity cycles in the coeval succession of south-eastern France.

Introduction

The Wieluń Upland is the northernmost morphological unit of the zone of occurrence of the Upper Jurassic limestones of the sponge megafacies in the Polish Jura, but also of the overlying Lower Kimmeridgian deposits preserved actually at the borders of the Upland.

The aim of the current study is recognition of the detailed succession and stratigraphy of the Lower Kimmeridgian deposits from the decline of the dominance of the sponge megafacies deposits responsible for original development of the sponge-cyanobacteria bioherm to basin facies pattern, up to the younger deposits of the Prusicko Fm. and the Burzenin Fm., representing already more uniform facies development. These Lower Kimmeridgian deposits, being the youngest preserved Jurassic deposits of the area of study, were exposed in the past in numerous exposures and penetrated by shallow boreholes, but they are generally poorly accessible nowadays. The partly revised and supplemented description of the whole succession given herein is based both on reinterpretation of the older data and ammonites collected before, as well as stratigraphical and taxonomical interpretation of the newly collected material. The succession recognized is the basis for a wider stratigraphical and palaeogeographical studies.

Geological setting and lithostratigraphy

The Oxfordian-Kimmeridgian deposits of the Wieluń Upland, belonging to the Częstochowa Sponge Limestone Formation, are represented by massive and bedded limestones of the cyanobacteria-sponge biohermal complexes which contact laterally with poorly fossiliferous micritic limestones of the Pilica Formation of the interbiohermal basins. The bioherm to basinal relief of the sea bottom was originally quite large attaining about 200 metres between the top of the bioherms and the base of the neighbouring basins (Matyja, Wierzbowski, 1996). The basinal micritic limestone and marls overlap the biohermal slope, and often are thinning towards the bioherms. Mass-gravity transport off the bioherms resulted locally in accumulation of breccias which occur at some levels within the micritic limestones. These deposits were formed as debris-flows, but some more fine-grained deposits showing graded bedding were of allodapic character (Matyja, Wierzbowski, 2006).

The deposits discussed show generally two partly overlapping phases in their development. The massive biohermal limestones represent the last phase of growth of the biohermal complexes. The well bedded micritic limestones and marls of the Pilica Formation represent the phase of gradual smoothing of the original sea-bottom topography between the biohermal complexes and the interbiohermal basins. This enabled the appearance of younger deposits of the Prusicko Formation, showing more uniform facies pattern.

The Prusicko Formation attains 150–220 m, occurring as the youngest Jurassic deposits along the eastern border of the Wieluń Upland due to pre-Albian erosion. It is represented commonly in its lower part by soft, friable, well-bedded chalky limestones, generally rich in fossils (siliceous and calcareous sponges, brachiopods, serpulids, and rarely heramatypic corals – mostly of the genus *Microsolena*). These deposits are in some sections replaced, and generally overlain by thin-bedded micritic limestones with marly intercalations and a poor benthic fauna. The higher parts of the Prusicko Formation are represented by marls and marly limestones with poor benthic fauna. The highest deposits of the Prusicko Formation are well bedded chalky limestones with cherts, rich in benthic fauna.

The younger deposits have been studied mostly in boreholes in the northern border of the Wieluń Upland at Kiełczygłów (Wierzbowski *et al.*, 1983). Very complete succession of the deposits is based on the borehole sections from the brown-coal fields at Szczerców and Bełchatów studied by E. Szewczyk *et al.* (unpubl. report), and the ammonites determined by the present authors. The stratigraphical succession presented below attains about 280 m in thickness. The following lithostratigraphical units may be recognized (from the base): (1) biodetrital chalky limestones with abundant fauna (hermatypic corals, brachiopods, bivalves – including *Trichites*, echinoderms – correlated with the upper part of the Prusicko Fm.); (2) blue grey marls or marly micritic limestones with poor benthic fauna; (3) micritic limestones with marly intercalations locally with common infaunal and seminfaunal bivalve fauna; (4) oolitic limestones, at the top with commonly occurring large colonies of the hermatypic corals, and thick-shell bivalves bored by lithophags; (5) micritic limestones with common infaunal and seminfaunal bivalves often in growth positions; (6) oncolitic limestones; (7) micritic limestones with bioclasts and oncoids overlain by marls and marly limestones heavily penetrated by burrows with common infaunal bivalves; (8) marls with intercalations of limestones with poor fauna; all the younger deposits are correlated with the Burzenin Fm., but some of them, recognized as the informal members because of peculiarities in development when compared with the typical succession of the formation at Burzenin.

In the area of Burzenin the deposits were seen in the outcrops (Kowalski, 1958), and studied in the boreholes (Wierzbowski *et al.*, 1983) and in the field by the present author. The oldest deposits are represented by the chalky limestones with common siliceous sponges, cyanobacteria structures (including *Tubiphytes*), serpulids and bryozoans, as well as the directly overlying micritic limestones and marly limestones with poor benthic fauna. The former are representing the Częstochowa Sponge Limestone Formation, the latter – the Pilica Formation. The overlaying deposits corresponding to the Burzenin Formation attain about 90 m in thickness, and may be subdivided into two members (from the base): (1) marls and marly limestones of the newly distinguished Kiełczygłów Marl Member; (2) micritic limestones, marly limestones with common infaunal and seminfaunal bivalves, and intercalations of organodetrital limestones, and marls of the newly distinguished Majaczewice Member; the base of this unit is marked by the oncolite limestones a few metres in thickness recognized as the Brzyków Oncolite Bed.

The abundant ammonites coming from the deposits studied enable the stratigraphical correlation between the particular sections in the area of study. This makes possible the interpretation of the palaeogeography, synsedimentary tectonics, and distinguishing of the climatically controlled sedimentary cycles.

Interpretation

The development of the deep-neritic cyanobacteria-sponge biohermal complexes in the southernmost and northernmost parts of the Wieluń Upland during the earliest Kimmeridgian (Bimammatum and Planula chrons) was strictly controlled by the synsedimentary tectonic activity. The southernmost biohermal complexes (the Mstów Biohermal Complex and the Rudniki Biohermal Complex, see Matyja, Wierzbowski, 2006) at the boundary between the Częstochowa Upland and the Wieluń Upland were stretching along the zone of the synsedimentary active fault or of a set of faults which caused a marked facies changes through the relative vertical movements. This influenced initially the growth of the biohermal complexes, and later during the late Planula Chron resulted in appearance of the bedded limestones strongly contrasted in thickness north and south of this tectonic zone. The area placed south of the active fault zone corresponding to adjoining parts of the Częstochowa Upland was evidently uplifted during the Early Kimmeridgian (Platynota Chron), as shown by appearance of the coral buildups on the tops of the sponge-cyanobacteria complexes, and the development of the shallow-water deposits of the carbonate platform (see Matyja, Wierzbowski, 1996).

Similar tectonic activity took place also during development of the sponge-cyanobacteria biohermal complex (the Działoszyn Biohermal Complex) in the northernmost part of the Wieluń Upland. During the late Planula Chron the biohermal structure was here buried also under the deposits of the Pilica Fm.

The area of the Wieluń Upland from the Rudniki Biohermal Complex in the southern margin of the Wąsosz Interbiohermal Basins, up to the Działoszyn Biohermal Complex in the northern part of the basin, was subsequently covered by deposits of the Prusicko Formation during the Platynota Chron, and the older biohermal complexes did not manifest their presence during the younger Kimmeridgian. The deposits of the Prusicko Fm. preserved actually along the north-eastern borders of the Wieluń Upland are developed as very flat biostromal limestones showing the presence of the siliceous spongies and the pioneer assemblage of the *Microsolena* corals, laterally and vertically replaced by the micritic limestones and marls. The character of these deposits indicates the moderately deep marine environment.

Another tectonic zone has been located along the present northern margins of the Wieluń Upland. This zone of highly complicated tectonic structure extends generally in WNW–ESE direction. The main system of faults originated after the formation of the Laramian structure (Kleszczów Graben filled with the Neogene brown-coal deposits), and additional tectonic complications appeared that time due to strong halokinetic processes of the Permian salts, responsible *e.g.,* for formation of the Dębina salt dome separating the Bełchatów sector of the Kleszczów Graben in the east from the Szczerców one from the west. Although the well-documented activity of the tectonic zone in question was related with the Oligocene–Miocene, its influence on the sedimentation of the Mesozoic deposits has been also indicated. According to Matyja and Wierzbowski (2014) the progradation of the Kimmeridgian shallow-water carbonate platform towards the west on the area of the northern border of the Wieluń Upland already during Late Oxfordian was controlled by the activity of the tectonic zone being the prolongation of the Holy Cross lineament.

Thus, the moderately deep basin of the Wieluń Upland filled with deposits of the Prusicko Fm. during Platynota Chron was bordered from the south and north by the shallow-water carbonate platforms. The deposits of the northern shallow-water carbonate platform show similarity to some members of the Prusicko Fm., but they are markedly thicker and show the presence of a shallow-marine fauna. Younger deposits of the Hypselocyclum and Divisum zones are well-recognized only here, being mostly removed from the southern areas due to the pre-Albian erosion. The preserved deposits developed as the very-fine grained oolites of the westernmost promontory of the carbonate platform in the north during early Hypselocyclum Chron, are followed by organodetrital limestones, oncolitic limestones and marls. These deposits show fairly uniform distribution in the whole discussed area, being the lateral counterpart of the Burzenin Fm. from the north–west.

The northernmost occurrences of the Kimmeridgian deposits of the Hypselocyclum and Divisum zones discussed in the study include the area of Burzenin in the western limb of the Laramian Łódź Synclinorium. It is the typical area of occurrence of the limestone-marly deposits of the newly distinguished Burzenin Formation which overlie directly the deep- neritic deposits of the Częstochowa Sponge Limestone Formation and the Pilica Formation ranging stratigraphically much higher here than in the Wieluń Upland. The character of the deposits of the Burzenin Fm. indicates the open-marine facies of the Polish Basin.

The deposits in the successions studied show generally closely interrelated changes in lithology and in faunal content which may be useful in interpretation of the palaeoclimatic cycles. The most characteristic are: strongly marked lithological variations (indicated by occurrence of well-developed carbonate and marly units), and the evidences of a slow sedimentation marked by well-developed levels of stratigraphical condensation – each of them well-dated by the ammonite faunas (represented mostly by different groups of Ataxioceratidae), and usually recognized at the top of the thicker carbonate units. The attempt is given here to interpret such marly-carbonate units in terms of the sequence stratigraphy – through the recognition of the condensation levels as corresponding to the "maximal flooding surfaces". In consequence the units are compared with the cycles, such as those recognized by Boulila *et al.* (2008, 2010) in south-eastern France where 15 short eccentricity cycles were recognized in the stratigraphical interval from the base of the Galar Subzone, up to the top of the Divisum Zone of the Lower Kimmeridgian well dated by ammonites (Atrops, 1982).

Three well-developed condensed stratigraphical level are recognized within the Prusicko Fm. The oldest one is shown by occurrence of ammonites of the Polygyratus Subzone, and the base the Desmoides Subzone (*i.e.*, the *enay* horizon) of the Platynota Zone, thus corresponding to the top of the eccentricity cycle no. 4 at the top of the Polygyratus Subzone after Boulila *et al.* (2008, fig. 2). The middle may be possibly correlated with the top of the cycle 5 in upper part of the Desmoides Subzone of the Platynota Zone. The upper one at the top of the Prusicko Fm. directly below the marly deposits of the Kiełczygłów Marl Mbr. (Burzenin Fm.) yielded ammonites indicative of the basalt part of the Hypselocyclum Zone, the *lussasense* horizon of the lowermost part of the Hippolytense Subzone. This indicates that the level in question may be correlated with the top of the cycle no. 6.

When compared the calculated rate of sedimentation as based on correlation with the duration of the eccentricity cycles recognized – it appears that during sedimentation of the older deposits of the Prusicko Formation from the eastern border of the Wieluń Upland, the rate of sedimentation was rather low (about 0.15–0.25 cm/1000 years). The rate of sedimentation at the topmost part of the Prusicko Fm. in the northern border of the Wieluń Upland, at the northern shallow-water carbonate platform was extremely high and it reached over 1 m/1000 years.

The levels rich in ammonites interpreted as the condensed stratigraphical horizons are recognized also in younger deposits of the Burzenin Fm. of the Burzenin area, and in the corresponding deposits in northern border of the Wieluń Upland. The oldest of them is recognized at the top of the Brzyków Oncolite Bed, at the base of the Majaczewice Mbr., where the ammonites indicate its correlation with the upper part of the Hippolytense Subzone of the Hypselocyclum Zone. This level may be correlated with the top of the cycle no. 9 of Boulila *et al.* (2008). Directly younger level with ammonites may be possibly correlated with the top of the cycle no. 10 and identified as representing the lowermost part of the Lothari Subzone.

The stratigraphical interval corresponding to the Hippolytense Subzone of the Hypselocyclum Zone is characterized by a marked facies changes. It corresponds to the decline of the northern carbonate platform in the northern border of the Wieluń Upland, the disappearance of the sponge megafacies and related deposits in the Burzenin area, and the following development of the fairly uniform deposits of the Burzenin Fm., widely distributed in the area of study. This resulted from the subsiding of a wide area between the SW margin of the Holy Cross Mts. and the Częstochowa Upland from the south and the Wieluń Upland and adjoining part of the southern Łódź Synclinorium from the north, which was possibly related with tectonic activity changing the subsidence pattern.

The younger condensed horizon yielded the ammonites indicative of the Lothari Subzone of the Hypselocyclum Zone. It yielded abundant ammonites indicative of the *hypselocyclum* horizon in the lower part of the Lothari Subzone. This horizon can be correlated with the top of the cycle 11.

The youngest condensed horizons may be reconstruct only on the basis of the older ammonite collection of Kowalski (1958), and relevant descriptions of the sections in the Burzenin area. The ammonites are indicative of the upper part of the Lothari Subzone – of the *semistriatum* horizon, and the *perayensis* horizon (see Atrops, 1982) and the lowermost part of the Divisum Zone. Because the detailed distribution of the ammonites in the sections is unknown, the discussed horizons may be treated jointly as corresponding to the top of the cycles 12 and 13 of Boulila *et al.* (2008). The youngest recognized condensed level in the Burzenin area yielded the ammonites indicative of the upper part of the Divisum Zone – the Uhlandi Subzone, and may be correlated with the top of the cycle 14.

The rate of sedimentation calculated on the correlation given for the well dated stratigraphical interval corresponding to the lower part of the Lothari Subzone of the Hypselocyclum Zone equals about 30 cm/1000 years in the northern border of the Wieluń Upland (Kiełczygłów, and the brown-coal fields). The stratigraphical interval from the topmost part of the Hippolytense Subzone, and the whole Lothari Subzone in the Burzenin area shows much lower rate of sedimentation (about 5 cm/1000 years).

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STRONTIUM ISOTOPE VARIATIONS IN MIDDLE–LATE JURASSIC SEAWATER

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Abstract: New fits of the Middle–Late Jurassic seawater strontium isotope curve based on published data, and new strontium isotope analyses of well-preserved samples are presented. The x-scales of the presented Sr isotope curves are based on the absolute radiometric numerical ages, and the chronostratigraphical scale. The fitted parts of the Jurassic seawater strontium isotope curve comprise both sides of its deep through with minimal $^{87}Sr/^{86}Sr$ ratio occurring at the Early–Middle Oxfordian transition. Strontium isotope stratigraphy may be used for dating of Jurassic sediments, and is the most precise in intervals characterized by a high rate of change of marine $^{87}Sr/^{86}Sr$ ratio (the Bajocian–Lower Callovian, and the Upper Kimmeridgian–Volgian).

The Middle–Late Jurassic marine strontium isotope curve is through-shaped, a comprises the deepest Phanerozoic minimum of the seawater $^{87}Sr/^{86}Sr$ ratio. Middle–Late Jurassic strontium isotope curves were built by McArthur *et al.* (2001, 2012), based on the absolute time frames. Precise data were, however, missing for the Oxfordian–Kimmeridgian, and some intervals around the Jurassic–Cretaceous boundary (*cf.*, Jones *et al.*, 1994a; Jenkyns *et al.*, 2002; Gröcke *et al.*, 2003). The present study aims at the presentation of new, well-defined Middle–Late Jurassic seawater strontium isotope curves based on both a revised absolute numerical time scale of the Jurassic, and a detailed biochronostratigraphical zonal scheme. New strontium isotope data have been obtained from intervals which were poorly sampled before.

Strontium isotope ratios of 50 new, stratigraphically well-dated, belemnite samples have been analysed. The state of preservation of the samples was screened using cathodoluminescence, and chemical analyses. The samples measured for strontium isotopes are non-luminescent, and characterized by low manganese, and iron concentrations, as well as high strontium content (C_{Fe} ≤150 ppm, C_{Mn} ≤50 ppm, C_{sr} ≥800 ppm). The same criteria were used for the selection of the most reliable, published strontium isotope dataset comprising 260 datapoints derived from uppermost Lower Jurassic–lowermost Cretaceous belemnite rostra, and oyster shells (data of Jones *et al.*, 1994a, b; Callomon, Dietl, 2000; McArthur *et al.*, 2000; Jenkyns *et al.*, 2002; Gröcke *et al.*, 2003; McArthur *et al.*, 2007; Page *et al.*, 2009; Wierzbowski *et al.*, 2012; Shurygin *et al.*, 2015). Analysed new samples were dissolved in 2.5 M hydrochloric acid. Strontium was separation using a cation resin (Bio-Rad 50 W-X8), and purified using a Sr-spec resin (Eichrom). Strontium isotopic composition was measured using a MC ICP-MS Neptune at the Institute of Geological Sciences, Polish Academy of Sciences. Instrumental mass bias was corrected using $^{86}Sr/^{88}Sr$ ratio of 0.1194 (*cf.*, Nier, 1938). Obtained results were normalized to the recommended SRM 987 $^{87}Sr/^{86}Sr$ ratio of 0.710248 (McArthur, 1994; McArthur *et al.*, 2001, 2012).

The chronostratigraphical time scale of the presented diagram is based on the assumed equal duration of ammonites subchrons (Fig. 1). The time scale of the chronological diagram is based on absolute ages determined using radiometric dating, cyclostratigraphical data, and some interpolated numerical ages (after Ogg *et al.*, 2012, 2016). Some chronological data have been further interpolated into the subzone level, and, if necessary, re-adjusted to the available data on the correlation between different ammonite zonal schemes. The strontium isotope curve was estimated using the LOWESS model. The 95% confidence interval was calculated by a Monte Carlo method taking account of uncertainties of measurements and the regression estimation (*cf.*, Hercman, Pawlak, 2012).

The seawater $^{87}Sr/^{86}Sr$ ratio oscillated around 0.70730 at the Toarcian–Aalenian transition, and started to fall in the Middle Aalenian. The rate of the fall was the largest during the Early Bajocian–Early Callovian (0.000077 $^{87}Sr/^{86}Sr$ ratio change per 1 Ma). It was also the steepest fall of the marine $^{87}Sr/^{86}Sr$ ratio during the Phanerozoic (McArthur *et al.*, 2012). The Phanerozoic minimum of the seawater $^{87}Sr/^{86}Sr$ ratio with the value of *ca.* 0.70687 occurred at the Early–Middle Oxfordian transition. This period was followed by a gradual increase of the ratio (up to *ca.* 0.70719 at the Jurassic–Cretaceous transition). The Middle Jurassic fall of the seawater $^{87}Sr/^{86}Sr$ ratio is linked to the enhanced hydrothermal activity of the seafloor, which resulted in the influx of isotopically light strontium to the oceans (*cf.*, Jones, Jenkyns, 2002; Wierzbowski *et al.*, 2012). Particularly, enhanced spreading rates during the initial breakup of Gondwana, and the formation of new Atlantic–Tethyan oceanic basins may have contributed to the release of large amounts on non-radiogenic strontium from the oceanic crust. These tectonic processes are dated mostly to the Bajocian–Callovian based on occurrences of ophiolites, rhyolitic magmas, as well as on stratigraphic sequence analyses, and palaeomagnetic studies.

The seawater strontium isotope curve based on absolute time scale is similar to the LOWESS fit of the curve presented by McArthur *et al.* (2012), which is based on GTS2012 time scale. Slightly higher seawater $^{87}Sr/^{86}Sr$ ratios, than those predicted by McArthur *et al.* (2012), are, however, noted in the Early–Middle Aalenian, and at the Jurassic–Cretaceous transition. Lower $^{87}Sr/^{86}Sr$ ratios are, in turn, determined for the Oxfordian–Early Kimmeridgian interval. The present calibration of the marine strontium isotope curve for the Middle–Late Jurassic is characterized by improved reliability, and good precision (below an ammonite zone level, or 0.2 Ma). The elaborated biostratigraphical correlation charts allows usage of strontium isotope data for chemostratigraphical dating of marine sediments from various palaeobioprovinces, where different regional or local biostratigraphical zonal schemes are nowadays applied.

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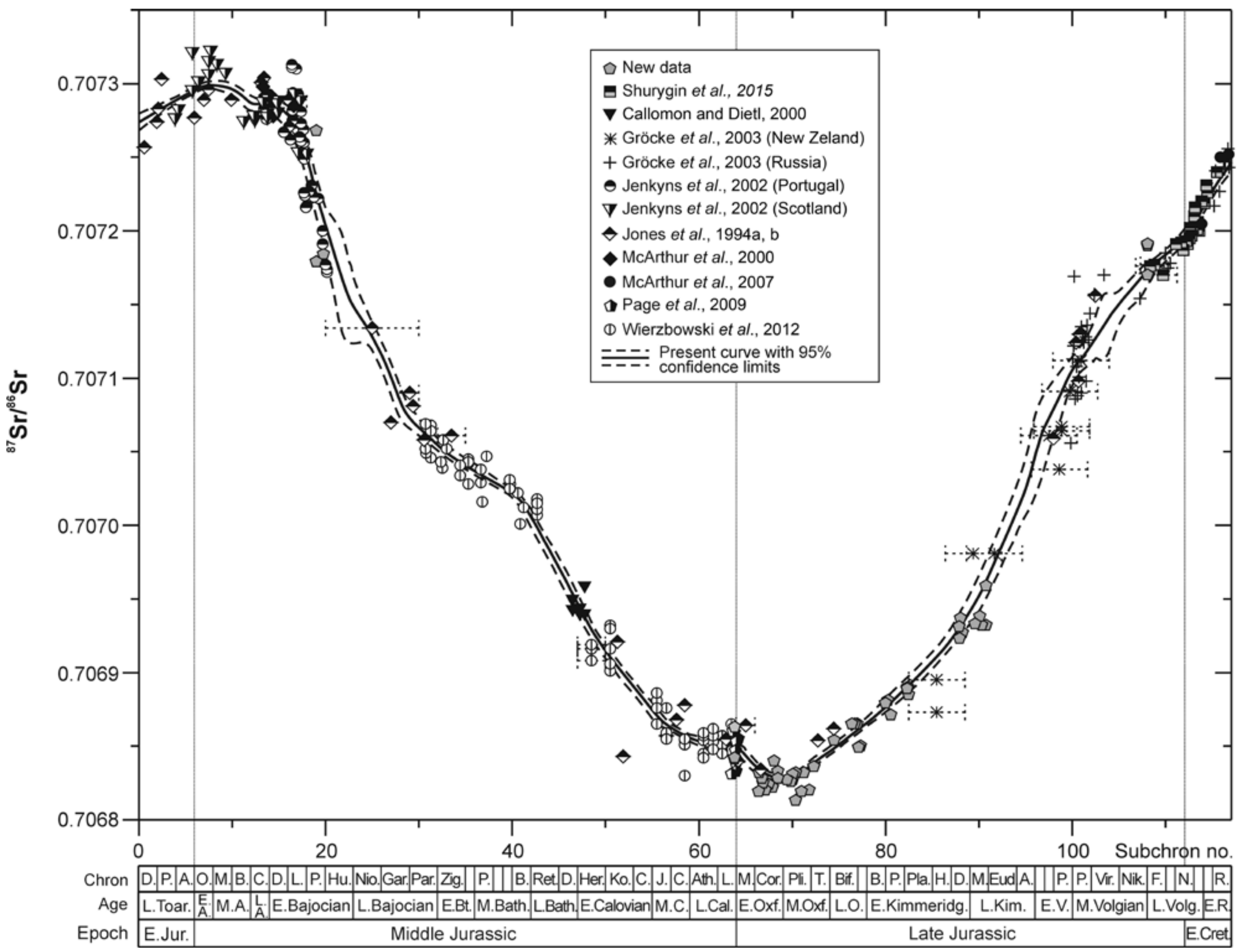

Fig. 1. Strontium isotope variations during the latest Early Jurassic–earliest Createceous

The Lowess curve (solid line), with given 95% confidence limits (dashed lines) is fitted to strontium isotope dataset of well-preserved fossils. The time scale of the diagram is based on assumed equal duration of ammonite subchrons. Dating errors higher than one subchron are marked

EFFECTS OF THE EARLY TOARCIAN OCEANIC ANOXIC EVENT ON THE MICROFAUNA (FORAMINIFERS AND OSTRACODS) OF WESTERN NEOTETHYS FROM HUNGARY

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Abstract: To detect the T-OAE, microfossils of one NW European and two Mediterranean sections were studied in Hungary. Taxonomic compositions of the foraminiferal fauna strongly differ between the two provinces. but the Pliensbachian and Toarcian assemblages are similar. These differ in the ratio of the ornamented, elongated and flattened forms. The Pliensbachian ostracod fauna of all studied sections are very similar in diversity and composition showing sublittoral environment, and there is a faunal turnover above the Pliensbachian/Toarcian boundary. The Toarcian ostracod fauna is characterized by the lack of ornamented cytheroids in Mediterranean sections which dominated in NW Europe.

The Early Toarcian mass extinction can be divided into two phases: the Pliensbachian–Toarcian transition event is caused by climatic cooling and eustatic sea-level fall; and then a longer period of climatic warming, sea-level rise and anoxia in Tenuicostatum–Serpentinum zones (*e.g.*, Cecca, Macchioni, 2004). The latter extinction caused by the Toarcian Oceanic Anoxic Event is represented by organic rich argillaceous sediments (black shale facies) best documented in the Tethyan Realm (*e.g.,* Müller *et al.*, 2017). However, in hemipelagic environments where black shale is absent, the climatic warming considered as the main driver of the extinction. Both of them have their own geochemical (^{13}C excursions) and palaeontological features (diversity changes, faunal turnovers, etc.) of different fossil groups (*e.g.,* Gómez, Goy, 2011).

Several studies dealt with foraminiferal and ostracod faunal changes in Lower Toarcian black shale and/or marl bearing sequences of the Tethyan Realm. Majority of them come from the epicontinental region, the NW European Province (*e.g.,* Hylton, 2000; Arias, Whatley, 2005). Microfauna of the Mediterranean Province were studied only from the Umbria Marche Basin (*e.g.,* Monaco *et al.*, 1994) and Ionian Basin (Pettinelli *et al.*, 1997) where black shale is intercalated in shale/marl series below the ammonitico rosso. In those areas (*e.g.*, Subbetic Cordillera) where red nodular limestone were developed without any black shale, hiatus has been recorded in the stage boundary and in the Polymorphum/Serpentinum Zone boundary, therefore, the T-OAE cannot be detected by fossils (*e.g.,* Reolid *et al.*, 2015). The foraminiferal and ostracod faunas of the pelagic eastern part of the Western Neotethys are hardly known, because it is difficult to extract microfossils from indurated rocks. The aim of our study to give palaeoecological interpretation of the foraminiferal and ostracod fauna of three Pliensbachian/Toarcian boundary sections from Hungary: shelf marginal Réka Valley from Mecsek Mountains with NW European affinity fauna and pelagic sections of Bakonycsernye and Tölgyhát from the Transdanubian Central Range with Mediterranean affinity (Fig. 1).

To extract the microfauna each samples of the limey samples were treated by glacial acetic acid, the argillaceous ones were soaked in a dilute solution of hydrogen peroxide. The washing residue of black shale and the boundary siltstone were barren for microfossils. Sorting the specimens by morphological groups was used for the palaeoecological evaluation (Fig. 2).

From Réka Valley, 99 foraminiferal taxa were identified. Elongated inbenthic taxa dominate the fauna and smooth forms are more abundant than ornamented ones throughout the section (Fig. 3). In the Liassic beds of Réka Valley poorly preserved relatively diverse ostracod assemblage (13 taxa) were determined. The Pliensbachian part of the sequence is dominated by smooth healdoids beside bairdiid, bythocyprid and cypridid ostracods. In the Early Toarcian the fauna replaced by ornamented cytheroids. In the Falciferum Zone the *Kinkelinella* and *Ektyphocythere* are frequent. There is no ostracod record from the Tenuicostatum Zone. From the Bakonycsernye succession 67 foraminiferal taxa were identified. Upwards to the boundary, the diversity rapidly increased; above it, the number of species decreased dramatically. The ratio of the dominant elongated and flattened forms increase onwards in the Toarcian. Ornamented forms are common in the Pliensbachian, while in the Toarcian, they are subordinated. Lower part of the Pliensbachian beds is characterized by well-preserved relatively diverse ostracod fauna (13 taxa) with the dominance of large sized *Lobobairdia* beside small and smooth healdiid, bairdiid, bythocyprid and cypridid ostracods. In the uppermost Pliensbachian the healdiid taxa are present in great abundance beside the above-mentioned small smooth r-strategists and polycopid taxa (together 18 taxa). Sculptured large sized bairdiids and healdiids disappeared in Pliensbachian/Toarcian boundary. The Lower Toarcian bed produced poorly diverse assemblage with great number of specimens of *Pontocyprella* and *Bythocypris*, and rare occurrences of cytherid *Patellacythere*. From Tölgyhát, 54 foraminiferal taxa were identified. In the upper Pliensbachian, continuous decrease of abundance and diversity of the fauna can be observed. The elongated and flattened forms are dominant, spirillinids are occasional. In the Toarcian, the deep inbenthic forms became dominant. The Pliensbachian ostracod fauna is well-preserved and very diverse (33 taxa) with the dominance of smooth healdoids and bairdiids. The fauna of the Bifrons Zone is very poor, only one genus, *Bythocypris* is present.

The three studied section are similar in inbenthic dominance of the foraminiferal fauna. The main difference is the relative frequency of agglutinated forms in the Pliensbachian of Bakonycsernye and the lack of spirillinids. The studied Pliensbachian ostracod faunas of Réka Valley with NW European affinity and Tölgyhát and Bakonycsernye with Mediterranean affinity are very similar taxonomically showing sublittoral environment. The very characteristic Liassic healdoids disappeared in the Pliensbachian/Toarcian boundary in Mediterranean sequences, while these exist in NW European sites in the Tenuicostatum Zone. The Toarcian fauna is characterized by the lack of ornamented cytheroids in Mediterranean sections which dominated in NW Europe. Similar differences could be shown in the foraminiferal fauna of the two provinces (Jaccard coefficient=14). In Réka Valley, the studied foraminiferal fauna suggested well-oxygenated conditions below and above the black shale. The ostracod faunal turnover (*e.g.*, extinction of a major group, healdoids and appearance of ornamented cytheroids) during the Toarcian can be explained by the seawater warming according to Gómez, Arias (2010). In Bakonycsernye, the morphological changes of the foraminiferal fauna indicate the decreasing of seawater oxygen level and current energy in the Tenuicostatum Zone. Based on the change of the ostracod fauna and the lithology it was caused by the abrupt deepening from sublittoral to bathyal depositional environment. In the Bifrons Zone of Tölgyhát, the microfauna suggests well-oxygenated bathyal environment. The Hungarian Pliensbachian/Toarcian boundary sections give a new insight to the biotic events at that time.

Acknowledgements: We thank András Galácz and István Szente (Eötvös Loránd University) for their helpful advice. The research was supported by the Hantken Foundation.

