Geologica Balcanica

XXI International Congress of the Carpathian Balkan Geological Association (CBGA)

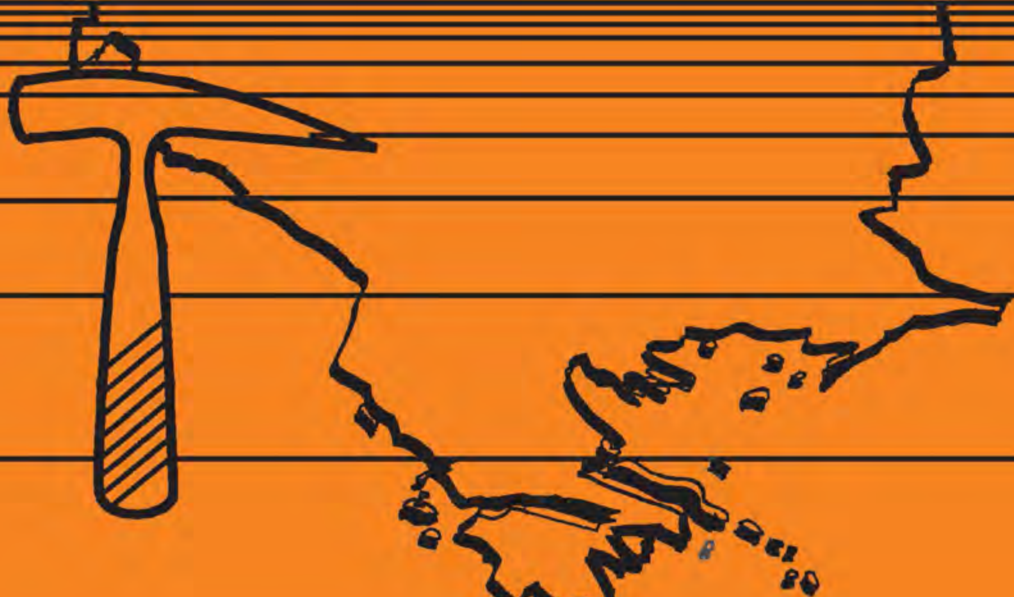
A B S T R A C T S

Advances of Geology in southeast European mountain belts

Franz Neubauer, Uwe Brendel & Gertrude Friedl
(Editors)

September 10–13, 2018
University of Salzburg, Austria

Bulgarian Academy of Sciences



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ABSTRACTS

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View from the Faculty of Natural Sciences to the Untersberg Massif in the southwest

Preface

Welcome to CBGA 2018 – the XXI Conference of the Carpathian-Balkan Geological Association (CBGA), which is held at the Paris-Lodron-University of Salzburg, Austria, from September, 10 to 13, 2018. As previous CBGA conferences (Thessaloniki 2010, Tirana 2014), CBGA 2018 aims to provide a forum where scientists, especially early career researchers, can present and discuss their recent research work and ideas with experts in all fields of geosciences. The regional focus of CBGA 2018 is mainly on mountain belts stretching from Eastern Alps over such in southeastern Europe to western Turkey and beyond. The geology of southeast European mountain belts can only understood when the western and eastern extensions are taken in consideration.

What is the Carpathian-Balkan Geological Association? This association has a nearly one hundred year of history, consists of sixteen member states and is affiliated to the Inter-Union of Geological Sciences (IUGS). Initially founded for discussion of the regional geology of Carpathian and Balkan region, the focus widened to neighbour areas like Alps and had its heydays during the political divide of the region after the Second World War.

This abstract volume of the XXI Conference of the Carpathian-Balkan Geological Association contains all abstracts submitted to the conference. The initial plan was to have a number of sessions proposed by conveners to General Themes covering all fields of recent research activities within that region. Finally, several sessions have been merged to 20 larger sessions and these sessions nicely reflect results of active international collaborations between researchers of various countries. The editors of this volume gratefully acknowledge the efforts of conveners to bring in their specific community and their help on organizing sessions and reading and assessing abstracts.

Within each session, the abstract volume gives the following sequence of abstracts according to the sequence of oral presentations and then poster presentations, allowing an easier overview on a specific field. The further plan after the conference is to publish several sets of thematically coherent peer-reviewed papers in international journals including such in the official journals of CBGA, Geologica Carpathica and Geologica Balcanica. This step for internationality is necessary to get more attention of the international geoscience community and give awareness to the geological peculiarities of the CBGA region.

The organizers also acknowledge support of institutions and companies in helping to organize the conference. Among these, we want particularly to mention the State Government and the of Salzburg, the Austrian Geological Survey, the Paris-Lodron-University of Salzburg and its Department Geography and Geology, but also many companies allowing access for geological field excursions.

The organizers of CBGA 2018 hope that the XXI Conference of the Carpathian-Balkan Geological Association results on many fruitful discussions and triggers many new international and multi-national collaborations for deepening of insights in the particular geology of the CBGA region.

Salzburg, August 2018

Franz Neubauer, Uwe Brendel & Gertrude Friedl
(Editors of the Abstract Volume)

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Alps, Carpathians and Dinarides-Hellenides: about plates, micro-plates and delamination

Stefan Schmid

Geophysical Institute, ETH Zürich, Switzerland

The Alps-Carpathians-Dinarides-Hellenides orogenic system developed during the progressive closing of two different oceanic branches. The northern branch of Neotethys of the Dinarides-Hellenides opened in Anisian times. Its closing started with intra-oceanic subduction in mid-Jurassic times, followed by obduction of the Vardar ophiolites at the end of the Jurassic. The onset of convergence in Neotethys was simultaneous with the opening of Alpine Tethys linked to the Atlantic spreading system. Hence it is the opening of the Alpine Tethys that contributed to plate convergence between stable Europe and the Adria-Tauride micro-continent, separated from Africa by the southern branch of Neotethys. Final closure of the northern branch of Tethys along the Sava-Izmir-Ankara suture zone did not occur before the end of the Cretaceous. Alpine Tethys started to close in Late Cretaceous times, i.e. after Cretaceous orogeny in the Austroalpine nappes and their equivalents in the Western Carpathians. Final closure of Alpine Tethys in the Alps and Western Carpathians occurred at around 40 Ma.

Considerable plate convergence continued after continent-continent collision in the Alps. A major changeover affected the Eastern Alps and their continuation into the Western Carpathians at around 22 Ma, associated with east-directed lateral extrusion of the ALCAPA block and north-directed indentation of the eastern Southern Alps east of the Giudicarie Belt. Mantle tomography shows that this changeover was associated with a change in subduction polarity east of the central part of the Tauern Window towards newly installed NE-directed ("Dinaridic") subduction of Adria. Slab break-off by the former S-dipping "Alpine" European slab was a prerequisite for this change in subduction polarity. This left the crust of Eastern Alps and Western Carpathians completely separated from its former lithospheric mantle underpinnings. In other words, lateral escape and CCW rotation of ALCAPA affected a previously thickened Alpine crust directly floating on asthenospheric mantle. Also the CW rotating Tisza-Dacia block floated on asthenosphere; the lithospheric mantle underpinnings of the former Cretaceous orogen building up the area of Tisza-Dacia are presently found in the "slab graveyard" beneath the Pannonian and Transylvanian basins.

In the Hellenides slab rollback started very much earlier, *i.e.*, during the middle Eocene and led to massive extension in the Rhodopes. This rollback was associated with the separation of the mantle lithosphere from previously shortened crust, while shortening propagated southward as the Hellenic slab, together with the trench, retreated southward. Substantial acceleration of rollback occurred since about 23 Ma when the southern branch of Neotethys entered the Hellenic trench. The present-day subduction rate of the Hellenic slab exceeds Africa-Europe convergence by a factor 9 according to GPS data, hence negative buoyancy of the delaminating Aegean mantle slab rather than plate convergence drives its subduction since the Miocene.

In the Dinarides, northwest of the Skutari-Pec transverse zone, the lateral continuation of the Hellenic slab retreated by a substantially smaller amount since the NW continuation of the Aegean slab underwent slab-break off. Slab retreat together with break-off led to extension and magmatism in the inner Dinarides, partly contemporaneous with ongoing compression in the outer Dinarides culminating in Mid-Eocene to Oligocene times.

Why less is more – high-time resolution from laser-ablation mass spectrometry in palaeo-environmental research and beyond

Wolfgang Müller

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Secondary Ion Mass Spectrometry (SIMS) during the 1980s and Laser-Ablation Inductively-Coupled-Plasma Mass Spectrometry (LA-ICPMS) since the 1990s have revolutionized our understanding of many Earth Science processes. Our ability to analyze trace concentrations and isotopic compositions at few µm spatial resolution in a wide range of geological materials has by now become almost routine and is more and more widely applied. Over the past ~15 years, the more recently developed LA-ICPMS methodology has surpassed SIMS in terms of applicability, broadly because of the lower capital cost of LA-ICPMS vs. SIMS. This is due to the fact that the mass spectra of LA-ICPMS are in many, albeit not all cases, much simpler that those of SIMS, owing to the plasma ion source after laser sampling, which facilitates the use of less expensive, low mass resolution mass spectrometers. LA-(MC-)ICPMS now even achieves isotope ratio precision nearly on par with TIMS, yet the routine stable isotope capability (*e.g.*, C, O) remains one of the key application areas of SIMS.

In this presentation I will briefly review some key relevant developments of spatially-resolved analysis, focusing on LA methodology. The main part, however, will showcase some of our recent applications of LA-(MC-)ICPMS in palaeoenvironmental research that aim at reconstructing past environmental processes at seasonal or better time resolution (cf. Müller and Fietzke, 2016). This will, for example, include the direct analysis of dust as proxy for atmospheric circulation in frozen, deep Greenland ice cores by cryo-cell LA-ICPMS to unravel the speed of natural abrupt climate change during the last glacial period.

As an outlook I will present ongoing work at developing true *in-situ* Rb/Sr dating in (metamorphic) micas using a recently developed 'triple-quadrupole'-ICP-MS/MS coupled to an LA system. This constitutes a paradigm shift for in-situ Rb/Sr geochronology with wide applicability, because no mass spectrometric separation of the two isobaric nuclides ^{87}Rb and ^{87}Sr is available so far given the required mass resolution (286000 (M/ΔM)). Yet chemical resolution using reaction cell gases (SF_6) achieves complete separation of ^{87}Sr from ^{87}Rb. For samples with large Rb/Sr-ratios, not uncommon among rock-forming micas, rapid *in-situ* single mineral age dating is possible with precisions of 1–2% directly in rock thin section.

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From the deep Earth to the surface: thermo-mechanical controls on lithosphere dynamics

Sierd Cloetingh

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Thermo-tectonic age and inherited structure exert the main controls on the bulk strength of the lithosphere in intraplate settings. Mechanical decoupling within the lithosphere strongly affects the interaction between deep Earth and surface processes. Thermo-mechanical models demonstrate the particular importance of the rheological stratification of the lithosphere in the preservation of ancient cratonic blocks, in the surface expression of plume- and mantle lithosphere interactions and their impact on the "dynamic" topography in general. The same is true for the effect of large-scale lithospheric folding on intraplate basin formation and associated differential vertical motions. Initiation of continental lithosphere subduction, crucial for linking orogenic deformation to intraplate deformation, appears to be facilitated by plume–lithosphere interactions. A discussion of these aspects will be presented (for recent work, see references given below), focusing on better process- understanding of continental deformation, in the context of a number of well-documented cases of intraplate deformation.

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Session GT1-1

Stable Isotopes in Earth System Sciences

Conveners:

Ana-Voica Bojar, Christophe Lecuyer, Gabriela Cristea and Andrzej Pelc

Isotopic indicators in mid-Badenian evaporites of northern Paratethys

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In mid-Badenian, 13.81 Ma, in the north-eastern part of Central Paratethys evaporite deposits (sulfates accompanied, in the axial part of the Carpathian Foredeep basin, by chlorides) have started to accumulate. The previous research proved that the isotopic compositions of both oxygen and sulfur show a similar trend of evolution throughout the Badenian gypsum sections. In some cases, in the lower part of gypsum sections a gradual decrease of $\delta^{34}S$ and $\delta^{18}O$ is observed and the upper part of the section shows fluctuations of quite high amplitude, but within a clearly defined interval. The variation of $\delta^{18}O$ values in the whole area is similar to that of $\delta^{34}S$ values although in particular facies the variation ranges are different. The recorded great spread of $\delta^{34}S$ and $\delta^{18}O$ values in the Badenian sulfates is related to the recycling of previously formed evaporites already during gypsum precipitation in the Carpathian Foredeep basin. Selenitic gypsum shows relatively narrow ranges of $\delta^{34}S$ and $\delta^{18}O$ values and hence it is especially useful for analyses of depositional conditions.

The Badenian gypsum sections studied are characterized by consistently increasing $^{87}Sr/^{86}Sr$ values. Assuming that the Badenian gypsum was formed between 13.8 Ma and 13.2 Ma, and taking into consideration the upper and lower confidence limits, the resulted $^{87}Sr/^{86}Sr$ values are expected to be between 0.708798 and 0.708810. However, the Badenian gypsum sections in southern Poland show steadily higher $^{87}Sr/^{86}Sr$ ratio compared to values expected for a Middle Miocene open ocean, up to 0.709154 to 0.709838 in western Ukraine. It is supposed that high-grade Archaean and Palaeoproterozoic igneous and supracrustal rocks of the Podolian domain of the Ukrainian Shield that are exposed some 100 km to the east of the margins of the Badenian evaporite basin, were the source of higher $^{87}Sr/^{86}Sr$ ratios recorded in the Badenian primary gypsum. The lowest $^{87}Sr/^{86}Sr$ values are recorded in the giant gypsum intergrowth unit that grew under a low level of supersaturation. The values in the Badenian anhydrite are generally much higher, and anhydrite isotopic signatures reflect highly radiogenic non-marine inputs to the basin due to mixing from terrigenous sources or expulsion of buried brines during the origin of the Carpathian orogen.

Isotopic signatures and geological-mineralogical peculiarities of the Phanerozoic evaporate-bearing formations as key indicators of the Precambrian sulfates' origin

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In spite of numerous sulfates finds in the Precambrian formations there is a steady skepticism on possibility its stability during metamorphism. Anhydrite is resistant to temperature coercion up to 1400 °C, and only in open physical-chemical system fluids will decrease temperatures of its decomposition. Many of sulfate finds are not disseminated along metamorphic sequences, and concentrated into separate lenses or layers within of geological bodies, so sulfates, similar to carbonates, are stable in such intercalations and the ion SO_4^{2-} is an inert component in this closed physical-chemical system analogous to the ion CO_3^{2-} in carbonate-bearing deposits.

Geological-mineralogical peculiarities and isotopic marks of the Phanerozoic evaporate-bearing formations from the Alpine Europe regions (Kasprzyk, 2005; Bojar *et al*., 2016) have been involved to get detail model data on composition of facies, style of their transitions and sulfates distribution within typical sequences.

Precambrian meta-sedimentary sequences of the Aldan and Ukrainian Shields have been analyzed to create a model of the Precambrian evaporate formations with the unusually high proportions of carbonate rocks, some rich in sulfates varieties, and in some area crown with salt (the Pamir). Metamorphic rocks with sulfates were most often identified in the Fedorovskaya Formation on the Aldan Shield, and studies have revealed the lithological control of mineralization.

It was established that an increase in the grades of metamorphic and metasomatic alterations is associated with the enrichment of carbonates in light carbon and oxygen isotopes. This opens the possibilities of using isotopic data to assay the extent of transformations of primary rocks. The isotopic composition of sulfur was determined in gypsum and anhydrite samples from all morphogenetic types, and the carbon and oxygen isotopes values were analyzed simultaneously in coexisting carbonates to determine degree of alterations.

Sulfur containing mineral phase commonly are heterogeneous and composed of several generations. First generations of anhydrite from concordant layers, lenses or segregations in marbles and gneisses are characterized positive $\delta^{34}S$ values (from +5.4‰ to +6.9‰). The studied gypsum from layered varieties is characterized by similar $\delta^{34}S$ values (up to +5.4‰). The associated carbonates have high $\delta^{13}C$ values (up to +6.00‰, PDB), and $\delta^{18}O$ values range from 19.40‰ up to 23.40‰, SMOW. Among the rocks examined, high $\delta^{13}C$ values were shown by apatite-carbonate rocks, whose protolith was produced chemogenically in shallow evaporate basins with oxidizing conditions.

Later anhydrite generations have $\delta^{34}S$ values (20.3–32.1‰) similar to the studied gypsums: from 22.5‰ to 30.1‰. Both $\delta^{13}C$ and $\delta^{18}O$ in the carbonate samples from the late veins and nests are much lighter than from the concordant carbonate rocks due to the subsequent transformations of the primary rocks by fluids. Preserved isotopic marks can be evidences of closed for separate blocks systems.

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Carbon isotope fingerprint – a proxy for climatic changes during the middle and late Holocene in a peat bog from the Maramureş Mountains (Romania)

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The main goal of this study was to use stable carbon isotopic composition of bulk peat sampled in Tăul Mare-Bardău peat bog, Maramureş Mountains, as tool to provide paleoclimatic information over the middle and late Holocene in this region. A peat core of 3.60 m was sampled for $\delta^{13}C$ analysis, and bulk peat samples were analyzed by IRMS method. $\delta^{13}C$ values reveal a maximum variation of 4.65‰ along a 3.6-m long peat core. We examined the vertical variation of $\delta^{13}C$ bulk peat and concluded that several factors could contribute to down core trends of $\delta^{13}C$. Four intervals of climatic variability could be related with variations of $\delta^{13}C$ values between ~6800 cal. yr BP to present: two wet periods (around 545 and 2800 cal. yr BP) and two dry periods (1430 and 6760 cal. yr BP). We concluded that variability in the $\delta^{13}C$ of bulk peat profile could be influenced most heavily by the water availably which, in turn, is related to the amount of precipitation at the time. Four intervals of $\delta^{13}C$ variations of the peat sequence between 225 cm to 25 cm can be related with generally accepted intervals of climatic variability that have occurred within the last 2000–2500 years (LIA, MWP, DACP and RWP). The climate was probably of warm-cold alternations, as revealed in our peat core by $\delta^{13}C$ variations between 2800 cal. yr BP to present. $\delta^{13}C$ values of peat profile showed two positive signals at 40 cm and 225 cm depth and two negative signals at 105 cm and 350 cm depth. We suggest that these could also represent a change in vegetation at the time.

Pliocene paleoenvironmental reconstruction in Carpathian–Balkan region based on stable isotope compositions of mammal teeth

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Stable isotope compositions of skeletal apatite of herbivorous mammals are outstanding archives of paleoecological, paleoenvironmental and paleoclimate information. Stable carbon isotopes of the apatite reflect the $\delta^{13}C$ composition of the plants consumed by the herbivores, hence, it can provide information about the photosynthetic pathway (C3 or C4), the openness of vegetation and/or the amount of precipitation. Stable oxygen isotope composition of apatite depends on the composition of the ingested water by the animal. The $\delta^{18}O$ value of the ingested water is often close to the $\delta^{18}O$ value of the local precipitation, while the isotopic composition of the precipitation can be linked to the mean annual temperature of the area. Tooth enamel of large, obligate drinking herbivores could be the best archives because enamel is the most resistant tissue to diagenetic alteration and these mammals track most closely the average $\delta^{18}O$ value of environmental water.

In this study, stable isotopes of fossil teeth enamel of rhinoceros and gomphothere species were investigated from the Carpathian Basin, areas from Bosnia and Herzegovina, and from Southeast Romania. Carbon isotopes were measured from the structural carbonates, while oxygen isotopes were measured from the phosphate fraction of the apatite. Besides the bulk analyses, several sub-samples were collected along a vertical profile from one of the rhinoceros teeth to gain information about seasonality. According to the biostratigraphy, the age of the samples ranges from Pliocene to Early Pleistocene, from biozones MN15 to MNQ17. Among the sites, there are new fossil localities that have not yet been exploited for palaeoclimate reconstruction. Because of this, the new isotope results can provide valuable data about climate and paleoenvironment in the Carpathian and Balkan region.

The $\delta^{13}C$ results range from around −10‰ to −16‰ (V-PDB), indicating pure C3 vegetation. The main flora type was woodland in most of the studied localities but spatial and temporal differences were also detectable. Relatively high $\delta^{13}C$ values in MN15 in the Carpathian basin and in Southeast Romania can reflect more open woodlands probably due to stronger continentality, while the low values from Anancus arvernensis samples from Cebara locality indicate forested vegetation with high mean annual precipitation. The reconstructed humid climate is not surprising, as modern-day precipitation values in that area are among the highest in Europe. This result can also indicate that these animals lived in mountainous areas in the karst Dinarides, although the $\delta^{18}O$ values do not support a very high altitude. The $\delta^{18}O$ values have a range from 10‰ to 16‰ (V-SMOW). The calculated $\delta^{18}O$ values of the precipitation are similar to present-day values and spatial distribution in the studied regions. The $\delta^{18}O$ values of a sequentially sampled tooth from Pula locality show a sinusoidal signal, most probably reflecting a one and a half year period of formation and mineralization of the tooth. However, quantitative estimation of the temperature differences between seasons is not possible due to the averaging of the environmental isotope signal. The $\delta^{13}C$ values also show seasonal differences. These could reflect the seasonally changing $\delta^{13}C$ values of the consumed vegetation or a seasonal migration of the animal, similar to what is observed in recent elephants.

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Ecophysiology of vent communities, Manus Basin, Papua New Guinea: insights from stable isotope geochemistry, minor element content and shell microstructure

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Hydrothermal vents are source of heat as well as sulphur and carbon compounds on which characteristic trophic levels forms. Around vents, the distribution of communities is limited by step temperature, salinity, pH gradients and nutrient availability. The fauna shows characteristic niche partitioning for different groups of animals associated with numerical dominance of a few species (Collins *et al*., 2012).

In the Western Pacific Ocean, a large and active hydrothermal field of the Manus Spreading Center is the hydrothermal field 1 at 2500 m depth. The gastropods *Ifremeria nautilei* and *Alviniconcha hessleri* are among the most abundant macroorganisms living at the site. *I. nautilei* reaches the highest density (500–700 adults/m^2) in the vicinity of active hydrothermal vents, where sulfide and methane emissions mix with sea water to form the 'shimmering water' zone, at ambient pressures of 250 bars (Reeves *et al*., 2012). Alongside with the two gastropods, a barnacle *Echionelasmus ohtai manusensis* and a deep-sea coral were investigated as well.

Shell microstructures as well as minor element contents and stable isotope compositions of the macroorganisms organisms provide information about local adaptation, niche characteristics, specific metabolic activity and food sources during their lifetime (Bojar *et al*., 2018).

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Use of hydrochemical and isotopic indices to trace water leakages from Lake Badovc (Kosovo) and Lake Koman (Albania)

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The hydrochemical and isotopic (^{2}H and ^{18}O) data were used to trace water leakages from Lake Badovc (Kosovo) and Lake Koman (Albania). The Lake Badovc represents the main source for drinking water supply of Prishtina city and surrounding settlements. It was built in 1965 along the course flow of River Graçanca. The geological formation where the dam is located is mostly composed of altered and intensively fissured serpentinites with subordinate phyllite schist, clastic formations and gabbro-diabase rocks. Lake Komani has the second highest (115.5 m high) dam of River Drini Cascade and in Albania, as well. It is a concrete faced rock fill embankment dam that was constructed from 1980 to 1985. The surrounding area of the dam is composed of hard rocks, mostly represented by Triassic schists, Jurassic–Cretaceous limestones and Paleogene flysch.

The monitoring of hydrologic components of Lake Badovc basin and respective calculations of Lake water balance for 2014 found a deficit of 3,738,905 m³ water that was considered as water loss from the Lake (Bublaku and Beqiraj, 2015) and was mostly attributed to water leakages from the bottom of the lake to Hajvalia Mine voids. Water of Hajvalia mine shows similar chemical composition with water of Lake Badovc, whereas its isotopic composition (δ^{18}O = –10.15‰; δD = –73.3‰) falls between isotopically lighter rain water (δ^{18}O = –16.56‰; δD = –129.6‰) and lake water (δ^{18}O = –9.2‰; δD = –67.2‰). The chemical and isotopic data favor the opinion that a continuous groundwater outflow from the lake is present that is caused by infiltration of lake water through the intensively developed fracture system in the lake basement formations. Considering that Hajvalia mine water is a mixture between rain water and lake water, from the isotopic mass balance of ^{18}O and ^{2}H (Cook and Herczeg, 2000) was found that the fraction of rain water in mine water ranges from 6% (according to ^{2}H) to 10% (according to ^{18}O), while the fraction of lake water varies from 94% (according to ^{2}H) to 90% (according to ^{18}O).

Some water leakage from the dam toe of Lake Koman were noticed in 2014 and they were considered to derive either from the lake or from the karst limestone massifs extending in the northwestern regions of the dam. Nine water samples, for both hydro chemical and isotopic analysis, were taken from dam toe water leakage, lake water karst spring near to the dam, grout gallery and from Bena karst spring located about 3 km north of dam. According to their inert and reactive nature, the chemical elements may be effectively used to trace physical parameters such as recharge rates and mixing (Herczeg and Edmunds, 2000). The chemical composition of water clearly distinguished two very different hydro chemical water: Ca-Mg-HCO_3 hydrochemical type for the water from lake, dam toe leakage, and grout gallery and Ca-HCO_3 hydro-chemical type belonging to Bena karst spring. The isotopic composition of ^{18}O and D strictly confirmed the results taken from the hydro-chemical data. The waters from the lake, dam toe leakage and grout gallery show the same isotopic composition (δ^{18}O = –9.39 ÷ 9.24‰; δD = –65.56 ÷ 62.24 ‰), which, in turn, is isotopically lighter (more negative δ values) than karst water of Bena spring (δ^{18}O = –8.25‰; δD = –50.4‰).

Finally, the isotopic composition of the water from the small karst spring near the dam falls between that of karst water and lake water (δ^{18}O = –8.69‰; δD = –57.8‰), showing that its water represents a mixture between lake water (57% and/or 51.5%) and karst water (43% and/or 49.5%), according to ^{18}O and D, respectively.

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Water column distribution (45 m depth) of stable isotopes in the Black Sea: a preliminary study

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The oxygen and hydrogen isotopic fingerprints of sea-water ($\delta^{18}O_{SW}$ and $\delta^{2}H_{SW}$) and the stable carbon isotope ratio of dissolved inorganic carbon ($\delta^{13}C_{DIC}$), conductivity, dissolved oxygen and the pH were determined in 80 samples collected from the Black Sea, at 13 m, 20 m, 30 m and 45 m depth, during the survey conducted on board in May 2018. The vertical profiles of $\delta^{18}O_{SW}$ and $\delta^{2}H_{SW}$ presented a clear depth signature. In addition, heavy metals concentrations (Cd, Pb, Hg, As, Cu, Zn) were analysed because they are stable, persistent, non-biodegradable, and toxic contaminants in aquatic environments, thereby potentially threatening the health of aquatic organisms and ecosystems and then humans through food chains. With the increased anthropogenic activities in coastal zones, heavy metal pollution has become a global concern. To obtain $\delta^{18}O$ and $\delta^{2}H$ values, the analysis were made by using a Liquid-Water Isotope Analyzer (DLT-100, Los Gatos Research). The isotopic fingerprint of carbon was measured with an Elemental Analyser, coupled with an isotope ratio mass-spectrometer IRMS (Delta V Advantage, Thermo Scientific). For elemental determinations, a ICP-MS (Elan DRC-e, Perkin Elmer) was used.

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Analysis of stable chlorine isotope composition with high accuracy

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Chlorine is the second element of the halogen group and has two stable isotopes ^{35}Cl and ^{37}Cl. The ^{35}Cl isotope has an abundance of 75.76% while the ^{37}Cl consist of the remaining 24.24%. The halogen elements are relatively rare in the Earth, the most common being chlorine with a concentration of 10.5 ppm for Earth. The halogen elements are however among the most volatile ones and they are they have a low compatibility with most of rock types. Especially chlorine is volatile and prefer to concentrate in fluid phases meaning that it is concentrated in the oceans as well as in evaporates.

The most common method used in the chlorine isotope ratio analysis employs the conversion of a chlorine sample to chloromethane (CH_3Cl) prior to the mass spectrometric analysis. For CH_3Cl preparation the exchange reaction between the iodomethane (CH_3I) and silver chloride (AgCl) is applied. We followed the procedure described by Eggenkamp (2004) with some modifications: (1) the aliquot of iodomethane is added to the preparation line by using the pipete connected to a container with pure liquid CH_3I, thereby the injection of iodomethene through a septum is eliminated; (2) the conversion of AgCl to CH_3Cl is performed in glass ampoules with Teflon stopcocks sealed with elastomer O-rings, thereby cracking tubes are eliminated; and (3) the obtained chloromethane is cryogenically separated from iodomethane using three traps (one with butyl acetate and two with trimethylpentane) connected in series.

The obtained chloromethane is then analyzed by the isotope ratio mass spectrometry (IRMS). For this purpose we have used a negative ion mass spectrometer which retains all the best features of IRMS, including dual inlet system with changeover valve, dual collector assembly and CH3Cl gas as analyte. In the modified ion source we have replaced the ionization chamber with electron beam by a metal tube with a hot metal filament inside. Within this tube the $^{35}Cl^-$ and $^{37}Cl^-$ ions are generated. No other ionic species were found in the mass spectrum except of traces of CN^- and CO^-. The method's precision is better than 0.01‰ (Pelc *et al.*, 2008; Hałas and Pelc, 2009).

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Stable isotopic and mineralogical investigations of rich in carbonaceous and carbonate flysch rocks of the Ukrainian Carpathians

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Sandstones, argillites and siltstones are permanent components of the flysch sequences of the Ukrainian Carpathians. Limestones, dolostones and marls are developed sporadically in variable amounts. The above-mentioned rocks in different proportions are typical for all regional units and tectonic zones of the studied area.

Significant role of terrigenous carbonates was established for the sandstones, argillites and siltstones. After detailed mineralogical investigations and due to high values of carbonates (up to 77.11 wt.%), the rocks were determined as calclithites after Folk's classification. Two main morphological and mineralogical generations of carbonates of different ages are distinguished within the calclithites after petrographic studies, X-ray powder diffraction observations, and microbeam analyses (Guliy *et al*., 2017). Early generation of the carbonates is represented by coarse grained detrital dolomite and finer calcite as cement is a late generation.

A set of secondary carbonate, carbonate-quartz, and carbonate-sulfide druses and veins is widespread in the different tectonic units of the Ukrainian Carpathians. This type of mineralization is distributed locally and mainly concentrated in the thrusts and transcurrent fault zones.

Medium- and coarse-grained and sometimes up to gravelitic sandstones (up to 90% of the total volume), and dark to black fine-grained argillites and siltstones are sporadically enriched in fine dispersed organic material similar to anthraxolite. Sporadically, it is distinguished as separate lenses or layers with thicknesses up to a few millimeters. In such cases, they are similar to rocks of the Menilitova Suite, rich in organic materials. According to X-ray powder diffraction observations, the material has complicated and multiphase composition and is mainly X-ray amorphous.

For the initial flysch rocks, the $\delta^{13}C$ isotopic composition of carbonates varies between –1.57‰ and +2.20‰ (PDB) and $\delta^{18}O$ from +21.42‰ to +29.54‰ (SMOW). There is a very small shift between isotopic composition of carbonates from clasts, cement, and separated geological carbonate bodies. Obtained data for the initial carbonates are typical for marine limestones, and detrital fractions as well as the cement have the same origin.

Later carbonate formations, according to carbon and oxygen isotopic data, have been formed due to interaction with the surrounding host rocks. Sometimes, younger generations of carbonates with lighter $\delta^{13}C$ composition could have crystallized from mixing fluids.

The observed organic materials are characterized by light $\delta^{13}C$ (up to –23.41‰, PDB), which is similar to humus coal (Taranik and Kanin, 2013). Preserved isotopic marks for carbonate-bearing rocks can be evidence of mainly closed for separate blocks systems, and replacing of primary materials happened only along some fractures and faults.

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Silicon isotopic fractionation during water-rock interaction

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The Si isotopic composition of natural waters is a promising proxy to gain insight into the processes that govern the global biogeochemical Si cycle. We measured the isotopic Si fractionation of opal, diatomite, quartz and amorphous silica during dissolution at pH 3 and 9 at 70 °C in an attempt to help quantify these processes.

The isotopic composition of the Si released from quartz is identical to that of the dissolving mineral. In contrast, the Si released initially by opal-CT, diatomite, and amorphous silica dissolution at pH 3 is isotopically light, but with time, the Si isotopic composition of the fluid phase becomes heavier and eventually exceeds that of the dissolving solids. In contrast, at pH 9, the fluids are initially enriched in isotopically heavy Si; these fluids become isotopically lighter with time, converging in the case of diatomite and opal towards the composition of the dissolving solids. This trend continues despite the fact that bulk equilibrium between fluid and solid has been attained. This observation confirms that minerals and their co-existing fluids can alter isotopic composition even after bulk equilibrium between fluid and solid is attained. Moreover the temporal pattern of the isotopic evolution in our experiments suggests that the two-way-transfer of material to and from the mineral surface is responsible for the observed release of Si isotopes during dissolution.

Session GT2-1

Mesozoic of the Tethys realm

Conveners:

Sigrid Missoni, Michal Krobicki, Michael Wagreich, Martin Djakovic, Hans-Jürgen Gawlick, János Haas, Adamantios Kilias, Tea Kolar-Jurkovsek and Jozef Michalik

Development, dolomitization and drowning of Middle Triassic isolated carbonate platforms,Transdanubian Range, Hungary

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In the Middle Anisian, extensional tectonic movements led to the development of isolated carbonate platforms in the area of the SW part of the Transdanubian Range. In the presentation comparative study of platform evolution, early diagenesis, dolomitization and drowning history of two coeval platforms will be discussed. The platforms are made up of metre-scale peritidal–lagoonal cycles bounded by subaerial exposure surfaces. One of the platform successions (Tagyon Platform) contains non-dolomitized, partially dolomitized, and completely dolomitized intervals, while the other one (Szentkirályszabadja Platform) is completely dolomitized. Based on investigations of the partially dolomitized section of the Tagyon Platform penecontemporaneous dolomite formation and/or very early post-depositional dolomitization were inferred in various lithofacies types. In shallow subtidal facies porphyrotopic dolomite was found preferentially in microbial fabric elements (micritic nodules and crusts, cortex of oncoids). Some of the stromatolite beds were also affected by early dolomitization. Microcrystalline dolomite probably of pedogenic origin was encountered in paleosol horizons. In the completely dolomitized succession of the Szentkirályszabadja Platform fabric-retentive dolomite is predominant. More positive $\delta^{18}O$ values were found in various fabric elements of every lithofacies type than in the corresponding samples taken from the partially dolomitized succession. It is probable that in this case after near-surface syndepositional and early diagenetic dolomitization processes intense mesohaline reflux led to almost complete dolomitization prior to the deeper burial. Drowning of the platforms took place in the Late Illyrian whereby submarine highs came into existence. Condensed pelagic cherty carbonate successions with volcanic tuff interbeds were formed on the top of the already drowned platforms. Above the Tagyon Platform phosphorite horizons occur in the basal beds which contain an extraordinarily diverse ammonite fauna. This unit is overlain by radiolarian-rich carbonates, locally with radiolarite interbeds. We suggest that the drowning process and the post-drowning sediment deposition were controlled partly by regional factors, i.e. the onset of opening of the Neotethys Ocean, and partly by local factors such as the bottom topography and related current activity, which may also be connected with the opening of the ocean. The predominance of the radiolarian-rich sediments suggests eutrophic surface water which may be explained by a monsoon-driven upwelling model. Since similar Middle to Late Anisian evolution was reported from many other units of the western Neotethys margin, the regional factors such as the establishment of an extensional tectonic regime and related marginal basin formation, monsoon-driven upwelling and related high surface water productivity seem to be of critical importance in the controlling of the depositional conditions.

Palynology of a Middle Triassic (Anisian) ramp system (NW Bulgaria): Towards a refined age control and depositional model

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The Anisian is a crucial time interval in Earth's history to understand carbonate platform reorganization in the aftermath of the most severe extinction event at the end of the Permian and incipient break-up of the supercontinent Pangaea. The northwestern Tethyan realm is thus best suited to study the Anisian comeback of shallow marine environments at the beginning of the Mesozoic.

The onset of an Anisian ramp system, after continental sedimentation in the Early Triassic, is well documented in the Western Balkanides of NW Bulgaria showing a prominent cyclic character of peritidal and shallow marine carbonates (Ajdanlijsky *et al*., 2018). Excellent exposures along the Iskar river gorge enable a detailed study of the Anisian ramp deposits and for the first time a palynofacies analysis was performed to better understand the controlling processes in the carbonate ramp evolution. Furthermore, this study aims at establishing a palynostratigraphic framework for the Middle Triassic of NW Bulgaria to overcome the previously limited regional correlation with Middle Triassic ramp deposits of the northwestern Tethyan and Peri-Tethyan realms.

Palynofacies parameters used to decipher transgressive-regressive trends within the succession are: (1) the ratio of continental to marine constituents (CONT/MAR ratio); (2) the ratio of opaque to translucent phytoclasts (OP/TR ratio); (3) the phytoclast particle size and shape; and (4) the relative proportion and species diversity of marine phytoplankton. A large-scale transgressive-regressive trend is clearly documented in the CONT/MAR ratio and phytoplankton abundance. Superposition of high frequency, low-amplitude sea-level fluctuations on the larger-scale sea-level trend is detected by pronounced cyclic signatures in changes of terrestrial input, preservation and sorting of phytoclasts, and prominent phytoplankton peaks indicating major flooding phases.

A first marine pulse in the early Anisian is followed by a major flooding event in the Pelsonian, detected by peak abundance of marine acritarchs. This prominent transgressive signature is recorded in carbonate ramp systems along the western Tethys shelf and characteristic diachronous facies successions in the northern Peri-Tethys Basin (Feist-Burkhardt *et al*., 2008) and might reflect a global warming episode (Retallack, 2013; Li *et al*., 2018).

Ongoing research addresses the identification of palynofacies patterns in the Milankovitch frequency band for high-resolution cyclostratigraphic interpretation.

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Carnian outer continental shelf succession in the Budva Zone (Montenegro)

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Along the coastal site of the Budva Zone in Montenegro, the deposition of open-marine sediments started in the Middle Anisian (Late Pelsonian), time equivalent with the oceanic break-up of the Neo-Tethys. Shallow-water carbonates, open-marine limestones, radiolarites, bentonite horizons, volcanic resediments, and silicified mudstones to hemipelagic carbonate sequences in upsection positon characterize in general the Middle Triassic sedimentation on the outer continental shelf. The paleoenvironmental evolution in the depositional setting was controlled by stratified volcanic activities and a related ocean-acidification. Shallow-water carbonate production on the mid continental shelf lasted from the latest Ladinian onwards. Hinterland influence and thickness of sediment deposition varies with the palaeogeographic position on the shelf.

In the Cordevolian, the studied open-marine succession in Canj consists of grey-reddish hemipelagic carbonates with stratified accumulations of halobiids. In this temporary very low-energetic environment shed mass transport deposits, whose clasts derived from the former horst complexes. A long-lasting submarine gap of the entire Julian to Tuvalian 1 is related to a very long lasting emergence of the Wetterstein Carbonate Platform. From the Tuvalian 2 onwards the continuing hemipelagic carbonatic sequence is characterized by an increasing energy level in the depositional environment that is reflected in unsorted accumulations of echinoids and halobiids, but also in a gradual oxygenating sediment colour. The shedding of the mass transport deposits lasted in repeating successions until the earliest Tuvalian 3, which corresponds with the time contemporaneous volcanic activity known in the eastern Mediterranean orogen. The clast spectra consist predominately of recycled Carnian sequences. An order of dissolution and recrystallization reactions in the lithifying breccia caused to a fermentative decomposition of the organic matter, metal sorption onto suspended particles, and to the formation of authigenic minerals. The latest Tuvalian 3 to earliest Lacian 1 is nicely documented by conodonts and associated macrofossils as *Halobia* sp., *H. beyrichi* (Mojsisovics) and *H. styriaca* (Mojsisovics) (Cafiero and De Capoa Bonardi, 1980). From the Late Carnian onwards lasted on the shelf a normal-marine depositional environment with high sedimentation rates of grey hemipelagic carbonates.

This Carnian trend in the open-marine Hallstatt limestone succession can be directly correlated with other high resolution Hallstatt limestone successions, dated by means of conodonts in the e.g. Eastern Alps, Western Carpathians, Dinarides and Turkey. A deposition in an independent deep-water basin (Mirdita-Pindos) is not mirrored in the depositional characteristics or tectonostratigraphic events.

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Lower Jurassic Bahamian-type facies of the Hronicum domain in the Tatra Mts (West Carpathians, Poland) conditioned by palaeogeography and palaeocirculation in the Western Tethys

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The Lower Jurassic (upper Sinemurian) succession of the Hronicum domain (Tatra Mts, Western Carpathians, Poland) represents typical tropical shallow-water carbonates of the Bahamian-type. In three sections with total thickness not exceed 145 m, eight microfacies were recognized. These are oolitic-peloidal grainstone/packstone, peloidal-bioclastic grainstone, peloidal-lithoclastic-bioclastic-cortoidal grainstone/packstone, peloidal-bioclastic packstone/grainstone, peloidal-bioclastic wackestone, spiculitic wackestone, recrystallized peloidal-oolitic grainstone and subordinate dolosparites (Rychliński *et al*., 2018a).

As follow from sedimentological an palaeontological record, the studied sediments were deposited on a shallow-water carbonate platform characterized by normal salinity, in high-energy oolite shoals, bars, back-margin, protected shallow lagoon and subordinately on restricted tidal flat environments. In some facies there are present microcoprolite Parafavreina, green alga Palaeodasycladus cf. mediterraneous (Pia) and Cayeuxia, typical of the Early Jurassic carbonate platforms of the Western Tethys (Rychliński *et al*., 2018b). The spiculite wackestone from the upper part of the studied succession was deposited in a transitional to deeper water younger sediments. The studied upper Sinemurian carbonates of the Hronicum domain reveal microfacies similar to the other Bahamian-type platform carbonates of the Mediterranean region (*e.g.*, from the Western Sicily, Central Apennines or Southern Alps). Thereby, they record the northern range of the Lower Jurassic tropical shallow water carbonates in the western part of the Tethys, albeit the thickness of the Bahamian-type carbonate successions generally decrease in a northerly direction.

The sedimentation of the Bahamian-type deposits in the Hronicum domain, located during the Early Jurassic at about 28ºN, besides other specific factors (*i.e.*, light, salinity and nutrients) was strongly controlled by the palaeocirculation of warm ocean currents in the Western Tethys area. The palaeogeographical situation of the area and its palaeocirculation is somewhat similar to the recent western middle Atlantic in the region of Bahamas.

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Lower Cretaceous (Neotethyan) flysch in the eastern Southern Alps (NW Slovenia)

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Lower Cretaceous syn-orogenic sediments derived from the obducted ophiolites of the Meliata-Maliac-Vardar (Neotethys) Ocean are typical of the Dinarides and the Austroalpine units. Correlative flysch-type deposits linking both regions through the eastern Southern Alps had been reported from the Bohinj area (NW Slovenia) but their stratigraphic and structural framework remained poorly known.

Our research focused on stratigraphic and structural field studies in a 50 km^2 area between Lake Bled and Lake Bohinj in the Julian Alps. The mixed carbonate–siliciclastic sediments, informally named Studor formation, range in age from the Valanginian (possibly late Berriasian) to the Aptian. They form the terminal sequence of two different stratigraphic successions. The first succession is entirely of deep-water origin from the Middle Triassic and was ascribed to the Bled Basin. The second succession consists of Upper Triassic to Lower Jurassic shallow-water carbonates overlain by a thin Jurassic–Cretaceous deep-water sequence and was located at the eastern margin of the adjacent Julian Carbonate Platform/Julian High. Practically identical Mesozoic successions are known from the Bosnian Zone in the central Dinarides, and closely similar successions characterize the Tirolic units of the Northern Calcareous Alps in Austria and the northeastern Transdanubian Range in Hungary. The equivalents of the Studor formation are the Vranduk Formation (lower part of the Bosnian Flysch) and the Oštrc Formation in the Dinarides, the Rossfeld Formation in the Northern Calcareous Alps and the Lábatlan Sandstone Formation in the Transdanubian Range.

The two stratigraphic successions are assigned to two superposed nappes. The succession of the Bled Basin belongs to the Pokljuka Nappe, which is the highest nappe of the original (Dinaric) nappe stack. The platform-to-basin succession is part of the underlying Krn Nappe. The original thrust contacts are completely obliterated by younger deformation. The present-day boundaries between these two nappes are steep NE-SW striking fault segments cross-cut by younger NW-SE striking faults. A detailed geological map with representative cross-sections in combination with data from the literature allowed us to recognize the following post-nappe deformation sequence: (1) Oligocene–Early Miocene NW-SE contraction; (2) Early–Middle Miocene extension; and (3) Late Miocene to recent inversion and transpression.

Early Jurassic (Pliensbachian–Early Toarcian) shallow-water environments with faunal and floral associations in the Albanian Alps

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The large bivalves (up to 50 cm long) of so-called "Lithiotis" facies, are most significant representatives of buildup-maker of shallow marine/lagoonal bivalve mounds ("reefs") in numerous places around the Pangea during Pliensbachian–Early Toarcian time. In Europe they constitute the Early Jurassic Alpine-Adriatic-Dinaridic-Hellenidic carbonate platforms with different kind of shallow sea environments, including peritidal to subtidal sedimentation regimes which are typical for Lithiotis-type bivalves (Lithiotis, Cochlearites, Lithioperna, Mytiloperna, Gervileioperna). One of the most spectacular section (ca. 300 m in thickness) with at least five horizons of bivalve-rich limestones, is located in north-western part of the Albanian Alps, along mountainous road between Rapsh and Grabom villages. These layers are intercalated by grey-dark bluish bioclastic and marly limestones. Taphonomic and autecological analysis of bivalves-rich horizons based on semi-quantitative observation of orientation of shells and density of their occurrence indicate dominance of parauthochthonous associations (the ratio of horizontal to vertical shells) with a few places with record of shells in life position (dominance of vertical orientation of shells and so-called bouquets). Some beds full of bivalves have oblique, lens-shape character with sharp boundaries both with under- and overlying beds and maybe correspond to biostrome nature in origin. Bivalve-rich limestones/marls are intercalated by oolitic/oncolitic layers which indicate extremely shallow-water environments with high-energy regimes, including beds of storm events. On the other hand this sequence comprises several coal-bearing intercalations between intertidal carbonate rocks of full-marine–lagoonal–land transitional lithofacies. Alteration of ingressions caused in the coastal area floods resulting in flora devastation and dryness of different degree, sometimes effecting in swamp formation. There were several coastal cycles, and at least in two cases aired roots confirm occurrence of mangrove(?) palaeoenvironments. Some leaf remains have been collected so far from the section, however, not from the same beds as roots. These are leaves of two species: one of them from the genus Pachypteris (seed fern), the second, Brachyphyllum (conifer). Particular species of both genera were supposed to be adapted to salty substrate and/or salty mist. Based on their gross morphology and cuticular structure as well as on depositional environments in which usually reminded, they were interpreted as growing in coastal habitats which here could be confirmed by root systems. Generally, the localities with in situ fossil record of ancient mangroves are extremely rare due to their sporadic distribution over the world and very low fossilization potential in such high hydrodynamic shallow-marine environments. Their identification up today was based mainly on the preservation of pollen and/or wood pieces, whereas the fossil record of root system of mangrove trees usually is missing, so, the recent knowledge about Mesozoic mangroves record is full of gaps. According to similar Early Jurassic sections with Lithiotis-type bivalves in almost whole Europe (Spain, Italy, Croatia, Slovenia, Greece) and outside of Europe (Morocco, Oman, Nepal) this locality is the most perspective for reconstruction first over the world, Early Jurassic sure mangrove ecosystem with such bivalves co-occurrence.

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Age and microfacies of a carbonate-clastic radiolaritic basin fill above the Koziakas Mélange (Hellenides, Greece)

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The Koziakas unit is located in northern Greece and thrust westwards over the Pindos unit during the Early Tertiary. Both units present a similar stratigraphy including Mesozoic and Lower Cenozoic deep water sediments. Toward the east, the Koziakas unit borders with a NW-SE trending dextral transpressional fault zone, the Mesohellenic Trough that is filled with Upper Eocene to Lower–Middle Miocene turbidites. The Mesozoic sequence of the Koziakas unit is thrust over by ophiolites with a Middle Jurassic (Bathonian) ophiolitic mélange at their base. The ophiolitic mélange was formed in front of the advancing ophiolites as sedimentary mélange containing a mixture of ophiolite and continent-derived material. In the western part of the Koziakas unit, the basin was not completely incorporated into the thrusting process and remained open, receiving sediments during the time span from the Callovian to the earliest Cretaceous.

We studied the higher part of the basin fill in the central eastern Koziakas unit near the village Kori where a more than 300 m thick radiolarite sequence was deposited above the mélange. In the higher part of the radiolarite sequence mass transport deposits appear, consisting of open-marine and shallow-water carbonate clasts. We studied parts of the radiolarite sequence below these carbonate-clastic resediments and analysed the components in the different breccia layers.

Few of the processed radiolarite samples yielded moderately preserved radiolarian faunas. The radiolarian association of a sample from the radiolarite sequence yielded Cinguloturris carpatica, Emiluvia orea, Emiluvia nana, Fultacapsa sphaerica, and Tethysetta matshitaensis which point to a middle-late Oxfordian age. The younger radiolarian sample, roughly 50 m above, yielded *Angulobracchia biordinalis*, *Suna echiodes*, *Paronaella mulleri*, and *Tritrabs casmaliaensis* indicating a middle–late Oxfordian to early Kimmeridgian age. Approximately 100 m upward, first turbidites consisting of limestone clasts are intercalated. Later, the amount of turbidites increases and the first fine-grained mass-transport deposits show a coarsening-upward trend.

Near the village Kori, the limestone components from a series of well outcropping mass transport deposits and turbidites in a radiolarian-rich and silicified wackestone matrix were studied. Beside limestone clasts from a contemporaneously formed carbonate platform (containing "*Tubiphytes*" sp., encrusting organisms, and ooids), limestone clasts with *Saccocoma* and deep-water *Calpionella*-limestone clasts are incorporated into the mass transport deposits. Poorly preserved calpionellids (*Crassicollaria brevis* or *Calpionella elliptica*) point to the Berriasian as the oldest age of redeposition. These Upper Jurassic clasts are mixed with rare clasts from the Late Triassic Dachstein Carbonate Platform (*e.g.*, *Aulotortus sinuosus*) and Middle Jurassic *Bositra*-limestone clasts. Ophiolitic material is missing in these mass transport deposits.

We interpret that the Upper Jurassic components are derived from (I) a shallow-water carbonate platform formed on top of the ophiolitic nappes, and (II) from recycled material of a distal continental margin. Similar situations are known from the Albanides or the Northern Calcareous Alps.

Microfacies and microfossils from the Upper Berriassian–Lower Valanginian carbonate deposits from “Guri i Pellumbave” section, Mirdita zone

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A detailed microfaciesal and micropaleontological analysis of the Lower Cretaceous deposits from “Guri e Pellumbit” section will help to better understand the age and the evolution of the post-obduction sedimentary carbonate deposits situated above the ophiolites of Mirdita zone.

The benthic foraminifera, calcareous algae and some enigmatic microencrusters (microproblematica) are the main components of Lower Cretaceous reefs and carbonate platforms and have proved to be extremely helpful in their zonation and for these purposes, they were analyzed together with the typical microfacies association.

The identified microfacies associations from Guri i Pellumbave section are typical for an allodapic limestone – in fact, the whole sampled section shows a mixture of elements typical for shallow water settings and calpionellids, elements characteristic for deep water environments which allow us to be interpreted them as slope sediments.

Based on the identified micropaleontological assemblages, the age of these deposits was assigned to Upper Berriasian- Lower Valanginian by taking into consideration the next micropaleontological associations with biostratigraphical significance: *Pseudocyclammina lituus, Protopeneroplis ultragranulata, Mohlerina basiliensis, Coscinoconus alpinus, Coscinoconus elongatus*, normally typical for Upper Jurassic deposits but also often identified in the lower part of the Lower Cretaceous, while the most important forms from biostratigraphically point of view are represented by: *Haplophragmoides joukowskyi, Montsalevia salevensis*, *Coscinoconus cherchiae*, *Coscinoconus delphinensis*, *Neotrocholina valdensis* and *Protopeneroplis banatica* which are exclusively Beriassian-Valanginian species. Among the calpionellids, *Calpionella alpina, Calpionella eliptica, Calpionellopsis simplex, Calpionellopis oblonga* and *Calpionellites darderi* confirm the Upper Beriassian-Lower Valanginian age.

The microbial structures and microencrusters are also important constituents of the studied deposits and abundant almost in the whole section: Crescentiella morronensis, *Radiomura cautica, Radiomura/ Perturbata crusta, Koskinobulina socialis, Mercierella dacica, Bacinella irregularis, Lithocodium aggregatum-Troglotella incrustans consortium, Lorenziella* sp., *Iberopora bodeuri,Terebella lapilloides, Thaumatoporella parvovesiculifera, Rodhpletzella* sp., cyanobacteria of rivularian type, bacinelloid nodules and peloidal microbial crusts.

Among the calcareous algae were identified: *Neomeris* sp., *Zujovicella polonini, Terquemella* sp., *Salpingoporella praturloni, Suppiluliumaella polyreme, Clypeina* cf. *radici, Actinoporella podolica, Steinmanoporella* sp., *Dissodoidella* sp., *Arabicodium* sp.

Numerous studies throughout the years have proved that in the regional context during Jurassic-Cretaceous, in the area there was a deep basin where the flysch “Firza” was deposited. In the central part of Mirdita zone and rarely in its eastern parts, during Berriassian-Valanginian sectors of shallow water carbonate deposits have been existed.

Given the typical identified microfacies and their micropaleontological associations, as well as from the geological context, the “Guri i Pellumbave” carbonates can be interpreted as an isolated platform, “haute fond” type.

Kimmeridgian/Tithonian boundary interval in the Lower Sub-Tatric and High-Tatric successions, Tatra Mts (Poland): integrated bio-, chemostratigraphy and magnetic susceptibility

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Kimmeridgian and Tithonian in the Tatra Mts occurs in two contrasting palaeofacial settings. These are pelagic to hemipelagic deposits within the Lower Sub-Tatric (Krížna Nappe; Fatricum domain) succession (radiolarites, radiolarian limestones, red nodular and platy limestones) and shallow marine, mostly oncoidal sediments in the High-Tatric succession (Tatricum domain). Kimmeridgian to Lower Tithonian interval in the Lower Sub-Tatric succession (Tatra Mts, Carpathians – Jach *et al*., 2012, 2014) is marked by a cessation of silica sedimentation and recovery of carbonate production. This is manifested by sedimentary change from radiolarian limestones of Czajakowa Radiolarite Fm to nodular limestones of Czorsztyn Limestone Fm (lower part of Moluccana dinocyst zone, ca. at the lower/upper Kimmeridgian boundary) and then towards the marly limestones of Jasenina Fm (close to the Kimmeridgian/Tithonian boundary). Relative decrease of terrigenous content is observed between the Czajakowa and Czorsztyn Fm. The lowermost part of Czorsztyn Fm is also enriched in P, Mn and trace elements and a notable peak of $\delta^{13}C$ is observed there (up to 2.39‰). The terrigenous content gradually increases towards the Kimmeridgian/Tithonian boundary and then decreases towards the Malmica Zone of the Lower Tithonian. The upper Kimmeridgian to lower Tithonian interval is characterized by steady decreasing trend of $\delta^{13}C$ curve towards the minimum values of 1.25–1.30‰ in the Pulla zone. The trends are well correlated with High Tatric succession of the Raptawicka Turnia Fm (Pszczółkowski *et al*., 2016). A detrital peak occurs there in the uppermost Kimmeridgian as well and distinct deterioration of oxygen conditions coincides with onset of Jasenina Fm in the Lower Sub-Tatricsuccession. Sedimentary changes in both, Fatricum and Tatricum realms must result from combined effects of regional palaeobathymetric and paleoclimatic variations. These include a transgressive trend between the early and late Kimmeridgian as well as climate aridization throughout the late Kimmeridgian and early Tithonian.

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Pliensbachian (Early Jurassic) radiolarians from Mt. Rettenstein, Northern Calcareous Alps, Austria

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Pliensbachian radiolarians are rare in the western Tethyan realm. Up until now, only two localities with isolated samples containing well-preserved radiolarians have been described. These localities belong to the Gümüşlü Allochthon in Turkey and to the Dürrnberg Formation in the Northern Calcareous Alps in Austria. Continuous stratigraphic sections with well-preserved radiolarians are known only from Haida Gwaii (Queen Charlotte Islands) in British Columbia, Canada. The aim of our study on well-preserved and diverse assemblages from Mt. Rettenstein is to provide new data on the stratigraphic distribution of taxa and to compare low-latitude (Tethyan) and mid-latitude (Haida Gwaii) faunas. Precise radiolarian dating will contribute new data to the geology of Mt. Rettenstein.