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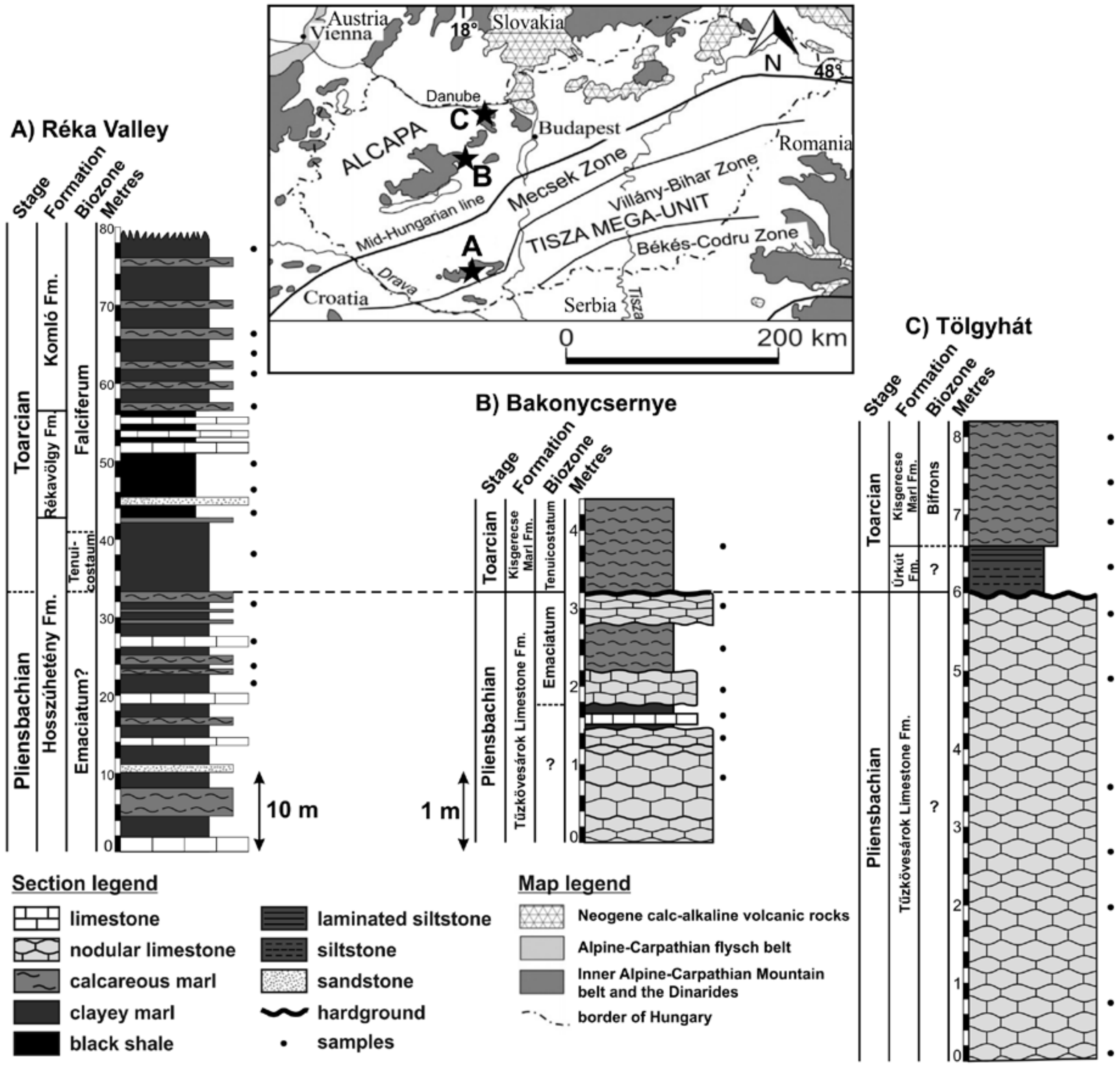

Fig. 1. Localities on the geological map of the Carpathian-Pannonian area (after Csontos, Vörös, 2004) and logs of the studied sections

A – Réka Valley (based on Baranyi *et al.,* 2016); B – Bakonycsernye (based on Galácz *et al.,* 2008); C – Tölgyhát

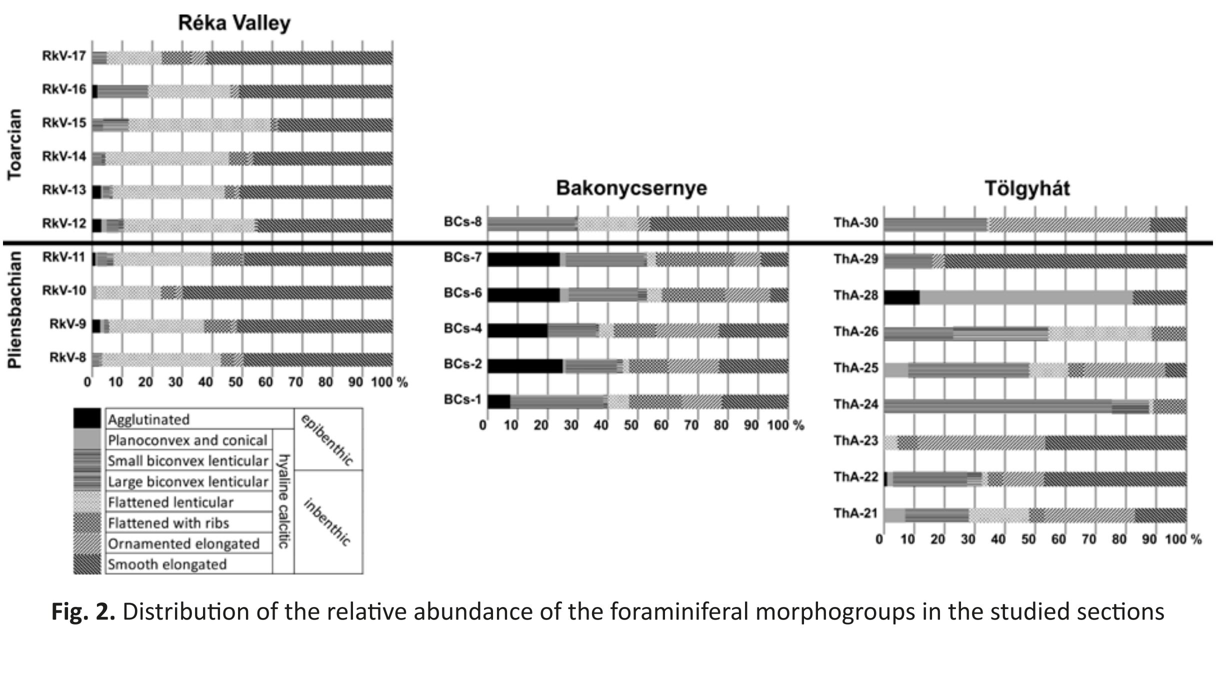

Fig. 2. Distribution of the relative abundance of the foraminiferal morphogroups in the studied sections

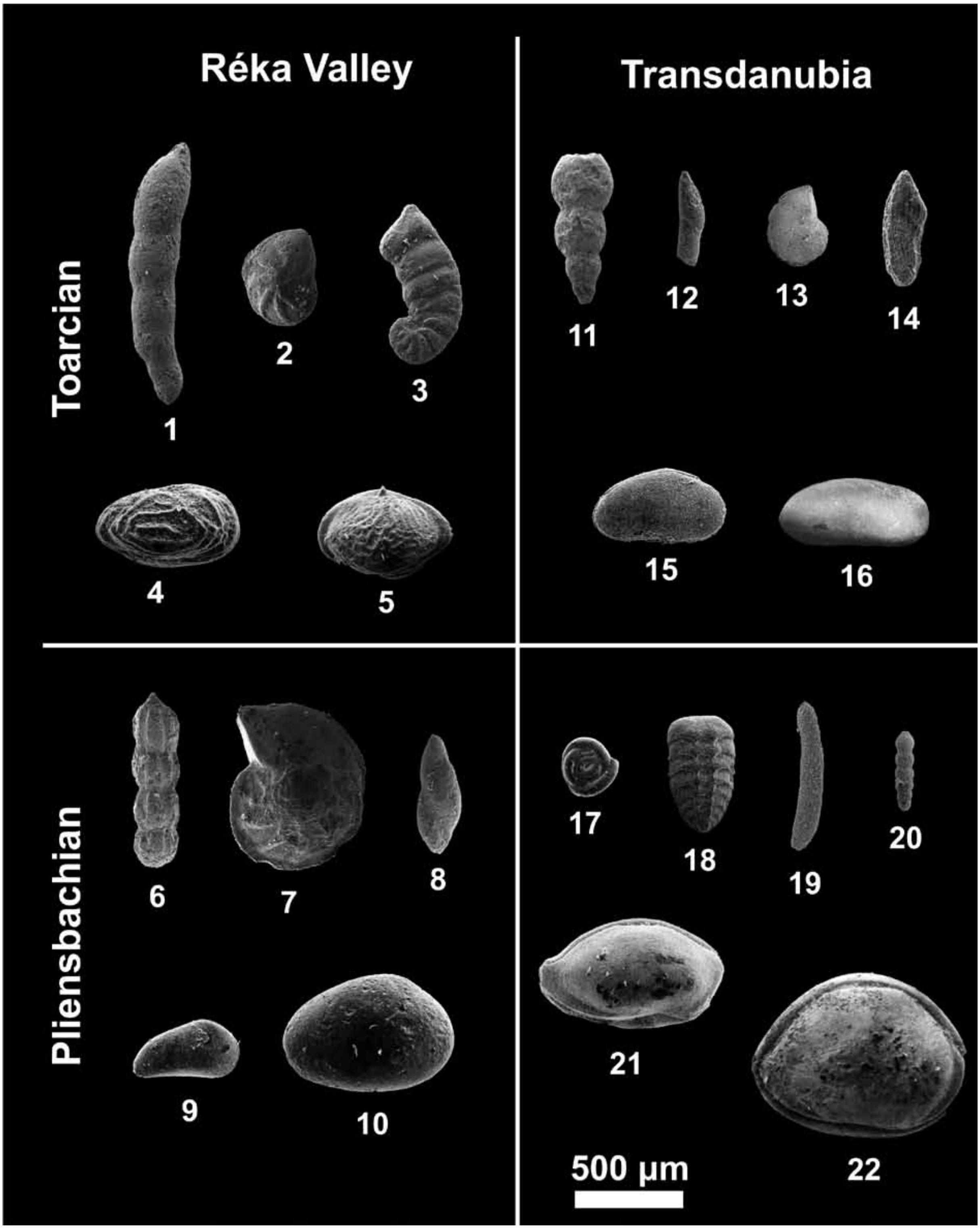

Fig. 3. Selected foraminifers and ostracods from the studied sections

1. *Prodentalina pseudocommunis* (Franke); 2. *Lenticulina toarcense* (Payard); 3. *Astacolus varians* (Bornemann); 4. *Kinkelinella* (*Ektyphocythere*) *laqueta* Klingler, Neuweiler; 5. *K. sermoisensis* Apostolescu; 6. *Nodosaria fontinensis* Terquem; 7. *Lenticulina helios* (Terquem); 8. *Eoguttulina metensis* (Terquem); 9. *Paracypris redcarensis* Blake in Tate, Blake; 10. *Ogmoconcha amalthei* (Quenstedt); 11. *Paralingulina dentaliniformis* (Terquem); 12. *Prodentalina* cf. *pseudocommunis* (Franke); 13. *Lenticulina muensteri* (Roemer); 14. *E. bilocularis* (Terquem); 15. *Bythocypris faba* Knitter; 16. *Pontocyprella* aff. *cavataformis oblonga* Monostori; 17. *Glomospira variabilis* (Kübler, Zwingli); 18. *Paralingulina testudinaria* (Franke); 19. *Dentalina* cf. *torta* Terquem; 20. *Nodosaria kuhni* Franke; 21. *Bairdia longoarcuata* Monostori; 22. *Lobobairdia rotundata* Monostori

PHYLOGENY OF *CAMPTOCYTHERE LATERES* TESAKOVA & SHURUPOVA, SP. NOV. (CRUSTACEA, OSTRACODA) FROM THE UPPER BAJOCIAN (JURASSIC) OF THE SARATOV REGION (CENTRAL RUSSIA)

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During the study of Apsheronian (Pliocene) ostracods, V.E. Livental' (1949) developed a new palaeobiogenetic method allowing a better stratigraphic resolution. The method was based on the search of distinct phylogenetic shifts of certain morphological features of a carapace towards earlier or later ontogenetic stages during an ostracod species existence. Livental' was able to demonstrate that during the phylogeny of Apsheronian individuals of *Cytherissa bogatchovi* Livental', a degeneration following by a reduction of three tubercles restricted to anterior-dorsal, posterior-dorsal, and posterior-ventral areas of a valve occurred; if these features were well-developed in juvenile individuals of the earliest representatives of the species, the juveniles of latest ones lost them already at the very beginning of their ontogeny. These finds allowed Livental' to subdivide the Apsheronian regional stage into three substages which was impossible to achieve by any other biostratigrathic method. Until nowadays, this useful tool has been never used again.

Meanwhile, modern geological-prospecting needs require a much better resolution of existing and newly developed biostratigraphic charts based on different fossil groups. Such a new chart has been worked out for the Jurassic of the Russian Platform judging by ostracods (Tesakova, 2014). Basic subdivisions of this chart are established by palaeogeographic data providing a necessary resolution. Ostracod phylozones are less concerned due to low rates of speciation in these crustaceans. However, the palaeobiogenetic method allows a further subdivision of the phylozones.

During the current study of the phylogeny of *Camptocythere lateres* Tesakova and Shurupova, sp. nov. from the Upper Bajocian Pseudocosmoceras michalskii Zone (Middle Jurassic) from the Sokur borehole (Saratov region), 7 ontogenetic stages of the life cycle are established each of which represents a subsequently moulted instar. In general ostracods possess 8 instars and in our specimens the earliest of them is absent only. Changes of the carapace sculpture (pits) and hinge are observed in both the ontogeny and the phylogeny of *C. lateres*.

The right valve of mature instars of this species has a hemimerodont hinge, which consists of a smooth middle groove, which is dipping in both ends, and of terminal elements, composing by 4 (anterior) and 5 (posterior) tiny, rounded teeth each, the size of which is diminished to the margin. In the ontogeny of *C. lateres*, the terminal elements are modified while the overall valve morphology is stable. For instance, if the 3rd juvenile instar has a bar-like tooth, this element becomes subdivided into rows of separate small teeth by the mature 7th instar. Such an ontogenetic pattern is stable during the entire Michalskii Zone.

A different ontogenetic pattern is observed in carapace sculpture of the same species. *C. lateres* has a moderately convex, laterally flattened carapace; a valve surface steeply, almost at right angle, runs to anterior margins and more flat to posterior one. Both margins are flattened in outlines. The sculpture itself is represented by pits of a variable size and shape, merging together on the flattened area of lateral sides, in places the pits are grouped in irregular rows imparting the entire lateral surface a rigid pattern of low and interrupted ridges; the pits are always separated on the steep areas of the same valve (type I sculpture). The type II sculpture differs by an arrangement of lateral pits into rosette-like structures rather than in rows. An intermediate type I-II sculpture pattern is also observed.

In the ontogeny of *C. lateres*, the development of sculpture follows from the distinct type I to an intermediate type I-II and is finalized in the distinct type II. The same trend is distinguished in the phylogeny of the same species during the Michalskii Zone. In application to the Sokur borehole itself, the shift from individuals possessing the type I sculpture to those having intermediate (type I-II) pattern is fixed at 50.7 m level, and the final shift to the type II sculpture is restricted to 37.4 m level. However, the same trend is retarded in juvenile instars being occurred at 42.3 m (I to I–II) and 33.0 m (to II) levels, respectively, while the youngest instars preserve the same type I sculpture during the entire species phylogeny being studied. Thus, several distinct shifts in the morphological development of *C. lateres* are observed, and application of such data to sections provides a better stratigraphic resolution.

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JURASSICA XIII

JURASSIC GEOLOGY OF TATRA MTS

FIELD TRIP GUIDEBOOK

FIELD TRIP A

JURASSIC AND LOWER CRETACEOUS OF THE KRÍŽNA NAPPE IN THE WESTERN TATRA MOUNTAINS

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Route (Fig. 1): All exposures are located near Huciska Glade (Polana Huciska) in Chochołowska Valley (Dolina Chochołowska). The hike starts from Huciska Glade, than leads through Huciański Klin ridge (stops A1–A4) and backdown to starting point at Huciska Glade. This part of the walk runs along unsigned trail through forest and is the most strenuous section of the walk. The relatively short loop walk of the second part of excursion starts from Huciska Glade and leads up along Długa Valley (Dolina Długa) to the Pośrednie ridge (stops A5–A6). The way back from the Pośrednie ridge is an easy downhill walk along Kryta Valley (Dolina Kryta; stops A7–A10).

Introduction to the trip

The Tatra Mountains are the highest ridge of the Western Carpathians with the highest peak Gerlach (2655 m). The Tatra Mts were uplifted during Neogene and form a block which is asymmetrically tilted to the north and bounded from the south by a prominent fault. The block consists of a pre-Mesozoic crystalline core (granitoidic intrusions and older metamorphic rocks), ?Permian and Mesozoic autochthonous sedimentary cover, allochthonous Mesozoic sedimentary rocks, detached locally from their crystalline basement in form of nappes and smaller thrust sheets (Kotański, 1965, 1971) (Fig. 2). The nappes were formed in Late Cretaceous. The Mesozoic sedimentary rocks are discordantly covered by the Central Carpathian Paleogene, which include "nummulitic" Eocene (*ca.* 100 m thick) and Oligocene flysch, more than 2000 m thick, in their upper part. The Mesozoic sedimentary rocks of the Tatra Mts dip are ascribed to three main tectonic-facies domains: Tatricum (High-Tatric autochthon and allochthon), Fatricum (Krížna Nappe = Lower Sub-Tatric Nappe) and Hronicum (Choč Nappe = Upper Sub-Tatric Nappe) on the basis of their characteristic facies successions and tectonic position. The Krížna Nappe overlies the High-Tatric units and is covered by the Choč Nappe (Kotański, 1965). It comprises Lower Triassic to Lower Cretaceous deposits and is built of several thrust sheets and so called "partial nappes".

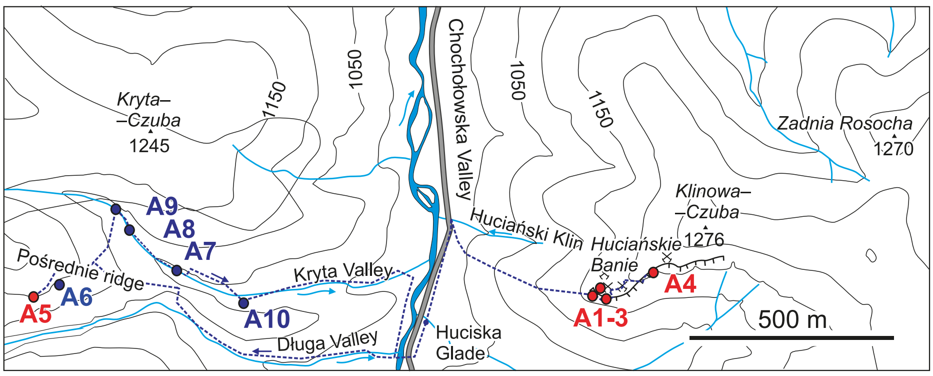

Fig. 1. Detailed itinerary of field trip A

Stops A1–4 – Huciański Klin ridge; stops: A5–10 – Długa Valley and Kryta Valley; red: part I; blue: part II

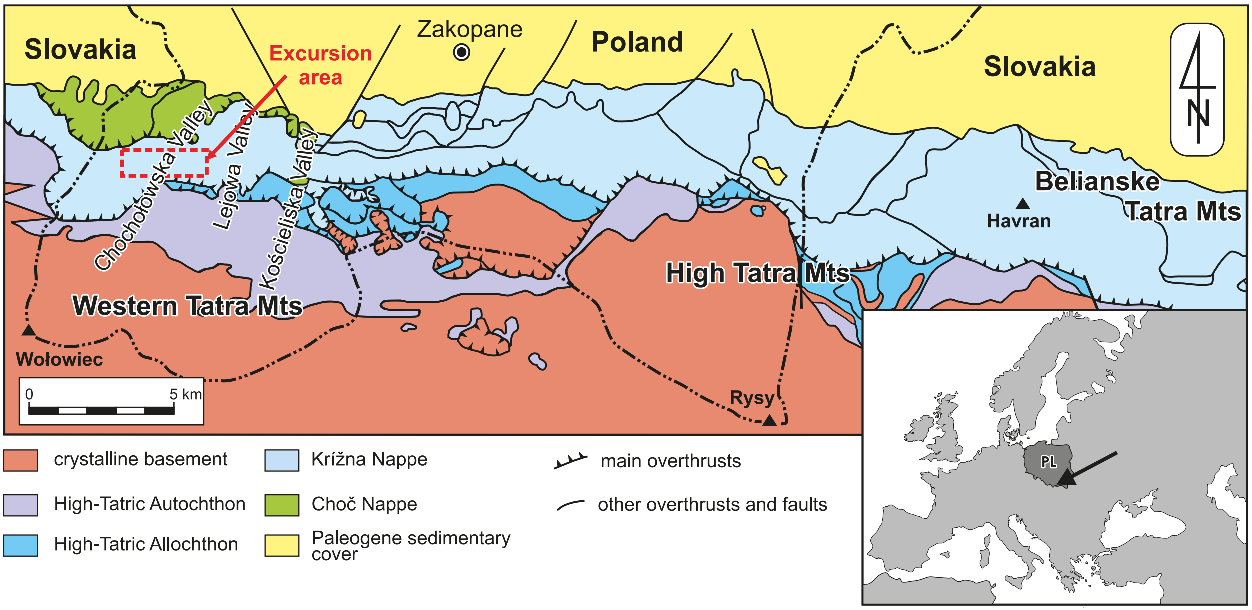

Fig. 2. Tectonic sketch map of the Tatra Mts showing location of the excursion area (after Bac-Moszaszwili *et al.*, 1979; modified)

PART I ▹ MIDDLE AND UPPER JURASSIC OF THE KRÍŽNA SUCCESSION

The Krížna Nappe belongs to the Fatricum Domain of the Central Carpathian block (Plašienka, 2012). During most of the Jurassic time, it was one of the domains located between the Alpine Tethys to the north and the Meliata Ocean to the south (Fig. 3; Thierry, Barrier, 2000; Schmid *et al*., 2008). As a consequence of its location, the succession studied displays a strong similarity to the Jurassic of other Tethyan basins. During the Jurassic, the Fatricum Domain was bordered by the uplifted Tatricum Domain to the north and the Veporicum and Hronicum domains to the south (Csontos, Vörös, 2004; Plašienka, 2012). The Fatricum Domain was regarded as being an extensional basin during the Jurassic, located on thinned continental crust (*e.g.*, Plašienka, 2012). As a result, the Jurassic successions of the Fatricum Domain are characterized by an almost continuous record of deepening, with a transition from littoral through hemipelagic to pelagic deep-sea sedimentation. The Jurassic deposits of the Krížna Nappe in the Tatra Mts represent a generally deeper sea succession of the Zliechov type (Michalík, 2007; Plašienka, 2012; Jach *et al*., 2014). The oldest Jurassic deposits are represented by dark shelf carbonates and shales, which refer to sea transgression onto emerged lands (Fig. 4; Gaździcki *et al*., 1979; Michalík, 2007). These Rhaetian–Hettangian formations have diachronic lower and upper boundary. The Early Jurassic basin featured wide basins and narrow horsts, characteristic of the first phase of extension (Plašienka, 2012). The second phase of extension took place during the latest Early Jurassic and resulted in extensional tilting of blocks, which formed a horst-and-graben topography (Wieczorek, 1990; Gradziński *et al*., 2004; Jach, 2005; Plašienka, 2012). The formation of horsts (*e.g.*, the excursion area) and grabens (in the High Tatra and the Belianske Tatry Mountains; see Field Trip B) led to distinct facies changes (Guzik, 1959; Jach, 2007). The subsiding basins were filled with *Fleckenmergel*-type sediments (bioturbated "spotted" limestones and marls, ranging from Sinemurian to Bajocian; Wieczorek, 1995; Iwańczuk *et al*., 2013). During the Late Pliensbachian–?Aalenian, the horsts acted as submarine highs with sedimentation of spiculites on their slopes (Jach, 2002a) and neritic crinoidal sedimentation (*e.g.*, crinoidal tempestites; Jach, 2005), replaced by condensed pelagic carbonates (Gradziński *et al*., 2004) that were deposited on a pelagic carbonate platform (*sensu* Santantonio, 1993). During the Middle Jurassic, significant topographic relief was still present and controlled facies distribution. The deposition of carbonate sediments terminated with the onset of a uniform radiolarite sedimentation during the Middle Jurassic (Jach *et al*., 2012, 2014). Generally, the Lower–Upper Jurassic sediments of the Fatricum Domain record a gradual deepening and transition from hemipelagic to pelagic deep sea environment.

A major recovery of carbonate sedimentation started in the Late Tithonian and Early Berriasian, when the Maiolica-like deep sea limestones and marls were deposited (Pszczółkowski, 1996; Grabowski *et al*., 2013). Widespread marl and marly limestone sedimentation started in the Late Berriasian and continued to the Aptian, with intercalations of turbiditic sandstones and calcareous fluxoturbidites in the Valanginian and Hauterivian (Pszczółkowski, 2003a).

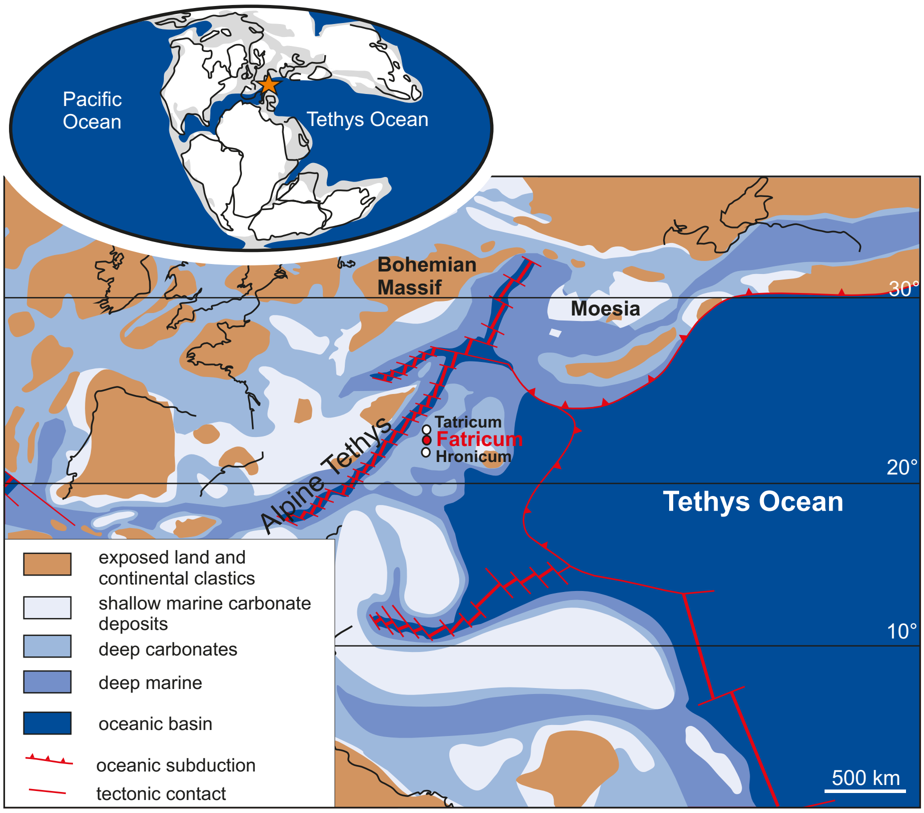

Fig. 3. General palaeogeographic position of the Fatricum Domain during the Callovian (after Thierry, Barrier, 2000; simplified)

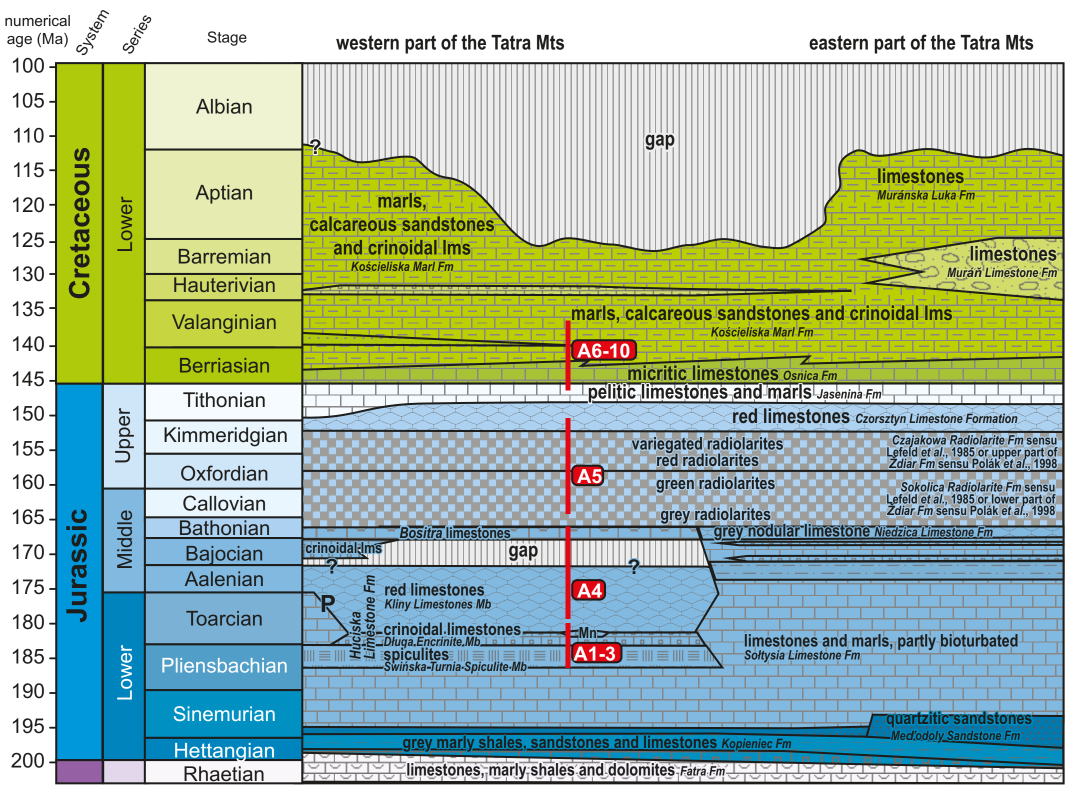

Fig. 4. Simplified litostratigraphic scheme of the Jurassic and Lower Cretaceous succession of the Fatricum domain in the Tatra Mts (partly after Lefeld *et al.*, 1985; modified)

The main aim of this excursion is to present general depositional history of the studied part of the Krížna Unit and to discuss factors controlling their sedimentary environment.

Attention: All the localities presented are in the protected area of the Tatra National Park. Please do not hammer the rocks.

▸STOP A1

HUCIAŃSKI KLIN RIDGE – UPPER PLIENSBACHIAN SPICULITES (49°15´37˝N, 19°49´17˝E)

LEADER: RENATA JACH

The section presented during the first part of the excursion is located on the forested southern slope of the Huciański Klin ridge. The oldest are 16–20 m thick spiculites which overlie basinal "spotted" limestones and marls of the Sinemurian–Lower Pliensbachian not exposed in the presented locality (about 150 m thick). Spiculites are well-exposed in crags a few metre high. Late Pliensbachian age is ascribed to the spiculites on the basis of their position in the section. They are dark, very hard and well-bedded, with bed thickness from a few to 30 cm. Siliceous sponge spicules, which belong to Hexactinellida and Demospongia (mainly Tetractinellida) with loose skeletons, are the major components of spiculites (Fig. 5A–C; Jach, 2002a). A gradual substitution of Hexactinellida by Demospongia is observed upward the spiculite section. Crinoidal ossicles, benthic foraminifera and detrital quartz grains have also been found in very small quantities.

Spiculites are interbedded with some crinoidal wackestones, packstones and grainstones, which form beds up to 20 cm thick. Limestone beds thicken upwards and show a general trend of grain coarsening, accompanied by an increase in their textural maturity from wackestones to grainstones (Jach, 2005). Low-angle cross-bedding, normal grading and erosional bases observed in crinoidal interbeds indicate that they are laid down in higher energy conditions than the intervening spiculites. This is attributed to the currents generated by storms that were capable of sweeping crinoidal material from shallow, elevated parts of the basin to the area inhabited by siliceous sponges. As such, they represent event beds deposited below storm wave base on the slopes of an elevation. The gradual replacement of Hexactinellida by Demospongia and grain coarsening and thickening of crinoidal intercalations indicate a shallowing trend during spiculite deposition (Jach, 2002a). Most probably this trend was related to local changes of seafloor topography caused by synsedimentary faulting in the Fatricum Basin (Jach, 2005). This notion is supported by the occurrence of packages displaying chaotic bedding within the spiculites in the upper part of the spiculite succession. They are interpreted as submarine slumps.

▸STOP A2

HUCIAŃSKI KLIN RIDGE – LOWER TOARCIAN CRINOIDAL LIMESTONES (49°15´36˝N, 19°49´21˝E)

LEADER: RENATA JACH

White, grey and slightly pinkish crinoidal limestones (grainstones) overlie spiculites. They crop out directly over spiculites in rock crags. The crinoidal grainstones, about 12 m in thickness, display irregular bedding with subtle cross-bedding, graded bedding and erosional bed amalgamation. Crinoid stem plates (columnals) are predominant components whereas cirri and arm fragments are less common (Fig. 5D; Głuchowski, 1987). Crinoid assemblage is dominated by *Isocrinus* sp., *Balanocrinus* sp. while Cyrtocrinida occur less commonly (Świńska Turnia crag; Głuchowski, 1987). Fragments of echinoid spines, mollusc and brachiopod shells, ostracods, bryozoans, belemnite rostra, and benthic foraminifera occur subordinately (Jach, 2005). An indistinct trend in coarsening of the crinoidal grains from 0.5 mm to 1–1.2 mm is observed upward the sections.