Mt. Rettenstein is located near Salzburg, at the southern rim of the Northern Calcareous Alps. A complete succession of Lower, Middle and Upper Jurassic sediments tectonically overlies the Middle Jurassic Hallstatt Mélange. The succession starts with an approximately 60 m thick sequence of marly and slightly siliceous bedded limestones (Sinemurian-Lower Pliensbachian). These limestones become more calcareous towards the top and pass abruptly into red marls and red marly limestones of the Adnet Formation with rich ammonite fauna, which indicates late Carixian (Early Pliensbachian) to Early Toarcian ages (Meister and Böhm, 1993). Above a hiatus, the first Middle Jurassic sediments are condensed Bajocian Bositra/Protoglobigerina limestones of the Klaus Formation. They are followed by Bathonian to Oxfordian radiolarites of the Ruhpolding Radiolarite Group. The overlying unit is Kimmeridgian-Tithonian shallow-water limestones of the Plassen Formation, which starts with a thin sequence of slope facies breccias (Auer *et al*., 2009).

Five samples taken from the southern flank and one taken from the western flank of the mountain, were studied for radiolarians. Altogether, 71 species belonging to 34 genera have been identified so far. Four samples were assigned to the early Early Pliensbachian *Zartus mostleri – Pseudoristola megaglobosa* Zone, based on FADs of *Bipedis fannini* Carter, *Canoptum anulatum* Pessagno & Poisson and *Noritus lillihornensis* Pessagno & Whalen, and on LADs of *Cyclastrum scammonense* Whalen & Carter and *Cyclastrum veracruzense* Whalen & Carter. Two samples were more loosely dated and assigned to the Early Pliensbachian *Z. mostleri – P. megaglobosa* or *Hsuum mulleri – Trillus elkhornensis* Zone based on *Lantus obesus* (Yeh), *Lantus praeobesus* Carter, and *Praeconocaryomma whiteavesi* Carter. Some of the identified taxa have not been found in samples of this age yet. These are *Tozerium* Whalen & Carter, *Ares sutherlandi* Whalen & Carter, *Cuniculiformis plinius* De Wever, *Gorgansium morganense* Pessagno & Blome, *Xiphostylus simplus* Yeh, and *Empirea hasta* Whalen & Carter.

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Late Jurassic evolution of the Steinernes Meer (Berchtesgaden, Germany), emplacement of the “Juvavic” Klippen, and the role of Hahn´s Miocene Hundstod overthrust

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Geological field work and rock analysis by the authors during the last 10 years and previous evaluations reveal that the Steinernes Meer (High-Tirolic nappe) consists of following parautochthonous Triassic-Jurassic sedimentary succession: Gutenstein and Steinalm Fms. (Early-Middle Anisian), Reifling Formation (Late Anisian to Late Ladinian), Wetterstein Formation (latest Ladinian to Early Carnian), Mid-Carnian carbonates/siliciclastics with overlying dolomites, carbonates of the Dachstein Carbonate Platform (Norian–Rhaetian), Adnet and Klaus Fms (Early–Middle Jurassic), radiolarites. Whereas in the south shallow-water conditions during Norian-Rhaetian times prevailed, the northern part of the Steinernes Meer is affected in the Rhaetian by Kössen influence. Therefore also the Early Jurassic Adnet Fm. in more southern positions changed to the north to more basinal deposits (Scheibelberg Fm.). In the late Middle Jurassic due to the change in the geodynamic setting mass transport deposits became intercalated into the radiolarites, rarely preserved in the Steinernes Meer. Upsection the radiolarite grades into the basinal to slope sediments of the Sillenkopf Fm. of Kimmeridgian to Lower Tithonian age consisting of a 20–120 m sequence of cherty, bituminous and siliceous limestones with intercalated mudflows, breccias and turbidites with shallow water organism. The shallow-water reefal material was shed from a newly formed carbonate platform on top of the today eroded accretionary prism south of the todays Northern Calcareous Alps.

This whole tectono-sedimentary sequence was in pre-Tertiary times preserved in a down-tilted block along an E-W striking normal fault. This block was inversely backthrusted to the S in the frame of the Miocene Lateral Tectonic Extrusion with an up to 2 km horizontal displacement and became later affected by sinistral strike-slip faults.

The Hundstod thrust system starts in the W with two subparallel S-directed thrusts: the northern one splits off from the strike-slip fault system of the Torrener-Joch-Zone and the southern branch of the Hundstod thrust develops around Weißbach from a swarm of small overthrusts, then strikes along lake Diesbach, and conjugates with the northern fault branch E of Mount Hundstod. Tertiary Augenstein Fm. and Lower to Middle Miocene coals in the overridden foot-wall block prove an at least Late Miocene age for the Hundstod thrust.

At an over-regional scale we interpret the Hundstod overthrust as a reaction on the Miocene N-movement of the Adriatic Indenter, combined on one side with a relative underthrusting movement of the southern part of the Steinernes Meer under its northern part and on the other side by a southward pressure impact from the Torrener-Joch-Zone during sinistral strike-slip movements. Such S-N shortening motions are still going on, accompanied by recent seismic activity along the W-E striking thrust system of the Werfen Schuppenzone, proving a northward shift of the Northern Calcareous Alps as reaction to the impact of the northwards directing Adriatic indentation, with dislocation of 0.5–0.8 cm/year of the Northern Calcareous Alps to the north.

Comparison and correlation of Jurassic and Lower Cretaceous successions of the Eastern Alps and the Transdanubian Range: Similarities and differences

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The Transdanubian Range was part of a huge carbonate platform until the earliest Early Jurassic. The first signal of the opening of the Penninic Ocean is the break of the carbonate platform system. The result of this process is the differentiation of the sedimentary environments into highs with comparatively thin, discontinuous and into deeper-water areas with condensed lithofacies, and thicker, continuous successions showing less condensation. There are differences in thickness and also in lithology of the Jurassic lithostratigraphic units in soutwest and northeast direction in the Transdanubian Range. The oldest Jurassic formation is the oncoidic and ooidic Kardosrét Limestone Fm developed from the Dachstein Limestone in the Bakony Mts but getting lacunose and thinning to the northeast direction and completely missing from the Gerecse Mts. Higher up the Jurassic succession is characterized by the alternation of cherty limestones (including radiolarite) , nodular and ammonite-rich limestones (Tölgyhát Limestone Fm and Pálihálás Limestone Fm) and subordinately by thin marl intercalations. The deep-water condition is also indicated by enrichments of other planctonic elements (Radiolaria, planktonic forams, calpionellids, etc.).

The shallowing tendency started in the Tithonian and continued in the Early Cretaceous in the entire territory of the Transdanubian Range. In this respect the great difference is that in the Gerecse Mts in addition to the coarse-gaind rock fragments (pebbles and graided sandstones) also developed in the Early Cretaceous. In the subsurface conditions it is strongly developed in South Slovakia too. This succession at the turning a facies conditions contains large limestone fragments of colonial fossils, indicating the shallow marine environment, but going upwards the size of varied rock fragments getting smaller and containing also volcanic rocks, wich is indicating the increased activity of the tectonic zone.

During this time in the South-Bakony completely different formation developed, which is getting thicker and more and more similar to the South-Alpine development. The formation is called Mogyorósdomb Limestone in Hungary. This maiolica type limestone is getting more and more similar to the South-Alpine development.

Tholeiitic basalts and ophiolitic complexes of the Mesorif Zone (External Rif, Morocco) at the Jurassic-Cretaceous boundary and the importance of the Ouerrha Accident in the palaeogeographic and geodynamic evolution of the Rif Mountains

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The stratigraphic series around the Jurassic-Cretaceous boundary of the External Rif, in particular those of the Mesorif Zone, exhibit many outcrops with volcanic materials spread East-Ouest over than 200 km. These materials show various aspects: basalt lithoclasts, reworked into calcareous breccia beds or in marly matrix breccias of Kimmeridgian-lower Tithonian age; interstratified lava flows and volcanoclastic complexes incorporated within the Berriasian marls (Benzaggagh, 2011). In the Central Rif, several magmatic blocks outcrop, usually regarded as granite scales from the Paleozoic basement (Suter, 1964) or as intrusive gabbros of Barremian age (Vidal, 1983). Actually, these magmatic massifs display typical ophiolitic sequences (Benzaggagh *et al*., 2014; Benzaggagh, 2016) and they are overlaid by mega-olistoliths of Jurassic materials and locally by radiolarite layers. Geochemical analysis of several basalt and gabbro samples belonging to the Mesorif Zone evidenced that both display a typical E-MORB magma, indicating at least a partial oceanization of the Mesorif basement. Concerning geodynamic evolution, the Mesorif Zone had undergone, at the Jurassic-Cretaceous boundary interval, two successive palaeogeographic frames (Benzaggagh, 2000): an uplift close to the emersion during the Kimmeridgian-early Tithonian interval, stressed by important submarine volcanic activities and intense brecciation of the carbonate formation; followed by a general collapse from late Tithonian, underlined by lava flows, slidings as mega-olistoliths and the formation of an oceanic crust, at least in the Central Rif. These magmatic materials, distributed on both sides of the Ouerrha Valley, evidence that this later, which extends westward the Nekor Accident, may correspond in the Central Rif, to two palaeo-subduction planes which become two major overlapping thrusts in the western part of the Rif Mountains.

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The type-Gosau Group of the Northern Calcareous Alps: Upper Cretaceous to Paleogene basins

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The Upper Cretaceous to Paleogene strata of the Gosau Group is characterized by a large variety of facies and depositional systems, from continental to deep-marine, as a consequence of incipient Alpine orogeny (the Eo-Alpine phases of orogeny). Equivalent Gosau-type sediments occur within the wider Alps area, the Carpathians and the Balcanides in the CBGA regions. The term "Gosauschichten" or Gosau-type sediments or Gosau-facies was used loosely for transgressive Upper Cretaceous successions within an area from the Eastern Alps of Austria up to the Carpathians of Romania.

At its type locality in the Northern Calcareous Alps (NCA) of Austria, the Gosau Group is defined by a basal angular unconformity above Permian to Lower Cretaceous rocks, thus marking a new sedimentary cycle starting in late Turonian times. These deposits follow a phase of Lower Cretaceous to Cenomanian deformation, which was attributed parlty to the "Austrian phase".

The Lower Gosau Subgroup (LGS, Upper Turonian -Campanian) at the type locality and other Gosau basins in Austria starts with terrestrial deposits. Widespread (karst) bauxites indicate weathering in subtropical-tropical climate and give evidence for subaerial exposure of wide areas for the first time in the Mesozoic. Alluvial and fluvial conglomerates indicate syntectonic sedimentation and considerably tectonic relief, including source areas mainly from the NCA, but also from "exotic" sources both to the north and to the south of the NCA. Alluvial sedimentation passes gradationally into shallow-marine successions with a mixture of various facies types, from fan-delta conglomerates to coastal strata and small rudist and coral bioherms and lagoons. Abundant fossils like rudists, solitary corals, molluscs (gastropods like *Trochacteon*, *Actaeonella*, *Nerinea*, etc.; bivalves such as inoceramids) and ammonites mark these "Gosau-type" facies. Individual basins show strong intrabasinal and interbasinal facies changes within a few kilometers, and a rugged topography. Basins of the NCA were interpreted as relatively small, strike-slip related basins due to extension after contractional deformation and thrusting, including piggy-back basins on thrusts. Strong, short-lived tectonic subsidence pulses characterize this phase of basin formation.

The occurrence of ophiolitic detritus including chrome spinel in heavy mineral assemblages is a prominent feature of these basins. Serpentinitic sandstones are known from Gosau basins especially in the southern thrust units of the NCA. This points to a common mechanism of tectonic basin formation related to Late Jurassic to Early Cretaceous Neotethys ophiolite obduction and suturing, to the south of these basins, building more widespread ophiolite bodies.

Above an unconformity, the Upper Gosau Subgroup (UGS, from Campanian onwards) comprises deep-water deposits such as marls and a broad variety of deepwater clastics such as turbidites up to the Eocene. A major subsidence pulse is present at the base of the UGS which deepens the whole NCA area step-by-step in bathyal to abyssal depths, with some of the northern basins showing deposition below the CCD. Metamorphic detritus from the exhuming Austroalpine basement complexes to the south of the NCA yielding garnet as the main heavy mineral forms the main sediment material.

Correlation of Mesozoic lithostratigraphic units of the East Alpine Bajuvaric and Tirolic units and the North-eastern part of the Transdanubian Range

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The Transdanubian Range is the only tectonic unit which has preserved the original Mesozoic transitional connection with both the Southern and Eastern Alps. The peculiarity of this transitional character is that the large part of the Upper Jurassic and Lower Cretaceous formations in the north-eastern part of the Transdanubian Range are identical with those of the Juvavic, Tirolic, in part of the Bajuvaric tectonic units, while the relationship with the Southern Alps is restricted to the Southern Bakony. The separation of the Southern Bakony and the Gerecse supervened in the early Late Jurassic.

After the Variscan orogeny large areas have been flooded during the Early Triassic as a result of the expansion of the Tethyan Ocean, when the starting clastic sedimentation is replaced by dominantly shallow marine carbonate environment. Therefore, similar formations are found on extremely large areas of the Alpine-Carpathian-Dinaric-Vardar Zone with smaller or larger differences in the internal basin environments. Here we focus the similarity of Mesozoic formations of the Northern Calcareous Alps and the Transdanubian Range only. The Middle and Late Triassic time almost all areas belonged to the lagoonal and reefal facies belt of the carbonate passive margin of the Tethyan Realm. The basic significance of Triassic succession of both the Alpine and the Transdanubian Ranges is the predominance of the carbonate platform, interrupted locally by shallow basinal marls in the Middle and Late Triassic times. The formations derived from the carbonate platforms with some basins within them can be correlated easily.

A black shale facies in the upper Werfen Formation: Indication of an anoxic event during the rifting of the Meliata Ocean?

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Within the Austroalpine and Southalpine domains of Eastern Alps and Carpathians, the Lower Triassic Werfen Formation with mostly reddish/purple siltstones and fine-grained siliciclastic sandstones in the lower part and detrital carbonates in the upper part represent a key formation often representing the first marine unit in the transition from Permian terrestrial to Triassic marine depositional environments. Within the Northern Calcareous Alps (NCA), three subformations are known from base to top: the Werfen Quartzite, the Werfen siltstones/fine-grained sandstones with rare bivalves and ammonites, and the Werfen Limestone. Within the NCA, we investigated a section exposing reddish-brownish siltstone, dark Werfen Limestone overlain by dark-colored bedded Anisian dolomites (Gutenstein Fm.). The section is located to the east of the Werfen type area, where also the stratiform Sulzau-Werfen iron mineralization is known just above the Werfen Formation.

Within the studied Werfen Limestone section, three microfacies types can be distinguished. All three types turn out to be sparitic, fine sandy limestones often transitioning into more siliciclastic, argillaceous marls or blackish slates always comprising some carbonate components. Secondary alteration include pressure solution, recrystallization (inhibited by graphitic material) and a conodont color alteration index of six indicating a metamorphic temperature significantly higher than 300 °C. Microfacies type 1 is characterized by grey, sandy, sometimes graded limestones and rare fossil remains. Microfacies type 2 is a transitional type between types 1 and 3, appears distinctively darker than type 1 and shows a mid to dark grey or even blackish color. The matrix mainly consists of silt-sized grains and phyllosilicates. Thin layers of fine sand with graded bedding are intercalated. On bedding planes, crinoids, detrital mica, pyrite and graphitic material can be identified. Microfacies type 3 usually comprises patterns of thin sandstone layers with graded bedding alternating with much thicker blackish layers of phyllosilicates. Sandstone layers resemble distal tempestites. High amounts of detrital white mica, the graphitic nature and the graded bedding suggest a deep depositional environment. Tests on conodonts revealed dominant single cone conodont elements, and some ramiform and rare platform elements; single cone elements remain an exception during Early Triassic. EDX investigations revealed the presence of sulfides like pyrite, chalcopyrite, and sphalerite, of sulfates like alunite, jarosite and celestine(?), and of carbonates like ankerite/siderite.

We interpret the depositional environment as in part anoxic with sulfides in deep basin overlain by stratified water column, from which Fe-carbonates were deposited. We interpret the formation of basins with an anoxic facies as driven by crustal extension, where potentially metal-bearing hydrothermal fluids were expelled on basin-confining faults similar as it was recently demonstrated for the western Southern Alps.

Anisian climate change inferred from a new $\delta^{18}O$ record from conodont apatite

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The Anisian marks the phase of complete recovery of marine and terrestrial ecosystems after the PT boundary event, with the first occurrence of scleractinian corals and their diversification in the marine realm and the occurrence of the oldest dinosauromorphs in the terrestrial realm, two prominent groups shaping the entire Mesozoic era. In this context, the study of Middle Triassic climate conditions is crucial to evaluate major stages in palaeoecosystem development.

Here, we present Anisian conodont assemblages from three marine key sections in eastern Germany (Steudnitz), southern Hungary (Bükkösd), and northwestern Bulgaria (Iskar gorge), representing ramp deposits of the northwestern Tethyan realm and its northern Peri-Tethys Basin (Feist-Burkhardt *et al*., 2008). Oxygen isotope compositions of discrete conodont elements where measured using secondary ion mass spectrometry (SIMS). This approach permits multiple highly targeted in-situ analyses of each specimen, thereby avoiding contaminants and enabling species-based comparisons.

The here obtained new oxygen isotope record derived from conodont apatite reveals variable short-term climate trends throughout the Anisian stage representing 6.4 Ma of the Triassic period. This record shows two prominent negative shifts reflecting intense warming episodes during the Bithynian and mid-late Pelsonian with distinct cooler intervals in the Aegean, early Pelsonian, and early Illyrian, indicating a highly fluctuating Anisian climate trend. The isotope signatures detected in all sections studied suggest they were at least Tethyan-wide events. The Pelsonian humid event was also detected by recent studies of Trotter *et al*. (2015) and Li *et al*. (2018) and might reflect one of the major greenhouse crisis in the Triassic (Retallack, 2013). The present study shows that the Anisian climate, being much more dynamic as previously stated, needs to be studied in much more detail. Ongoing research might prove the global significance of the Anisian humid events setting the course for Mesozoic palaeoecosystems.

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Bithynian cherty limestones of the Rosni virovi locality, Budva zone (southern Montenegro)

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Cherty limestones of Triassic age in southern Montenegro were so far considered as Ladinian. However, in Rosni virovi occur grey to purple colored limestone beds with chert concretions together with thin-layered intercalations of shallow-water debris, arenitic beds, and volcanic ash layers. The carbonate-siliciclastic sediments are sandwiched between radiolaritic sequences. Stratified beds in this reduced depositional environment provide an ammonoid fauna of Bithynian age.

The small ammonoid fauna is comprised of five specimens, belonging to five different species: *Acrochordiceras hyatti* Meek, *Schreyerites*? sp., *Gymnites toulai* Arthaber, *Ptychites opultentus* Mojsisovics and *Parapinacoceras* sp. The presence of the species *Acrochordiceras hyatti* Meek restricts the age of the sequence to the Bithynian. The other ammonoid species have extended stratigraphic ranges beyond the Bithynian. Some meter up-section of the ammonite bearing horizon, a conodont fauna confirms further a Late Bithynian age, with *Nicoraella microdus* (Mosher), *Paragondolella bulgarica* (Budurov & Stefanov), and *Neogondolella* ex gr. *regalis* Mosher. Even though the ammonoid fauna is very scarce, it can be best compared with the fauna from Gebze area in Turkey (Fantini Sestini, 1988) and also from Nevada, USA (Monnet and Bucher, 2005), both of Bithynian age.

Open-marine influenced Early-Middle Anisian sedimentary rocks are rarely preserved in the entire Western Tethyan realm. Depositional environments of this time span can be best characterized by restricted shallow-water carbonatic sedimentation. Ammonoid faunas of Bithynian age are unknown from Montenegro until now and are undescribed in the Western Tethys. However, Early-Middle Anisian open-marine influenced sedimentary rocks occur in different mountain ranges in the eastern Mediterranean, often as isolated blocks or pebbles in Middle Jurassic mélange complexes with a limited preserved thickness of the reworked sequences. In Montenegro, relatively thick and well-preserved Anisian successions are present but not well studied. In addition, these cherty limestone successions may provide possibilities to close the lack in knowledge about the Early–Middle Anisian open-marine influenced sedimentary history in the Western Tethyan realm prior to the opening of the Neo-Tethys Ocean from Late Anisian times onwards. In combination with occurrences of older open-marine influenced sedimentary rocks, we expect hints for the evolution and position of the Palaeo-Tethys in the eastern Mediterranean.

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A Late Triassic–Early Jurassic open-marine succession from the western Pindos (Greece)

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Stratigraphy, microfacies characteristics and depositional history of the Late Triassic–Early Jurassic sedimentary succession in northwestern Greece are not very well constrained; comparisons with other age-equivalent open-marine sequences of the Western Tethys realm are missing. By this reason the palaeogeographic provenance/position of the Pindos unit is discussed controversially.

The Early Norian part of the studied succession in the Western Pindos Mountains (dated by the conodonts *Norigondolella navicula* and *Epigondolella* sp.) consists of bedded grey wackestones with filaments and radiolarians. Intercalations of distal turbidites of filament and radiolarian rich packstones are abundant, and thin resediment layers consisting of shallow-water debris are rare. Upsection occur condensed Middle Norian red nodular limestones and Late Norian grey open-marine limestones. The Late Norian radiolarian-filament-rich wackestones are intercalated by turbiditic layers with resediments (dated by the conodonts: *Epigondolella slovakensis*, *Epigondolella postera*, *Norigondolella steinbergensis*, and *Epigondolella bidentata*). The age of this redeposit is Late Norian or slightly younger.

The change from the Late Rhaetian marly-siliceous sediments to the red Early Jurassic radiolarites is gradual. The uppermost Rhaetian is characterised by silicified distal turbidites with few filaments and radiolarians, but without shallow-water debris. The boundary layer of the Triassic/Jurassic boundary was not detected in the first preliminary study. Therefore, a negative carbon isotope excursion at the Triassic/Jurassic boundary as known from the Budva basin (Crne *et al.*, 2011) could not be confirmed.

The stratigraphic, litho- and microfacies evolution of the Late Triassic to Early Jurassic succession resembles the depositional characteristics of the outer shelf of the Western Tethyan realm (Hallstatt facies zone), and is similar in the stratigraphic and facies evolution to the Bic Mountains in Serbia (Gawlick *et al.*, 2018), or the Budva basin in Montenegro (Crne *et al.*, 2011).

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Triassic Foraminifera from the Carbonate blocks of the Transilvanian Nappes of the Eastern Carpathians (Romania)

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The sedimentary of the Transilvanian Nappes from the northern sector (Rarău Syncline) of the Eastern Carpathians appears only in allochthonous position, consisting of few unitary litostratigraphical members and many isolated blocks sedimented within the Hauterivian–Albian wildflysh of the Bucovinian Nappe.

The Triassic sedimentary is almost exclusively made up of pelagic carbonates represented by synchronous heteropic facies, fact that reveals different marine depositional environments. The association of the carbonate deposits with ophiolitic volcanic products proves that the Transilvanian sedimentary has been formed within a labile zone of spreading oceanic crust.

The dimension of olistholiths varies from metric blocks to real massifs, like those outcropping in the Rarău Syncline: Piatra Zimbrului, Piatra Şoimului, Pietrele Albe, Pietrele Sparte, etc. Carbonates are fossiliferous, offering rich macrofauna assemblages, some of them been considered unique in the Carpathian space. All Triassic stages are confirmed by the diverse macrofauna.

The "Werfen Formation" outcropping in Valea Seacă klippe is the most representative for the Transilvanian Lower Triassic from the Eastern Carpathians. From a lithological and faunistic point of view, the deposits of the "Werfen Formation" are correlated with the stratotype from the Southern Alps. Their bioclastic content consist of: bivalves, brachiopods, crinoids, echinids, foraminifera (*Meandrospira pusilla*, *Earlandia dunningtoni*, *Earlandia tintinniformis*), and algae (*Macroporella alpina*).

The Anisian micropaleontological assemblage (base of Piatra Șoimului klippe, Botuș quarry) is represented by *Nodosaria ordinata*, *Nodosaria elongata*, *Earlandia amplimuralis*, *Earlandia gracilis*, ?*Oligoporella pilosa.*

The most important Ladinian carbonates appear in the Rarău Massif (Piatra Zimbrului, Piatra Şoimului) and on the slopes of the Cailor and Măceș brooks. Ladinian carbonates are rich in ammonites, nautiloids, bivalves, gastropods, echinoderms, conodonts, and foraminifera (*Agathammina austroalpina*, *Tetrataxis*).

The Ladinian–Carnian interval is justified by the fossiliferous content of the limestones that form the biggest part of the Piatra Șoimului klippe: foraminifera (*Ophthalmidium exiguum*, *Earlandia amplimuralis*, *Earlandia gracilis*) and algae (*Diplopora annulata*, *Macroporella*, *Solenopora*).

The Carnian carbonate deposits offered a micropaleontological association characterised by foraminifera (*Agathammina austroalpina*, *Glomospirella* aff. *facilis*, *Endoteba* ex gr. *obturata*, *Trochammina alpina*, *Glomospirella paucispira*, *Frondicularia woodwardi*, *Glomospira*) and algae (*Solenopora cassiana*).

The limestones exposed in Popii Rarăului klippes were attributed to the Carnian–Norian interval based on an assemblage consisting of mainly foraminifera and rare algae: *Ophthalmidium exiguum*, *Trochammina almtalensis*, *Agathammina austroalpina*, *Turriglommina carnica*, *Ammobaculites*, *Tetrataxis*, ?*Glomospira*, *Thaumatoporella parvovesiculifera*.

The red limestone klippe located on the Timon brook is unique in the Romanian Carpathians through its tipical Norian fauna represented by tens of species of ammonites, nautiloids, brachiopods, and bivalves. To the foraminifera assemblages quoted in the geological literature, we add some species of Lituolidae, Lagenidae, Miliolidae, etc.: *Angulodiscus tenuis*, *Angulodiscus gaschei gaschei*, *Angulodiscus impressus*, *Trochonella crassa*, *Trochonella acuta*, *Miliolipora cuvillieri*, *Quinqueloculina nucleiformis*, *Pseudonodosaria vulgata multicamerata*, *Permodiscus praetenius*, *Permodiscus minutus*, *Aulotortus* cf. *tenuis*, *Auloconus permodiscoides*, *Ophthalmidium lucidum*.

The presence of the Rhaetian is demonstrated by few foraminifera species: *Semiinvoluta clari*, *Angulodiscus tenuis*, *Involutina tumida*.

In addition, the Anisian–Carnian associations also contain microproblematica (*Baccanella floriformis*, *Ladinella porata*, *Tubiphytes*, *Globochaete alpina*) and sponges (*Cryptocoelia zitteli*, *Dictyocoelia manon*, *Uvanella irregularis*).

Bulog limestone and volcano-sedimentary peperites of Željeznica river (southern Montenegro)

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Lithostratigraphic mapping units of Anisian formations in the southern Montenegro are: the Ravni Formation, the Bulog Formation, Crmnica conglomerates, and the Tuđemili Formation (Čađenović *et al*., 2014). The Anisian succession near the fortress Crni krš, in the valley of Željeznica River starts with red nodular hemipelagic limestones, consisting of wackestones to packstones with bivalves. Upsection continue a hemipelagic environment with stratified intercalations of volcanic rocks and tuffs. The pyroclastic peperites represent in this depositional facies sharp edged chunks of andesites within an altered muddy sediment matrix. The Early Illyrian conodont microfauna from the Bulog Limestone above the peperites yielded *Gladigondolella tethydis* and *Paragondolella bifurcata*.

In the locality near the Željeznica River, a scarce ammonite fauna, also of Illyrian age, was collected. It is represented *Lanceoptychites indistinctus* (Mojsisovics), *Flexoptychites flexuosus* (Mojsisovics), *Flexoptychites* sp., *Philippites erasmi* (Mojsisovics), *Leiophyllites* cf. *suessi* (Mojsisovics), *Parapinacoceras schneideri* (Welter) and *Costigymnites*? *palmai* (Mojsisovics) that would point to the *Paraceratites trinodosus* Zone, very common in the Dinarides.

The Middle Anisian carbonate ramp (Ravni Formation) was drowned in the late Middle Anisian (Late Pelsonian) by the open-marine limestones of the Bulog Formation, due to the opening of the Neo-Tethys Ocean. The break-up formed on the continental shelf a horst-and-graben morphology that was accompanied by regional volcanism. Beside the Late Pelsonian mobilization of older rocks on the newly formed escarpments, also the extensional regime of the Illyrian created a paleorelief with intense volcanism. Pyroclastic flows and brecciation resulted in mass transport deposits with hydrothermal alteration effects.

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Age and genesis of the Hallstatt Mélange in the Inner Dinarides of Serbia

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The late Middle to early Late Jurassic Hallstatt Mélange (Gawlick *et al*., 2017) in the Inner Dinarides (SW Serbia), defined as Zlatar Mélange (Gawlick *et al*., 2018), plays a crucial role for the reconstruction of: (1) the Triassic-Jurassic western passive margin configuration of the Western Neo-Tethys Ocean; and (2) the Middle to Late Jurassic geodynamic history of the Inner Dinarides.

Deformation and accretion of the western Neo-Tethys Ocean started with intra-oceanic thrusting in the late Early to early Middle Jurassic. The onset of the west-directed obduction of the accreted ophiolites onto the continental slope and outer shelf (Adria margin) is dated as Middle Jurassic (Bajocian). In the middle to late Middle Jurassic contractional tectonics reached in the course of west-directed ophiolite obduction the outer parts of the former shelf attaining now a lower plate position. Deep-water trench-like basins formed in sequence in front of the advancing nappes and obducted ophiolite sheets, respectively. Thick successions of gravitatively redeposited sedimentary rocks accumulated in these trench-like basins and a detailed analysis of the basin fills including matrix dating and component analysis allow: (1) to complete existing palaeogeographic reconstructions with until yet overlooked facies belts of the Neo-Tethys shelf configuration in the Dinarides; and (2) a more precise reconstruction of the Middle Jurassic mountain building processes related to ophiolite obduction in the Dinarides.

The sedimentary Zlatar Mélange occurs in a transported position below the west-directed obducted ophiolite mélange/ophiolites on top forming together a far-travelled nappe and mélange complex resting today in a position which corresponds to the Triassic–Jurassic central shelf of the Neo-Tethys (lagoonal Dachstein Limestone facies zone). An autochthonous position of a Triassic Ocean with its shelf sediments (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 clearly excluded. This ocean would have existed in the lagoonal area of the Triassic carbonate platform in the Dinarides separating the open lagoon in two independent shelf areas without transition to open-marine environments.

The situation of the Zlatar Mélange in the Dinaridic Ophiolite Belt with the obducted ophiolite sheets on top corresponds to the situation known to the south in the Albanides, to the north in the Eastern Alps and Western Carpathians with similar mélanges formed in Middle to early Late Jurassic times and is therefore part of the same orogen, the Neotethyan Belt.

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Open marine Carnian succession from the Apuseni Mountains (Codru-Moma Nappe System, Romania)

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Triassic sequences in the Northern Backa–Upper Codru zone, the southernmost tectonic units of the Apuseni Mountains (Tisza unit), were over 100 years compared with facies sequences known from the Northern Calcareous Alps (NCA), especially with those of the Dachstein carbonate platform (Bleahu *et al*., 1994).

Based on lithostratigraphic correlations, open-marine Middle to early Late Triassic sedimentary rocks of the Codru-Moma nappe system are subsumed to the Rosia Formation. The age of the Rosia Formation at the type-section Coupe de Strimtura near the village Sohodol is defined as Late Anisian to Early Carnian (Patrulius *et al*., 1976). Unfortunately, other Carnian to Early Norian grey deep-water limestones around Sohodol are also added to this formation. The overlying sedimentary rocks of the Rosia Formation can be either Carnian shallow-water carbonates (Strimtura Limestone equivalent to the Wetterstein Carbonate Platform), or siliciclastic Middle Norian sedimentary rocks (Codru beds). The so far in spotlights dated sections originate from various palaeogeographic provenances and belong most probably to different tectonic units, respectively. First detailed microfacies analyses and high-resolution biostratigraphy on the hemipelagic sediments figured out the need for a re-evaluation of the Rosia Formation. In this frame we investigated in Sohodol (Finis nappe) a ca. 70-m thick part of the 270-m thick type-section. Our succession consists of Carnian open-marine limestones with stratified intercalations of turbidites: The basal 50 m of the succession yielded near the base earliest Carnian conodonts: *P*. *polygnathiformis* and *G*. *malayensis*. Upsection, *P*. *tadpole* and *P*. cf. *palata* point to the higher Julian 1. This part of the section consists of grey thin-bedded radiolarian-, filament-, and crinoid-bearing wackestones with intercalated turbidites, consisting predominately of recycled clasts from the Wetterstein Carbonate Platform. The depositional environment is comparable with those of the distal Raming-Formation (NCA) or the Trnava Formation (Inner Dinarides). A clastic interval or turbidites are missing in the Middle and Late Carnian wacke- to packstones. Higher Tuvalian 2 is proven by the co-occurrence of *P*. *polygnathiformis* and transitional forms between *P*. *carpathica* and *P*. *nodosa*. Around the Carnian/Norian boundary, a diverse conodont fauna from the latest Carnian conodont radiation zone *sensu* Orchard is proven, including *M*. *parvus*.

This Carnian succession resembles the facies evolution of the outer continental shelf in the NCA. Our first proof of a Carnian open-marine shelf provenance in the south-eastern Tisza Unit with clear Neotethyan affinity evidenced a re-evaluation of the complex Codru-Moma nappe system. Clear definitions of formations based on stratigraphic data combined with microfacies analysis will unravel the Triassic shelf configuration of Southern Tisza and their mode of emplacement.

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Callovian contractional tectonics in the Muráň Nappe, Western Carpathians (Slovakia)

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Numerous models try to explain the tectonic and paleogeographic controversies of the Silicicum in the Inner Western Carpathians, but none of them accounts the structural and facies relationships with satisfaction. The composition of the tectonic outliers, their diagenetic/thermal overprint, and their emplacement structures belong to the open questions in the geodynamic evolution of the Western Carpathians. On the official geological map the Silicicum of the Muráň plateau mirrors a continuous shallow-marine carbonate platform evolution from the Anisian to the Rhaetian. Locally, open-marine carbonates of the Early Jurassic occur. Our new data from the western Muráň plateau contrasts clearly the actual concept to interpret the Silicicum as a unified superunit: the Silicicum on Mt. Červená exist in two depositional settings with differences in the facies zones and stratigraphic ranges. Older sediments from the detached middle continental shelf rest on younger ones that formed the proximal shelf, separated by a Callovian thrust fault.

The (overlying) thrust nappe consists of a latest Ladinian–Early Carnian sedimentary sequence: Forereef limestones from the Wetterstein carbonate platform margin characterize the lowermost depositional sequence of this nappe outlier. Increased slope highs reduced the rate in the platform progradation and led to a retrogradation in reddish siliciclastic to silicified mud lenses and collapse breccia deposits. Sponges, microbes and other reef-builders of the reef core are only poorly preserved. Beyond the end-Wetterstein platform sea-level drop a new platform established on the continental slope and shed shallow-water debris in the open-marine setting (= Leckkogel Formation).

The (parautochthonous) carbonate basement consists of a ?latest Norian – Callovian sedimentary sequence: Open lagoonal to backreef sediments from the Dachstein carbonate platform characterize the lowermost depositional sequence of the Late Triassic proximal shelf. After the emergence of the Dachstein platform and a sea-level rise in the late Hettangian deepened the paleoenvironment (= Hierlatz Limestones), and a pelagic carbonate platform formed upsection (= Adnet Formation). Exposures of Middle Jurassic sediments are so far not well studied. The parautochthonous sequence on Mt. Červená ends with Callovian radiolarites deposited in a restricted paleoenvironment. Previous publications on Silicicum outliers confirm the Callovian age, but the interpretation is modified now (Dumitrică and Mello, 1982; Sýkora and Ožvoldová, 1996).

Our results show that the Middle–Late Jurassic contractional tectonics affected also the Muráň unit of the Silicicum, and substantiate the interpretation that the Silicicum is not a single nappe (Gawlick *et al*., 2002). The timing in the emplacement of the Silicicum on the underlying Veporicum remains enigmatic.

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Paleogeography, lithostratigraphic units and organic-rich Jurassic rocks in the Protosilesian Basin (Carpathians)

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The Protosilesian Basin, also known as the Severin-Moldavidic Basin, developed within the North European Platform as rift and/or back-arc basin during Late Jurassic times. It extended from the Bohemian Massif to Moesia. It was separated by the Silesian Ridge and its Bucovino-Getic equivalent from Jurassic Alpine Tethys. During Late Cretaceous times, it was divided into several smaller basins. Today, this area belongs to the Outer Carpathians, which contain Jurassic, Cretaceous, Paleogene and Neogene allochthonous, mainly flysch rocks forming the complex imbricate structure thrust over the North European Platform.

Traditionally, the marginal part of rifted North European Platform was included by into the Protosilesian Basin. This part is represented by the Baška-Inwałd Ridge as well as the Bachowice and Mikulov basins.

The Godula development, distinguished in Czech Republic and adjacent Polish Silesia represents the basinal zone of the Protosilesian Basin. The Vendryně Formation (Kimmeridgian–Early Berriasian) represents the oldest deposits of this zone. It is covered by the Cieszyn (Těšín) Lst. Fm. (Late Tithonian–Middle Valanginian). The Jurassic/Cretaceous boundary is located within this formation. The lower member of the Sinaia Fm. constitute the Romanian equivalent of the Cieszyn (Těšín) Lst. Fm.

The Baška–Inwałd Ridge and slope contain mainly carbonate deposits belonging to the Baška Development. This ridge originated as shoulder uplift and separates the Bachowice Basin from the Protosilesian Basin. The Štramberk Lst. Fm. (Kimmeridgian–Early Berriasian) represent the oldest rocks within the Baška Development.

The Leśna Lst. Fm. (Callovian–Early Oxfordian) represents the oldest deposits of the Bachowice Basin. The younger are the Roczyny Lst. Fm. (Oxfordian–Early Tithonian) and Bachowice Lst. Fm. (Tithonian). The Gresten and Nikolčice formations represent the oldest deposits of the Mikulov Basin. They are followed by Vranovice (limestone and dolomite), Mikulov (marlstone), Kurdějov (limestone) formations, and finally the Ernstbrunn Fm. (limestone).

The Vendryně and Mikulov formations contain organic-rich rocks. The samples from the shales of the Vendryně Fm. indicate 0.48–2.32% TOC. The kerogen belongs to type II-III.

The Mikulov Marlstones, representing world-class source rock, were found in the wells in southeastern Czech Republic and northeastern Austria. These 1400 m thick organic-rich rocks with TOC value 0.2–10%, type II and III kerogen sourced oils in the Vienna Basin and Carpathian subthrust. They can also represent unconventional resources known as shale-gas and shale-oil. The similar organic-rich rocks perhaps exist in the deeper subthrust areas in Polish, Slovak and Ukrainian Carpathians.

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Well-preserved Late Bathonian to Callovian radiolarian faunas from the Lókút Radiolarite in the Gerecse Mountains (Transdanubian Range, Hungary)

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The age of the Lókút Radiolarite in the Gerecse Mountains is believed to be of Bajocian to Oxfordian age, but direct age data from the radiolarites, i.e. well dated radiolarian faunas are not available. The estimated age of this radiolarite formation is established from well constrained ammonite faunas, which occur in the limestones below (Tölgyhát Formation) and above the radiolarite (Pálihálás Formation, Saccocoma Limestone). The Jurassic of the Gerecse Mountains show an important change in sedimentation in the (Late) Oxfordian or around the Oxfordian/Kimmeridgian-boundary with the deposition of mass transport deposits ("Oxfordian breccia") which occur above the Lókút Radiolarite or, in rare cases, is intercalated in the radiolarite succession. These mass transport deposits contain reworked parautochthonous material.

To get exact ages from the Lókút radiolarite we studied two key-sections in the Gerecse Mountains. In the Margittető section the mass transport deposits are intercalated in radiolarites, in the Tölgyhát quarry section they rests on top of the radiolarite. Moderate to good preserved radiolarian faunas from these two successions yielded Late Bathonian to Middle Callovian radiolarian faunas. The lower part of the Lókút Radiolarite has: *Striatojaponocapsa conexa*, *Striatojaponocapsa synconexa*, *Theocapsommella bicornis*, *Theocapsommella medvednicensis*, *Semihsuum amabile*, *Praewilliriedellum* cf. *robustum*, *Protunuma* cf. *turbo*, *Gongylothorax* sp. aff. *favosus*, *Pantanellium riedeli*, *Saitoum trichylum*. Similar radiolarian fauna exists in the upper part: *Striatojaponocapsa synconexa*, *Striatojaponocapsa conexa*, *Praewilliriedellum robustum*, *Hemicryptocapsa marcucciae*, *Hemicryptocapsa yaoi*, *Hemicryptocapsa buekkensis*, *Theocapsommella cucurbiformis*, *Kilinora spiralis*, *Saitoum trichylum*.

In the Tölgyhát quarry the youngest datable radiolarian sample is 50 cm below the "Oxfordian breccia". The silicified limestone directly below the breccia could not be dated and therefore the age of the breccia horizon could be not more precisely defined as known from literature. Of more importance is the Margittetö section with intercalated mass transport deposits in the radiolarite. The age of the radiolarite below the breccia horizon is Callovian as constrained by following radiolarian association: *Hemicryptocapsa carpathica*, *Striatojaponocapsa synconexa*, *Semihsuum* cf. *amabile*.

A radiolarian sample above the mass transport deposits yielded a similar radiolarian fauna, with *Gongylothorax* sp. aff. *favosus*, *Pantanellium* cf. *riedeli*, *Saitoum* cf. *trichylum*, *Striatojaponocapsa conexa*, *Striatojaponocapsa synconexa*, *Striatojaponacapsa naradaniensis*, and point to Late Bathonian to Middle Callovian. Some species give a hint that this sample can be a little younger, but surely not younger than Early/Middle Oxfordian, as constrained from the Tűzköves-árok section near Tardos.

Our radiolarian data confirm the known ages from the radiolarites deposited on the pelagic platforms in the Western Tethyan realm on top of the drowned Late Triassic Hauptdolomite/Dachstein Carbonate platform, *i.e.*, in a central to proximal shelf position. The Lókút Radiolarite in the Gerecse Mountains as part of the Transdanubian Range belongs therefore to the overall Jurassic radiolarite event in the Callovian–Oxfordian. Early Late Jurassic mass transport deposits of the Gerecse Mountains experienced an influence of the Middle to early Late Jurassic mountain building process in the Western Tethyan realm.

Jurassic planktonic foraminifera – and overview

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The object of our current research is the earliest planktonic foraminifera in time. The first record is known from the late Early Jurassic, around 180 Ma. We try to assess evolution and biodiversity and, in the process, substantially revise the taxonomy, which suffered from oversplitting.

All taxa are microperforate with pores under 1 µm and rarely 1.5 µm, and tests often small in size (65–125 µm and rarely over 200 µm). Generally, they are globigeriniform, trochospiral, with a high to low spire, with common kummerform last chamber (bulla). From several localities tests analysed are calcitic, but aragonitic tests are known from Lithuana, France and Poland. The perfectly state of preservation of the aragonitic tests within black anoxic shales suggest that is the aragonitic tests are the original building mineral of the wall of the earliest planktonic foraminifera. Calcitic tests maybe the result of diagenesis.

Ten Jurassic species belonging to the two genera are distinguished and five earliest Cretaceous species belonging to 4 genera:

- *Globuligerina* probably appeared in the late Toarcian (late Early Jurassic). It is characterized by low- to high-spired trochospiral test, with almost smooth to pustulose wall, becoming rarely reticulate in isolated specimens from the Oxfordian onwards. In the Jurassic, it is represented by seven species: *G. dagestanica* (Morozova), *G. avariformis* (Kasimova), *G. balakhmatovae* (Morozova), *G. oxfordiana* (Grigelis), *G. oxfordiana* (Grigelis) subsp. *calloviensis* Kuznetsova emended, *G. bathoniana* (Pazdrowa), *G. jurassica* (Hofman), and *G. tojeiraensis* Gradstein;
- *Conoglobigerina* first occurred in the middle Oxfordian. It is characterized by medium high-spired trochospiral test and reticulate wall surface texture. In the Jurassic, it is represented by three species: *C. helvetojurassica* (Haeusler), *C. grigelisi* Gradstein, and *C. gulekhensis* (Gorbachik & Poroshina);
- *Favusella*, *Hedbergella*, *Lilliputinella* and *Gorbachikella* appeared in the Berriasian, with the taxa F. *hoterivic*a (Subbotina), *L. eocretacea* (Neagu), *L.* aff. *similis* (Longoria), *H. handousi* Salaj, and *G. grandiapertura* Boudacher et al.
- The oldest planktonic foraminifera are described from the Toarcian to Aalenian, but they are poorly recognized, only on the basis of thin-sections, preventing observation of the critically important test wall texture. Two principal evolutionally groups of planktonic foraminifera developed in the early Bajocian. One is the *G. oxfordiana* group with relationship to the Callovian–Kimmeridgian species *C. helvetojurassica*, *G. tojeiraensis* and *G. oxfordiana* subsp. *Calloviensis*; the other one is the *G. bathoniana* group with relationship to the species *G. dagestanica* and *G. jurassica*. In the late Bajocian appeared two next groups: one represented by *G. balakhmatovae* with earliest Cretaceous connection to *L. eocretacea*, and other represented first by *G. avariformis* with relationship to *C. grigelisi*.

An optimum in the development of the foraminiferal plankton took place in the Kimmeridgian. This relatively large taxonomic diversity and abundance of planktonic foraminifera may be connected with high global sea level and greenhouse conditions.

During the Jurassic, early planktonic foraminifera spread from regions of the Eastern Canada to the north up to areas of the Western Australia offshore to the south. The migration way was connected with the western margin of the Tethys. They settled only in shallow waters on the marine shelf and are not known from the more open-ocean, truly pelagic environments.

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Comparison of Darwin atoll and the Mecsek type atoll (or reef?)

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Thanks to Charles Darwin, the relation between the activity of volcanoes and coral reefs above the oceanic plate has been well known since his travel around the Earth more than one and a half centuries ago. In the formation of the three step phase (fringing reef, barrier reef and Darwin atoll), hotspots in the mantle and movements of the thin oceanic crust play definitive role. While studying the Urgon facies, characteristic of the tropical and subtropical climate during the Early Cretaceous, I also investigated the Lower Cretaceous succession in the Mecsek Mts, where volcanic and sedimentary rocks alternate. In the clastic sediments, in addition to varied limestones with rudist bivalves and colonial coral fragments, reworked volcanic rocks (basalts and trachytes) can also be found. From the arrangements of the well-rounded basalt pebbles, it became obvious that the macrofossils from one or two hundred meters below the sea derive from the eroded surfaces of the basalt volcanoes. They could form real reef bodies temporarily because of two reasons: (1) the frequently eroding volcanic rocks destroyed the coral reefs; and (2) the rate of subsidence must have been slower than those above the oceanic plate, which was moving away from the hotspot area.

As both the volcanic activity and the type of sedimentation above the oceanic and the continental crust are different, the products are also different. I had to draw the conclusion that we cannot use the term atoll in the Mecsek Mts I proposed formerly, thus I suggest that we call it Mecsek-type reef.

The Jurassic/Cretaceous boundary in the Outer Western Carpathians: high-resolution stratigraphy and paleoenvironmental interpretation

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High-resolution studies of calpionellids, calcareous and non-calcareous dinoflagellate cysts, palynomorphs, calcareous nannofossils, and microfacies compared to magnetostratigraphy allowed stratigraphic and paleoenvironmental interpretations across the Jurassic/Cretaceous (J/K) boundary at the Kurovice Quarry, Magura Group of Nappes, Outer Western Carpathians. A nearly 77-m long section is formed by allodapic and biomicritic limestones with thin intercalations of marlstone deposited under the enhanced water dynamics. Standard microfacies types SMF2, SMF3 and SMF4 indicate deep shelf margin passing into the distal basin. The section spans the stratigraphical interval from the Early Tithonian (*Malmica* dinocyst Zone, nannozone NJT15, magnetozone M21r) to the Early Berriasian (*Elliptica* calpionellid Subzone, nannozone NK-1, magnetozone M17r). The J/K boundary is marked by the quantitative rise of *Calpionella alpina* within nannosubzone NJT17b and magnetozone M19n2n.

The following micro- and nannofossil events were found: at the base of the section, the *Malmica* Zone is marked by the presence of *Polycostella beckmannii*. The first occurrence (FO) of *Helenea chiastia*, NJT16a, is recorded in the *Semiradiata* dinocyst Zone followed by the *Tenuis–Fortis* Zone and the crassicolarian *Remanei* Subzone. The FO of *Nannoconus globulus minor*, NJT17a, and the last occurrence of *P. beckmannii* fall into the lower part of *Intermedia* Subzone. The FO of *N. wintereri*, NJT17b, was found in the upper part of *Colomi* Subzone. Onset of common *C. alpina* indicates the Berriasian Stage. The FO of *N. steinmannii minor*, NKT, belongs to the lower part of *Calpionella alpina* Subzone. The FO of *N. kamptneri kamptneri*, NK-1, coincides approximately with the base of *Ferasini* Subzone. The top of section is marked by the *Elliptica* Subzone, still falling into NK-1, and by the FO of *Speetonia colligata*.

The depositional area of the Outer Western Carpathians is presupposed at the NW margin of the Tethys (Golonka *et al*., 2006). Low numbers of nannoconids and scarce “predominantly tethyan taxa” (*sensu* Bown and Cooper, 1998) compared to nannofossil assemblages from other sites of Tethys, and random *Nannoconus compressus* mentioned mainly from the Atlantic Ocean highlight the influence from high northern latitudes. Rare calpionellids represented mainly by hyaline forms, the absence of chitinoidellids, and also the occurrence of neocomitid ammonites in the Silesian Unit (Vašíček *et al*., 2017) confirm the cold sea currents from the north.

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Microbial structures and microencrusters from the Upper Beriassian-Lower Valanginian of Guri I Pellumbeve section, Mirdita zone. Albania

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Microbial structures, including microencruster associations are the main components of the Lower Cretaceous reefs and play an important role in paleoenvironmental and paleobathymetric reconstructions.

In the Guri I Pellumbave section, a large range of microbial structures and microencrusters was identified and, together with other organisms such as foraminifera, calcareous algae, calpionellids and different macro-organisms as corals and stromatoporoids, were important constituents of the studied deposits and abundant almost in the whole section. The mixture of elements typical of shallow water environments and those of deep water environments represented by calpionellides, allowed us to interpret the carbonate deposits of the studied section as slope sediments.

The most important encountered species are: *Crescentiella morronensis, Radiomura cautica, Radiomura/Perturbata crusta*, *Koskinobulina socialis*, *Mercierella dacica*, *Bacinella irregularis*, the consortium *Lithocodium aggregatum–Troglotella incrustans*, *Lorenziella* sp., *Iberopora bodeuri*, *Terebella lapilloides*, *Thaumatoporella parvovesiculifera*, *Rodhpletzella* sp., cyanobacteria of rivularian type, bacinelloid nodules and peloidal microbial crusts. The coral bioconstructions were intensely encrusted by microbial, algal and foraminiferal structures. Most of these structures are related to shallow-water reef environments with variable hydrodynamic regimes.

U-Pb detrital zircon ages of the Upper Cretaceous Groși Unit (Apuseni Mts, Romania) – constraining the potential sediment sources

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The Upper Cretaceous Groși Unit is a Gosau-type sedimentary basin located in the Highiș-Drocea Mts, in the south-western part of the Apuseni Mts. Following the currently subdivision of the Gosau facies (Wagreich and Faupl, 1994), the Groși unit can be separated into shallow marine deposits (Lower Gosau Subgroup) and deep marine turbidites (Upper Gosau Subgroup) (Schuller, 2004). Detrital zircons for two sandstone samples, one from each of the two subgroups, were investigated by means of the laser ablation inductively coupled plasma mass spectrometry to obtain the U-Pb age spectra, in order to establish the age of the source rocks, and possibly contribute to their identification.

For the Lower Gosau Subgroup, 110 zircon grains were ablated and 119 U-Pb ages were obtained, 74 being 90–110% concordant. The ages are distributed in the 237–273.5 Ma age span, with two dominant populations of about 261 Ma and 380 Ma, which represent the age of the main source rocks. In the case of the sample from the Upper Gosau Subgroup, 115 zircons provided 120 U-Pb ages. Of them, 71 ages are 90–110% concordant and span between 255 Ma and 269.3 Ma, with several peaks at about ~280 Ma, 345 Ma, 470 Ma and 600 Ma. The dominant population for the Groși Upper Gosau has an age at about 470 Ma, indicating the main sediment source.

Both subunits have almost similar U-Pb detrital zircon age span, but with different age distribution, especially in which concern the younger ages. The dominant sources for the Lower Gosau (ca. 260 and 380 Ma) are younger than the main source for upper part (ca. 470 Ma), but were exhumed and eroded earlier. If protolith ages about 470 Ma were mentioned in the Baia de Arieș metamorphic complex (Balintoni *et al*., 2010), ages about 380 Ma or 261 Ma can be correlated with the pre-Variscan tectogenesis and/or Late Variscan magmatism, possible sources being the Arieș migmatites or the Muntele Mare granite.

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Some Upper Cretaceous carbonate-clastic complexes in Serbia: implications for Gosau-type basin development

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The Upper Cretaceous carbonate-clastic complexes, correlated with the Gosau-type of sediments widespread in the Alps and the Carpathians, have been investigated in several oil exploration wells and Mt. Fruška Gora outcrops in Northern Serbia (Vojvodina), and some outcrops in Western Serbia (sections on Mt. Rajac, near Breždje and Struganik villages).

In oil wells of Banat area (Vojvodina) sediments of carbonate-clastic complex are in tectonic contact with Proterozoic-Palaeozoic metamorphites of the Tisza Mega-unit or Albian-Cenomanian deep-water clastites of the Eastern Vardar Zone. On Mt. Fruška Gora sediments of this complex were discovered at Srednje Brdo locality, in tectonic contact with Triassic or Jurassic formations. In the sections of Rajac, Breždje and Struganik localities in Western Serbia, carbonate-clastic complex belongs to Upper Cretaceous sedimentary cover, which unconformably and transgressively overlies Triassic limestones or Jurassic ophiolites and ophiolite mélange.

On the basis of lithological, biostratigraphic and genetic characteristics, the investigated carbonate-clastic complexes show great resemblance to one another (Petković *et al*., 1976; Čanović and Kemenci, 1999; Dulić *et al*., 2004; Djerić *et al*., 2009; Gajić, 2014; Dunčić *et al*., 2017). They are predominantly represented by biosparites, biosparudites, red and light-grey hemipelagic and pelagic biomicrites with very rich planktonic and benthic foraminiferal associations and other diverse micro- and macrofossil assemblages (calcareous nannoplankton, calcified radiolarians, palynomorphs, inoceramids, as well as reef-fossil detritus, transported to deeper parts of the basin). Transgressive sequences of the successions, represented by coarse-grained clastites, are identified only in one well in Banat area and in some localities in Western Serbia. According to biostratigraphical analysis, the defined units of the carbonate-clastic complex of Northern Serbia have Campanian–Maastrichtian age, while the results of biostratigraphical studies of the sediments in Western Serbia implied that basin formation began during the Santonian.

Based on the results of micropalaeontological, biostratigraphical, palaeoecological and petrological studies, the investigated Upper Cretaceous complexes were most probably formed in ocean island arc zones, *i.e.*, in Gosau-type basin.

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Upper Cretaceous fauna from platform carbonates in eastern Serbia (Vrbovac Beds)

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Platform carbonates bearing shallow water fossil assemblages of Campanian age outcrop at two localities in eastern Serbia: Bačevica and Dubrava.

These sediments are generally known as "Vrbovac Reef" or "Vrbovac Beds". The lower parts of the Vrbovac Beds consist of coarse-grained carbonate breccia with fragments of andesite and basalt, which overlies the igneous rocks of the Timok Eruptive Complex (Sladić-Trifunović, 1998). The upper levels of the Vrbovac Beds are represented by clastite-sand carbonates with diverse associations of rudists, gastropods, corals and macroforaminifera. Carbonates, mostly calcarenites, calcrudites and biomicrites, are the main source of rudist fauna, which was subsequently redeposited into other sediments. Clastites that belong to the Vrbovac Beds are mostly fine- to coarse-grained sandstone, shale and marlstone.

At Bačevica locality, fossiliferous horizons are difficult to find. Fossils are abundant, but they are mostly found in the soil. Only two horizons are distinguished. The first one mainly consists of limestone blocks with diverse shallow-marine fauna with domination of large rudists (*Pironaea*), large gastropods (*Trochactaeon giganteus* Sowerby) and solitary corals (*Cunnolites*). These limestone blocks are loosely cemented, so the fauna from this level is mixed into older sediments, which represent the second fossiliferous horizon, in which *Vaccinites loftusi*, *Radiolites* sp., *Pseudopolyconites* sp. and *Laperousia* sp. are abundant. According to Swinburne *et al*. (1992) *Vaccinites loftusi* points to a middle to late Campanian age. This *Pseudopolyconites*-bearing strata seem to be included within a few fossiliferous lithosomes (Alceo *et al*., 2010). Dubrava locality is located several hundreds of meters from Bačevica locality and it exposes biomicrites with numerous rudists, gastropoda and corals. The beds are sub-horizontal and several centimeters thick. The association of rudists from Dubrava locality is similar to that of Bačevica assemblage, but with absence of *Pironaea*. Most numerous are *Vaccinites loftusi*, *Radiolites angeoides* and *Pseudoplyconites* sp. Clearly visible sections of rudists indicate their autochthons position at Dubrava locality. Rudist assemblages could not be determined due to large number of chaotically oriented fragments with longitudinal and oblique crosscuts of shells. Hermatypical corals are found at Dubrava locality together with rudists which, according to Alceo *et al*. (2010), often make associations with rudists due to populating same or nearby habitats. Compared to Bačevica locality, no *Cunnolites* or large individuals of *Trochactaeon* were found at Dubrava locality. The observed sediments at Bačevica and Dubrava localities are typical rudist-bearing deposits of the shallow central Tethys.