A lack of stratigraphically diagnostic fossils hindered the precise age determination of the crinoidal limestones. They are ascribed to the Lower Toarcian since they are overlaid by red limestones of the latest Early–Late Toarcian (Lefeld *et al.*, 1985; Myczyński, Lefeld, 2003; Myczyński, Jach, 2009; see stop A4). Chemostratigraphic data from crinoidal limestone indicate that in their uppermost part a significant $\delta^{13}C$ positive excursion occurs ($\delta^{13}C$ ~3.6‰; Krajewski *et al.*, 2001). According to Jenkyns (2003), pronounced positive $\delta^{13}C$ excursion is associated with Early Toarcian Tenuicostatum and Falciferum zones; the excursion is interrupted with the negative shift in the early Exaratum

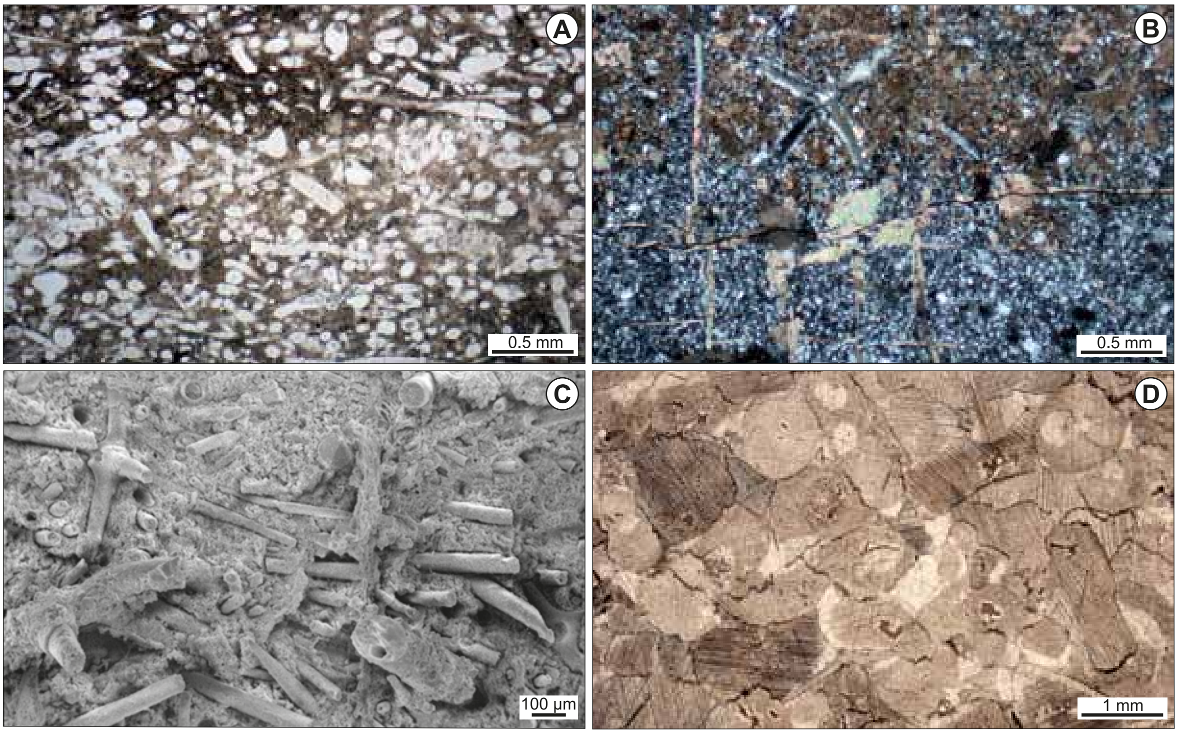

Fig. 5. Spiculites and crinoidal limestones

A – Spiculite in thin-section. Plane-polarised light; B – Spiculite in thin-section. Cross-polarised light; C – Densely packed siliceous sponge spicules. SEM image of HF-etched surface; D – Crinoidal grainstone with syntaxial cements. Thin-section, plane-polarised light

subzone of the Falciferum Zone. As the isotope excursion occurs in the upper part of the crinoidal grainstones, it can be assumed that this part of the section refers most probably to the Tenuicostatum Zone of the Early Toarcian.

All the above described sedimentological characteristics point to a multiple reworking and winnowing of crinoidal material by storm-induced oscillatory currents from elevated parts of the basin. Thus, the sedimentation of the crinoidal grainstones took place between the storm and fair-weather wave bases. The succession of the crinoidal intercalations in the spiculites and the overlying crinoidal grainstones show a vertical transition from distal to proximal tempestites, which is a record of a progressive shallowing upward trend (Jach, 2005).

▸STOP A3

HUCIAŃSKI KLIN RIDGE – LOWER TOARCIAN MANGANESE DEPOSITS (49°15´37˝N, 19°49´20˝E)

LEADER: RENATA JACH

The Mn-bearing deposits of the Krížna Unit in the Western Tatra Mts occur locally between the crinoidal tempestites (Lower Toarcian) and the pelagic red limestones (Lower Toarcian−?Aalenian). They crop out exclusively between the Chochołowska and Lejowa valleys where they were mined as Mn ore in the 19th century (Jach, 2002b). The Mn-bearing deposits form a lens which is up to 2 m thick and stretches at the distance of a few hundred metres at the Huciański Klin ridge. The old shafts provide the only accessible outcrops of these rocks there. The longest of them is 41 m long (Jach, 2002b). The Falciferum Zone of the Early Toarcian may be estimated for the Mn-bearing deposits on the basis of their position in the section (Krajewski *et al.*, 2001; Myczyński, Lefeld, 2003; Myczyński, Jach, 2009).

For the purpose of simplicity the Mn-bearing deposits are subdivided in three parts: rocks underlying the Mn-rich bed (30–70 cm thick), the Mn-rich bed (up to 110 cm thick), and rocks overlying the Mn-rich bed (up to 40 cm thick; Jach, Dudek, 2005; Fig. 6).

Generally rocks underlying the Mn-rich bed consist of: (i) a Fe-rich layer, (ii) an X-ray amorphous Mn-oxide layer, (iii) shales, and (iv) a massive jasper bed. The 15 cm thick Fe-rich layer comprises up to ~30 wt.% Fe (mainly hematite). The overlying 10 cm thick Mn-oxide layer is composed mainly of amorphous Mn oxide (up to 46 wt.% Mn). Some 2–15 cm

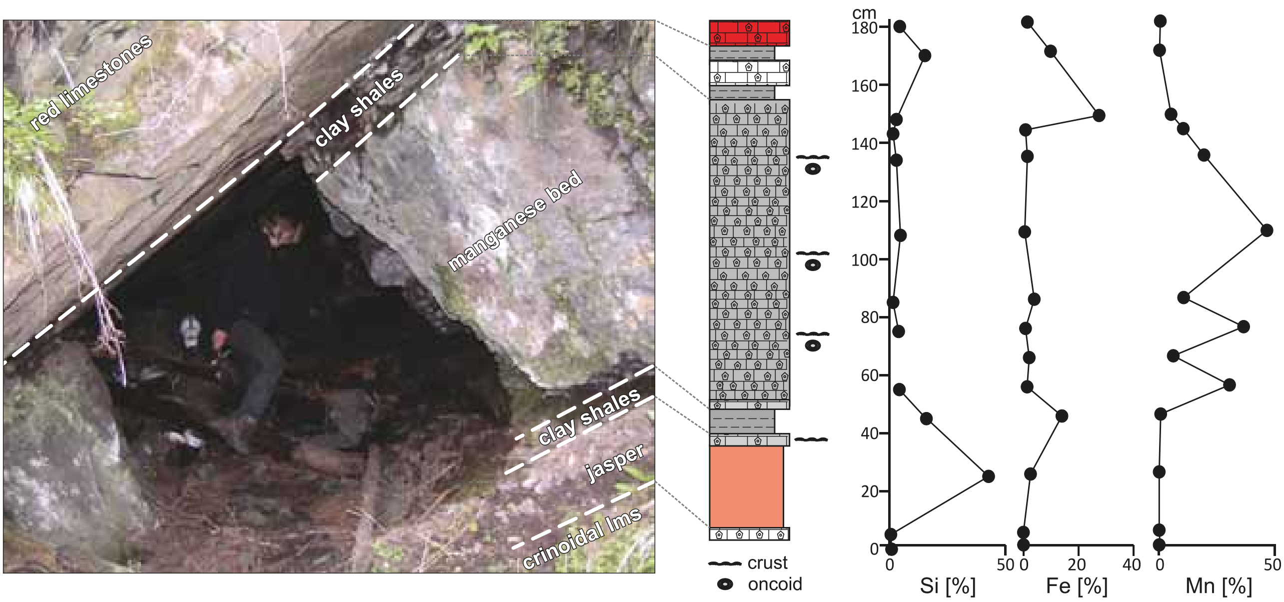

Fig. 6. Manganese-bearing deposits cropping out in a shaft entrance. Lithological section with general geochemical characteristic (Si, Fe and Mn)

thick shales occur between the rocks described above and the main Mn-rich bed. Clay minerals comprise a complex suite dominated by mixed-layer clays with chlorite, smectite, and vermiculite layers (Dudek, Jach, 2006). The Fe-rich layer, and the Mn-oxide layer underwent locally silicification which resulted in the development of a massive jasper bed, which is 10 to 50 cm thick (Figs 6, 7A, B).

The Mn-rich bed, with sharp and well-defined top and bottom, ranges in thickness from 35 cm to 1.1 m. It comprises clearly defined, lenticular zones composed either of Mn carbonates or of Mn silicates (Fig. 7C–E). The carbonate zones are purple-red, whereas the silicate zones are usually black.

The Mn-carbonate zones are built of calcite and Mn-calcite, with various Ca/Mn ratios whereas Mn silicates (braunite, caryopilite) occur in minor amounts (Korczyńska-Oszacka, 1978; Jach, Dudek, 2005). Pure rhodochrosite forms small lenses up to 6 cm long in the upper part of the bed (Korczyńska-Oszacka, 1979). Conversely, the silicate zones are dominated by braunite, forming frequently idiomorphic crystals (Fig. 7F), and caryopilite. Calcite and subordinate amounts of dolomite, apatite, and barite have been identified as non-manganese minerals. The chemistry of the carbonate and silicate zones differs mainly in the Mn content: ~5 wt.% Mn in the former ones in contrast to more than ~50 wt.% Mn in the latter ones (Jach, Dudek, 2005). The Mn-rich bed comprises low concentrations of transitional elements (Co + Ni + Cu <0.01 wt.%). On a ternary diagram of Co+Ni+Cu, *versus* Fe and Mn, our samples plot in the area of Mn deposits of hydrothermal and diagenetic origins. In contrast, it is enriched in Ba (up to 4500 ppm). Total REE (8 elements) contents range from 83 to 151 ppm which may indicate that the deposits studied may have formed by both hydrothermal and hydrogenetic processes.

The Mn-rich bed, especially the silicate zones, abounds in microbial structures: crusts and oncoids (Fig. 7C, E; Jach, Dudek, 2005). Crusts cover and bind bioclasts. Oncoids, 3–30 mm across, are usually elongated, rarely isometric. The nuclei of the oncoids are usually composed of bio- and lithoclasts, less frequently of barite crystals (*cf.*, Krajewski, Myszka, 1958). Their cortex is composed of concentric laminae of Mn-silicates and Mn-calcite. Microbial structures are accompanied by bioclasts, namely fragments of echinoids and crinoids. Tests of benthic foraminifera, shells of molluscs, ostracods, holothurian sclerites, and bryozoan fragments are less common. This assemblage of fauna and microbial structures occurs exclusively within the Mn-rich sequence; it is not found in the overlying or underlying deposits or in deposits that are lateral equivalents of the Mn-rich sequence.

Rocks overlying the Mn-rich bed are composed of two layers of shale separated by a layer of bioclastic limestone. The agglutinating foraminifera, represented almost exclusively by *Recurvoides*, occur in the upper shale (Tyszka *et al.*, 2010). The clay fraction of the shales is dominated by illite and illite-rich illite-smectite mixedlayer clays (Dudek, Jach, 2006).

The Mn-bearing deposits are interpreted as formed in several stages controlled by a pulse-like activity of a shallow submarine exhalative vent (Krajewski, Myszka, 1958; Jach, Dudek, 2005). It is proved by sedimentological, mineralogical and geochemical evidence, coupled with the occurrence of specific microbial structures and a peculiar fauna assemblage (Jach, Dudek, 2005). The limited lateral extent of the Mn-bearing sequence may be an effect of low efficiency of the vent and/or of the seafloor topography. The specific faunal assemblage dominated by deposit feeders was intimately associated with trophic conditions which persisted near the vent orifice. During cessation in the vent activity, the sediments would have been exposed to and would have interacted with sea-water. Other early diagenetic processes included silicification and reduction of Mn oxides during suboxic diagenesis (Krajewski *et al.*, 2001). Hydrothermal activity was the most likely source of colloidal silica. Idiomorphic shapes of braunite crystals

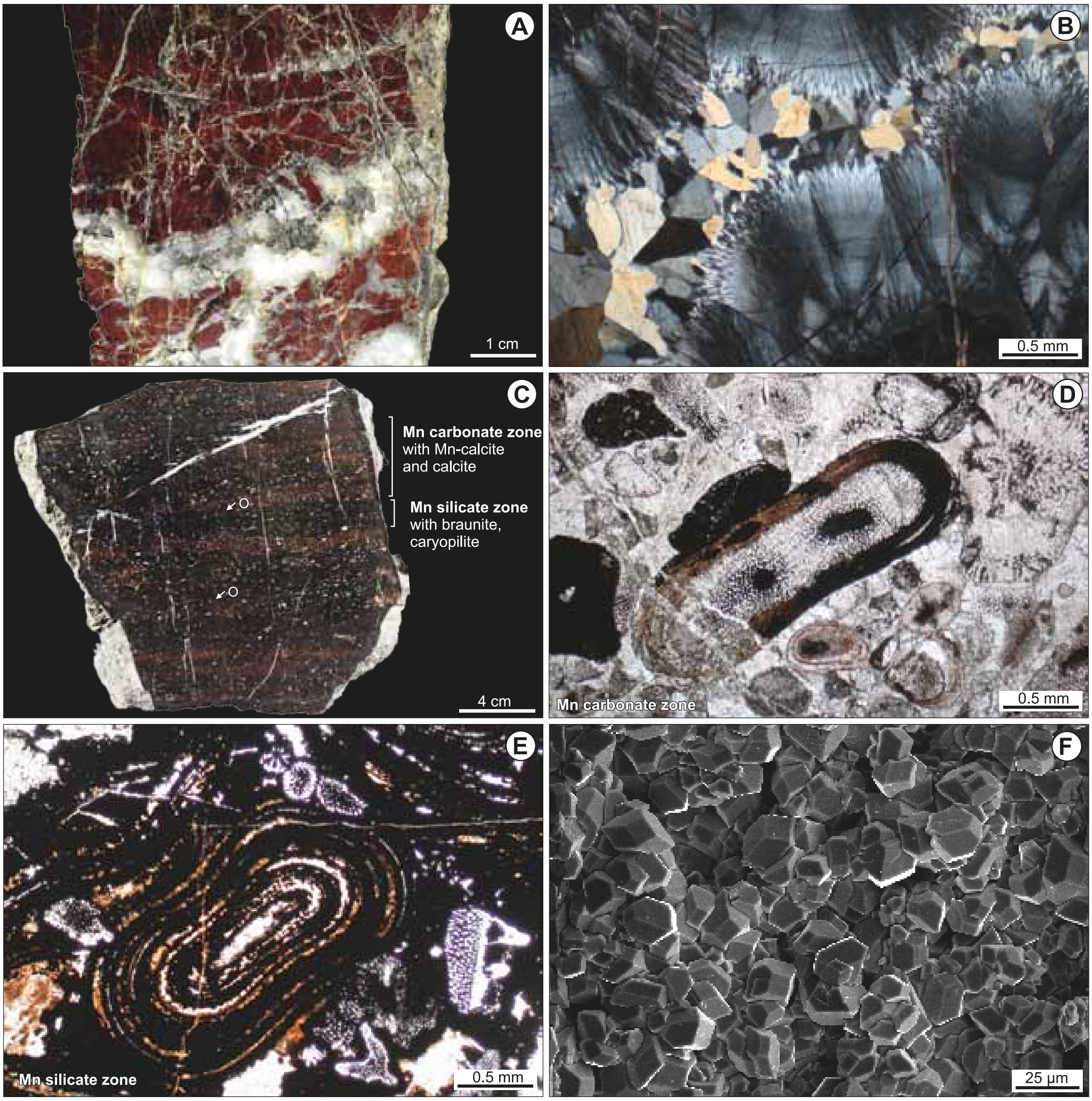

Fig. 7. Manganese-bearing deposits

A – Jasper, polished slab; B – Internal structure of jasper bed, fibrous chalcedony and blocky quartz. Thin-section, cross-polarised light; C – Mn-bearing bed shows subtle stratification underlined by occurrence of carbonate and silicate zones. Polished slab; D – Carbonate zone. Manganese oncoide within echinoderm grainstone, mainly echinoid-crinoidal, with syntaxial cements built of calcite and manganese calcite. Thin-section, plane polarised light; E – Silicate zone with abundant microbial structures, mainly oncoids. Thin-section, plane polarised light; F – Silicate zone. Authigenic idiomorphic crystals of braunite, SEM image of HCl-etched surface

embedded in Mn-calcite indicate that silicification preceded crystallization of Mn carbonates. The process of silicification resulted in the formation of Mn silicates in the Mn-rich bed, the massive jasper bed in the lower part of the sequence, and possibly also numerous silica lenses in the underlying crinoidal grainstones. The following stage of diagenesis – precipitation of Mn carbonate cements in the Mn-rich bed, was controlled by abundance of organic matter in the sediments. The latter is interpreted as genetically related to the microbial productivity *in situ*.

The position of the Mn-bearing deposits over the crinoidal tempestites and below the red pelagic limestone indicates that they were laid down at neritic depths. Moreover, it implies that Mn-bearing deposits mark a substantial change from relatively shallow (tempestites) to deeper water (red pelagic limestones) sedimentation milieu. This change most probably resulted from synsedimentary tectonic activity. It is in line with expelling of fluids by the vent. It was associated with extensional faults which provided channelways for geofluid migration upward (Jach, Dudek, 2005). The internal facies variation of the Mn-bearing sequence may be explained by changes in bottom-water chemistry, geofluid temperature or by lateral migration of the vent orifices.

▸STOP A4

HUCIAŃSKI KLIN RIDGE – LOWER TOARCIAN–?AALENIAN RED LIMESTONES AND MARLSTONES AND BATHONIAN BOSITRA LIMESTONES (49°15′37″N, 19°49′24″E)

LEADERS: ALFRED UCHMAN, RENATA JACH

The Mn-bearing sequence is covered by red limestones and marlstones, about 4 m thick, which in turn, are overlain by thin-shelled bivalve-bearing limestones (hereafter called *Bositra* limestones). The latter are up to 3 m thick (Figs 8, 9A; Jach, 2007). The ammonites found in the red limestones indicate the upper part of Lower Toarcian–Upper Toarcian (Serpentinum–Pseudoradiosa zones; Myczyński, Jach, 2009). The outcrop of red limestones is located at the entrance to one of the Mn adits. The red limestones and marlstones are characterized by concentrations of pelagic fauna remains (Fig. 9B), such as ammonites, belemnites and fish teeth, which are a common feature of the Jurassic pelagic limestones deposited on elevated settings (pelagic carbonate platforms *sensu* Santantonio, 1993). Six microfacies have been distinguished within red nodular limestones: crinoidal-ostracod packstone, crinoidal packstone, crinoidal wackestone, marly mudstone, *Bositra* packstone and *Bositra*-crinoidal packstone (Gradziński *et al.*, 2004). Fining-upward trend (from packstones to wackestones), is accompanied by increasing upward abundance of microborings.

Crinoid and echinoid fragments are most abundant within microfossil assemblage. Fish teeth, benthic foraminifera, smooth-walled ostracods, juvenile ammonites are less common (Gradziński *et al.*, 2004). Echinoid fragments dominate in the lower part of the red nodular limestone section and decrease upwards. Conversely, fish teeth are relatively rare in the lower part of the section and abundant in the upper part.

The upper part of red limestones and marlstones displays several features, such as concentration of nektonic fauna remains, occurrence of stromatolites and oncoids, and abundance of microborings typical of condensed section deposited on submarine elevations (Fig. 9A–D; Jenkyns, 1971; Bernoulli, Jenkyns, 1974). The features mentioned above collectively indicate a low depositional rate. Microbial-foraminiferal oncoids, which have been recognized in the upper part of the red deposits, are the most peculiar feature of the studied section (Fig. 9C, D; Gradziński *et al.*, 2004). The oncoids are up to 10 cm across and mostly display discoidal shape. Intraclasts or internal moulds of ammonites have acted as oncoid nuclei whereas oncoid cortices are composed of dark red laminae (mainly of iron hydrooxides/oxides), encrusting foraminifera (Fig. 9D; *Nubecularia* aff. *mazoviensis*, *Dolosella*, and agglutinated *Tolypammina*) and calcite cements. The dark red laminae dominate the oncoidal cortices and show a reticulate ultrastructure which is interpreted as

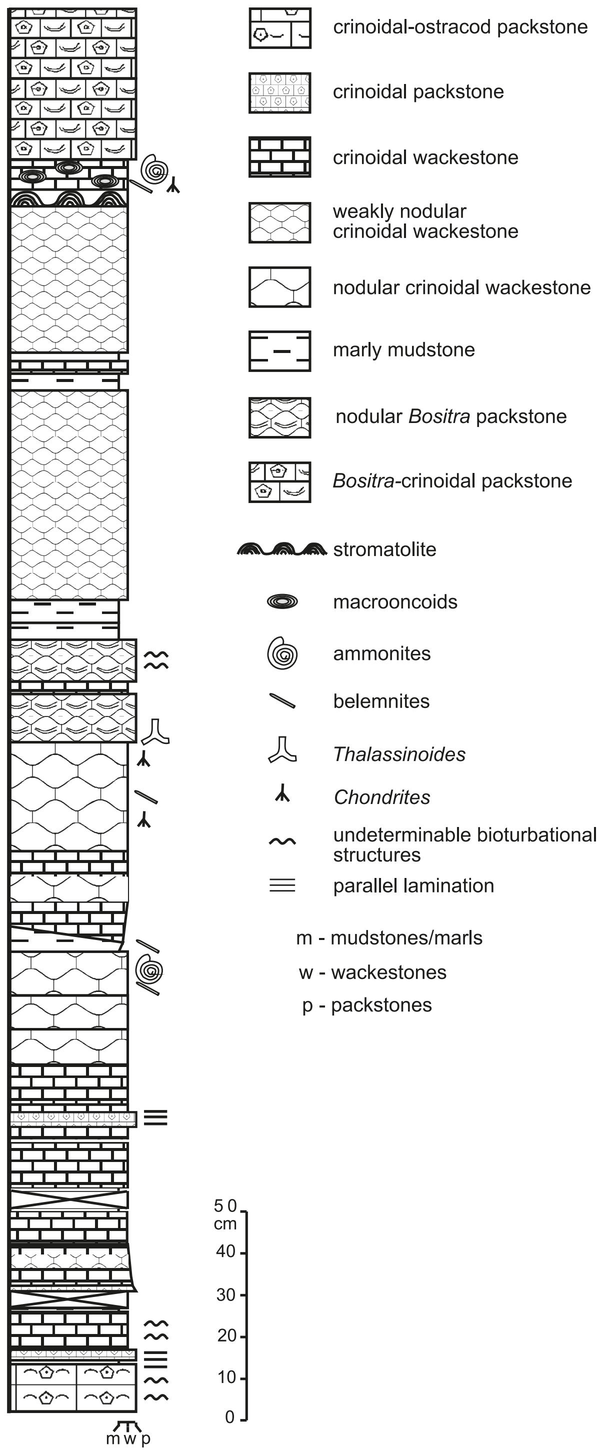

Fig. 8. Lithological section of the red limestones in the Huciański Klin site (Gradziński *et al.*, 2004)

mineralized biofilm, visible under SEM. Mineralized microbial bodies, globular and filamentous in shape, also built of iron hydrooxides/oxides, are abundant within the laminae. The association of foraminifera with microbes is supposed to be an adaptation of foraminifera to oligotrophic condition on the sea floor. It is very probable that biofilms served as food source for encrusting foraminifera. Formation of oncoids was possible under periodic water agitation (Gradziński *et al*., 2004). The red limestones locally display nodular structure and contain a few discontinuity surfaces in the studied section (Gradziński *et al*., 2004). Some of such surfaces are burrowed with *Thalassinoides*, which indicates colonization of a firmground by crustaceans. Another discontinuity surface, which occurs in the uppermost part of the section, is manifested by concentration of internal moulds of ammonites and some fragments of ammonite shells covered with a stromatolite (Fig. 9B). There is a concentration of glaucony grains and crusts in the topmost part of the section, just at the contact of the red limestones and the *Bositra* limestones.

Overlying *Bositra* limestones are composed of *Bositra*-crinoidal packstones, and *Bositra* packstones/grainstones in this section (Jach, 2007). The latter dominate in the uppermost 3 m of the section. They were laid down in a relatively high-energy setting, which controlled the good sorting of these deposits. However, the domination of the *Bositra* bivalves seems to have resulted from some ecological factors, such as eutrophication of the water column. The dissolution of non-calcitic bioclasts is also suggested. *Bositra*-limestones lack of index fossils; their age is inferred as Lower Bathonian, based on superposition (Jach *et al*., 2014).

The red nodular limestones and the overlying *Bositra* limestones were formed during gradual deepening of the basin, which caused lowering of the depositional rate and, hence, condensation (Wieczorek, 2001). The deposition of *Bositra* limestones marks the first stage of unification of facies, which probably took place during Early Bathonian. This process was later manifested by the deposition of radiolarites in the whole Fatricum Basin (Ožvoldová, 1997; Polák *et al*., 1998; Jach *et al*., 2012, 2014). Thus, the deposition of *Bositra* limestones reflected the intermediate stage in the basin evolution leading to formation of radiolarites (Lefeld, 1974; Jach, 2007).

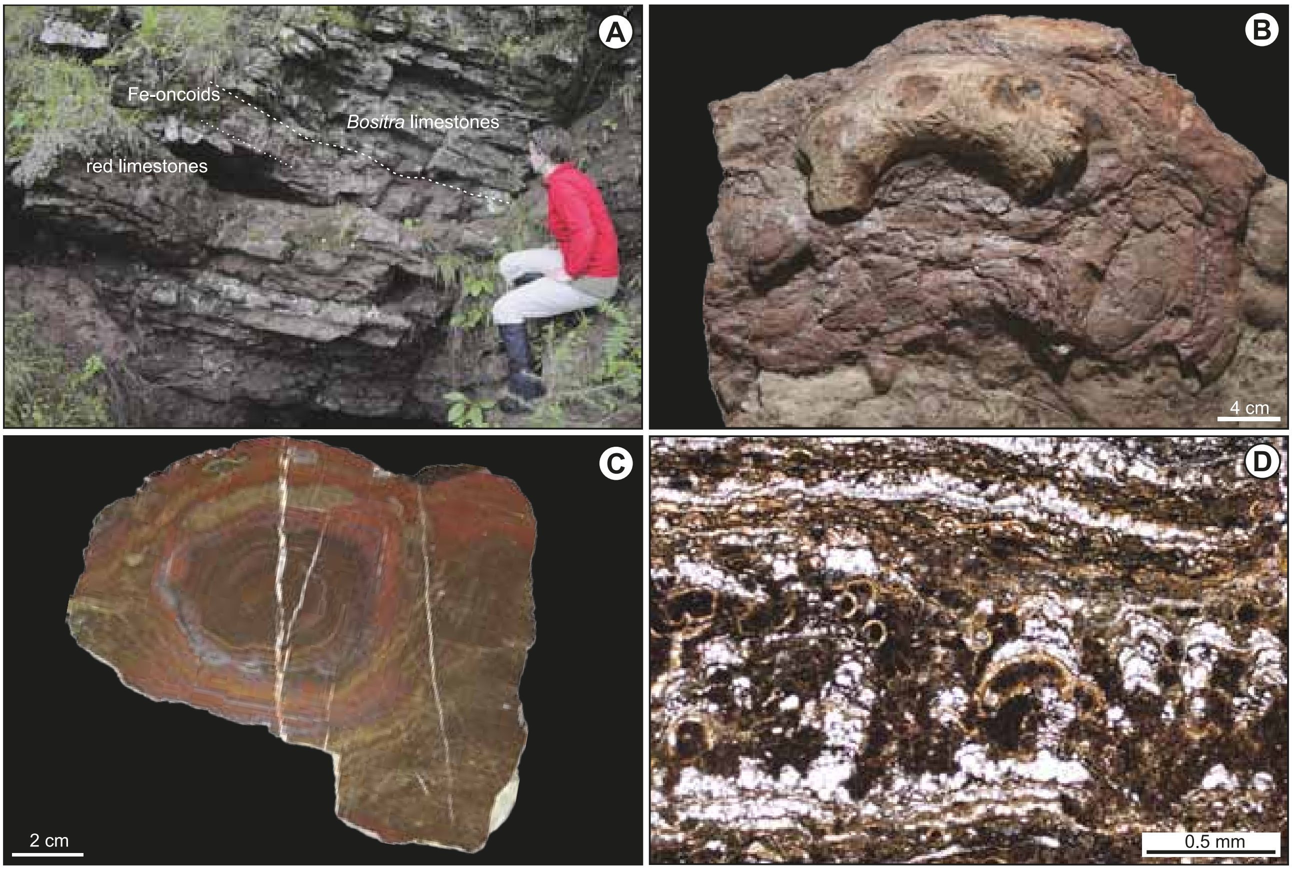

Fig. 9. Red limestones

A – Section of the red limestones and Bositra limestones at the entrance to one of the adits; B – Omission surface with ferruginous stromatolite encrusting ammonite mould and shell (*Lytoceras* sp.). Weathered surface; reprinted from Myczyński and Jach (2009);
C – Cross-section through a microbial-foraminiferal ferrugineous macrooncoids. Polished slab;
D – Cortex of oncoid built of encrusting foraminifers; thin-section, plane-polarised light

▹STOP A5

DŁUGA VALLEY, POŚREDNIE RIDGE – MIDDLE–UPPER JURASSIC RADIOLARITES (49°15′37″N, 19°48′04″E)

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The Middle–Upper Jurassic radiolarites crop out in the rock cliff located in the Długa Valley along the southern slope of the Pośrednie ridge (Fig. 1). The radiolarite-bearing succession comprises the following facies: (1) grey spotted radiolarites, (2) green radiolarites, (3) variegated radiolarites, and (4) red radiolarites (Fig. 10). They are overlain by red limestones. The radiolarian-bearing deposits are ~30 m thick. The radiolarites, on the basis of $\delta^{13}C$,

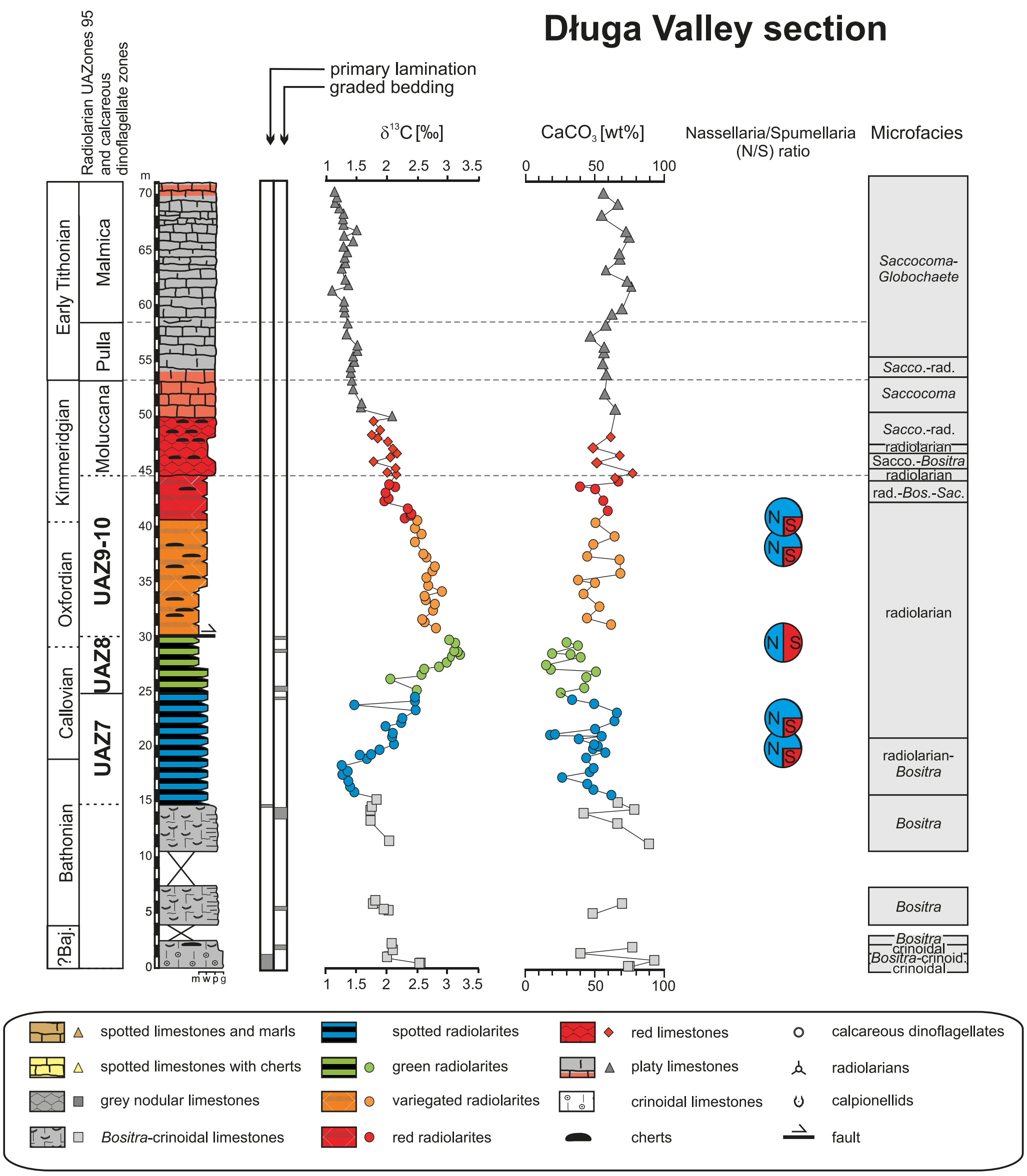

Fig. 10. Długa Valley section. Lithology, radiolarian and calcareous dinoflagellate biostratigraphy and results for carbon isotope measurements, $CaCO_3$ content and microfacies analysis (after Jach *et al.*, 2014; modified)

radiolarians and calcareous dinoflagellata are of the Late Bathonian–early Late Kimmeridgian age (Fig. 10; Unitary Association Zones 7–11; Moluccana Zone; Polák *et al.*, 1998; Jach *et al.*, 2012, 2014). The broad negative excursion recorded in spotted radiolarites is Late Bathonian in age, whereas the pronounced positive $\delta^{13}C$ excursion detected in green radiolarites is referred to Late Callovian. It is worth mentioning that this excursion coincides with a distinct increase in radiolarian abundance and an extreme carbonate production crisis (Bartolini *et al.*, 1999; Morettini *et al.*, 2002). The variegated and red radiolarites and the overlying limestones display a pronounced decreasing $\delta^{13}C$ trend in the Oxfordian–Early Tithonian (Jach *et al.*, 2014).