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Clay mineralogy of a 10 Ma interval in the NW Tethyan Upper Cretaceous (Postalm, Austria)

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In this study, the changes in clay mineralogy of Upper Cretaceous sediments of the Northern Calcareous Alps over a time span of 10 Ma were investigated. The Upper Santonian to Upper Campanian Postalm section (Gosau Group, Nierental Formation, Austria) comprises more than 180 m of alternating and cyclic pelagic limestones and marlstones with a distinct CORB (Cretaceous Oceanic red Beds) facies. The section was logged bed-by-bed, a total of 369 samples were taken for sedimentological and stratigraphical investigations. Selected samples were investigated for clay minerals as proxies for palaeoclimatic conditions. Chlorite and illite are interpreted as indicators for predominantly physical weathering during cooler palaeoclimate, whereas smectite and kaolinite are indicators for predominantly chemical weathering under more warm-humid climate.

The limestones and marlstones were treated with hydrogen peroxide and subsequently the clay fraction was separated by sedimentation. The clay fractions were further treated with different saturations (Mg-ions, K-ions, ethylene glycol and glycerol), analyzed with x-ray diffraction and quantified.

Results show that the clay fractions mainly consist of illite (54–76%), 10–31% smectite, 6–17% chlorite and 4–13% kaolinite. The amount of smectite increases towards the middle of the section, whereas kaolinite is decreasing. Up the section the amount of smectite decreases and kaolinite increases again. This mineralogical change could indicate a shift from a more humid climate (late Santonian–early Campanian) to a dryer climate in the middle part of the succession (middle Campanian) and then back again to a more humid climate (late Campanian).

Facies of Paleogene deep-water deposits of the Upper Gosau Subgroup at Gams (Styria, Austria)

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The Gosau Group of Gams comprises deposits of late Turonian to Ypresian age, which rest unconformably upon Permian–Jurassic strata of Tirolian nappes (Northern Calcareous Alps, NCA). Several outcrops of the Nierental Formation (Upper Campanian–Selandian) and the Zwieselalm Formation (Maastrichtian–Ypresian) are exposed along Gamsbach creek and its tributary creeks in the eastern Gams basin.

Detailed sedimentological studies within the Upper Gosau Subgroup above the K/Pg were made, including bed-by bed measurements of sections. Additionally, heavy mineral, microprobe, thin-section and biostratigraphic nannoplankton analyses were conducted. Based on biostratigraphic data, a composite section was created for the investigated area. The four correlated facies assemblages are: 1) gray and red marls with thin turbidites; 2) carbonate-poor turbidites; 3) carbonate-rich turbidites; and 4) marl bearing turbidites.

The Danian section of the Nierental Formation (NP1–NP4) consists of hemipelagic to pelagic red and gray marls and marly limestones, intercalated with minor thin, normally graded, sandy and silty turbidite beds as well as slump beds and submarine debris flow deposits. Turbiditic sandstones are rich in carbonate and include redeposited material from NCA, bioclasts (foraminifera, corallinacea) are common. Debris flow deposits include also Paleocene limestones. Variable geometries (channel-fill, lenses) and textures (matrix- to clast-supported) of these mass transport complexes are present.

The basal part of the Zwieselalm Formation (NP5–NP12) is indicated by the first thick (>1 m) turbiditic sandstone bed. An interval (NP5–NP9) of carbonate-rich sandy and silty turbidites (*i.e.*, “classical turbidites”), gray marls and marly claystones changes into a carbonate-poor succession (NP9–NP10) of sandy and silty turbidites and claystones. Turbiditic shales are dark gray, only a few centimeters thick and mostly free from carbonate. The Paleocene/Eocene boundary interval is characterized by thin-bedded turbidites with russet to brown claystones, deposited below the calcite compensation depth (CCD). An interval (NP10–NP11) of turbiditic sandstones with higher carbonate contents follows, intercalated with gray, reddish and greenish marls. Towards the top of the Zwieselalm Formation (NP12), the thickness of fine-grained sandstone beds decreases.

Breccia layers at the base of turbidites and several slump beds are characteristics of the Zwieselalm Formation. Thicker sandstones show Bouma Ta-e sequences, more frequent thinner beds often only show Tcd sequences. Water escape structures, bioturbation and amalgamation of turbiditic sandstones are visible in all sections. Thinning- and fining-up cycles indicate small turbidite fans prograding into a confined slope basin.

Heavy mineral- and thin section analysis suggest a mixed siliciclastic-carbonate source from the rising metamorphic hinterland, the NCA and small contemporaneous carbonate platform areas. Material delivered from the south filled up a (partly) confined slope basin along the active margin of the Austroalpine microplate. Sedimentation rates for the Zwieselalm Formation are high, approximately 20 cm/kyr are estimated.

The Paleogene basin system developed in a weakness zone of the Central Western Carpathian orogenic wedge

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The Paleogene basin system of the Central Western Carpathians (CWC) embraces various basin types (wedge-top, fore-arc or back-arc), dependent on their geodynamic position and tectonic processes active at the given stage of orogenic wedge collision with the European Platform. The diachronous subsidence of the fore-arc basin depocentres was mainly driven by extension of the overriding plate and so indicates a strong roll-back effect of the Magura subduction, appearing not only in the front, but in the whole escaping crustal wedge of the future Neogene ALCAPA Mega-unit during the Cenozoic.

The Mid-Slovakian Paleogene depositional system (MSPD) developed between the north-westward progressing accretionary wedge (Gosau-type basins in the Middle Váh Valley) and the north-eastward moving crustal fragments of the CWC. Remnants of the MSPD are documented in the Žilina, Rajec, Domaniža, Pružina, Horná Nitra, and Turiec depressions. Their common feature is a superimposition of the wedge-top and fore-arc basins, which indicates a zone of crustal weakness of the MSPD during Middle Eocene to Oligocene times.

Northern basins of the MSPD were superposed as a wedge-top basins on frontal CWC nappes and Peri-Klippen units. Late Paleocene–early Eocene transgression led to development of thrust-top carbonate platforms (Kambühel Fm., *Alveolina* Lms.), calciclastic fans and shelf mudstones. Synsedimentary tectonics of the Súľov-Domaniža Basin started by normal faulting and disintegration of the orogenic wedge. This wedge-top basin was filled with mass-transport deposits of the Súľov Conglomerates, the thick lithosomes of which are intercalated by deep-water claystones with planktonic and agglutinated foraminifera. The subsidence was accelerated by gravitational collapse and subcrustal tectonic erosion of the CWC plate. During the late Ypresian–Lutetian, the Súľov-Domaniža Basin and related basins of the MSPD subsided to lower bathyal up to abyssal depth. Basin deepening was enhanced by Lutetian transgression, which enabled a marine connection with the Magura Ocean. Lutetian formations are formed by hemipelagic marls and turbiditic sequences, non-calcareous red claystones with Reticulophragmium amplectens and other deep-water deposits. Southern basin in the Horná Nitra Depression is akin to a Krappfeld-type succession with basal reddish terrestrial sediments followed by late Paleocene/early Eocene shallow-marine formations and Lutetian deep-water marls. This implies a southward connection of MSPD with the Carinthian embayment of the Mediterranean Tethys and northward connection with Alpine Tethys. Lutetian sea also transgressed into the Central-Carpathian Paleogene fore-arc basin with development of carbonate ramps (Borové Fm.).

Post-Lutetian basin inversion and orogenic wedging in western part of the CWC was accompanied by eastward lateral migration of the Late Eocene – Oligocene depocentres of the Central Carpathian Paleogene Basin (CCPB). Late Eocene formations of the MSPD are composed of gray and dark-grey weakly calcareous claystones. They still reveal a deep-water deposition with agglutinated and planktonic foraminifers, which differ from coeval claystone formations of the CCPB (Huty Fm.). Early Oligocene claystones and menilite shales developed from Late Eocene formation of the MSPD with correlative conformity to high-stand formations of Globigerina Marls in the CCPB. Late Oligocene formations of the MSPD are formed by turbiditic and sandy-rich facies of submarine fan deposystems of the CCPB.

Session GT2-2

Climate and biota of the Cretaceous and early Paleogene

Conveners:

Hans Eggerand and Alfred Uchman

High-resolution study of possible regional GSSP key sections of the Jurassic/Cretaceous boundary in Slovakian Western Carpathians

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West Carpathian Brodno, Snežnica, Strapková and Hlboča sections have been selected as the key J/K boundary regional stratotypes in the Western Carpathians. Plankton (calpionellids, calcareous dinocysts and nannoplankton), O and C isotope fluctuations and palaeomagnetic record have been studied in detail in these sequences.

Preliminary results of the sequence studied start in greenish, brownish to brown-greenish pseudonodular limestones with silicite nodules. Predominantly *Saccocoma* packstones contain succesion of calcareous dinoflagellates on the base of which the early Kimmeridgian *Parvula* Acme Zone, late Kimmeridgian *Moluccana* and *Borzai* zones, early Tithonian *Pulla*, *Tithonica* and *Malmica* zones (*sensu* Reháková, 2000) have been recorded. Overlying bioclastic crinoidal packstones contain rather seldom chitinoidellids of the *Longicollaria dobeni* Subzone, latest early Tithonian in age. Tithonian Rosso Ammonitico nannofossil assemblages were dominated by *Conusphaera*. *Polycostella* abundance increasesing at the base of the calpionellid *Chitinoidella* Zone and decreases towards the *Crassicollaria* Zone. *Helenea chiastia*, accompanied by the first small nannoconids, appeared during the middle Tithonian. Obliquipithonellid abundance in the *Semiradiata* Zone indicates surface water warming.

Upper Tithonian biomicrite wackstones contain calpionellid associations determining the *Crassicollaria* Zone. The base of the late Tithonian *Crassicollaria* Zone correlates with the reverse magnetic Kysuca Subzone described from the Brodno Quarry (Houša *et al*., 1999; Grabowski *et al*., 2010). In the frame of it, *Intermedia* Subzone alodapic layers built of laminated, *Saccocoma* wackstones to packstones containing cysts of early Tithonian *Pulla*, *Malmica*, *Tithonica* and *Dobeni* zones/subzones were observed. In these beds, bioclasts show distinct gradation. Small nannoliths, such as *Hexalithus noeliae* and *Litraphidites carniolensis*, appeared within the *Microstaurus chiastius* Zone. Stable isotopes ($\delta^{18}O$, $\delta^{13}C$) and a low C_{org} content indicate generally colder period, disturbed by a warmer latest Tithonian episode.

Close to the J/K boundary, crassicollarian association decreases in abundance, being replaced by biomicrite wackstones with domination of small sphaerical specimens of *Calpionella alpina*. The base of the standard *Calpionella* Zone has been traced below the reverse Brodno magneto-subzone. Poorly diversified nannofossils (*e.g.*, *Watznaueria*, *Cyclagelosphaera*, *Conusphaera*, and *Polycostella*) are relatively abundant. Boundary interval is designated by the *Nannoconus wintereri* FO together with small nannoconids at the base, and the *Nannoconus steinmanni minor* FO at the top. As indicated by $\delta^{18}O$ isotopes, the late Tithonian cooling has been followed by a temperature increase. Nannoconids bloomed due to temperature/salinity changes associated with earliest Berriasian warm water influx.

The overlying Biancone-limestone sequence contains biomarkers of the *Ferasini* and *Elliptica* subzones of the standard *Calpionella* Zone (Reháková and Michalík, 1997). $\delta^{13}C$ isotope record illustrates typical decrease of isotope ratios during the Tithonian and their shift to stable values around 1.00‰ in the boundary interval (Michalík *et al*., 2009, 2016). Increasing $\delta^{13}C$ and $\delta^{18}O$ variability in the higher part of the sequence signalizes isotope values discontinuity in changing hydrological and palaeoecological conditions.

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Lower Cretaceous sedimentary evolution of carbonate platforms in the Manín Unit (Western Carpathians, Slovakia)

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Lower Cretaceous sequence of the Manín Unit croping out in the Middle Váh Valley consists of Valanginian–Barremian pelagic carbonates and neritic carbonate complex (Urgonian facies s.l.). The demise of lower Cretaceous platforms is considered to coincide with the 'mid-Aptian crisis' of the Tethyan platform systems. However, the input of clasts of platform sediments in allodapic facies indicated that the platform growth was still active during the late Aptian–Albian, suggesting that the carbonate factory production in the Western Carpathians terminated later than in other Tethyan regions (Michalík *et al.*, 2012; Fekete *et al.*, 2017). Planktonic foraminifers allow to restrict the growth and the demise of the carbonate platforms within the Manín Unit and provide a schematic model displaying lithofacies architecture and platform development. The platform margin and upper slope facies of the "Urgonian" Barremian–Aptian sequence, originally forming the higher highstand platform were eroded and its former slope was overlain by platform margin and upper slope facies of the lowstand platform. The lowstand carbonate platform sequence starts with upper slope facies with planktonic foraminifers *Hedbergella trocoidea*, *Globigerinelloides ferreolensis*, *G. barri*, *G. aptiensis*, *G. algerianus* indicating late Aptian zones and *Ticinella primula*, *T. roberti, T. cf. madecassiana* of the Albian *Ticinella primula* Zone. Rare colomiellids, *e.g.*, *Colomiella mexicana, C. recta, Cadosina semiradiata olzae* with *Calcisphaerula innominata*, also occur. The calcareous nannofossil assamblage is dominated by *Watznaueria*, *Nannoconus*, *Assipetra* and *Micrantholithus*. The upper slope facies passes upwards continuously into peri-reef facies with accumulations of caprinid rudists shell fragments and orbitolinids *Palorbitolina* ex gr. *lenticularis* and *Mesorbitolina* gr. *parva–texana*. $\delta^{13}C$ and $\delta^{18}O$ isotope values in the studied sequences share similarities. Distribution of $\delta^{13}C$ reveals eustatic sea-level oscillation and suggests neritic conditions and continual marine diagenesis. During the late Aptian eustatic changes, this highstand carbonate platform sequence has been destroyed by erosion. Carbonate clasts were accumulated on toe of the slope of the new mid-Albian lowstand carbonate platform. After stabilization and aggradation stage, carbonate platform growth was stopped and the platform collapsed. A hardground surface was formed, overlain by Albian–Cenomanian pelagic marls with a thin layer of calcisphaerulid limestones characterized by calcareous dinoflagellates from the late Albian *Innominata* Acme Zone and planktonic foraminifera from the *Thalmanninella appenninica* Zone related to the top of the late Albian.

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Albian–Turonian benthic foraminiferal bio-events: a case study from the Bey Dağları Carbonate Platform, Western Taurides, South Turkey

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The studied section is located at the eastern flank of the North-South trending Toçak anticline in the southeastern of the Bey Dağları Carbonate Platform. Approximately 550 meters thick outcrop section presents a continuous shallow-water sedimentation during the Albian–Turonian times. The aim of the study is to document disappearance (extinction or emigration) and appearance (origination or immigration) of benthic foraminiferal taxa throughout the section. The Albian–Cenomanian boundary is characterised by last occurence (LO) of the late Albian survivor *Protochrysalidina elongata* and the first occurence (FO) of the alveolinids including *Ovalveolina maccagnoae* and *Sellialveolina viallii*. These taxa are followed by other Cenomanian species such as *Biplanata peneropliformis, Biconcava bentori, Chrysalidina gradata, Praealveolina iberica, Cisalveolina lehneri, Pseudolituonella reicheli, Vidalina radoicicae, Pseudorhipidionina casertana, Pseudorhapydionina laurinensis,* and *Pseudorhapydionina dubia*.

In the Apennine Carbonate Platform (ACP) of southern Italy, a two-step pattern of extinction of larger foraminifera was documented from the Cenomanian–Turonian boundary (Parente *et al*., 2008). This event has been recorded also in the shallow-water carbonates of the Bey Dağları Carbonate Platform. In the first step of extinction, the mainly Cenomanian taxa comprising *Pseudorhapydionina laurinensis, Pseudorhipidionina casertana, Vidalina radoicicae, Biplanata peneropliformis, Biconcava bentori* and *Nezzazata gyra* disappeared. In the second step of extinction, the few survivors, *Pseudorhapydionina dubia, Pseudolituonella reicheli*, and *Chrysalidina gradata* wiped out. After the disappearance of the larger benthic foraminifera, renewed (post-extinction) foraminiferal assemblages in the Turonian were characterised by low diversity and dominated by morphologically simple and less known/new taxa such as *Finikella gediki* n.gen., n.sp. and other taxa including *Pseudocyclammina sphaeroidea, Moncharmontia apenninica, Fleuryana* sp., smaller-sized *Spiroloculina* sp. This bio–event probably corresponds to the Cenomanian–Turonian boundary. Few taxa such as *Cuneolina pavonia, Nezzazata simplex* and *Nezzazatinella picardi* survived during the Albian–Turonian interval.

Sedimentologic and micropaleontologic analyses suggest that the Albian–Turonian platform carbonates in the Toçak Mountain deposited in peritidal environments of restricted platform including shallow pond settings.

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Biostratigraphy of Upper Cretaceous sediments (Western Georgia) and some data on palaeoenvironment based on macro- and microfauna

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The territory of Georgia covers the north-western part of the Caucasian segment of the Alpine fold system. Upper Cretaceous sediments are widespread of the Western Georgia. They are most developed in the Gagra-Java zone and Caucasus intermountain region. The Upper Cretaceous in the studied sections along the rivers Tskhenistskali, Rioni, Khotevi belongs to the composed tectonic units of Racha sinkage, Okriba-Khreiti subzones, and Ajaria-Trialeti zone (Gamkrelidzeat *et al*., 2013). The analyses made possible to establish six foraminiferal zones in the studied sections. Complex I – *Marginotruncana pseudolinneiana* was found together with mollusks of the *Inoceramus lamarcki* Zone and corresponds to the nannoplankton zone of *Eiffellithus eximius*. The complex is dated as late Turonian. Complex II, at the top of the limestone layer with *Marginotruncana coronata* corresponds to the *Inoceramus sturmi* mollusk Zone and the *Marthasterites furcatus* nannoplankton Zone. The age is determined as early Coniacian. Complex III, comprising *Marginotruncana sigali* and *M. renzi*, stratigraphically corresponds to the *Inoceramus involutus* Zone. It is dated as late Coniacian. Complex IV includes *Contusotruncana fornicata* and the *Ahmuellerella mirabilis* nannoplancton Zone. It is dated as late Santonian. Complex V with *Globotruncana arca* is characterized by the abundance of index-species and it corresponds to the layer with *Micraster schroederi*. It is dated as early Campanian. Complex VI of *Globotruncana ventricosa* corresponds to the layers with *Belemnitella mucronata* and to the *Ceratolithoides aculeus* Zone, and partly to the *Uniplanarius trifidus* nannoplankton Zone. The age is determined as middle Campanian (Kopaevich and Vishnevskaya, 2016).

At present, a definite methodology exists for reconstruction of some parameters of the paleobasin that is based on quantitative interrelations of foraminiferal associations. This technique is based on actualistic data from contemporary water areas. The PF (Planktonic Foraminifera) data can be used to interpret the fossil material data applicable in palaeogeographic reconstructions for specifying palaeodepths. According to the percentage of left- and right-coiling species of Globotruncanidae, the temperature conditions of the late Cetaceous basins have been estimated (Krasheninikov, 1960).

During the late Turonian–early Santonian, on the territory of Western Georgia existed superficial, heat-water basin, with normal salinity. The analysis of distribution of deposits and their structure allows judging the presence of three stages and three large cycles of sedimentation: Cenomanian–early Turonian, late Turonian–Campanian, and Maastrichtian–Palaeogene.

The second cycle lasted from the beginning of the late Turonian and to the end of the Campanian. While a regressive period comprises mainly the Santonian–Campanian, that evidences relation in time with the Laramian folding phase (Ghambashidze and Iasamanov, 1980).

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Stratigraphic constraints, biotic changes and palaeoenvironmental proxies of K/T and early Palaeogene events in the Western Carpathians

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K/T boundary has been previously constrained in Western Carpathians, but its existence is still uncertain due to Laramian erosion and absence of lowermost P-series biozones (P0–P1). New evidence of the K/T boundary has been gathered from the study of stratigraphic drillings in Mid-Váh Valley area, Horná Nitra Depression and Magura Zone.

K/T boundary is most properly marked in the Kršteňany KRS-3 borehole by LO of *Abathomphalus mayaroensis* and FO of *Parvularugoglobigerina eugubina*. Transitional inteval is also well dated by microperforate species *Globoconusa daubjergensis*, *Eoglobigerina simplicissima*, etc. The section grades upward to the Selandian formation with *Praemurica inconstans* and *Morozovella angulata*, and Thanetian formation with acme of acarininids (*A. wilcoxensis, A. coalingensis, A. pseudotopilensis*, etc.). The PETM interval is approximated by negative carbon isotopic excursion, magnetic reversal chron C24, and appearance of excursion taxa (*Acarenina sibaiyensis*, *Discoaster araneus*). Ypresian formations are rich in diversified morozovellids (*e.g., M. formosa, M. subbotinae, M. aragonensis, M. lensiformis*), and higher up in Lutetian formations the succession is characterized by *Morozovella gorrondatxensis, Turborotalia frontosa, Acarinina topilensis, Globigerinatheka kugleri,* etc. Considering that, the Kršteňany section provides a most complete stratigraphical record from the K/T boundary up to the Zone E10, that corresponds to the late middle Lutetian (MECO).

K/T boundary in Hradisko ZA-2 borehole near Žilina is developed in plankton-rich sequence, which allows to obtain a high-quality stratigraphic record. The sequence begins with Maastrichtian marlstones with globotruncanid and heterohelicid foraminifers such as *Abathomphalus mayaroensis*, *Gansserina gansseri, Racemiquembelina fructicosa*, etc. This formation passes into dark bioturbated marls with impoverished microfauna, which higher up abruptly changed to *Parasubbotina*- and *Subbotina*-rich associations of the lowermost Palaeocene. Middle Palaeocene sequences are significaltly enriched in large-sized morozovellids (*e.g., M. angulata, M. acuta*), globanonalinids (*e.g., G. pseudomenardi, G. compresa*), and muricate acarininids (*e.g., A. strabocela*, *A. soldadoensis*). Marly sequence also contains coralgal limestones of Kambühel Formation. Middle Eocene formations are rich in clavate and stellate foraminifers (E8 Zone), subbotinids, globigerinathekids and subquadrate acarininids (E9–E10 Zone). Alike in Matsee section in Austrian Helveticum, an evolutionary changes from *Clavigerinella* to *Hantkenina* species has been recorded in the Lutetian formations.

K/T boundary is also infered in deep-water sequence of the Magura Zone. It is marked by rich microfauna of guembelitrids, which indicates *Guembelitria* bloom at the K/T boundary. This stress microfauna is well documented by the species *Guembelitria cretacea*, *G. danica*, and *Woodbringina hornerstownensis*, which correspond to the P0 biozone. Palaeocene sediments above *Guembelitria*-bearing formations differ by appearance of *Parasubbotina* species.

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The Palaeocene sediments in the Bosnian Flysch Unit (Internal Dinaridic Platform, Bosnia and Herzegovina)

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The Bosnian Flysch Unit stretches from the border belt of Croatia and Slovenia in NW, via central parts of Bosnia and Herzegovina and Montenegro up to the border belt between Montenegro and Albania in SE. Tectonically trapped between the most external belt of Dinaride ophiolites (Aubouin, 1973) and East Bosnia-Durmitor unit in the NE, and units of the Mesozoic carbonate platform of the Adriatic plate in the SW, it is one of the most imposing tectonic-stratigraphic units of the Dinaride orogen.

Sedimentation of the Flysch Unit started during the latest Jurassic and became progressively younger in the more external parts. The unit is subdivided into two sub-units (Mikes *et al*., 2008): carbonate-marly dominated Ugar Formation (Upper Cretaceous) and predominantly sandy-clayey Vranduk Formation (Upper Jurassic to the Lower Cretaceous).

Stratigraphic investigation of the upper part of the Ugar Fm. based on calcareous nannofossils were performed on three localities: 1) area of Jajce (Western Bosnia); 2) area of the Vlašić Mountain (Ugar Valley); and 3) Dramešina-Dražljevo-Mrđenovići area (Eastern Herzegovina).

Sediments NE of Jajce, at locality Donji Bešpelj (Western Bosnia) can be attributed to the Palaeocene based on abundant and well-preserved nannofossils (*Chiasmolithus danicus, Coccolithus pelagicus, Cruciplacolithus tenuis, Markalius inversus, Ellipsolithus macellus, Fasciculithus tympaniformis, Heliolithus kleinpellii, Heliolithus riedelii*, etc.). Stratigraphically youngest sediments in this area contain *Discoaster multiradiatus, D. lenticularis*, and *D. delicatus* and belong to the NP9 of Martini (1971) (uppermost Palaeocene, Thanetian). Marly sediments from the Ugar Valley (Vlašić Mountain) contain *Chiasmolithus danicus, Coccolithus pelagicus, Cruciplacolithus tenuis, Cr. asymmetricus* and can be assigned to the lower Danian (NP3). Palaeocene sediments on the southern edge of the Ugar Formation in the Eastern Herzegovina (Dramešina-Dražljevo-Mrđenovići zone) could be distinctly distinguished from Upper Cretaceous in the north of the area. Calcareous nannofossil associations of investigated sediments from this area (*Chiasmolithus danicus, Cruciplacolithus tenuis, Fasciculithus ulii, F. tympaniformis, Prinsius martinii*, etc.) allow an attribution into zones NP2 to NP5 (Danian/Selandian).

In summary, recent investigations in the Bosnian Flysch zone documented existing of ca. 600 km long Palaeocene sedimentary basin, within this tectonic unit. This siliciclastic sediments overlaying carbonate-dominated Ugar Formation can be continuously traced from the NW to the SE along this unit.

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Bispiraloconulus serbiacus gen. et sp. nov., a giant arborescent benthic foraminifera from the Berriasian of Serbia

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A new giant (centimetre-sized) benthic foraminifera displaying arborescent morphology is herein described as *Bispiraloconulus serbiacus* gen. et sp. nov. from Berriasian shallow-water carbonates of the Kurilovo area, eastern Serbia. The sample yielding the new taxon belongs to a carbonate succession cropping out north-north-east of Niš, in the vicinity of Kamenica Village. The limestones from this area belong to the Kurilovo fold structure or anticline that is part of the Gornjak-Stuva Planina unit, the westernmost part of the Carpatho-Balkanids of Eastern Serbia. North of the Danube River it continues with the Sasca unit belonging to the Getic domain of the South Carpathians.

The new form is characterized by an initial part with a short spire, adult part with rectilinear chambers, thin septa exhibiting cribrate foramina, chamber interior containing (bio)clasts fixed (agglutinated) to the septa by means of micritic pillar-like elements, and a thin wall (epiderm) with short subepidermal network. All these features are characteristic for the genus *Spiraloconulus* Allemann & Schroeder (Aalenian–Berriasian) with its three species *S. perconigi* Allemann & Schroeder, *S. giganteus* Cherchi & Schroeder, and *S. suprajurassicus* Schlagintweit. The branching-arborescent test morphology, however, differentiates the Serbian form from *Spiraloconulus* being unbranched conical to cylindro-conical. Following current classifications of agglutinating foraminifera, test bifurcation is considered a generic criterion (*e.g.*, compare *Reophax* vs. *Bireophax*) and consequently, a new genus is established: *Bispiraloconulus*. With this characteristic *Bispiraloconulus* can be compared with the Barremian–Aptian *Torremiroella* Brun & Canerot and the Cenomanian *Thomasinella* Schlumberger. Among the agglutinating foraminifera, *Bispiraloconulus* is unique by its arborescent test combined with a wall displaying an exoskeleton (subepidermal network). *Bispiraloconulus* belongs to a group of larger benthic foraminifera with a peculiar type of endoskeleton. It consists of bioclasts interconnected by segregated micritic pillar-like elements, forming a three-dimensional network and filling large parts of the chamber interior: *Spiraloconulus* Allemann & Schroeder (Aalenian–Berriasian), *Bostia* Bassoullet (Bathonian), *Robustoconus* Schlagintweit & Velić (Bajocian), and *Torremiroella* Brun & Canerot (Barremian–Aptian). This internal structure obviously contributed considerably to test rigidity allowing an adaptation to agitated shoal and near-shoal paleoenvironments. Delicate large-sized arborescent agglutinated taxa (without exoskeleton/endoskeleton) instead were reported from bathyal depths.

Upper Cretaceous fish teeth from Peștera, Dobrogea (Romania)

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Upper Cretaceous deposits from Dobrogea (south-east Romania) have been studied intensively since the mid-19th century and various fossils were described from this region. However, no fish remains were known until recently, when teeth belonging to five genera of sharks (Gallemí *et al*., 2011) were reported from the Cenomanian (Peștera Formation; Dragastan *et al*., 1998) of Peștera open pit (Moesian Platform, Southern Dobrogea sector). After that, intensive surface and bulk sampling of this location revealed a rich fauna belonging to Chondrichthyes and Actinopterygii.

The assemblage herein reported comprises *Protoscyliorhinus* cf. *bettrechiensis, Cretalamna appendiculata, Scapanorhynchus* aff. *raphiodon, Squatina* sp., *Paranomotodon* sp., *Ptychodus* sp., *Hexanchus* sp., *Protolamna* sp., *Squalicorax* sp. 1, *Squalicorax* sp. 2, *Carcharias* sp., *Heterodontus* sp., cf. *Enchodus* sp., *Pycnodontiformes* sp. indet., and *Actinopterygii* sp. indet.

None of these taxa is a convenient stratigraphic marker, but based on the previous finds (Gallemí *et al*., 2011) and the geology of the area, this assemblage could be considered Cenomanian. However, it is also possible that some of these teeth could be reworked from older sediments (Albian) as few invertebrates were reported to be (Chiriac, 1981).

Unfortunately, the preservation of these teeth is very poor. This is due to the transport of the teeth in a highly dynamic environment before their burial. The specimens were deposited into a well-sorted microconglomerate. The sorting process likely influenced the size range of the preserved fossils, since most of the teeth do not exceed the size of microconglomerate clasts. Due to the hard transport, most of the teeth lack part of their diagnostic features. Only 2–3% of the collected teeth can be assigned as genus or species.

The reported fauna is by now the only marine Upper Cretaceous fish fauna from Romania. Very rarely, isolated teeth were reported until now from other Romanian geological structural units, documenting some taxa, but never an assemblage.

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Eocene dinoflagellate cyst assemblages from the northwestern Tethyan margin (Adelholzen section, Eastern Alps, Germany)

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Rich and well-preserved assemblages of organic-walled dinoflagellate cysts (dinocysts) found within 28 samples collected from the Eocene sediments of the Adelholzen section in southeastern Germany are herein presented. The sediments accumulated during the Lutetian and Priabonian at a ramp-type margin of the northwestern Tethys. One hundred organic-walled dinocyst species were found at the section, which is riddled with unconformities. The composition of the successive dinocyst assemblages reflects the sea-level changes within the depositional area. *Areoligera coronata* and *Cordosphaeridium gracile* dominate the assemblage within the glauconite-rich siliciclastic sandstone (lower Adelholzen beds) of the lower transgressive system tract, which spans the calcareous nannoplankton subzones NP15a and NP15b. A hiatus comprising at least ca. 1.5 million years truncates these deposits and indicates an erosional episode. Rapid sea-level rise in Biochron NP16 caused a new transgression and the deposition of calcareous marlstone and limestone rich in nummulitids. In this part of the section (middle Adelholzen beds), *Homotryblium tenuispinosum* is by far the most abundant dinocyst species, and rare but consistent occurrences of *Impagidinium* spp. suggest a more open marine environment. A lithological shift from limestone to marlstone, a change from nummulitids to discocyclinids, and finally the complete disappearance of larger benthic foraminifera indicates continuous deepening of the environment. An increase in *Spiniferites* spp., *Operculodinium* spp., and occurrences of *Homotryblium floripes* characterize the dinocyst assemblage of this marlstone (upper Adelholzen beds). A 0.5 m thick condensed layer, which consists essentially of iron-coated glauconite grains and scattered phosphate nodules, represents the maximum flooding surface of the transgressive sequence, for which a palaeodepth of ca. 300 m is assumed. The overlying marlstone ("Stockletten") of the highstand system tract is punctuated by a hiatus of ca. 4.3 million years spanning the entire Bartonian. The stratigraphically important species *Rhombodinium longimanum, Rhombodinium perforatum, Distatodinium ellipticum, Nematosphaeropsis labyrinthus and Selenopemphix nephroides* have their lowest occurrences in the Priabonian (zones NP18 and NP19) of the section.

Session GT2-6

New developments in Paratethys Research

Conveners:

Mathias Harzhauser and Werner Piller

Regional stages of the Paleogene and Neogene sedimentary formations of Ukraine: biostratigraphy and correlation

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In Ukraine, the Paleogene and Neogene sediments are well developed within the Eastern Carpathians (western region), Black Sea, Crimea and the Kerchian peninsula and the Black Sea and Azov Sea offshores (southern region), as well as on the East European Platform (northern region). The formations are presented by sediments that are typical for the Carpathian-Black Sea segment of the Tethys (western and southern Ukraine) and Northern Atlantic Boreal province (northern Ukraine).

The stratigraphic charts for these regions contain regional stages (highest taxonomic units) selected on litho- and bio- stratigraphic criteria. The geological age of the regional stages are commonly based on planktonic microfossils from marine facies (foraminifera, nannofossils, dinocysts) and benthic macro/microfossils from marine and continental facies.

Carpathians. Paleogene regional stages include the Rusychansky (Danian–Selandian), Karpiysky (upper Selandian–Priabonian), Ombronsky (Rupelian–Chattian). They characterize the three stages of flysch sedimentation. Neogene regional stages are represented by the Eggerian (upper Chattian–lower Aquitanian), Eggenburgian (upper Aquitanian–lower Burdigalian), Ottnangian (Burdigalian), Karpatian (upper Burdigalian); Badenian (Langhian–lower Serravallian), Sarmatian (upper Serravallian), Pannonian (Tortonian), Pontian (Messinian), Dacian, Romanian (Pliocene). Lower–Middle Miocene regional stages represent mollase sedimentation. Here, open marine conditions prevailed during the Sarmatian and Early Pannonian. Pliocene regional stages reflect a freshwater sedimentation.

Crimean Black Sea region. Paleogene regional stages: Belokamyansky (Danian–Selandian), Kachynsky (Thanetian), Bachchisaraysky (lower part of Ypresian), Simferopolsky (upper Ypresian–lower Lutetian), Novopavlivsky (Lutetian), Kuma (Bartonian), Almian (Priabonian), Planorbelovy (lower Rupelian), Molochansky (middle Rupelian), Kerleutsky (Chattian), Caucasian, Lower Caucasian regional substage (upper Chattian). Neogene regional stages: Upper Caucasian regional substage (Aquitanian), Batisifon (Burdigalian); Tarkhanian (lower Langhian), Chokrakian (upper part of Langhian), Karaganian (upper Langhian), Konkian (lower Serravallian), Sarmatian (Serravallian–lower Tortonian), Meotian (upper Tortonian), Pontian (Messinian); Kimmerian (upper Messinian–Zanclean), Kuyalnikian (Upper Pliocene). The mentioned regional stages reflect time of marine sedimentation with episodes of desalination, and renewed links with the marine realm after the Sarmatian.

East European Platform. Paleogene regional stages: Sumskyi (including regional substages: Psolsky (Danian–Selandian), Merlinsky (Thanetian)), Kanivsky (Ypresian), Buchaksky (Lutetian), Kyivsky (upper Lutetian–Bartonian), Obuchivsky (Priabonian), Mezhigorsky (Rupelian), Bereksky (Chattian). Neogene regional stages: Novopetrovsky (Upper-Middle Miocene), Sarmatian (upper Serravallian–lower Tortonian). These regional stages reflect prevailing marine conditions with episodic regressions. As a result, they are composed of marine, shallow water and continental facies.

The regional stages of the Carpathians correlate well with those from southern and northern Ukraine, namely the Rusychansky (Paleogene part) corresponds to the Psolsky regional substage, and the lower Belokamyansky regional stage; Karpiysky correlates to the range of the upper part of Belokamyansky to Almian regional stages, and also from Merlinsky to Obuchivsky of northern Ukraine; Ombronsky regional substage corresponds to the Planorbellovy, Molochansky, Kerleutsky regional stages, Lower Caucasian regional substage, and to the Mezhigorsky and Bereksky regional stages of northern Ukraine; Egerian corresponds to the Caucasian s.l. regional stage; Ottnangian and Karpatian correlate with the Batisifon of southern Ukraine, while the Badenian correlates to the Tarkhanian, Chokrakian, Karaganian, Konkian; Sarmatian; Pannonian corresponds to the Sarmatian and Meotian. Finally, the Romanian regional stage correlates with the Kuyalnikian.

The Rupelian–Chattian transition in the north-western Transylvanian Basin (Romania) revealed by calcareous nannofossils: implications for biostratigraphy and palaeoenvironmental reconstruction

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The studied sediments are part of the Vima Formation and are located south of the Preluca Massif, in the NW Transylvanian Basin (Romania). In this area, three outcrops (Fântânele section) have been sampled in order to establish the precise age and to reconstruct the paleoenvironmental conditions. The investigated section consists of an alternation of claystones, marlstones and siltstones with thin sandstones intercalations. Sampling resolution varies from 10 cm to 50 cm, seventy-five samples having been analysed for calcareous nannofossil content. Multivariate Hierarchical Clustering by Ward's Method and Non-metric Multidimensional Scaling were applied to all counted samples.

Forty-nine calcareous nannofossil species were identified, 38 of them being autochthonous, while 11 species were reworked from Mesozoic and lower stages of the Paleogene. Based on the obtained results, the studied section falls into NP24 (*Sphenolithus distentus* Zone)–NP25 (*Sphenolithus ciperoensis* Zone). Thus, the age is late Rupelian–early Chattian.

The most abundant species from the assemblage are *Cyclicargolithus floridanus*, *Reticulofenestra minuta*, *Braarudosphaera bigelowii*, *Pontosphaera multipora*, *Coccolithus pelagicus*, *Reticulofenestra* gr. 3–5 µm, *Reticulofenestra bisecta*, *Cyclicargolithus abisectus*, *Reticulofenestra lockeri*, *Pontosphaera pygmaea*, *Reticulofenestra daviesii*, *Reticulofenestra stavensis*, *Helicosphaera recta*, *Sphenolithus moriformis* and *Pontosphaera desueta*. In the upper part of the third outcrop, a bloom of *Braarudosphaera bigelowii* and *Reticulofenestra minuta* was registered. A drastic decrease in the number of species (5 species) has accompanied this bloom.

The Multivariate Hierarchical Clustering indicates four main clusters and eight sub-clusters which are well differentiated. Cluster I comprises nine samples and groups the highest proportion of *Pontosphaera* spp.; Cluster II concentrates the highest number of samples containing the highest amount of *Cyclicargolithus* spp.; Cluster III has 13 samples from the first and the third outcrops and displays the highest amount of small reticulofenestrids and Cluster IV includes only 4 samples from the upper part of the third outcrop where the bloom of a single species (*Braarudosphaera bigelowii*) was registered.

The palaeoenvironmental conditions of Fântânele section are going from more stable open-marine regime, with temperate sea-surface temperatures interfering locally with influx of cooler water and enriched cool-nutrient supply for the late Rupelian–earliest Chattian (NP24) interval to shallower and possibly warmer near-shore marine eutrophic environment, with salinity fluctuations, increased terrigenous material run-off and freshwater influx for the remaining early Chattian (NP25).

New biostratigraphic, sedimentological, and radiometric data from the Lower–Middle Miocene of the Zaječar area (westernmost part of the Dacian Basin, eastern Serbia)

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This study presents results of detail logging of cores from five exploration boreholes (RTN-1501, RTN-1502A, RTN-1503, NRKR-17001 and NRKR-17002). Stratigraphically, the Miocene succession is divided into three units: Lower Miocene, Middle Miocene Badenian and, Middle Miocene Sarmatian deposits. Based on all the collected data a continental-lacustrine environment existed during the Early Miocene. There are a few dominant lithofacies, which are interpreted as basal clastites, varicolored fine-grained clastites of a mud plain, lithofacies of grey fine-grained clastites, sediments from marsh facies, clastic sediments from marginal-lake facies, and clastics of alluvial-lacustrine facies. In some boreholes, sediments of marsh facies contain clastic deposits, clay, coal-bearing sediment, carbonate rock and tuff. The observed thickness ranges from 25 m to 90 m. The succession includes from two to 10 levels of coal that are variable in thickness (up to 4 m). Marsh facies includes the assemblage of fossil mollusk, particularly of gastropods. Fossil remains are found in carbonate rocks, commonly revealing lamination. Biostratigraphically, there are no good fossil markers within this series. Tiny forms of *Gyraulus*, *Planorbarius* and *Planorbis*, as well as gastropod opercula (*Bithynia* sp.) are dominant. Thin, fragmented and badly preserved ostracods, such as *Candona* sp., *Fabaeformiscandona* sp., *Ilyocypris* sp. *Candonopsis* sp., and *Cypria* sp. have been recognized.

Within this facies, a few tuff layers are exposed, especially in the base of coal series as well as in its cover part, too. Radiometric age (16.9 Ma) of zircon grains from the vitroclastic tuff has been obtained. This is the first evidence concerning the Early Miocene age and precise chronostratigraphic position of the coal series (Karpatian) within the so-called Serbian Lake System in Miocene (SLS). The whole thickness of the lacustrine Miocene ranging from 110 m to 260 m.

Badenian marine flooding sediments as well as Sarmatian marine-brackish rocks are overlying the lacustrine series. They are divided based on fossil association of mollusks, foraminifers and ostracods. In some boreholes, in the very footwall of the Lower Sarmatian (Volhynian), a rich foraminifer and ostracod association (*e.g.*, *Ammonia* ex gr. *beccarri* Linne, *Asterigerinata planorbis* (d'Orb.), *Bolivina* cf. *dilatata* Reuss, *Bulimina elongata* d'Orb., *Cancris auricularis* (Fichtel & Moll), *Fursenkoina acuta* d'Orb., *Cytheridea* cf. *acuminata* (Bosq.), *Krithe papillosa* (Bosq.), etc.) suggests the *Bulimina – Bolivina* Zone of the Upper Badenian.

In all of the boreholes, Sarmatian (Volhynian) marine-brackish sediments have been documented on the basis of mollusks such as *Granulolabium bicinctum* (Brocchi), *Acteocina lajonkaireana* Bast., *Mohrensternia* cf. *pseudoangulata* Jekel., *Ervilia* cf. *dissita* (Eichw.), *Irus* cf. *gregarius* (Partsch), *Abra* sp., *Hydrobia* sp., *Cerithium* sp.

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Biostratigraphy of the Middle Miocene from the boreholes of south-west Banat, Serbia

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Middle Miocene sediments in the south-west Banat area were identified based on deep exploration drilling. Based on the identified macrofauna, microfauna and microflora from 15 wells of southwestern Banat, detailed biostratigraphy of the Middle Miocene sediments was made. The biostratigraphy of the studied Middle Miocene sediments of southwestern Banat is based on the standard biozones and biozonations used in several areas of Central Paratethys (Petrovic, 1970; Jiricek, 1975; Papp and Schmid, 1985; Cicha *et al*., 1998; Harzhauser and Piller, 2004; Harzhauser and Piller, 2007; Hohenegger *et al*., 2014).

Micropaleontological studies were performed using two methods: washed residues and thin sections method. During micropaleontological studies, the semiquantitative analysis determined relative abundance of planktonic and benthic foraminifera, as well as the presence of other fossil organisms (calcareous nanoplankton, ostracodes, molluscs).

On the basis of determined foraminifera associations, two biostratigraphic zones were established into the Badenian Stage and two biostratigraphic zones into the Sarmatian Stage. In the Badenian sediments, there are associations of foraminifera that correspond to upper levels of the Lower Badenian (*Globigerinoides trilobus/Orbulina suturalis* Zone) and upper levels of the Upper Badenian (*Ammonia beccarii/Elphidium crispum* Zone). In the Sarmatian sediments, there are associations of foraminifera corresponding to the lower parts of the Lower Sarmatian (*Elphidium reginum* Zone) and the higher parts of the Lower Sarmatian (*Elphidium hauerinum* Zone).

The results of the biostratigraphic research show that foraminifer zones of the Middle Miocene are not developed in the area of southern Banat (Lower lagenide zone, *Spiroplectinella carinata* Zone, *Bolivina-Bulimina* Zone and *Porosononion granosum* Zone). If we consider that these biostratigraphic zones are developed in depressions south from the Sava and Danube rivers (Drmljanska, Markovacka, Gradistanska, etc.), it can be concluded that, in the research area of southern Banat, several tectonic phases during the Middle Miocene can be registered, which will be subject to further research.

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Sedimentation timing of the foredeep deposits from the Gura Vitioarei section, Romanian Carpathians: implications for the stratigraphy of the Lower Miocene in the Paratethys domain

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The Gura Vitioarei section is located in the Carpathian Bend Zone, on Teleajen Valley. It displays alternating clay and sandstone turbidity flow-related deposits, with two tuff beds in the lower part of the sedimentary interval. To constrain the age and the depositional environment of the sediments, the section was the subject of an integrated study, including sedimentological analysis, investigation of calcareous nannofossil and foraminifera assemblages, as well as U-Pb tuff zircon dating.

In the lower and middle part of the studied outcrop, dark grey, reddish, greenish mudstones with siltstones and very fine sandstone intercalations were identified. The upper part, consisting of pebbly muddy sandstones, quartz-rich sandstones, dark grey-greenish mudstones and organic rich shalestones (dysodiles), is thrusted due to a reverse fault. The depositional environment was interpreted as being represented by distal levee with overbank lobes for the lower unit, while for the upper, thrusted unit, by distal levees with overbank channels beds and thick amalgamated channels stories, deposited in a slope setting due to the presence of slumps.

The calcareous nannofossil assemblages contain 35 species, *Coccolithus pelagicus* (14–66%) being the dominating one, followed by *Reticulofenestra pseudoumbilica* (10–60%), *R. minuta* (1–37%) and *Helicosphaera ampliaperta* (1–24%). Based on the last occurrence of *Sphenolithus belemnos* and first occurrence of *S. heteromorphus*, the lower–middle part of the studied section falls within zones NN3/CN2–NN4/CN3. In the upper part of the section, due to the reverse fault, zone NN3 is present again, as indicated by *Sphenolithus belemnos*. The foraminifera assemblages are scarce. Biostratigraphically, no clear taxa were found within the samples, as most of the identified small planktonic foraminifera have large ranges. Thus, the relative age of the units is middle to late Burdigalian.

Sixty-four zircons extracted from the stratigraphically lower tuff layer were investigated by LA-ICPMS, seventy U-Pb ages being obtained. Of them, forty U-Pb ages are 90–110% concordant. Thirty-three ages are within an extremely narrow range of 17–19 Ma, while the rest includes Paleozoic or older ages. The youngest 21 ages form a tight cluster, with a concordia age of 17.146 ± 0.095 Ma (MSWD = 0.00086), which is interpreted as the timing of the magmatic crystallization of the zircons, and as maximum age of the tuff eruption. In the Gura Vitioarei section, the U-Pb dated tuff seems to correlate with zone NN3/CN2. However, the NN3/NN4 boundary, marked by the last occurrence of *Sphenolithus belemnos* and stratigraphically situated above the dated tuff layer, was astronomically calibrated at 17.94 Ma, thus being inconsistent with the isotopic age of the tuff. A similar ca 17-Ma old tuff intercalated in nannoplankton zone NN3 was reported in Hungary. Therefore, the data sets (U-Pb and nannofossil ages) from different geographical localities from Central Paratethys support the necessity of calibration of the regional stratigraphic scale.

Seismic-based lower and middle Miocene stratigraphy in the northwestern Vienna Basin (Austria)

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New high-resolution 3D-seismic data of the OMV-AG reveal spectacular insights into the tectonic setting of the highly structured northwestern Vienna Basin (VB). Strongly tilted lower Miocene strata are separated from middle Miocene formations by a major erosional phase and discordance, including canyon-like features. An integrated approach allows establishing a modern lithostratigraphic scheme for all seismic units. Based on biostratigraphy and correlation with adjacent parts of the VB, these units are discussed in terms of chronostratigraphy and paleogeography. Synsedimentary tectonics is considerably strong during the early Ottnangian and strengthens again during late Karpatian times, when erosive features become widespread. Terminal Karpatian deposits reflect a “pre-Styrian Tectonic Phase”.

The overlaying Iváň Formation, a sedimentary infill of the 500-m-deep canyon, can be dated for the first time as early Badenian (Langhian). This canyon cuts into strongly tilted lower Miocene strata and clearly postdates the major tectonic reorganization during the Styrian phase, when the area became terrestrial. Thus, the hiatus between the Karpatian and the onset of marine sedimentation during the Badenian spans about 1 Ma, providing ample time for tilting and major erosion during the Styrian Tectonic Phase.

A second major outcome of the study is the first documentation of evaporites in the Vienna Basin, that had formed during the Badenian Salinity Crises. The corresponding sea level of about 200 m, resulted in a rapid shift from deeper marine depositional environments to coastal and freshwater swamps. This is the first evidence of evaporite precipitation during the Badenian Salinity Crisis in the Vienna Basin.

Organic and inorganic geochemistry of Miocene sediments from the Lopare Basin (Bosnia and Herzegovina)

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The organic and inorganic geochemical composition of mainly marlstones associated with lacustrine evaporites from the Miocene piggy-back Lopare Basin, Bosnia and Herzegovina of Internal Dinarides, was investigated. This basin belongs to the Miocene Dinaric Lake system. The testing was conducted on total of 46 samples originating from two boreholes Pot 1 (depth of 193 m) and Pot 3 (depth of 344 m). The results show that the average element abundances of these two boreholes like B (668 ppm), Li (302 ppm), Sr (500 ppm), U (67 ppm), Cr (192 ppm), Ni (164 ppm), MgO (4.84 ppm), Na_2O (4.80 ppm) and CaO (9.83 ppm) are much higher than in the average of the upper continental crust (Taylor and McLennan, 1985; McLennan, 2001). These chemical compositions may results from at least two different sources: (i) ophiolites (oceanic source) occurring in the neighborhood in the north; and (ii) a reworked dacitic-andesitic pyroclastics source mixed with other continental basement components.

The sedimentation is influenced by strong evaporation resulting in a partly hypersaline lake, which formed either during a warm climatic period, the Miocene Climatic Optimum, or during the subsequent Badenian salinity crisis, a cool period. A brief episode of humid climate conditions resulted in filling-up of the basin and deposition of felsic sediments with Th enrichment. The organic geochemistry shows that the majority of investigated sediments contains predominantly immature to marginally mature algal organic matter deposited under anoxic and saline/hypersaline conditions. Values of geochemical saline and hypersaline indicators are: high Sr/Ba ratios (average value is 19.56), the average value for squalane/n-C_{26} alkane ratio is 3.73, C_{28} sterane average content accounts 30.56 % in total distribution of C_{27}–$C_{29}\alpha\alpha$(R) regular sterane homologues, gammacerane index average value is at 1.74, relative content of β-carotane in the overall distribution of hydrocarbons is at 7.00%, while isoprenoid alkanes in the range of C_{21}–C_{25} are abundant. The paleoenvironmental indicators such as C-value, Sr/Ba, U/Th and organic geochemical parameters suggest that the investigated sediments of the Lopare Basin contain predominantly immature to marginally mature algal organic matter deposited under anoxic, saline to hypersaline conditions during arid/semiarid conditions. The source input of organic matter is mainly controlled by primary bioproductivity and arid climate whereas its preservation is closely related to stratified water column and highly reducing bottom water conditions during deposition. The stratified water column due to salinity/hypersalinity with anoxic conditions in the bottom water enhanced the preservation of organic matter.

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Session GT3

Sedimentary petrology as a tool for understanding of the geological history of the Carpatho-Balkan region

Convener:

Katarzyna Górniak

Upper Cretaceous variegated marl facies in the Outer Carpathians (Węglówka Marl): where does the marl fit in the Cretaceous Oceanic Red Beds event

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In the Outer Carpathians, the Upper Cretaceous variegated Węglówka Marls are exposed mostly in the Sub-Silesian Unit. These marls are considered to be pelagic sediments deposited above the CCD, representing a facial equivalent of deep-water variegated shales. The marly facies were developed on submarine elevations created during the Late Cretaceous reconstitution stage of the Carpathian basin. The marls are up to 600 m thick.

Although Upper Cretaceous fine-grained red oceanic deposits (CORBs) occur all overall the world, it is thought that they resulted from a combination of various regional and local earth processes. The Węglówka Marls are regarded as CORBs, which is indicated by their macroscopic features and the interpretation of geological history of the Carpathians. Currently, a record of sedimentary and diagenetic conditions of fine-grained rocks can be deciphered from micrometer scale petrography performed using microscopic techniques. Such data can help improving the model of CORB sedimentation.

This study focuses on high-resolution petrography of the Węglówka Marls in order to decipher controlling factors on their deposition and lithology. The type section of the marls located in the Węglówka Tectonic Window was sampled. Optical and Field Emission Scanning Electron Microscopy, X-ray diffraction, and chemical analysis were applied to study 21 samples.

The data obtained revealed that the Węglówka Marls: (1) show features of muddy contourites (Górniak, 2011); (2) are composed of biomicrite (coccolith fragments) and clay, therefore petrographically they refer to impure chalk (Górniak, 2017); (3) like other chalks they were deposited in starved basins, under tropical, shallow water conditions and normal salinity; (4) are macroscopically homogeneous, fine-grained, structureless, and bioturbated; (5) contain 46–62% clay, 21–34% calcite, 11–18% quartz, 2–3% feldspar, and 3–5% hematite; (6) were homogenized due to burrowing and re-deposition; (7) contain illite-smectite and volcanic index minerals (biotite, zircon, apatite) suggesting that the clay may have originated from the alteration of volcanic material; (8) show colours of interbedding red and green varieties, formed during early diagenesis due to a variable supply of organic matter; (9) contain hematite originating from alteration of biotite during early diagenesis in an oxygenated environment, documented by burrows; (10) have a content of Fe in the red variety of 3.81%, and in the green variety of 2.42%, but the latter contains more divalent iron (Fe^{+2}/Fe^{+3} is 0.22 and 0.67, respectively) suggesting re-distribution of iron during early diagenesis.

The data obtained suggest: (1) tectonic differentiation of the morphology of the seafloor of Outer Carpathian Basin; (2) limited detrital and organic matter supply; (3) high productivity related to the input of volcanic material, which also acted as a source for clay and iron; and (4) fine-grained depositional material, which influenced lithology.

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A new approach to the problem of the ophiolite from Osielec–Magura Nappe, Outer Carpathians, Poland

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In the early fifties of 20th century, in Osielec village located in Beskid Makowski Mts., a block of ultabasites, has been discovered in the Magura Nappe. It was described as “ophiolite from Osielec”. Authors conducted recently a detailed geological investigations around the Osielec village and during geological mapping found a new outcrops with large blocks of the discuused igneous rock.

The Magura Nappe around Osielec village consists mainly of Upper Cretaceous–Palaeogene deposits represented by the Rača Subunit. There, in the lithostratigraphic log occur the Pasierbiec Sandstone Fm., middle Eocene in age, which consists mainly of thick-bedded sandstones. The olistolits of metabasites occur within olistostrome in the Pasierbiec Sandstone Fm. as chaotically defragmented sandstone layers with crumpled shales in between and debrites that consists of sandy-gravel matrix with numerous shaly clasts and pebbles, boulders and blocks of different exotic rocks, *e.g.*, granitoids, gabbro, micaceous schists, quartz, limestones, marls, and glauconitic sandstones. Within others there occur blocks of metabasite, 0.5 m up to 3.5 m in dimension.

Studied metabasite, is a medium-grained rock, dark green or green in colour, showing massive texture. In some parts the rock is strongly dynamically altered and there occur neogenic minerals such as chlorite, epidote, and calcite. Plagioclases and amphiboles are the main minerals of the rock studied. Plagioclases are represented by subhedral albite which is characterized by multiple twinnings of albite law and undulatory extinction. Central parts of albite crystals are filled by small grains of neogenic minerals: epidote and zoisite. Amphiboles are represented by olive hornblende. Hornblende tends to form elongated crystals and is altered in various degree. This mineral is partially replaced by aggregates of secondary minerals: epidote, sphene, chlorite, and opaque minerals. Accessory minerals are represented by apatite, ilmenite, and zircon. In some blocks, metabasite rock cut calcite vein containing pyrite and chalcopyrite.

The zircon grains have been separated from the rock and used for detemnation of absolute age. Cathodoluminescence analysis of internal zircon structure revealed a single population with simple one stage growth. We conducted preliminary laser ablation ICPMS U-Pb dating on 10 randomly selected crystals which define mean ^{206}Pb–^{238}U age of 601±10 Ma. This age is interpreted as reflecting zircon crystallization during the gabbro formation. Its mean that these igneous rocks formed during the late Proterozoic as result of the Cadomian Orogeny. These new evidence makes invalid the concept that metabasite emerged during the Alpine orogenic cycle, and could be remnants of supposed oceanic floor of the Magura Basin. The source area of the exotic rocks with metabasite fragments, basing of the paleocurrent directions, were situated towards the north of the Magura Basin.

The Slovenj Gradec Miocene basin: palaeogeography and reflection on the Pohorje tectonic block unroofing

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The Pohorje tectonic block (PTB) in northern Slovenia was a subject of investigations in the frame of several projects. Gathered data comprise structural, petrographic, radiometric, palaeomagnetic, and geochemical studies. In recent years, new evidence of its unroofing was obtained on the basis of the Slovenj Gradec sedimentary basin (SGB) evolution (Ivančič *et al*., 2017). The focus of this study is the basins' Miocene palaeogeographic evolution obtained through provenance of the sedimentary rocks, their tectonic setting, and sequence stratigraphy. The work is based on mapping, section recording, nannoplankton biostratigraphy, petrography, and tectonic evolution of the wider area of PTB (Trajanova, 2013).

The SGB evolved at the margin of the Pannonian Basin System (PBS) in connection with global third-order cycles. Sedimentation started in terrestrial environment at the transition of the Ottnangian to the Karpatian and terminated in the late early Badenian. During this period, three transgressive-regressive cycles can be traced, corresponding to the TB 2.2, TB 2.3 and TB 2.4 cycles. The sediments reflect proximity of the hinterland and evolution from fluvial/limnic via transitional to marine environment in advanced stages of transgressions. At the highstand system tract in the early Badenian, the sea flooded the entire SGB and obtained connection with the Mediterranean. At the end of early Badenian, the SGB connection with the Central Paratethys was closed. Deposition terminated with fresh-water coal, marking basins' dying-out. After the late early Badenian, the area of SGB was exposed to compressional deformations and erosion.

Structures of the SGB sedimentary fill show east- to south-eastward deepening of the basin, excluding sediment delivery from this area. The material originated mostly from its north-western to south-western hinterlands. Lithological composition of the basin fill without indicative granodiorite clasts opposes erosion of the PTB. This is in accordance with the apatite fission track ages, which are as low as 10 Ma for the eastern Pohorje (Sachsenhofer *et al*., 1998), and indicate that PTB was exposed to erosion after the early Badenian. The results suggest that PTB granodiorite was not subjected to erosion in the Karpatian as argued earlier.

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Exotics of the Protocarpathians in the western area of the Silesian Nappe

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The original material coming from the Carpathian basement plays a key role in the palaeotectonic reconstructions of the Protocarpathians. The Carpathian Tethys domain developed on the Palaeozoic and/or Precambrian basement during Mesozoic and Cenozoic times. The large fragments of this basement are exposed within the Marmarosh Ridge in the Easter Carpathians (Ukrainian territory), but to the west this basement is covered by several kilometers thick series of clastic sediments originated in the Carpathian basins during long-lasted period of marine sedimentation. However, fragments of the Protocarpathian rocks, in form of pebbles and boulders, occur as clastic components of these sedimentary cover. The rocks of the Silesian Unit, belonging to the Upper Cretaceous–Palaeocene Istebna Formation are relatively rich in that material. This formation consists of sandstone complexes divided by packets of darks shales. Within the sandstone complexes, thick-bedded conglomerates occur containing different-sized clasts of crystalline rocks, known as “crystalline exotics”.

The Istebna Formation containing the exotic-bearing deposits stretches along the entire Silesian Unit of the Polish Outer Carpathians, but conglomerates with the largest exotic block occur in its westernmost part, cropping out in the Istebna area. The exotic boulders (of granitoids, pegmatites, gneisses, mica-schists) found in this site reach size up to 1.6 m in diameter, although usually their size ranges from 5 cm to 30 cm. The lithology and sedimentary features of deposits hosting exotic rocks correspond to sequence described by Lowe (1982). Within individual layers, the R2-R3-S1 or R3-S1 divisions can be recognized, *i.e.*, very coarse and coarse-grained conglomerate with reverse grading (R2), upwards with normal grading (R3), turning into coarse-grained sandstone with lenses of pebble (S1). The largest crystalline boulders are enclosed in R3 division, representing the basal part of the Lowe sequence, being a result of deposition from hyper-concentrated flows. The lateral continuity of such deposits along the Silesian Unit suggests their accumulation in a form of linear apron depositional system and are typical for turbidities deposited by high-density turbidity currents. The large exotics are concentrated within very thick-bedded (3–6 m in thickness) layers, usually in their lower parts, within normally graded coarse conglomerates (R3 interval) and very coarse-grained sandstones (S3 interval). They are usually accompanied by sequences with different share of R2, S2 and S1 intervals. Generally, the Istebna Formation deposits are interpreted as the effect of gravity mass movements forming aprons with significant lateral extension.

The Istebna Formation palaeocurrent directions indicate transport from the north. The hypothetic submarine elevation, Silesian Ridge, is suggested as the source area for the clastic material. During Late Mesozoic and early Palaeogene times, it divided the Carpathian Basin into two separate domains, the Magura Basin on its northern site, and the Silesian Basin in the south. Clastic material was supplied into both basins following this ridge destruction. The intensification of erosional processes significantly increased in the Late Cretaceous when the erosional basis exposed the crystalline core.

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Middle Eocene Rastiš formation and upper Eocene–Oligocene? Adriatic flysch formation in southern Montenegro (South Adriatic zone)

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In the area of southern Montenegro, north of the town of Ulcinj, clastic sediments of Eocene age are developed, *i.e.*, molassic sediments of the Rastiš Formation (middle Eocene), and sediments of the Adriatic Flysch Formation (upper Eocene–Oligocene?).

The Rastiš Formation is 450 m thick and comprises sandstones, marls, aleurolites and clays in the lower part, and conglomerates and coarse-grained sandstones in the upper part. Calcareous sandstones are the dominant member of the lower part of the formation. They are represented by litharenites and sublitharenites. Main components are quartz, rock fragments, feldspars and mafic minerals, while the matrix is composed of carbonate. Horizontal and cross-bedded stratification is common in these rocks. Sandstones often contain the ichnofossil *Ophiomorpha* sp. In the upper part of the formation, conglomerates and coarse-grained sandstones are equally represented. Conglomerates are poorly sorted, with clast size up to 15 cm, rarely larger, consisting of Upper Cretaceous and middle Eocene limestones, rarely cherts and volcanic clasts. Coarse-grained sandstones often have graded bedding. These rocks actually represent molassic sediments, formed under shallow-marine conditions on the upper part of continental shelf, at times dominated by fluvial processes of sedimentation, and they are not turbidites as previously interpreted. The age of the series, based on calcareous nannoplankton (*Blackites gladius*, *Chiasmolithus gigas*, *Chiasmolithus grandis, Coccolithus formosus, Discoaster barbadiensis, Dictyococcites hesslandii, Sphenolithus spiniger, Reticulofenestra dictyoda*, etc.) is determined as middle Eocene (Lutetian), *i.e.*, it belongs to nannoplankton biozones NP14/NP15.

In the Adriatic Flysch Formation, that is around 140 m thick, it is possible to observe sequences with graded calcarenites (Ta), a lower interval of parallel lamination with coarse-grained laminae (Tb), an interval of cross lamination, ripple lamination and convolute lamination (Tc), upper interval of parallel lamination with fine-grained laminae (Td), and interval with pelagic to hemipelagic clayey or marly sediments (Te). Dominant members of this series are thin-bedded sandstones with carbonate grains and matrix, while clayey and marly sediments are rare. Sedimentary structures are often represented by linguiform flute casts, and rarely by overlapping elongated flute casts and groove casts. In sandstones, trace fossils are represented by ichnogenera *Scolicia* (trace made by echinoids) and *Palaeodictyon*. Čađenović *et al.* (2010) considered these sediments to be of late Eocene to Oligocene age in the region of Bar. Calcareous nannoplankton sampling north of Ulcinj did not indicate this age, but also gave middle Eocene forms. Considering that these are flysch sediments, it is possible that these forms are reworked, so late Eocene to Oligocene age is conditionally accepted. Further sampling of marly sediments for calcareous nannoplankton will give a more accurate age.

Clastic sediments of Eocene age in southern Montenegro indicate a gradual deepening of the basin, where shallow-water molassic sediments of the Rastiš Formation were deposited first, and after that the depositional environment changed, so that turbidite deposits of the Adriatic Flysch Formation were formed.

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Development of the Blatné Depression and its effect on the lower/ middle Miocene coarse-grained sediments (Danube Basin, Slovakia)

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The studied wells are situated in the Blatné Depression, which is located in the NW part of the Danube Basin, thus representing one of the northernmost subbasins of the Pannonian Basin System. During the work we studied four wells, namely Suchá and Parnou-3, Cífer-2, Bučany-2, and Trakovice-4. General description of the wells was done by Pagáč (1959), and it was later revised by Biela (1978). Nonetheless, the conglomerates were newer analysed in detail. Therefore, we carried out sampling in the repository of Nafta a.s. (Gbely town). The results show that the conglomerates were formed by multiple layers. The conglomerates from the basal parts of the wells were formed in alluvial fan environment and were deposited as debris flow. Later on, the alluvial fan prograded to fan delta. The poorly sorted, poorly rounded conglomerates can be linked to the distal part of fan delta. The better sorted, rounded and well-rounded clasts in conglomerates indicate transition to the proximal part of fan delta. The provenance of all the processed conglomerates points to the Central Western Carpathian source.

From the tectonic point of view, the accommodation space of conglomerate may be associated with the early Miocene tectonics, connected with NW–SE oriented fault system. These faults participated on the rise of horst and graben structure in the westernmost part of the Central Western Carpathians (Kováč *et al*., 2018). This process developed under a transtensional/extensional tectonic regime with NNW-SSE to N-S oriented compression (Marko *et al*., 1991; Marko and Kováč, 1996) led to disintegration of the pre-Neogene basement of the Danube Basin.

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Sand sediments from Neogene basins in SW Bulgaria

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Textural characteristics of sand, along with mineralogical composition, is a useful tool for reconstruction of dynamics of sedimentation, depositional history, tectonic regime, climate and relief in the source area, and hence, some aspects of the basin evolution.

Sands collected from five Neogene basins in southwest Bulgaria were studied and compared. These are the Sofia, Gotse Delchev, Kostenets, Sandanski, and Strumeshnitsa basins. The basins were formed during middle to late Miocene and Pliocene time as graben structures. They were filled in by fluvial sediments: proluvial, alluvial, lacustrine and marsh. According to their grain size, studied sands are mostly fine- to medium-grained, with various amounts of silt and clay admixtures. Statistical parameters calculated show that they are poorly and very poorly sorted with slight positive skewness. The sorting improved a little from the oldest to the youngest sands in the Sofia, Gotse Delchev, and Kostenets basins, whereas in the Strumeshitsa and Sandanski basins values of σ_1 remain similar. The plots of standard deviation vs. skewness show typical shape of river bench and river channel deposits. The grains' shape is sub-angular and sub-rounded. The textural maturity of sands places most of them on immature, rarely on sub-mature stage.

Quartz is the principal rock-forming mineral, followed by feldspars and micas. A large range of heavy minerals was registered: epidote, titanite, amphibole, garnet, zircon, rutile, tourmaline, staurolite, apatite, zoisite, anatase, brookite, biotite, kyanite, and opaque minerals. Depending on the rock composition of the source areas for each basin, the presence of unstable minerals, non-resistant to weathering processes and long transportation was registered, which made these sediments mineralogically immature. The composition of heavy mineral fraction evidenced for closely located source areas with steep-slope relief.

Textural and mineralogical immaturity of the sands evidenced for active tectonic regimes during deposition as well as in the source areas, where mechanical weathering prevails over chemical one. The results obtained confirm concepts on the neotectonic evolution of these basins by other authors.

Characteristics of sediments of a fault scarp in the Northern border of Sofia basin, western Bulgaria

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Holocene fault scarp is detected in the northern bord of Sofia basin in the area of Gorni Bogrov village (Radulov *et al*., 2011). Gorni Bogrov is situated in Sofia kettle 17 km NE from Sofia, western Bulgaria. Fault scarp has height of 10.2 m (Wallace, 1977). The fault scarp is described with precise topographical measurements of the relief and electro resistance profiling are made. Three drillings on both sides of the fault scarp are made with the help of a hand drill. The collected samples are subjected to a sieving and mineralogical analysis to determine the types and composition of the sediments in the hanging and footwall (Folk, 1954, 1974; Shepard, 1954; Schlee, 1973). In the footwall sands and gravel of the Neogene Lozenetz Formation are observed, covered by a quaternary proluvial sediments. The most of the hanging wall is a part of the floodplain terrace of the Lesnovska River.

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High-resolution sedimentology study of laminated lake sediment from East Carpathian Mountains, Romania

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Lake sediment is one of the most used materials for palaeoenvironmental and palaeoclimate studies. The lacustrine sediments, especially the laminated depositional forms are important indicators of changes in the lake catchment system. The high-resolution analyses of the laminae contribute to understanding the sedimentary processes, the *in situ* transformations and the climatic parameters. In addition, the analyses of the sediment allow detecting microbial footprints, which gives direct information on lake and sediment chemical parameters.

The research area is located in the East Carpathian Mountains, Romania. The maximum water depth is 5.1 m with small water-surface (around 3 km^2) and a catchment area of 310 km^2. The water–sediment interface is anoxic. The total sediment section represents the last ~ 6000 years based on C-14 AMS dating, which was corroborated by ^{210}Pb isotope analyses. Recently analyzed sediment core was retrieved in November 2013. The time period examined in this pilot study covers approximately 700 years.

Analyses were carried out on four representative thin-sections using high-resolution optical microscopy and FTIR-ATR spectroscopy. Observations shown micro-lamination of samples that was mostly parallel, but in some cases represents irregular laminae, and rarely microfossils were also found. High magnification showed widespread filamentous pearl necklace-like mineralized microbially produced biosignatures, which basically contribute to the sample material.

FTIR-ATR study determined feldspar as the main constituent followed by quartz. Rarely, ferrihydrite (FeOOH), apatite, montmorillonite, and chlorite were detected. Highly variable embedded organic matter occur in all samples (C=N/CH-amid, graphite, O=C, dCH2, C–O).

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Strontium-mineral genesis in brownish salt rocks of the Wieliczka Salt Mine

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The Wieliczka salt deposit is situated in southern Poland, within the Carpathian Fore-deep basin, among the folded Miocene sediments in the Carpathian orogenic front. During the inspection of the workings at Level III of the east section of the Wieliczka salt deposit in the 1960s, brownish-pink salt was found in one of the chambers (Prochazka *et al.*, 1968). These salts are of diverse colours, mineral and geochemical compositions from surrounding salt rocks. Pale brown salt from Level III, subjected to our studies were found near the Franciszek Müller gallery, in the chambers of the 3rd level in the Wieliczka salt mine. The complex of brown rock salts occurred within a large block, approximately 15 m thick.

Petrological investigation showed that within the halite crystals relicts of primary fluid inclusions assemblages (FIA) in the form of chevrons, and numerous secondary FIA were stated. Their mutual spatial relations indicate that halite crystals were partly recrystallized. In the recrystallized parts of halite occur anhydrite, celestine ($SrSO_4$), and rare gypsum crystals. Celestine crystals represent elongated platy crystals, forming fan-shaped aggregates and granular aggregates, strongly associated with anhydrite. In these parts of crystals secondary inclusions show very variable gas to liquid ratio. Some of the inclusions also have daughter minerals as celestine and gypsum confirmed by Raman spectroscopy. During Raman spectroscopy investigation, organic matter at different stadia of transformation was also observed.

Residual materials from dissolution of brownish salt rocks were re-examined, using X-ray powder data, SEM-EDS analysis, Raman spectroscopy, and EPMA. These researches revealed that primary anhydrite crystals are porous, partly eroded and the pores were filled by celestine and dolomite crystals. Celestine in these pores is small, in the form of distinctly elongated plates or creates fan-rosette aggregates. Moreover, within the larger celestine concentration also tin mineralizations were stated.

The data obtained suggest that strontium mineralization could have been enriched with external fluids after sedimentation. Development and paragenesis of those minerals suggest a post-sedimentary origin of these rocks connected with diagenetic and transformation processes. An important observation confirmed that there was a transformation of fine crystalline anhydrite into platy crystals, recrystallization and transformation of gypsum and anhydrite, as well as partial disappearance of the zonal structure of halite.

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Session GT4

Magmatism in the Alpine-Carpathian-Balkan realm

Conveners:

Milan Kohut, Anca Dobrescu, Ioan Seghedi, Dejan Prelević, Kristina Šarić, Vladica Cvetković, Károly Németh, Réka Lukács and Fritz Finger

Volcanology, petrology and geodynamic aspects of the Miocene magmatism in the Apuseni Mountains – a review

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The Miocene magmatism of the Apuseni Mountains in the Carpathian-Pannonian area hosts some of Europe's largest porphyry epithermal Cu–Au ore systems, mostly associated with shallow subvolcanic intrusions. This presentation is a review of the published volcanological features, rock ages, geochemical analyses, Sr–Nd isotopes data, paleomagnetic data, etc., along some unpublished data.

The Neogene magmatic rocks develop in the southern Apuseni Mountains and as a rare occurrence in the northern Apuseni Mts., at Moigrad. The igneous activity developed in NW-SE-oriented small basin system, in association with coeval Miocene in extension-controlled sedimentation that from the north to south are: (1) Roşia Montană – Baia de Arieş – Bucium; (2) Zărand – Brad – Zlatna, the most extended; (3) Săcărâmb and (4) Deva – Uroi. The rocks are dominantly andesitic subalkaline and K-alkaline and made composite volcanoes, monogenetic and polygenetic volcanic cones, dome/flow complexes and subvolcanic intrusive complexes.

The processes of magma generation that account for the unique mineralization processes in this region goes hand in hand with its geotectonic evolution. The magmatic activity developed between 14.7 and 7.4 Ma and after a gap ceased at around 1.6 Ma. The generation of the Roşia Montană andesite-dacite volcanic structure at 13.2–13.6 Ma representing one of the largest gold deposits in Europe, suggests distinctive petrological features. The evolution of magmas from normal to adakite-like calc-alkaline and alkaline, generally, was time-dependent, in direct relation with mantle source composition assumed to be heterogeneous. Fractional crystallization-assimilation processes in shallow magma chambers are suggested for early magmatic activity, but were almost absent for the late magmatic activity, as associated to an increasingly extensional regime. The youngest K-alkalic (shoshonitic) magmatism at 1.6 Ma is asthenosphere/lithosphere-derived, but in a younger extensional event, being almost coeval with the OIB-like Na-alkali-basaltic magmatism (~2.5 Ma) occurring along the South Transylvanian fault system. The fluid-present melting of the source seems to be the critical factor for the presence of the copper-gold-bearing mineralizing fluids.

Geotectonic conditions at the time of magma generation were characterized by regional transtensional and rotational tectonics, which generated horst and graben structures and do not support contemporaneous subduction processes. The geochemical "subduction signature" of the magmas emphasizes the significant involvement of fluids (mantle lithosphere and/or lower crust), as mostly inherited in the development of previous geodynamic events. The mechanism of magmagenesis is considered to be related to various degrees decompression melting of a heterogeneous source situated at the crust-lithosphere mantle boundary. Mixing with asthenospheric melts generated during the extension-related attenuation of the lithosphere may also be inferred.

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Towards the integrated paleotephra record of the large Miocene silicic volcanic eruptions of the Carpathian-Pannonian Region

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Lukács *et al*. (2018) showed that a massive silicic volcanic eruption phase occurred between 18 and 14.4 Ma in the Pannonian basin that could be considered the largest volcanism in Europe for the last 20 Myr. The cumulative eruptive material during this ignimbrite flare-up episode is estimated to have been more than 4000 km^3, and the individual eruptions could eject several 100s km^3 volcanic ash. Such large volcanic material is obviously covered large areas. Indeed, several Miocene basins in the Alpine and Mediterranean area contain volcanic ash. Although they have undergone various degrees of alteration, zircons could still preserve their eruption ages as well as magma composition characters and therefore they can be used for correlation purposes. The proximal deposits of this volcanism are best preserved and exposed in the Bükkalja volcanic field (BVF) and in the Tokaj-Slankske Mts., Northern Hungary. In the BVF at least three large explosive eruption events were recognized (Mangó ignimbrite eruption at 17.055±0.024 Ma, Demjén ignimbrite eruption at 14.880±0.014 Ma and Harsány ignimbrite eruption at 14.358±0.015 Ma), each providing large amount of volcanic ash. In addition, at least three large-volume, calderas forming eruptions occurred in the Tokaj-Slanske Mts. postdating the BVF eruptions.

A zircon perspective correlation has been performed using the new zircon U-Pb age data, trace element and Hf isotopic compositions from the BVF (Lukács *et al*., 2015, 2018) and other published results from ashes accumulated in various Miocene sub-basins along the Alpine forelands during the Paratethys era (*e.g.*, Rocholl *et al*., 2018) and in the La Vedova marine sedimentary section near Ancona, east-central Italy (Wotzlaw *et al*., 2014). Lukács *et al*. (2018) demonstrated that on chronostratigraphic ground many of these distal volcanic ash occurrences show a remarkable fit with one of the three eruption events occurred in the BVF. However, this geochronological correlation requires independent support such as trace element composition of zircons. Thus, a new cooperative work has just started involving further known Miocene distal volcanic occurrences and applying a zircon perspective methodology to constrain better the far-reaching effect of the Mid-Miocene ignimbrite flare-up of the Pannonian basin. This could yield a strong chronostratigraphic framework to improve the correlation of scattered Paratethys sedimentary deposits.

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Uncommon, composite volcanic structures in the Gutâi Volcanic Zone (Eastern Carpathians, Romania). Implications for the petrogenetic model

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The Gutâi Volcanic Zone (GVZ), NW Romania, belongs to the Neogene-Quaternary volcanic chain of the Carpathians. A sub-alkaline intermediate, mainly andesitic volcanism of Middle-Late Miocene age (13.4–7.0 Ma) developed in GVZ displaying a surface expression of a series of composite volcanoes, volcano-tectonic depressions and extrusive domes.

Three uncommon volcanic structures with different locations and related to three different volcanic events, show a similar architecture, with a distinct central zone of dacite/rhyolite volcanic rocks and a marginal zone of andesitic/dacitic rocks. The composite volcanic structures are distinct to the surrounded volcanic rocks in petrography, geochemistry, and age. 1. The Dăneşti and Piatra Roşie-Cetăţele related domes form a large volcanic structure (7 × 4 km) comprised of biotite dacite-rhyolite (69–72 wt.% SiO_2) of 11.6 Ma age (Dăneşti) in the center, and pyroxene dacite (62–66 wt.% SiO_2) at the margins (Piatra Roşie-Cetăţele). 2. The Pleşca Mare volcanic structure (3 × 2.5 km) comprises a 9.3 Ma biotite dacite (67–69 wt.% SiO_2) extrusive dome coated by pyroxene+biotite andesite (58–60.5 wt.% SiO_2) lavas of the same K-Ar age; 3. The Laleaua Albă volcanic structure, a small composite magmatic body (0.8 × 0.5 km), is comprised of a sanidine-quartz-biotite macroporphyritic dacite (64.5–67.5 wt.% SiO_2) core (8.4–8.0 Ma) and an aphanitic high-silica andesite (59–61 wt.% SiO_2) envelope (8.5 Ma).

The interface of the two distinct rock types in each of the described volcanic structures, and the K-Ar radiometric ages constrain a similar, bi-stage volcanic evolution: a first volcanic stage, when the currently marginally sitting rock types extruded, followed by the second stage, when the volcanic rocks of the central zone grew. The presence of xenocrystic minerals in the acidic rocks of the central zone such as the magnesiohastingsite (Mg#>70) and chromian diopside/titanian augite (Mg#>80), of corroded quartz crystals and strongly embayed sanidine macrocrysts, and of compositionally and texturally different plagioclase crystals in the same rocks, are constraints pointing towards the involvement of similar magma mixing and mingling processes. The quartz crystals with pyroxene coronas in the andesites of Laleaua Albă envelope, and the mafic microgranular enclaves (MME) of basaltic composition (48–51.5 wt.% SiO_2) in the acidic rocks of Laleaua Albă and Dăneşti, with similar mafic phenocrysts as the xenocrysts of the host rocks, confirm the magma mixing and mingling processes.

P-T data (based on the amphibole and pyroxene geothermobarometers) indicate mixing and mingling of basaltic magmas generated in the lower crustal magmatic reservoirs (20–27 km depth) with more evolved, silicic magmas of upper crustal reservoirs (5–7 km). The composition and facies architecture of the volcanic structures reflect bi-stage, intra-crustal magmatic processes. Deep basaltic magmas mixed and mingled with more evolved magmas in a first stage, and generated the hybrid volcanic rocks now preserved in the marginal zone of the structures. A new basaltic magma ascended into the shallow magmatic reservoirs of the same plumbing system in a subsequent stage, and emplaced the hybrid more acidic rocks in the central zone of the volcanic structures.

Interstitial glass-bearing pyroxenitic and monzonitic lithics: Possible magmatic origin of Gölcük volcanism (Isparta-Turkey)

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Potassic to ultra-potassic volcanism associated with the Gölcük caldera (Isparta, South West of Turkey) is represented by mainly trachytic, trachy-andesitic ignimbrite sheets and pyroclastic deposits of phreatomagmatic activity throughout Pliocene to Pleistocene. Up to 81 percent crystalline, ultramafic, intermediate and felsic lithics, are frequently found in phreatoplinian pumice fall levels of Gölcük caldera, were classified into seven sub-groups as olivine clinopyroxenites, clinopyroxenites, mica clinopyroxenites, garnet pyroxenites, diorites, monzonites and syenites according to mineral modes. Porous (10–20%) pyroxenitic and monzonitic cumulates are characterized by including brown and colorless, aphyric and highly vesicular interstitial glass films/droplets along junctions of clinopyroxenes and in the partly embayed feldspar crystals, respectively. Geochemical characteristics of the interstitial glass, mineralogy and mineral textures of the lithics, that are in a relation with the host volcanic products, are possible key to explain magmatic source and related process in the magmatic reservoir/s of Gölcük volcanism.

Geochemistry results revealed that the glasses (47.39–63.20 wt.% SiO_2) have phonolite and trachy/trachydacite compositions and also represent identical elemental characteristics in terms of both trace and rare earth elements to the host volcanic series. In order to understand the unique geochemical affinity between glass and host volcanic series, coherent partial melting models were applied using an average compositions for intermediate lithics as a source composition of magmas. Both numerical models and petrographical evidences demonstrated that the glass-bearing vesicular pyroxenites could be residual solid after melting of feldspar content in the felsic and intermediate lithics. Consequently, all petrological markers included pyroxene-liquid, plagioclase-liquid and amphibole-plagioclase thermobarometry calculations from magmatic lithics indicated that nearly crystalline magmatic lithics might be a possible magmatic origin of their host volcanic products.

Magmatic rocks of the Dinaric evaporite mélange: evidence from the Adriatic carbonate platform

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Magmatic rocks of the Kosovo, Sinjsko and Vrličko polje in External Dinarides associated with evaporites, carbonates and clastic rocks represent a part of the Dinaric evaporite mélange. Magmatic rocks of Dinaric evaporite melange in selected fields have been classified as amphibole-bearing dolerite according to IUGS classification, based on primary mineral assemblage of these rocks. The rocks have been divided in four main types according to ratio of the primary amphibole/pyroxene amount in the sample from 10/90 to 90/10, which shows evolution of magma. The microstructure of the samples is mostly subophitic to intergranular.

Primary magmatic association is composed predominantly of plagioclase, clinopyroxene (Cpx), brown amphibole, and minor amount of opaque minerals, zircon and titanite. It is overprinted by medium-grade secondary hornblende after Cpx or brown amphibole. Low-grade secondary mineral assemblage is predominantly composed of sericite, chlorite, actinolite, tremolite and minor amounts of prehnite, clinozoisite, secondary quartz, cristobalite, and pumpellyite.

Electron microprobe analysis of selected minerals allow the following conclusions: Feldspar grains show mostly the composition of albite and rarely orthoclase. Amphibole shows various composition according to careful examination of BSE images. Edenite/pargasite found as primary amphibole in the cores rimmed by edenite, and magnesiohornblende. The last overprint on amphibole is actinolite, which is classified as low-grade mineral association. Most of the chlorite grains show the composition of Fe-Mg chlorites, with a bit more pycnochlorite than diabantite. Mg-chlorite is scarce and there is more penninite than clinochlore. According to results from the microprobe it was possible to calculate the formulas for chlorite, prehnite, clinozoisite and ilmenite.

$^{40}Ar/^{39}Ar$ analysis of primary amphiboles revealed an age of 215–220 Ma variably overprinted by secondary amphibole at ca. 125 Ma or even younger amphiboles.

Temperature and pressure conditions of the selected rocks were estimated using plagioclase-hornblende thermobarometry. The estimated temperatures then were compared with temperature values obtained by the geothermometer based on Ti contents in amphibole. The following model of crystallization is proposed.

Edenite and pargasite are primary minerals in studied magmatic rocks of the Dinaric evaporite melange, which crystallized at temperatures of 800 °C±30 °C and depths of ~9–14 km. The rims of the primary amphibole that crystallized at depth of 9 km, still have edenite compostion. With the slight decrease of temperature, pressure and of (Na+K), the conditions for magnesiohornbende are established, which formed at 700±30 °C and pressure of 2–3 Kbar at depth of 5–9 km. The conditions for crystallization of actinolite occured at depth of 2–5 km and under temperatures of 600–650±30 °C. The last detected temperature is the low-temperature formation of chlorite (210–270 °C). The span of temperatures in-between actinolite and chlorite crystallization was suitable for formation of most of described secondary minerals, whereas some, like prehnite-pumpellyite, were formed most likely even below these temperature conditions.

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Results of the petrographical, geochemical and geochronological reinvestigation of the Triassic metavolcanic rocks at Bükkszentlászló, Bükk Mts. (NE Hungary)

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The Triassic stratigraphic sequence of the Bükk Mts (Northeast Hungary) involves various volcanic formations, particularly in the Eastern and Northern parts of the mountain. They form several kilometres long belts. The volcanics suffered anchi-epizonal alpine metamorphism. Among them, the largest continuous volcanic zone is found near to Bükkszentlászló, east of Miskolc. The volcanic rocks were classified into the Bagolyhegy Metarhyolite Formation (Less *et al*., 2005). However, no detailed studies have been yet conducted on the original magma geochemistry as well as on the accurate eruption age. The formation has two main volcanic group: a felsic and a basaltic-dacitic type, we name them by their chlorite-content: the felsic type is the chlorite-poor and the basaltic-dacitic type is the chlorite-rich metavolcanics. Detailed characterization of the petrologic and geochemical features helped to constrain the magmatic processes, whereas zircon U-Pb geochronology was used to determine the eruption ages.

Based on the petrologic features, the areal distribution of the two main rock formations was delineated: the chlorite-poor series is found exclusively in the southwestern part of the studied area with the total surface spread of two square kilometres. They could have an erosional contact with the chlorite-rich rocks, but presently they both occur in overturned position. The chlorite-poor rocks were formed at 246.7±1.9 Ma (based on the youngest age population of zircon U-Pb dates) by effusive and explosive eruptions of a highly differentiated magma. The chlorite-rich suite involves much more variable volcanic rocks and represents the Early Ladinian volcanic activity occurred in the Dinarides-South Alpine system. The new zircon U-Pb age suggests 240.3±1.3 Ma eruption age. The chlorite-rich rocks show similar geochemical character with the volcanic series of the Szentistvánhegy Metaandesite Formation (Harangi *et al*., 1996) and could have formed in the same extensional geodynamic condition.

The distinct eruption ages of the chlorite-poor and the chlorite-rich volcanic rocks and the lack of genetic relationship between them do not support their classification into the same lithostratigraphic unit. Finally, it is noteworthy to mention that the subsequent K-metasomatism, the siliceous alteration and the later alpine metamorphism changed substantially their original geochemical characters. Careful evaluation of the immobile and incompatible trace elements could, however, be used to reconstruct their original magmatic features.

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Triassic magmatism, Cenozoic subduction and exhumation of the Sifnos subduction zone complex, Aegean Sea

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The Greek Cycladic island of Sifnos is well known for its well preserved ultra-high pressure rocks representing a former subduction zone complex with an Eocene age of peak metamorphic conditions (Dragovic *et al*., 2015). However, it is only the northern part of the island that does not show much of subsequent metamorphic overprint and is built on by blueschist and eclogite belonging to its Eclogite-Blueschist Unit. This study focuses on the Greenschist Unit (GSU) of southeastern Sifnos, the structurally deepest unit with scarce relics of high-pressure metamorphism (Avigad *et al*., 1996; Lister and Raouzaios, 1996). Geochemical investigations reveal a calcalkaline, mafic composition of the rocks suggesting generation in a setting of island arc magmatism. The Mid Triassic age of magmatism is indicated by an initial laser-ablation U-Pb zircon age of 237.9±5.7 Ma. Thin section analyses combined with structural field data enable the establishment of the succession of metamorphic and deformation events as well as their relation. In total, five metamorphic stages and a succession of deformation phases could have been distinguished and put in context with phases of subduction and exhumation. Electron microprobe data represent the evolution of metamorphism and indicate frozen maximum P-T condition of approximately 16 kbar and 550 °C for rocks of the GSU within epidote blueschist conditions overprinted by higher greenschist facies.

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Permian volcanism in the Tisza Mega-unit: new petrographic, geochemical and geochronological results from Hungary and Romania

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During the Late Paleozoic times several intramontane sedimentary basins were formed along the central-eastern part of the European Variscan Orogenic Belt controlled by an extensional tectonic setting. This extension was associated with an intense volcanic activity often having bimodal character and is also exposed in the southernmost part of the central European mountain belts including outcrops of the Tisza Mega-unit. Outcrops are known from Southern Transdanubia, in the Western Mecsek Mts, Hungary, in the Apuseni Mts, Romania and Permian volcanic rocks were also discovered by cored deep drillings in the basement of the Pannonian Basin. Corresponding to the locality of the primary outcrop in S Transdanubia all Permian felsic volcanic rocks within the Tisza Mega-unit were considered as "Gyűrűfű Rhyolite Formation" in the Hungarian lithostratigraphy (Fülöp, 1994). Based on the petrographic, geochemical and geochronological observations Permian volcanic rocks of the Tisza Mega-unit could be handled together as the products of the same volcanic system. In this study the focus is on the felsic volcanic and volcaniclastic rocks, especially on crystal-rich ignimbrites from S Transdanubia and the Apuseni Mts.

Based on the immobile element ratios (Zr/TiO_2 vs. Nb/Y) the Permian volcanic and volcaniclastic rocks of the Tisza Mega-unit are represented by dominantly rhyolitic–dacitic ignimbrites. However, in the northern foreland of the Villány Mts (S Transdanubia) and within the basement of the Pannonian Basin felsic lava rocks, while in the Apuseni Mts mafic-intermediate lavas (as the results of bimodal volcanism) also occur.

Ignimbrites are similar in all the studied areas. They are rich in flattened, devitrified pumices and have 30–40% feldspar, quartz (resorbed crystals are common) and hematitized biotite phenocrysts. In some pyroclastic samples (both in S Transdanubia and the Apuseni Mts) strongly altered pyroxene and rarely garnet crystals are present. Lavas are porphyric with the same main mineral assemblage as ignimbrites and have various recrystallized textures. All samples are enriched in Rb, Th and U and depleted in Ba, Nb, Sr and Ti. The chondrite-normalized REE patterns show higher enrichment in LREEs, slighter enrichment in HREEs and a strong negative Eu anomaly. Most of the rocks, however, are affected by post-magmatic alterations (K-metasomatism, hydrothermal alteration, Alpine low-grade metamorphism) causing significant changes in their major and sometimes in immobile trace element compositions. Based on zircon U-Pb geochronology, rhyodacitic/dacitic rocks equally show an age of ~265 Ma.

Sr–Nd isotope geochemical data suggest magma generation within the lower crust during the emplacement of mantle-derived magmas that provided heat to partial melting. The crystal-rich character of the rocks, corresponding to the immobile element composition, refers to the so-called monotoneous intermediates with initial rhyodacitic/dacitic composition. The latter contradicts the suggested formation name (Gyűrűfű Rhyolite) used in the regional lithostratigraphy. Resorption textures of quartz and feldspar crystals imply the rejuvenation of crystal mush within a lower crustal reservoir, while the pyroxene and garnet crystals in pyroclastic rocks could be potential evidence of mixing with mantle-derived mafic-intermediate magmas.

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Mineralogy and geochemistry of the A-type granites from the Eastern Croatia

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Alkali feldspar (AF) granite and subordinate syenite are situated in the basement of the Pannonian basin in the Privlaka area (Eastern Croatia). The granites are composed of orthoclase containing albite exsolution lamellae, quartz, subordinate albite, biotite and amphibole. The accessory minerals include magnetite with ilmenite exsolutions, zircon, apatite and thorite. The syenite contains orthoclase and microcline with albite exsolution lamellae, albite, subordinate quartz, biotite and amphibole. The mineral chemistry of biotite and amphibole obtained in AF granite points to A-type granite affinity. Biotite is Fe-rich and corresponds to annite. In the Al_{tot} versus Mg_{cpfu} diagram the biotite shows mainly alkaline to peralkaline affinity. Amphibole is classified as ferro-edenite and is characterised by high Fe/(Fe+Mg) ratio, which varies between 0.79 and 0.85 and points to the crystallization under low fO_2. Al-in-hornblende geobarometer (Mutch *et al*., 2016) yields pressures of 2.0 to 2.7 kbar. This should be taken with caution, because the pressure could be overestimated due to low fO_2. The whole-rock geochemistry is consistent with mineral chemistry. The rocks are metaluminious and ferroan granites/syenites, plotting in the within-plate field in a Y versus Nb diagram and the A-type field in a 10000*Ga/Al versus Zr diagram. Trace element patterns of granites normalised to primitive mantle display Ba, Nb, Sr, P and Ti depletion, while syenite shows Cs, Th, Pb, Sr, P and Ti depletion. REE patterns normalised to chondrite are characterized by apparent LREE enrichment, with significant Eu depletion in granites and no Eu anomaly in syenite. The lack of Eu depletion in syenite could point to a cumulate origin for this rock. Magma evolution was controlled by fractional crystallization. Overall, characteristics of the rocks point to an origin by melting reduced, lower crustal rocks and relatively fast ascent of the magma to shallow levels. These rocks are formed in the extensional tectonic regime, most probably in the post-orogenic setting.

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Petrology, geochemistry and U-Pb zircon ages of Variscan granitoids of the East Serbian Carpatho-Balkanides

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As part of the European Variscan belt, there are nine larger granitoid bodies that intrude the basement of the East Serbian Carpatho-Balkanides. Four of them, namely: Brnjica, Neresnica, Ziman and Blizna-Gornjane-Tanda granitoids belong to the Getic unit, whereas five bodies: Aldinac, Janja, Ravno Bučje, Plavna and Suvodol occur within the Danubian units. The only pluton with the so far available U-Pb zircon age is the Blizna-Gornjane-Tanda granitoid, whereas research concerning the age, petrology and geodynamic evolution of other plutons is still lacking. In this study we present interim data of the systematic investigation that is still in progress.

Most granitoids from both Getic and Danubian units are predominantly represented by metaluminous, I-type biotite-hornblende tonalite, granodiorite to monzogranite rocks, very often cut by lamprophyric dykes. The I-type granitoids sometimes show transitions to slightly peraluminous facies. The garnet-bearing muscovite granitoid of Ziman is the only entirely peraluminous pluton in the Getic unit. Petrological observations imply that the Ziman granitoid exhibits evidence of syn-tectonic crystallization. On the other hand, the emplacement and crystallization of the I-type granitoids are post-tectonic.

The ages of the granitoids of the Getic unit are better constrained by LA-ICP-MS U-Pb zircon dating. The concordia age of ~326 Ma for the syn-tectonic Ziman granitoid likely represents the minimum age of collision in this part of the Variscan belt, whereas the post-tectonic granitoids of the Getic unit reveal an age range from ~323 Ma to ~290 Ma.

The ages of the Variscan plutons belonging to the Danubian units are of lower resolution, but the obtained U-Pb data certainly represent a good basis for future investigations. The only concordia age of ~323 Ma is acquired for the Janja granitoid body. Although zircons from the Aldinac rhyodacite gave an age with a high error (319±20 Ma) and the zircons analyses from the Ravno Bučje granitoids gave only a lower intercept (~324 Ma), their similar petrographic (*e.g.*, enrichment in accessory minerals, in particular in apatite and allanite) and geochemical features (almost identical mantle- and chondrite-normalized rare-earth element and trace element patterns, respectively), along with the presence of variably enriched U-mineralization, strongly suggest that all these three plutons might have the same age of emplacement.

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Permian evolution and correlation of the specialised S-type granites in the Gemeric unit (Western Carpathians)

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The Permian granites in the Gemeric unit are named the specialised S-type granites because their apexes contain rare metal mineralisation presented by Nb-Ta-W minerals, cassiterite, topaz, molybdenite, fluorite, etc. They crop out in small cupolas intruded into low-grade Palaeozoic metavolcano-sedimentary rocks bodies in Gemeric unit, which is the uppermost Alpine nappe stacked on Veporic unit during Cretaceous era. The granites are part of a larger hidden granite body which is indicated by geophysical gravimetric data. The granite chemical composition shows S-type characteristics, moreover a prevalence of K over Na is typical as well as high contents of volatiles B and F. Therefore, the tourmaline is spread in granites. The specialized mineralization of these granites is a result of the formation of hydromagma in shallow crustal level under carapace. This process was primarily responsible for the formation of the special accessory mineral assemblages, which significantly extended the former simple S-type accessory paragenesis typical in presence of monazite-(Ce) and xenotime-(Y). In the volatile rich granite cupolas, Li-granites were formed by the in situ differentiation as well as numerous veins in country rocks with such phases like tourmaline, cassiterite or other rare metal phases. The proposed origin of Gemeric granites is still disputed. According to current theories, these granites are a product of: (1) subduction related geotectonic regime (Radvanec *et al*., 2009), or (2) extension regime (Romer and Kroner, 2016). The possible correlation of Gemeric granites is located in the Black Sea area where some Permian-Triassic granites resemble the Gemeric S-type granites due to prevalence of K over Na in the bulk composition, zircon typology and some other specific mineral characteristics. Our ongoing research will contribute to the understanding of the evolution of Gemeric granites and their genesis in framework of Permian evolution.

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Adakitic-like granitoids at west Getic basement of the South Carpathians: petrogenesis and thermotectonic events evidenced by zircon geochemistry

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Research on two granitoids from Buchin (BG) and Slatina-Timiş (STG) at west Getic Domain of the Semenic Mountains (South Carpathians) identified trondhjemites, tonalites, granodiorites and granites of I-S type and adakitic signature. High Na_2O, Al_2O_3 and Sr, depleted Y (<18 ppm) and HREE (Yb<1.8 ppm) contents, high Sr/Y (>40), $(La/Yb)_N$ (>10) ratios and low (+/–) to no Eu anomalies overlap the high-silica adakites (HSA) main characteristics, though differences like lower Mg# and Ni contents, slightly increased K_2O contents and $^{87}Sr/^{86}Sr$ ratios revealed. The comparison with HSA and the results of experiments indicates a mafic source melting at >12.5 kbar and 900–800 °C as main genetic process, leaving residues of garnet granulite to garnet amphibolite type.

U-Pb age data on zircons acquired by LA-ICP-MS were interpreted exclusively on their internal structure as Ordovician igneous crystallization time, Neoarchean–Neoproterozoic$_1$ inheritance, Neoproterozoic$_{2–3}$ source material and Variscan recrystallization imprint (Dobrescu *et al*., 2010). Considering the debate on a possible BG consanguinity with the Poniasca-Sicheviţa magmatism during the post-collisional Variscan orogenic phase, the age data interpretation was reviewed by a geochemical study on the dated BG and STG zircons analyzed by secondary-ion mass spectrometry (SIMS). Uranium contents of 114–305 ppm, high Th/U (~1) and low U/Yb (0.2–0.8) ratios for zones of 462 Ma and 434 Ma on BG zircons, U contents of 234–396 ppm, reasonably high Th/U (~0.6) and low U/Yb (0.6–0.8) ratios for zones of 493 Ma and 465 Ma on STG zircon argue for magmatic origin. Increased HREE contents, positive Ce and negative Eu anomalies confirm the igneous crystallized zones at Ordovician time. By contrast, the outer zircon rims with ages between 357–309 Ma have significantly higher U (553–3891 ppm) contents, low Th/U (0.032–0.200) ratios, increased Hf (9037–9952 ppm), lower Y (240–892 ppm) and Yb (29–290 ppm) contents and high U/Yb (6–30) ratios, recording the recrystallized overgrowth effect of a high-temperature tectonothermal event. Ordovician magmatic ages are quite widespread in the Sebeş-Lotru basement as in the protoliths of Căpâlna augen gneiss (459 Ma), Latoriţa orthogneiss (466 Ma) and Tău metagranite (473 Ma), some surrounded by Variscan overgrowths as a consequence of partial or total resetting during the high-grade metamorphic event (Medaris *et al*., 2003; Balintoni *et al*., 2010).

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Carnian volcanic activity in the Transdanubian Range

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The Transdanubian Range Unit was located close to the Southern Alps before the Cretaceous-Cenozoic Alpine nappe and strike-slip tectonics disconnected them. These carbonate platform-dominated units were affected by volcanic activity in the Middle Triassic to Carnian interval. Dikes and lava rocks are exposed in the south-eastern part of the Transdanubian Range (Szár Hill) and penetrated by two cored wells in the Buda Hills. Furthermore, Upper Eocene conglomerates contain volcanic pebbles among other detritus derived by the erosion of the Triassic sedimentary sequences. Volcaniclastic rocks were found in the Triassic succession in the Eastern Bakony Mountains and in the Zsámbék Basin. Studies on petrographic characteristics and U-Pb age determination of these volcanic rocks made possible to compare them to coeval volcanic formations of the Southern Alps.

Mostly intermediate lava rocks (andesite) occur in the quarry of Szár Hill and in the Buda Hills. However, in the latter area, acidic lava rocks and pyroclastic rocks were also encountered among the pebbles of the Eocene conglomerate. In the Eastern Bakony and in the Zsámbék Basin the mafic-intermediate lava rocks (basalt, andesite, trachyte) are predominant, although subvolcanic rocks (microgabbro) subordinately also occur. The acidic volcanic rocks (rhyolite tuff, rhyolite, and microgranite) are also present in smaller quantities.

In the Transdanubian Range zircon U-Pb ages were determined mostly on redeposited volcanic fragments taken from clastic sediments. Ages between 238 and 230 Ma (Carnian) were determined on zircon-bearing volcanic rock samples. In the Southern Alps, similar ages were determined: 232 Ma (Ivrea-Verbano zone – Zanetti *et al*., 2013); 226–231 Ma (Eastern Lombardy – Cassinis and Zezza, 1982); 234–237 Ma (Western Dolomites – Mundil *et al*., 1996).

Our studies led to the conclusion that akin to that in the Southern Alps, the mid-Triassic "pietra verde" volcanism was followed by volcanic activity during the Carnian also in the area of the Transdanubian Range. The comparison of the petrographic features of the Carnian volcanic rocks of the Transdanubian Range and the volcanic rocks of the Southern Alps (especially Eastern Lombardy – Brescian Alps and Western Dolomites) suggests a definite similarity of the volcanic rocks of the Eastern Bakony and the Zsámbék Basin to those of Western Dolomites (strong K-affinity, from basalt to rhyolite in composition), while the volcanic rocks from the quarries of Szár Hill and Buda Hills show affinity rather to the those of Eastern Lombardy (more calc-alkaline character). The Triassic volcaniclastic successions of the Eastern Bakony and the Zsámbék Basin are similar to the Wengen Formation in the Southern Alps.

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Characteristic features of titanite, apatite, zircon, magnetite and ilmenite during magma mingling and mixing in Petrohan Pluton, Western Balkan, Bulgaria

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The late Paleozoic Petrohan pluton is located in the core of the Berkovitsa anticline, Western Balkan. The pluton is metaaluminous I-type with calc-alkaline and high-potassium calc-alkaline affinity. It is built up of gabbroic to granitic rocks with prevalence of the acid and intermediate varieties, formed via combined assimilation and fractional crystallization processes. Specific feature of the Petrohan pluton is the presence of mafic magmatic enclaves (MME), whose composition varies between gabbro and diorite as result of the magma mixing and mingling. The rocks of the pluton are characterized by diverse accessory mineralogy including titanite, apatite, allanite-(Ce), thorite, zircon, garnet, and Fe-Ti oxides – magnetite, ilmenite, hematite, and rutile. In the present work, several indicative features evidencing the magma mixing processes in the Petrohan pluton were identified in the accessory minerals: Needle-type apatite crystals found in the MME and in the host granodiorite in the contacts with MME is direct indication for the magma mixing. Presence of zones with clear signs of growth break and dissolution in a part of long prismatic crystals is indication of significant change in the chemical composition of crystallization media associated with the magma mixing. The content of Sr in the apatite correlates with the silica content in the rocks due to the influence of basic magma incoming into the magma chamber. The established values of $Sr_{Ap}/Sr_{HostRock} > 1$ in the host granitoids and some hybrid rocks with dioritic composition confirm essential participation of mafic magma in the pluton formation. The magma mixing process affects the chondrite normalized ratio Ce_{cn}/Yb_{cn} in the apatites which is the highest in the granitoids.

The Zr/Hf ratios in the zircons being 41.9–68.53 for MME, 48.75–56.88 for host granitoids, 43.18–61.97 – for hybrid diorite are indication for mixed but mantle dominated source of magma for the rocks of Petrohan pluton. Increase of Nb/Ta ratio, contents of U, Th and REE in zircons from basic to acid rocks typical for differentiated magma complexes are not established in the present study.

The content of La, Ce and Pr in the studied titanites does not follow the tendency to decrease toward the acid varieties of rocks as is typical for differentiated magmas. It is found that the chondrite-normalized distributions of REE in the titanite are similar for the host granitoids and MME and are different from those for the hybrid rocks.

Application of in-situ LA-ICP-MS and ID-TIMS U-Pb geochronology for zircons and titanite allows one to reveal the later intruding of the basic (gabbroic) magma into the granitoid magma mush, thus evidencing for the magma mixing processes during the formation of the Petrohan pluton.

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The Cadomian granites within the Variscan basement of the Alpine units in the Western Carpathians

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The opening of the Rheic Ocean was associated with igneous activity, and numbers of igneous and/or (meta-igneous) rocks – witnesses of this process are documented within the European realm today. The most common rocks of this suite are felsic granites, often referred to as "Older Granites", appearing in the form of the "augen" and/or "banded" othogneisses within the Variscan basement.

The Western Carpathians as a part of Stille's (1924) Neo-Europa form a piece of an extensive, equatorial, orogenic belt extending from the Atlas Mountains in Morocco, through the Alps, Dinarides, Pontides, Zagros, and Hindukush to the Himalayas and to China. Recent structure of the Alps and Carpathians was derived from the Late Jurassic to Tertiary (Alpine) orogenic processes connected with the evolution of the Tethys Ocean, in a long mobile belt sandwiched between the stable North European Plate and continental fragments of the African origin. A typical feature of this mobile belt is the presence of huge reworked slices of the Variscan, and Pre-Variscan crystalline basement within the Mesozoic and the Cainozoic sedimentary successions that have been deformed into large-scale nappe structures. Granitic rocks of various origins form an important constituent of these basement fragments. Albeit the Western Carpathians belong to Neo-Europa, their pre-Mesozoic basement rocks represent distinctive analogues of the basement components known in the Meso- and Paleo-Europa (Stille, 1924).

The Cambrian–Ordovician felsic magmatites/volcanites that were sheared during the Variscan orogeny to orthogneisses are presented mainly within the polymetamorphosed basement in the Veporicum, Tatricum and Zemplinicum units. The Western Carpathians orthogneisses (WCO) are typical felsic coarse-grained and porphyric to medium-grained rocks with K-feldspar, plagioclase, albite, quartz, biotite, phengitic white mica, minor monazite and garnet. Geochemical characteristics: SiO_2 varies in 70-77 wt.%, K_2O/Na_2O = 0.54–1.38; Rb/Sr = 0.8–2.3; contents of Ga, Y, Th, U, and Co have slightly enriched, whereas Sr and Zr have depleted. Generally, WCO have peraluminous character (ASI = 1.0–1.4). REEs have moderate values and show typical fractionated pattern with distinct negative Eu anomaly, and partly elevated HREE contents controlled by presence of monazite and apatite. Initial $^{87}Sr/^{86}Sr$ values range 0.709–0.725 and $\delta Nd_{(i)}$ varies between –8.3 and –2.6 as they are suggesting rather for their crustal source alike their Pb/Pb isotopic characteristics ($^{206}Pb/^{204}Pb$ = 19.58–20.65, $^{207}Pb/^{204}Pb$ = 15.67–15.76 and $^{208}Pb/^{204}Pb$ = 38.95–40.10) with hint of the lower crustal metaigneous source. The Early Palaeozoic zircon $\delta Hf_{(i)}$ variation between –7.7 and –2.8 reflect their crustal character, whereas the Proterozoic restitic zircon cores having $\delta Hf_{(i)}$ from +3.8 to +13.0 indicating former mantle character for part of the sedimentary protolith components. The stable isotopes with $\delta^{18}O$ = 11.0–11.7‰ and $\delta^{7}Li$ varying from –4.5 to +1.6‰ call for crustal source. Protomagmatic ages of these orthogneisses were dated by SHRIMP at 515-460 Ma (Putiš *et al.*, 2009; Kohút, 2014), whereas metamorphic conditions were party masked by the Variscan migmatization reaching up to ca. P = 0.8-1.0 GPa and T = 700-800 °C. However, their cooling ages in Ar/Ar system are similar to the neighbouring Variscan "Younger Granites" having ages between 338-330 Ma.

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Some constraints on final stage of the Meliata Ocean evolution as follow from study of the blueschist facies metamorphosed rocks of the Meliatic Superunit (inner Western Carpathians)

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Blueschist facies metamorphosed rocks related to evolution of the Triassic-Jurassic Meliata Ocean in the Western Carpathians are concentrated in a part of Meliatic Superunit originally labeled as the Bôrka Nappe. This term includes in reality a strongly reduced stack of tectonic slices or sheets composed of various lithotectonic units differ in age, lithology, original geotectonic setting and metamorphic evolution. Directly connected with the oceanic environment are only some of them represented by Jurassic sedimentary mélange with embedded blocks of metabasalts, metadolerites and rarely also metagabbros together with serpentinized mantle ultramafic rocks and metamorphosed radiolarites, cherts and carbonates. The age of blocks is supposed to be the Upper Triassic according to their close similarity with non-metamorphosed analogues in the Meliatic Superunit. Geochemical signature of igneous rocks in blocks varies considerably among similar to IAT through BABB to N-MORB. Matrix of mélange is composed of dark pelitic, less psammitic clastic sediments alternating with redeposited basic volcanic material together with some patches of cherts and carbonates. Mélange metamorphosed as a whole in the blueschist facies conditions was consequently retrogressed to greenschist facies rocks in some of tectonic sheets. Beside the ophiolite mélange complexes also lithotectonic units with clearly continental affinity has been identified in the stack of slices. They are represented by the Early Palaeozoic or Permian volcano-sedimentary complexes both metamorphosed in blueschist facies conditions too. The older complex, minimally Devonian in age, is composed of succession of basic volcaniclastic rocks intercalated by fine-grained siliciclastic sediments together with some subvolcanic dolerites and gabbros, all with calc-alkaline geochemical signature. Its metamorphic evolution includes transformation in epidote-amphibolite facies conditions overprinted by younger stages in blueschist and greenschist facies conditions. Slices of Permian in age are built up by metamorphosed clastic and acid volcaniclastic sediments with sporadic metarhyolite bodies of calc-alkaline signature. Variability in lithology and tectonic settings of rock complexes in the stack of tectonic slices which experienced the high pressure subduction zone metamorphism during Upper Jurassic (150–160 Ma) sheds a new light on evolution of the Meliata Ocean. Presence of blueschists compositionally similar to IAT or BABB in ophiolitic mélange seems to be clear evidence for intraoceanic subduction and suprasubduction character at least a part of the Meliata Ocean crust. High-pressure metamorphosed Palaeozoic complexes containing calc-alkaline volcanic rocks suggest for involvement of continental crust in the subduction zone to the end of oceanic closure and final plate collision. Lithology of these complexes indicate that the Meliata Ocean could be opened in the terrain with the geological structure similar to the Gemeric Superunit probably parallel to the Variscan oceanic suture.

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New age and re-evaluated whole rock geochemical data of the Szarvaskő magmatic unit (NE-Hungary): Back-arc basin or N-MORB-type magmatism?

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The main part of the Bükk Mts. are built up by sedimentary sequences of Dinaric affinity deposited on the western – south-western extended continental margin of the Neotethys Ocean during the Late Paleozoic–Late Jurassic interval. This margin was thrust over by the Dinaric Ophiolite nappe from the Late Jurassic. The Bükk nappe system is built up by 4 main nappe slices. The lowermost Bükk nappe represents the attenuated continental margin, the Mónosbél and Szarvaskő nappe consists of Middle–Late Jurassic sedimentary complexes, while the uppermost, Darnó nappe is a tectono-sedimentary mélange, but no ophiolite sheet is present in the area. Besides Jurassic fine grained siliciclastics and shale, the Szarvaskő nappe contains mafic magmatic rocks as well: gabbros and basalts together with plagiogranitic differentiates and ultramafic cumulates. We carried out Sm-Nd age dating on garnets from the contact of the gabbro and the plagiogranite, which yielded an age of 164.7±1.6 Ma. This made a considerable refinement of the previously available K-Ar data (Árva-Soós *et al*., 1987).