The oldest radiolarites are grey and green, highly siliceous, thin- to medium-bedded, alternated with 0.2–2 cm thick siliceous shales (Fig. 11A, B). These chert-shale couplets are the most characteristic feature of the grey and green radiolarites. Average $CaCO_3$ contents in grey radiolarites and in green radiolarites are 36 wt.% and 25 wt.%, respectively (Fig. 10). The grey and green radiolarites show transition from *Bositra*-radiolarian to radiolarian microfacies, with calcified and extensively dissolved radiolarian tests (Fig. 11D). Grey spotted radiolarites are intensively bioturbated whereas green radiolarites locally show subtle microscopic lamination. The primary lamination can be referred to incidental rapid sedimentation marked by a subtle increase in grain size, or a short episode of anoxia.

The variegated and red radiolarites are calcareous, distinctly bedded, with bed thicknesses of about 10–15 cm (Fig. 11C). They have a higher content of $CaCO_3$, 50 wt.% on average (Fig. 10). The common occurrence of massive chert nodules of various colours, mainly reddish or greyish, is typical of this facies. The very rare occurrence of thin shale intercalations is characteristic of the variegated radiolarites. The red radiolarites are calcareous, red and greyish red, and thin- to medium-bedded, with beds from 5 to 30 cm. The variegated and red radiolarite facies show upward transition from radiolarian to the *Bositra* and *Saccocoma* microfacies. They contain calcified or partially silicified radiolarians, sponge spicules, crinoids, planktonic foraminifera *Globuligerina* and cysts of calcareous dinoflagellates.

Almost all radiolarite and the associated deposits are bioturbated (Jach *et al.*, 2012). They contain the trace fossils *Chondrites*, *Planolites*, *Zoophycos*, *Teichichnus*, *Phycodes*, *Trichichnus*, *Phycosiphon* and *Thalassinoides* (Uchman, Jach, 2014). They belong to the *Zoophycos* ichnofacies, which characterizes deeper shelf – basin plain settings with pelagic and hemipelagic sedimentation. Generally, the abundance and diversity of trace fossils decrease up the succession. In the Upper Bathonian–Lower Callovian, the grey spotted radiolarites display typical spotty structures, that is relatively dense and diverse crosssections of trace fossils *Chondrites*, *Planolites*, *Thalassinoides*, and *Zoophycos* are common. Up the succession, in the green,

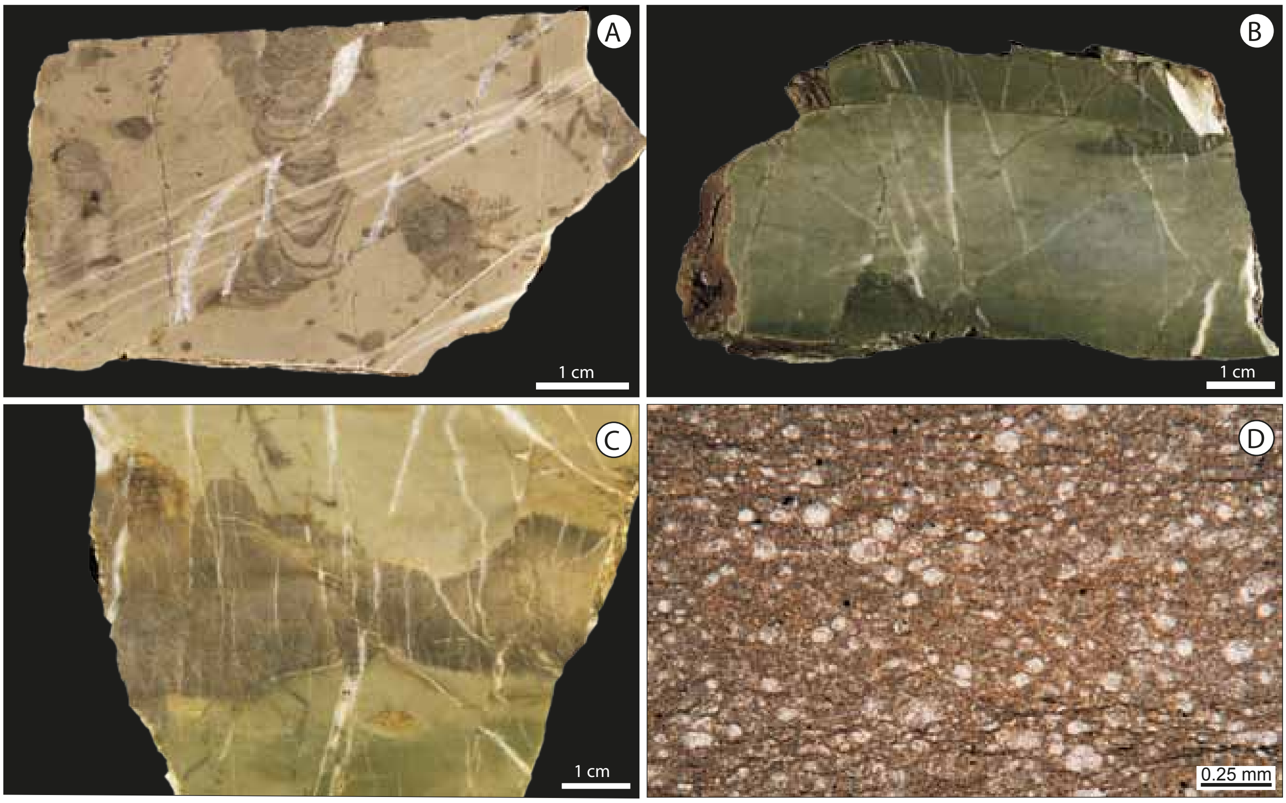

Fig. 11. Radiolarites

A – Bioturbated grey spotted radiolarites, polished slab; B – Green radiolarites, polished slab; C – Variagated radiolarites, polished slab; D – Green radiolarites, radiolarian wackestone-packstone. Thin-section, plane polarised light variegated and red facies, the spots decrease in density, contrast and diversity, up to disappearance.

The changes are not ideally linear, but fluctuations in these features do not discard the general trend. They are not related to grain size or lithology. The changes of ichnological features in the studied interval are caused mainly by decrease in food content in the sediments (Jach *et al*., 2012; Uchman, Jach, 2014). With deepening of the basin and decreasing sedimentation rate associated with generally advancing flooding of epicontinental areas, less and less food was supplied to the basin from shallower areas and less and less of it was buried in sediment. In more eutrophic conditions (lower part of the interval), organisms penetrated deeply in the sediment, where distinct trace fossils were produced. A thicker layer of nutritional sediment gave an ecospace for a higher diversity of burrowing organisms. In more oligotrophic conditions (higher part of the succession), the organic matter was concentrated in the soupy sediment near the sediment-water interface, where preservation of distinct trace fossils was limited or impossible.

In the Długa Valley section, the Nassellaria/Spumellaria (N/S) ratio among radiolarians fluctuates, most probably in accordance with bioturbation intensity (Jach *et al*., 2015). It seems that the greater abundance of trace fossils coincides with the Nassellaria-dominated assemblage. It is thus possible that the observed pattern results from ecological requirements of these two groups of radiolarians. Spumellaria, which tend to be predominantly symbiont bearing, develop in more oligotrophic near-surface waters, whereas Nassellaria are non-symbiotic forms, which live in more eutrophic, deeper water column. Such a correlation may be explained by fluctuating input of nutrients from the neighboring lands, caused most probably by climate changes, for instance by enhanced continental weathering and runoff (*cf.*, Baumgartner, 2013). An increased input of nutrients during humid climate leads to sea-water eutrophication, whereas decreased input leads to its oligotrophication. The Late Bathonian–Kimmeridgian radiolarites are an evidence of deepening, with sedimentation taking place between the ACD and CCD or below the CCD. The middle Oxfordian–upper Kimmeridgian, variegated and red radiolarian-bearing facies, and finally red nodular and platy micritic limestones, record the recovery of carbonate sedimentation. It is evidenced by the middle Callovian–lower Oxfordian intervals characterised by drastically reduced $CaCO_3$ content, whereas an increase of carbonate content occurs in the middle Oxfordian–upper Kimmeridgian part of the section.

PART II ▹ TITHONIAN–LOWER VALANGINIAN LIMESTONES AND MARLSTONES: BIOSTRATIGRAPHY, MAGNETOSTRATIGRAPHY, CARBON ISOTOPE STRATIGRAPHY AND PALAEOENVIRONMENTAL CHANGES

LEADERS: JACEK GRABOWSKI, ANDRZEJ PSZCZÓŁKOWSKI [1]

[1] *Polish Academy of Sciences, Institute of Geological Sciences, Twarda 51/55, 00-818 Warsaw, Poland*

The Uppermost Jurassic (Tithonian) and Lower Cretaceous limestones and marlstones of the Krížna Nappe crop out in the Kryta Valley and in neighbouring ridges between the Kryta and Długa valleys (Fig. 1). Lithostratigraphically, this interval is divided into three units (Fig. 12). Shaly marls and olive grey, thinly-bedded micritic limestones occur in the upper part of the Jasenina Formation (Upper Tithonian to lowermost Berriasian). The light grey, calpionellid-bearing limestones of the Osnica Formation (Berriasian) overlie the Jasenina Formation deposits. The limestones are 25–37 m thick in various sections (Pszczółkowski, 1996) and pass gradually into the overlying strata of the Kościeliska Marl Formation (Lefeld *et al*., 1985). This formation, of Late Berriasian-Aptian age, comprises marls and limestones about 260 m thick (Lefeld *et al*., 1985; Kędzierski, Uchman, 1997; Pszczółkowski, 2003a).

Magneto- and biostratigraphic data were obtained from the Tithonian and Berriasian strata (Fig. 12; Grabowski, 2005; Grabowski, Pszczółkowski, 2006a), which enabled correlation of these sections with GPTS (Geomagnetic Polarity Time Scale), estimation of sedimentation rates and of palaeolatitudinal position of the area in the Berriasian (28°N, ±4.5°). Detailed magnetic susceptibility (MS) and field gamma ray spectrometry (GRS), supported by geochemical analyses were used for reconstruction of palaeoenvironmental changes (Grabowski *et al*., 2013; see Fig. 13).

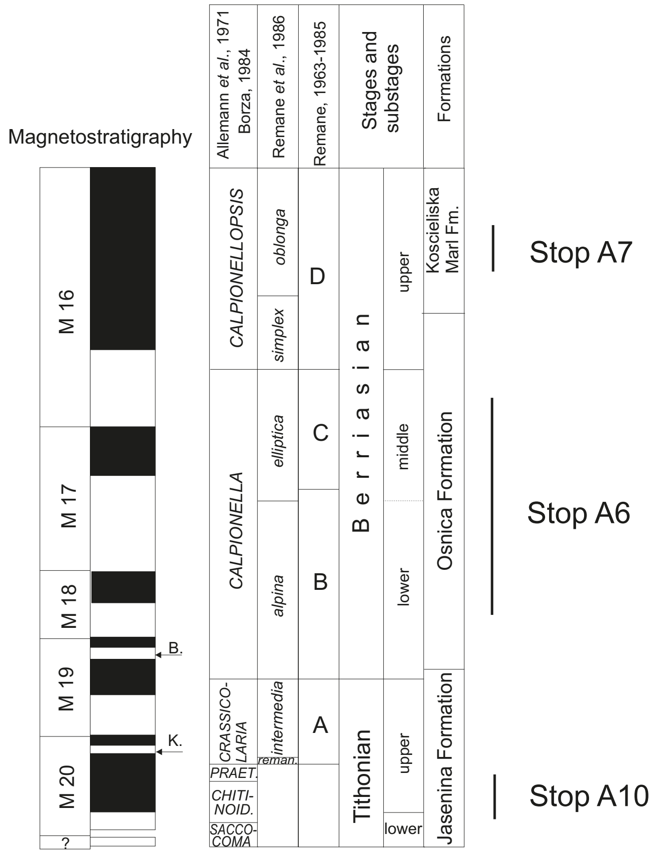

Fig. 12. Litho-, bio- and magnetostratigraphic scheme of the Upper Tithonian and Berriasian of the Lower Sub-Tatric (Krížna Nappe) succession in the Western Tatra Mts (not to scale), after Grabowski, Pszczółkowski, 2006b

B – Brodno magnetosubzone (M19n1r); K – Kysuca magnetosubzone (M20n1r)

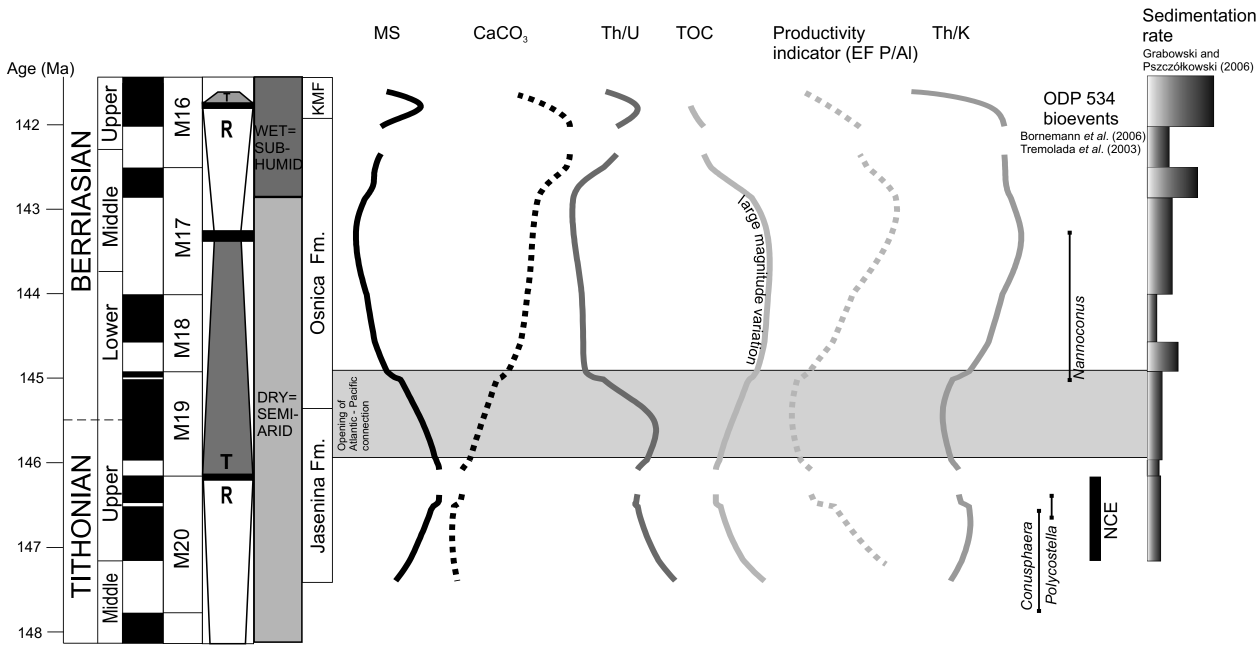

Fig. 13. Summary of magnetic and geochemical palaeoenvironmental trends at the Jurassic–Cretaceous boundary interval in the Pośrednie III section, Western Tatra Mts (after Grabowski *et al*., 2013; slightly modified)

The transgressive/regressive (T-R) cycles in the Tethyan domain, after Hardenbol *et al*. (1998); paleoclimatic trends in ODP 534 after Bornemann *et al*. (2003) and Tremolada *et al*. (2006); general paleohumidity trends after Abbink *et al*. (2001) and Schnyder *et al*. (2006). NCE – Nannofossil calcification event

▹STOP A6

SECTION POŚREDNIE II. CALPIONELLID LIMESTONES OF THE OSNICA FORMATION (LOWER BERRIASIAN)

The well bedded calpionellid limestones crop out on the southern slopes of the Pośrednie Ridge, above the Długa Valley. These are olive gray micritic limestones (mudstones to wackstones) with abundant pelagic microfossils: calpionellids, globochaete and radiolarians. The section, *ca.* 30 m thick (Fig. 14), covers upper part of the Lower Berriasian, from magnetozone M18r (upper part of the Alpina Subzone) to the lower part of magnetozone M16r (upper part of Cadischiana Subzone). The sedimentation rate of the Osnica Formation brackets between 10 and 17 m/My, and increases upward to 18–23 m/My in the lower part of the Kościeliska Marl Formation (Grabowski, Pszczółkowski, 2006a).

The Osnica Formation represents interval of carbonate sedimentation with limited influx of detrital material (Grabowski *et al.*, 2013). It is characterized by relatively low MS values, low contents of Th and K and other lithogenic elements (Fig. 13). The interval bears evidence of slightly oxygen depleted conditions (low Th/U ratio, elevated enrichment factors (EF) of Cd, Ni and Mo, enhanced productivity (higher EF P and EF Mn). The phenomena seem to be coeval with the warming period documented in the DSDP 534A core in the central Atlantic between magnetozones M18r and M17n (Tremolada *et al.*, 2006). Magnetic susceptibility and content of lithogenic elements in the Osnica Formation is comparable to that of Oberalm Formation in the central part of Northern Calcareous Alps (see Grabowski *et al.*, 2017 – this issue). It is an order of magnitude higher than in coeval formations of the Pieniny Klippen Belt (Pieniny Limestone Formation) and Transdanubian Mts (Mogyorosdomb Formation) which means that sedimentation areas of Osnica and Oberalm formations were affected by increased amount of terrigenous influx, most probably due to relative proximity of the Neotethyan collision zone (Missoni, Gawlick, 2011).

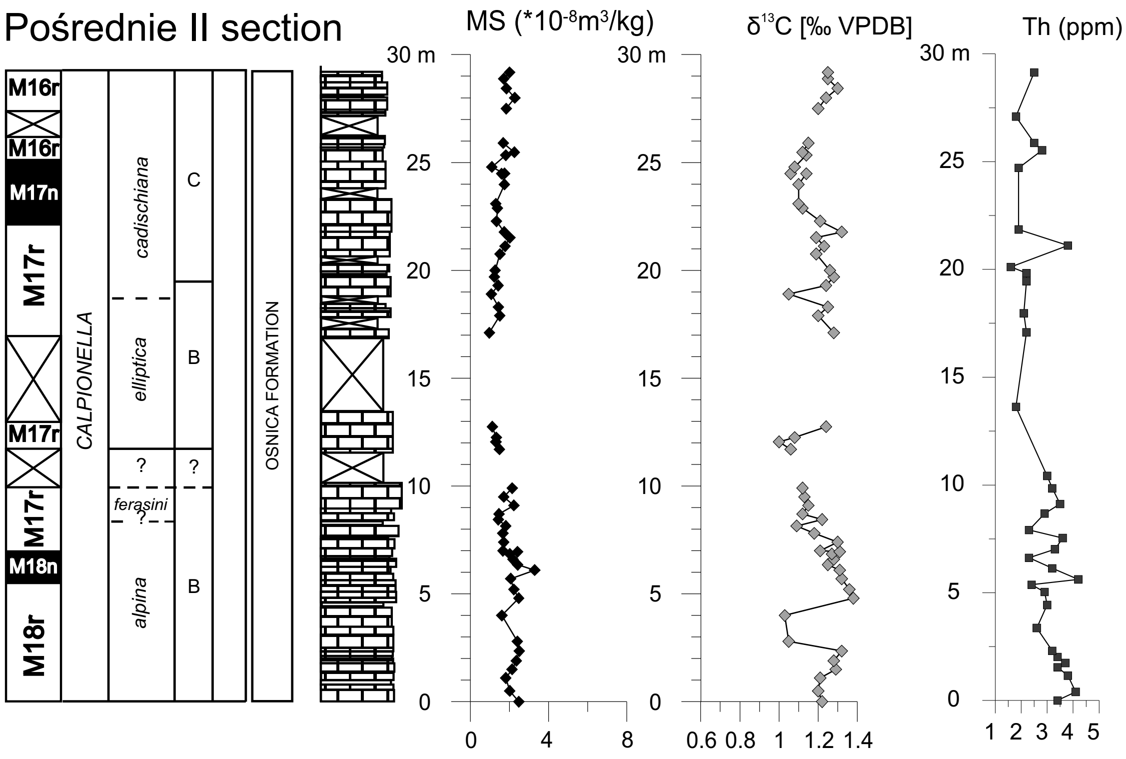

Fig. 14. Integrated stratigraphy of the Pośrednie II section. Bio- and magnetostratigraphy after Grabowski, Pszczółkowski (2006a). Magnetic susceptibility (MS), carbon isotopes and Th – unpublished data

STOP A7

KRYTA VALLEY SECTION. MARLY LIMESTONES AND MARLS OF THE KOŚCIELISKA MARL FORMATION (UPPER BERRIASIAN)

We observe micritic limestones with *Calpionellopsis oblonga* (Cadisch) indicating the Oblonga Subzone (*sensu* Remane *et al*., 1986) of the Upper Berriasian (Figs 12, 15). They belong to the lowermost part of the Kościeliska Marl Formation. The gradual passage between the limestone-dominated Osnica and the marl-dominated Kościeliska formations is covered in the Kryta creek. In the section localized in the adjacent Pośrednie ridge and section Rówienka (in the Lejowa Valley), the boundary between the two formations is situated in the lower part of the M16n magnetozone (close to the boundary between the Simplex and Oblonga subzones; see Fig. 12). In this section, the boundary between the Calpionellopsis and Calpionellites zones (*i.e.*, the Berriasian–Valanginian boundary) falls in the magnetozone M14r (Grabowski, unpublished data). The transition between the Osnica and Kościeliska formations is manifested again by an increase in sedimentation rate, higher terrigenous influx, lower productivity and higher redox indices. The latter feature is independently supported by ichnofossil assemblages (Kędzierski, Uchman, 1997). The onset of terrigenous fraction delivery in the Late Berriasian might be regarded as a regional event within the Krížna (Fatric Domain) succession, also in the Slovak part of the Central Western Carpathians (*e.g.*, Grabowski *et al*., 2010). It can be followed as well, in similar stratigraphic position, in many sections of the Western Tethys: Northern Calcareous Alps, Western Balkan and Western Cuba (Grabowski, Sobień, 2015).

STOP A8

VALANGINIAN SANDSTONES (KRYTA MEMBER)

The Kryta Member of the Kościeliska Marl Formation is well-exposed in the Kryta creek. This is the stratotype section of the member, containing marls interbedded with sandstones and marlstones, 15 m thick (Fig. 15).

The sandstones are mainly medium-grained lithic and arkosic arenites. However, hybridic arenites also occur (Świerczewska, Pszczółkowski, 1997). Magnetic separation revealed that Cr-spinels are an important component of the sandstones. The sandstones occur in similar stratigraphic position in the Oravice area, Slovakia, just 6–7 km west of our locality. After this locality, the Oravice event has been distinguished (Reháková, 2000; Pszczółkowski, 2003b). According to Reháková (2000), the Oravice event took place in the uppermost part of the Calpionellites Zone which was correlated with the ammonite Pertransiens Zone. Pszczółkowski (2003a) dated the sandstones as the upper part of the Calpionellites Zone and the lowermost Tintinopsella Zone (higher part of the Lower Valanginian).

Rocks of the Meliata suture zone situated to the (present day) east and/or south east of the Zliechov Basin (Slovakia) were probably the source of the clastic sediment (Vašiček *et al*., 1994). The sedimentation rate within the Calpionellites Zone is estimated at 20–28 m/My.

STOP A9

RECORD OF THE WEISSERT EVENT IN THE KOŚCIELISKA FORMATION (VALANGINIAN)

Within the upper Valanginian marls of the Kościeliska Marl Formation, a complete record of the $\delta^{13}C$ event was documented (see Fig. 16; Pszczółkowski, 2001; Pszczółkowski *et al*., 2010; see also Kuhn *et al*., 2005). The $\delta^{13}C$ values increase quickly from the values below 1‰ up to 2.15‰ close to the lower–upper Valanginian boundary. The event occurs in the interval of marly sedimentation and is not marked by any black shale deposition. This is similar to other Tethyan sections where anoxic sediments do not occur within the anomaly interval (*e.g.*, Westermann *et al*., 2010). The integrated palaeoenvironmental study of the Kryta section is in progress, comprising detailed magnetic susceptibility logging and geochemical investigations.

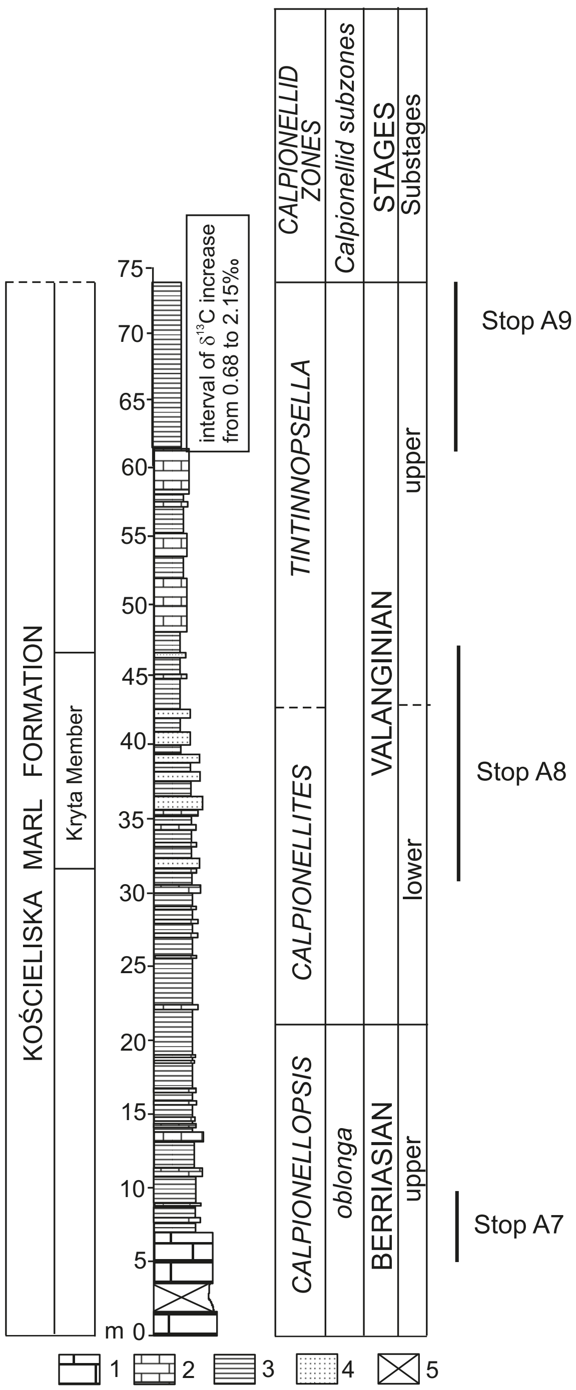

Fig. 15. Generalized stratigraphical section of the Kościeliska Marl Formation (lowermost part) in the Kryta Valley. After Grabowski, Pszczółkowski (2006b), slightly modified. Calpionellid zones after Allemann *et al*. (1971) and Remane *et al.* (1986). Position of $\delta^{13}C$ event after Pszczółkowski (2003b), Pszczółkowski *et al*. (2010)

1 – pelagic limestones; 2 –micritic and marly limestones; 3 – marlstones; 4 – sandstones (turbidites); 5 – covered intervals

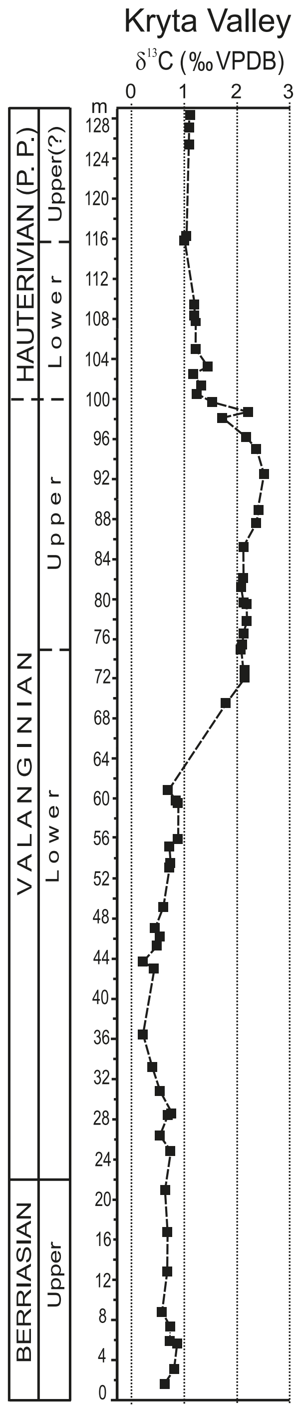

Fig. 16. $\delta^{13}C$ isotope curve within the uppermost Berriasian–Hauterivian interval of the Kryta section (after Pszczółkowski *et al*., 2010)

▸STOP A10

TITHONIAN MARLS (JASENINA FORMATION)

Platy, green to grey, micritic limestones of the Jasenina Formation, dipping to the north, are exposed along the road (Fig. 17).

The thickness of the section amounts to 6 m. In the lower part limestones prevail, while the upper part is dominated by marlstones. Limestones contain numerous remnants of crinoids (Saccocomidae) and chitinoidellids. The latter microfossils indicate the Boneti Subzone of the Chitinoidella Zone. The uppermost part of the section belongs to the Praetintinopsella Zone (Upper Tithonian). Bed K-1 is reversely magnetized while the bulk of the section, between beds K-2 and K-17, belongs to a normal magnetozone (interpreted as M20n). The sedimentation rate for the Boneti Subzone is estimated as 5.8–7 m/My (minimum value, without influence of compaction). In the neighbouring Pośrednie III section, the sedimentation rate calculated for entire magnetozone M20n is even lower (4.83 m/My). The distinct rhythm manifested by marlstone/limestone couplets might be related to Milankovich cyclicity (precession cycles of *ca.* 20 ky). The interval observed represents a local maximum of clastic input towards the basin. It is characterized by relatively high MS, high contents of Th, K and other lithogenic elements (Al, Ti, Zr, Rb etc.). High values of the Th/U ratio, abundant hematite horizons and rather low values of EF (enrichments factors) Cd/Al, Ni/Al and Mo/Al are evidences of well oxidized bottom waters. Decreasing values of productivity indicators (EF P/Al and Mn/Al) negatively correlate with terrigenous input (Fig. 13). The interval might be correlated to middle to a late Tithonian cooling phase evidenced by changes in calcareous phytoplankton (Tremolada *et al.*, 2006).

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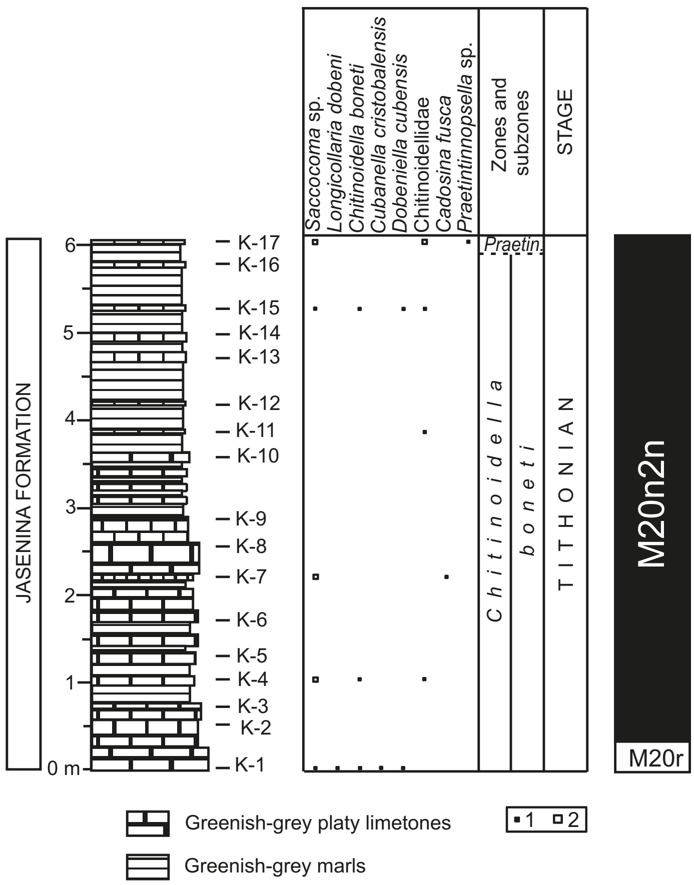

Fig. 17. Kryta section of the Jasenina Formation (Kryta Valley).
Praetin – Praetintinopsella after Grabowski, Pszczółkowski (2006a)

Taxon frequency: 1 – rare; 2 – common

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FIELD TRIP B ▹ FIELD TRIP B

TRIASSIC/JURASSIC BOUNDARY AND LOWER TO MIDDLE JURASSIC OF THE EASTERN PART OF LOWER SUB-TATRIC (KRÍŽNA) SUCCESSION

LEADERS: JOLANTA IWAŃCZUK [1], JOZEF MICHALÍK [2]

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PART I ▹ "*FLECKENKALK – FLECKENMERGEL*" (SPOTTED LIMESTONES AND MARLS) FACIES OF THE KOPY SOŁTYSIE AREA

LEADER: JOLANTA IWAŃCZUK

Route (see Fig. 1): The first part pf the field trip runs partially along unmarked paths. It is a relatively easy walk, mostly along the creeks where most stops are located. Stops B1–B4 are located in the Sucha Voda Valley, relatively close (1–1.5 hr) from the bus. Later, we transfer by bus to the mouth of Filipka Valley, where stops B5–B6 are situated. Stops B7 and B8 are optional, of cultural and touristic character. The second part of the trip consists of only one stop (B9) situated in the Belanske Tatra Mts in Slovakia. It is a steep and high rocky slope with excellent section, not far from the bus (1 hr). Caution is required accessing this locality due to narrow paths and exposition.