Based on whole rock geochemical data, previous authors concluded that these rocks have an N-MORB affinity (*e.g*., Harangi *et al*., 1996; Aigner-Torres and Koller, 1999), however subduction-related geochemical fingerprints were also hypothesized (Kiss *et al*., 2011). Regardless of the geochemical differences, all authors placed the magmatic rocks to a back-arc basin environment. Here we present the same dataset (completed with some new measurements) plotted on several different geochemical classification systems to illustrate the complexity of geotectonic discrimination based on whole rock geochemical data.

As a result of the re-evaluation of the old dataset, an N-MORB-type origin of the mafic magmatic rocks is plausible without subduction-related components, which affects the geotectonic reconstruction of the area. The former, back-arc basin origin would automatically mean an upper plate position with respect to the subduction, while the new classification enables different paleogeographic interpretations.

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Age and Sr-Nd-Hf isotope characteristics of Petrochan and Mezdreya plutons in Western Balkan, Bulgaria: implications for their position in the Variscan orogen

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A combination of methods are applied in present study to define the exact age of the Petrochan and Mezdreya plutons in the Western Balkan, Bulgaria, and trace their magma evolution. Field, petrological and geochemical studies of the Petrochan pluton (PP; Tacheva *et al*., 2006) revealed its complex evolution and emphasized the role of magma mingling and mixing, complimentary to the normal assimilation and fractional crystallization (AFC) processes. Using high precision conventional U-Pb ID-TIMS zircon and titanite dating in combination with CA-LA-ICP-MS zircon dating and tracing we suggest an incremental growth of a common Petrochan-Mezdreya pluton (PMP). It was assembled over minimum four-five Ma from 311.14±0.48 Ma – 308.12±0.33 Ma (CA-ID-TIMS U-Pb concodia ages of granitoids and hybrid varieties of PP) to 307.54±0.54 Ma (Mezdreya granite). The younger age of the gabbro intrusion, compared with granitoid ages of PP provides numerical proofs for the magma mingling/mixing processes in the generation of the pluton.

Whole-rock strontium-neodymium (initial $^{87}Sr/^{86}Sr$ ratios of 0.70521–0.70527 to 0.70462 and $^{143}Nd/^{144}Nd$ at 0.51221 to 0.51210) and Hf-zircon isotope data (ε-Hf from –5.8 to +3.6) suggest interaction of mantle derived magma with crustal melts but also mixing and mingling with transfer of zircon grains between the gabbroic and granitic melts. Possible petrogenetic processes include AFC in lower-middle crustal chamber and mixing/mingling in middle/upper crustal chamber. To explain this complex and long-lived growth we assume stacking of the mantle and hybrid magma in the lower-middle and upper crustal chambers over 3–5 Ma in a possible compressional/transpressional tectonic setting, followed by local transtension/extension. Possible scenarios include mantle delamination or mantle underplating that lead to melting of subcontinental mantle lithosphere and crust and further evolution trough AFC and mingling/mixing processes.

Considering the PMP as part of the Variscan orogeny in SE Europe our new data support the accretion/collision of both Balkan and Sredna Gora/Getic Units with Moesia in the Early Carboniferous followed by syn- and post collisional Carboniferous and Permian magmatism. The Lower Units of the Rhodopes and the Sakar-Strandzha zone reveal a similar Variscan evolution of protoliths, which are overprinted by later tectonics and metamorphism.

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The Cadomian exotics in the Polish Outer Carpathian flysch

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The crystalline exotics represented by magmatic and metamorphic rocks were found in the Eocene olistostrome in the vicinity of Osielec in the Magura Nappe in the Polish Outer Carpathians. These olistostrome is a part of the Cretaceous-Paleogene flysch of the Magura Basin (Cieszkowki *et al*, 2017). The exotics were redeposited from the Silesian Ridge, which separated Outer Carpathian Tethyan basin during Jurasic-Paleogene times.

The exotics, represented by magmatic and metamorphic rocks, are the remnants of the Precambrian-Paleozoic Proto-Carpathian basement, which was probably formed during separate paleotectonic stages. The blocks of dioritic composition, with marked metamorphic overprint were studied. Primary mineral assemblage comprise Mg-hornblende to ferro-tschermakitic hornblende, plagioclase (An_{48-51}), accessory quartz, ilmenite, F-apatite and zircon. Pseudomorphs after pyroxene were also noted. Secondary mineral components are: high-Ti biotite (Ti = 0.64–0.74 a.p.f.u; #fm = 0.45–0.57), titanite, rutile, epidote, chlorite (#mg ~0.56). They represent magnesian, metaluminous magmatic suite (#mg = 0.61–0.68; ASI = 0.84–1.03), with Zr content in the range of 116–224 ppm, and flat C1-normalized REE patterns (Ce_N/Yb_N = 4.75–5.52; Eu/Eu* = 0.81–0.94). LA-ICP-MS U-Pb dating of zircon from two samples (OS-2 and D6) point out the magmatic protolith age of 613.3±2.6 and 614.6±2.5 Ma, adequately. No inherited cores and no younger overprint was noted in zircon CL-images.

These magmatic ages allow to suppose the link to Małopolska and Brunovistulian terranes as a possible source areas for the exotic blocks. The relatively mafic character of the studied rocks suggest their mafic (gabbroic?) protolith. They represent ophiolites formed in the Paleoasian Ocean (Gawęda *et al*., 2017) and obducted on the Gondwana margin during Cadomian orogeny.

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Integrated assesment of paleomagnetic, geochronological and volcano-stratigraphical constraints from the Tokaj Mts, NE Hungary, Carpathian-Pannonian region

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The Tokaj Mountains is a north to south trending, arcuate volcanic chain located in northeastern part of the Carpathian Pannonian Region (CPR) The bimodal, calc-alkaline volcanism occurred in the Mediterranean type back-arc system that opened in response to lithospheric stretching behind the Carpathian arc. The variable scale subsidence (up to 2000 m) associated with sedimentary, volcaniclastic and volcanic infill with a gradual transition from submarine to subaerial settings.

The volcanism comprises contemporaneous intermediate – silicic volcanic activity. during the Badenian through Pannonian period Silicic calderas (Pálháza, Szerencs, Boldogkőváralja) represent the eruptive sources for the variable thickened (up to 500 m) ignimbrite deposits. Lava dome building extrusions pre or post-dated the explosive eruptions (Telkibánya, Erdőhorváti, Bodrogkeresztúr). Coeval andesitic composite volcanoes with erosional calderas occur in the northern (Hollóháza) and the central (Regéc-Baskó) segments. Several subvolcanic bodies (andesite-dacite) intruded into the volcaniclastic succession (Sátoraljaújhely-Sátor Hills, Tállya-Kopasz Hill, Gönc-Hársas Hill). The volcanic activity terminated by andesitic fissure volcanism (Telkibánya, Gönc) pyroxene-dacite cones (Tokaj, Szegi), olivine bearing andesite domes (Erdőbénye) and a basaltic diatreme (Sárospatak).

A large number of published and unpublished K/Ar data (over 200), are available from the Tokaj Mts. They were obtained either on whole rock or biotites and amphiboles. These constrain the duration of the volcanism from 15.2±1.3 to 9.4±0.5 Ma and provide isotope ages for the activities of the above described volcanic centres. The volcanism is also well-represented by 73 site-mean directions (most of them radiometric dated) based on several independently oriented samples. The data set, when treated as one population, points to a moderate CCW rotation of the Tokaj Mts., after the termination of the volcanism. Another way to treat the data is to define subsets, based on declination (one group deviates in CCW sense from the present N and S, respectively, the other exhibits very small CW rotation and magnetic polarity (normal or reversed). The oldest products of the volcanic activity (including the ignimbrites and rhyolite domes at the base of the volcanic area) exhibit CCW rotation and have normal polarity. In contrast, ignimbrites and lava domes marking a second eruption event show reversed polarity and small CW rotation. It stands to reason to conclude that the CCW rotation of the Tokaj Mts took place during the volcanism. Thus, based on paleomagnetic data, we can define a first phase erupting and intruding during normal polarity of the Earth magnetic field (Late Badenian) followed by those having formed during reversed polarity chron (Sarmatian) These eruptions predated the CCW rotation. Those postdating the rotations erupted first in a reversed polarity magnetic field (Late Sarmatian –Early Pannonian), while the youngest ones (Pannonian) during normal polarity. The above pattern closely follows the time evolution of the volcanism as reconstructed on geological grounds and harmonizes with a substantial part of the K/Ar isotope ages.

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Ophiolitic complex of Puka

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The mantle section of the Albanian ophiolites represented by: (1) Western Belt: Zemblak, Rehove, Voskopoja, Morava, Devolli, Vallamara, Shpati-Kuterman, Skanderbeu, Pilinarda, Puka, Gomsiqe, Krrabi, and (2) Eastern Belt: Bitincke, Shebenik-Pogradec, Bulqiza, Lura,Kuksi, Tropoja, according to $^{40}Ar/^{39}Ar$ hornblende age metamorphic sole: 160–164 Ma in the north, 165–172 Ma in the middle part, 169–174 Ma in the south, 163–173 Ma in gabbros, 162.3–165.5 Ma of zircons from N Albanian gabbros (Dilek *et al*., 2008 and references therein).

The Puka ultramafic massif belongs to the western ophiolite belt of Albania and occurs in the northen part of this bet. It covers an area about 210 km^2. The western contact of the Massif with the volcanic-sedimentary formation of the Middle–Upper Triassic in the area Gomsiqe-Kçire and with “block in matrix” mélange of Jurassic to Cretaceous age in the Kçire-Kashnjet is represented by a strong fault zone. These formations mark the boundary between Puka massif and the Gomsiqe and Pilinarda ones. In the northern, eastern and southern parts the contact of Puka massif is with volcanic basic roks or with gabbro-micro-gabbro of Gojani and Kaçinari massifs or with plagiogranite. The Puka (Terbuni) ophiolitic complex is represented by:

(1) The lherzolitic ultrabasic mantle, which is predominant and represented by mantle lherzolite and clinopyroxene-bearing hartzburgite with rare and small lenses of dunite are predominant and constitute the deepest part of the mantle section, and dunite with intercalations of clinopyroxene-bearing harzburgite and lherzolite, which have various distributions.

(2) Cumulate sequences and volcanic rocks as well as the sheeted dykes have a relatively limited distribution and are represented by small massifs of gabbro-troctolite, olivine gabbro, gabbro, ferrogabbro, gabbronorite, olivine-gabronorite and volcanic rocks.

The Puka ultramafic unit, so far as we sampled, consists of harzburgites and depleted lherzolites, with evidence for a MORB origin.

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The emplacement depth of granitoid intrusions from the Gaoligong strike-slip shear zone: new insights from Al-in-hornblende barometry and U-Pb and ^{39}Ar–^{40}Ar geochronology

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Lateral extrusion of continental blocks during continent-continent collisional orogeny is a well-known process. However, vertical motion along confining these blocks remains poorly constrained. The Cenozoic Gaoligong strike-slip shear zone (GLSZ) is located in the southeast of the Eastern Himalayan Syntaxis (EHS) in western Yunnan, China, and separates the Baoshan block in the east from the Tengchong block in the west. The GLSZ plays a vital role in our understanding of the collision between the Indian and Eurasian plates. Along the GLSZ exposes large volumes of granitoids and granitic gneisses, which are composed of varying proportions of quartz, plagioclase, K-feldspar, biotite, hornblende, sphene, magnetite, apatite and zircon. Geothermobarometric calculations using hornblende-plagioclase thermometry and aluminum-in hornblende barometry have been investigated on the granitoids and amphibolite rocks in the GLSZ. The undeformated granodiorite outside of the GLSZ were emplaced at average temperatures and pressures ranging between 643 and 729 °C and 4.0 to 5.8 kbar, respectively. The average emplacement depth estimates for the investigated granitoids is constrained, therefore, at about 14 to 21 km. The strongly deformed granitic gneisses were emplaced and deformed at average temperatures and pressures ranging between 568 and 745 °C and 1.2 and 3.5 kbar, respectively. The average deformation depth estimates for the investigated granitoids are constrained at about 4.4–12.7 km. The U-Pb zircon and ^{39}Ar–^{40}Ar white mica dated of the deformed granitic mylnoites reveal that the Cenozoic strike-slip shearing occurred after 35 Ma, and continued until to 15 Ma. These results indicate that crustal rocks of GSZ have been exhumed at least 16 km during shearing at an approximate exhumation rate of 0.08 mm/year. This rate is in a similar order of magnitude as in other shear zones related to the same lateral extrusion process in Indochina.

Debris avalanche deposits of the Călimani-Gurghiu-Harghita volcanic range (Eastern Transylvania, Romania)

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Volcanological observations supported by K/Ar dating document the migration of volcanism from NNW to SSE along the Călimani-Gurghiu-Harghita (CGH) volcanic range, suggesting an almost continuous eruptive activity between 10.2 and 0.03 Ma that built up a row of closely spaced, juxtaposed or partially overlapping medium-sized composite volcanoes displaying typical proximal, medial and distal facies association. Two of these – Călimani and Fâncel-Lăpuşna evolved to the caldera stage almost simultaneously (7.0–6.8 Ma).

Two major debris-avalanche deposits (DADs) have been identified previously at the western periphery of CGH. The largest one belonging to the Rusca-Tihu volcano (Călimani Mts.) has displaced ca. 26 km^3 of volcanic debris. The second one, originated in the Vârghiş volcano (North Harghita Mts.), has dispersed ca. 13 km^3 of collapsed material. The assignment of the volcaniclastic deposits at the western periphery of CGH to different eruption centers has taken into account various genetic types of volcaniclastic deposits (pyroclastic, debris-avalanche, debris flow). In some cases, identifying the volcanic source has been difficult because of the rather monotonous petrography and geochemistry characterizing the entire range.

Detailed geological mapping, petrographic observations, and K-Ar geochronology enabled recently a new comprehensive view about the origin and emplacement history of the volcanoclastic deposits including various DADs in the CGH. Major volcanic edifice failure events, besides caldera-forming eruptions, considered “major events”, shaped the volcanic evolution of CGH. We identified and outlined three new, previously unknown, DADs in the Gurghiu and South Harghita Mts. The DADs are typically represented by tens of meters thick chaotic mega-breccia with an unsorted, massive, polymictic character. They are heterogeneous at the outcrop scale, displaying sharp lateral variations in texture and lithology. DAD-specific features such as jigsaw cracks, breccia-in-breccia, and plastic (soft sediment) deformation are common. Several volcanoes experienced edifice-failure events and generated large-volume DADs at some point in their evolution: Rusca-Tihu (Călimani Mts.) at ~7.8 Ma, Fâncel-Lăpuşna (Gurghiu Mts.) at 6.8 Ma, Vârghiş (North Harghita) at ~4.8 Ma, and Luci-Lazu (South Harghita) at ~4.0 Ma. A smaller volume DAD originating in the ~1.7 Ma Pilişca volcano (South Harghita Mts.) has been also identified recently.

We suggest that most of the edifice failure events are closely related to a series of tectonic processes including the opening and southward propagation of the Borsec/Bilbor, Gheorgheni, Upper and Lower Ciuc Intermountain Basins and the growth of new volcanoes. The contemporaneous formation of basins and activation of volcanism, the southward propagating fault system, as well as the geometry of the faults and alignment of volcanic centers indicate strike-slip and normal extensional tectonics. All the known DADs were displaced in the SSW from their source volcanoes, most likely following the preexisting topography sloping toward the Transylvanian Basin.

The Fâncel-Lăpuşna DAD appears to be closely related to the Plinian caldera-forming event and collapse of the southern volcano flank. In the South Harghita Mts., the Luci DAD has strongly influenced the evolution of the Baraolt Basin, which acted as a depocenter for the DAD and associated epiclastic deposits. Consequently, several small-size lacustrine basins developed atop the Luci DAD, which host diatomite deposits. Our recent volcanological observations indicate that the medial-distal volcanic facies on the western periphery of CGH is volumetrically dominated by DADs (>75%) in association with debris flow deposits, and are locally overlapped by proximal-medial facies products of the neighboring younger composite volcanoes.

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Session GT5-1

Tectonometamorphic processes in Alpine and pre-Alpine orogenic belts

Conveners:

Marian Janák, Mirijam Vrabec, Sha Wali Faryad and Dušan Plašienka

Pre-Alpine basement units in the southernmost Austroalpine domain: Significance for Alpine-Carpathian tectonics and paleogeography

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Among all distinct Austroalpine tectonic basement units of Eastern Alps and Western Carpathians, the Nötsch-Veitsch-Ochtina (NVO) unit is particularly interesting because of two reasons: (1) it comprises elsewhere unknown Lower Carboniferous clastic shallow water formations overlain by Upper Carboniferous terrestrial conglomerates and sandstones, interpreted to represent molasse deposits to the early Late Carboniferous Variscan orogeny; and (2) the Veitsch (Eastern Alps) and Ochtina (Western Carpathians) nappes are the lowermost units overlain by a pre-Variscan amphibolite-grade metamorphic basement unit as well as a Lower Paleozoic phyllitic basement, all representing tectonic units in the footwall of the Late Jurassic/Early Cretaceous oceanic Meliata suture. The Nötsch area is located between the Periadriatic and another major regional strike-slip fault (the Drau Range South margin fault) in the southernmost part of the Austroalpine domain, and comprises, from base to top, similar three tectonic units as the NVO unit in the north: (1) the non-metamorphic Carboniferous Nötsch Group, (2) the retrogressed amphibolite facies metamorphic Nötsch basement, and (3) the rare fossil-bearing Silurian-Devonian greenschist facies metamorphic Gailtal basement.

In the Gailtal basement, the U-Pb zircon age of 441.6±6.7 Ma obtained from the Dellach augengneiss points to a Silurian magmatic protolith, metamorphosed during the Carboniferous (Ar-Ar sericite ages of 321±1 Ma to 345±1 Ma) and overprinted by a second thermal event with a maximum age of 265±3 Ma. In the Nötsch basement, U-Pb zircon ages of 480.3±9.4 Ma and 442.5±1.7 Ma from mylonitic orthogneisses indicate similar intrusion ages. Ar-Ar white mica ages range from 408±2 Ma to maximum 430±2 Ma constraining a cooling after the pre-Variscan metamorphism. Both, biotite and K-feldspar plateau ages vary from 344±2 Ma to 337±2 Ma and are overprinted by a younger event between 213±1 Ma and 198±1 Ma, interpreted as a result from an advanced stage of an Alpine rifting. White mica from orthogneiss boulders of the Pölland Fm. from the Nötsch Group show plateau ages ranging from 343±4 Ma to 380±2 Ma, affected by a post-depositional very low-grade metamorphic overprint.

New data demonstrate, beside its significance for the Variscan history, that the tectonic succession of the Nötsch area at the southernmost part of the Austroalpine unit has a strong similarity to the nappe stack (including the NVO unit) of the northern Austroalpine sectors (Greywacke zone and Ochtina area). Therefore, we consider these three units of the Nötsch area as a remnant of the root zone of the basement and cover nappes in the footwall of the Meliata suture. The structural relationships point to a more than 150–200 km large-scale nappe transport of the Meliata suture remnants in the Eastern Alps as well as the involvement of large, hitherto undetected Cenozoic strike-slip faults into the Austroalpine structure.

The pre-Mesozoic basement of the Danubian nappes, South Carpathians

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The Danubian Window is exposed in the southwestern part of the South Carpathians, in the Parâng, Vulcan, Mehedinţi, Retezat, Ţarcu, Cernei, Almăj Mts. in Romania, and south of Danube in the Miroć Mts. of NE Serbia, including sedimentary deposits from Early Jurassic to Late Cretaceous overlying older basement formations. Overviews on the Danubian pre-Mesozoic basement were presented by L. Pavelescu at the 5th CBGA Congress in 1961, and by T. Berza and A. Seghedi at the 9th CBGA Congress in 1981 followed by papers of V. Iancu, A. Seghedi, R. Dimitrescu, T. Berza, J.P. Liégeois, J.C. Duchesne, I. Balintoni, C. Balica, G. Plissart.

The Late Carboniferous and Permian sedimentary and volcanic formations are known only in the basement of the Upper Danubian Nappes from Banat and Miroć, but similar in age granitoid plutons (320–290 Ma; U/Pb zircon data of C. Balica, J.P. Liégeois, O. Laurent and I. Peytcheva) are presented in the basement of both Upper and Lower Danubian nappes, up to the eastern tip of the window´s exposure.

Ordovician to Devonian sedimentary formations crop out in restricted areas in the Lower Danubian basement (Valea Izvorului, Coarnele, Tusu), but are more frequent in the Upper Danubian basement (Nijudimu, Brustur, Râul Rece, Sevastru, Drencova, Ieşelniţa). An ophiolitic massif, dismembered by the Cerna-Porećka dextral fault in Tisoviţa-Iuţi (Romania) and Deli Jovan (Serbia) massifs, exposes various portions of the Devonian oceanic crust (G. Plissart), separating two distinct older high-grade metamorphic formations from the basement of the Upper Danubian Svinecea Nappe.

The pre-Ordovician metamorphic and igneous bodies represent 90% of the basement outcrop areas in the Lower Danubian Schela and Lainici nappes, with two main lithologies in tectonic contact: metaclastic and carbonate for the Lainici-Păiuş Group (L-P) and igneous metabasic or metaacidic for the Drăgşan Group (DG). Based on detrital zircon U/Pb data, I. Balintoni and C. Balica established the minimal age of the sedimentation for L-P Group as 610 Ma and age peaks, pointing to a Ganderian origin. For the DG Group, the intrusion age of the acidic igneous protolith was determined by J.P. Liégois at 780 Ma, while C. Balica, not founding clastic zircons younger than 1200 Ma, claimed an Avalonian origin. A stack of Pan-African granitoid plutons, intruding the L-P Group, with zircon U/Pb ages of ca. 590 Ma, was studied by Duchesne and T. Berza, but C. Balica and O. Laurent have determined for two granitoid plutons U-Pb zircon ages of 300 Ma and for one – 320 Ma. The granitoid plutons, intruding the DG group are exclusively Variscan in age, being dated zircon U/Pb from 290 to 300 Ma by J.P. Liégeois and C. Balica.

For the basement of the Upper Danubian nappes, other names (Măru, Zeicani, Măgura Marga, Godenele, Neamţu, Corbu, Poiana Mraconiei) are used for pre-Ordovician metamorphic sequences, intersected only by Variscan granitoid plutons (C Stremţan). In Almăj Mts., as the Poiana Mraconiei gneisses do not belong to the Drăgşan Group, the Tişoviţa-Iuţi ophiolite do not represent a Devonian suture between DG and L-P terranes, as it was recently proposed.

Alpine, Permian and Variscan metamorphism in the Tisza and Dacia Mega-Units: Sm-Nd garnet and U-Th-Pb monazite dating in the Apuseni and Rodna Mountains (Romania)

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The Tisza and Dacia mega-units constitute a central part of the Alps-Carpathians-Dinarides system of orogens. Polyphase medium-grade metamorphism, observed in mineral assemblages from the crystalline basement has been correlated with Variscan and pre-Variscan events. However, a mid-Cretaceous Sm-Nd garnet age (104±2 Ma) from the Apuseni Mountains is at odds with this interpretation. Electron-microprobe U-Th-Pb dating of monazite in samples from the Apuseni and Rodna Mountains, as well as the Şimleu Silvaniei, Ticău and Preluca inselbergs revealed a complex pattern of Alpine and pre-Alpine age clusters. Pre-Variscan and Variscan ages were obtained from the core of zoned monazite grains and from samples that apparently escaped the Alpine overprinting. Relictic monazite in the latter is often replaced by rhabdophane and/or surrounded by allanite coronas. Permian to Early Triassic monazite ages correlate with the intrusion of granitic melts and pegmatites. Early Cretaceous ages from rims of chemically zoned grains and from monazite inclusions in garnet, biotite and staurolite, represent newly formed metamorphic grains that crystallized on the prograde path during an Alpine metamorphism. Petrographic observations of prograde allanite breakdown reactions, Sm-Nd garnet analyses and thermobaric estimates (500–550 °C/5–8 kbar) from the Tisza and Dacia mega-units constrain medium-grade conditions during Early Cretaceous times. Exclusively mid-Cretaceous monazite ages from the inselbergs and Rebra-Unit of the Rodna Mountains, allow extending the Alpine prograde overprint across the Transylvanian basin. Taking together with other studies from the basement of the Pannonian basin, this implies that the Dacia Mega-Unit and parts of the Tisza Mega-Unit experienced a medium-grade metamorphic overprint and synkinematic garnet-growth during late Early Cretaceous times. The Alpine prograde overprint is distributed along the contact between the Tisza and Dacia mega-units, forming a continuous belt with the Cretaceous metamorphic imprint in the Eastern Alps, when back-rotated to its original position during the Cretaceous.

Microstructural and crystallographic characteristics of diamond and moissanite from Pohorje UHP terrane, Eastern Alps, Slovenia

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Metapelitic crustal rocks of Pohorje Mountains in the Eastern Alps host diamond- and moissanite-bearing garnets, occurring as single or polyphase inclusions. Metasedimentary rocks are predominantly gneisses, representing parts of the Austroalpine metamorphic units of the E-Alps. During the Cretaceous orogeny (ca. 95–92 Ma), continental crustal rocks were subducted to the mantle depths (below 100 km) and metamorphosed at pressures exceeding 3.5 GPa and temperatures 800–850 °C.

Advanced analytical techniques were applied to determine microstructural and crystallographic characteristics, phase compositions of the inclusions as well as the host garnets: optical microscope in plane polarized transmitted light, electron probe microanalysis (EPMA) with wavelength-dispersive X-ray spectrometry (WDS) and field-emission scanning microscope (FEG-SEM) with energy-dispersive X-ray spectroscopy (EDS), micro-Raman analysis, and several techniques of transmission electron microscopy (TEM), which included high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM), combined with EDS and electron energy-loss spectroscopy (EELS). To prepare electron transparent TEM lamellae selectively a dual-beam Focused Ion Beam/SEM (FIB/SEM) was employed.

Diamond inclusions in garnet show a pronounced crystallographic orientation, expressed by the parallel alignment of the one side of the cube. Detailed study of several TEM lamellae, cross-sectioned from the host garnet crystal matrix, revealed a rather complex internal structure. The negative crystal facets of the main inclusion body were typically decorated with up to 1 μm thick layer, reflecting the general garnet composition with slight variations in Fe/Ca/Mg/Mn content. Within these layers, in all analyzed samples, ELNES analysis revealed the presence of a 28–30 nm thick layer of amorphous carbon. The very last layer corresponds to composition of SiO_2. Within the inclusion, besides diamond and moissanite alumosilicate mineral with a pronounced layered structure, iron sulphides and chlorine were identified under TEM and CO_2 and CH_4 using Raman. Micro-Raman analysis revealed sharp, first-order diamond bands occasionally accompanied by graphite bands, implying that a transformation of a diamond back to graphite occurred. Moissanite is found as a single crystal or composed of numerous highly textured nano-crystals with an average size of 10 nm. Moissanite inclusions were found embedded inside the garnet crust implying that moissanite crystalized well before the deposition of the amorphous layer.

From the microstructural, crystallographic and chemical observations so far we can deduce, that polyphase inclusions in diamond bearing garnets from Pohorje most probably crystallized from reduced supercritical fluids. Based on the layered interface structure of the host mineral, a multiphase process of crystallization is possible. The presence of microdiamonds and moissanite in rocks from Pohorje demonstrate that these parts of the E-Alps were the most deeply subducted domains of the Austroalpine units of the Alps, and were subsequently exhumed back to the surface without a complete breakdown of UHP mineral phases, allowing an opportunity to study them in-situ.

Permian pyroxenite dykes in a harzburgite associated with eclogites (Austroalpine Unit, Eastern Alps): origin and and tectono-metamorphic evolution constrained by zircon U–Pb ages

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The Upper Austroalpine Sieggraben structural complex (SSC) represents a Variscan basement fragment that underwent a Cretaceous eclogite-facies metamorphism (Putiš *et al*., 2002 and references therein) and is composed of mafic eclogites, ortho- and paragneisses, marbles and rare peridotites. This fragment contains Permian (256±3 Ma, sample GS-8; zircon SIMS U–Pb age) granite veins. The Cretaceous subduction was dated at 90±4 Ma (s. SW-1) on zircon from an Ordovician gabbro-eclogite (469±5 Ma, s. S-202-3) exposed between Sieggraben and Schwarzenbach, ca. 80 km south of Vienna.

Websterite and garnet ortho- and clinopyroxenite dykes crosscutting a km-size fragment of harzburgite occur in the hanging wall of the SSC between Steinbach and Gschorrholz villages in southeastern Austria. The dyke textures reflect P–T conditions changes in the mantle, subduction channel and accretionary wedge environments, which the studied mantle fragment passed through. A clinopyroxenite dyke was dated at 252±2 Ma on zircon by U–Pb SIMS. The depleted mantle source of the dyke is constrained by εHf(t) values of 16–8, and the dykes' petrogenesis is most likely related to sub-crustal cumulate-type melts. Magmatic melts of highly evolved ortho- and clinopyroxenites could be products of a partial melting of a hydrated (ancient Variscan, SSZ?) peridotite.

The porphyroclastic Cpx1 (10–13 mol.% Ca-Ts), Opx1, Spl1 and Amp1 (Mhb or Prg) are inferred remnants after magmatic phases. They contain Ti-Spl and Ilm exsolutions due to a cooling of the dykes in the mantle Spl stability field (D0-1 stage). Garnet exsolutions in Cpx1, Opx1 and Amp1, and Cpx exsolutions in Amp1, demonstrate a continuous cooling and/or pressure increase (D0-2 stage). The Grt coronas around Spl1, Opx1, Cpx1 and Amp1, and the granoblastic matrix of Grt (or Cr-Spl in websterites), low-Al Cpx, low-Al Opx, Fe-enriched Ol, Zo, Ky, Rt, Prg, ± Mgs and Dol, record a subduction (D1) stage. The Cpx–Grt or Amp-Grt symplectites replacing the Cpx1 and Amp1 rims suggest a HP–HT exhumation (D2-1) stage. The Grt (or Cr-Spl) replacement by Spl, and Opx1, Cpx1 and Prg replacement by Ol–Spl, Opx–Spl or Prg–Spl symplectites indicate continuous exhumation (D2-2) stage. The MP/MT conditions of an accretionary wedge were estimated from Tr, Grs-rich Grt, Sr-Ep, Czo, Cl-Ap, Ttn, Chl, Srp and Tlc assemblage (D3 stage). Anticlockwise P–T path was reconstructed for the D0 to D1 stages, followed by almost an isothermal exhumation (D2) and emplacement in the Cretaceous accretionary wedge (D3). The Perpele_X pseudosection P–T calculation from a clinopyroxenite dyke yielded 850–825 °C and 25–28 kbar (D1).

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Trace element characteristics of rutile and Zr-in-rutile thermometry of high-pressure metamorphic rocks from northwest Turkey

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In northwest Turkey, high-pressure metamorphic rocks occur as tectonic slices in the Çetmi mélange located to the south of the Biga Peninsula. The Çetmi mélange is composed mainly of various types of blocks within a detritic matrix. Rutile chemistry and rutile thermometry obtained from the eclogite and associating garnet-mica schist in the Çetmi mélange give significant information about the source-rock lithology of detrital rutiles and trace element behaviour of the subducted oceanic crust. Cr and Nb contents in rutile from the garnet-mica schist vary from 355 to 1026 µg/g and 323 and 3319 µg/g, respectively. According to the Cr-Nb discrimination diagram, the results show that 85% of the rutiles derived from metapelitic and 15% from metamafic rocks. However, eclogites in the Çetmi mélange have compositions typical for metamafic source rocks.

Zr concentration of rutiles in the garnet-mica schist vary from 24 to 89 µg/g. Zr-in-rutile temperatures range between 540 °C and 624 °C with an average of 586 °C at pressures of 2.3 GPa for rutiles. Rutile grains from the matrix of the eclogites have high Zr concentrations and range from 79 to 150 µg/g. Zr-in-rutile thermometry for eclogites yielded matrix rutile formation temperatures of 611 °C and 659 °C with an average of 630 °C at pressures of 2.3 GPa.

Nb/Ta ratios in metamafic rutiles from the garnet-mica schist have a relatively large range (11–25), which is slightly larger than in metapelitic rutiles (7–24). This could reflect differences in the source-rock lithology. The metapelitic detrital rutile grains have mostly subchondritic Nb/Ta ratios (7–24) with an average of 15. However, Nb/Ta ratios of rutiles in eclogite vary from 9 to 22. The increase in Nb/Ta and Zr/Hf ratios in eclogites is mainly caused by a decrease in Ta and Hf contents. This suggests that differential incorporation of Nb and Ta into rutile during its growth is a basic cause for the Nb/Ta differentiation due to a significant difference in their mass. The rutile grains from eclogites are dominated by subchondritic Nb/Ta ratios. It should be noted that subchondritic Nb/Ta may record rutile growth from local sinks of aqueous fluids from a metamorphic dehydration.

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Kyanite-andalusite gneisses from Thracian lithotectonic unit (Parvenets complex), Bulgaria: refining the peak metamorphic conditions

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Parvenets complex comprises the northernmost parts of the Central Rhodope Mountain and was attributed to different tectonic units with a regional extent. According to Sarov (2012), the Parvenets complex is a part of the Thracian lithotectonic unit, which rocks are deformed by the Maritsa dextral strike-slip shear zone. New structural and geochronological studies suggest a polymetamorphic history of the unit, with a high-grade metamorphism, followed by greenschist Alpine metamorphic overprint (Naydenov *et al*., 2008). We studied samples from kyanite-andalusite gneisses (in the vicinity of Hrabrino Village) and here is presented first mineral chemistry data and Perple_x thermodynamic modelling in order to clarify the P-T evolution of the Parvenets complex.

The studied samples are fine-grained, with quartz-dominated matrix, and plagioclase with an advanced static recrystallization. Abundant small, fresh, idioblastic biotite flakes define the foliation. From relict paragenesis of garnet-kyanite-staurolite-plagioclase-quartz described in previous studies (Ichev and Pristavova, 2004; Naydenov *et al*., 2008), kyanite inclusions in andalusite are scarce. Garnet is presented as fragmented big grains in the matrix or as more idiomorphic inclusions in andalusite and biotite. Staurolite forms small prismatic grains orientated along the foliation planes. Andalusite is syn-kinematic with biotite, garnet and opaque inclusions. Chlorite replaced garnet and biotite, while muscovite rimmed andalusite or formed elongated bands within the matrix. The accessory minerals are large monazite and zircon grains, rutile and abundant opaque minerals.

On Perple_x phase diagram, the paragenesis of garnet-kyanite-staurolite-plagioclase-biotite-quartz-rutile-H_2O is stable only in a narrow range at 630–660 °C, from 0.9 to 0.7 GPa, in the upper part of the staurolite stability field. We assume a peak assemblage of garnet-kyanite-biotite-white mica-feldspar-quartz-rutile-H_2O, stable at higher P-T range (T 620–685 °C, P 1.25 to 0.7 GPa). These conditions correspond to the maximum presence of kyanite (5.7 vol %), garnet (X_{Mg}0.24) and plagioclase (An_{28}) composition, and are very close to the wet melting reaction (T ~700 °C). Prismatic staurolite is stable during the retrogression or during later metamorphic event at lower pressure and temperature. Andalusite is stable at a moderate temperature (500–600 °C) and low pressure (under 0.4 GPa), together with biotite (X_{Mg}0.52), plagioclase (An_{21-25}), chlorite (X_{Mg}0.55), and muscovite. Post-kinematic crystallization of chlorite (max 15.6 vol %) and white mica should be assigned to greenschist facies conditions (below 480 °C).

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Magnetic fabric of serpentinized ultramafic rocks and its bearing on deciphering their tectonic history (examples from West Carpathians and Bohemian Massif)

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In the high-grade Moldanubian Zone of the European Variscides of the Bohemian Massif, numerous bodies of ultramafic rocks (often partially serpentinized) occur embedded in granulite. In granulite, the magnetic fabric conforms to the mesoscopic fabric, *i.e.* the magnetic foliation is parallel to the metamorphic foliation and the magnetic lineation is near the mineral alignment lineation. In ultramafite, the magnetic fabric elements often show different orientations than in granulite even though both rock types underwent at least a partially common structural history. The componental movements forming the granulite fabric, mostly during an amphibolite facies retrograde metamorphism, were evidently not intensive enough to strongly overprint the magnetic fabric of ultramafite and the magnetic fabric of such rocks probably represents the mantle-originated fabric.

In the Central Western Carpathians, the ultramafic rocks occur as tabular or lens-like bodies emplaced into low and medium grade metamorphic rocks, Triassic and even Palaeogene sedimentary rocks. They are frequently serpentinized, so strongly to be referred to as serpentinites. The AMS in these rocks is carried by a new magnetite, originated during the serpentinization. In the serpentinized ultramafites occurring within crystalline basement, the magnetic fabric resembles that in the host metamorphic rocks, indicating a crustal deformation origin. In serpentinites, occurring within the Carboniferous metasediments, the magnetic fabric also often conforms to the mesoscopic fabric, which indicates at least partial upper crust deformation origin.

It is known from the deformation experiments that the increasing serpentinization is characterized by decreasing the rock strength. It is likely that the strongly serpentinized ultramafites lost their mechanical strength during serpentinization, which may have taken place during the exhumation, and may have undergone a ductile deformation together with the surrounding crustal rocks.

Clues of ultra-high pressure metamorphism of the Paleozoic Dunhuang Orogenic Belt, northwest China

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Three to four stages of metamorphic mineral assemblages have been found in the garnet clinopyroxenite roof pendant from within an undeformed granitic pluton, Sanweishan area, northeastern Dunhuang Orogenic Belt, northwest China. The prograde assemblage (M1) is the inclusion (hornblende + plagioclase + clinopyroxenite + ilmenite) preserved in the garnet porphyroblast. The metamorphic peak assemblage (M2) consists of garnet and clinopyroxene, plus minor high-Al titanite, magnetite, zircon and apatite. The early retrograde assemblage (M3) is represented by either the symplectite rimming the garnet, consisting of intergrowth of hornblende + plagioclase + minor titanite + rutile + ilmenite + biotite + piedmontite + spinel, or an exsolution lamellea of clinopyroxene, or retrograded clinopyroxene or ilmenite. The final stage of the retrograde assemblage (M4) consists of chlorite and actinolite. Application of the geothermobarometry suggests that: (a) both the Western-Alpine type and the Franciscan type P-T paths were retrieved from the garnet clinopyroxenite roof pendant; (b) metamorphic peak P-T conditions of the roof pendant lie in the coesite or even in the diamond stability field, which are ascribed to the granulite facies and ultra-high pressure P/T facies series; and (c) large gaps of the metamorphic peak pressures were also found among these different samples, which imply that the roof pendant were subducted to different depths and later amalgamated in the granitic magma chamber. Finally, the roof pendant was brought up to a shallower depth by the magma. This paper first reports the signature of ultra-high pressure metamorphism in the Paleozoic Dunhuang Orogenic Belt.

Short-lived granulite facies overprint in rocks from the Malyovitsa lithotectonic unit (Western Rila Mts.), Bulgaria

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The P-T path of the high-grade metamorphic rocks after reaching the pressure peak of metamorphism may be different as the high temperature overprint (granulite facies) during exhumation is one of the possible ways of evolution. Here are presented evidence for such a thermal event in rocks from the Malyovitsa lithotectonic unit (MLU).

The MLU crops out in the western Rila Mts. between the intruded Kalin and Western Rila granitic batholiths. The unit is tectonically covered by the rocks of Ograzden unit. The MLU consists of predominant orthometamorphic rocks (metagabbros, metadiorites, metaultramafites), and subordinate metapelites, marbles, and biotite gneisses (Sarov, 2012). The metagabbros and metadiorites show evidence of a premetamorphic magma mingling and some of the amphibolites are former eclogites. Gorinova *et al*. (2014) determined an early Cambrian (~527 Ma) protolith age for the metaigneous rocks of the unit.

The HP assemblage of the metaeclogites is fully replaced by symplectitic intergrowts of brown-green Hbl+Pl, and only relicts of Mg-rich garnet partly replaced by Hbl are preserved.

The metapelites have very complex metamorphic evolution as evidenced by the presence of three Al_2SiO_5 polymorphs in a non-equilibrium association and retrograde staurolite (Kolcheva, Cherneva, 1999). The granulite facies assemblage is represented by a high-temperature potassium feldspar with exolution lamellae of plagioclase ($An_{29–34}$), inclusions of phlogopite rich biotite, basic plagioclase and potassium feldspar in garnet. The garnet shows typical high-temperature diffusional zoning with retrograde rims. Gorinova *et al*. (2015) presented evidence for a high-tempetature incongruent melting in these rocks.

Large (up to 5 cm) garnet porphyroblasts were formed in the metagabbros and metadiorites during the HT stage. They are Mg-rich and preserved only as relicts. During the next main stage of metamorphism, a replacement by Hbl (Mg-Hbl) + Pl ($An_{35–44}$) aggregates occurred. The estimated P-T conditions of this stage are in the range 650–700 °C and 7–9 kbar. It is referred, that the formation of an equilibrium mineral assemblage hornblende + cummingtonite in these rocks points to P-T conditions, corresponding to the granulite facies – amphibolite facies transition.

The presented evidence shows that the exhumation of rocks from the MLU was accompanied by a short-lived metamorphism under granulite facies conditions and subsequent metamorphism in amphibolite facies. This type of P-T path was also recognized in other lithotectonic units of the Rhodope metamorphic complex. Therefore, it is suggested that this is a common process during the exhumation of high-grade metamorphic rocks in an extensional regime.

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Eclogites from Biala-Reka-Kechros metamorphic dome, E Rhodopes (Bulgaria): petrological features and protolithic age

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A metaophiolite melange suite (serpentinized peridotites, layered and isotropic metagabbros, eclogites, retrogressed garnet amphibolites, graphite-bearing metaquartzites and metapelites) is exposed as an allochtonous sliver of Biala-Reka-Kechros metamorphic dome in the Eastern Rhodopes. Metaeclogites occur as lenticular bodies at the base of the serpentinized ultrabasites and as boudins in metasedimentary matrix and orthogneisses. The rocks are commonly completely retrogressed. Well preserved eclogite paragenesis of Grt + Gln/Barr + Omph + Ru + Pg and Qtz is scarce. Glaucophane is observed only as small inclusions in garnet, while omphacite is widespread, enclosed in both the garnet and the matrix. This fact suggests a transition from blueschist to eclogite facies metamorphism. The retrogression of high-pressure paragenesis by an almost isothermal decompression led to the replacement of glaucophane/barroisite by Ca-amphiboles, plagioclase and epidote, and formation of common epidote amphibolites. Metaeclogites contain a relatively small number of minerals, many of which show extensive solid solutions. Eclogite garnet is almandine-grossular in composition ($Alm_{51–60}Grs_{28–35}Prp_{3–12}Sps_{0–16}$) with increasing pyrope component and decreasing spessartine from core to rim. Amphiboles from the HP association are sodium or sodium-calcium. As inclusions in garnet porphyroblasts, they vary in composition from glaucophane to barroisite. Coarser-grained matrix amphiboles have barroisite composition. The amphibolite facies recrystallization led to changes of the amphibole composition with decreasing Na content and increasing of Al, Ca and Mg. Pyroxenes are mainly Na-augites and rarely fall in the field of omphacites with Acm component from 18–20% to 6–14% for the grains in garnet, or in the matrix, respectively.

P-T conditions of eclogitization with a peak pressure of 12–13 kbar and 540 °C have been calculated, in agreement with published values of 1.2–1.6 GPa and 570–620 °C (Miladinova *et al*., 2018). The time of eclogitization was recently dated at 81.6±3.5 Ma by Lu–Hf chronometry by the same authors.

Zircon U-Pb isotope dating and tracing of amphibolitized eclogites from the metaophiolitic part of the Byala Reka Unit near Chernichevo village in the Eastern Rhodopes give evidence for a possible Devonian age of the protoliths 381.4±2.2 Ma. Hafnium isotope data (epsilon Hf ~10) of these zircons argue for their mantle source. Partial recrystallization of the zircons during the metamorphism is suggested by the trace element distribution, CL imaging and age data. Based on the new isotopic data, we can conclude that the metaophiolites of the Byala Reka metamorphic unit represent a remnant of the Rheic ocean/Paleotethys or of other small oceans that appeared between Gondwana and Laurentia-Baltica before the formation of the Pangea supercontinent. Its present position resulted from the unique evolution of the Rhodope area, including multiple Alpine subduction and collision events as well as a final Late Alpine extension and erosion.

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Monazite behaviour in the Ordovician metagranitoids of the Northern Veporic unit (Western Carpathians)

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Investigated metagranitoid rocks occur in the area of pre-Alpine basement in northern parts of the Veporic unit (Heľpa). The metagranitoids associate with orthogneisses, retrogressed eclogites with subordinate metaultramafites and metagabbros, as blocks and lenses of meter to tens of meters in size. The rocks are variously deformed – from apparently undeformed metagranitoids to orthogneisses, showing a strong Alpine metamorphic rework of the earlier magmatic assemblage: biotite is rimmed by garnet coronas and replaced by fine-grained intergrowths of Grt + Ky or Grt + Ms, Ms + Mrg + Ctd + Grt. Large, probably Variscan porphyroblasts (up to 1 cm) of garnet and kyanite are also found. Typical is a late, probably hydrothermal graphite. Metagranites are commonly Ca poor (CaO < 1 wt.%), strongly peraluminous due to metamorphic overprint.

P-T conditions of metamorphism in metagranite and metadiorite were determined by conventional thermobarometry (average PT, thermodynamic modelling) on presumably Variscan assemblages. All obtained data indicate medium-pressure/high-temperature metamorphism at P = 9–11 kb and T = 700–770 °C. However, the compositions of phengite (Si = 3.3 apfu) suggest that rocks experienced higher pressures, up to 18 kb. This is in accordance with the HP metamorphism recorded by eclogites (P = 25 kb and 700 °C; Janák *et al*., 2007) in the same area, hosted by metagranitoids and orthogneisses.

Monazite: The rocks contain abundant monazite which is found in the matrix (Bt, Kfs, Pl, Qz) as well as in the garnet porphyroblasts. Three chemical/textural types could be distinguished, a low-Th type I (minor, mostly dark centres), two high-Th types, a low-Y type II (brighter margins), a high-Y type III (dominant, irregular embayments to types I, II). From type I to II, Eu anomaly strongly deepens from Eu/Eu* 0.7 to 0.01. Modelling of the REEs showed that this chemical evolution cannot be explained by a fractionation of monazite, which is not able to fractionate Eu down to the observed values. Therefore, an interaction with fluid is suggested: in reducing conditions, due to the abundant graphite in the rock, Eu occurs as Eu^{2+}. The deficiency of mobile Eu^{2+} species may be explained by a preferred sorption (together with LREE) from the coexisting fluid (Bau, 1991), which prefers LREE and Eu^{2+} and would result in the observed decrease of these elements in monazite.

Age was determined by U-Th-Pb microprobe dating in metagranite: monazite (128 points) yields consistently Ordovician age, 472±4 Ma. Although overlapping within error type I seems to be older, 481, types II-II giving ca 470 Ma.

In rarely occurring rock type with higher CaO (4 wt.%) characteristic coronas are observed around monazite, consisting of monazite breakdown products, apatite and REE-epidote. This contrasts with common low-Ca metagranites, where monazites do not break down. It is concluded that the decompression P-T path of the low-Ca metagranites did not encountered the mnz/aln stability boundary (Spear, 2010), whereas the high Ca rocks did. Therefore, the breakdown is probably a result of retrogression rather than of an (Alpine) overprint.

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UHP kyanite eclogites and monazite age data from the Ograzhden Unit in the Rhodope Metamorphic Complex (SW Bulgaria)

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Kyanite eclogites and their host gneisses from the Ograzhden Unit of the Rhodope Metamorphic Complex (RMC) in southwestern Bulgaria have been investigated, providing important information about the peak-pressure conditions and timing of metamorphism. Textural relationships, phase equilibrium modelling and conventional geothermobarometry together with U-Th-Pb dating of monazite were used to constrain the metamorphic evolution.

Investigated rocks come from the two localities: Belitsa (southern Rila Mountains, 1 km NW of Belitsa Village) and Gega (southern Ograzhden Mountains, SE periphery of Gega Village). Both sampled eclogite bodies are hosted by high-grade basement rocks within the Ograzhden lithotectonic Unit. The eclogite from Belitsa shows garnet porphyroblasts with inclusions of omphacite (up to 42 mol % Jd), phengite (up to 3.5 Si pfu), kyanite, polycrystalline quartz, pargasitic amphibole, zoisite and rutile. Garnet is zoned with increasing Mg (X_{Mg} = 0.31–0.37) and decreasing Ca (X_{Ca} = 0.23–0.18) and Mn (X_{Mn} = 0.03 – 0.01) from the core to the rim, reflecting a prograde growth. In contrast, the eclogite from Gega shows rather homogeneous or reverse distribution of the major elements with X_{Mg} = 0.35–0.30, X_{Ca} = 0.24–0.20 and X_{Mn} = 0.01–0.02, reflecting a modification of the original growth zoning by diffusion. Maximum pressure values for Belitsa eclogite are 3.1–3.2 GPa at 650–680 °C and fall within the stability field of coesite. The Gega eclogite recorded a lower pressure condition of 2.8 GPa but higher temperature of 730 °C. During exhumation, the peak pressure assemblage garnet + omphacite + phengite + kyanite was variably overprinted by a lower pressure one, forming symplectitic textures, such as diopside + plagioclase after omphacite and biotite + plagioclase after phengite. The development of sapphirine + spinel + corundum + anorthite assemblage in the kyanite-bearing domains suggests a thermal overprint in the granulite facies stability field, documented also by formation of orthopyroxene in Belitsa eclogite. This thermal event was followed by a cooling under amphibolite facies conditions; a retrograde kelyphite texture involving plagioclase and amphibole was developed around the garnets.

Electron microprobe dating of monazite from a kyanite-garnet gneiss hosting eclogites at Gega yields exclusively Variscan ages (400–300 Ma), suggesting two metamorphic events: (1) 380–370 Ma (HP/UHP), and (2) 350 Ma (LP/HT). Our results add to the already existing evidence for UHP metamorphism from the kyanite eclogite from the Obidim Unit in the Pirin Mts. (Janák *et al*. 2011), which is regarded as a tectonic klippe of the Ograzhden Unit within the Upper Allochthon of the RMC. Our monazite age data suggest that Variscan continental crust with UHP rocks was involved into the Alpine nappe edifice of the Rhodopes.

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Bracketing the timing of clastic metasediments and marbles from Pirin and Sakar Mts, Bulgaria: Implication of U-Pb geochronology of detrital zircon samples and $^{87}Sr/^{86}Sr$ of carbonate rocks

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Determining depositional age and correlation between carbonate-dominated successions from various parts of the Rhodope metamorphic complex are of a huge importance to better understanding the geodynamics of Tethyan realm in the Aegean region. So far, performed attempts to determine the depositional timing of the marbles from Pangaion-Pirin Unit (West Rhodopes) and Sakar Unit (SE Bulgaria) using fossil fauna findings bracket a wide span from Silurian to Triassic. This study provides a combination of U-Pb detrital zircon geochronology of clastic metasediments and $^{87}Sr/^{86}Sr$ of marbles, timing a considerably shorter span between deposition of both successions from Pirin and Sakar Mts.

Pangaion-Pirin Unit is a marble-dominated succession that constitutes the lower Rhodope thrust system of Bulgaria and Greece. Based on a single coral finding, Pangaion-Pirin Unit is considered as Silurian to Carboniferous. In this study thin layers of amphibole-biotite schist and calcschist have been sampled near the villages of Ilindentsi and Petrovo for zircon geochronology as well as the hosting marble for Sr isotopic chemistry. Sakar Unit within the Alpine orogen in SE Europe is composed to a large extent by granites and metagranites of Late Carboniferous – Early Permian age, that are overlain by several formations from base to top of the succession: 1) metaclastic Paleocastro Formation of a presumable Early Triassic age; 2) metaclastic-metacarbonate Ustrem Formation of a Middle Triassic biostratigraphic age; 3) Middle Triassic fossil-bearing marbles to slightly recrystallized limestones of the Srem Formation. This study comprises a sample of Paleocastro clastic metasediment for LA-ICP-MS U-Pb zircon geochronology along with two samples from Ustrem and Srem marbles for ID-TIMS Sr isotopic chemistry.

Within Pangaion-Pirin Unit, the youngest zircon out of 92 grains analyzed from Ilindentsi amphibole-biotite schist yielded an age of 266.4±4.8 Ma defining mid-Permian maximum depositional age. The Early Permian maximum depositional age of Petrovo calcschist is given by a concordia age at 299.5±1.3 Ma, defined by four analyses out of 105 performed. Sr isotopes of two samples of the hosting marble from Ilindentsi and Petrovo, ranging within 0.707539–0.707653, are consistent with mid-Permian depositional age. As for the Sakar Unit, the youngest zircon population obtained out of 102 analyses from the Paleocastro metasandstone is aged 259.1±5.8 Ma, indicative of a Late Permian maximum depositional age. The $^{87}Sr/^{86}Sr$ ratio of Ustrem and Srem marbles vary from 0.707816 to 0.707897, matching the sea water composition at a time span within Early–Middle Triassic.

This study demonstrated, that sedimentary successions of Pangaion-Pirin and Sakar units were deposited from mid-Permian to mid-Triassic as derived from detrital zircon geochronology of clastic metasediments and further confirmed by Sr isotopes of marbles. The presence of Middle-Late Permian marine sedimentation at the base of Rhodope thrust system is confirmed for the first time. Studied metasediment records have resulted from different mid-Permian (Pangaion-Pirin) to mid-Triassic (Sakar) terrestrial and shallow-marine depositional environments at the continental margin of Eurasia.

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Genesis of two tourmaline and epidote generations from pelagic metasediments of the Bôrka Nappe (Meliatic Unit, Western Carpathians, Slovakia)

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Two generations of tourmaline and epidote have been found in metamorphosed pelagic sediments of the Bôrka Nappe in the surroundings of town Dobšiná (locality Dobšiná–Stirn). The first generation of homogeneous tourmaline (Tur1) does not contain any inclusions. The second, younger generation (Tur2) typically comprises numerous inclusions (quartz, albite, epidote 2, Fe-oxides, titanite and also Tur1). Based on microprobe analyses, Tur1 differs from Tur2 by a higher content of Al_2O_3 (33–35 wt.%), and lower contents of FeO (<8 wt.%) and MgO (<6 wt.%). Weight contents of Tur2 amount to 25–27% of Al_2O_3, 10–14.5% of FeO and 6–7.5% of MgO. Compared to Tur2 tourmalines, Tur1 generation is characterized by a higher number of X-site vacancies and higher Mg/(Mg+Fe) ratio. Both tourmaline types belong to the group of alkali tourmalines and their chemical compositions vary in the range of the dravite–schorl continual series. Tur1 shows a homogeneous chemical composition and represents dravite, whilst schorl is prevailing in rims of Tur2.

In the same sample of the metamorphosed pelagic sediments, two generations of epidote were identified as well. Epidotes of the first generation (Ep1) are homogeneous and without inclusions. The second generation (Ep2) always includes Ep1 as well as numerous other inclusions (quartz, albite, titanite, Fe-oxides). Ep1 is often surrounded by a thin (less than 3 um) transitional zone of Ep1-2. Chemical composition of Ep1 differs from Ep2 by a higher content of Al_2O_3 (23–33 wt.%) and lower content of FeO (1–7 wt.%) and MnO (< 0.5 wt.%). Contents of Al_2O_3 vary in the range 21–23 wt.%, FeO 10–15 wt.% and MnO between 0.5 and 1.3 wt.% in Ep2. Compared to Ep1, the transitional zone (Ep1-2) shows higher content of FeO (7–10 wt.%), MnO (4–6 wt.%) and REE (7–11 wt.%).

Content of Altot apfu in Ep1 is higher than in Ep2, while contents of Fe apfu and Mn apfu are lower. Contents of Fe apfu and Mn apfu are highest and Altot apfu lowest in the transitional zone (Ep 1-2). By its composition, Ep1 corresponds to clinozoisite and Ep2 to epidote.

Genesis of two epidote generations is interpreted in a similar way like that of two tourmaline generations. The first generation of Tur1 and Ep1 originated in the blueschist-facies metamorphic conditions (HP/LT), whereas blastesis of the second generation Tur2 and Ep2 was connected with the superimposed greenschist metamorphism (LP/LT), which affected the studied metasediments during exhumation of the Bôrka Nappe.

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Evolutionary model of the Infratatric Early Cretaceous–Eocene accretionary wedge in the Western Carpathians constrained by ^{40}Ar–^{39}Ar, ZFT and AFT ages

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The Infratatricum of the Inner Western Carpathians (IWC) is exposed in front of the Tatric part of the Považský Inovec Mts. in NW Slovakia. The Infratatric Inovec Nappe micaschist basement and the Upper Carboniferous to Lower Cretaceous cover underwent a mid-Cretaceous low-temperature tectono-metamorphic overprint (D1 stage). This event was determined at ca. 114 and 106 Ma from a Lower Cretaceous cherty slate or ca. 101 Ma from a Permian meta-sandstone by ^{40}Ar–^{39}Ar dating of the phengitic white mica aggregates. Permian meta-sandstone yielded a zircon fission track (ZFT) age of ca. 102 Ma. These ages are in contradiction to the general model of the outer part of the IWC, where white micas from the hanging wall thrust faults of the northern Tatric margin in Malé Karpaty and Lúčanská Malá Fatra Mts. yielded ages between ca. 90 and 73 Ma (Putiš *et al.*, 2009). The NW-vergent km-scale recumbent folds and the overthrust structures of the crystalline complexes, including the Upper Palaeozoic and Mesozoic cover, are typical of the D1 stage. Herein, we propose a model in which the Infratatric Inovec Nappe, after partial Tatricum wedging-out, was thrusted from the North-Veporic (*s.l.*) on to the Tatric foreland, inferred the Váhic (~South-Penninic) continental margin following the Manín Nappe with the foreland synorogenic Albian Klape flysch.

Younger ^{40}Ar–^{39}Ar age of ca. 83 Ma from the Inovec Nappe Permian meta-sandstone is consistent with the posterior portion of this nappe thrusting (D2 stage), supplying the foreland wedge-top (Belice) flysch trough by olistoliths of a metamorphosed material derived from this nappe. The Santonian to Maastrichtian flysch trough formation was thus a heralding of the South-Penninic (~Váhic) subduction below the Albian–Cenomanian Infratatric wedge.

The younger tectonic structures of the Infratatricum include weakly anchimetamorphosed Upper Cretaceous sediments, indicating an Eocene accretionary wedge formation (D3 stage) due to the closure of the Magura (~North-Penninic) Ocean. This event is constrained by an ^{40}Ar–^{39}Ar white mica plateau age of 48 ± 2 Ma from the out-of-sequence (Hrádok–Zlatníky) thrust-fault blastomylonite of the Tatricum hanging wall, and an whole-rock K–Ar age of 46 ± 3 Ma from the footwall basalt olistolith in the Late Cretaceous flych. Exhumation of the re-buried Inovec Nappe slices from below the northern Tatric edge and/or the Palaeogene sedimentary cover is documented by the ZFT ages of ca. 57–37 Ma. Final exhumation and cooling in the Miocene is determined by the apatite FT ages of 21 to 13 Ma.

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Microstructural analysis of the Western Tatra Mts. fault-related crystalline rocks: size, shape and self-similarity of the grains

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The aim of the present study is to show possibilities and results of the grain size, shape and self-similarity analyses, performed using an optical microscopy as well as SEM backscattered electrons imaging (SEM-BSE). The image analyses were conducted with a combination of methods applied, including machine learning algorithms.

The material of the study are samples of both cataclasites and mylonites, derived from crystalline rocks from the Polish – Slovak border ridge of the Western Tatra Mts. The characteristic feature of the region is an abundance of sub-horizontal brittle-ductile shear zones, including both cataclasites and mylonites. The zones show various grade of deformation with an overprinting of different kinematic structures.

Two independent analytical procedures were applied. First one, used for a SEM-BSE imagery comprised the following main stages: an image improvement by a noise reduction, defining of training polygons and maximum likelihood classification with an unconventional application of the GIS software, a vectorization, size and shape statistical analyses. The second procedure was used for thin sections high-resolution microphotographs, which were classified with Support Vector Machine algorithm (a self-learning neural network based method). As an input, both plane polarized light and cross polarized light images were used. Then, the classified rasters were vectorized and analyzed with statistical methods. The main advantage of these procedures is a possibility of getting quantitative microstructural datasets, embracing the grain size distribution and grain shape characteristics, as well as derivative data such as fractal dimension, determined on large, statistically important number of measurements.

The methodology applied here seems to be very convenient, especially due to using of very popular software and well-established analytical methods. However, it needs more testing certainly. The results for the studied rocks are compared with those obtained from deformed granitic rocks by Keulen *et al*. (2007) as well as manually obtained by Kania (2014). The data seems to be quite comparable with those presented by Keulen *et al.* (2007) in spite of methodological differences. The grain size distribution was analysed with a focus on the distribution self-similarity. Generally, the fractal dimensions obtained in this study are smaller in the small grains subset than in large grains. Moreover, the small-grains self-similarity is a bit better when taking small grains only, instead the whole sample.

All the obtained data allows to the following conclusions: (1) The analysed samples from the Western Tatra Mts. recorded two components with three mechanisms of grain size – a mylonitic component with a metamorphic growth of grains and grain size reduction due to dynamic recrystallization as well as a cataclastic component with a grain size reduction due to mechanical crushing. The fractal dimension reveals a partially self-similar grain size distribution, especially in the mylonites. (2) The observed grain size distribution is a snapshot during going to the self-similarity of the distribution according to the constraining comminution model of grain size distribution evolution.

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Thermo-tectonic history of an Avalonian terrane revealed by zircon U-Pb LA-ICP-MS geochronolgy: Lainici-Păiuș terrane from the basement of the Lower Danubian Nappes, South Carpathians, Romania

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Ionescu-Bujor (1912) described as “hornfels”, a rock with sillimanite-andalusite-cordierite-garnet-biotite-graphite-plagioclase-quartz composition, foliated and with a mineral lineation (sillimanite). The protolith of this km-sized graphite gneiss layer is a bituminous clay, a distinctive lithology for the Lainici-Păiuş terrane. This HT/LP gneiss (Berza, 1978) hosts two zircon types: transparent, with typical habitus, and pink with isometric, octogonal habitus, usually associated with graphite flakes. Zircons from the gneiss were firstly considered together. A correlation of age *vs.* U/Th ratio was revealed by the 58 dated grains: grains older than 611 Ma have a U/Th ratio of 7.12; grains between 611–575 Ma have a U/Th ratio of 11.7; grains between 566–532 Ma have a U/Th ratio of 0.1. Two ages of 508 Ma were disregarded, due to a lead loss. To understand this arrangement, a further separation of the whole zircon population into two groups has been done: totally clear crystals with typical habitus, and pinkish grains with octagonal habitus. A set of 32 U-Pb ages from the first group and one of 88 U-Pb ages from the second group were obtained. The transparent zircons show ages between 593–728 Ma and a U/Th ratio around 6, while the age of the pink zircons is bracketed between 533–588 Ma with a U/Th ratio of 0.1. We consider the group older than 611 Ma to represent detrital stable zircon, the group between 575 and 611 Ma as detrital reset zircon, and the group between 532–566 Ma as new metamorphic zircon, which ages partially overlap with the reset zircon ages.

Zircon ages of old granites intruding the Lainici-Păiuș terrane from the basement of the Alpine Lower Danubian Nappes (*i.e.* Arsasca, Şuşița, Tismana, Novaci, Olteţ granites,see Balintoni and Balica, 2012) range within 575–606 Ma interval. The presented data allow several important inferences to be made. First, the acid magmatism in the Avalonian-type Lainici-Păiuș margin strated at least before 600 Ma and stopped around 575 Ma. Second, metamorphic reactions in the detrital sequence hosting now the acid plutons lasted up to 530 Ma, 40 Ma after the ceasing of the magmatic activity. Third, the HT/LP metamorphosed sediments in the Lainici-Păiuș Terrane are older than ca. 610 Ma, as reported from detrital zircon (Balintoni and Balica, 2012). Fourth, there is no other regional metamorphic events, affecting the Lainici-Păiuș Terrane, even if at 300 Ma new plutons were emplaced in some areas (Duchesne *et al*., 2017).

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Fingerprint of Pre-Alpine deformation fabrics and mineral textures in the basement rocks from the Gemer unit, Western Carpathians

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The early Paleozoic basement rocks of the Gemer unit show metamorphic transformations mostly in greenschist facies conditions, but some fragments of amphibolite facies rocks are present in the marginal parts of this unit as well. Multistage metamorphic and deformation events of Pre-Alpine and Alpine ages in the Gemer unit are generally accepted, but their mineral associations and fabrics are difficult to distinguish from each other. One of the criteria to distinguish deformation fabrics of Pre-Alpine and Alpine events are their assumed opposite vergencies of southward and northward directions of thrust tectonics, respectively. The Alpine deformation fabrics mostly penetrated those formed during the Variscan orogeny and their intensity increased southwards. The pervasive cleavage was one of the main criteria to classify the Alpine structures that are followed by granite intrusions and related mineralized veins in the central part of the basement rocks (Grecula, 1982; Rozloznik, 1979). However, radiometric data indicated Permian age of granite in the Gemer unit (Kovách *et al*., 1986, Poller *et al*., 2002). As the recrystallization and deformation during Alpine event were localized along boundaries of lithotypes with a contrasting rheology, most granite bodies are thrusted along the Alpine structure plans, but the relation of some mineralized fractures following the same direction remained unclear. In this contribution, we present minerals and their textures that were formed during thermal event related to the granite intrusion and document the existence of Pre-Alpine cleavage. This recall the older interpretation of Snopko (1967) and Rozloznik (1965), suggesting that not all cleavage fabrics were formed during Alpine deformation, but some beingrelated to axial fabrics of a folding formed during the Variscan orogeny. Although, both Pre-Alpine and Alpine metamorphism had close PT range, the Alpine metamorphism occurred slightly at higher pressure, where new garnet, phengite, kyanite and stilpnomelane were stabilized in granite and surrounding rocks in the contact aureoles.

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Fluid-rock interaction and formation of a vein system in eclogite from the Biga Peninsula, NW Anatolia

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High pressure/low temperature eclogite-facies rocks are commonly regarded to represent exhumed fragments of subducted slabs. Eclogites, representing the remnants of an oceanic crust, occur as a tectonic slice in the Çetmi mélange, located in the southern part of the Biga Peninsula. The main mineral composition of these rocks is omphacite, garnet, glaucophane, phengite, quartz, epidote, rutile, titanite and zircon.

Eclogites contain abundant veins, characterized by garnet-phengite-quartz mineral association. Vein systems in eclogite-facies rocks are a direct result of dehydration of an oceanic crust and fluid activity in the subduction zones. The garnet-dominated vein is enveloped by a fine-grained omphacite-rich reaction selvage. Other phases in the selvage are epidote, garnet and glaucophane, and are texturally identical to the host rock. Textural evidence shows that this selvage is formed as a consequence of a fluid-rock interaction. Garnet in matrix is characterized by a heterogenous distribution of inclusions (quartz, epidote, glaucophane, rutile), whereas garnet in vein is usually inclusion-free.

Based on quartz-rutile geothermobarometer, the P-T conditions from quartz and rutile minerals in matrix, selvage and vein are identical to one another, giving the peak metamorphic conditions of 624 ± 17 °C and 22.6 ± 1.6 kbar. Petrology and geothermobarometry suggest that vein system resulted from the influx of external fluids into the rock volume. These fluids derived from fluids related to the breakdown of hydrous phases (amphibole, chlorite, epidote) during prograde metamorphism in other parts of the subducting slab. Due to the distinct composition of the source rock, these fluids are not in equilibrium with the rock volume. Therefore, the dissolution-precipitation processes caused the formation of different metasomatic selvages. Vein systems in eclogites were developed prior to peak metamorphic conditions, while the rock was still subducting.

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The initiation of subduction in the Caribbean realm: The La Tinta mélange, eastern Cuba

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The subduction initiation processes have been traditionally documented by the presence of boninite rocks and more recently, by a forearc basalt (FAB) and boninite sequence. Gabbroic rocks occur below the FAB and above the mantle peridotites in an undeformed forearc sequence (Ishizuka *et al*., 2011). FAB lavas and related dikes have chemical composition similar to a mid-ocean ridge basalt (MORB) (Reagan *et al*., 2010; Ishizuka *et al*., 2014; Pearce, 2014), although FAB use to present lower TiO_2 (<1–1.5 wt.%) and a slight depletion in high field strength elements (HFSEs, *e.g*. Nb, Ta), indicating a light, initial subduction component. When these sequences are deformed and incorporated in the crust, they show a deformation and commonly appear as serpentinitic matrix mélanges with blocks of different lithologies. This is the case of the La Tinta mélange, a small, but singular ultramafic mélange sheet, cropping out in eastern Cuba. It is composed of dolerite-derived amphibolite blocks embedded in a serpentinite matrix. The basic blocks have a mid-ocean ridge basalt (MORB)-like composition, showing little if any imprint of subduction zone component, similar to most FAB and MORB worldwide. One of the amphibolite blocks have a hornblende $^{40}Ar/^{39}Ar$ age of 123.2 ± 2.2 Ma, suggesting that the protoliths of the amphibolite blocks correspond to some of the older lithologies of the Caribbeam realm formed during the earlier stage of subduction initiation of the Early Cretaceous Caribbean arc. The La Tinta amphibolites would correspond to fragments of sills and dikes of hypoabyssal rocks formed in the earlier stages of a subduction initiation scenario in the Pacific realm (ca. 136 Ma). The protoliths of the amphibolites formed at the beginning of subduction of the Proto-Caribbean (Atlantic) slab by a partial melting of upwelling fertile asthenosphere, with no interaction with slab-derived fluids/melts. This magmatic episode probably correlates with Early Cretaceous basic rocks described in Hispaniola (Gaspar Hernandez serpentinized peridotite-tectonite). Following the magmatic episode, the dikes and sills cooled and metamorphosed due to hydration at a low pressure (ca. 3.8 kbar) and medium to high temperature (up to 720 °C) amphibolite-facies conditions and reached ca. 500 °C at ca. 123 Ma. At this cooling stage, the hydration of the ultramafic upper mantle resulted in the serpentinite formation, favoured by a faulting during extension of the fore-arc that indicates an early stage of dike and sill fragmentation and serpentinite mélanges formation. The full development of the mélange, however, could have taken place during the tectonic emplacement (obduction) onto the thrust belt of eastern Cuba during the latest Cretaceous.

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New mineralogical-chemical data on mylonitic schists from Rodna Mountains

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Previous studies on shear zones ages by the Ar/Ar method in Rodna Mountains (Culshaw *et al.*, 2012) raise questions about the correlation between ages and phyllosilicate chemistry in shear zones of greenschist facies conditions associated to basement nappe detachment zone from this area. Petrographic mesoscale and microscopic research evidenced a penetrative Alpine (K) mylonitic crenulation foliation (S_3), a relic Variscan S_2 foliation and NV-SE trending extension crenulation lineation (L_3). Electron microprobe analyses on mylonitic schists mineral parageneses from Variscan shear zones (P-T) revealed intensively remobilized elements during Alpine nappe stacking events and evidenced two mineral assemblages. The first one is a relictic one, oriented along S_2, consisting of quartz, white micas of muscovite-phengite series $[K_{0.49–0.58}Na_{0.08–0.12}(Mg_{0.08}Fe^{2+}{}_{0.02}Ti_{0.01})Al_{2.01}(Al_{0.92}Si_{3.08})(O,OH)_{11}]$, cloritoid-1 $[(Fe^{2+}{}_{1.39}Mg_{0.42}Mn_{0.01})Al_{4.04}Si_{2.02}(O,OH)_{12}]$ rosettes and porphyroblasts with asymmetric pressure shadows oriented parallel with S_2. This is superimposed by association dominated by stilpnomelane $[(K_{0.05}Ca_{0.04}(Fe^{2+}{}_{4.44}Mg_{2.07})(Si_{5.70}Al_{6.02})(O,OH)_{27}]$, chloritoid-2 $[(Fe^{2+}{}_{1.29–1.66}Mg_{0.4–0.48})Al_{4.11–4.93}Si_{2.05–2.45}(O,OH)_{12}]$ and quartz along the S_3. In rocks from Variscan shear zone, which were only slightly recrystallized during Alpine event, relic mineral association frequently comprises muscovitic fish-form white micas $[(K_{0.62–0.94}Na_{0.11–0.05})Mg_{0.12–0.15}Fe_{0.11–0.14}Ti_{0.01–0.02}Al_{1.78}(Al_{0.95}Si_{3.05})(O,OH)_{11}]$, more or less mixed with celadonitic component (phengite) $K_{0.73}Na_{0.15}Mg_{0.15}Fe_{0.13}Ti_{0.02}Al_{2.73}Si_{3.04}(O,OH)_{11}$–$K_{0.7}Na_{0.12}Mg_{0.14}Fe_{0.12}Al_{2.6}Si_{3.0}(O,OH)_{11}$, chloritoid-1 $(Fe_{2.27–2.31}Mg_{0.24}Al_{3.34–3.88}Si_{1.64–1.95}(O,OH)_{12})$, magnetite and monazite. Oriented along the S_3 paragonitic white micas $(K_{0.09–0.13}Na_{0.43–0.68}Fe_{0.03–0.05}Al_{3.08}Si_{2,96–2.98}(O,OH)_{11})$, chloritoid-2 $(Fe_{2.12}Mg_{0.24}Al_{3.28}Si_{1.8}(O,OH)_{12})$, rutile needles and pyrophyllite $(K_{0.26}Na_{0.05}Mg_{0–0.06}Fe_{0.01–0.03}Al_{2.06}(Al_{0.94}Si_{3.06})(O,OH)_{11})$ were developed as a result of last dynamic retrograde transformation.

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Alpine nappe structure of the Danubian Window, South Carpathians

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On the tectonic map of the South Carpathians, from Prahova Valley to Timok Valley, presented in 1910 at 11th IGC in Stockholm by Gh. Munteanu-Murgoci, the Getic Nappe, described by him in papers published in 1905 in Paris, surrounds eastwards, northwards and westwards a huge window with an Autochtonous outcropping between several Getic outliers. In 1940, Al. Codarcea extracted from the Autochtonous of Banat and Mehedinţi, called by him Danubian Autochtonous, the Severin Nappe, located just below the Getic Nappe and later this unit was recognized eastwards till the eastern end of the window, and southwards till the Timok Valley. Other tectonic units were later proposed by several authors, but a distinct new concept and set of names were introduced at the 9th CBGA Congress at Bucharest in 1981 by T. Berza, H.G. Kräutner, R. Dimitrescu, and checked in the field by the participants using the Guidebook prepared by Kräutner and others. In the 80-90ies, T. Berza, A. Seghedi, A.Drăgănescu have refined and extended this nomenclature in the Parâng Mts., R. Dimitrescu and T. Berza in the Ţarcu Mts., V. Iancu and A. Seghedi in the Cernei Mts., H.G. Kräutner in the Almăj Mts. and, south of Danube, in the Miroć Mountains. Since then, the division of the Danubian terrane in Upper and Lower Danubian nappes was accepted and used by most Romanian and foreign geologists, even if the limits, contents and names of some nappes are still fluctuating.

The Getic Nappe has a metamorphic basement and Upper Carboniferous–Upper Cretaceous sedimentary cover, whereas the Severin Nappe is composed of Upper Jurassic–Lower Cretaceous turbidites including slabs of pillow basalts and ultramafics, and both nappes overly Mesozoic sedimentary deposits or pre-Alpine metamorphic basement of the Upper or Lower Danubian nappes.

Our tectonic model is based on the interpretation of a main thrust (Gherasi line, after the first geologist to map it), dipping N in the Retezat Mts., curving W and then S in the Petreanu and Godeanu Mts., a plane crosscutting several distinct tectonic units in the upper and lower walls. Along the Gherasi line various types of metamorphic sequences, ascribed to several alpine tectonic units (Arjana, Svinecea-Măru-Urdele, Presacina-Poiana Mărului and Godenele Upper Danubian nappes) overlie, with a mylonitized sole, low-grade metamorphosed sequences: sandstones and chloritoïde bearing slates (Lias); marbles (Upper Jurassic–Lower Cretaceous); shales (Upper Cretaceous), representing the Mesozoic cover of the Lower Danubian Lainici Nappe. A thrust of metamorphic units on similar low-grade metamorphosed Mesozoic sequences, was also found by us south of the dextral Cerna – Jiu fault system, in the northern Vulcan and Parâng Mts. This array of tectonic units was interpreted in 1994 by A. Seghedi and T. Berza as a double duplex structure, with the Getic thrust as roof thrust, the first (pre-Cenozoic) thrust over the Moesian Platform as sole thrust, and the Upper/Lower Danubian thrust separating them.

Evolutionary model of the Infra-Tatric Early Cretaceous–Eocene accretionary wedge in the Western Carpathians constrained by ^{40}Ar–^{39}Ar, ZFT and AFT ages

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The Inner Western Carpathians (IWC) formed as north-prograding orogenic wedge due to closure of the Neo-Tethys (Meliata–Hallstatt) and Atlantic Tethys (Váhic ~ South-Penninic) oceans and a large intracontinental system of the Fatric and Tatric basins from ca. 150 to 50 Ma (Putiš *et al.*, 2009 and references therein). This paper addresses the IWC Orogen front Infra-Tatric Unit as a lower and frontal structural complex of the Tatricum (Putiš, 1992) exhibiting a strong imprint of an Early Cretaceous tectono-thermal event which is otherwise typical for the tectonic units south of the Tatricum. The study area is in Považský Inovec Mountains in W Slovakia. The Infra-Tatric Inovec Nappe basement and Upper Carboniferous to Lower Cretaceous (Humienec) cover succession underwent very low-temperature tectono-thermal overprinting determined at 114 and 106 Ma from a Lower Cretaceous cherty slate or at 101 Ma from a Permian meta-arkose by ^{40}Ar–^{39}Ar plateau ages of the phengitic white mica aggregates (Putiš *et al.*, 2009). This meta-arkose yielded zircon fission-track (ZFT) age of 102 Ma. The Infra-Tatric Inovec Nappe thus formed within an Albian to early Cenomanian accretionary wedge (D1 stage, 115–95 Ma), although at that time a large part of the Tatricum remained in extension being covered by the Albian to Turonian or rarely lower Santonian sediments. While the foreland Klippen Belt-type hemipelagic Turonian/Coniacian to lower Santonian red marls and upwards syn-orogenic upper Santonian to Maastrichtian flysch deposited on frontal attenuated part of the Inovec Nappe in inferred Váhic (~South Penninic) supra-subduction zone (D3 stage, 85–65 Ma). This flysch contains already metamorphosed material, including the Lower Cretaceous slates as olistoliths to clasts, supplied from the exhumed (ca. 12–15 km) and northward thrust Inovec Nappe posterior part (D2 stage, 95–85 Ma). The D3 ^{40}Ar–^{39}Ar plateau age of 83 Ma from a Permian meta-arkose of the Inovec Nappe is consistent with the foreland (Horné Belice) wedge-top basin supply, but also with the Tatricum northward thrust blastomylonites white mica ^{40}Ar–^{39}Ar ages of 85–70 Ma from the Malé Karpaty, Tríbeč and Malá Fatra Mts. (Putiš *et al.*, 2009).

The Inovec Nappe with infolded slightly anchi-metamorphosed Upper Cretaceous sediments suggests formation of a Palaeocene–Eocene accretionary wedge (D4 stage, 65–40 Ma) partly overlapping with the Magura (~North-Penninic) Ocean closure. This event is constrained by ^{40}Ar–^{39}Ar reactivation plateau age of 48±2 Ma from the Tatricum hanging wall blastomylonites and the whole-rock K–Ar age of 46±3 Ma from a Permian basalt olistolith in the footwall Infratatric Horné Belice flysch (Putiš *et al.*, 2009). Exhumation of the Inovec Nappe from below the transpressionally overthrust Tatricum and the Palaeogene sediments is documented by ZFT ages of 57–37 Ma. The obtained results document far-north reaching Early Cretaceous structure of the IWC Orogen although exhibiting the Late Cretaceous and Eocene tectono-thermal imprints determined in the orogen front Infra-Tatricum. Final exhumation and cooling in the Miocene is determined by the apatite FT ages of 21 to 13 Ma (Danišík *et al.*, 2004).

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Geological position and features of amphibolites from Sakar Mountain, Bulgaria

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The subject of this study are the amphibolites from the two main rock metamorphic complexes (Volcanic-Terrigenous Complex (VTC) and Topolovgrad group (TG)) from the Sakar Mountain region, which are part of the Sakar-Strandzha zone. According to tectonic partition of Bulgaria (Ivanov, 2017), this zone is separated as an independent tectonic unit that is part of the Inner Balkans. In regional structural plan Sakar is attached to so-called Thracian metamorphic terrain, which in turn is considered as a building block of the Thracian lithotectonic unit (Sarov, 2012).

Based on terrain relationships, petrographic and geochemical studies, the presence of ortho- and paraamphibolites in these complexes has been demonstrated and criteria for their differentiation have been established. The equilibrium mineral compositions in them are established and the P-T conditions of their metamorphism are determined one- time in the range of low-temperature amphibolite facies.

Orthoamphibolites are revealed as "layered" bodies and lenses only in the rocks of the VTC or as xenoliths in the Sakar pluton. They are melanocratic, often with a massive structure. As a result of the primary heterogeneity of the protolith, there is also an irregular alternation of melanocratic and leucocratic bands. They consist of amphibole, quartz, plagioclase, epidope, biotite, chlorite, hematite and ilmenite. Their texture is nematoblastic, granonematoblastic, porphyroblastic.

Paraamphibolites are mainly found in the lower parts of the section of TG in association with impure marbles and carbonate-rich schists. They are melanocratic, small-grained, thin-banded and strongly foliated with nematoblastic texture. The rocks consist of amphibole, quartz, epidote, plagioclase, tourmaline, chlorite, rutile, magnetite, iron oxides and hydroxides.

The SiO_2 content of the rocks varies from 46.47 to 52.33%, and both rock types are indistinguishable. Distribution of the Rare Earth Element (REE) in orthoamphibolites is typical for basic magmatic rocks – a slightly pronounced slope of curves, showing slight enrichment of LREE and low negative Eu anomaly (Eu*/EuN=0.51–0.99). The distribution of REE in paraamphibolites is much more irregular, with positive Eu anomaly, and in general the REE distribution patterns are much more "flat". Due to their geochemical characteristics, orthoamphibolites can be discriminated as island-arc basalt.

The P-T conditions of the metamorphism are in the range of 510–555 °C (6–8 kbar) for paraamphibolites and 625–635 °C (6.5–8.0 kbar) for orthoamophibolites (geothermobarometer of Plyusnina (1983). Higher temperature values obtained for orthoamphibolites are probably due to their position in the section – they are part of the VTC.

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Session GT6

Minerals – building blocks of rocks and man-made materials: Properties, stability, and alteration processes

Convener:

Andreas Lüttge

Mineralogical and textural parameters affecting the production of refractory chromite sands: the Khajeh-Jamali enrichment plant, Southern Iran

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Chromite foundry sands form the mold in which molten metal is contained until it solidifies in the desired shape. Chromite is used because of its resistance when exposed to heat and is chosen over typical silica sand when a higher casting temperature is required. Chromite sands must be as pure as possible as small amounts of low-T melting gangue minerals can damage the resins that bind sand. Moreover, a very narrow sand grain size range is required. In refractory industry Acid Demand (AD) test, a titration method that keeps into account the amount of acid consumed at three different pH levels, is used as a proxy of the sand-resin reaction potential, while for grain-size the Fineness Index (FI) test is used.

At Cheshmeh Bid chromite Mine, Southern Iran, refractory sands are produced for the internal foundry market. In the plant a high-Cr_2O_3 chromite lumpy is crushed and grinded and the resulting sand is split in two feeds: coarse (0.2–2 mm) and fine (<0.2 mm). Each feed is enriched using a shaking table that produces a concentrate and a tailing. For the present work feeds, concentrates and tailings from the plant were sampled and the concentrate yield of each table was estimated through flow rate measure. AD and FI were determined together with bulk composition (XRF), mineralogy (XRD) and mineral chemistry (SEM). Liberation degree was assessed by means of modal analysis under reflected light microscopy on epoxy resin incorporated sand thin sections and Separation Efficiency (SE) was calculated according to Wills and Napier-Munn (2006).

While only the coarser concentrate falls in the suitable range for FI, neither do match the AD quality parameters, with a worse performance for the coarser one. SE is much higher for the fine sand (93.3%) than for the coarse one (33.2%). Liberation degree analysis shows that this is due to much higher middlings content in the latter.

When compared with South African reference foundry sand, the results of bulk composition show that difference in SiO_2 content cannot explain the wide gap in AD values. XRD and SEM data suggest that different gangue mineralogy can be the main factor affecting the different AD performance. Serpentine is the main gangue mineral of Iranian chromite sands with only rare relict olivine grains, while South African gangue is mainly pyroxene with minor amphibole and rare apatite. Further AD tests on pure pyroxenite and serpentinite show that the second one is more reactive than the first one.

In conclusion neither sands meet quality parameters for European market but coarse one quality could be improved by a better tuning of shaking table and a further grinding to a lower grain size. However serpentine gangue of Iranian sands negatively affects AD values and hence their concentrate has to reach lower SiO_2 contents than South African one to meet market parameters.

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Mineralogical insights into the composition and microstructure of ancient ceramics

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The ancient ceramic artefacts aroused a special interest of mineralogists only in the 80s of the last century, despite that the relation between geosciences and archaeology has a much longer history. It originates from the need to answer the questions such as: Which were the original raw materials and which was their geological source? Which were the technological conditions for producing the ancient pottery? Was the ware locally produced or was imported? The ceramic artefacts may be preserved unaltered over thousands of years of burial and may offer information about the economic, cultural and social context of an ancient society.

By studying ceramics, there is an obvious benefit for mineralogists, not only for the archaeologists. The ceramics is the first artificial material ever produced by man and consists of a complex and highly porous mixture of crystalline and amorphous phases. It offers an excellent field to study high-T low-P anthropogenic metamorphism. The initial mixture of mudstone(s) and various mineral and organic tempering materials transforms upon firing at a temperature generally between 700 °C and 950 °C, into a puzzle of micro-domains. The latter are not in equilibrium but yet “coexist”, due to both the short time of firing and rapid cooling/quenching. The ceramic body is a “frozen” image of the system at the maximum temperature reached. Two lines of evidence support in general the estimation of the firing temperature: the microstructural modification of the matrix and the formation of new phases, the latter regarded as temperature-markers.

A wide range of analytical methods are involved in investigating ancient ceramics, *e.g.* polarized light optical microscopy, X-Ray diffraction, electron microprobe, scanning electron microscopy, Fourier transform infrared spectroscopy, Raman spectroscopy, electron paramagnetic resonance and even micropaleontology. Additionally, vertical scanning interferometry (VSI), cold field emission scanning electron microscopy (CFE-SEM-EDX) and field emission gun electron microprobe (FEG-EMPA) were newly applied.

VSI is a non-destructive technique for analyzing the surface roughness and topography and provides a reliable tool to discriminate among two main surface processing techniques, i.e. smoothing and burnishing. CFE-SEM-EDX investigates to a high-resolution the physical details and the chemistry of ceramics. The sample surface is scanned with a very finely focused electron beam, smaller than 10 nm. The method provides insights into the degree of sintering and vitrification process, the thermal alteration of some components, and the shape and composition of firing phases.

With a resolution under 0.1 µm, FEG-EMPA allows the perfect visualization of the tiny phases composing the matrix and facilitates the selection of the micropoints to be analyzed. As the results are influenced also by the quality of the thin sections, the ion-etching technique (Ar ion-beam) is used for the final stage of polishing. Case studies of ancient pottery found in Romania are presented.

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TitaniQ thermometer and trace element composition of rutile in metaophiolitic rocks from the Kazdağ Massif, Biga Peninsula, NW Turkey

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Ophiolitic metagabbros are exposed on the Kazdağ Massif located in the southern part of the Biga Peninsula. Trace element composition of rutile and quartz was determined for metagabbros from the Kazdağ Massif by LA-ICP-MS. The Zr content of both matrix rutiles and rutile inclusions in garnet range from 176 to 428 µg/g (average 335 µg/g). Rutile grains usually have a homogeneous Zr distribution. The rutile grains from studied samples in the Kazdağ Massif are dominated by subchondritic Nb/Ta (11–23) and Zr/Hf ratios (20–33). Nb/Ta and Zr/Hf show positive correlation, which is probably produced by silicate fractionation. The Nb/Ta and Zr/Hf ratios increase with a decrease in Ta and Hf contents. The core of rutile grains is generally characterized by low Nb/Ta ratios of 17–18 whereas the rims exhibit relatively high Nb/Ta ratios of 19–23. Trace element analyses in rutile suggest that these rutile grains were grown from metamorphic fluids.

Ti-in-quartz can be used as a thermobarometer when used in combination with Zr-in-rutile thermometer. P-T conditions of ophiolitic metagabbros were calculated by Ti content of quartz and Zr content of rutile, which are in equilibrium with each other. Ti contents of quartz are ranging between 28 and 42 µg/g (average 36 µg/g). A P–T estimate can be obtained from the intersection of the Ti-in-quartz isopleths with the Zr-in-rutile isopleths, which yield ~660 °C and 10 kbar. The P-T conditions of meta-ophiolitic rocks suggest that they occur as a different separate higher-pressure tectonic slice in the Kazdağ Massif. Amphibolite-facies metamorphism resulted from northward subduction of the İzmir-Ankara branch of the Neo-Tethyan Ocean under the Sakarya Zone. Metamorphism was followed by internal imbrication of the Kazdağ Massif resulting from southerly directed compression during the collision.

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Mineralogical study of historical mortar from Kikino House monument, Gjirokastër, Albania

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Scientific analyses of historical mortars, plasters, and renders are important tools in studies concerning investigation and restoration of historical monuments. The results of such analyses are not only useful in the academic research, but are also essential in selecting compatible restoration materials, recipes, and techniques. This study deals with the characterization of mortars collected from Kikino monumental building in Gjirokastra, Albania. Located in Southern Albania, Gjirokastra is one of the highlights of the Great Balkan Ride. In 2005, the historic core of Gjirokastra became a World Heritage Site, under the patronage of UNESCO (2005). This Museum City offers insights on a rich past through picturesque stone architecture, and fantastic views. The old city consists of several neighbourhoods with historical buildings, among which the bazaar quarter is particularly renowned.

The first scientific studies on the houses of Gjirokastra, including their two-fold typology and building characteristics, were performed several years later. The Kikino House is an example of a single-tower kulla, and was built in 1825 in the Manalat neighborhood (Riza, 2004). Our mortar samples were selected after a careful observation of the building, in order to be representative. The mineralogical and petrographic compositions of the mortars were determined by means of optical microscopy, scanning electron microscopy (SEM) and microprobe (EMPA). Furthermore, the granulometric analyze was carried out to determine the binder/aggregate ratio and ratios of compositional fractions. The mineralogical characterization points to their geological origin and thus can give valuable information about their provenance (Elsen, 2005).

In order to characterize the texture of the mortars, to define the type and content of individual components of the aggregate and binder, and to determine the aggregate/binder ratios, the initial approach was to examine polished thin sections of the mortars by polarized optical microscopy. Polished thin sections of the mortar samples were studied using Leitz microscopy equipment. Mineralogical analyses of the mortars were performed on both binder-enriched fraction and aggregate. Both fractions were separated by gently crushing the mortar samples in order to avoid destroying the aggregate particles, and then sieving through a mesh size less than 63 μm. The fraction between 0 and 63 μm should mainly be composed of material from the binder in the mortars (Kramara *et al*., 2011). Mortars samples consist of a weakly- to moderately sorted sand aggregate with a prevailing carbonate component and subordinate chert. The carbonate component consists of angular to poorly rounded grains of sparitic and micritic limestones. The additive material consists of marl, wood coal pieces, straw and goat wool. The binder/aggregate ratio is 2.5:1.

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Mineralogical composition and grain size distribution in samples along Karvounoskala stream (NE Chalkidiki, Northern Greece)

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The present study focuses on the mineralogical composition and the grain-size distribution in samples along Karvounoskala stream which is located near Stratoni village and discharges in Ierissos Gulf, in the wider region of one of the mining activities of Greece (Chalkidiki Peninsula). Geologically, the study area belongs to the Kerdylia formation, part of the Serbomacedonian massif. In this area, the Stratoni granodiorite intrudes marbles, biotite- and hornblende-biotite-gneisses and amphibolites which are overlain by alluvial deposits (Vavelidis *et al*., 1983; Wagner *et al*., 1986).

Twenty-one samples were in total collected downstream Karvounoskala stream as follows: 7 rock samples, 10 soils and 4 sediments. Grain-size composition of soils and sediments was determined by sieving. Mineralogical composition was determined by the performance of X-ray diffraction (XRD) analysis in all bulk samples. Elemental analyses were evaluated by scanning electron microscope (SEM). According to Folk *et al*. (1970), 7 samples are classified as muddy sandy gravels, 6 samples as gravelly muddy sands and 1 sample as a gravelly mud. According to the mineralogical composition results, metallic minerals like pyrite, chalcopyrite, galena, pyrrhotite, ilmenite, magnetite, Ti-oxide, goethite-limonite and U and Th minerals were determined in the rock samples, with a content less than 3 wt.%. The determined non-metallic minerals in the rock samples are quartz (32–74 wt.%), plagioclase (5–29 wt.%), K-Feldspar (1–6 wt.%), biotite (5–14 wt.%), clay minerals (1–10 wt.%), calcite (7 wt.%), amphibole (6 wt.%) while Cl-apatite, epidote, allanite, gypsum and barite were found in traces.

Soils and sediments mineralogy appears rather uniform, as expected since both of them derive from the weathering of the rocks in the study area. Metallic minerals determined in soils and sediments include pyrite, ilmenite, magnetite, goethite-limonite, hematite and Fe-Mn oxides in percentages <3 wt.%. Jarosite (3–6 wt.%) and titanite (<3 wt.%) were also recognized in the soils. Sediments additionally contained monazite (<3 wt.%) and slags (<3 wt.%). Concerning the non-metallic minerals, both soils and sediments are comprised of quartz, plagioclase, K-Feldspar, biotite, clay minerals, calcite and amphibole while epidote, allanite, pyroxene and muscovite were found in minor amounts. The mineralogical study of all samples revealed that the metallic mineral contents are mainly sulphides, Fe-Mn oxides and Fe-Ti minerals. The most abundant non-metallic mineral is quartz, with plagioclase and K-Feldspar to follow. Concerning the metallic minerals, pyrite is dominant in almost all samples. Elemental analyses revealed that apart from Fe and S, pyrite contains also Ni, Co and As in low concentrations. All the determined minerals have derived from the weathering of the surrounding geological formations, as well as from the metal occurrences that they host.

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New Insight on a Seasoned Topic: Crystal Dissolution Kinetics Revisited

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From the model prediction of global climate change to the development of new and better medicine, drinking water quality, CO_2 sequestration techniques, the corrosion of pipeline steel, bridge constructions, ship hulls, and last but not least (nuclear) waste management, the dissolution kinetics of minerals and their synthetic analogues are at a center point of our attention. In a bottom-up approach that builds on sophisticated experimental and analytical instrumentation and powerful computer-based modeling techniques such as Density Functional Theoretical (DFT) calculations, Kinetic Monte Carlo (KMC) simulations, and Molecular Dynamics (MD) calculations our capability to up-scale the large amount of data will be critical for our success. Our ability to correctly predict system behavior during extended time periods depends on our ability to bridge scales from nanoscopic investigations to system sizes of macroscopic importance. This is a real challenge, because we must consider not only the length scale but also the time scale. Processes that occur at the femtosecond time scale, *i.e.*, the making and breaking of bonds in crystalline materials, determine the fate of the materials in years to come. That means with respect to the geological field the defects that were built into minerals millions of years ago, will affect their dissolution behavior and reaction kinetics today and in the future.

Here, we present new insight from experimental studies and recent theoretical investigations, *e.g.*, the pulsating dissolution behavior of some minerals and synthetic crystals in aqueous solutions. In addition, we will summarize some of our results of RAMAN coupled vertical scanning interferometry during mineral dissolution and steel corrosion. This one-of-its-kind instrument is capable of measuring spatially resolved the reaction progress during dissolution and growth processes with nanometer to sub-angstrom precision. At the same time, the system is coupled with a RAMAN spectrometer that produces detailed information of the spatially resolved phase distribution at the mineral surface or the mineral-water interface. Next, we will discuss the impact of these results on our understanding of fluid-mineral interactions resulting in the consequence to consider rate spectra instead of simple reaction rate constants. And finally, we will highlight the consequence of this insight for some of the applications mentioned above.

Aragonite-calcite relations from the Erma Reka geothermal water precipitates, South Bulgaria

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A vast and unique for Bulgaria hydrothermal anomaly is situated in the area of Erma Reka, South Bulgaria. Various studies and complex exploration have been performed in the region. The thermal water is accumulated in karst and cavernous marble body, part of the Rhodopean crystalline complex, located at a depth of 450 m below the surface (Petrov and Andreev, 1973). Based on chemical composition the thermal waters are hydrocarbonate, sulfate-sodium, and calcium. The total mineralization ranges from 0.6 to 1.6 g/l with prevailing measure at 1 g/l (Andreev, 1995). The water temperature is from 30 to 90 °C and can be expected that several other factors control the deposition of oversaturated water with respect to corresponding mineral phases.

The carbonate precipitations from geothermal water of the Erma Reka underground mines were observed as incrustations in casing wells, as encrustations on wallrocks and as solidified fragments. The incrustations have grown from the margins towards the channel axis of the casing well and represent concentric rhythmic precipitation of crystalline and porous layers (Atanassova *et al*., 2014).

Under SEM it is revealed that the crystalline layer consists of radial fans of elongated and distorted calcite individuals, while the porous layers are composed of spherical aggregations of acicular fine aragonite crystals. Calcite displays diverse morphology variations from thin platy crystals with skeletal development to complex rhombohedral individuals. Aragonite is arranged mostly in spherulitic or bundle-like aggregates composed by thin (~10 μm) acicular crystals. On places it is observed that pseudo cubic calcite rhombohedra overgrow thin aragonite needles.

The studied peculiar mineral habits of aragonite and calcite and their relations evidenced the two polymorphs often alternate, showing changeable conditions of hydrothermodynamic environment for crystal growth at non-equilibrium conditions. The mineral formation sequence is variable and the two polymorphs, which often alternate showing changeable conditions of hydrothermodynamic environment.

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Andradite-grossular garnets from skarn Pb-Zn deposits of Madan district, Central Rhodopes: mineralogy, geochemistry and potential as geochronometer

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Mineralogical and geochemical characteristics of late hydrothermal garnet from the mineralized skarns of the Zapadno Gradishte deposit, Madan district were studied to evaluate its potential for U-Pb geochronology with *in-situ* LA-ICP-MS. The Madan district, located in the Central Rhodopes in southern Bulgaria, is renowned for its Tertiary base metal vein and carbonate replacement ore bodies (Vassileva *et al*., 2009). The deposits are controlled by six regional NW-trending structures cutting across the gneissic host rocks and being interpreted as the primary fluid conduit for economic Pb-Zn sulphide mineralization. At the intersections of the faults with marble lenses infiltration-driven reactions lead to the formation of distal clinopyroxene skarns that predate the mineralization event. An important part of the resources is concentrated by neutralization of the acid fluids resulting in retrograde skarn alteration, which favors the deposition of galena-sphalerite-pyrite mineralization. The primary Fe-Mn clinopyroxene skarns normally do not contain garnets, although rare finds in some deposits have been occasionally reported (Bonev, 1998).

The studied garnets are associated with Mn-hedenbergite, fibrous amphibole, rhodonite, bustamite, carbonates and sulphides. The well-shaped, yellow to brown, mm-sized, rhomododecahedral crystals are formed by combined mechanism of open space filling in nests with later carbonates occurring among the altered skarns and metasomatic replacement. They overgrow and replace the pyroxene radiating aggregates and their hydrothermal formation is evidenced by sphalerite-galena inclusions in the crystals.

The garnets show pure andradite composition without any Al-incorporation. A significant increase in the Mn-content is typical, reaching ~2 wt.% MnO in the central parts of the crystals and decreasing towards the rims, probably inherited from the skarn pyroxenes. Trace element signatures reveal stable incorporation of Sc (~7), Cr (~30), V (1–2), Y (1–7 ppm), while Ga (5–13), Ge (22–35) and As (40–113 ppm) content show incensement toward the cores. Although sphalerite inclusions are typical in the central parts of the grains, Zn content is below 7 ppm evidencing that Ga and Ge are isomorphically included, rather than sulphide contamination. Significant amounts of W in the central parts of the garnets exceed values of 400 ppm, reducing its content in the intermediate zones to 53–78 ppm and increasing in the rims (130 ppm). Traces, important for age determination – U (<0.31), Th (<0.16) and Pb (<0.25 ppm) remain generally low and the potential for U-Pb geochronology of the ore mineralization with postskarn andradite (as shown by Seman *et al*., 2017) is still controversial.

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Secondary beryl in cordierite/sekaninaite pseudomorphs from granitic pegmatites – an indicator of elevated content of beryllium and Mg/(Mg+Fe) ratio in the precursor

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Cordierite-group minerals (CGM) particularly from granitic rocks typically contain trace to minor concentrations of Be (*e.g.*, Bertoldi *et al*., 2004; Gadas *et al*., 2016). The CGM are usually strongly or completely replaced by mixtures of secondary minerals. The early generation includes various phyllosilicates as dominant phases. The late stage of CGM alteration produced dominant smectite-group minerals. Secondary beryl was observed as a breakdown product of CGM, however, due to its inconspicuous appearance and scarcity in pseudomorphs it has been likely overlooked. We examined textural relations and chemical composition of fresh CGM and secondary beryl using the electron microprobe and LA-ICP-MS equipment.

We examined 5 samples with CGM from various granitic pegmatites from the Bohemian Massif (Drahonín, Věžná I, Zimnik, Szklary) and from Canada (Mt. Begbie) where both the relics of CGM and secondary beryl were identified in secondary assemblage I. Late low-T secondary generation (smectite-group minerals) never contained secondary beryl. Secondary beryl forms isolated anhedral to subhedral grains up to 300 µm or their aggregates, solely observed within the pseudomorphoses intergrowing with minerals of secondary assemblage I. The volume of secondary beryl changes from rare isolated grains to almost 10 vol.% and positively correlates with content of Be in the CGM-precursors. The recognition of secondary beryl in pseudomorphs is becoming a good indicator of elevated contents of Be in primary CGM and, a very useful indicator of elevated degree of fractionation of the host rocks.

The CGM examined are characterized by variable contents of Fe, Mg and Mn comparing individual localities, nevertheless the chemical composition is quite homogenous within the individual localities. The CGM correspond to cordierite with Crd72-77Sek22-27Mn-Crd1-2 (Věžná I), Crd49-50Sek26-30Mn-Crd21-25 (Szklary) or sekaninaite with Crd9-13Sek71-74Mn-Crd16-17 (Drahonín), Crd33-34Sek43-53Mn-Crd14-24 (Mt. Begbie), Crd1-2Sek71-75Mn-Crd23-28 (Zimnik). LA-ICP-MS data yielded highly variable contents of Be in CGM ranging from 0.15 a.p.f.u. (Drahonín) to 0.43 a.p.f.u. (Szklary) with variability ±0.05 apfu within individual localitites. Secondary beryl is more or less enriched by Mg, Fe, Mn. The zonality is influenced by #Mg = Mg/(Fe+Mg) especially when they vary from almost zero in beryl from Zimnik through the values between 0.20–0.24 (Drahonín), 0.39–0.49 (Mt. Begbie), 0.54–0.67 (Szklary) to 0.64–0.84 in beryl from Věžná I. The contents of Mn are low, not exceeding 0.05 a.p.f.u. Based on EMPA data the #Mg ratios in secondary beryl significantly positively corelate with #Mg in CGM-precursor within individual localities according the equation: $\#Mg(CGM)_{avg}=(\#Mg(Brl)_{avg} - 0.05)/0.91$ with correlation coefficient R2 = 0.978. The relation could be very useful for estimation of #Mg in CGM where there no relics of CGM and, at the same time secondary beryl were found in CGM pseudomorphs.

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Mineralogical control of REE and trace element distribution in the skarns from Zvezdel-Pcheloyad ore deposit, Eastern Rhodopes, Bulgaria

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Skarn xenoliths (nodules) were found to occur in mine gallery No 68 from the Zvezdel-Pcheloyad Pb-Zn ore deposit. They are hosted by monzonitic rocks of the second intrusive phase of the Zvezdel pluton without relation with the carbonate-bearing protolith.

According to mineral assemblages two main stages of the skarn-forming processes have been distinguished – magmatic and postmagmatic one. The products of the magmatic stage: melilite (gehlenite:åkermanite ratio 60:40), fassaitic clinopyroxene ($CaAlAlSiO_6$ – 1.00–24.00 mol.%; esseneite ($CaFe_3$+$AlSiO_6$) – 17.39–50.21 mol.%) and wollastonite-2M are overprinted by metasomatic anhydrous mineral assemblages of the postmagmatic stage: Ti-rich andradites (TiO_2 up to 13.10 wt.%), garnets of the grossular-andradite series ($Adr_{96.61–3.10}$), clinopyroxene of the diopside-hedenbergite series ($Di_{91.17–27.12}$), wollastonite-2M and plagioclase. Titanite, apatite and magnetite are present as accessory minerals. Infiltration of late-stage fluids at lower temperature results in formation of epidote, prehnite, chlorites, thaumasite, gypsum, zeolites, quartz, and calcite.

Trace elements of the analysed minerals have been normalized to unaltered monzonitic rock, in order to compare the mobility of these elements during the skarn process. The fassaitic clinopyroxenes are enriched in Ti, Zr, Hf, V, Sc, Co, Ni, and Sn. Slight depletion is observed of Nb, Ta, and Th. The ΣREE content ranges from 77.95 to 92.74 ppm and is significantly higher than that in the clinopyroxenes of the Di-Hd series. The chondrite normalized REE patterns of the fassaitic clinopyroxenes exhibit predominance of LREE over HREE (La_N/Yb_N ratio 4.26–10.43) and negative Eu anomaly, while the Di-Hd clinopyroxenes are relative depleted in LREE (La_N/Yb_N ratio 0.84–2.41).

Compared to grossular-andradite garnets, Ti-rich andradites are characterized by higher contents of V, Zr, Y, Sc, Th, and Hf. Chondrite-normalized REE patterns of garnets display LREE enrichment with the form of an upward-facing parabola with maximum at Ce, Pr, Nd and Sm and a relatively flat HREE distribution, and show negative or positive Eu anomalies. The ΣREE content in the Ti-rich andradites (264.8–929.2 ppm) is clearly higher than that observed in the skarn rocks (62.6–100.3 ppm) and in the grossular-andradite garnets. Comparison between the effective ionic radius of Ca^{2+} and the trivalent REE in eight-fold coordination shows the closest correspondence in radii between Ca, Pr and Nd. This would suggest that garnet–aqueous fluid partitioning should produce LREE-enriched chondrite-normalized patterns in garnets, possibly with a preference for Pr and Nd entering the Ca-site.

All studied titanite crystals show high concentrations of V, Zr, Y, Nb, Ni, Hf, Sr, Sn, Ta, and Th. Chondrite-normalized REE patterns display LREE enrichment with La_N/Yb_N ratio 5.41–6.65 and negative Eu anomaly. Titanite have extremely high contents of ΣREE – 1893–2687.9 ppm.

These observations suggest a relative mobility of Zr, Hf, Ti, V, Sc, Y, and LREE during the skarn processes. Their concentration is controlled by the similarity in ionic radii between these elements and major cation in the octahedral sites of the clinopyroxene crystal structure, in the eightfold-coordinated X site of the garnet and in the sevenfold-coordinated position in titanite structure.

Fluid inclusions in post-magmatic diopsides of Jolotca ore field (Ditrău Alkaline Massif)

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The Ditrău Alkaline Massif (DAM) is a Mesozoic igneous complex in the Eastern Carpatians (Romania). The goal of our research is to specify the REE-bearing vein fillings located at northern part of DAM, to identify the vein filling mineral phases and the reconstruction of the evolution of the postmagmatic sulphide dominant veins using the fluid inclusion assessment. The research rock material comes from the proximity of the Teasc-brook (Jolotca). From these rock samples we isolated two vein types: one that contains REE-minerals and one that contains clinopyroxene.

The clinopyroxene-bearing vein type has significant ammount of chalcopyrite. The chalcopyrite has galena as inclusions. Apart from the chalcopyrite carbonate minerlas and phyllosilicates, mostly phlogopite, are present. A diopsidic clinopyroxene has a nestlike structure with radial – lath-like appearance. The laths may be as long as 5 mm. The pyroxenes enclosed liquid dominant three-phase (L+V+S), and two-phase (L+V) fluid inclusions, which can reach 30 µm in scale. We analysed the inclusions with FI (fluid inclusion) microthermometry and Raman spectroscopy. For most of the inclusions nucleation happens between (Tn) –80 °C and –60 °C. The initial melting points are between (Te) –56 °C and –50 °C. The ice melting happens between (Tmice) –28 °C and –25 °C. The salt hydrate turned out to be hydrohalite according to the Raman spectroscopy, it melts (TmHH) between +12 °C and +18 °C. We use halite homogenization at that had a solid phase at room temperature (Tlab). The homogenization temperatures are (ThH) +140 °C – +180 °C. Pyroxene may contain two-phase inclusions whose nucleations happens as low as –56 °C, and the hydrohalite melts earlier (–24 °C) than the ice (–17 °C). The fluid inclusions homogenization temperatures are between (ThL) 400 °C and 426 °C.

The data provided by the FI microthermometry suggests NaCl–$CaCl_2$–H_2O system. The calculated NaCl-concentration is 19.4–22.5 m/m%, the $CaCl_2$-concentration is 10–12 m/m% in this system. Therefore, we may conclude that clinopyroxene nests genesis was accompanied by high salt levels and temperatures (T>400 °C).

Probing mineral forming processes in the Cu-Fe-S system – insights from laboratory *in-situ* and *ex-situ* hydrothermal experiments

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The Copper-Iron sulfide system constitutes an important class of ore-forming minerals, exhibiting a vivid variation in composition and texture. This compositional and textural evolution in the Cu-Fe sulfide system is often governed by mineral replacement reactions – where one mineral is replaced by another in the presence of fluid at hydrothermal conditions. Recently, coupled dissolution –reprecipitation (Putnis, 2009; Xia *et al*., 2009) (CDR) has emerged as a viable mechanism to interpret these complex mineral replacement reactions.

We have undertaken a comprehensive *in-situ* and *ex-situ* hydrothermal experimental approach to study the mineral forming processes in the Cu-Fe sulfide system – with the replacement of chalcopyrite ($CuFeS_2$) by chalcocite (Cu_2S)/djurleite ($Cu_{1.96}S$) at hydrothermal conditions (200–300 °C, 80–100 bars) in acidic chloride-rich fluid medium as a model reaction. SEM/EDX imaging of the run products reveal a pseudomorphic replacement of chalcopyrite by chalcocite/djurleite with well-developed porosity and secondary reaction textures. In order to grasp a comprehensive understanding of the mineral replacement of chalcopyrite by chalcocite/djurleite, a number of *in-situ* experiments at hydrothermal conditions (0–40 bars, 180–240 °C) were carried out the Australian Synchrotron. The results from the *in-situ* experiments were in agreement with the quenched laboratory experiments; additionally, the *in-situ* experiments provided key insights into the reaction mechanism and the fate of metastable species produced during the course of the reaction.

Mineral replacement reactions are ubiquitous in geological mineral systems and the current reaction under investigation is of great economic importance as an emerging alternative method to upgrade the copper content in mineral Cu concentrates.

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Secondary minerals on buildings materials of different types

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The investigations were carried out in a part of the 13th century Holy Trinity Church of the Dominican monastery in Cracow, Poland. They focused on the southern façade of the Myszkowskis chapel erected in the 1st half of the 17th century. The chapel was probably designed by Santi Gucci of Florence and constructed by his workshop. The façade is made of Tertiary limestone blocks that make a characteristic rusticated wall. Its lower part is covered with cement (Krzywobłocka-Laurów and Siemaszko-Lotkowska, 2006), whereas the exposed foundation is made of irregular fragments of Jurassic limestone, partly replaced by and bound with cement. The wall reveals clear signs of damage ranging from dark gray soiling of the surface, scaling to efflorescences. The last ones occur mainly on the border between the limestone blocks and the cement replacements in the part of the foundation.

Laboratory tests included mineralogical, chemical and petrophysical analyses. Optical microscopy, Scanning electron microscopy (SEM-EDS), micro-Raman spectroscopy and X-ray diffractometry (XRD) were used for analysing deterioration products of the building materials while their petrophysical properties were performed using mercury intrusion porosimetry. The samples were collected during the restoration campaign of 2017.

The secondary minerals detected include mainly gypsum $CaSO_4 \cdot 2H_2O$, thenardite Na_2SO_4, (and/or mirabilite $Na_2SO_4 \cdot 10H_2O$), aphithitalite $(Na,K)_3Na(SO_4)_2$, darapskite $Na_3(SO_4)(NO_3) \cdot H_2O$, nitre KNO_3, nitratine $NaNO_3$ and halite NaCl. The limestone blocks of the rusticated wall reveal mainly the presence of gypsum and traces of nitre and nitratine. The lower blocks of the façade covered with cement contain chiefly gypsum and halite, the Jurrasic limestone and cement of the foundation – gypsum and nitre; whereas the efflorescences – gypsum, thenardite and/or mirabilite, aphithitalite, darapskite and nitre. Darapskite, one of the minerals found, is known from only a few natural occurrences and is a rare compound in the efflorescent salts formed when moisture is transported through building materials (Holtkamp and Heijnen, 1991; De Clercq *et al*., 2013). The dark gray surface cover on the building blocks contains also numerous dust particles and a carbonaceous matter (probably soot; Sadezky *et al*., 2005). The origin and the differences of the salts have been discussed and attributed to the composition of the building materials and their physicochemical properties.