Introduction to the trip

The Jurassic succession of the Kopy Sołtysie area constitutes a fragment of the Lower Sub-Tatric nappe stretching to the east of the Sucha Woda and Pańszczyca valleys, and north of the Koszysta and Wołoszyn massifs in the eastern part of the High Tatra Mts of Poland. The succession continues eastward into the Belianske Tatra Mts of Slovakia and differs from the coeval deposits of Lower Sub-Tatric succession in the Western Tatra Mts (see Field Trip A; Fig. 2). The stratigraphic and tectonic interpretation of the Lower Jurassic and lower part of the Middle Jurassic in this area was given by Iwanow (1973, 1979a–c, 1985). Iwanow recognized these deposits as representing a new subdivision of the Lower Sub-Tatric nappe called the Havran (Hawrań) sequence. This subdivision is characterized by occurrence of white quarzitic sandstones (Baboš Quartzite Member) and a thick succession of basinal deposits represented by spotted limestones and marls of the Sołtysia Marlstone Formation. These deposits were subdivided into several formal lithostratigraphic units of member and bed rank within the proposed lithostratigraphic scheme (Iwanow, 1985) (Fig. 2–4).

The succession is an equivalent of the Lower Jurassic Janovky Formation of Gaździcki *et al.* (1979) which is based on the sequence about 300 m in thickness, exposed in the Janovky gully, on the southern slopes of Havran mountain (see Andrusov, 1959; Borza, 1959; Mišík, 1959) in the Belianske Tatra Mts in Slovakia. Another similar lithological unit is the Allgäu Formation which includes deposits of the *Fleckenkalk – Fleckenmergel* facies already distinguished by Gümbel (1856) in the Alps. This lithostratigraphic classification has been modified recently by Birkenmajer (2013) who upgraded the Sołtysia Marlstone Formation into the Sołtysia Group, and proposed its subdivision into three newly erected formations. The sedimentation of Sołtysia Marlstones was controlled by the rifting phases during the Early and early Middle Jurassic (Plašienka, 2003, 2012). Because of the monotonous development of the deposits of the Kopy Sołtysie area their detailed stratigraphic interpretation has to be based on ammonite findings. Early collections of ammonites described by Kuźniar (1908), including some specimens from the older collection of F. Bieniasz and Siemiradzki (1923) (specimens collected by V. Uhlig),

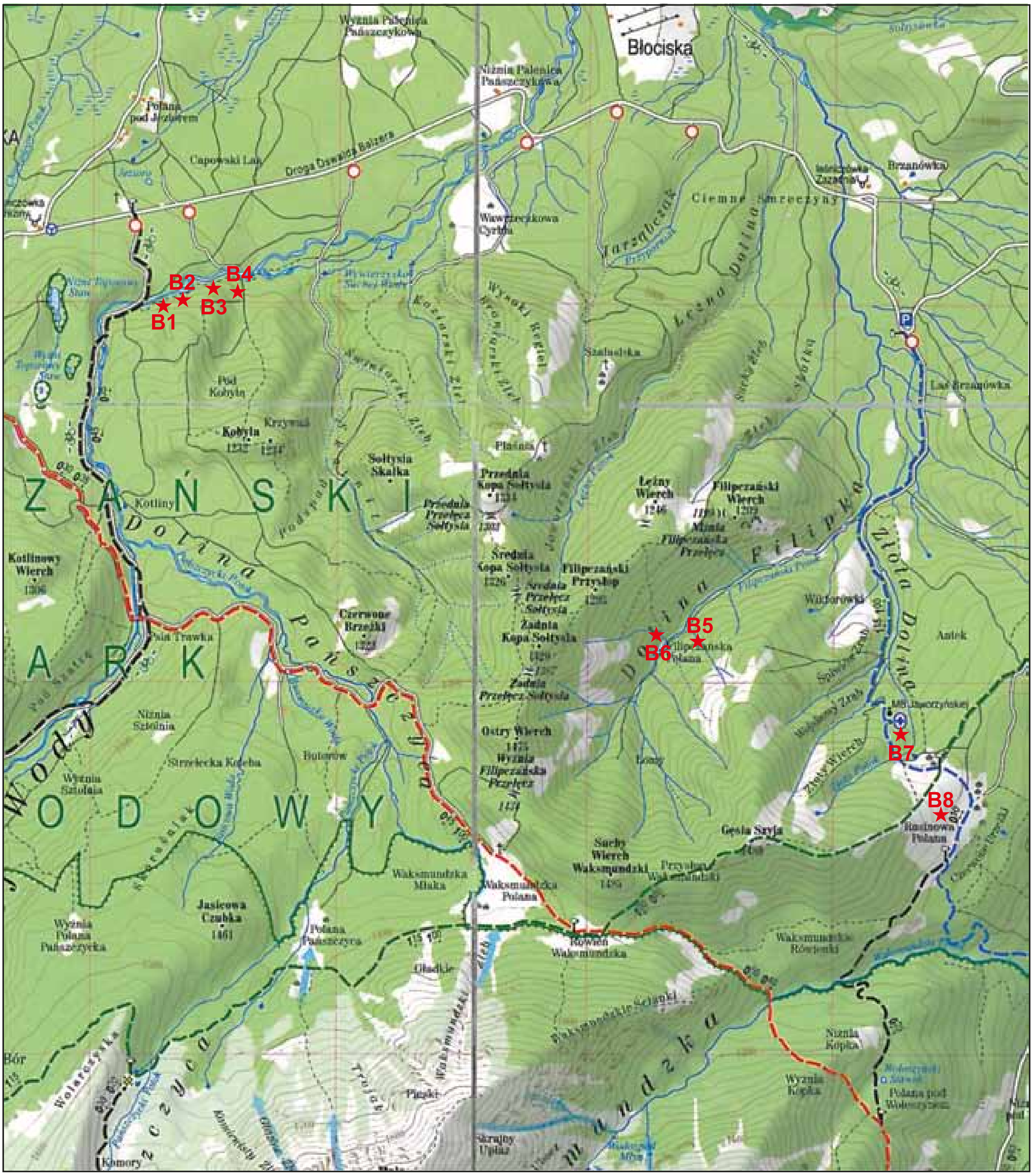

Fig. 1. Fragment of the topographic map of "High and Belianske Tatra Mts., Polish and Slovakian" 1 : 30 000, with the area of investigation (Tatry Wysokie..., 2008) and the location of field trip stops

gave the first information on the biostratigraphy of the younger part of the succession. The extensive field work and collecting by A. Iwanow during 1967–1973, offered the basis for the detailed chronostratigraphical interpretation of the whole succession (Iwanow, 1973, 1985; see also 1979d). However, full interpretation of the stratigraphy of the deposits, with descriptions of the most important ammonites was given by Wierzbowski (Iwańczuk *et al.,* 2013).

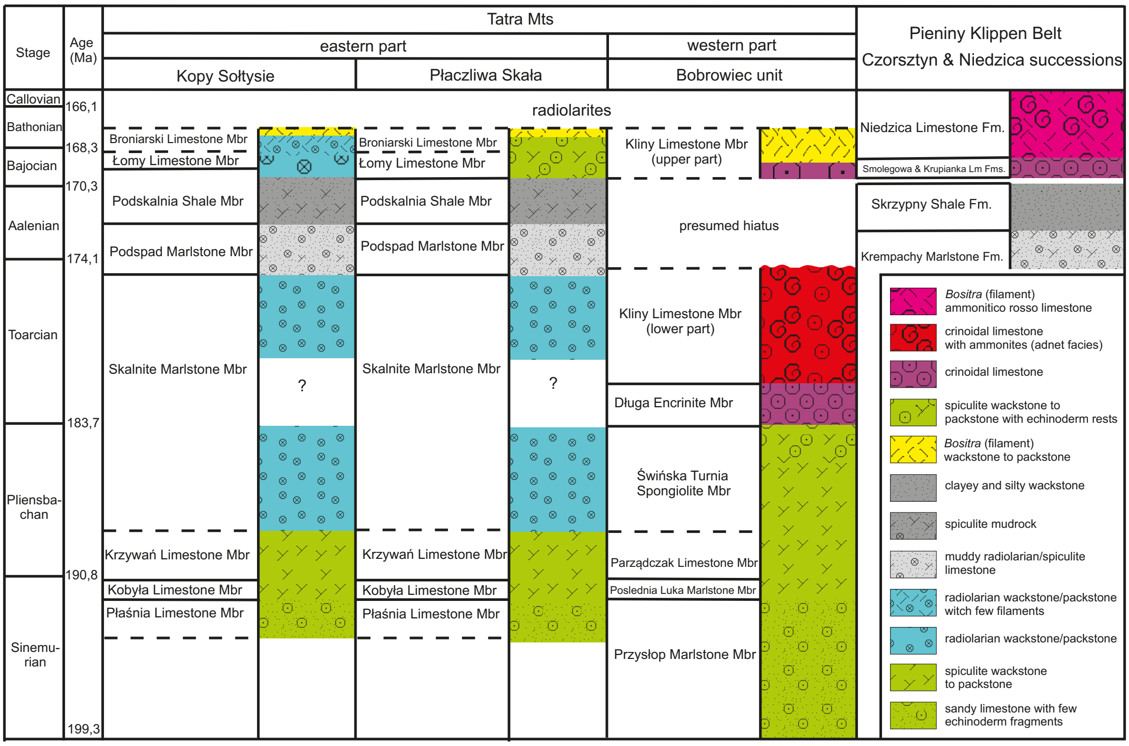

Fig. 2. Correlation of the main lithostratigraphic units between the eastern and western areas of the Lower Subtatric (Krížna) nappe in the Tatra Mts, and the Pieniny Klippen Belt, showing the distribution of microfacies, at the background of the stratigraphical time scale (after Ogg *et al.*, 2012) after Iwańczuk *et al.*, 2013

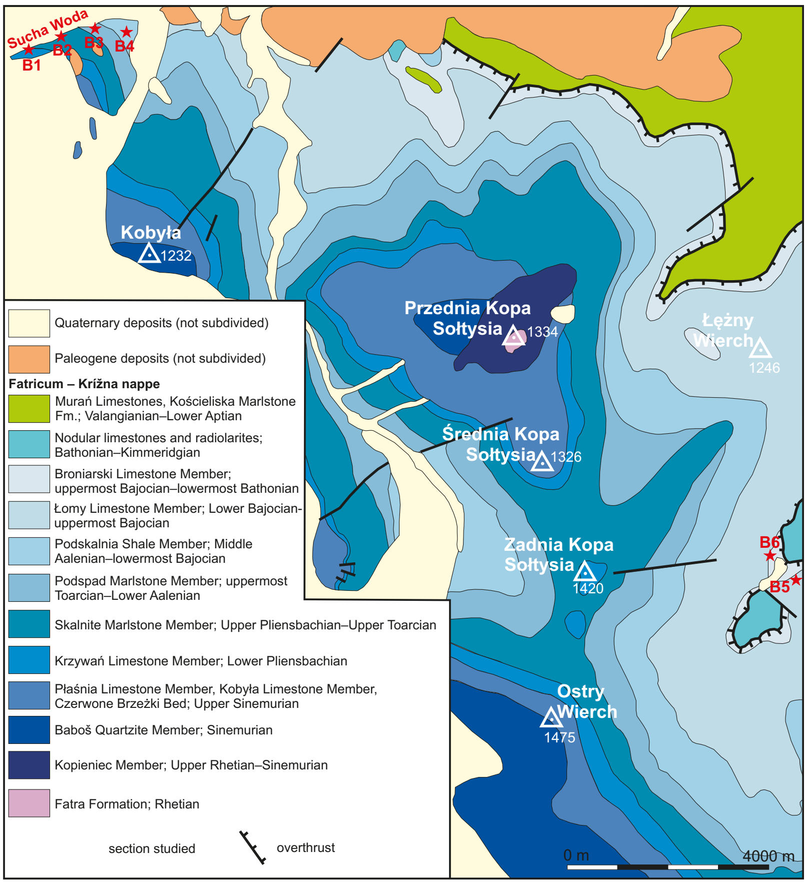

Fig. 3. Fragment of the geological map of the High Tatra Mts in Poland 1 : 10 000 (Zakopane – Toporowa Cyrhla sheet, after Iwanow *et al.*, 2007b; and Łysa Polana sheet, after Iwanow *et al.*, 2007a; simplified), showing the Kopy Sołtysie area and the location of field trip stops

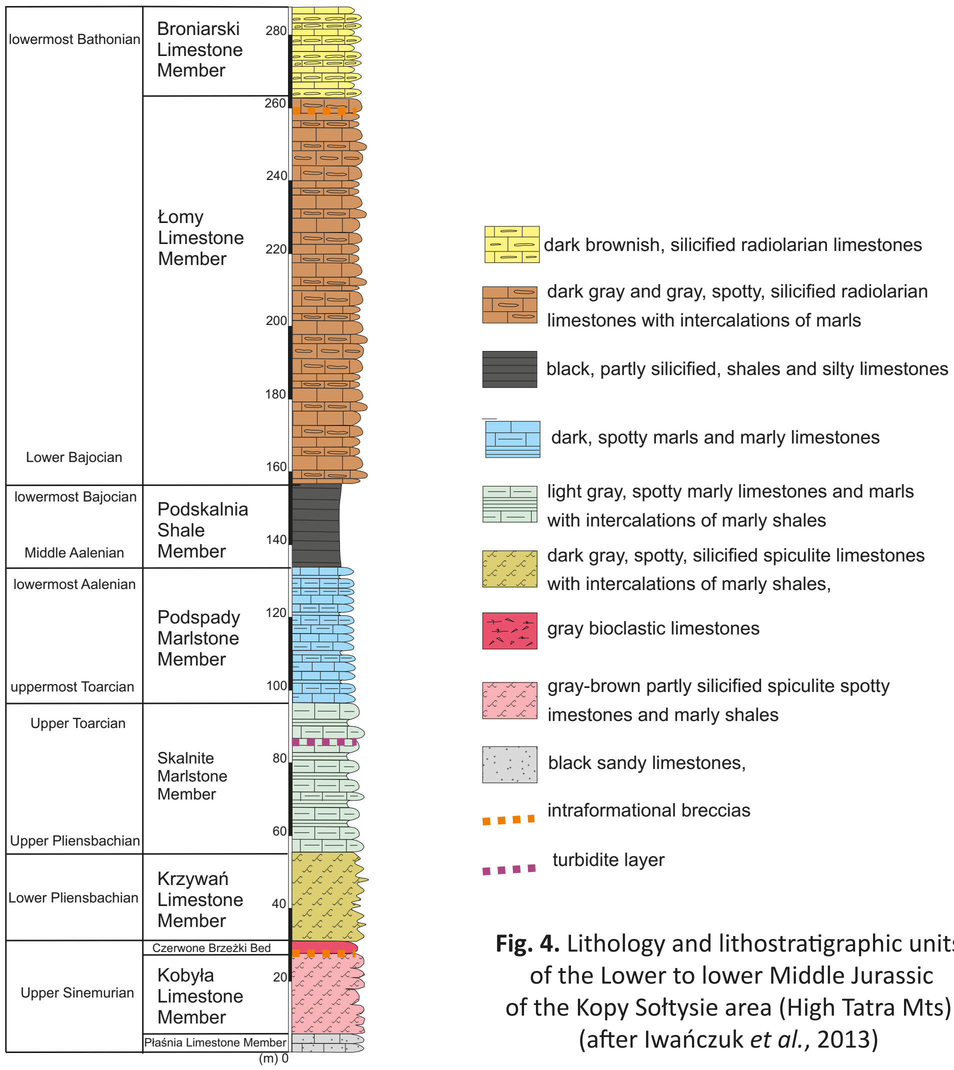

Fig. 4. Lithology and lithostratigraphic units of the Lower to lower Middle Jurassic of the Kopy Sołtysie area (High Tatra Mts) (after Iwańczuk *et al.*, 2013)

▸STOP B1

SUCHA WODA – PLIENSBACHIAN SPICULITE (FIG. 5) (49°17.036´N, 20°02.373´E)

The section is located in the Sucha Woda valley, in the trough of the Sucha Woda creek. Steep cliffs are well visible in a dark forest, after *ca.* 500 m walk from the red tourist path (leading to the Gasienicowa Alp) down the creek Sucha Woda on its right side. These are dark gray, spotty, strongly silicified, bedded limestones with intercalations of marly shales, representing the Krzywań Limestone Member (Iwanow, 1985; Iwańczuk *et al.*, 2013). The sediments contain relatively rare belemnite rostra and cherts especially common in a middle part of the Member. The common occurrence of sponge spicules results in the appearance of spiculite wackestones-packstones in some intervals of the succession. Some beds contain fragments of echinoderms, as well as foraminifers of the family Nodosariidae (*Nodosaria* sp., *Lenticulina* sp.). The thickness of particular beds ranges from 0.1 to 0.7 m, whereas that of the interstratified shales – from 0.02–0.1 m. A general decrease in thickness of beds is observed towards the top of the unit. Trace-fossils are common and include: Chondrites, Zoophycos and Planolites. Ammonites are rare in the Krzywań Limestone Member. The occurrence of Tropidoceras sp. indicates the Lower Pliensbachian ("Carixian") age, especially the Jamesoni and Ibex zones (Iwańczuk *et al.,* 2013).

The Czerwone Brzeżki Bed underlays the Krzywań Limestone Mb. It is a 2–3 m thick bed of a light gray limestones of wackestone type with abundant bioclasts (echinoderms, bivalves and foraminifers) and fairly common belemnite rostra. This is the most characteristic layer in the whole sequence because limestones are not spotted. The bed starts with an intraformational breccia composed of clasts of dark limestones; the clasts show poorly marked

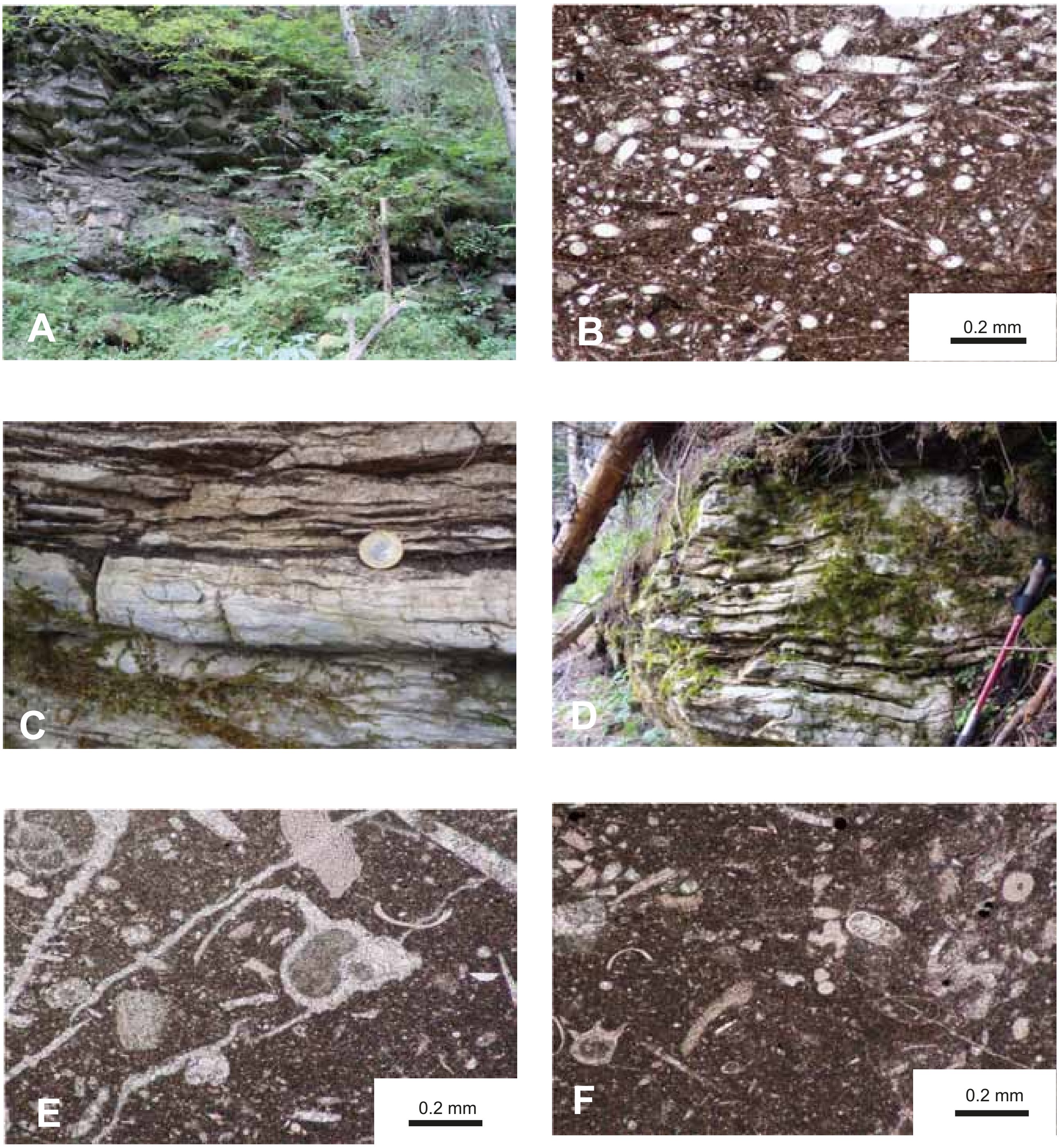

Fig. 5. A – Krzywań Limestones Member in the Sucha Woda valley; B – Spiculite packstone, Krzywań Limestones Member in the Sucha Woda valley; C, D – Czerwone Brzeżki Bed at type locality; E, F – Bioclastic wackstone with broken bioclasts of echinoderms, foraminifers of the Nodosaridae family and snails shells, Czerwone Brzeżki Bed at type locality

boundaries and contain abundant fossil fragments of echinoderms, bivalves, brachiopods, as well as sponge spicules, juvenile ammonites, and foraminifers (*Involutina liassica* Jones, *I. turgida* Kristan, *Ophthalmidium leischneri* Kristan-Tollmann, *Nodosaria* sp.). The breccia matrix is a detrital limestone of the packstone/grainstone type containing abundant bioclasts and foraminifers of the family Nodosariidae. The limestones representing the bulk of the bed are topped by marly limestones about 0.5 m in thickness. The Bed is interpreted as redeposited from the shallow part of the basin. No ammonites have been found within this bed, but its stratigraphical position near the Sinemurian/Pliensbachian boundary is proved by ammonite findings in the underlying and overlying beds. These deposits are interpreted as a record of the Zliechov rifting phase (Iwańczuk *et al.,* 2013).

▸STOP B2

SUCHA WODA – TOARCIAN CALCITURBIDITE (FIG. 6)

Further 50 m down the creek, light gray, bedded, spotty marly limestones and marls with intercalations of marly shales crop out. They belong to the Skalnite Marlstone Member (Iwanow, 1985; Iwańczuk *et al.*, 2013). The thickness of particular limestone and marl beds ranges from 0.1 m to 0.7 m, whereas that of the intercalations of shales is from 0.02 to 0.3 m. Radiolarian wackestones/packstones constitute the dominating microfacies but subordinately filament (Bositra) packstones are also encountered. The deposits are usually highly bioturbated, and the

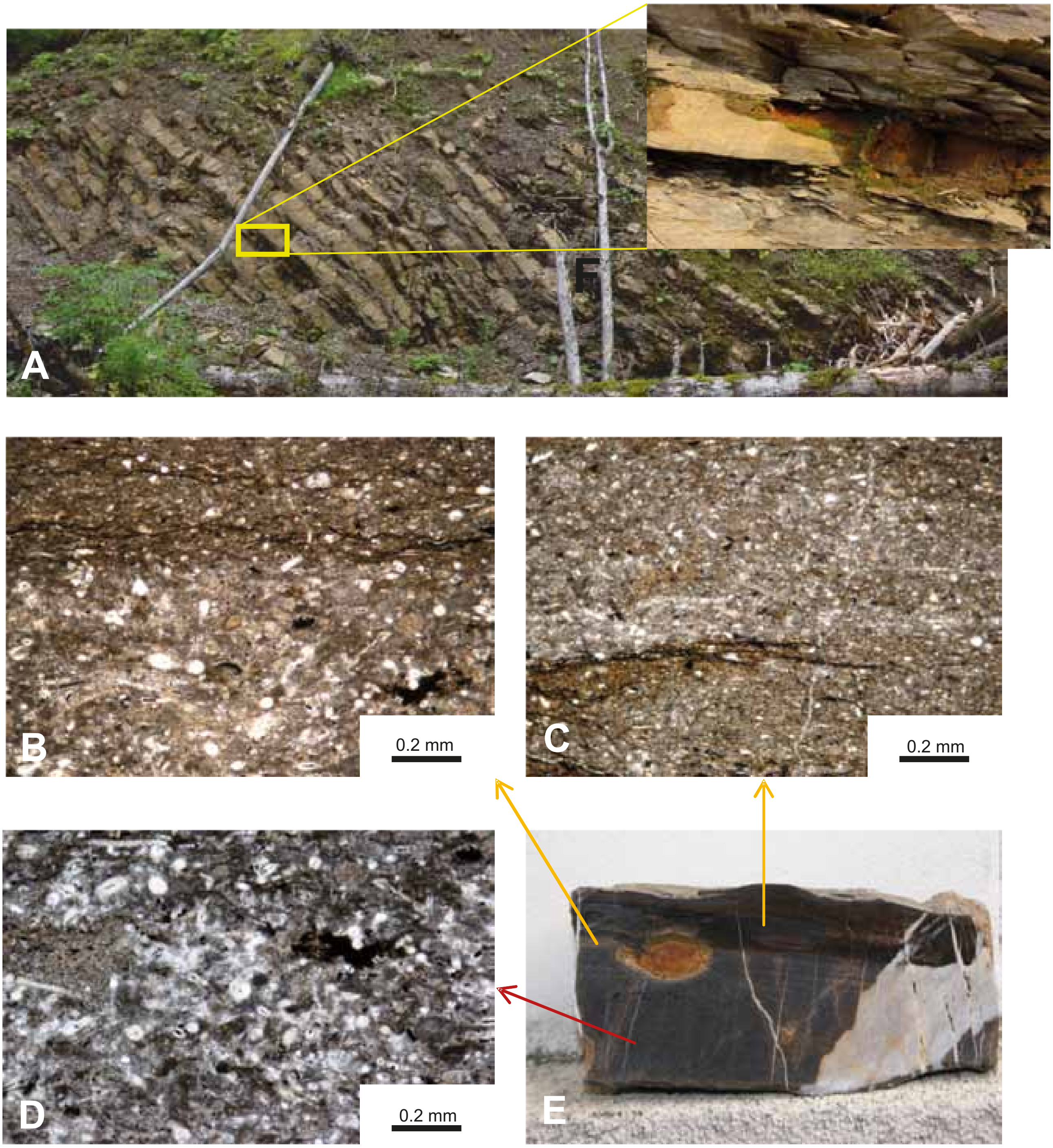

Fig. 6. Skalnite Marlstone Member in the Sucha Woda valley
A – outcrop in the Sucha Woda valley with turbidite layer; B – spiculite wackestone; C – wackestone; D – spiculite packstone; E – turbidite layer without bioturbation, containing ferruginous concretions

assemblages of ichnofossils differ in particular beds (from one composed entirely of Chondrites, through those composed of Zoophycos–Chondrites or Planolites–Chondrites, up to dominated by Planolites–Chondrites–Zoophycos assemblage) (see Iwańczuk, Tyszka, 2009; Iwańczuk, Sobień, 2011). Some rare limestone beds (0.2–0.3 m in thickness) are devoid of bioturbation and differ markedly from the dominating lithology of the unit. They contain a characteristic succession of microfacies – from spiculite packstone/grainstone with ferrugineous concretions (from 0.02 to 0.1 m in diameter) up to graded and laminated spiculite packstone/wackestone and the crinoidal packstone/grainstone. According to these features – the beds may be interpreted as distal turbidites (Iwańczuk, Tyszka, 2009) which corresponds to the Devin rifting phase described by Plašienka (2003). Ammonites are numerous, occurring mostly in lenses in marly limestones; they represent several ammonite faunas of different age; from Margaritatus Zone of the Upper Pliensbachian, through the Bifrons and Variabilis zones of the Middle Toarcian and the Thouarsense Zone and Dispansum Zone of the Upper Toarcian (Iwańczuk *et al.*, 2013).

▹STOP B3

SUCHA WODA – UPPERMOST TOARCIAN–LOWERMOST AALENIAN MARLY SHALES (FIG. 7)

Continuing the walk along the creek, to the west, we notice a change in lithology. Dark, in places almost black, spotty marls and marly limestones with common intercalations of marly shales appear, showing a marked admixture of fine siliciclastic material (quartz grains and mica flakes). They represent the Podspad Marlstone Member (Iwanow, 1985; Iwańczuk *et al.*, 2013). The marls and marly limestones are medium to thick bedded. They show some similarity to deposits of the Skalnite Marlstone Member, but differ in a marked admixture of siliciclastic material (which is easily visible macroscopically). They are more dark-coloured, and may be classified as muddy allochem limestones after Mount (1985). Radiolarians as well as some rare benthic foraminifers and single bioclasts may be seen in thin-sections. Rare ammonites indicate age from the Pseudoradiosa and the Aalensis Zones of the uppermost Toarcian to the lowermost Aalenian (the Opalinum Zone of the English subdivision, corresponding to the lower and middle parts of the Opalinum Subzone of the Opalinum Zone of the French–German subdivision).

▹STOP B4

SUCHA WODA – MIDDLE TO UPPER AALENIAN BLACK SHALES

The Podskalnia Shale Member (Iwanow, 1985; Iwańczuk *et al.*, 2013) appears on the slope near the old path to Kobyła hill. The Member consists of black, partly silicified, indistinctly spotty shales and silty limestones rich in siliciclastic material (quartz grains and mica flakes). The limestone beds attain about 0.2 m in thickness. Bivalve shells of *Bositra buchi* (Roemer) are commonly encountered on bed surfaces. Sections of thin Bositra shells (filaments) are recognized also in the rock; moreover pyritized tests of foraminifers (Nodosariidae), and pyrite framboids can be seen; sponge spicules sometimes have also been found. Microfacially the sediment corresponds to the allochemic mudrock of Mount (1985), rich in siliciclastic material. The Podskalnia Shale Member yields generally poorly preserved ammonites of the genera Ludwigia – which indicated the Middle to Upper Aalenian age – from the Murchisonae Zone, through the Bradfordensis up to the Concavum Zone. The younger forms were also found which are characteristic for the lowermost Bajocian – the Discites Zone.

▹STOP B5

FILIPKA VALLEY – RADIOLARITES AND MICROBRECCIAS (BAJOCIAN–BATHONIAN) (FIG. 7) (49°15.917´N, 20°04.178´E)

The youngest deposits of *Fleckenkalk* – *Fleckenmergel* facies are exposed in the upper parts of the Filipka Valley. They are well bedded, dark gray and gray, spotty, hard, silicified limestones with some intercalations of soft marl. They belong to the Łomy Limestone Member (Iwanow, 1985; Iwańczuk *et al.*, 2013). The limestone beds range from 0.2 m to 1 m in thickness, whereas the intercalations of marl are about 0.02 m thick. The trace fossils

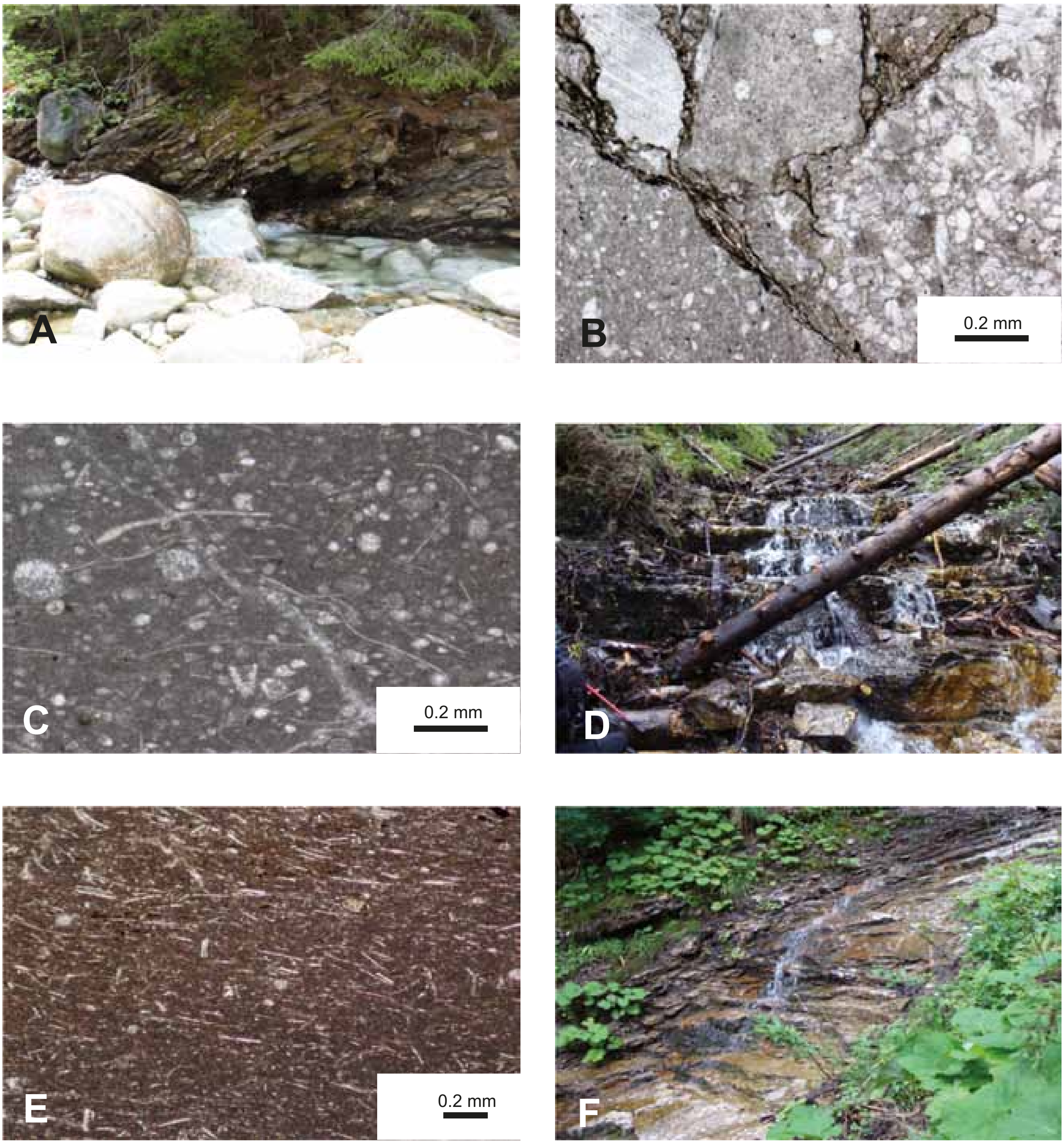

Fig. 7. A – Podspad Marlstone Member in the Sucha Woda valley; B – Microbreccia, Łomy Limestone Member, Filipka valley; C – Radiolarian wackestone, Łomy Limestone Member, Filipka valley; D – Łomy Limestone Member, Filipka valley; E – Bositra wackestone, Łomy Limestone Member, Filipka valley; F – Łomy Limestone Member, Filipka valley

Chondrites, Planolites, and Zoophycos are common. The limestones show the presence of the radiolarian wackestone microfacies; moreover thin Bositra bivalve shells (filaments) are sometimes encountered. At the top of the unit, radiolarites may appear locally. In the upper part of the Łomy Limestone Member, a well defined bed originally distinguished as the Łężny Encrinite Bed is recognized (Iwanow, 1985). A detailed study of the rock shows, however, its somewhat different lithological character – which is dominated by breccias. The thickness of the bed attains usually about 0.2 m; the bed is an intraformational breccia, consisting of sharp-edged small clasts (up to about 0.01 m in diameter) of several types of rocks: (1) spiculite wackestone/packstone, (2) crinoidal packstone, (3) marly wackestone, containing fragments of sponge spicules, unidentified echinoderm fragments, and ?plant debris; the matrix is marly wackestone with abundant pyrite grains. At the Płaczliwa Skała section (Belianske Tatra Mts) the breccias contain fragments of still older breccias composed of similar clasts, and showing at least two episodes of clast formation. These intercalations were possibly the distal "tails" of mass movement deposits including the spiculite and crinoidal sediments developed along the elevated areas such as that placed close to the Płaczliwa Skała area, but also that between the Kościeliska and the Chochołowska valleys in the western part of the Tatra Mts. The existing contrast between sedimentation of the limestones with radiolarian microfacies (basinal), and the appearance of crinoidal limestones and spiculite limestone (elevated areas) could be related to the Krasín rifting phase of Plašienka (2003). Ammonites are rare in the Łomy Limestone Member. These include: Bradfordia sp., *Nannolytoceras tripartitum* (Raspail) (Myczyński, 2004), and Cadomites (Polyplectites) sp. (Myczyński, 2004). The former is indicative of the Lower Bajocian, whereas the two latter indicate the uppermost Bajocian–lowermost Bathonian (see Sadki, 1994; Wierzbowski *et al.*, 1999; Iwańczuk *et al.*, 2013).

▸STOP B6

FILIPKA VALLEY – RADIOLARITES (BAJOCIAN–BATHONIAN) (FIG. 7) (49°16.113´N, 20°04.302´E)

The youngest part of the succession studied is the Broniarski Limestone Member (Iwanow, 1985; Iwańczuk *et al.*, 2013) – dark brownish (yellowish when weathered), indistinctly spotty, well bedded, hard silicified limestones with thin, rare radiolarite chert intercalations, occurring in the topmost part of the unit. The limestone beds attain usually 0.1–0.2 m in thickness. The deposits show the presence of the Bositra (filament) wackestone microfacies; radiolarians as well as small planktonic and benthic foraminfers (Involutina sp.) have been recognized. Rare ammonite findings include *Nannolytoceras tripartitum* (Raspail) which indicates the uppermost Bajocian and/or lowermost Bathonian (*cf.*, Wierzbowski *et al.*, 1999; Iwańczuk *et al.*, 2013).

▸STOP B7

WIKTORÓWKI CHAPEL, THE SANCTUARY OF OUR LADY OF JAWORZYNA, QUEEN OF THE TATRA (PLACE OF RELIGIOUS WORSHIP)

We will visit this place only if time and weather allow us.

▸STOP B8

RUSINOWA POLANA (FIG. 8)

Rusinowa Polana (Rusinowa Alp) is a mountain meadow offering a magnificent view of the crystalline peaks of the High Tatra Mts. The Rusinowa Alp is covered with moraine deposits which overlay the Lower Sub-Tatric succession (Lefeld, 1999). Outcrops of Variscan granite are shifted to the north, in respect to the western part of the Tatra Mts, due to existence of local tectonic elevation of crystalline core in the area of Koszysta peak (Kotański, 1961). High-Tatric tectonic elements are largely reduced and Lower Sub-Tatric nappe is situated in direct proximity of the crystalline basement.

Fig. 8. One of the most beautiful places with panoramic views of the High Tatras – from the Rusinowa Alp

PART II ▹ RHAETIAN AND TRIASSIC–JURASSIC BOUNDARY IN THE EASTERN PART OF KRÍŽNA (LOWER SUB-TATRIC) SUCCESSION

▹STOP B9

KARDOLINA SECTION, THE HUSÁR HILL ON THE WESTERN SLOPE OF THE MT PÁLENICA, BUJAČÍ NAPPE, CARPATHIAN KEUPER, FATRA AND KOPIENIEC FORMATIONS, RHAETIAN TO HETTANGIAN (49°1459.43´N, 20°1854.57´E)

LEADER: JOZEF MICHALÍK

The late Triassic was a period of regression on the continental shelves, accompanied by a hot and equalized continental climate. At the end of the Triassic, these conditions began to change gradually: the rising sea intruded into intracontinental basins (Michalík *et al.*, 1979; Michalík, 1980) and formed shallow marine bays. Even areas not yet reached by transgression have been affected by an increase in seasonality associated with more frequent precipitations (Michalík *et al.*, 2010).

Terrigene clastic-carbonate sediments called the "Carpathian Keuper" form larger part of the Upper Triassic sequence in the Fatric Křížna Unit (similar to that of the Tatric Unit). The Carpathian Keuper sequence in the Křížna Unit reaches a thickness from 130 (Uchman, 2004) to 300 metres (Turnau-Morawska, 1953; Gaździcki *et al.*, 1979). Variable thickness and large lateral facies variability of the Carpathian Keuper could reflect synsedimentary movements of the tectonic blocks of the basement (Rychliński, 2008). This

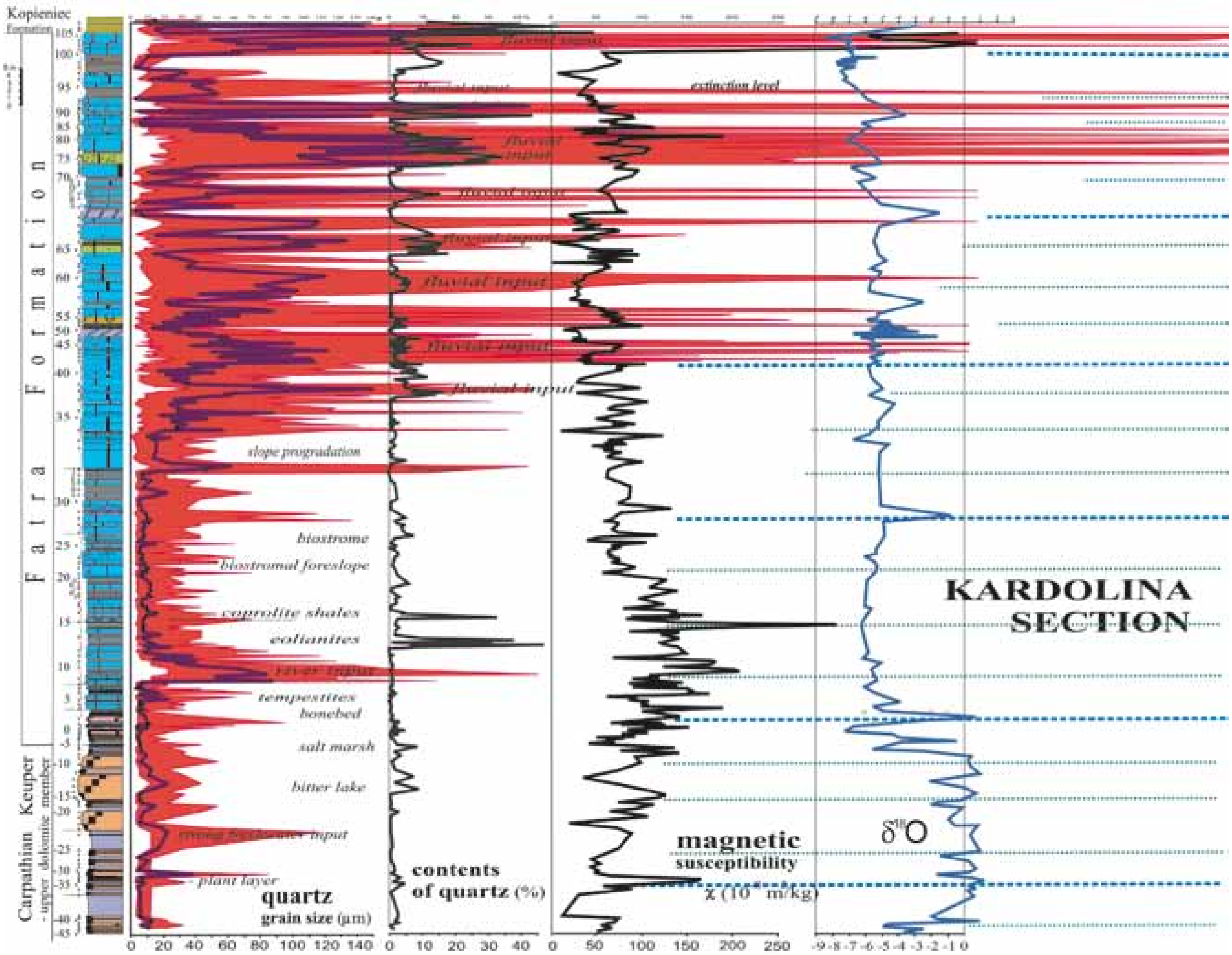

Fig. 9. Lithology, sedimentology, magnetic susceptibility and oxygene isotopic ratio in the Keuper and Rhaetian of Kardolina section

sequence mostly consists of variegate argillites, the lower part with intercalations of sandstones, sometimes conglomerates formed by clasts of pedogenic carbonates (typically in the Havran Unit). In the mentioned unit the Carpathian Keuper sequence sporadically contains products of marshy environment with fragments of tree trunks and thin coal laminae. Sandbanks (sometimes with cross lamination and graded bedding) were considered to be a product of fluvial sedimentation (Borza, 1959; Rychliński, 2008).

Although these sediments contain palynomorphs of terrigene character (Planderová in Gaździcki *et al.*, 1979), they were considered to be marine deposits (Turnau-Morawska, 1953; Al-Juboury, Ďurovič, 1992). The frequence of variously thick dolomite layers increases upwards, varicoloured clays also often contain dolomite concretions. These dolomite layers represent a sediment of hypersaline environment (Al-Juboury, Ďurovič, 1996; Rychliński, 2008), as evidenced by findings of marine microflora and microfauna (Gaździcki *et al.*, 1979).

Rhaetian deposits (which recorded one of the most critical developmental crises of life on the Earth) in the Krížna Unit in the Tatra Mts have been the subject of interest of geoscientists since the nineteenth century. Uhlig called them as the "leading star of the Carpathian field geologist" in his monograph (1897).

The Fatra Fm continually exposed in the Kardolina section rests on the Carpathian Keuper. The boundary is not sharp, it is denoted by an increase of carbonate content in the uppermost part of the Carpathian Keuper sequence. The faunal remnants are represented by foraminifers *Agathammina austroalpina*, shark teeths, lingulid brachiopods and bivalve mollusks. The base of marine carbonate sequence is denoted by "bone bed layer" with fish teeths and phosphate coatings (Michalík *et al.*, 2013). Special part of the sequence is formed by tempestite beds with loadcasts and *Thalassinoides* traces on lower bedding planes and with abundant bivalves and gastropods. Higher on, the sea storm facies is substituted by silty shales with rich eolian quartz grains – products of sand storms. The stabilization of marine regime is recorded in coprolite beds followed by megalodon and coral limestones. The middle part of the section is formed by thick bedded organodetrital limestones. They contain Rhaetian foraminifers *Triasina hantkeni* and rich benthic macrofauna including index forms of bivalves (*Rhaetavicula contorta*, *Chlamys valoniensis*), corals, brachiopods (*Rhaetina gregaria*, *Austrirhynchia cornigera*). The amount of nutrients favored opportunistic fauna, represented by ostracods and microgastropods. Plants are dominated by terrestrial components (*Ricciisporites tuberculatus*) and abundant phytoclasts. Rare residues of marine microorganisms (*e.g.*, dinoflagellous cysts *Rhaetogonyaulax rhaetica*) and nannofossils indicate normal marine sedimentation environment (on the other side, ammonites and conodonts have been not found). Eutrophic conditions allowed flowering of the phytoplankton, which led to the consumption of oxygen in the water column and stress conditions for benthic organisms.

The diversity of the benthic fauna decreases in the youngest part of the Fatra Fm ("Muria Noha Mb" or "transition beds"). The boundary of the Triassic and Jurassic periods is marked by crisis in the deposition of carbonates. This crisis has been evoked by massive outbursts of carbon dioxide into the atmosphere due to the MORB volcanism, coupled with the release of methane clathrates resulting in a sudden warming of the atmosphere. A break in the climate regime followed, coupled with a increase of precipitations, bringing the terrigene clay material of the Kopieniec Fm into the sea basin.

The association of palynomorphs from these strata is characterized by an increase in the number of trilete spores, in particular *Deltoispora* spp. and *Concavisporites* spp. In the marine fraction of palynoasociation, the dinoflagellate cyst *Dapcodinium priscum* prevails. These changes were also caused by a significant humidification of the climate, which allowed the spreading of sporophyta vegetation (Ruckwied, Gőtz, 2009).

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FIELD TRIP C

JURASSIC OF THE UPPER SUBTATRIC (CHOČ) NAPPE IN THE DOLINA KOŚCIELISKA VALLEY REGION

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Route (Fig. 1): From the accommodation place to the entrance of the Kościeliska Valley to the **Brama Kantaka rocky gate** (stop C1), to **Zawiesista Turnia crag** region (stop C2A, B), to **Czerwony Gronik (Jaworzynka Miętusia)** (stop C3), to **Gronka crag** (stop C4), to the **Staników Żleb gully** (stop C5), and to Nędzówka. It is a moderately easy walk partially along unmarked paths, occasionally passing steep and rocky slopes.

Introduction to the trip

The Mesozoic succession of the Choč Nappe (Upper Subtatric) belongs to the Hronicum Domain of the Western Carpathians. In the Tatra Mountains. The Jurassic part of the succession, 250–300 m thick, is present only in three small uprooted thrust sheets in the Dolina Kościeliska valley region (Fig. 1), which different facies development has been noticed long time ago (Zejszner, 1852; Stache, 1868; Uhlig, 1897; Sokołowski, 1924). The facies (Fig. 2) are represented by the Lower Jurassic peloidal-oolitic limestones, bioclastic limestones of the Hierlatz facies, crinoidal limestones, and the silicified crinoidal limestones with spiculites (Sokołowski, 1924; Grabowski, 1967; Uchman, 1993), which belong to the Miętusia Limestone Formation (Lefeld, 1985; Gaździcki, Lefeld, 1997), and by the possible Middle Jurassic red micritic limestones (Uchman, 1988). The crinoidal and bioclastic limestones are dated to the upper Sinemurian–lower Pliensbachian (Domerian) on the basis of brachiopods (Uchman, Tchoumatchenco, 1994). The Lower Jurassic limestones reveal rapid lateral changes referred to “Horst-und-Graben” basin topography caused by the early Jurassic rifting in the Western Tethys (Bernoulli, Jenkyns, 1974) extending to the presented domain (Uchman, 1993). The silicified crinoidal limestones with spiculites represent sediments deposited in basins between elevations.

The presented sections, about 250 m thick, belong to the Brama Kantaka and Kończysta thrust sheets (Kotański, 1965), which show basically overturned succession. The Upłaz Thrust Sheet (about 60 m thick succession of the Lower Jurassic Hierlatz-type, crinoidal limestones, and

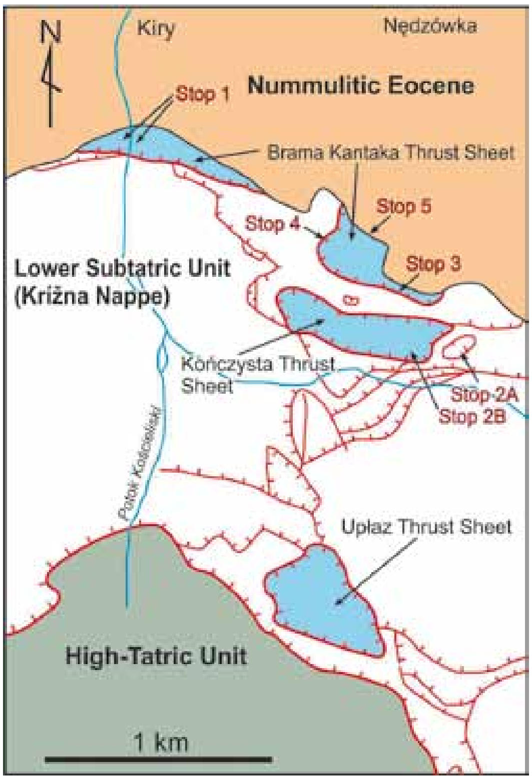

Fig. 1. Three thrust sheets of the Choč Nappe (Upper Subtatric Unit) containing Jurassic rocks (in blue) in the lower part of the Kościeliska Dolina valley region, with indication of the stops

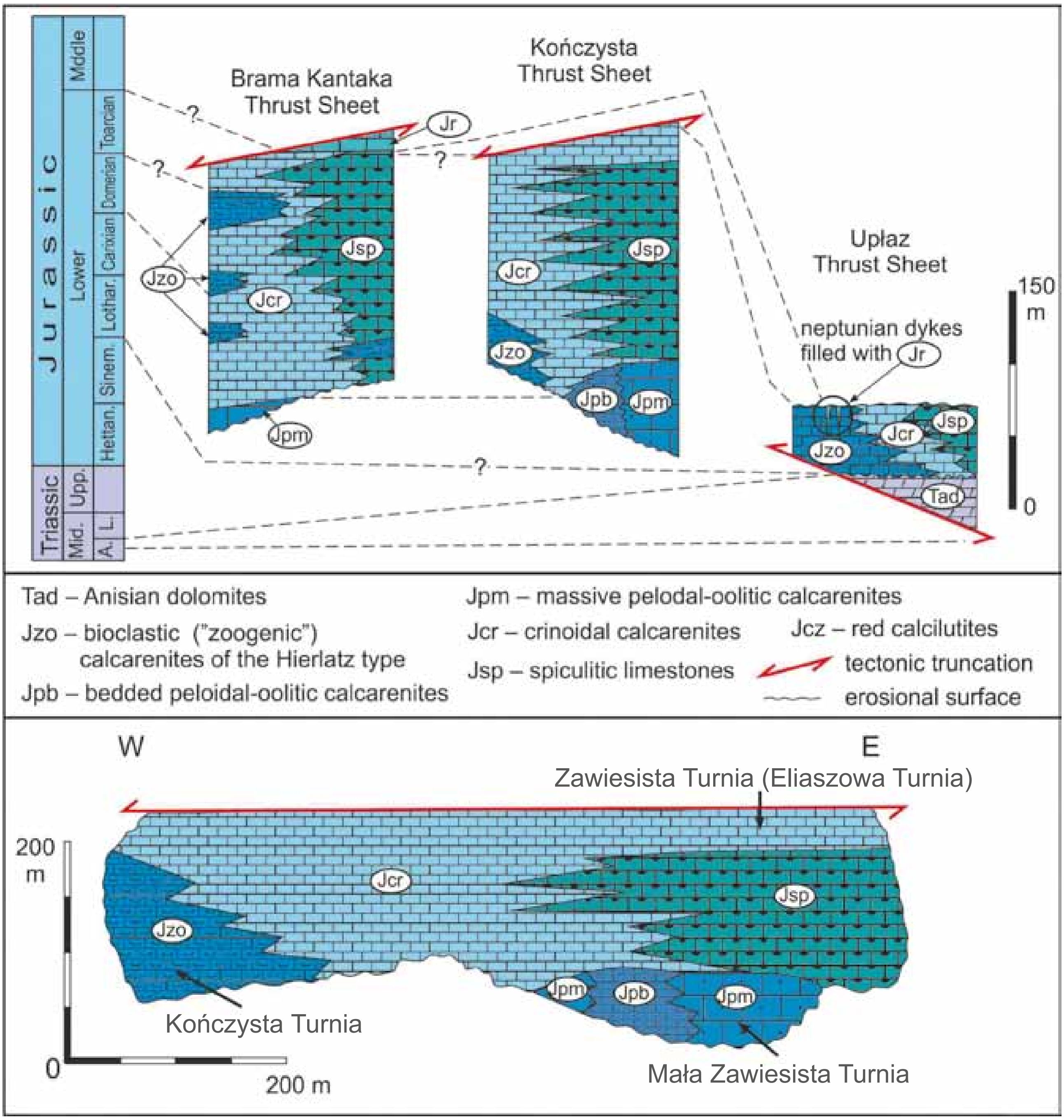

Fig. 2. Stratigraphic scheme of the Jurassic succession in the Choč Nappe in the Dolina Kościeliska valley region and facies section of the Kończysta Thrust Sheet

silicified crinoidal limestones resting on the Anisian dolomites and limestones) is omitted in this field trip. All the Choč Nappe thrust sheets rest on Mesozoic (mostly Cretaceous) sediments of the Krížna Nappe of the Fatric Domain.

▹STOP C1

BRAMA KANTAKA (BRAMA KOŚCIELISKA NIŻNA) ROCKY GATE (WESTERN AND EASTERN SIDES): LOWER JURASSIC PELOIDAL, CRINOIDAL, SPICULITIC AND HIERLATZ-TYPE LIMESTONES OF THE CHOČ NAPPE

LEADERS: ALFRED UCHMAN, TOMASZ RYCHLIŃSKI, ANDRZEJ GAŹDZICKI

The route runs from the entrance to the Dolina Kościeliska valley to the south along the western bank of the Potok Kościeliski. We pass (in reverse stratigraphic order, through beds dipping to the north) nummulitic limestones, dolomite calcarenites, grey conglomerates and red conglomerates of the Eocene (Lutetian–Priabonian) cover, which belong to the transgressive succession of the Inner Carpathian Paleogene. They rest unconformably with an erosive surface on different Mesozoic units, herein on limestones of the Choč Nappe (Brama Kantaka Thrust Sheet). The conglomerates contain clasts from the Choč succession, with lithologies which were eroded.

The first crag of the Choč Nappe is built of grey, massive limestones which are 17 m thick (Fig. 3). A few microfacies were recognized herein. They represent different environments of a shallow carbonate platform: from high-energy environment of platform margin (oolitic-peloidal grainstone) through moderate energy (bioclastic-peloidal grainstone/packstone; Fig. 4A, B) to low-energy inner platform deposits (peloidal-bioclastic packstone/wackestone). It is noteworthy that these deposits, besides other bioclasts, contain crushed remnants of the green alga *Palaeodasycladus* sp. (Fig. 4C), ostracods and gastropods (Fig. 4D). This is the most northern occurrence of *Palaeodasycladus* Pia. This alga is known from the Sinemurian–Pliensbachian sediments of the southern part of the Western Tethys.

Further to the south, the limestones pass into grey or pale rose massive crinoidal grainstones, which are poorly outcropped on the forested slope and better exposed in the cliffs of the rocky gate. Locally, the limestones are silicified. Rarely, they contain fragments of bivalves, brachiopods and benthic foraminifers.

Close to the flat top of the rocky gate, reddish grey bioclastic calcarenites can be observed in small outcrops and in a low cliff from the south. They contain bioclasts of brachiopods, bivalves, sclerosponges (Fig. 4E, F; determined as such by B. Kołodziej), holothurian sclerites and benthic foraminifers. These limestones represent a sort of the Hierlatz-type facies. They contain the brachiopod *Spiriferina alpina alpina* Oppel, *S.* cf. *alpina alpina* Oppel, *Cuneirhynchia retusifrons* (Oppel), *Zeilleria* aff. *subnumismais* (Davidson), which point to the Domerian (Uchman, Tchoumatchenco, 1994). Components of the Hierlatz-type limestones were deposited on the top of elevated blocks, but could be redeposited to the surrounding basins.

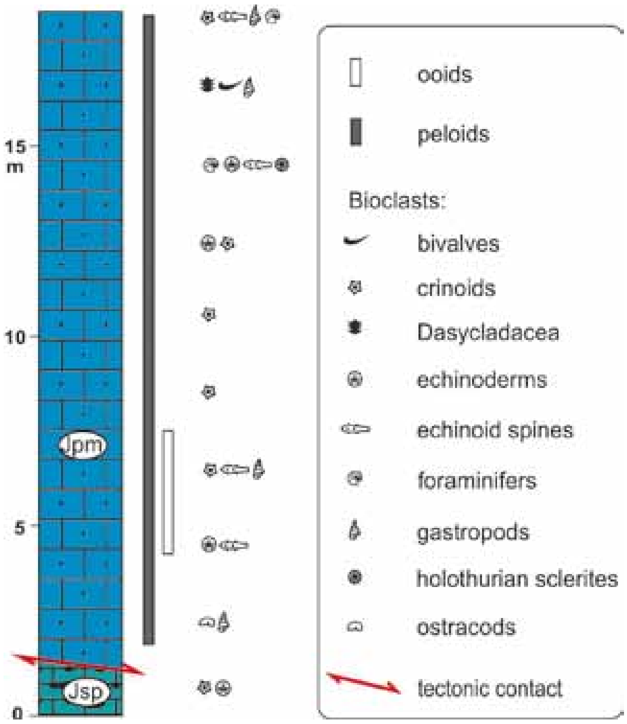

Fig. 3. Lithological column of the massive peloidal-oolitic limestones (Jpm) in the western part of the Brama Kantaka rocky gate

The spiculitic limestones (Jsp) at the base is interpreted as a block which tectonically displaced from a higher stratigraphic position

The western part of the rocky gate displays a flat top, which is a rocky Pleistocene terrace of the Kościeliski Potok stream. Boulders of different lithologies from the Tatra Mountains can be found here. In feet of the southern cliff of the rocky gate, a short adit cuts the tectonic contact between the limestones of the Choč Nappe and the grey marlstones of the Kościeliska Marl Formation (Beriassian–Hauterivian, maybe also Aptian–Albian; see Kędzierski, Uchman, 1997 and references therein; Pszczółkowski, 2003) of the Krížna Nappe.

Coming back to the entrance of the Kościeliska Valley, the route runs up the valley. We pass the Eocene succession, which mirrors the western side of the valley.

Coming to the Brama Kantaka (Brama Kościeliska Niżna) rocky gate, silicified crinoidal limestones from the

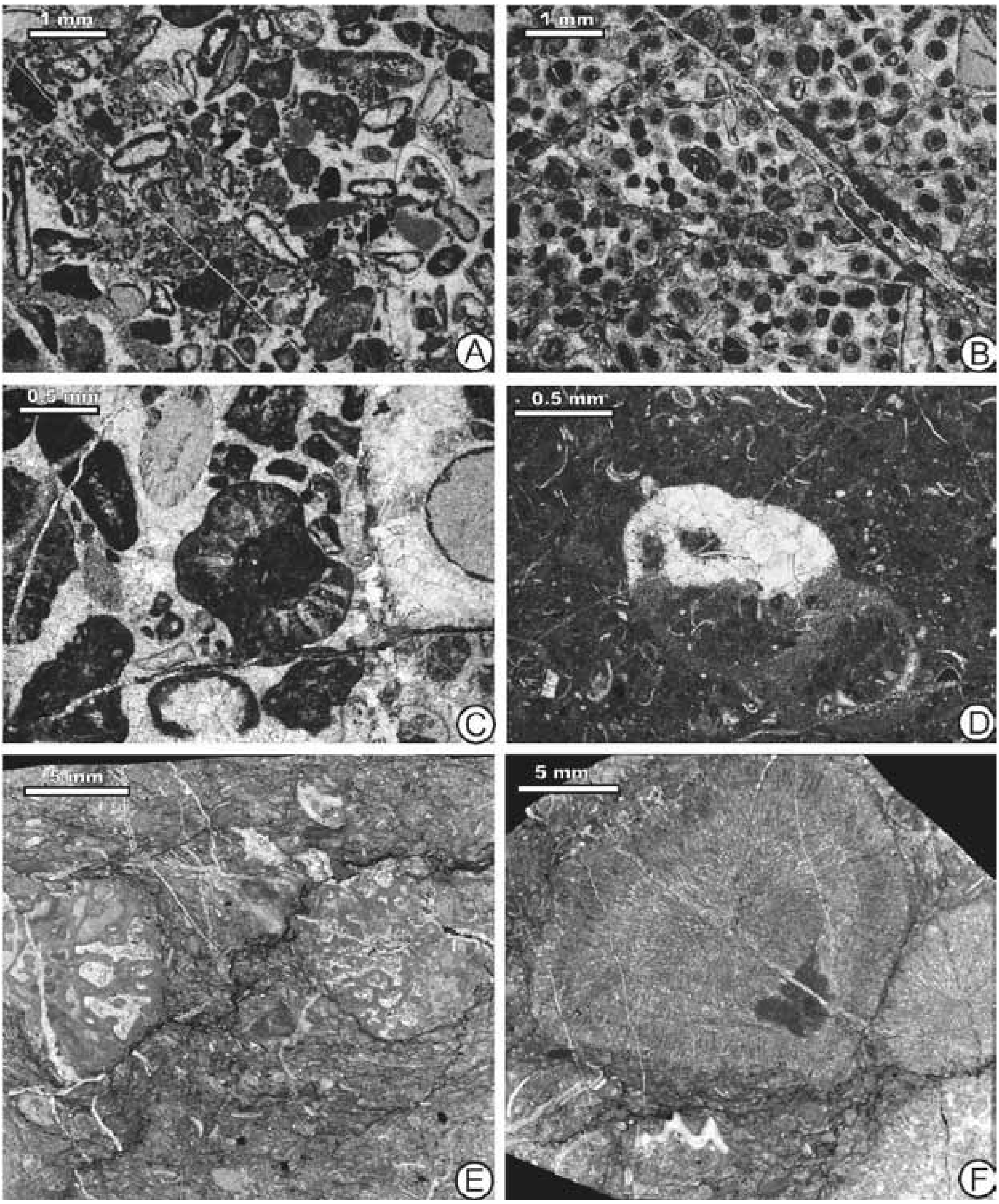

Fig. 4. Some microfacies of limestones at Stop C1, Brama Kantaka rocky gate

A – Peloidal-bioclastic grainstone/packstone; B – Oolitic-peloidal grainstone with echinoderm and other recrystallized bioclasts, some with thin micrite envelopes; C – Oolitic-peloidal grainstone the green alga *Palaeodasycladus* sp. (in the middle); D – Bioclastic wackestone with ostracods and ghost structure after gastropod shell; E, F – Sclerosponges in bioclastic grainstones of the Hierlatz type

northern side and grey or pale rose massive crinoidal limestones from the southern side can be observed. The silicified crinoidal limestones display discontinuous beds of grey spiculites. The limestones in the rocky gate are cracked into blocks of different cubature. In places, the limestones are brecciated, mostly along some fissures. The fractures are basically of the tectonic nature. However, synsedimentary tectonics in the basin is not excluded. Part of the fissures are filled by hematitic substance, which can be even a few centimetres thick. Not rarely, fine breccias are associated with the fissures. The tectonic disturbances make difficulties in interpretation of the stratigraphic order, but the order from the western side of the rocky gate is a strong evidence for an overturned succession in the Brama Kantaka Thrust Sheet in general.