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Session GT7-1

Tethys-related tectonics in southern Eurasia

Conveners:

Yongjiang Liu, Bo Wan, Wenjiao Xiao, Fuyuan Wu and Franz Neubauer

The Hellenides, a complicated multiphase Alpine orogenic belt. New aspects for the geotectonic evolution of the Hellenides: A review

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Here is presented the main geological structure and architecture of the Hellenic orogenic belt, as well as the new aspects for its geotectonic evolution during the Alpine orogeny, based on the recent studies and experience about the deformational history of the Hellenides, but also on more modern views, published from others colleagues, concerning the Alpine geotectonic reconstruction of the belt. The structural evolution started with the continental rifting of the Pangaea Supercontinent during the Permo-Triassic and the opening of the Neotethyan ocean. Bimodal magmatism and A-type granitoid intrusions accompanied the initial stages of the continental rifting. Deformation and metamorphism are recorded in six main deformational stages from the Middle-Jurassic to present day (D1–D6). Compression, nappe stacking and high-pressure metamorphism were replaced progressively through time with an extension, orogenic collapse and medium- to high-temperature metamorphism, partly migmatization, thus leading to an uplift and exhumation of deep crustal levels as tectonic windows or metamorphic core complexes. South- to south-westward migration of the dynamic peer compression *vs.* extension is clearly recognized during the Alpine orogeny in the Hellenides. In any case, the extension and crustal uplift followed the compression and nappe stacking. It is suggested, that all ophiolite belts in the Hellenides originated from a single source and this was the Neotethyan Axios/Vardar ocean basin. The latter was finally closed during the Late Cretaceous-Paleocene subduction under the European continental margin. In this case, the ophiolite nappes should be considered as far-travelled nappes on the Hellenides continental parts associated with a deposition of Mid- to Late Jurassic ophiolite mélanges in basins at the front of the ophiolite thrust sheets. The upper limit of their emplacement is the Kimmeridgian/Tithonian, as it is showed by the deposition of the Upper Jurassic sedimentary series on the top of the obducted ophiolite nappes.

The suture zone between the Pelagonian nappe and External Hellenides (Apulia plate) was coeval with the suturing, which has taken place during the Tertiary along the Nestos thrust between the Rhodopes nappes, in detail, between the lower carbonate Pangaion unit and the Sidironero unit. The lower-most Pangaion Rhodope unit should be the marginal part of the Apulia plate, which was unterthrusted below the Internal Hellenides, *i.e.* the Pelagonian nappe and the Serbo-Macedonian massif. The latter is supposed as the European margin at the eastern part of the Neothethyan Ocean realm. In this scenario is assumed, that the Vardar/Axios ophiolites are also allochthones and the Axios/Vardar suture zone is traced in between the Rhodope nappes. Furthermore, the Internal Hellenides thrust stack should be rooted along the northern boundary of the Rhodope massif with the Strandja/Sredna Gora massifs, being progressively younger to the W-SW up to the External Hellenides thrust sheets.

A retreating subduction zone and roll back of the subducted lithospheric slab under the Pelagonian and the other Internal Hellenides nappes stack related to orogenic collapse of the overthickened crust or mantel delamination, could explain well the Tertiary extensional tectonics in the Internal Hellenides, which has taken place simultaneously with the compression in the External Hellenides and the Hellenic foreland.

The Hindu Kush suture and its relation to Paleotethys and/or South Tian-Shan orogeny

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The Kabul block occurs at the triple junction of three continental masses (Eurasia, India, and other fragments of former Gondwana). Its relation to Eurasia and Gondwana is not always clear. Together with Central Afghan, Lut and Central Iran blocks, it is usually interpreted as the leading edge of Gondwana that was detached during opening of Neotethys and subsequently collided with Eurasia during the Late Cretaceous-Early Paleogene (Tapponnier *et al*., 1981). Based on the Paleozoic evolution of Central Asia (Boulin, 1991; Xiao *et al*., 2013), there were two east-west trending oceans, the Tethys in the south and the Tian-Shan in the north, which separated the North China, Tarim and Karakoram from each other. Relationships of the Central Afghan blocks to the Kazachstan and Tarim blocks and those of Lhasa and Lut-Central Iran blocks to Gondwana during Precambrian evolution is assumed by Golonka *et al*., (2006). Possible relation of the Kabul and Central Afghan blocks with Tarim block is assumed based on their Archean and Paleoproterozoic evolution (Faryad *et al*., 2016). Such configuration is supported by the interpretation of Boulin (1991), who considers the Hindu Kush mountain belt as a multiple suture zone, which separated the Afghan-Tajik block from the Afghan Central blocks. Closure of the Paleozoic Hindu Kush Ocean in this model is assumed by the presence of Devonian blueschist facies rocks in the Western Hindu Kush. Based on the present configuration, the Hindu Kush Ocean could be a continuation of the South Tian-Shan Ocean during Devonian to the Late Carboniferous and it separated the Central Afghan blocks from the Afghan-Tajik block. In this contribution is analyzed petrological and geochronological data from the Precambrian basement of the Kabul block and western Hindu Kush and discussed their relative position in relation to up-to-date paleogeographical reconstruction models in this part of the Alpine-Himalayan orogenic belt.

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The Variscan suture in the Romanian Carpathians

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The Romanian Carpathians contain assemblages of crustal fragments with a pre-Alpine evolution. One of these assemblages is the Crystalline-Mesozoic Zone of the Eastern Carpathians (CMZ), structurally being made up by the Bucovinian Nappes of the Middle Dacides (Săndulescu, 1984). Other pre-Alpine terranes occur in the South Carpathians: the Getic-Supragetic (Middle Dacides) and Danubian (Marginal Dacides) nappes, and in the Apuseni Mountains (Inner Dacides). Traditionally, the pre-Alpine terranes of the Romanian Carpathians have been considered as Variscan terranes. However, the research published lately pointed toward a differentiated approach with regard to the accretion of the pre-Alpine terranes in the Carpathians.

The CMZ contains an Ordovician suture (Munteanu and Tatu, 2003; Balintoni and Balica, 2013), involving a peri-Gondwanan crust made up of the Rebra Group (carbonate platform) and Pietrosu Bistriţei volcano-sedimentary formation, and a continental margin made up of the Bretila Group, which was the upper plate in the collision. The suture is marked by the presence of Tulgheş Group, a back-arc sequence with Ordovician sedimentation, magmatism and metallogeny. Zircon ages indicate an Ordovician imprint throughout the Rebra Group, Pietrosu Bistriţei formation and Bretila Group, but no Variscan ages. Variscan events were suggested by the K-Ar dating as well as the weak metamorphism of the infill of a continental basin located north-eastward (EEC-ward, in present coordinates) of the Ordovician suture. Because of the weak manifestation of the Variscan orogeny in the Eastern Carpathians, Munteanu and Tatu (2003) proposed a Caledonian/Avalonian accretion of the Gondwana-derived terranes in this Carpathian sector.

Krautner and Bindea (2002) considered, that the rocks in the Bucovinian Nappes and in the Getic and Supragetic Nappes of the Southern Carpathians were initially parts of a single Bucovino-Getic microplate. Zircon dating indicate widespread occurrence of Ordovician ages in the Getic-Supragetic realm (Balintoni *et al*., 2010). Nevertheless, in the Southern Carpathians, unlike the Eastern Carpathians, Variscan ages were also revealed by the zircon dating. If the presence of the Ordovician suture in the CMZ shows a polarity of the Bucovino-Getic microplate with respect to the cratonic Europe, then, the pre-Alpine terranes of the Southern Carpathians were located at the opposite margin of the microplate, where the influence of the Variscan orogeny was strong enough to generate geodynamic and magmatic effects. Therefore, we consider that the Variscan suture is located in the Southern Carpathians, not in the Eastern Carpathians.

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The emplacement depth of granitoid intrusions from the Gaoligong strike-slip shear zone: new insights from Al-in-hornblende barometry and U-Pb and ^{39}Ar–^{40}Ar geochronology

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Lateral extrusion of continental blocks during continent-continent collisional orogeny is a well-known process. However, a vertical motion along confining these blocks remains poorly constrained. The Cenozoic Gaoligong strike-slip shear zone (GLSZ) is located in the southeast of the Eastern Himalayan Syntaxis (EHS) in western Yunnan, China, and separates the Baoshan block in the east from the Tengchong block in the west. The GLSZ plays a vital role in our understanding of the collision between the Indian and Eurasian plates. Along the GLSZ are exposed large volumes of granitoids and granitic gneisses, which are composed of varying proportions of quartz, plagioclase, K-feldspar, biotite, hornblende, sphene, magnetite, apatite and zircon. Geothermobarometric calculations using hornblende-plagioclase thermometry and aluminum-in hornblende barometry have been made on the samples from granitoids and amphibolite rocks in the GLSZ. The undeformed granodiorite outside the GLSZ were emplaced at average temperatures and pressures ranging between 643 and 729 °C and 4.0 to 5.8 kbar, respectively. The average emplacement depth estimates for the investigated granitoids is constrained, therefore, at about 14 to 21 km. The strongly deformed granitic gneisses were emplaced and deformed at average temperatures and pressures ranging between 568 and 745 °C and 1.2 and 3.5 kbar, respectively. The average deformation depth estimates for the investigated granitoids are constrained at about 4.4–12.7 km. The U-Pb zircon and ^{39}Ar–^{40}Ar white mica data from the deformed granitic mylnoites revealed, that the Cenozoic strike-slip shearing occurred after 35 Ma, and continued until 15 Ma. These results indicate that crustal rocks of GLSZ have been exhumed at least 16 km during shearing at an approximate exhumation rate of 0.08 mm/year. This rate is in a similar order of a magnitude as in other shear zones related to the same lateral extrusion process in Indochina.

Paleozoic tectonics in the eastern part of Central Asian Orogenic Belt

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The Central Asian Orogenic Belt (CAOB) is the largest accretionary orogen in the world, which is responsible for a considerable Phanerozoic juvenile crustal growth. The NE China and its adjacent areas composed the eastern segment of the CAOB, which is a key area for providing important evidence of the CAOB evolution and understanding the NE Asian tectonics. The eastern segment of the CAOB is composed tectonically of four micro-blocks and four sutures, *i.e.*, Erguna block (EB), Xing'an block (XB), Songliao-Xilinhot block (SXB), Jiamusi block (JB), Xinlin-Xiguitu suture (XXS), Heihe-Hegenshan suture (HHS), Mudanjiang-Yilan suture (MYS) and Solonker-Xar Moron-Changchun-Yanji suture (SXCYS). The EB and XB were amalgamated by a westward subduction, oceanic island accretions and final collision in ca. 500 Ma. The XB and SXB were amalgamated by a subduction-related Early Paleozoic marginal arc, Late Paleozoic marginal arc and final collision in the late Early Carboniferous to early Late Carboniferous. The JB probably had been attached to the SXB in the Early Paleozoic, but broken apart from the SXB in the Triassic and collided back in the Jurassic. The closure of Paleo-Asian Ocean had experienced a long continue/episodic subduction-accretion processes on margins of the NCC to the south and the SXB to the north from the Early to Late Paleozoic. The final closure happened along the SXCYS, from west Solonker, Sonid Youqi, Kedanshan (Keshenketengqi), Xar Moron River through Songliao Basin via Kailu, Tongliao, Horqin Zuoyizhongqi, Changchun, to the east Panshi, Huadian, Dunhua, Yanji, with a scissors style closure in the interval from the Late Permian-Early Triassic in the west to the Late Permian-Middle Triassic in the east. The amalgamated blocks should composed a united micro-continent, named as Jiamusi-Mongolia Block (JMB) after Early Carboniferous, which is bounded by Mongo-Okhotsk suture to the northwest, Solonker-Xar Moron-Changchun suture to the south and the eastern margin of JB to the east.

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Geological control of the eastern Great Wall: mountain-basin relationships in eastern North China Craton

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The eastern Great Wall in China was built by the Chinese emperors on Yinshan-Yanshan mountains (in the study area, on the Qinglong pop-up, see below) to protect the inhabitants of China mainland, living in the plain to the south of this mountain belt from invading nomadic tribes. This plain is obviously the western extension of the marine Cretaceous to recent Bohai Bay basin. However, which geological processes created this mountain-basin couple?

Relationships between mountains and adjacent syntectonic basins are in accordance to one of the following three end member models: (1) extensional (rift) basin flanked by a rift shoulder, (2) compressional basin, a peripheral foreland basin flanked by the overriding thrust sheet, and, a less studied case, (3) uplifted mountains by an inflation of large volumes of magmas crystallizing at depth, creating an uplifted area. Such a tectonic situation could have been created by decratonization, driven by the subduction of the Paleopacific plate and this was the case in the eastern North China Craton during Mesozoic times. Until now, it is entirely unknown how the distribution of magma bodies controls patterns of the surface uplift by an inflation.

The present study is aiming to resolve the relationship of the Qinlong pop-up of the eastern Yanshan to the adjacent basins. The Qinglong pop-up is separated by a conjugate WNW–ESE and ENE-trending fault belts from a Jurassic and Early Cretaceous basin in the south and north. The Qinlong pop-up includes Jurassic (our new ^{207}Pb/^{206}Pb ages of 167.3±1.3 Ma and 185.1±4.2 Ma from such granites) and/or Early Cretaceous granites, whereas mostly Cretaceous volcanic tuffs are found in the adjacent northern and southern basins. From 72 stations in the Qinglong pop-up and adjacent basins, we collected four post-Early Cretaceous deviatoric paleo-stress tensor groups with partly still uncertain relative ages. These include: post-Early Cretaceous ENE–WSW extension (135–100 Ma; Dong *et al.*, 2007), leading to the formation of numerous half-graben type extensional basins such as the Chengde basin (Zhao *et.al.*, 2004), NNW–SSE strike-slip compression, WSW–ENE strike-slip compression and WNW–ESE strike-slip compression, all events closely related to the geodynamics of eastern North China. These events indicate that magma-inflation driven uplifted areas are affected by an Early Cretaceous extension and then by mentioned compressional events, resulting in a thrust inversion of normal faults. This model matches with regional events, such as Xialiaohe basin in the eastern North China Craton. Data show that the extensional conditions dominated during Early Cretaceous, and the subsequent stress condition is dominated by a compression, *e.g.*, inversion at the Early to Late Cretaceous boundary, then during Late Cretaceous. A final, Early Eocene exhumation event is dated by an apatite fission track age of 47±4 Ma, which is consistent in (U-Th)/He ages in basement rocks further to the east.

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Multistage anatexis during the tectonic evolution from oceanic subduction to continental collision: A review of the North Qaidam UHP Belt, NW China

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The North Qaidam ultra-high pressure (UHP) metamorphic belt in the northern Tibetan Plateau is considered as a typical Alpine-type UHP metamorphic belt due to the Early Paleozoic subduction of the Qaidam Block beneath the Qilian Block. The well-preserved Paleozoic metatexite and diatexite migmatites, felsic sheet/dyke and anatectic granite in the North Qaidam UHP metamorphic belt provide us with an excellent opportunity to study the generation, transport and final fate of crustal melt and geodynamic processes associated with the orogenesis. Based on structural relationships, petrology, geochronology, whole-rock geochemistry and Sr-Nd isotope data, the Early Paleozoic anatexis during oceanic subduction to continental collision in the North Qaidam UHP metamorphic belt can be further divided into three stages of development ~470 Ma, 446–428 Ma and 432–420 Ma. The first-stage granitic leucosomes are rich in K, poor in Na, with low Sr/Y and an enrichment of LILEs. They were probably derived from a partial melting of an ancient felsic gneiss in continental arc settings during an oceanic subduction. The second-stage Na-rich leucosomes and tonalite plutons are characterized by high Na, Sr, Sr/Y and La/Yb and low HREEs, with positive εNd(t) values of 0.1~4.3 and zircon εHf(t) values of 8.3–10.2, similar to typical tonalite-trondhjemite-granodiorites (TTGs). These TTG-like magmas were produced through a partial melting of newly emplaced gabbroic rocks with an arc affinity under high-pressure (HP) granulite-facies conditions in a thickened lower crust during a continental collision. The volumetrically significant migrated plutons evolved from TTG-like melt will become segments of a continental crust and contribute to the crustal growth, with partial residual products of HP granulite and/or garnet pyroxenite to the mantle by a delamination. Evidences of the third stage of anatexis were preserved in both migmatitic UHP gneiss and eclogite in the Xietieshan and Luliangshan terranes. The Kfs-rich felsic leucosomes inside UHP gneisses in the third stage are characterized by high alkali contents and a low mafic component with FeOT + MgO + TiO_2 less than 2%. In trace element distribution diagrams, these Kfs-rich leucosomes exhibit parallel patterns to their host gneisses, but lower element contents and slightly positive Eu and Sr anomalies. The Pl-rich leucosomes within the retrograde eclogite have geochemical features as follows: (1) rich in CaO, Na_2O and poor in K_2O, with Na_2O/K_2O ratios greater than 2.0; (2) high La/Yb and Sr/Y, and low Y and HREEs; (3) high Al_2O_3 and low Mg# values; and (4) enriched in LILEs (*e.g.*, Rb, Ba, K, Sr, Pb) and poor in HFSEs. Partial melting of UHP eclogite and felsic gneiss during the initial retrogression stage with a Pl-rich and Kfs-rich leucosome formation was triggered by a dehydration melting involving predominant zoisite and muscovite. The anatectic melts from partial melting of deeply subducted UHP gneiss have accumulated and migrated outside the deeply subducted crustal slice in the form of syn-collisional plutons. The melt evolution from the leucosomes produced at the early exhumation stage to syn-collisional granitoids produced at the late exhumation, might contribute greatly to the exhumation of the North Qaidam UHP metamorphic belt from mantle depths to the lower crustal levels.

Geochronology and geochemistry of the Neoarchean-Paleoproterozoic Yudongzi complex, northwestern margin of the Yangtze Block, China

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The Archean-Paleoproterozoic basement Yudongzi complex is a key to understanding the early Precambrian crustal evolution of the Yangtze Block. It comprises mainly orthogneiss, paragneiss and amphibolite, which protoliths are tonalitic-trondhjemitic-granodiorites (TTG), sedimentary and basic-intermediate volcanic rocks, respectively. The TTG gneiss, amphibole plagiogneiss and granitoid gneiss yield magmatic zircon LA-ICP-MS U–Pb ages of 2815±18 Ma, 2692±26 Ma and 2477±18 Ma, respectively. Metamorphic overgrowths on a zircon from amphibolite have an age of 1848±5 Ma. TTG gneisses show medium Sr/Y and variable high (La/Yb)N ratios with low Y and Yb contents. They are characterized by positive Eu anomaly and a distinct depletion of HREE together with negative Nb, Ta and Ti, implying amphibole, garnet and minor rutile as residual phases. Their positive εHf(t) values of +2.1 to +8.1 with TDM2 of ca. 2.80–3.10 Ga suggest a significant rework of a juvenile crust. Amphibole plagiogneisses display a strong enrichment of LREEs and depletion of Nb, Ta and Ti. Additionally, a relative enrichment of Ba, Rb, Pb and Zr, as well as high Cr and Ni contents and Mg# values, imply a mantle source with the participation of continental crust material. Zircon εHf(t) values vary between –0.9 and +3.9, suggesting a proportionally significant input of a juvenile material and therefore interaction between the mantle and pre-existing continental crust. The granitoid gneisses samples are characterized by high Na_2O and Al_2O_3 contents, moderate-high Sr/Y, (La/Yb)N and Na_2O/K_2O ratios, no obvious Eu and Sr anomalies, and depleted Nb, Ta and Ti values that are similar to those of Archean TTG-suits, indicating their property that belonging to TTG-series rocks. They display apparently low MgO, Mg#, Ni and Cr contents, corresponding to those TTG-suits formed via melting of a thickened lower crust, suggesting that they were derived from a partial melting of ancient crustal materials. Zircon εHf(t) values from the granitoid gneisses sample vary from –10.1 to –6.9 with TDM2 of ca. 3.59–3.40 Ga, which demonstrate their crust-originated source nature as well. Thus, the Yudongzi complex probably has experienced significant rework of a juvenile crust at ca. 2.82 Ga and a subsequent crustal growth at ca. 2.69 Ga, followed by a second stage of a rework of an ancient crust at ca. 2.48 Ga. During the Late Paleoproterozoic, the Yudongzi complex was probably involved in the amalgamation of the Paleoproterozoic supercontinent Columbia, and affected by a post-collisional metamorphic event at ca.1.85 Ga.

Early Paleozoic crustal shortening and transpressional deformation in central South China

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South China was formed through the amalgamation of the Yangtze and Cathaysia blocks during the Neoproterozoic. After the amalgamation, the Phanerozoic evolution of South China was a history of crustal reworking, punctuated by three orogenic events in the early Paleozoic, Triassic, and Jurassic-Cretaceous. Among these, the early Paleozoic orogenic event–the most intense–caused extensive crustal shortening and melting, as expressed by a conspicuous Middle or Late Devonian unconformity, a Silurian hiatus, extensive Ordovician-Silurian ductile deformation, metamorphism and magmatism. Despite many advances, the origin of the early Paleozoic orogenic event is still controversial. Several competing tectonic models, involving northwestward underthrusting or overthrusting of the Cathaysia block, or combined underthrusting of the Yangtze block and an eastern terrane beneath the Cathaysia block, have been proposed. Such a controversy mainly rises from the lack of rigorous structural constraints, which has hampered further understanding of early Paleozoic structural framework of South China. To address the controversy, we conducted structural coupled with thermochronological and geochronological studies in the Jiangnan and Cathaysia areas, central South China. Our results indicate that (1) combined E-trending dextral and NW-directed thrust shearing occurred under greenschist facies conditions in the Jiangnan area; and (2) sinistral oblique shearing along arrays of NNE-oriented, steep-dipping zones occurred under amphibolite facies conditions in the northeast Cathaysia area. Combined dating by zircon U-Pb and mica $^{40}Ar/^{39}Ar$ shows that the above-stated strike-slip and thrust shearing commenced at ~460 Ma, and terminated around 420 Ma. The coexistence of strike-slip and thrust shear structures indicates NNW-SSE transpressional shortening deformation. The synthesis of our data with published magmatic and metamorphic data allows us to delineate an Early Paleozoic orogen that extends through the Jiangnan area into the northeast Cathaysia area, with the southeast Yangtze acting as a foreland belt. In summary, this early Paleozoic orogen is manifested by significant NNW-SSE crustal shortening, possibly associated with subduction/collision between South China and Australia during final assembly of Gondwana.

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Session GT7-3

Orogenic processes in the Alpine-Balkan-Carpathian-Dinaric orogen: The relationship between tectonics and basin formation

Conveners:

Liviu Matenco, Marinko Toljic and Franz Neubauer

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Task Force VI Sedimentary Basins

Massive Cenozoic carbonate breccia in the Karst Dinarides of Croatia

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The Karst Dinarides are a part of the Alpine–Dinarides mountain chain, situated along the NE Adriatic coast, and formed during a mid-Eocene to Oligocene contraction of a thick succession of predominantly carbonates Carboniferous to Eocene rocks.

A very interesting, but yet poorly understood lithostratigraphic unit of the Karst Dinarides is a massive Cenozoic carbonate breccia found in their central part, known as Jelar or Velebit breccia. According to the basic geological maps it covers more than 1000 km^2, forming several larger outcrop areas (the largest one, along SW slopes of Velebit Mt., covers almost 700 km^2) and more than 400 smaller erosional outliers. Data of the thickness on the breccia are limited, indicating a wide range from very thin erosional remnants to more than 500 m thick sequences.

Breccia is massive, mostly clast-supported, monomictic to polymictic, non-bedded, without gradation or any other visible arrangement. It contains exclusively carbonate clasts, ranging in size from less than 1 mm to several centimetres, only sporadically to meter-sized blocks. Clasts are predominantly angular, often tectonically fractured before deposition, and mostly derived from neighbouring rocks, while rare extraclasts originated from overlying, originally younger rocks. Matrix is carbonate, grey or yellowish to reddish, and contains small lithoclasts and recrystallized calcite without fossils or cements indicating a subaqueous deposition.

This type of breccia is usually very tightly connected to cataclastic breccia, formed by an intense fracturing of neighbouring limestones (some areas designated on maps as Cenozoic carbonate breccia are predominantly represented by cataclastic breccia).

Most of the studied contacts between the breccia and neighbouring carbonate rocks exhibit up to several meters wide gradual transition from intact limestones and fractured limestones to cataclastic breccia and finally monomictic to polymictic breccia. In addition, at some outcrops small conglomerate bodies have been found within breccia, as well as karstified breccia and zones fractured by subsequent tectonics.

Breccia could be found in different tectonic settings: the Velebit breccia *s.s.* covers the SW slopes of the Velebit Mt. in the hanging-wall of the SW-dipping Lika thrust fault, while other occurrences could be found along regional reverse faults, hinges of overturned anticlines or in the form of erosional remnants of previously much wider breccia sheets. Significantly, all these positions are characterized by NE-verging thrusts and folds, which are less common in the Dinarides. This fact contradicts to the traditional interpretation of the deposits as talus breccia shed from the front of inferred SW-propagating thrust faults.

The breccia was probably formed by an intense in-situ fracturing, controlled by extension in apical parts of anticlines, resulting in disintegration of carbonate rocks into cm-sized clasts within km-wide zones, followed by a deposition by rockfall mechanisms into a complex system of deep fractures, while some clasts were transported by surficial processes. Breccia deposits were subsequently tectonized, diagenetically altered, intensely karstified and denuded during the long post-emplacement exposure, therefore resulting in a present day very complex appearance.

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Structural architecture and tectonic evolution of the Velebit Mt. in the central part of the External Dinarides in Croatia

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Velebit Mt. is the most prominent geomorphological structure in the central part of the External Dinarides fold-thrust belt, formed by a contraction along the eastern margin of the Adriatic plate during Cenozoic convergence between the Adriatic and European plates. Detailed outcrop-scale analysis of fault-slip data were used in evaluation of the existing tectonic models, reconstruction of the present-day structural architecture and tectonic evolution of the mountain. Our analysis shows the prevalence of dip-slip and top-to-NE motions along major Velebit's faults, verifying that these faults are NE-verging thrusts and not NE-dipping normal faults as previously thought. Consequently, we also challenge earlier tectonic models that interpret the Velebit Mt. as a SW-vergent antiformal stack or thrust duplex formed above the major NE-dipping thrust system. Our data rather validate the concept of a passive roof duplex recently tested by Balling *et al*. (2017) by the construction of forward modelled balanced cross sections.

Based on the orientation and kinematic compatibility criteria of recorded fault-slip data, we have separated six groups of conjugate fault sets used for assessing the paleostress directions. Relative chronology between analysed sets and separated groups is partly defined. Presumably, the oldest two groups contain fault sets with prevailing dip-slip and reverse kinematics: a first one is composed of antithetic NNW-striking sets that indicate the ENE–WSW trending contraction; the second group contains a WNW-dipping set, which indicates WNW-ESE trending contraction. Structures of both groups strike parallel and slightly oblique to the structural grain and mountain front. Thus, it is supposed that they were formed during the major contractional tectonic phase in this part of the External Dinarides.

Most of the recorded fault-slip data comprise structures with a normal sense of shear. These are separated into three groups: the most robust subgroup is composed of NW-striking antithetic fault sets, indicating a NE-SW trending extension; a second group comprises NNE-striking antithetic sets, which show a WNW–ESE extension, while a third group includes W-striking antithetic sets related to a N–S extension. Although separated into three kinematically homogeneous subgroups, these structures possibly resulted from a single state of stress, characterised by a radial extension, that according to the good preservation and frequency of occurrence, may have played an important role in the formation of extremely voluminous carbonate breccia exposed along the SW slope of the mountain.

The remaining group of faults comprises sets of subvertical, conjugate NW-striking dextral and NE-striking sinistral faults, which indicate N–S trending contraction. Outcrop- to map-scale overprinting relationships, suggest these to be the youngest brittle deformation structures in the study area.

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The tectonic setting of the Promina Beds – A flexural foreland basin induced by a contrasting style of along strike deformation in the External Dinarides

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The long-lasting convergence between the European and Adriatic plate led to the formation of the Dinarides fold and thrust belt. The Cretaceous deformation of the Internal Dinarides, composed by ophiolite-baring nappes, is older than the mid Eocene deformation of the External Dinarides. The later consists mainly of shallow marine Mesozoic and Cenozoic carbonate platform rocks. Besides the overall younging trend of the start of the deformation from the internal to the external part, the Dinarides show a very prominent NW-SE "Dinaric" strike of the main folds and faults. However, a large-scale dextral strike-slip fault, the Split-Karlovac-Fault (SKF) striking N-S is interrupted this homogenous deformation pattern within the External Dinarides. Within the most external part, the fault changed its strike to the "Dinaric" NW-SE strike and its kinematics turned to a pure top-SW thrusting. In close proximity to this change of fault kinematics, most of the heterogeneous 2 km thick mid-Eocene to late Oligocene sedimentary sequence is exposed – the Promina Beds. These beds are syn-tectonic and date the latest major deformation event within the External Dinarides and cover older Mesozoic and Cenozoic platform carbonate rocks in a progressive angular unconformity. Former sedimentological studies stated that the Promina Beds show an overall trend from deeper over shallow marine to fluvial depositional conditions, documenting the evolution from an underfilled to an overfilled basin. The overall tectonic mechanism for the subsiding of the Promina Basin is a matter of debate, whether the accommodation space was created by a subsiding piggyback basin or in a flexural foreland basin setting.

To validate one of the both tectonic settings, we have forward- and backward-modeled three balanced cross-sections on both sides of the SKF. Interestingly, the SKF marks a paleo-facies transition from a hiatus in the west to Permian evaporites in the east. The presence *vs.* absence of Permian evaporites led to areas of a contrasting style of deformation. The deformation in the western non-evaporitic segment of the SKF is characterized by a SW-vergent duplex system, which expands to the NW and is associated with a large-scale NE-vergent back thrust. In contrast, within the eastern segment the evaporites served as a main detachment, which is used to tectonically double the entire carbonate platform by a SW-vergent nappe stack.

Our results show, that the complex and contrasting hinterland deformation is related partly to the presence of evaporites, leading to a nappe stack in the eastern segment, which produced a lithosphere flexure and enough subsidence. This favours the flexural foreland basin hypothesis for the origin of the Promina Basin, because most of the present-day outcropping sediments can be solely found in a close proximity to this eastern nappe stack. The Promina Beds solely contain carbonate platform rocks, proving that the catchment did not substantial changed throughout time.

Thermal history and exhumation of the central part of the Karst Dinarides, Croatia

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This study was undertaken to obtain the thermochronological data to unravel the thermal history of the central part of the Karst Dinarides, exposed along the NE Adriatic coast in the Velebit Mt. and neighboring areas. The lower part of the sedimentary section (Upper Carboniferous to Triassic), covered by a succession of Mesozoic carbonates has been studied by an apatite fission track (AFT) and apatite and zircon (U–Th–Sm)/He thermochronology.

The ZHe ages are between 80 and 70 Ma (full range is from 257 to 41 Ma), while the actinide content ranges from 133 to 874 ppm eU. No correlation between the ZHe ages and the eU content can be detected. Reproducibility of replicates is good for the majority of samples. The ZHe ages increase in the SE structural domains.

AFT ages are younger than the corresponding stratigraphic ages and yield a single population of grain ages. Central ages range from 81 to 24 Ma, with the vast majority clustering between 50 and 30 Ma. The mean track length varies from 14.4 to 11.9 µm, with the vast majority around 13 µm. Due to the relatively low uranium content only six samples yielded the track numbers > 50. Considering samples, where the track number is sufficient and the track length > 12.9 µm with narrow distribution (SD < 1.6) we can assume that they experienced after the burial a slow cooling through the apatite partial annealing zone (PAZ ~60–120 °C). AFT ages plotted against their mean track lengths show a classic 3/4 boomerang trend, representing the progressive overprinting of an older component of tracks by a heating in a single dominant palaeothermal event. Older samples (> 60 Ma) have longer mean track lengths; these decrease with a decreasing age (60–55 Ma), increase again in samples of 55–30 Ma. This trend may suggest rapid cooling at 50–30 Ma. The measured Dpars range from 2.5 to 1.5 µm, indicating that samples have a variable annealing kinetics. There is no correlation between the AFT ages and the elevation of the samples in general.

AHe ages corrected for the alpha ejection showed the age range from 53 to 28 Ma, with eU contents that range from 7 to 88 ppm and the majority of ages are clustered around 30 Ma. No correlation between the AHe ages and the eU content can be detected.

All AFT ages are younger than the corresponding ZHe ages and overlap within an uncertainty with the AHe ages, which is in agreement with the closure temperatures of these thermochronometers. Rapid exhumation started in the studied structural domains between 80 and 35 Ma, *i.e.* between the Campanian and the end of Eocene, followed in some domains by a younger exhumation and cooling pulse.

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Cretaceous tectonic evolution of the Sava Zone as seen from the Klepa-massif, Macedonia (FYROM) – a combined geochemical and paleostress study

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The waning stage(s) of the Tethyan ocean(s) in the Balkans are not well understood (Prelević *et al*., 2017). Controversy centres on the origin and life-span of the Cretaceous Sava Zone, which is allegedly a remnant of the last oceanic domain in the Balkan Peninsula, defining the youngest suture between Eurasia- and Adria-derived plates (Gallhofer *et al*., 2015). In order to investigate to what extent Late-Cretaceous volcanism within the Sava Zone is consistent with this model, we combine age and geochemical data, including trace-element and Sr-Nd–Pb isotope data for the basaltic lavas from the Klepa Massif (FYROM), with the new palleostress data on the Paleozoic basement rocks and the preliminary $^{40}Ar/^{39}Ar$ ages on the synkinematic mica from the mylonitic Scaglia Rosa limestone.

Our results show, that the Cretaceous Klepa basalts (81 Ma) are considerably different from the other volcanic sequences in the Jurassic ophiolites of the Balkans. The Klepa basalts mostly have Sr-Nd–Pb isotopic and trace-element signatures that resemble enriched within-plate basalts, substantially different from Jurassic ophiolite basalts with MORB, BAB and IAV affinities. Trace-element modelling of the Klepa rocks indicates 2–20% polybaric melting of a relatively homogeneously metasomatized continental rather than oceanic lithospheric mantle source, suggesting an intracontinental within-plate origin for the Klepa basalts (Prelević *et al*., 2017).

We further apply a paleostress reconstruction, analyzing calcite twins from the basement rocks surrounding the Klepa Massif. We performed measurements of both the calcite c-axes and twin plane orientation on Palaeozoic marble samples located near the Klepa Massif, using an automated fabric analyzer microscope at a 5 µm/pixel resolution. According to our view, the basement around the Klepa Massif evolved in two stages as a response to the stress field and tectonic conditions during the Cretaceous. The earlier stage of deformation obviously postdated the Variscan, early Permian and Middle Triassic ductile deformations, as well as the greenschist facies retrogression in the Early Jurassic, observed within the basement of the Klepa Massif (Antić *et al*., 2016a, b, 2017). We observed the presence of twinned, but not dynamically recrystallized calcite grains within the micaschists and marbles close to the contact with the magmatic sequences, indicating deformation temperatures between 150–250 °C. Quartz and calcite-filled microcracks, crosscutting the previous foliation in micaschists and single quartz grains are only found close to the central parts of the massif. Our interpretation of these microcracks is that they were formed during this earlier stage, representing the Klepa early- to syn-intrusive event. The paleostress/paleostrain results of twelve marble samples indicate an extensional tectonic regime, which we tentatively interpret as extension related with the transtentional tectonics. The later stage of deformation is indicated by NE-SW striking microcracks, inducing a twinning of calcite grains within the extensional fractures of the earlier stage. Related to the previous one, this deformation stage signifies a compressional stress regime, which is superimposed by a strike-slip.

Finally, we study the synkinematic white mica extracted from the sheared reddish clay-rich Scaglia Rossa hemipelagic limestone (Prelević *et al*., 2017), overlaying the magmatic sequence of the Klepa Massif. The deposition age of the Scaglia Rossa limestone is presumably Campanian, by analogy with the North Kozara Mts., occurring also within the Sava Zone (Grubić *et al*., 2009, Ustaszewski *et al*., 2009). The limestone is composed by a fine-grained carbonate matrix and up to 200 µm large carbonate and few quartz clasts. The carbonate clasts are mainly symmetrically flattened, indicating a major component of co-axial pure strain deformation. Few clasts, however, show sigmoidal shapes indicating both, dextral and sinistral sense of shear. The measurements of the 100 µm large, syntectonically grown, white mica grains gave $^{40}Ar/^{39}Ar$ age of 78 ± 3 Ma, which corresponds to the later stage deformation observed in the Scaglia Rossa from the Klepa Massif surrounding shear zones.

Our preliminary interpretations of the above presented data are as follows:

(1) The magmatic sequence of the Klepa Massif resulted from a intracontinental volcanism triggered by an extension and elevated heat flow, which tapped the continental rather than the oceanic mantle lithosphere. Therefore, the Klepa basalts does not represent ophiolite remnants of an alleged Late Cretaceous oceanic domain.

(2) The most viable model for the Sava Zone is that it delimits a diffuse strike-slip tectonic zone. The transtensional tectonic along the central axis of Balkan Peninsula was recognized previously (Marović *et al*., 1998; Marović *et al*., 1999; Marović *et al*., 2000; Marović *et al*., 2001), but its inferred timing based on the lacustrine sedimentation was post-Oligocene. Our new data constrain the onset of the transtensional tectonics in the Balkans much earlier.

(3) Our data establish a clear causality between the origin of the sediments, the deformation of the basements and the trigger of the magmatism within the Klepa Massif, which are all related to the extensional stage within such limited basin along a diffuse transtensional tectonic zone.

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Some features of the Mirdita zone relations with the other zones of the Albanides

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Mirdita zone is one of the most interesting zone of the Abanides, not only for its position, but also for the history of its formation and development. Mirdita zone is situated in the central part of Albanide and is bordered by Alps and Gashi zone in the north, Krasta and Kruja zones in the west and Korabi zone in the east. Contacting to the most of structural-facial zones of Albanides, it is interesting the relationship between these zones and Mirdita zone. The latter is composed mainly by ophiolitic rocks, formed during Middle Triassic – Middle Jurassic interval.

Based on many geological studies, Mirdita zone is divided in two ophiolite belts – western and eastern. This division is based on petrology, structural and metallogeny features. The western ophiolite belt is considered as middle oceanic ridge MORB type, formed during Middle Triassic – Middle Jurassic time. The ophiolites of the eastern belt were formed during the Middle Jurassic period in island arc settings, above the subduction zone.

Being the products of a geotectonic evolution during the Triassic–Jurassic interval, and being placed in a contact with many of the tectonic zones of Albanides, these ophiolites have interesting relationships, mirroring the geotectinic evolution of the Albania territory.

In this article are reflected some facts and figures about some rock species, which are assumed to be formed as a result of the dynamics of the Mirdita Zone in relation with the other areas during the evolution of the its forming and, later, during the tectogenesis phases, which the Albanides have suffered. They are considered as products of the contact of the Mirdita Zone with the other zones. Serpentinites are connected with the following phases:

- Serpentinite of the first phase, during the rifting;
- Serpentinite of the obduction phase (lithosphere flows);
- Serpentinite formed during different orogenesis (tectonic) phases.

Also, the metamorphic formations with ophiolitic composition, such as amphibolites, quartzites, etc., are overviewed in light of the relations of the Mirdira Zone with the other zones.

Effects of a partial reset on zircon (U-Th)/He data: the case of the Drau Range, Eastern Alps and adjacent Southern Alps

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(U-Th)/He dating has become a widely-used tool among the rapidly advancing low-temperature thermochronology methods. Beside apatite, zircon is now a common phase for this application. Radiation damage due to self-irradiation, substantially influences the diffusivity of He in zircon. Thus, a more complex kinetics causes a wide range of closure temperatures from ca. 210 to <50 °C. In a typical zircon suite, the internal damage stored within the crystals will usually vary to a significant degree and range somewhere between fully crystalline (or undamaged) to metamict. Such difference in radiation damage from crystal to crystal in the same rock severely influences the geochronological systematics of that sample and thus needs to be considered carefully. This is particularly the case for samples which spent prolonged residence time in the He partial retention zone and/or were exposed to temperatures sufficiently cool for radiation damage to accumulate.

In this study, we address the question whether ZHe data from very low-grade metamorphic units may be transformed into geologically meaningful age information and as such may enhance thermal history reconstructions. We applied ZHe dating to blocks, adjacent to the eastern part of the Periadriatic fault in the Eastern European Alps and the Southern Alps, which underwent deep diagenetic to very low-grade metamorphic transformations. In that area, folded and faulted Austroalpine units (with the Permomesozoic Drau Range in its center) are juxtaposed to southward tilted Southalpine units across the Periadriatic fault. The Periadriatic fault exposes deformed Oligocene tonalites, which intruded at ~30 Ma at depths of ca. 12–16 km.

We found a large variability in ZHe data: 28 from these samples allowed an averaging the single-grain ages and yielded mean sample ages from 283 to 29 Ma, while 8 samples shown a scatter in excess of analytical uncertainties. These overdispersed data all show negative date-eU correlations. However, the detected age groups fit well to thermal effects known from the geological history of the study area. Samples from the Austroalpine Drauzug block and adjacent basement units yielded several geologically significant age groups, which are: ZHe ages around 260 to 250 Ma are associated with a Permian rift-related thermal pulse, whereas ages of 190 to 180 Ma monitored a subsequent cooling, consistent with published data. An age group with a wider range between ca. 130 to 90 Ma reflect the Cretaceous peak of collisional metamorphism, whereas data ranging from 60 to 50 Ma monitor regional cooling after metamorphism. Finally, samples with ZHe data around 30 Ma are related to the thermal effects of Oligocene intrusions, which obviously affected wider Austroalpine areas as previously thought.

We conclude that ZHe data acquired for a complex, in parts partially reset sample suite, may enhance thermal history reconstruction.

The Gurktal tectonic conundrum of Eastern Alps revisited: thrusting vs. normal faulting

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Orogenic thrust wedges can be superposed by a large-scale extensional deformation as a result of orogenic collapse, when rheologically weak layers are activated as ductile normal faults during an exhumation of higher-grade metamorphic units. A heavily disputed example within the Austroalpine nappe stack is the Gurktal nappe complex, which is underlain by the Bundschuh nappe complex (retrogressed polymetamorphic Bundschuh basement overlain by the monometamorphic Stangalm Mesozoic). Previous estimates of metamorphic conditions indicate that approx. 200 °C of the metamorphic profile is missing between the Bundschuh nappe (approx. 480–500 °C) and the higher part (250–280 °C) of the Gurktal nappe complex, suggesting a metamorphic break in between. To solve this paradox, we studied micro- and meso-scale fabrics of these units supplemented by studies of metamorphic T conditions and Ar-Ar white mica dating. The resulting data is presented here from footwall to hangingwall units.

Structural evidence suggests an ESE-directed ductile low-angle normal faulting passing from ductile, through ductile-brittle to purely brittle conditions under the same external kinematics. Dolomite microfabrics of the metamorphic Stangalm Mesozoic comprise symmetric as well as asymmetric fabrics indicating a mixture of coaxial and non-coaxial deformation regimes, implying partitioning of the shear strain. Calcite-dolomite thermometry gives a bimodal distribution of temperatures with maxima at approx. 360 °C and approx. 450 °C, while a white mica concentrate gives an Ar-Ar plateau age of 96.2±0.4 Ma.

The overlying phyllites and phyllonites of the Phyllonite zone are regionally considered to be part of the Murau nappe of the Gurktal nappe complex. The structure shows fabrics passing from initial ductile to subsequently cataclastic and brittle conditions, illustrating the passage through the ductile-brittle boundary during cooling. Raman spectroscopy indicates a preliminary deformation T of 319–382 °C (all Raman calibrations are after Kouketsu *et al*., 2014). A white mica concentrate gives an Ar-Ar plateau age of 87.1±0.5 Ma (age of ductile shearing), whereas another sample gives a mixed Ar-Ar age of 204.3±0.5 Ma suggesting the polymetamorphic nature of the Phyllonite zone. White micas of the first sample are more phengitic in composition than that one with the older age.

The higher part of the Gurktal nappe complex is comprised of two structural units, the lower Pfannock basement-cover unit and the overlying Stolzalpe nappe, with a nappe contact in between. Graphitic carbon from a semi-ductile shear zone within Upper Carboniferous conglomerate gives a deformation T between 260 and 288 °C, indicating the temperature of thrusting of the Stolzalpe nappe over the Pfannock basement-cover unit, potentially towards WNW according to the preliminary kinematic data, predating the ductile low-angle normal fault at the base of the Pfannock unit.

Consequently, we argue that a nappe stack was formed during a late Early Cretaceous continental collision, subsequently overprinted by an orogenic collapse stage, which also led to exhumation of high-pressure metamorphic units elsewhere within the Austroalpine nappe stack.

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Development and provenance of the Meliatic subduction/accretion mélanges (Western Carpathians, Slovakia) – a tentative model

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The Late Jurassic – Early Cretaceous tectonic evolution of the southern Western Carpathian zones was governed by the subduction/accretion processes related to closing of the Meliata Ocean. The northern Austroalpine passive margin (Gemericum) was overthrust by the Meliata Superunit (Meliaticum), which consists of three distinct, but tectonically welded units: (1) the Bôrka nappe as a largely independent blueschist-facies unit of continental provenance in the lowermost structural position; and two mélange complexes: (2) polygenic, in part ophiolitic mélange of the Jaklovce Unit; (3) purely sedimentary mélange of the Meliata Unit *s.s.* Meliatic units were overridden by the Turnaic continent-derived nappes and jointly imbricated to form a united fold-thrust system. Later on (probably during the Late Cretaceous), the Meliatic–Turnaic thrust stack was superposed by the Silicic cover nappes with a marked structural and metamorphic discordance.

The Jaklovce-type polygenic mélange (2) is partially sedimentary and partially tectonic in origin. The Jurassic shaly-marly-sandy matrix of the former and sheared serpentinitic matrix of the latter contain variously sized blocks of a wide spectrum of rock types. Part of basic magmatites underwent the HP/LT metamorphism, a fraction of which was retrogressed in the greenschist facies, part underwent only LP/LT transformation, and part remained almost intact. Metamorphic pressures of incipient blueschist-facies metamorphism at 600–700 MPa were probably achieved at the sole of the thickened accretionary wedge, or in shallow levels of the subduction channel.

In contrast, the Meliata Unit *s.s.* (3) is represented by the sedimentary mélange, *i.e.* an olistostrome with mass-flow bodies and isolated olistoliths embedded in Jurassic shaly-sandy-radiolarite matrix, deposited below CCD. Clasts are dominated by Triassic limestones of mostly deep-water facies, except of lower Anisian platform carbonates, and less by Ladinian radiolarites. Blocks of basalts and silicified rhyolites are rare. Turbiditic sandstones are rich in intermediate and acid volcaniclastic material and various carbonates. The Meliata-type mélanges were affected only by anchimetamorphic transformations.

These two mélange types correspond to the “end members” of a wide range of their mutual transitions, tectonic mixing or imbrication, complicated also by presence of blueschist slivers usually affiliated with the Bôrka Nappe. Based on the structural and metamorphic relationships as well as on the composition of various mélange types, it is inferred that: (i) the Bôrka Nappe represents the former lower-plate distal margin involved in and exhumed from the subduction channel and then imbricated with (ii) the Jurassic Jaklovce mélange complex derived from the ocean-continent transition and with (iii) Jurassic oceanic hemipelagites and olistostromes, scraped off the subducting Meliatic lithosphere and piled in an accretionary wedge sequentially with (ii) and (i). During the Late Jurassic final closure of the Meliata Ocean, the wedge was overridden by (iv) the Turnaic nappes derived from the upper plate margin. Finally, united units (i) to (iv) overrode the Gemeric units of the Austroalpine passive margin during the earliest Cretaceous.

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Geodynamic background of the origin of Variscan and Paleo-Alpine metamorphic core complexes in the Western Carpathians and their metallogenetic importance

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The Proto-Tethys, Paleo-Tethys, Neo-Tethys and Proto-Atlantic (Vahic) zones, which existence is evidenced by the rock sequences of the Western Carpathians, here is interpret as relatively narrow intra-Pangea mobile zones. Numerous steeply dipping crustal-scale faults of an equatorial trend, have been produced during the multiple disintegration (rifting) of continental crust from Paleozoic till recent, which later facilitated the onset of subduction processes during convergences, leading in final stages to collisional closures of the basins. The crustal-scale discontinuities facilitated the fluids migration and contributed to the origin of stratabound and vein mineralization. The environment of relatively narrow divergent zones (Proto-Tethys, Paleo-Tethys, Neo-Tethys and Proto-Atlantic), input of a convection heat from the mantle, fluids circulation due to the disintegration of weakened zones by steeply dipping faults, development of a specific oceanic-type crust, which has a complex evolution are specific in comparison with those of ideal Circum-Pacific type processes. Specific subduction and exhumation processes have produced dismembered ophiolites, as well as exhumed blocks of continental crust.

The complexity of the intra-Pangea mobile zone is magnified also by the partial overlapping of divergent and convergent processes of subsequent orogenic phases, which can be documented at least by the partially overlapping evolution of the Proto-Tethys and Paleo-Tethys in parallel zones in Paleozoic, but also of Neo-Tethys and parallel later established Proto-Atlantic (Vahic) zone in Cretaceous.

As demonstrated by the research of the last years, the Variscan and Paleo-Alpine collisions thickened the continental crust, and with the contribution of the mantle heat (mantle plume, hot line) originated the metamorphic core complexes. It has occurred twice in the geological history of the Western Carpathians – in Permian (late Variscan metamorphic core complex) and Late Cretaceous (Paleo-Alpine metamorphic core complex). The metallogenetic processes related to these two metamorphic core complexes produced two generations of ore veins – Permian and Late Cretaceous.

Owing to the contribution of above described processes, four principal metallogenetic periods can be distinguished during the geodynamic evolution of the Western Carpathians: (1) Metallogeny of the Early Paleozoic Variscan riftogeneous phase (stratabound mineralization); (2) Permian metallogeny – the product of the evolution after Variscan collision, including the Permian metamorphic core complex and a start of new Paleo-Alpine rifting (vein and stratabound mineralization), (3) Late Cretaceous metallogeny, being a product of evolution after the Paleo-Alpine collision within the Inner Western Carpathians (Late Cretaceous metamorphic core complex – vein mineralization), and (4) Miocene neo-Alpine volcanism-related phase (vein and stratabound mineralization).

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Application of the high-resolution, LiDAR based DEM to identifying tectonic features, case studies from the Polish Outer Carpathians.

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Almost two decades have passed since an airborne LiDAR (light detection and ranging) surveying was deployed in order to acquire high-resolution data used to create digital elevation models (DEMs). The spatial resolution of the models is so high, that they have gained many new applications. In geological sciences this technique has become an essential tool in detection of fine-scale tectonic–geomorphic features. After completion of the national airborne LiDAR mapping program spanning 2010 to 2015, the LiDAR data became available for the most area of Poland. We have applied them in our geological mapping in the Carpathians. During the conference presentation we would like to demonstrate through a range of examples in which the precision and enhanced resolution of LiDAR-based DEM highly improved our understanding of the geological structure of the Carpathian fold and thrust belt.

In several geological mapping projects, which we carried out in various parts of the Polish Outer Carpathians and in the north-eastern Romanian Carpathians, we involved remote sensing analysis as the essential method, supporting a structural interpretation principally based on field data. Before LiDAR data became available, we had used shaded relief images generated from 30-meter resolution DEM, based on data collected from the Shuttle Radar Topography Mission (SRTM) or ASTER mission as well as a subordinately radar and satellite imagery, provided by satellites equipped with SAR (Synthetic Aperture Radar) antennae. These techniques enable a determination of linear morphology features that may be linked to tectonic structures. However, their results require confirmation by further geologic studies in the field and/or detailed comparison with data from other sources (*e.g.*, geophysical).

Using the above mentioned images in geologic-structural studies most often boil down to lineament identification, *i.e.* drawing a network of lines to indicate visually perceived linear features of Earth’s surface. It is assumed, that at least part of the lineaments reflects tectonic phenomena occurring in the bedrock. Nevertheless, relying only on remote sensing analysis, without a verification by other methods, such as ground-based geology and geophysics, can lead to misinterpretation. Moreover, satellite imagery is useful for a structural interpretation at a regional scale, thus their applicability in a detailed geological mapping is limited. Traditional DEMs derived from photogrammetry gives better results, but still many details and small surficial features are obscured due to their rough resolution.

In comparison to the above techniques, the high-resolution LiDAR DEMs (1 m pixel size and vertical accuracy of 0.2 m) give much more legible images, thus they represent a completely new quality in structural interpretations. We provide examples of how a “bald earth” LiDAR DEMs can be used to improve the mapping process by clarifying interpretation of densely forested areas and allowing identification of fine-scale land surface features not originally distinguished in both the above mentioned images as well as in the field. The LiDAR DEMs interpretation of (i) continuity of stratigraphic boundaries, (ii) normal and strike-slip faults, (iii) thrust related faults is more reliable than their interpolation from field data alone.

Eocene high-pressure metamorphism to Miocene retrogression of a metamorphic core complex: Naxos, Cyclades, Greece

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In this study, we report new microfabrics, pressure–temperature estimates and $^{40}Ar/^{39}Ar$ ages from a high-pressure (HP) metamorphism to low-temperature retrogression and deformation of Naxos in Cyclades, in the Aegean Sea. Most metapelitic rocks contain two generations of white mica, high-Si phengites crystallized during HP metamorphism and low-Si white mica, formed during a subsequent retrogressive overprint. $^{40}Ar/^{39}Ar$ dating of five white mica samples yielded ages of approximately 51–40 Ma, with a mean at 45 Ma for the peak pressure conditions and approximately 35–29 Ma for the retrogressive greenschist-facies overprint. We have found a variable retrogressive deformation within the Naxos metamorphic core complex (MCC), which even pervasively affected significant portions of the migmatite-grade metamorphic core as well as the remnant high-pressure areas of the MCC, where retrogression led to a pervasive formation of new fabrics at greenschist facies metamorphic conditions during the brittle-ductile transition. Within a continuum of retrogression, $^{40}Ar/^{39}Ar$ white mica dating allowed us to deduce three retrogressive ages at 16.52±0.39 Ma (within the Naxos MCC), 12.6±0.28 Ma (Moutsounas detachment shear zone on the eastern boundary of the Naxos MCC), and 10.43±0.44 Ma to 8.40±0.76 Ma (last ductile activity along the Naxos-Paros shear zone to the north of the Naxos MCC). A further stage of retrogression at 12–11 Ma occurred along distinct low-angle normal faults within the Middle Miocene Naxos Granite (Cao *et al.*, 2017). The Middle-Late Miocene retrogression events are also reflected by a similarly aged tectonic collapse basin in the hanging wall unit above the detachment. The wide temporal range of retrogression within the Naxos MCC coincides in age with a retrogressive deformation within other MCCs of the Aegean Sea. We interpret the long temporal range of retrogression to reflect outward, southwestward retreat of the subduction and sequential activation of major detachment zones.

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Exhumation velocities and topography of the Eastern Alps derived from a low-temperature thermochronology

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Age distributions derived from a low-temperature thermochronology are commonly used to resolve the late history of evolving mountain belts. We present a technique that builds on the age-elevation technique, but allows implementing variable exhumation paths, isotherm perturbation and no-steady exhumation. Cooling age data are interpreted to reflect travel times between the moments when a rock particle crossed the relevant closure isotherm to present. The distance a sample travelled since closure is equal to the integral of the exhumation rate from the present day to the age of the sample. This small, but significant change in the interpretation of cooling age data allows, together with published erosion rate data, the calculation exhumation rates, crustal thickening rates and surface uplift rates for the Eastern Alps since the Oligocene. We used ca. 750 published zircon and apatite (U-Th)/He and fission track data from the Eastern Alps to construct maps, showing the rates of exhumation, crustal thickening and uplift for different time-slices for the last 35 Ma. From this the relief evolution of the Eastern Alps can be estimated.

In the Eastern Alps, and probably in general, high exhumation rates resulted from an erosion and crustal thinning that goes along with a relief destruction and decrease of a mean surface height. The spatially and temporally heterogeneous distribution of exhumation centres suggest that the Eastern Alps are not in isostatic equilibrium, but dynamically supported. Combined view on time-slice maps suggests that the Austroalpine units experienced a major exhumation with mean rate of ca. 0.5 mm/yr prior to ca. 24 Ma. The domain to the west of the Tauern Window was continuously thickened until ca. 12 Ma and maintained high topography, while the Austroalpine to the east of the Tauern Window was continuously thinned since ca. 24 Ma with a late topography built-up during the last 12 Ma. In the eastern Tauern Window and the Seckau Schladming Block exhumation initiated at ca. 20 Ma and the exhumation centre shifted to the western Tauern Window, where highest rates exceeding 1.5 mm/yr were reached at ca. 12 Ma. The Tauern Window was thickened until ca. 16 Ma and continuously thinned thereafter. The topography evolution, estimated from the back-stripping of uplift rates from the present relief suggests an early built-up of mountainous relief from 25–20 Ma along the southern belt, next to the Pariadriatic Lineament, followed by a northward shift of the drainage divide, when the Tauern Window started to exhume (ca. 20 Ma). Western Austroalpine units (Ötztal) maintained high altitudes, whereas eastern sectors (Gurktal Mountains) subsided through a crustal thinning. The eastern Tauern Window together with the Seckau-Schladming Mountains show a major uplift between 20–16 Ma. Rise of the thickening and uplifting Seckau-Schladming Block controlled the formation of the sinsitral W-E trending shear zones, defining the Ennstal depression and the Mur-Mürz Fault system. From 12 million years onwards, a second phase of exhumation along the southern belt occurred with topography built-up in the Karawanken Mountains and gravel deposits in the Klagenfurt Basin, supplied from the Tauern Window and the Karawanken Mountains.

Backthrusting in the west part of Western Carpathians: Timing and possible causes

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The Western Carpathians are generally considered as north-vergent thrust belt. However, thrust belts, apart of thrust faults with tectonic transport to the foreland (forethrusts), contain also thrusts and reverse faults, where the tectonic transport direction is opposite to the regional transport direction. Backthrusts occur in various tectonic settings and depend on the thrust belt geometry, thus could be generated during various deformation phases within the different zones of the orogen. Generally, south-vergent backthrusting was observed in various regions and tectonic units of the Western Carpathians.