▹STOP C2

ZAWIESISTA TURNIA CRAG REGION: MIDDLE TRIASSIC-LOWER JURASSIC SEDIMENTS OF THE KRÍŽNA NAPPE MISLEAD FOR THE CHOČ NAPPE SUCCESSION AND PELOIDAL AND OOLITIC LIMESTONES OF THE CHOČ NAPPE

LEADERS: ALFRED UCHMAN, TOMASZ RYCHLIŃSKI, ANDRZEJ GAŹDZICKI

C2A. "Nad moreną" section (49°15.739´N, 19°53.248´E)

The route runs to the entrance of the Dolina Miętusia valley and further towards the Przysłop Miętusi pass. On the way, calcilutitic marls and limestones and calcarenitic limestones of the Kościeliska Marl Formation (Krížna Nappe, Fatric Domain) crop out. On the forested southern slope, above a Pleistocene glacial side moraine, a poorly exposed succession composed of the Middle Triassic dolomites, Rhaetian limestones and Lower Jurassic marly mudstones and sandstones, as well spotty marls (Fleckenmergel type) is known as the "Nad moreną" section (Stop 2A, Fig. 5). It was considered as a part of the Choč Nappe succession (Sokołowski, 1959; Kotański, 1965, 1971; Grabowski, 1967) because of the absence of the Carpathian Keuper facies and the vicinity of the indisputable Choč Nappe, but this view was questioned (*e.g.*, Uchman, 1994, 1997; Uchman, Tchoumatchenco, 1994) on the basis of strong similarities to the Krížna Nappe facies, according to some previous data (Guzik, 1959). The latest view is proven by the presence of fossil assemblage, typical of the Fatricum Domain, with the brachiopod *Rhaetina gregaria* (Suess) and the megalodont bivalve *Conchodon infraliasicus* Stoppani in dark grey limestone of the Fatric Formation (Rhaetian–lower Hettangian) (Gaździcki, Uchman, 2012). The limestones crop out in two low crags, the eastern (49°15.739´N, 19°53.248´E) and the western ones, which are 8 m apart.

A similar succession on the western slopes of the Dolina Lejowa valley (*ca.* 3 km to the west) previously considered as a part of the Hronicum succession was also ascribed to the Fatric Domain (Gaździcka *et al.*, 2009). It can be concluded that the basically clastic Kopieniec Formation (upper Rhaetian–lower Sinemurian) and other Jurassic rocks, which are cropping out therein and in the "Nad moreną" section do not belong to the Choč Nappe.

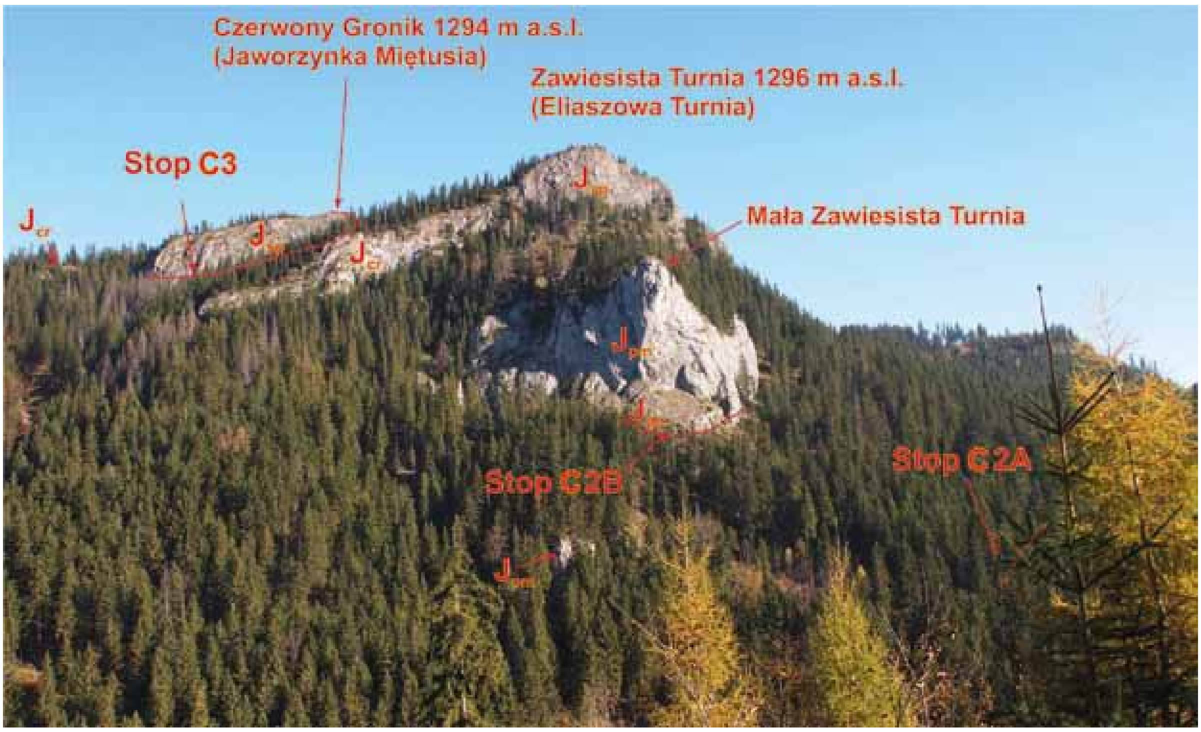

Fig. 5. View to Zawiesista Turnia crag and the surrounding from the opposite slopes of the Dolina Miętusia valley, with indication of the main lithostratigraphic units and visited stops

Indications of lithostratigraphic units as in Fig. 2

C2B. Feet of Zawiesita Turnia crag (49°15.745´N, 19°53.175´E)

Feet of Zawiesista Turnia (Mała Zawiesista Turnia; Stop 2B, Fig. 5) crag are built of light grey, bedded, peloidal and oolitic grainstones/packstones (Fig. 6) with echinoderms remnants and subordinately of peloidal and bioclastic wackestones. The section starts in the western part (GPS co-ordinates: 49°15.741´N, 19°53.99´E). Different types of ooids are present. They range from types with small nuclei and thick cortices to forms with superficial cortices which do not exceed a half of whole ooid diameter. The most frequent bioclasts are represented by echinoderm plates, while small gastropods, bivalves and benthic foraminifers are subordinate. Aggregate grains, lithoclasts and crustacean faecal pellets *Parafavreina* (Fig. 6) are also present in individual beds. Between some beds, 1–2 cm-thick layers of yellow-weathering dolomites can be observed (Fig. 6). The described rocks represent a shallow-marine carbonate platform with marginal parts and deposition of the oolitic grainstones to a platform interior in which peloidal-bioclastic wackestones accumulated. The bedded limestones in the feet of the crag passes into massive limestone of the same type which are exposed in the cliff of the crag in the eastern side (GPS co-ordinates: 49°15.745´N, 19°53.175´E).

Walking to the north east along the cliff, a gradual transition to crinoidal limestones with spiculitic cherts can be observed.

The succession is in the overturned position. It belongs to the Kończysta Thrust Sheet. In the succession of this thrust sheet, in Kończysta Turnia crag, grey bioclastic limestones of the Hierlatz-type are present. They are considered as a younger unit than the peloid-oolitic limestones. The bioclastic limestones are replaced to the east by crinoidal grainstones. The northern side of Eliaszowa Turnia (Zawiesista Turnia) crag crest is built of crinoidal grainstones, which overlie the spiculitic limestones.

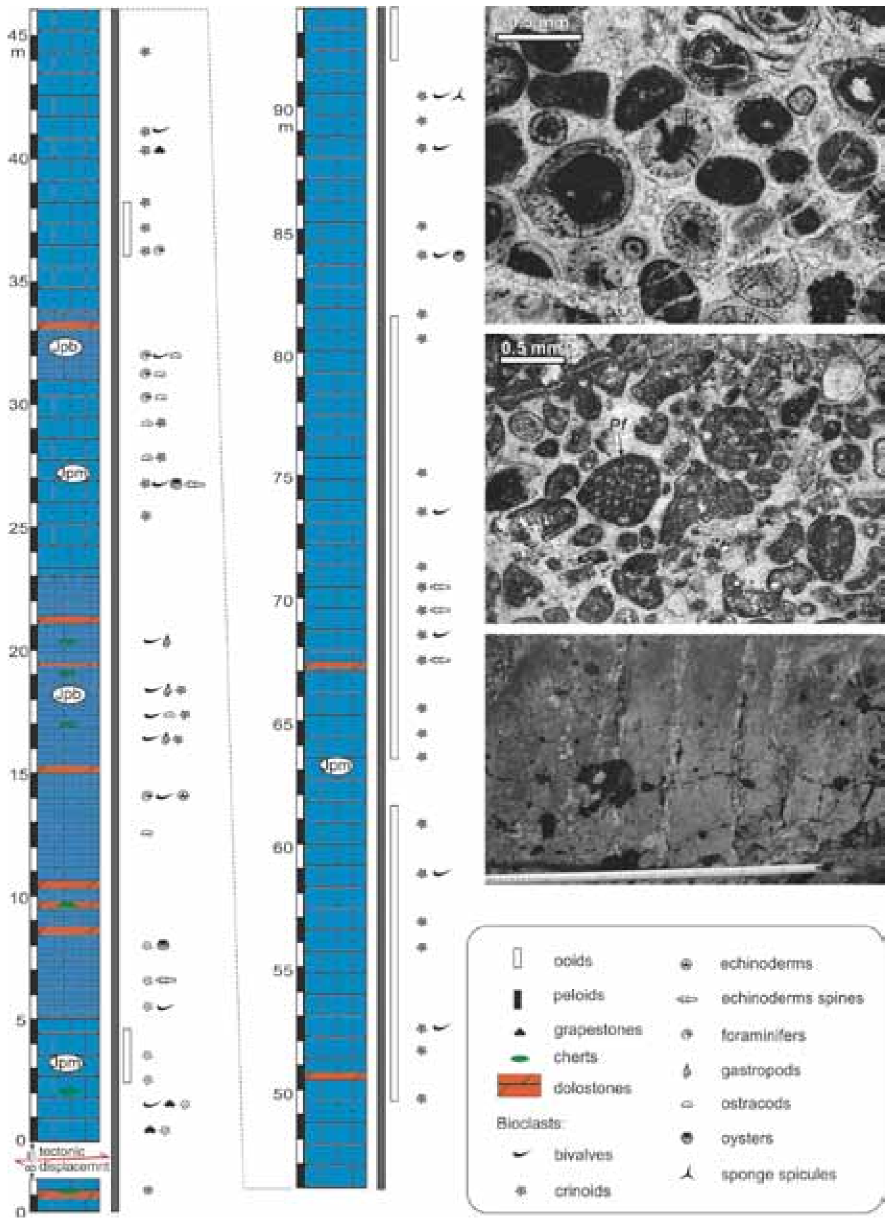

Fig. 6. Lithological column of the massive and bedded peloidal-oolitic limestones (Jpm and Jpb, respectively) in feet of Mała Zawiesista Turnia crag and photographs of oolitic-peloidal grainstone (at the top), oolitic-peloidal grainstone with the microcoprolite *Parafavreina* (Pf) (in the middle) and dolomitic intercalations (light bands) between beds of peloidal-oolitic limestones (at the base)

▹STOP C3

JAWORZYNKA MIĘTUSIA (CZERWONY GRONIK) CRAG: SPICULITIC LIMESTONES

LEADERS: ALFRED UCHMAN, WERONIKA ŁASKA, ANDRZEJ GAŹDZICKI

The main cliff of Jaworzynka Miętusia (Czerwony Gronik) crag is built of inclined beds of spiculitic and crinoidal limestones with brownish cherts of the Brama Kantaka Thrust Sheet. The limestones are spicule-rich wackstones, bioclastic wackstones or crinoidal packstones/grainstones (Fig. 7A, B) displaying different degree of silification. They also contain in variable proportion differently preserved bioclasts of brachiopods, bivalves, ostracods, bryozoans, foraminifers (?*Cyclogyra* sp., ?*Cornuspira* sp., ?*Glomospirella* sp., ?*Nodosaria* sp.), echinoid spines and worm tubes (*Spirorbis* sp.). Commonly the cherts form interfingering beds, which are up to 35 cm thick that extends laterally for 3–10 m. They occur also either as rough irregular nodules or patches in limestones, ranging in size from a few mm to 30 cm. Usually, they stand out in relief against the weathered surface of the host rock. The cherts are built of the mass composed of microquartz and subordinate amount of fibrous chalcedony and megaquartz. The siliceous mass locally contain preserved relics of original matrix and bioclasts represented mostly by crinoids and rare sponge spicules clearly evidencing that the cherts were formed by silification of originally limestone beds similar in composition to the surrounding limestones. Moreover, the presence of scarce sponge spicules (mainly monaxones), commonly preserved as moulds, indicates that the silica has had probably intraformational source and it has been derived from dissolution of siliceous spicules. Noteworthy is diversified susceptibility of various bioclasts to silification observed both in the cherts and in the limestones. The most susceptible for silification are brachiopod shells (Fig. 7C, D) and crinoid fragments (Fig. 7A, B) often being partly of totally replaced by microquartz. More resistant to silification are bryozoan skeletons, foraminiferal tests, ostracode carapaces and bivalves shells. According to Young *et al.* (2012), differences in the resistance to silification are connected among others with shell microstructures, skeletal mineralogy, biological group and size of organism.

In the eastern part of the cliff, in one bed rich in bioclasts (silicified Hierlatz-type facies?), *Spiriferina* cf. *haueri* Suess was found. *S. haueri* is a Hettangian species, and the aforementioned specimen probably was redeposited (Uchman, Tchoumatchenco, 1994).

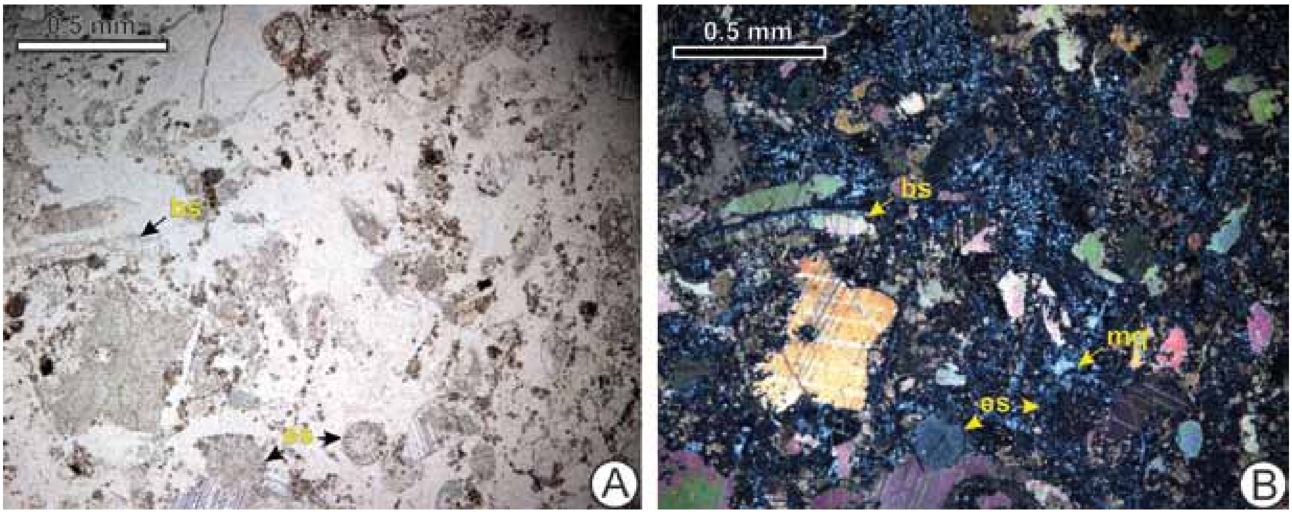

Fig. 7. Microfacies of spicule-bearing limestones from the Miętusia Limestone Formation
A, B – Partially silicified crinoidal packstone: partially or totally silicified crinoids, ?brachiopod shell (bs), echnoid spines (es) within silicified matrix composed of microquartz and subordinately megaquartz (mq); Jaworzynka Miętusia

A – plane polarized light; B – crossed nicols

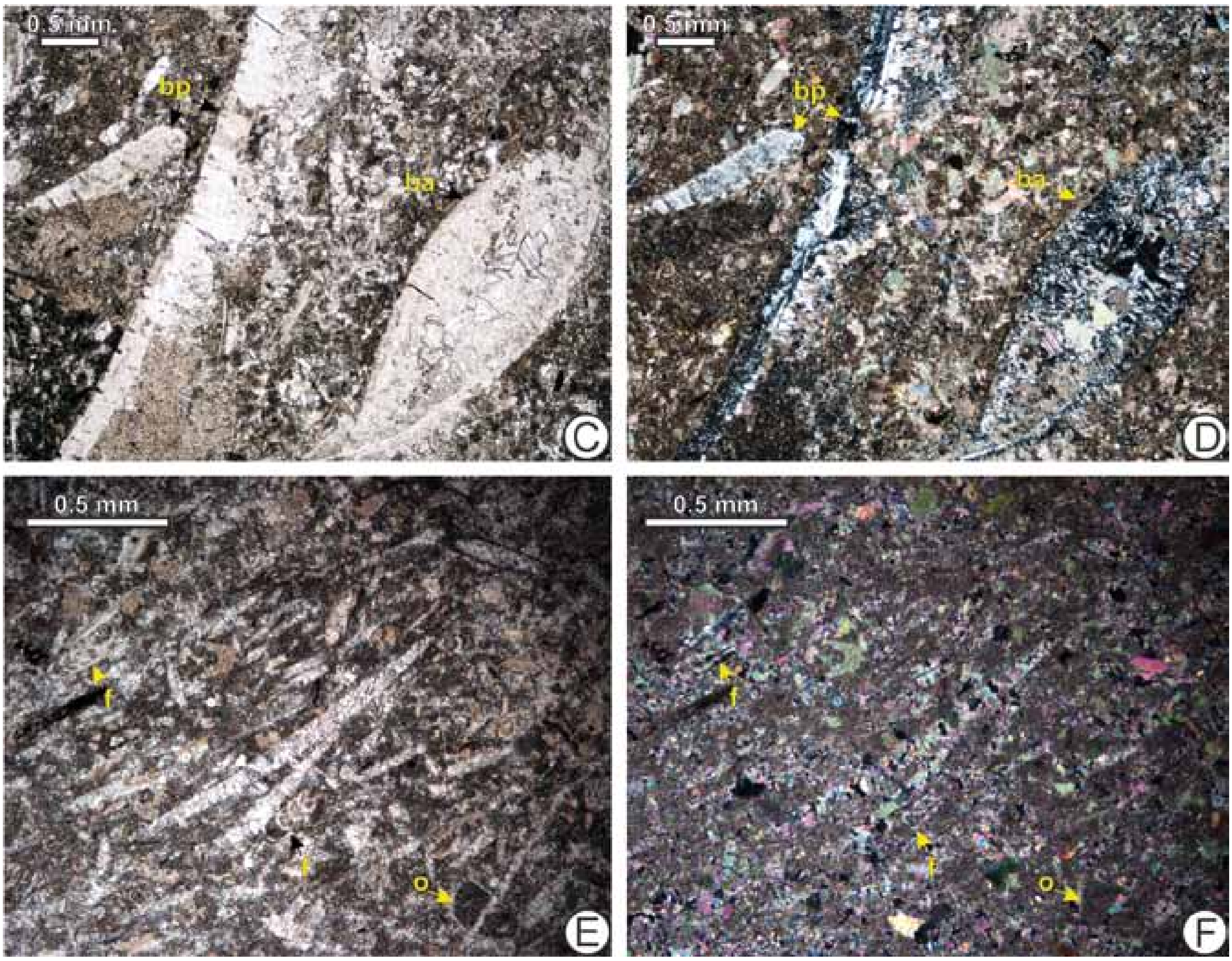

Fig. 7. Microfacies of spicule-bearing limestones from the Miętusia Limestone Formation – continuation
C, D – Partially silicified spiculitic brachiopod wackstone: silicified punctate brachiopod with well-preserved shell microstructure (bp), articulated brachiopod mould (ba) filled with microquartz and calcite set in recrystallized micritic matrix, Jaworzynka Miętusia

C – plane polarized light, D – crossed nicols

E, F – Spiculitic foraminiferal wackstones: calcite filled spicule moulds, foraminiferal tests (f), ostracode carapace (o) set in a recrystallized micritic matrix, Staników Żleb

E – plane polarized light, F – crossed nicols

▹STOP C4

GRONKA CRAG: CRINOIDAL CALCARENITES, SILICIFIED CRINOIDAL CALCARENITES AND RED CALCILUTITES

LEADER: ALFRED UCHMAN

The prolongation of Jaworzynka Miętusia crag to the west and the cliff of Gronka crag are cut by vertical faults, which are marked by brecciated zones. They separate blocks built of crinoidal grainstones and silicified crinoidal grainstones with cherts. In two faulted blocks, small outcrops of brownish and reddish bioclastic wackstones were found. They contain shells of *Bositra* (filamentous facies), crinoids, calcitized radiolarians (?) and juvenile ammonites (Uchman, 1988, 2014). They are considered as the youngest deposits (probably Middle Jurassic) of the Choč Nappe in the Tatra Mountains. Limestones of this type also occur in neptunian dykes in the northern part of the crag and in the Upłaz Thrust Sheet (Hala pod Upłazem glade), where the dykes cut the Hierlatz-type limestones (Uchman, 1988, 2014).

In the north western part of the crag, some breccias composed of crinoidal grainstones and silicified crinoidal grainstones with cherts are probably of synsedimentary origin. They can be related to tectonic escarpments bounding the elevated blocks. In the Hierlatz-type limestones of Kończysta crag and in the Upłaz Thrust Sheet, some loose blocks of breccias with Triassic dolomites have been found. Isolated clasts of Triassic dolomites are dispersed in crinoidal limestones in many places. Some of them are bored with *Trypanites*. They prove erosion of elevated Triassic rocks during the sedimentation.

▹STOP C5

STANIKÓW ŻLEB GULLY: CRINODAL CALCARENITES AND SPICULITIC LIMESTONES

LEADERS: ALFRED UCHMAN, WERONIKA ŁASKA, ANDRZEJ GAŹDZICKI

Along the cliff running to the bottom of the Staników Żleb, grey and pale rose, massive, crinoidal grainstones are cropped out. In the middle of the slope, Stanikowa Dziura Wyżna cave (13 m long) offers an outcrop of the tectonic contact between limestones of the Choč Nappe and the grey marlstones of the Lower Cretaceous Kościeliska Marl Formation of the Krížna Nappe.

After a fault in the axis of the gully, spiculitic limestones crop out in the prolongation of the cliff. Spiculitic limestones contain in varying proportions other bioclasts and range from spiculitic wackstone through spiculitic foraminiferal wackstone (Fig. 3E, F) to spiculitic crinoidal wackstone. They include foraminifers such as ?*Cyclogyra* sp., ?*Cornuspira* sp., ?*Glomospirella* sp. Between uneven, strongly fractured, commonly, discontinuous beds of cherts, silicified crinoidal limestones (crinoidal packstone/grainstone) are present. They contain rare, in some cases silicified bioclast of brachiopods, bryozoans and benthic foraminifers. The outcropping cherts have the same origin as those outcropping in the Czerwony Gronik crag (stop C3). They were mostly formed by silification of originally crinoidal limestones.

Moving down the gully to Nędzówka, we pass a succession of the Eocene cover, from conglomerates to limestones, up to the shaly flysch of the Zakopane Beds (Oligocene). This succession forms the lower part of the Podhale Basin filling.

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FIELD TRIP D

JURASSIC OF THE HIGH-TATRIC SUCCESSION, WESTERN TATRA MTS: DOLINA KOŚCIELISKA AND DOLINA MIĘTUSIA VALLEYS, WIELKA ŚWISTÓWKA

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Route (Fig. 1): The first part of the excursion (stops D1–D4) leads along the Kościeliska Valley. This is an easy walk on the bottom of the valley, on a broad path. The second part (stops D5–D6) in the Miętusia Valley leads partly on unmarked, narrow paths, still in the lower part of the valley.

INTRODUCTION TO THE GENERAL GEOLOGY OF THE TATRA MOUNTAINS

The Tatra Mountains are one of the so-called core mountains of the Central Western Carpathians. They are composed of a Variscan crystalline core and of a Permo-Mesozoic sedimentary cover, which is exposed mainly on the northern slopes of the massif. The sedimentary rocks occur in both autochthonous and allochthonous position in relation to the crystalline core. In the latter case they have been detached from the basement and thrusted northwards, and are preserved as nappes. Palaeogeographically, particular tectonic units represent different palaeoenvironmental areas of the Central Western Carpathians (*e.g.,* Andrusov *et al.,*1973; Kotański, 1979), referred to as the

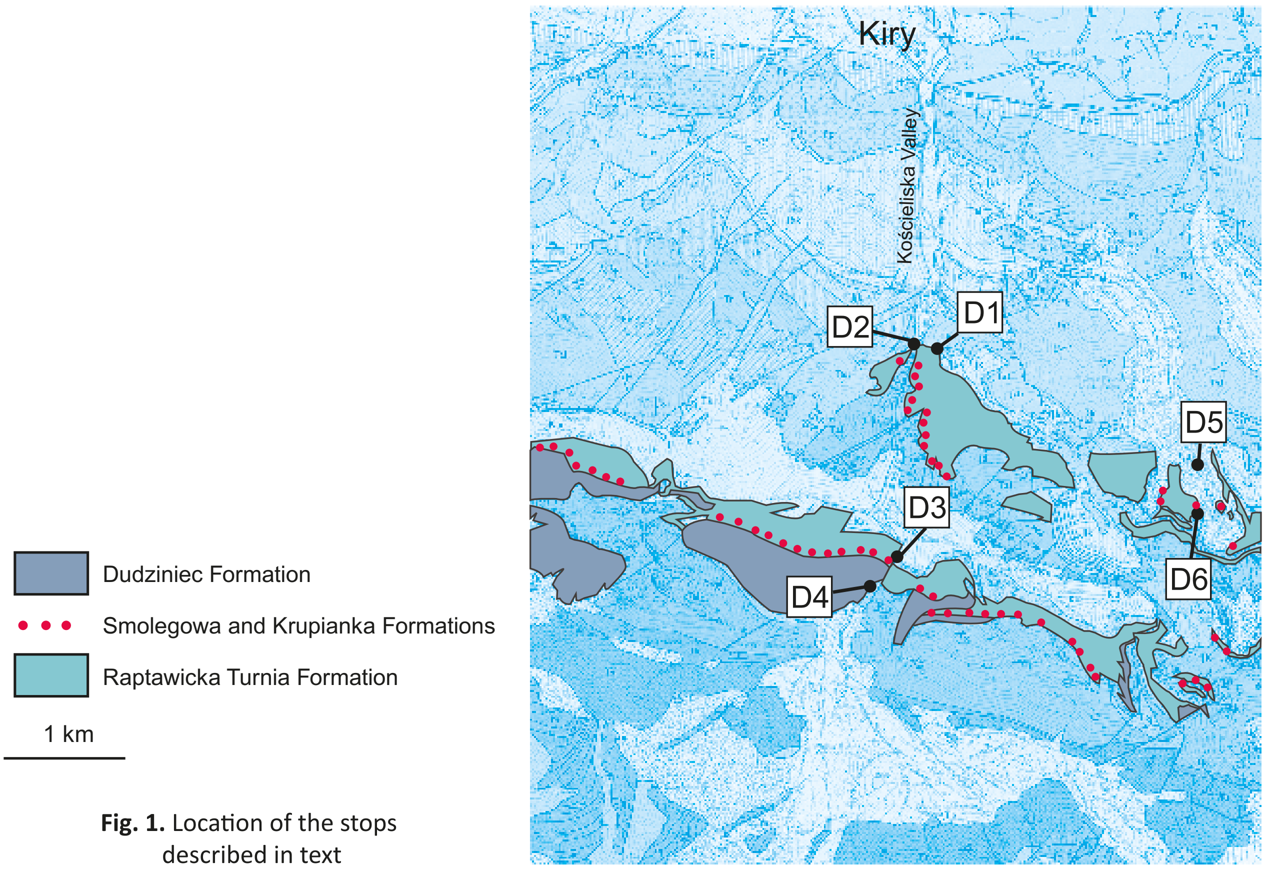

Fig. 1. Location of the stops described in text

tectonic-facies domains – the **Tatricum**, the **Fatricum** and the **Hronicum** (from the north to the south).

The sedimentary cover of the Tatra Mountains is traditionally divided into two major successions (or series), which substantially differ in their facies development. The **High-Tatric succession** (as the name suggests) is generally exposed in topographically higher parts of the mountains and embraces deposits in both autochthonous and allochthonous positions (Fig. 2). It is generally represented by relatively shallow-water facies, marked by numerous stratigraphic gaps. In terms of palaeogeography the High-Tatric series corresponds to the Tatricum tectonic-facies domain. The allochthonous **Sub-Tatric succession** is exposed in the lower parts of the massif and is generally composed of deeper facies and is stratigraphically more complete. It is represented by two units (or nappes) – the **Lower Sub-Tatric** (**Krížna**) and the **Upper Sub-Tatric** (**Choč**). In terms of the tectonic-facies division the two nappes correspond to the Fatricum and Hronicum domains respectively. Previously a Stražov Nappe (highest) was also distinguished within the Sub-Tatric series (corresponding to the Silicicum tectonic-facies domain), however, recently it is accepted that it does not exist in the Tatra Mountains, and that the successions that have been previously ascribed to it in fact represent the Hronicum domain (*e.g.*, Uchman, 2014). The Jurassic of various Sub-Tatric successions is a subject of alternative field trips held during this conference.

The High-Tatric succession is exposed in three tectonic units: **Kominy Tylkowe**, **Czerwone Wierchy** and **Giewont** (*e.g.*, Rabowski, 1959; Kotański, 1961; Fig. 2). In the Kominy Tylkowe unit, the deposits rest directly on the crystalline basement (*e.g.*, Passendorfer, 1961), and therefore it is also referred to as the **autochthonous unit**. It embraces also the *sc.* parautochthonous folds, with sediments detached from the basement and moved on minor distances, but palaeogeographically still representing the same domain (Tatricum). The Czerwone Wierchy and Giewont units (allochthonous, and also referred to as foldic) are detached from basement and thrust northwards over the autochthonous unit to form the High-Tatric nappes. Therefore, palaeogeographically they represent areas situated south of the autochthonous series. Analogically, originally the deposits of the Sub-Tatric succession accumulated south of the High-Tatric area. The formation and northward propagation of nappes took place in the Late Cretaceous, beneath the sea and under high overburden pressures in short episodes of movement, separated by periods of tectonic stability (Jurewicz, 2005, 2012).

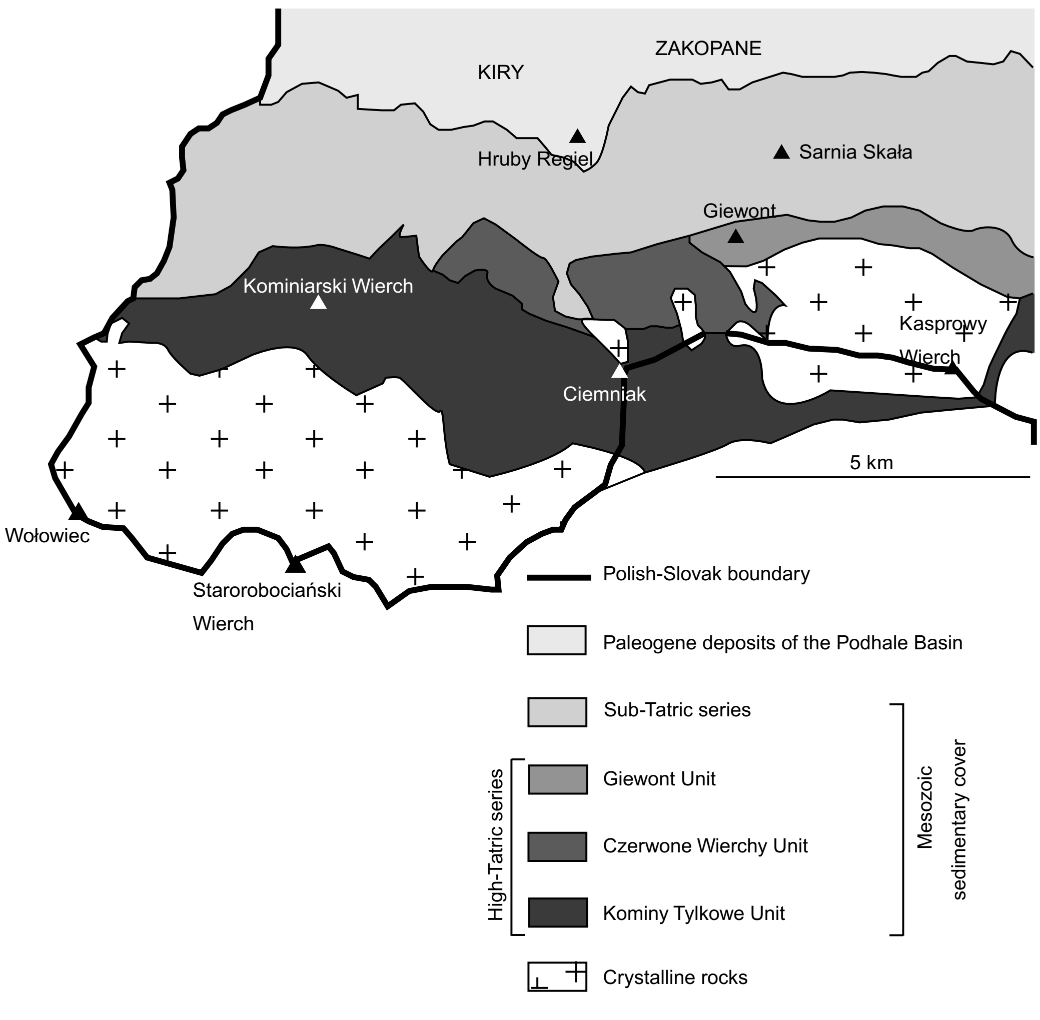

Fig. 2. Structural map of the western part of the Polish sector of the Tatra Massif (after Łuczyński, 2001)

JURASSIC OF THE HIGH-TATRIC SERIES

The High-Tatric Jurassic deposits are organised into lithostratigraphic units (Lefeld *et al.*, 1985). **The Dudziniec Formation** is of the Lower Jurassic and the lowermost part of the Middle Jurassic (Aalenian) age, the **Smolegowa** and **Krupianka formations** are respectively of Bajocian and Bathonian age, and the **Raptawicka Turnia Formation** is of Callovian and Upper Jurassic age and embraces also the Lower Cretaceous (Fig. 3).

The Jurassic deposits occur in all three High-Tatric tectonic units. The most complete succession of the High-Tatric Jurassic is exposed in the autochthonous (Kominy Tylkowe) unit, whereas in the allochthonous unit and in the parautochthonous folds it abounds in stratigraphic gaps, embracing the whole or the parts of the Lower and the Middle Jurassic. In these areas, the Middle Triassic (Anisian) is commonly directly overlain by the Smolegowa, Krupianka or even the Raptawicka Turnia formations. In the Czerwone Wierchy and Giewont units, the Smolegowa and particularly the Krupianka formations are preserved as laterally discontinuous lenticular bodies, with thicknesses ranging from few centimetres to a couple of metres (Fig. 4; Łuczyński, 2002). In many places particular formations are either missing or limited to neptunian dykes only (Łuczyński, 2001a; Jezierska, Łuczyński, 2016). In the autochthonous unit, the Middle Jurassic formations usually form more continuous lithosomes and reach bigger thicknesses up to a dozen metres.

In the Kominy Tylkowe unit the stratigraphic succession is complete across the Triassic/Jurassic boundary and the Lower Jurassic is developed as sandy-carbonate deposits of the **Dudziniec Formation** (Radwański, 1959; Wójcik, 1981; Jezierska *et al.*, 2016), represented mainly as sandy-crinoidal facies. Detrital material contains mainly quartz grains, carbonate lithoclasts and scattered bioclasts (bivalves, crinoids, brachiopods and belemnites). The formation reaches its greatest thickness of around 600 m between the Chochołowska and Kościeliska Valleys on the southern slopes of the Kominiarski Wierch. The age of the formation, based on belemnite and brachiopod fauna has been determined as Hettangian-Aalenian (Horwitz, Rabowski, 1922; Lefeld *et al.,* 1985). A number of subordinate lithostratigraphic units are distinguished within the formation (Fig. 5): Kopieniec Starorobociański Bed, Kobyla Głowa Limestone Member, Kobylarka Limestone Member, Smytnia Limestone Member, Iwanówka Limestone Member and Kominy Dudowe Limestone Member.

In the autochthonous unit, the Dudziniec Formation is overlain by the **Smolegowa Formation,** which in the al-

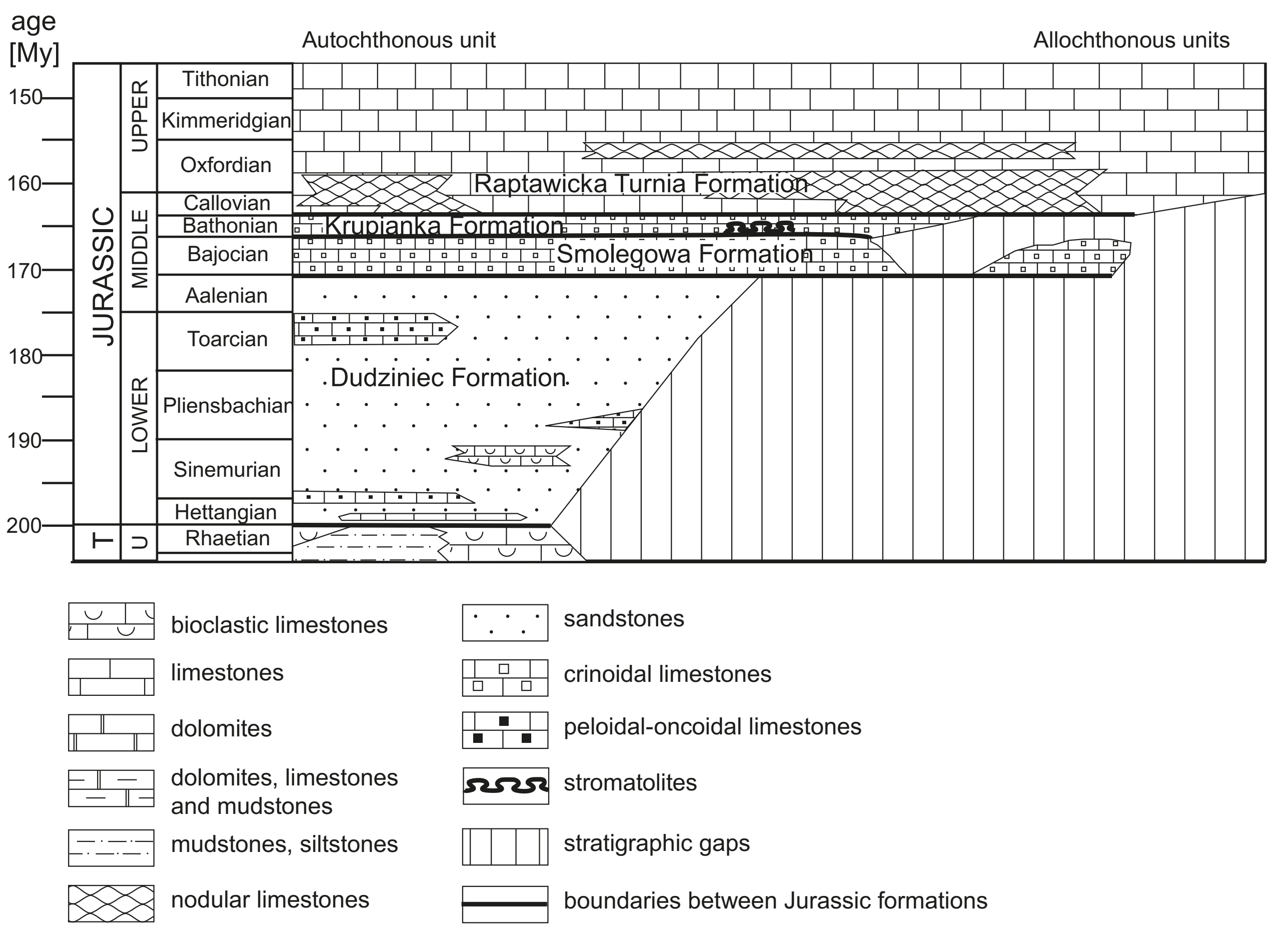

Fig. 3. Jurassic lithostratigraphic units of the High-Tatric series (after Uchman, 2014)

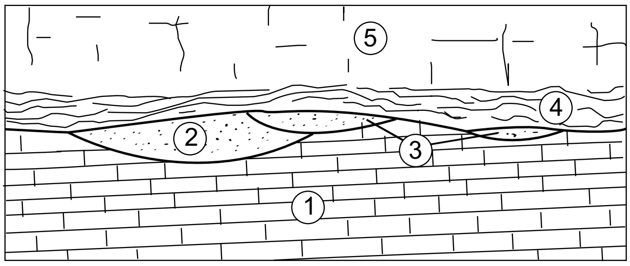

Fig. 4. Idealized spatial relations between the Middle Jurassic lithosomes in the High-Tatric foldic units:

1 – Middle Triassic limestones and dolomites, 2 – white coarse crinoidal limestones of the Smolegowa Formation (Bajocian), 3 – red ferruginous and crinoidal limestones of the Krupianka formation (Bathonian), 4 – wavy-bedded limestones of the Raptawicka Turnia Formation (Callovian), 5 – massive limestones of the Raptawicka Turnia Formation (Oxfordian)

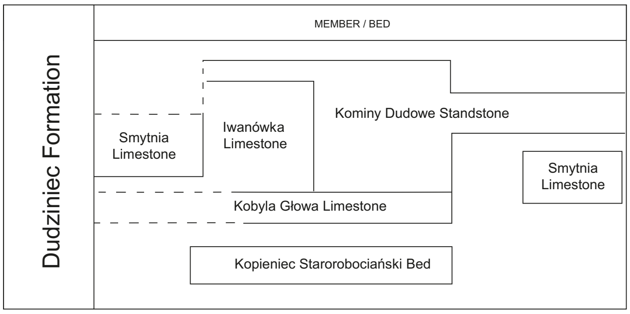

Fig. 5. Subdivision of the Dudziniec Formation (after Lefeld *et al.*, 1985)

lochthonous units rests directly on the Middle Triassic (Anisian). The formation is uniformly developed as white, grey and pinkish, coarsely crystalline and mainly massive crinoidal limestones generally represented by pure encrinites. Its age has been determined as Bajocian based on brachiopod fauna (Horwitz, Rabowski, 1922 – “white Bajocian crinoidal limestones”; Lefeld *et al.*, 1985). The formation does not exceed a thickness of a dozen or so metres, outcrops in laterally discontinuous bodies and is often missing in the stratigraphic succession, especially in the Czerwone Wierchy unit. White crinoidal limestones ascribed to the Smolegowa Formation occur also in neptunian dykes penetrating the Triassic substrate (Łuczyński, 2001a).

The High-Tatric Bathonian is represented by the **Krupianka Formation**. Its age is based mainly on rich ammonite fauna from Wielka Świstówka in the Miętusia Valley (Czerwone Wierchy unit) (Passendorfer, 1935, 1938 – «red Bathonian crinoidal limestones»; Lefeld *et al.*, 1985). The formation occurs in three major lithofacies – crinoidal, ferruginous and nodular limestones, with gradual transitions between them (Łuczyński, 2002). Common features of all three lithofacies are: intensely red colour, occurrence of more or less rich pelmatozoan material and a relatively abundant terrigenous admixture (quartz, limestone, dolomite and ferruginous clasts). The actual differences between them are mostly an effect of late diagenetic pressure solution and compaction (Łuczyński, 2001b). The ferruginous limestones are characteristic of the Czerwone Wierchy unit, the nodular limestones occur in the autochthonous unit, while the crinoidal limestones are most common, and can be found in all three tectonic units. The Krupianka Formation is characterized by a very limited thickness, rarely exceeding a meter, and by a laterally discontinuous occurrence. It is often missing in the normal stratigraphic succession, particularly in the allochthonous units, and the Bathonian red crinoidal and ferruginous limestones are in many areas limited only to vast systems of neptunian dykes penetrating the Triassic (Łuczyński, 2001a).

The Smolegowa and the Krupianka formations together constitute the Dunajec Group. All these units were first established in the Pieniny Klippen Belt (Birkenmajer, 1977), where particular deposits are generally similarly developed as in the Tatra Mountains, but attain bigger thicknesses and their chronostratigraphic position is better documented (Wierzbowski *et al.*, 1999, 2004; Schlőgl *et al.*, 2005). The Pieniny lithostratigraphic division has been partly adopted in the Tatra Mountains. However, the exact chronostratigraphic ranges of particular formations in the Tatra Mountains are commonly poorly documented, based only on fauna examinations made in single localities, and expanded on the whole unit basing purely on lithological analogies. It is especially controversial if particular deposits are laterally discontinuous and their occurrence is limited to separated lenticular bodies, as is the case with the Smolegowa and Krupianka formations in the allochthonous units, and if the lithological analogies are drawn between deposits belonging to different tectonic units.

The Callovian and Upper Jurassic deposits of the High-Tatric series form the lower part of the **Raptawicka Turnia Formation**, which embraces also the Lower Cretaceous (up to the Hauterivian). The thick successions of the so-called “Malmo-Neocomian” build many of the important massifs of the Western Tatra Mountains, such as Giewont and Kominiarski Wierch (Kominy Tylkowe). In most sections the formation rests with a sharp boundary on various Jurassic units, or even lies directly on the Triassic. Continuity of sedimentation at its base occurs only in some sections of the autochthonous unit (Jezierska, Łuczyński, 2016). Most of the Raptawicka Turnia Jurassic deposits are developed as monotonous grey massive limestones. The basal wavy bedded part of the formation yielded Callovian ammonites (Passendorfer, 1935, 1938). The Callovian/Oxfordian boundary, which is traditionally placed at the transition to the overlying massive limestones (*e.g.*, Rabowski, 1959; Kotański, 1959) , has no palaeontological basis. Two members are distinguished in the Jurassic part of the formation (Lefeld *et al.,* 1985). The Czorsztyn Limestone Member is developed as pink nodular limestones of Oxfordian age and outcrops mainly in the Chochołowska Valley and in the Kominy Tylkowe Massif (autochthonous unit). The Tithonian Sobótka Limestone Member is represented by crinoidal limestones with limburgite and tuffite interbeds and outcrops in Slovakia (autochthonous unit).

Recent investigations in the area of Giewont proved that Upper Jurassic (Kimmeridgian–Tithonian) part of the Raptawicka Turnia Formation is much thicker than previously estimated (Pszczółkowski *et al.*, 2016) and contains partially also dark limestones which were traditionally assigned to Neocomian (Lefeld, 1968). Moreover, due to detailed microfossil and stable isotope stratigraphy, it was possible to correlate the Upper Jurassic interval of the Raptawicka Formation with the coeval rocks of the Lower Sub-Tatric succession (Jach *et al.*, 2014).

THE KOŚCIELISKA AND THE MIĘTUSIA VALLEYS

The **Kościeliska Valley** is located in the Western Tatras and is one of the biggest main valleys in the Tatra Mountains. It is *ca.* 9 km long and crosses all the main structural units of the Tatra massif. One of its characteristic features is that it is composed of consecutive wider parts (*sc.* clearings or glades) separated by narrow passages (*sc.* gates), which is of course an effect of running through various lithological units (Fig. 6). The field trip is dedicated to the High-Tatric Jurassic, but a brief list of the main units passed on the way is presented here.

The valley starts in Kiry (part of Kościelisko). Its first relatively wide part – **Niżnia Kira Miętusia**, runs through Paleogene (Eocene) deposits, structurally belonging to the Podhale basin, which contacts with the Tatra massif on the north (see also Field Trip C). A rock built of nummulitic limestones is exposed on the right side of the valley. The structural boundary of the Tatra massif is located at the first narrow passage – **Kantaka Gate**, built of Lower Jurassic crinoidal limestones of the Upper Sub-Tatric (Choč) nappe (for more details see Field Trip C). The following wide clearing – **Wyżnia Kira Miętusia**, runs through soft, marly Lower Cretaceous deposits of the Lower Sub-Tatric (Krížna) nappe. A trail leading to the Miętusia Valley starts here. The next glade – **Cudakowa Polana**, is developed in soft, red shales and sandstones of the *sc.* Carpathian Keuper (Upper Triassic) of the Krížna nappe. Traces of an old (XVIII century) metallurgical settlement of **Stare Kościeliska** can be recognised here.

Starting from another narrow passage – **Kraszewskiego Gate** (Stop D2), the valley cuts through the High-Tatric series. A big rising karst spring – **Lodowe** Źródło (Stop D1) occurs at the contact of permeable High-Tatric Jurassic limestones and non-permeable Sub-Tatric Carpathian Triassic. In the Kościeliska Valley section it is the Czerwone Wierchy unit that directly contacts with the Sub-Tatric nappes, as the Giewont unit is exposed only further to the east. Continuing south, the route cuts the Middle Triassic of the Czerwone Wierchy unit, and crosses the last important structural boundary – the contact between the autochthonous and the allochthonous units of the High-Tatric series. The valley opens again to form the **Hala Pisana** clearing, which is developed in soft Albian and Upper Cretaceous marls. The clearing is closed from the south by the **Wincentego Pola Gate** (Stop D3), developed in Upper Jurassic limestones. A bifurcation of the trail runs eastwards through the **Wąwóz Kraków** gorge – a karstic valley developed mainly in the Lower Creta-

Fig. 6. The Kraszewskiego Gate, RT – Raptawicka Turnia Formation

ceous limestones, and returns to the Hala Pisana glade. The last bedrock deposits accessible along the trail are the Lower Jurassic carbonate-sandstone sediments outcropping above the Wincentego Pola Gate (Stop D4). The upper part of the valley is largely filled with Quaternary deposits left by a Pleistocene mountain glacier. The trail reaches a mountain hostel on the **Polana Ornaczańska** clearing, which offers a perfect view on the upper parts of the Tatra massif, built of mainly metamorphic rocks of the crystalline core.

The second part of the field trip is dedicated to the **Miętusia Valley**, which is a branch of the Kościeliska Valley. Its lower part is a big clearing – **Rówień Miętusia** (filled with Quaternary, with no good exposures) offering a magnificent view on the Czerwone Wierchy Massif. The most interesting exposures are located in the uppermost part of the valley – in the **Wielka Świstówka** cirque (Stop D6), on the walls of which a complex tectonic structure of the Czerwone Wierchy unit can be observed. The *sc.* Czerwone Wierchy fold is built of Triassic, and Middle and Upper Jurassic formations. The trail to Wielka Świstówka passes through a large Pleistocene rockfall debris composed of large rock fragments, referred to as **Wantule** (Stop D5).

STOP D1
LODOWE ŹRÓDŁO (KOŚCIELISKA VALLEY)

Lodowe Źródło (Ice Spring) is a big rising karst (vaucluse) spring (500–800 l/s) located on the east side of the Kościeliski Stream. The spring is situated at the contact of the High-Tatric Czerwone Wierchy unit and the Sub-Taric Krížna nappe (Lower Sub-Tatric). The water flows to the surface under pressure at the base of massive limestones of the Raptawicka Turnia Formation, which directly contact here with black non-permeable Campilian shales.

The spring dehydrates large parts of the Czerwone Wierchy Massif built mainly of Triassic and Jurassic carbonate rocks (Barczyk, 2008). The massif is famous *i.a.* for its rich karstic phenomena with numerous caves, including the deepest cave systems in Poland. The subsurface flow in the area generally follows different directions that on the surface, running from SE to NW. This has been confirmed by fluorescent colouring of water samples, *e.g.,* in Wielka Śnieżna cave in the Mała Łąka Valley located *ca.* 4 km to the east. The coloured water after several days surfaced in the Lodowe Źródło spring (Dąbrowski, Rudnicki, 1967).

STOP D2
BRAMA KRASZEWSKIEGO (KOŚCIELISKA VALLEY)

Brama Kraszewskiego (Ťhe Kraszewskiego Gate) is a second narrow passage in the Kościeliska Valley, and is located within the Czerwone Wierchy Unit (High-Tatric series). The gate is built of Upper Jurassic grey massive limestones, which form steep walls on both sides of the Kościeliski Stream (Fig. 7). The Jurassic section, which consists of the Smolegowa and Raptawicka Turnia formations is accessible on the western slope of the valley.

The Jurassic section begins with **the Smolegowa Formation** (Bajocian), which rests directly on the Middle Triassic (Anisian). The stratigraphical gap embraces the Upper Triassic and the Lower Jurassic (the Dudziniec Formation). The Smolegowa Formation is developed as grey crinoidal limestones with indistinct bedding and thickness exceeding 10 m (Łuczyński, 2002; Jezierska, Łuczyński, 2016). The presented outcrop is one of few exposures of the Smolegowa Formation in the Tatra Mountains, in which the Bajocian crinoidal limestones are characterized by such a large thickness. Deposits are composed of unbroken pelmatozoan fragments with preserved original pentagonal or circular shapes of crinoid ossicles. Recrystallized crinoidal material constitutes over 90% of the rock volume and forms almost pure encrinites. The rock contains a scarce admixture of terrigenous material (*ca.* 1%) composed mainly of carbonate clasts derived from the eroded High-Tatric Triassic. Preservation state of crinoidal material and a low content of clastic admixture indicate an *in situ* crinoidal sedimentation, close to the crinoidal meadows, in calm waters below fair-weather base.

The Smolegowa Formation is overlain by the **Raptawicka Turnia Formation**. Absence of the Krupianka Formation (Bathonian) is probably a result of erosion or non-deposition during the Bathonian. The bottom part of the Raptawicka Turnia Formation is developed as grey wavy-bedded limestones with marly and silty intercalation (Callovian) and nodular limestones (Oxfordian), passing upwards into thick grey massive limestones (Oxfordian). The occurrence of the Raptawicka Turnia Formation designates the beginning of a unified pelagic sedimentation, which took place in the whole High-Tatric domain.

The Early to Middle Jurassic interval was a period of intense tectonic activity leading to disintegration of a Triassic carbonate platform and to formation of fault-bounded blocks. Individual blocks were subjected to uplift, and their differentiated subsidence resulted in a horst-and-graben morphology. Syndepositional faults led to an increase of accommodation space in some area, which resulted in an increased thickness of the deposits. The existence of such faults explains the relatively large thickness of the Smole-

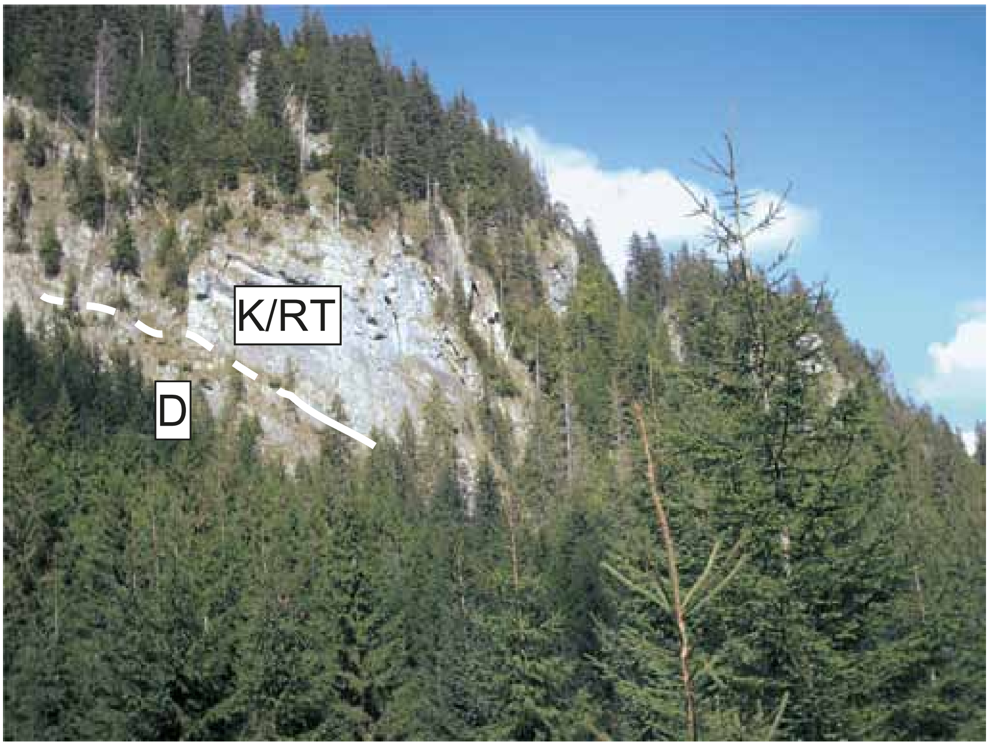

Fig. 7. Raptawicka Turnia, D – Dudziniec Formation,
K/RT – Krupianka and Raptawicka Turnia formations

gowa Formation in the Kraszewskiego Gate. The prevailing extensional regime led to drowning of the carbonate platform, on which shallow-water sediments were replaced by pelagic deposits. During the final drowning of the High-Tatric area, the sedimentation of the Raptawicka Turnia Formation led to relief unification.

▹STOP D3

BRAMA WINCENTEGO POLA (KOŚCIELISKA VALLEY)

Brama Wincentego Pola (The Wincentego Pola Gate) is located in the Kominy Tylkowe (autochthonous) unit, in place where the Upper Jurassic massive limestones build another narrow passage of the Kościeliska Valley. The western wall of the gate is formed of slopes of the Raptawicka Turnia crest, which is a part of a long ridge descending from the Kominy Tylkowe massif. The eastern slopes of the valley form a high steep wall, called Skała Pisana (Written Rock). Its surface is covered with signatures of many generations of tourists and famous people. A karst spring occurs at the bottom of the rock, located at the contact between the limestones of the Raptawicka Turnia Formation and impermeable marls of the Upper Cretaceous Zabijak Formation.

The Jurassic succession of the autochthonous unit exposed in the upper part of the Kościeliska Valley embraces the Dudziniec, Krupianka and Raptawicka Turnia Formations. However, in the Wincentego Pola Gate, the Krupianka Formation is missing, as it occurs only in lenses at the bottom of the Raptawicka Turnia crest.

The Krupianka Formation (Bathonian) is represented by red crinoidal limestones. The Bathonian crinoidal deposits distinctly differ from their counterpart of the Smolegowa Formation. Main differences are in size, abundance and preservation state of crinoidal fragments, as well as in a higher admixture of terrigenous material. The pelmatozoan material constitutes 30–80% of rocks volume and consists of small broken crinoidal ossicles. The clastic admixture includes ferruginous clasts and clasts with ferruginous envelopes. Disseminated ferruginous compounds are responsible for the intensely red colour of the rock. The deposition of the Krupianka Formation took place in a shallow, high-energy environment, above the crinoidal meadows. The crinoidal material was derived from the south, most probably from the Giewont Unit (Łuczyński, 2002), in which the crinoids are best preserved and the content of terrigenous material is smallest. Loose crinoidal material was transported over the sea bottom in the form of megaripples, which probably explains the lenticular shape of the lithosomes.

The Krupianka Formation is overlain by Callovian wavy-bedded limestones and Oxfordian massive limestones of the Raptawicka Turnia Formation, which are uniformly developed in the whole High-Tatric domain.

STOP D4

DUDZINIEC FORMATION IN THE UPPER PART OF THE KOSCIELISKA VALLEY (KOŚCIELISKA VALLEY)

Above the Wincentego Pola Gate, the Kościeliska Valley cuts through the deposits of the **Dudziniec Formation** (Hettangian–Aalenian). The Lower Jurassic deposits occur only in the Kominy Tylkowe Unit, whereas in the Czerwone Wierchy and Giewont units, there is a stratigraphic gap embracing the Upper Triassic and the Lower Jurassic. Thickness of the Dudziniec Formation increases to the west, reaching up to 600 m in the Chochołowska Valley. In the Kościeliska Valley, the exposures of the Lower Jurassic are located on both western and eastern slopes of the valley, between the Raptawicka Turnia crest and the Wąwóz Kraków gorge on the north, and the Smytnia Valley on the south.

The Dudziniec Formation is represented by a variety of sandy-crinoidal facies, ranging from sandstones to crinoidal limestones (Wójcik, 1981). The detrital material is composed mainly of quartz grains, lithoclasts and bioclasts (bivalves, crinoids, brachiopods and belemnites). Several members or beds are distinguished within the formation (Lefeld *et al.*, 1985; see also Fig. 5): Kopieniec Starorobociański Bed – thin and medium bedded, grey, dark grey or blue-grey sandy limestones; Kobyla Głowa Limestone Member – mediumbedded, dark grey encrinites with small amounts of clastic admixture; Kobylarka Limestone Member – massive grey encrinites; Smytnia Limestone Member – poorly bedded grey to dark grey and black limestones containing brachiopods and bivalves; Iwanówka Limestone Member – thin to medium bedded, grey to black encrinites with an admixture of quartz, Triassic dolomites and spiculites composed of loose sponge spicules; Kominy Dudowe Sandstone Member – medium bedded, light grey, pinkish-grey and yellowish conglomeratic-quartzitic sandstones, calcareous in places.

Wójcik (1981), based on studies in the Chochołowska Valley, distinguished several cycles within the Dudziniec Formation. A complete cycle is composed of quarzitic sandstones, mixed carbonate-clastic sediments consisting of quartz grains, peloids and crinoids, and crinoidal limestones containing sponge spicules. The origin of such cycles is associated with periodic syndepositional tectonic activity, which led to uplift of some blocks and to differentiation of the bottom morphology. The uplifted blocks were subjected to intensive erosion, which caused increase in the supply of clastic material and in consequence resulted in sedimentation of sandy facies. Crinoidal facies were deposited during periods of tectonic stability. The clastic material was transported from the south and comes from erosion of uplifted blocks, most probably located still within the High-Tatric domain. Various types of extraclasts came from multiple sources. Quartz grains and feldspars most probably come from eroded Keuper (Upper Triassic) and Werfenian (Lower Triassic) rocks. The same source has been suggested by Popiołek *et al.* (2010) for the Lower Jurassic deposits of Krížna Unit. Carbonate clasts come from the erosion of Middle Triassic rocks.

In the Kościeliska Valley, the Dudziniec Formation is represented by the following lithofacies: (i) pinkish-grey/pinkish-white **hybrid sandstones** composed of carbonate intra- and extraclasts and non-carbonate extraclasts, (ii) pinkish-purple **sandy pebbly limestones** containing abundant debris of broken bivalves and brachiopod shells, (iii) dark grey **sandy pebbly limestones** with abundant brachiopods and bivalves (corresponding to the Smytnia Member), (iv) dark to light grey **calcareous lithic limestones**, (v) white to light grey **siliceous pebbly sublithic sandstones** (corresponding to the Kominy Tylkowe Member), (vi) grey-cherry **crinoidal limestones** and (vii) light pink/grey-cherry **hybrid crinoidal sandstones** (Jezierska *et al.*, 2016).

In the Kościeliska Valley area, the cycles are not as well developed as in the Chochołowska Valley, and the deposits are generally characterized by a higher amount of clastic admixture. Sedimentation took place here in a shallow-water environment in a close vicinity to the source areas. In contrast to that, the Chochołowska Valley sections contain also relatively deeper facies, represented by crinoidal limestones with sponge spicules. Such lithofacies distribution along the E–W direction indicates that during the Early Jurassic the autochthonous basin was inclined westwards.

In some sections, the Dudziniec Formation is cut by neptunian dykes, which run parallel or obliquely to bedding, and which are characterized by variable width and various shapes. Fissures are filled mainly by white to red micrite with an admixture of quartz grains or by red hybrid arenite, which is similar to the surrounding host rock. The occurrence of dykes filled by deposits of the Dudziniec Formation, suggests that development of the neptunian dykes in the High-Tatric region took place also in the Early Jurassic. Walls of some dykes are covered with calcite cements, which indicates that the process of infilling of dykes was multistage, with time breaks between the opening of voids and their infilling.

▸STOP D5
WANTULE (MIĘTUSIA VALLEY)

The name Wantule (plural) comes from the word "wanta", which in the local highland dialect means a large rock (boulder). Above the Wyżnia Rówień Miętusia clearing, the upper part of the Miętusia Valley is covered by a massive rockfall debris. A large rock and ice avalanche occurred here in Late Pleistocene at the end of the last glacial episode in the Tatra Mountains. A large part of the Chuda Turnia mountain – its slope called Dziurawe, fall down on the surface of a mountain glacier, and the debris was further transported by ice about 0.5 km down the valley. The Wantule covers an area of around 0.25 km^2, and the total weight of the debris is estimated as 45 million tons, with some of the individual rocks weighting *ca* 2500 tons (Radwańska-Paryska, Paryski, 2004). Most of the rock fragments are Upper Jurassic massive limestones of the Raptawicka Turnia Formation. The fall developed mainly along the steeply dipping northwards boundary between the Organy and Zdziary units–subordinate tectonic units within the Czerwone Wierchy unit (Kotański, 1971). Probably, it partly developed also along bedding planes of the northward dipping Jurassic limestones.

▸STOP D6
WIELKA ŚWISTÓWKA – ŚWISTÓWKA PASSENDORFERA (MIĘTUSIA VALLEY)

An outcrop of condensed ferruginous limestones of the Krupianka Formation located in the western part of the Wielka Świstówka cirque (Fig. 8) is famous mainly for its rich ammonite fauna. The locality has been described by Professor Edward Passendorfer in his classic monographs (1935, 1938), who determined its Middle Bathonian age, and after whom the place has been named (Łuczyński, 2002). On this base all the High-Tatric "red crinoidal limestones" of the Krupianka Formation have been ascribed to the Bathonian (ammonites of this age were found also in Mała Świstówka, and on the slopes of Giewont). The fossiliferous layer, once covering an exposed steeply dipping surface, has been mostly exploited, today is hardly accessible and occurs only at the base of a steep wall.

Rusty coloured, condensed Bathonian bed is 8–12 cm thick and rests on Middle Triassic shallow-water carbonates. Red Bathonian limestones are also present in neptunian dykes penetrating the underlying Triassic strata. The bed starts with stromatolites forming polygonal layers and covering large areas (today mostly not visible; Szulczewski,

Fig. 8. Wielka Świstówka

black arrow – Świstówka Passendorfera

1963). The polygons have very distinct interstices, commonly infilled by abundant ferruginous extraclasts. Rich terrigenous material composed of ferruginous clasts and Triassic limestones and dolomites is present also in the layer directly covering the stromatolites.

The bed yielded rich nautiloids, ammonites (*e.g.*, *Phylloceras*, *Lytoceras*, *Perisphinctes*, *Stephanoceras* and *Oppelia*), belemnites and brachiopods accompanied by less common bivalves and gastropods. Most probably the cephalopods are redeposited from deeper into more shallow-water settings. Recent revision of the fauna collected by Passendorfer (Galácz, Matyja, 2006) allowed to determine the age as higher Middle Bathonian Bremeri Zone, which is indicated by such diagnostic forms as: *Prohecticoceras ochraceum* and *Bullatimorphites eszterensis*. However the collection contains also some macrocephalitids and rare *Hecticoceras* suggesting the presence also of the Lower Callovian. Most probably these fossils come from an intermittent Callovian layer overlying the Bathonian, which however, today is not exposed.

The fossiliferous layer is overlain by massive pelagic limestones of the Raptawicka Turnia Formation, wavy bedded in their lowermost part.

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