The contribution is based on field observations (including structual and paleostress data) mainly from the western to northwestern portion of the Internal Western Carpathians. The main objects of this study are the Považský Inovec, Malé Karpaty, Strážovské vrchy and Malá Fatra Mts.

Backthrusts are presented along the Cenozoic accretionary prism of Flysch and Pieniny Klippen belts. They occur as well at the contact of the Pieniny Klippen Belt with its backstop (*e.g.* at the contact with the Central Carpathian Paleogene Basin), and affected the Inner Carpathian Meso-Alpine nappes (Tatricum, Fatricum and Hronicum) as well. Zone of backthrusting in the Inner Western Carpathians is presented between the Malé Karpaty Mts. and Malá Fatra Mts. In the Malé Karpaty Mts., backthrusts are documented mainly along the basal décollement of the Fatric nappe. Eastwards, in the Považský Inovec Mts. the backthrusting is more diffused in the whole Tatric-Fatric-Hronic nappe stack, similar as in the Malá Fatra Mts. Moreover, backthrusts in the Malá Fatra Mts. deformed Paleogene sediments, therefore age of this event should be latest Oligocene to early Miocene. Recent study in the Strážovské vrchy Mts. suggests that also this mountain range does not differ from this trend. Backthrusts deformed Fatricum, Hronicum as well as overlying Paleogene sediments. Backthrusting in the region south of the Pieniny Klippen Belt is generally considered as related to the final phases of deformation during the latest Paleogene or early Miocene. This phenomenon was traditionally explained as a result of a wrenching along the contact of the External and Internal Western Carpathians during early Miocene subduction.

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The drainage development of the Tauern window (Eastern Alps): a strike-slip dominated metamorphic core complex overprinted by indentation

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The Tauern window has formed as a metamorphic core complex since the late Oligocene. The major fault systems correlate with the main river systems of the Eastern Alps. The drainage pattern hence documents the complex updoming history of the Tauern window. In this study, we have investigated the morphological expression of the drainage pattern and compiled it with sedimentary depositional ages and geomorphic markers to constrain the fault activities during the updoming phase.

The drainage morphology of the Tauern window area describes an arc-like bending by 30-degrees to each side of the dome center. The maximum deflection is located between the two highest peaks of the Tauern window and leads to the development of a radial drainage system oriented to the dome center. In contrast, the drainage system at the northern boundary is linearly draining to the upper Salzach Valley, as part of the Salzach-Enns-Mariazell-Puchberg-Fault (SEMP), and is highly asymmetric along the course of the fault system. Besides the SEMP, the Katschberg normal fault (KNF) shows also dominant drainage asymmetries along the eastern edge of the Tauern window. In contrast to the SEMP, where the drainage asymmetry is explained by the dome-like shape of the Tauern window, the asymmetry at the KNF is explained by the predominant activity of the fault system. Overall, we are able to distinguish four different stages of fault activity with a rejuvenation trend from north to south. The first step is dominated by a left-lateral overstep along the SEMP and the Defreggen-Antholz-Valles fault during the early Miocene. Contemporaneously, an eastward directed extrusion generated fault related sedimentary basins during the second stage. During the middle Miocene, the fault activity migrated to the south and generated sedimentary basins along the Mur-Mürz fault system, until the activation of the Möll valley fault during the Plicocene, leding to the indentation of a crustal block into the Tauern window. The observed arc-shaped deflection of the drainage pattern is explained by such an indentation of a crustal fragment.

A fifth fault period addresses recent tectonic activities of the Tauern window and is found predominantly at the upper Salzach Valley, where geomorphological features, *e.g.*, a tectonic overstep, partly dextral doglegs and asymmetries in the deposition of alluvial fans are observed.

Recent fault kinematics along the Getic Unit of the East Serbian Carpatho-Balkanides

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The East Serbian Carpatho-Balkanides consist of an east-vergent nappe-stack system that originated during the early Cretaceous thrusting within the Europe-derived Dacia mega-unit. The Getic Unit is one of the nappe piles of the Carpatho-Balkanides, situated in-between the Serbo-Macedonian Unit (in the west) and the Danubian Unit (in the east). The main compressional event within the E Serbia Carpatho-Balkanides was the one which formed first-order thrusts, but the entire area was deformed during the Oligocene – Miocene due to rotation of the Dacia mega-unit around the rigid Moesian indenter. This complex rotation was accommodated by the activation of large strike-slip faults (*i.e.*, the Timok fault). This strike-slip event most obviously was not homogeneous across the entire area, but was characterized by local areas of transtension and transpression, that likely multiply reactivated older tectonic structures.

In this abstract, we present evidences about the youngest and recently active brittle tectonic deformation phase of the E Serbian Carpatho-Balkanides, focusing on the westernmost part of the Getic Unit. We combine new data on fault kinematics and paleostress tensors with data about earthquake focal mechanisms within the research area. Data about fault kinematics were collected on the outcrops on the surface, as well as within two caves. The recent activity was attributed to the faults cutting the speleothems or form fault breccias, incorporating cave sediments.

The results show that the research area is characterized by a strike-slip tectonics, most likely resulting from the far-field stress generated by the collision of the Adriatic microplate, the Moesian indenter and the tectonic units in-between. Such stress field is shown to be highly heterogeneous even in this relatively small research area, so local areas of transtension and transpression have also been very important in controlling the fault kinematics along the Getic Unit.

Extensional neotectonic regime through the W-SW edge of the Konya graben, Central Anatolia, Turkey

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The Konya graben is located at the eastern limit of the west Anatolian extensional province. The west-southwestern part of the Konya graben was developed upon low-grade metamorphic rocks of Paleozoic and Mesozoic ages as well as ophiolite slabs of a possibly Upper Cretaceous age and their Middle Miocene-Lower Pliocene cover rocks. The recent topography in this part of the graben is characterized by alternating elongate grabens and horsts, trending E-W and NW-SE. The evolutionary history of the grabens is episodic as evidenced by two graben infills; older and younger graben infills separated by an angular unconformity. The older infill consists of fluvio-lacustrine sequence intercalated with calc-alkaline lavas and pyroclastic rocks. This infill is folded; thrust faulted and Middle Miocene-Early Pliocene in age. The younger and undeformed basin fill consists mainly of Plio-Quaternary conglomerates, sandstone-mudstone alternations of alluvial fan and recent basin floor deposits. The western and southwestern margins of the Konya graben are marked by the NNE-SSW trending Konya fault zone and NW-SE trending Seçme fault zone, respectively. These fault zones comprise a set of discontinuous range front normal faults. The faults of the zone juxtaposed the Plio-Quaternary infill with either older infill or basement rocks. The Konya fault zone is active and has the capacity to produce small to moderate earthquakes. Three major tectonic phases are differentiated based on a detailed mapping, morphological features and kinematic analysis. Approximately N-S-trending extension began in the Middle Miocene to Lower Pliocene in the region with the formation of E-W, NW-SE-trending grabens. Following NE-SW-directed compression deformed the older basin fill deposits by folding and thrusting, a second period of ENE-WSW-trending extension have taken place in the Late Pliocene and continue to the present.

On the mechanisms driving the coupled evolution of mountains and sedimentary basins in the Carpathians – Dinarides system

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The formation and evolution of mountains is intrinsically linked with the evolution of sedimentary basins. Classical models of the orogenic evolution assume that back- and fore-arc sedimentary basins form in response to a static relationship with the location of the main subduction zone. Such models cannot explain the variety, distribution and evolution of syn- to post- orogenic sedimentary basins in many areas, such as the Mediterranean or the SE Asia. These areas offer the possibility of studying the link between basin formation and orogenic evolution in a dynamic setting, where the type, geometry and sediment infill of basins change with time, and is markedly influenced by inherited rheological asymmetries and by a dynamic change in the infill across multiple basin systems. Mountain systems affected by slab roll-back are associated with significant amounts of a continental subduction, foreland migration of orogenic exhumation and crustal thickening, out-of-sequence thrusting, a transition from thin- to thick- skinned deformation and the formation of asymmetric basins, where their type changes and deformation migrates with time and in space. The type and symmetry of deformation combined with the sub-lithospheric forcing is of critical importance for, and can be recognized in the resulting geometry of the basin infill. In the recent presentation is documented this evolution by observations in the Carpathians-Dinarides system and associated sedimentary basins. These observations are quantitatively analysed by numerical and analogue modelling studies focussed in linking the different spatial scales of processes, acting in the formation and evolution of these mountains and sedimentary basins. It is shown that topography building and sedimentation in the Carpathians and Dinarides Mountains and their Pannonian-Transylvania back-arc system is strongly influenced by large-scale zones of a rapid acceleration of sediment dynamics, driven by a migration of collision towards the orogenic foreland, where couples of uplift and subsidence shifted rapidly during the Miocene to recent times and are controlled by a large scale plates rheology. It is also shown, that the inherited contractional rheology of the Dinarides has a strong impact in the formation of the Miocene intra- and inter-montane basins and their subsequent inversion by an Adriatic indentation that make the connection between the active tectonic areas of the Southern Alps and the one of the Hellenides.

Stratigraphic and tectonic setting of Upper Cretaceous sediments and magmatites in Belgrade area (Central Serbia)

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Cretaceous-Paleogene interplay between ongoing convergence of the Adriatic- and European-derived units as well as the roll-back of the subducting slab during the closure of the Neotethys Ocean controlled deposition in the basins situated on the Adriatic passive margin, trench and the fore-arc basin on the active European margin. Sedimentary infill of the fore-arc basin is associated with syn-depositional bimodal magmatites. Both age and genesis of magmatites are unclear. The aim of this study is the interpretation of a stratigraphic and tectonic position of syn-depositional bimodal magmatites based on biostratigraphic and structural characteristics of formations, situated in the vicinity of the suture zone in the Belgrade area.

Cretaceous sediments of the Adriatic margin show record of an Albian-Cenomanian transgression, and Late Cretaceous subsidence recognized in a gradual deepening of the sedimentary facies. The trench basin infill is made up by Cretaceous deep water turbidites and Paleogene molasse sequence. The fore-arc basin on the active European margin, developed over the obducted ophiolites and their mélange, was primarily filled with Lower Cretaceous calciturbidites, which demonstrate an upward transition into shallow water Urgonian limestones and regressive Albian-Cenomanian clastics. Albian-Cenomanian contraction and exhumation of the fore-arc basin were followed by a Coniacian-Santonian phase of extension, which caused new subsidence and sedimentation of shallow water carbonates associated with syn-depositional basalts, trachydacites and their volcaniclastics (Toljić *et al*., 2018) and intrusions of lamprophyres, which age is reported as 86.80 ± 0.5 Ma (Sokol *et al*., 2018). Biostratigraphic study of sandy marls, associating with volcaniclastics, defined a Santonian age of sediments and magmatites, based on a foraminifera association with *Dicarinella aff. asymetrica*. This was followed by deposition of Campanian-Maastrichtian calciturbidites and Paleogene molasses. Similar succession is characteristic along the entire strike of this zone, interpreted as the Central Vardar zone or the East Vardar ophiolitic unit (Toljić *et al*., 2018 and references therein).

Structural setting of the suture was established during the Cretaceous-Paleogene collision when lithostratigraphic contents of the fore-arc basin were thrusted over the deep water trench turbidites of Sava Zone, along complex west-vergent Bela Reka reverse fault (BRF). Early Late Cretaceous extensional evolution of the fore-arc basin is controlled by a roll-back of the subducted Neotethys oceanic slab, while a post-Maastrichtian basin inversion and exhumation was related to the continental collision. Interestingly, the Late Cretaceous tectonic evolution of the fore-arc basin is stratigraphically and kinematically correlative with the evolution of the continental rift interpreted as back-arc basin (Gallhofer *et al*., 2015), situated further east.

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Strike-slip deformation in an oroclinal bending: preliminary results on the geometry and kinematics of the southern segment of the Cerna fault (southwestern Romania and eastern Serbia)

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The highly curved geometry of the Southern and Serbian Carpathians segments of the Carpatho-Balkanides orogenic system was formed during a Paleogene-Miocene oroclinal bending of an initial Cretaceous nappe-stack. The oroclinal bending was associated with regional structures that accommodated the rotation and translation around the Moesian promontory. One of such structures is the curved, high offset dextral Cerna fault (Berza and Drăgănescu, 1988; Ratschbacher *et al.*, 1993). It outcrops between Petroşani basin in the Southern Carpathians and Timok basin in the Serbian Carpathians. Cerna fault truncates the entire Getic-Ceahlau-Severin-Danubian nappe-system, including its pre-Alpine metamorphic basement and Mesozoic sediments. The geometry (Berza and Drăgănescu, 1988) and kinematics (Ratschbacher *et al.*, 1993) of Cerna fault in the Southern Carpathians were well studied, but structural characteristics of the southern segment remain unknown. Here we present preliminary results on the geometry and kinematics of the Cerna fault between the Orşova and Timok basins.

In the studied area, Cerna fault can be separated in three segments with a different strike: a NE-SW oriented segment along the Danube gorge; N-S along the Poreč valley; and NNW-SSE - along the western flanks of Deli Jovan Mountains. In the Danube gorge, Cerna fault displays multiple, closely spaced, subparallel faults with the main strand outcropping in the Dubova area, where meters thick cataclastic fault gouge and meters scale slickensides on subvertical fault planes demonstrate a dextral shearing. On the Serbian side of the gorge, minor branches of the Cerna fault with less offset could be observed. Along the Poreč valley, the fault is oriented N-S and its effects become less obvious because of a subsequent covering by Quaternary sediments. In this area, part of the Cerna offset is taken by normal fault(s), controlling the Donji Milanovac basin. Based on the distance between Deli Jovan and Tisovita ultramafics, Cerna fault in the studied area accumulates ~35 km dextral offset, which is in accordance with the offset reported in the Southern Carpathians (Berza and Drăgănescu, 1988). However, the topographic expression of the Cerna fault (*i.e.* valleys of Jiu, Cerna, Danube and Poreč rivers) almost completely disappears in the area of Deli Jovan, where the fault changes its orientation to NNW-SSE. We attribute this to the S-ward decrease in offset and its distribution between different branches of the fault in a horsetail-like structure. Furthermore, some of the Cerna fault offset is taken by older normal faults reactivated in a dextral strike-slip regime. Although the age of the Cerna fault is reported to be Oligocene (Berza and Drăgănescu, 1988), we infer a significant Miocene activity along segments in the studied area due to the formation of the Donji Milanovac and Orşova basins as releasing bends in areas, where Cerna fault changes its orientation.

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Post-magmatic (ore) transpressive deformation, controlling the closure of the Late Cretaceous basin – a case study from the Panagyurishte strip, Central Srednogorie Zone, Bulgaria

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The Panagyurishte strip of Central Srednogorie Zone, Bulgaria is a part of the Upper Cretaceous magmatic arc belt Apuseni-Banat-Timok-Srednogorie. At the end of the Cretaceous, the basin evolution is controlled by a transpressive deformation as a result of the oblique southward rejuvenating subduction with retreat and roll-back of the slab of the Neotethys Vardar ocean beneath the European continental margin. Several regional deeply penetrative oblique-slip faults with NW-SE orientation are bounding segments of the volcano-sedimentary local basins. Some of them controled or displaced porphyry copper epithermal deposits and their study is significant to decipher the position of ore systems.

The transpressive tectonics following ore mineralizations is preserved and well outcropped in the vicinities of the village of Petrich (Zlatitsa district), where the Petrich fault is one of the prominent structures. This area is a subject of a voluminous intermediate magmatism during the late Turonian to the boundary of Coniacian, followed by a deposition of carbonate and sandy turbidites till Maastrichtian. The study is focused on the structural analysis and detailed mapping of the Petrich fault in order to estimate the deformation mechanisms and its influence on the Late Cretaceous basin evolution.

The Petrich fault juxtaposed various units from the Late Cretaceous volcano-sedimentary succession and Triassic epicontinental sediments. The fault zone is several hundreds of metres wide. A characteristic feature is the presence of slices of different lithologies, forming imbricate fans and contractional duplexes within the fault zone. Push-up blocks of Triassic sediments give evidence for a vertical thickening. The fault follows the main NW-SE (130°) orientation of the structures in the Panagyurishte strip and terminates in a horsetail splay. Deformation of the affected rocks is brittle to brittle-ductile at a macroscopic view. The Middle Triassic dolostones are brecciated and transformed into cataclasites. The deformation of the clayey-terrigenous, epiclastic turbidites and limestones within the Late Cretaceous section is penetrative and presented by several types of folds, flower structures, cataclastic foliation, axial cleavage. The dominant folds are open to isoclinal, decametre to metre in size, with hinges plunging steeply (30–60°) to W or NW (280–330°). Folding of a primary bedding with subvertical hinges is also often found. Part of the Late Cretaceous section near to the fault zone is overturned. Slickenside fibres, geometry of Riedel shears, parasitic and drag folds indicate a dextral transpression.

The present-day fault configuration in the Panagyurishte strip usually reactivates the older strike-slip structures that controlled previously the basin opening and the magmatic-hydrothermal system formation. Dating the later transpressive deformation that has led to the basin closure and displacement of the ore systems is significant for the analysis of the post-magmatic tectonics. Some evidence for the age of the latest faults is found in the Panagyurishte region, where the displaced Paleocene conglomerates are found. The movements along the Petrich fault are probably related to the last stages of the Late Cretaceous basin evolution and closure. The exact age will be well constrained by the ongoing thermochronological studies.

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Tectonics and sedimentation during juxtaposition of ALCAPA and Tisza micro-continental blocks along the Kapos Line (Mid-Hungarian fault zone)

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Although the convergence of both the ALCAPA and Tisza micro-continental blocks into the Carpathian embayment represents one of the key issues in the evolution of the Pannonian Basin, it is not well-known in terms of associated effects on the sedimentary systems and structural evolution during syn- and post-rift basin evolution. Most contact between ALCAPA and Tisza is covered by syn- and post-rift deposits (Csontos and Nagymarosy, 1998; Tischler *et al*., 2007), this geological setting can be observed along the Mid-Hungarian fault zone, by which the micro-continents are separated by a broad zone of deformation (*e.g.* Fodor *et al*. 2005). Repeated periodical strike-slip movements took place along this fault zone from the Paleogene (Kázmér and Kovács, 1985; Fodor *et al*. 1992) to the Late Miocene (Balla 1984; Balla *et al*. 1987) and significant block rotations are documented in Paleogene to Early Miocene times (Csontos and Vörös, 2004; Horváth *et al*. 2006). The convergence between the invading continental blocks led to thrusting of the ALCAPA onto Tisza–Dacia (Csontos and Nagymarosy, 1998). This process culminated during the Early Miocene at the Pienide nappes, Northern Romania (Săndulescu *et al*., 1981). The main driving force of the emplacement of these continental blocks into the Carpathian embayment is the slab retreat at the margin of the Carpathian foreland (Royden, 1993).

The aim of this work is to provide some additional data to understand the tectonic evolution of the Pannonian Basin. Sedimentological data on the facies, combined with some micropalaeontological data and 2D well calibrated seismic lines constrain the tectonic history of the contact zone between ALCAPA and Tisza. Lithofacies of the syn-rift deposits were controlled by the tectonic settings, *i.e.* the Tengelic wells, drilled close to each other, represent different Sarmatian successions. The investigated 2D seismic sections of the Kapos Line are located in the middle part of the region, stretching from the Igal high to the Kecskemét area. Due to the absence of Palaeogene–Early Miocene strata, a significant tectonic constrain should be assumed for the area and due to the lack of borehole data the earlier story remains obscure along the lineament. This work supports the hypothesis that the southern limit of Mid-Hungarian fault zone, *i.e.*, the Kapos Line cannot be considered as a unified master (border) fault. The particular section of the zone shows different tectonic style and activity during geological times.

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The Permomesozoic Stangalm Group and its correlatives in the Gurktal nappe complex: significance for paleogeography and tectonics of the Eastern Alps

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Detached, imbricated and tectonically decapitated cover successions of passive continental margins are often preserved in mountain belts within basement-cover thrust sheets. Based on a new mapping of Permomesozoic cover strata, we investigate the paleogeographic and tectonic origin of the Lower Triassic to Upper Jurassic Stangalm Group, which represents the post-Variscan cover of the Bundschuh nappe (basement) and is tectonically overlain by the Gurktal nappe complex (GNC; with Murau, Ackerl, Pfannock and Stolzalpe nappes) of the Austroalpine nappe stack. The Stangalm Permomesozoic unit was affected by an early Late Cretaceous nappe stacking under low-grade metamorphic conditions and subsequent extension during the Late Cretaceous. Lithostratigraphic peculiarities of the Stangalm Group include: only a thin siliciclastic Permian base, if any, and thin Lower Triassic quartzites, black phyllites, black calc-schists and related synsedimentary ore mineralizations of Anisian age, relatively thin Middle and Upper Triassic dolomites separated by Carnian siliciclastic beds – the latter show extreme thickness variations interpreted to result from synsedimentary normal faulting – and Jurassic cherty limestones and thin Upper Jurassic cherts. In contrast, the cover units between the Murau and Stolzalpe nappes range from Permian Alpine Verrucano Fm., Buntsandstein-type quartzites, Anisian rauhwacke to Anisian black marble/black calcareous schists. These strata belong to the Stolzalpe nappe or represent, more likely, a correlative to a similar Permomesozoic cover of the Ackerl nappe. The non-metamorphic to very low-grade metamorphic cover on the overlying Stolzalpe nappe starts with the post-Variscan intramontane molasse-type uppermost Carboniferous Stangnock and thin Permian Werchzirm Formations. These are spatially separated from several 100 meters thick Permian terrestrial red beds and relatively thin Middle-Upper Triassic carbonate platform sediments of the Eberstein Permotriassic in the eastern central, and, at Rosegg and Viktring, Permomesozoic strata along the southern margin of the Gurktal nappe complex.

We interpret the very thin siliciclastic successions at the base of the Stangalm Group to represent deposition on a rift shoulder – this feature contrasts with many other Austroalpine Permian to Mesozoic cover successions. We interpret the Triassic strata of the Stangalm Group to reflect an extension of the rifting stage, which also enhanced synsedimentary Early Anisian iron mineralizations, potentially related to normal faults as well as a second stage of extension during Early Carnian.

The Upper Carboniferous to Triassic cover successions of the GNC are dissimilar to those of the Drauzug unit, which is exposed to the SW of the GNC, and resemble those of the westernmost Northern Calcareous Alps. The new data makes it necessary to reconsider currently popular paleogeographic and tectonic models of the Austroalpine domain. The term Drauzug-Gurktal nappe system should be dismissed because: (1) the Drauzug unit does to represent a nappe in contrast to the GNC, (2) the paleogeographic dissimilarities of Permian and Triassic successions, and (3) eastern paleogeographic extension of the Drauzug unit in the North Karawanken thrust sheet overlying there the southern margin of the GNC.

Jurassic to Eocene tectonic history of the Untersberg region within the Northern Calcareous Alps: on terrestrial erosional phases, basin formation and destruction

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Although of high explanatory value for the tectonic evolution of Northern Calcareous Alps (NCA), the tectonic history of the Untersberg region SW of Salzburg city got less attention. This region belongs to the Upper Juvavic nappe and includes mainly uppermost Permian to Lower Jurassic strata, unconformably overlain by Upper Jurassic Plassen Limestone, which is again overlain, after an angular unconformity, by Upper Cretaceous shallow marine mainly, and Eocene deep marine strata. Our study is focused on the tectonic significance of these major breaks between these sedimentary units and brought the following preliminary results.

The Lower Jurassic Hierlatz Limestone is overlain by a monomictic breccia with either purely Hierlatz Limestone components or by polymictic breccia beds with various limestone clasts and marls with an intercalated potential paleo-soil, whereas other section include conglomerates with boulder-sized clasts. The observed brecciation gives a hint for a phase of emergence of the carbonate platform above sea level and erosion in Mid Jurassic times. This development contrasts the Middle-Upper Jurassic development of other Austroalpine units, except the purely investigated Oberalm Basal Conglomerate of the Tirolic Osterhorn nappe, exposed to the southeast of the Untersberg. This phase underlines the importance of a Middle/early Late Jurassic tectonic phase within the NCA.

Separated by an angular unconformity and bauxite lenses, the Upper Jurassic Plassen Limestone is again overlain by Upper Cretaceous strata of the Gosau Group. These relationships indicate a significant pre-Gosau northward tilting of Jurassic strata and a terrestrial erosional phase, following the Austrian tectonic phase. Furthermore, sedimentary structures like Neptunian dykes and structural evidence argue for ca. N-S extension during the initial stage of the Gosau basin subsidence. Upper Cretaceous Gosau strata are dominated by carbonate detritus derived from underlying Mesozoic strata. During the Paleogene, a significant clastic input with metamorphic components, including a detrital white mica with Cretaceous ages indicates an Austroalpine basement source. Transport indicators in siliciclastic turbiditic sandstones argue for SW-directed sediment transport during Eocene, which would also indicate a halfgraben-like tilting of Eocene strata to the SW, towards the Triassic and Jurassic strata and the presence of a normal fault in between. Interestingly, although very close to the northern margin of the NCA thrust front, the internal deformation of the Gosau strata is very weak.

Finally, the weakly deformed Gosau stratigraphic units overlie a fluvial Nagelfluh-like conglomerate, where high-grade metamorphic clasts dominate. Their clastic composition is similar with the Ramsau Conglomerate in the SW of the Untersberg. We assume, therefore, deposition from the same river, which drained a distant source like Silvretta/Ötztal basement source.

Determination of the active tectonic regime of Thessaly, Greece: A geodetic data based approach

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The region of Thessaly is located in the central part of Greece and is characterized by an active tectonics, as well as by occasional destructive seismic events. The most recent geological structures of the area are the Pliocene – Lower Pleistocene, NW – SE trending grabens and horsts, formed by the post-orogenic collapse, created by the NE–SW extensional regime of the area, and the Middle Pleistocene – Holocene, E–W to ESE–WNW normal faults, related to the N–S to NNE–SSW extensional regime.

The broader Thessaly area is monitored by 27 permanently installed GPS stations, collecting geodetic raw data for a seven-year time period, using Eurasia as fixed reference frame. Processing the primary geodetic data was performed by the triangulation of the GPS stations, combining the data combination of three different GPS stations. The triangulation process led to the formation of different triangles and for their centroids a series of parameters is calculated. Those parameters are: maximum horizontal extension, total velocity, maximum shear strain, area strain and rotation. One hundred ninety-three different triangle centroids were determined and the aforementioned parameters were calculated for each of them.

The estimation of maximum horizontal extension shows a dominant N–S direction, which is in agreement with the recent, documented active fault zones of the area. However, a sparse distribution of E–W maximum horizontal extension vectors is probably related to local tectonic structures, while limited compressional vectors at the western margin of Larissa plain are also present. Regarding total velocity, the calculated vectors show a NE–SW direction, leading to the conclusion that the broader Thessaly area is moving to the SW, receiving at the same time the highest and lowest values at its southern and northern flanks respectively. The maximum shear strain parameter is directly associated with the activation of fault zones, while the highest values of the study area are concentrated at the eastern part of Thessaly, close to the North Aegean region. The recent activation of the North Aegean fault zones (seismic events) was imprinted at the GPS recorded data, causing the high maximum shear strain values. Concerning area strain parameter, it is associated with the dilatation (mainly extension) and contraction (mainly contraction) of the study area. The highest contraction values are located at the eastern part of the study area, close to the Pindos mountain range, where a compressional tectonics is documented, while the highest dilatation values, coexisting with high contraction values, are recorded at the Pagasetic Gulf region. The existence of both dilatation and contraction values indicates the presence of strike-slip structures and therefore the wider Pagasetic Gulf area is probably affected by the North Aegean Trough, the westward continuation of the North Anatolian fault zone. The interpretation of rotation values shows a dominant clockwise rotation of the area, while limited and regional counter-clockwise rotation vectors are also observed.

Active faulting in NE Italy and NW Slovenia – insights from field studies, geophysics, and high-resolution DEMs

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In NE Italy and NW Slovenia, the style of the active faulting changes from head-on collision on E-W striking thrusts in the Alps to right-lateral motion on NW-SE striking faults in the Dinarides, thereby accommodating the northward motion of Adria. This region has the highest seismicity in the Adria-Alpine collision zone with historical and instrumental earthquakes exceeding M6. Deformation is rather slow compared to other collisional settings, and the slip rates of individual faults are probably not more than 1–2 mm/yr. Several aspects of the active tectonics in the study area need further research. We know little about the slip rates of individual faults, their earthquake history, their seismic potential, and the impact of active tectonic deformation on catchment-wide erosion rates. Crustal deformation may be distributed across many active structures, but yet it could also be one or a few major faults that take up most of the deformation. Furthermore, the transition between thrusting in N Italy and right-lateral motion in Slovenia is not well understood. In the framework of SPP 2017 'Mountain building processes in 4D', our project 'Earth surface response to Quaternary faulting and shallow crustal structure in the eastern Adria-Alpine collision zone and the Friulian plain' aims to solve these open questions.

The slow deformation in the study area complicates the investigation of the regional tectonic regime with earthquake seismology and geodetic techniques. The effects of the active tectonics, however, are still preserved in the landscape, although human modification, intense karstification, and the moderate climate are not perfect conditions for the preservation of fault scarps, offset river terraces and similar landscape features. We will investigate the geometry of major active faults, their sense of motion, and how they drive the erosion with a variety of different methods. High-resolution digital elevation models from airborne LiDAR surveys and drones will be used to analyze the tectonic geomorphology. Shallow geophysical surveys will allow to image surface traces and the sub-surface structure of active faults. Palaeoseismological trenching will be performed to determine long-term slip rates, earthquake recurrence intervals, and palaeomagnitudes. In-situ cosmogenic 10Be from quartz samples in river sediments will reveal the erosional response to active faulting using catchment-wide erosion rates.

In this contribution I present first results from field work in 2017/18. I focussed on the major NW-striking "Dinaric" faults in Slovenia and used field mapping, the analysis of high-resolution topographic data, and near-surface geophysics to show that traces of surface-rupturing earthquakes can be found in the landscape. I worked on offset slopes, displaced alluvial fans, and deformed river terraces that point to surface deformation during the Holocene. Based on the results of this field work, paleoseismological trenching studies will commence in the next phase of the project.

Session GT8-1

Quantifying landscape evolution during the Plio- and Pleistocene and natural hazards

Conveners:

Zsófia Ruszkiczay-Rüdiger, Christopher Lüthgens, Jörg Robl and Bernhard Salcher

Origin and formation of loess in the Lower Volga region of Russia: A multi-method approach

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The Lower Volga region of Russia is characterized by the alternating influence of both marine and continental environments, with distinct preserved sediment deposits. However, the continental sedimentary material in the area has gained very little research attention compared to the under- and overlying marine deposits. As a result the area has never been characterized as a classic loess region even though many Russian as well as international researchers agree on the appearance of an abundant loess material in the continental deposits. A key obstacle to loess research in the Lower Volga region is the contrasting definitions of the loess and its formation, particularly whether loess is a wind-blown or in situ formed material. As such, prior to undertaking extensive climate or dust research on the Lower Volga loess, it is crucial to test the formation and origin of these deposits. This information can also elucidate which environmental factors controlled the evolution of the different depositional environments in the region, helping to address multiple research questions, including Caspian Sea level fluctuations, Volga river dynamics and not least regional dust dynamics as well as atmospheric conditions during the Quaternary. As such, the aim of this work is to test whether the loess material can be defined as windblown and essentially non-reworked by fluvial or slope processes. For this purpose, multiple techniques and approaches are combined.

Three natural outcrops of an alternating marine and continental stratification in the wetlands of the Volga-Akhtuba province are studied here: Srednaya Akhtuba, Leninsk and Raigorod. With special emphasis on the apparent loess units, a detailed investigation of all exposed material is carried out in order to address the materials properties, provenance and age. Grain size and multiple types of magnetic susceptibility analyses (frequency dependent, temperature dependent, phase dependent and its anisotropy) were applied using an Agico MFK1-FA Kappabridge instrument. Bulk sediment geochemical investigations were carried out via XRF, while single zircon and rutile grains recovered from the loess and potential source material were analyzed for U-Pb age.

Magnetic susceptibility values provide a clear differentiation between the single lithologies of a section and a valuable evaluation of their magnetic mineral content, allowing to test whether the material is detrital and dust source related or was formed in situ as a result of weathering processes. Anisotropy of magnetic susceptibility points towards a calm sedimentation under slow current with the development of mostly oblate magnetic fabric during deposition. The attempt to distinguish undisturbed and redeposited loess points towards a reworked air-fallen material. Initial U/Pb data support the possibility of Lower Volga loess being a potentially windblown sediment.

Pleistocene aeolian, alluvial and glacio-fluvial sediments in the northern part of the eastern Adriatic coast, Croatia

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The eastern Adriatic coast is made up predominantly of Mesozoic and Cenozoic carbonate sedimentary rocks, while Eocene flysch and other less resistant sediments including Pleistocene sediments, cover approximately 6% of the coast (Pikelj and Juračić, 2013). Pleistocene sediments on the eastern Adriatic coast and islands usually cover smaller surfaces and form outcrops, which thickness rarely exceeds 10 m. They are represented by various types of sediments which include: gravel, sand, loess like sediment, silt and sandy silt, deposited in different environments. In the northern Adriatic loess-like and sandy sediment on the Susak island is well described and dated (Cremaschi, 1990; Wacha *et al*., 2011, Mikulčić-Pavlaković *et al*., 2011). Gravel, sand and silt of Pleistocene age occur in many isolated points along the Adriatic coast and several sand outcrops were described on the southern Croatian islands (Babić *et al*., 2013; Pavelić *et al*., 2014; Wacha *et al.*, 2016; Kovačić *et al.*, 2017). As a part of the ongoing research we have sampled different sediments from 5 outcrops situated in the middle part of the eastern Adriatic. Vrsi-1, Karin-1 and Novigrad-1 outcrops are located on the shore line, while Smilčić-1 and Ražanac-1 are just in few kilometers inland from the coast. Deposited material was analyzed to get the insight in depositional mechanisms and environment, paleo-climate and characteristics of the sedimentary basin, which evolved in the coastal belt dominated by high-relief mountains composed mostly of carbonate rocks.

The preliminary results point to the complex origin of the studied sediments. Different facies are identified and described in all of the five outcrops. Ražanac-1 and Smilčić-1 are dominantly sand deposits with gravel lenses and layers; Karin-1 is comprised of silt, gravel and blocks; Novigrad-1 displays sand, sandy loess and gravel; while sand and gravel interplay in the form of channel type gravel lenses, eroding medium to coarse grained sand in Vrsi-1 outcrop is similar to the sediment described on the nearby Vrgada island (Banak *et al*., 2017). It seems that two major depositional forces, both climate-controlled, may have formed the sediment: alluvial and aeolian. Aeolian silt and fine-grained sand were deposited at an arid climate, while coarse-grained sand and gravel – at more humid and warm climate. We have distinguished a third depositional force as well – a glacio-fluvial one, which is detected at Karin-1 and Novigrad-1 outcrops in the form of dropstones and 20 cm+ blocks.

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Cosmogenic nuclide dating of a “sticky stuff” deposition: Principles and applications of the authigenic $^{10}Be/^{9}Be$ dating in comparison with well-established geochronological methods

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Regularly used geochronological approaches in Plio-Quaternary science often face methodological obstacles, especially regarding the time range of ca. 0.5 to 5 Ma. A novel method, authigenic $^{10}Be/^{9}Be$ dating, provides an exceptional potential to overcome common problems in dating of Pleistocene and Pliocene terrestrial sequences, with a possibility to date sediment as old as 14 Ma (Bourlès *et al*., 1989).

The method uses the ratio of atmospheric cosmogenic radionuclide ^{10}Be, delivered from the atmosphere to the terrestrial environment by precipitation, and stable nuclide ^{9}Be, which originates from bedrock in the drainage basin. Following the transport in river, lake or marine water, both isotopes adsorb to the surface of clay minerals during the sedimentation. The isotopic ratio than decreases proportional to the decay of ^{10}Be. The initial $^{10}Be/^{9}Be$ isotopic ratio in a drainage basin is dependent on variations in cosmic radiation, on drainage network changes impacting on the flux of ^{9}Be and on a character of the depositional environment. The initial $^{10}Be/^{9}Be$ ratio needs to be constrained to date sediments using the half-life of ^{10}Be. It is usually calibrated using recent alluvial or lacustrine sediments, assuming that the ratio has remained stable over the geological time. The approach is similar to well-known radiocarbon dating, where the initial ratio of carbon isotopes is resolved by calibration. Since the method focuses on the authigenic phase, it is not affected by exposure/burial history of a sample, in contrast to in situ cosmogenic nuclide dating methods. The sample processing requires only few grams of clayey sediment, what makes the method highly advantageous.

So far only several applications of the method were published, for example from cratonic settings of the Central Africa (Lebatard *et al*., 2008) and from the Late Miocene to Quaternary sequences of the Danube Basin (Šujan *et al*., 2016). In the latter work, the application enabled to trace a shifting of deposystems through time due to a prograding shelf of Lake Pannon, as well as the following dominance of alluvial environment up to the earliest Pliocene. In another application, an outcrop of braided river deposits known for the presence of mixed large mammal fossils of the late Pliocene to Early Pleistocene age was a subject of dating of clay intraclasts. The dating provided a time range of 1 Ma, in good accordance with the expected age of redeposited sediment. A dating of Plio-Quaternary well-cores combined with the $^{26}Al/^{10}Be$ burial dating implied a variance of initial $^{10}Be/^{9}Be$ ratio, what calls upon a future investigation of initial $^{10}Be/^{9}Be$ variability trough time.

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The Upper Pleistocene lacustrine shores in the Romanian Plain (Dacian Basin)

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The idea sustained in this paper is about maintenance of lacustrine areas on the surface of the actual Romanian Plain during the Upper Pleistocene, till the lower limit of the Holocene. On the other hand, this paper is a continuation of our attempts in paleogeographical reconstructions presented at CBGA meetings in Beograd (2006), Thessaloniki (2010) and Tirana (2014), focused mainly on Pannonian Basin during the Upper Pleistocene. In this area the lacustrine shores elevation, at the Pleistocene–Holocene limit, was about +100 m. Another paleoshore at +85 m reflects the situation during the Lower Holocene. The gradual water retreat of the Dacian Basin towards the Black Sea Basin went continuously during the Quaternary. After Wallachian phase, Lower Pleistocene is characterized by an accumulation of coarse deposits (Cândeşti Beds and Frăteşti Beds) and then finer, marly deposits, in the Middle Pleistocene. But, also the loessoid deposits, specific for the Upper Pleistocene, could be of lacustrine origin, without denying the contribution of the eolian transport. Besides the general process of the shores retreat during the Pleistocene in Paratethys, the level variations for the lacustrine areas were imposed by the cold and warm phases of a 100,000 yrs period cycle, characterizing the Quaternary Glaciation. In disagreement with the classical concept, we connect the red Pleistocene deposits with ice age cold phases and the loessoid deposits between these red deposits were accumulated during the interglacial warm phases. Moreover, the loess beds of the Upper Pleistocene are rich in calcareous concretions, proving high temperatures of the lacustrine waters. In these conditions the red deposits show a minimum water level, and oxidizing conditions. So, the appreciation of these red deposits as paleosol seems to be justified. Having all these genetic aspects in view, our field work consisted in analysis through morphology of the land of the possible paleoshores of the Pleistocene lakes, till now considered as scarps of fluvial terraces. Among all these paleoshores the most evident are to be found at the following elevations: +120; +100; +75; +50 and +20 meters. One of these corresponds to the paleogeographic reality at the Pleistocene-Holocene boundary and our opinion for now is the +20 m one. It must be noted here, that the most visible Pleistocene paleoshores are those at +100 m, +50 m and +75 m, the last easy to recognize in Bucharest city. The shores levels at +100 m and +50 m are especially evident downstream the Danube gorge, with very good examples on Serbian territory and in Romania. For Romania our study was made also between Prahova and Siret rivers, in the southern part of the Moldavian Plateau, along the Prut River and in northern Dobrudja. From this perspective, it results that the finalization of the actual Danube course, downstream Turnu Severin, was accomplished gradually. The newer portions of the Danube course appeared where lake waters had receded and Danube flow went in lakes with smaller and smaller surfaces. That is why the number of Danube “terraces” diminishes as we approached its actual mouth.

Candidates for Global Boundary Stratotype Section and Point (GSSP) for an Anthropocene chronostratigraphic unit

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The Anthropocene, as a potential new unit of the International Chronostratigraphic Chart, is assessed in terms of stratigraphic markers and approximate boundary levels available to define the unit base. The task of assessing and selecting potential GSSP candidate sections, a requirement in seeking formalisation of the term, is being actively pursued. Here, we review the suitability of different stratified palaeoenvironmental settings and facies as potential hosts for a candidate GSSP and auxiliary sections, and the relevant stratigraphical markers for correlation.

A marked upturn in ^{239}Pu and ^{14}C radioisotopes abundance, approximately in 1952 and 1954 respectively, broadly coincident with a downturn in $\delta^{13}C$ and $\delta^{15}N$ values, is applicable across most environments. Other airborne signals, such as fly ash, nitrates and to a lesser extent sulphur and sulphates, CO_2 and CH_4 concentrations and $\delta^{18}O$ are highly resolved, widespread and provide additional means of correlation.

Principal palaeoenvironments examined include settings associated with accumulations of anthropogenic material, marine anoxic basins, coral reefs and marine bivalves, estuaries and deltas, lakes at various latitudes, peat bogs, snow/ice layers, speleothems and trees. Many of these geographically diverse palaeoenvironments offer annual/subannual laminae that can be counted and independently dated radiometrically (*e.g.*, by ^{210}Pb) with the possibility of correlation at annual/seasonal resolution; anthropogenic deposits and peats lack such laminae, making them less suitable as a GSSP candidate, but still show high stratal accumulation rates and may provide potential auxiliary stratotypes. Decadal-scale lagged responses to environmental signals evident in speleothems and in some cases within deep waters associated with marine anoxic basins can limit their suitability as GSSP candidates. A time lag between the age of glacial ice and the included air bubbles affects CO_2, CH_4, $\delta^{13}C$ and N_2O values, but a broad spectrum of annually resolvable atmospheric signals including radionuclides, $\delta^{18}O$, sulphates, nitrates, $\delta^{15}N$, Pb and other metals are robust in ice. Lakes may show thin Anthropocene successions, but are advantageous as settling rates of key signals are minimal in relatively shallow waters, commonly there are few omission surfaces and in hypoxic sediments bioturbation is minimal. Anthropogenic deposits and estuarine and deltaic deposits may suffer from strong modulation by local influences, a lack of lateral continuity, and the common presence of omission surfaces. Although biotic organisms have not previously hosted a GSSP, very-high resolution records and relatively rapid growth rates present in corals and trees provide a potentially suitable medium.

From among such a range of palaeoenvironments, a small number of potentially representative sites require the acquisition of more systematic and comprehensive datasets, with correlation established between sections, to allow selection of a candidate GSSP and auxiliary stratotypes. In many circumstances the thickness of Anthropocene strata is limited to a few centimetres, but the signals of change are still clearly resolved and laterally extensive. This assessment suggests that a Holocene–Anthropocene boundary would be workable in practice across a wide range of environments, and this study aids finding optimal stratotype locations among these environments.

Lithology or base level? – What controls the evolution of different landscapes in the northern Alpine Foreland?

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The evolution of topography is driven by a climate and tectonics, and strongly influenced by bedrock properties and different base levels. The contributions of these factors may vary in space and time and are thus difficult to constrain. Our study area in the northern Alpine Foreland, the Hausruck – Kobernaußerwald range, has a rather uniform climatic and tectonic history, but is drained by rivers with different base levels and consists of contrasting sedimentary rocks, mainly due to different sedimentation environments. This makes them an ideal location to study the effects of lithology and base level on topography.

To decipher the roles of these influences, we used a high resolution digital elevation model and performed a series of morphometric analyses. Longitudinal river profiles indicate that all channels in the study area, independent from base level, bed rock and overall morphological expression, are well graded. Hypsometry shows no evidence for base level effects on the present topography, while variations in the hypsometric curves coincide with lithological differences. This is also reflected in contrasts of mean elevation and slope distributions. Lithology-dependent variations in channel concavity and catchment-wide hypsometric integrals show that lithology controls both channel incision and hillslope processes in the study area. Our results further indicate that variations in channel and catchment metrics are not linked to the prevalence of different rock types alone, but to different successions of lithological units within the channels and catchments. Variations in channel slope and geomorphological mapping suggest that a lithology-dependent landsliding is the dominant process, causing the observed large-scale landscape diversity in the Hausruck – Kobernaußerwald range.

Predominant western moisture transport to the Tatra Mountains during the Last Glacial Maximum, inferred from glacier palaeo-ELAs

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Reconstructing of equilibrium line altitudes (ELA) from palaeoglaciers gives an insight into the palaeoclimate. The ELA depends on both temperature and precipitation. The distribution of precipitation is much more spatially variable than temperature, thus ELA trend of palaeoglaciers is valuable information of the dominant moisture advection and orographic induced precipitation in the past. The general atmospheric circulation model in Europe during the Last Glacial Maximum (LGM) is disused in the literature on the base of multiproxy palaeoclimate data and computer models. A southward movement of the polar front and associated southern circulation pattern during the LGM evidenced in the Alps and Mediterranean region is contrasting with the present-day condition in these regions. In contrast, we present the evidence that during the LGM western/north-western circulation pattern dominated in Eastern Central Europe in the Tatra Mountains, which similar to the present-day conditions.

The Tatra Mountains have one of the best-evidenced glacier geometry and chronology of LGM glaciation in the Carpathian-Balkan realm. Strong elongation (50 km long/15–20 width) and latitudinal extent of the Tatra massif yields a discrete representation of the LGM palaeoglaciers exposition to the north (n 14) and south (n 20). This considerably simplifies the role exposition on ELA variability and gives the possibility to trace W-E ELA trend. In previous studies in the Tatra Mountains, a Pleistocene ELA reconstruction was used with the Hoffer's and AAR methods. This study is presenting first results of a LGM glacier ELA reconstruction based on a full set of glaciers and AABR method. For ELA calculation we used published glacier geometry (Zasadni and Kłapyta). From all 55 LGM glaciers, we chose palaeoglaciers larger than 1 km^2 (n 32) as this is the commonly used glacier size threshold in glacio-climatic studies. We tested several methods (AAR, size-specific AAR, AABR) and ratios in ELA reconstruction. Our analysis indicates that the most consistent results gave the global average AABR method.

The average LGM ELA in the Tatra Mts. was 1580 m. ELA asymmetry between north and south slopes was 130 m, which is a typical value associated with the N-S exposition of glaciers. In both slopes of the massif ca. 100–130 m ELA rise from the west to the east is observable on the distance of 32–40 km. The lowest ELA occurred in NW sector (1450 m, n 8) and the highest in the SE sector (1680 m, n 10). This pattern of ELA mimics the present-day orographic induced precipitation anomaly in the massif with the highest precipitation in NW sector and precipitation starving in SE sector. This suggests a similar condition during the LGM, with a strong influence of W/NW moisture transport and orographic induced precipitation causing a ELA rise to from the west to east. This trend cannot be explained by the southern circulation pattern.

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Tracing the extent of the Most Extensive Glaciation in the Tatra Mountains, Western Carpathians

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In the High Tatra Mountains sediments of Most Extensive Glaciation (MEG) commonly occur in the lower parts of valleys and foreland outside terminal moraines of the Last Glacial Maximum (LGM). In contrast to the fresh shaped LGM moraines, the MEG extent is poorly defined in landforms. Mostly it is traced as patches of highly degraded, solifluction overprinted till covers without moraine walls. Oldest glacial sediments grade into proglacial outwash fans and gravel covers with similar sedimentological and morphological characteristics (diamicton of granitic material, subdued relief). Therefore, the extent of MEG in Tatra Mts. was widely discussed in the literature and a lot of contradictory hypotheses was proposed.

In this study, we present sedimentological and morphological criteria which can be used for mapping the extent of MEG in the Tatra Mts. We applied a detailed field mapping with clast shape analysis (19 sites) and boulder size measurements (ca. 1000 boulders) in the area (15 km^2) of the terminal zone of the largest glacier in the Tatras during the LGM (13 km long) in the mouth of Białka Valley. Probably the oldest preserved glacial sediments in Polish Tatra Mts. occur in the study area on the flat hill-top surface of the Hurkotne site, 210 meters above the current valley bottom and LGM terminal moraines.

Our results show that for both MEG till cover and LGM moraines exhibit similar maximum diameter of boulders, which reaches 4–5 m. Till covers and water-laid sediments can be distinguished using difference in maximal boulder size and clast shape analysis. Boulders with a diameter larger than 1.5 m (a-axis) are typical for till cover, whereas, in fluvial sediments boulders are never larger than 1.5 m.

Two subunits (zones) within MEG till cover could be distinguished on the base of sedimentological properties of surface morainic material. In the younger subunits, large granitic boulders can be observed directly on the topographic surface, which contrast with a lack of surface exposure of boulders in the older subunit. They can be observed only on the steeper slopes and erosional undercuts, where they emerge to the surface due to mass movement processes. It cannot be excluded that younger subunit within the MEG till cover zone represents the Penultimate glaciation. The Białka glacier during this glaciation had the similar topographic condition as during the LGM, but reached ca. 1000 m down valley beyond the LGM limit. Interestingly, the MEG (older subunit) reaches also similar length but in a completely different topographic settings. We infer that MEG sediments were deposited on the flat surface on a mountain foreland before this area was uplifted and the valley was incised ca. 200 m. This suggests a rather old age of this glaciation. Our results show that the feedback between glacial erosion, valley morphology evolution and extent of glaciation during the Pleistocene should be taken into account in analyzing the morphological position and extent of MEG in the Tatra Mts.

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Releasing bends along the Salzach-Enns-Mariazell-Puchberg (SEMP) fault (Upper Enns Valley, Austria)

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Quaternary glaciations combined with neotectonic activity formed the topography of the Upper Enns Valley (Eastern Alps), located along the sinistral Salzach-Enns-Mariazell-Puchberg (SEMP) strike-slip fault. The focus of this study is to describe a previously not known releasing, resp. restraining bend and to re-interpret the course of the SEMP fault. Geomorphology of the study area and the tectonic environment suggest the SEMP fault does not represent a simple straight fault line. Between Gröbming and Öblarn, the valley appears divided into two sections, a northern and a southern one with the Mitterberg block in between. Mt. Mitterberg exposes a relictic Pleistocene valley bottom and the overlying gravel infill between the paleosurfaces south and north of the Upper Enns Valley. Provenance analysis from Pleistocene Mitterberg conglomerate indicates the principal material flux across the SEMP fault from the south. The occurrence of carbonates derived from the Northern Calcareous Alps indicates bipolar transport directions. We conclude that the sedimentary pattern has undergone a change between Pleistocene and Holocene, forming a half-graben north of Mt. Mitterberg and a new fault zone. The conglomerate of Mt. Mitterberg also records tectonic deformation indicated by normal faults and primarily extensional regimes. A prominent NW-trending fault cuts the Mitterberg block in the west, geomorphic evidence argues for a dextral displacement. Structural data from the northern slopes of the Ennstal phyllite area also indicate dextral shearing. There is no evidence for sinistral strike-slip along steeply NNW-dipping normal faults as could be expected from the principal sinistral nature of the SEMP fault. The basins of Bramberg, Zell/See and Wagrain, the Miocene Ennstal basin and the basin between Liezen and Admont widen the valley, hence, they partly contribute to releasing step-overs of the SEMP fault. Simultaneously, Mt. Mitterberg and Mt. Frauenberg, between two faults restrained, enforce a step-over of the SEMP fault.

Glacier reconstruction, deglaciation chronology and paleo-environment reconstruction, Retezat Mountains, Southern Carpathians, Romania

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Several previous studies described the extended past glaciations of the Southern Carpathians, and have already proposed that extensive valley glaciations occurred and that large ice fields may have occupied the high elevation plateau-like surfaces (>2000 m a.s.l.). Despite the availability of published data, regarding the past extent of the glaciations, the chronology of the deglaciation is poorly constrained.

The Retezat Mountains are one of the most glaciated parts of the range. Glacier reconstruction (Pellitero *et al*., 2016), based on a detailed geomorphological mapping, enabled distinguishing six deglaciation phases from ~21 to ~14 ka. The Equilibrium Line Altitudes (ELAs) were calculated on the basis of the reconstructed glacier geometries using the ssAAR and AABR methods (Pellitero et *al*., 2015; Kern and László, 2010; Rea, 2009).

The chronology of the deglaciation relies on the Cosmic Ray Exposure (CRE) age determination of glacial landforms (moraines, erratic boulders, polished bedrock) derived from in-situ produced ^{10}Be concentrations (Ruszkiczay-Rüdiger *et al*., 2016 and new data). According to the data from the northern and southern valleys, the most extended glaciation occurred during the Last Glacial Maximum (LGM). At the most probable ^{10}Be CRE age of ~21 ka glaciers extended down to ~1000 m a.s.l. (1260–850 m). The reconstructed ELA in the north was at ~1840 m a.s.l., while it was at ~1670 m a.s.l. in the south.

At the beginning of the Lateglacial (~18 ka), the glaciers withdrew and the north-south difference between the ELAs decreased (~1980 m and ~1930 m a.s.l., respectively). The ELA difference vanished by ~17 ka ago, when it was at ~2080 m a.s.l. The last glacial phase in the area, characterized by small cirque glaciers occurred at ~14 ka. By this time, the ELA was shifted to ~2190 m a.s.l. Due to the small glacier size, this value may have been influenced by local topoclimatic factors. So far, no data support Younger Dryas or Holocene glaciation in the Retezat Mts.

The north-south elevation difference of the ELAs during the LGM may suggest: (a) more humid air masses arriving from the south; (b) extensive plateaus of the southern area may have fed a considerably more ice to the glacier system than it is accounted for in the current reconstruction, causing an ELA underestimation.

Using a Chironomidae-based summer temperature (TJJA) reconstruction from the area (Tóth *et al*., 2012), TJJA and mean annual precipitation (P) at the ELA were calculated for the ~15.3 ka stage. Based on Ohmura *et al*. (1992), a ~4.5–4.9 °C decrease of TJJA and a ~10-15% increase of P compared to the present values were calculated.

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Origin of the Pleistocene/Holocene dunes in the floodplain of the Dyje river (South Moravia, Czech Republic)

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Floodplain alluvia represent important archives of natural and anthropogenic processes. The archaeological locality Pohansko (South Moravia, Czech Republic) provides evidence of a significant Early Medieval centre in the core area of the Great Moravian Empire, 9th century AD (interpreted as a munitio, emporium and palatium of the Moravian Early Medieval rulers). The site lies at an altitude of about 155 to 157 m a.s.l. and is situated within an extended flood plain near the confluence of the Morava and Dyje rivers filled with Holocene flood loams. The beginning of flood loam sedimentation is estimated to be about 3000–4000 BP at the initial phase of the Subboreal period. The marginal slopes of the valley protrude some 5 m above the flood plain and are composed of Middle Pleistocene (Riss) fluvial sandy gravels with Late Würmian dunes. In some places these dunes also protrude from under Holocene flood loams in the flood plain; one of them was used to build the Early Medieval fortified site. Originally the sand dunes had a height between 6 and 8 m, but recently because of younger flood loam deposits, they are only 1–2 m above the flood plain. Some lower dunes were even buried under the flood loams. The bedrock of the Quaternary deposits in the area of Pohansko is represented by grey clays of the Pannonian Age (8.5–11.5 Ma) of the Vienna Basin.

The yellowish to brownish fine- to medium-grained sands, forming the dunes, are traditionally interpreted as eolian in origin formed by wind-blown sands. Newly outcropped profiles produced during the archaeological research were subjected to detailed lithofacies analyses. Surface textures of quartz grains were studied in selected samples. Based on these results, fluvial units predominate in the sedimentary succession and the dunes are interpreted as levees and point-bars. Aeolian origin of some part (?) of Pleistocene/Holocene dunes is therefore questioned.

Age interpretations based on optically stimulated luminescence (OSL) analyses proved that dunes were formed during a relatively long period (7000–16 000 BP). The significant variations in the climatic/hydrological conditions could be supposed during their formation.

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Morphology and sediments of the Mishin Kamik Cave, NW Bulgaria

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In the karst literature, it is accepted that the phreatic and vadose hydrologic zones of the carbonate terrains (below and above the water level of the karst massifs) create different morphological features in the cave galleries. The phreatic passages are characterized mainly by an oval cross-section and the presence of ceiling pockets on the ceiling of the gallery. They are formed by the impact of pressure karst waters. Such phreatic passages are rare in the Bulgarian 6085 caves.

The Mishin Kamik Cave, with a length of 695 m, is entirely phreatic, which makes the cave a geomorphological phenomenon for the country. The cave is situated on the right bank of the Prevalska Ogosta River in West Stara Planina (Balkan) Mts, NW Bulgaria and is protected national geosite since 1962.

The entrance is 30 m above the local base level. The formation of the cave could be associated with the sharp incision of the river at the beginning of the Quaternary. This maze cave has two main directions – west and south. The labyrinth character is mainly due to the numerous columns that fill two large chambers. The average height of the galleries is 2.2 m. The speleothems are stalactites, stalagmites, columns, draperies and rimstone dams. Most of them are massive and dry. The petrographic studies show that the cave was formed in fossiliferous biomicrite limestones. An alternation of clayey siltstones, mudstones and silty sands with rare limestone cobbles represents the sedimentary fill of the galleries.

A characteristic feature of the Mishin Kamik Cave is the presence of buried speleothems, such as small stalagmites up to 5 cm high and flowstone with thickness up to 10 cm, which implies multiphase speleogenesis – an alternation of dry and humid periods with intense speleothem deposition. In order to clarify the genesis of the Mishin Kamik and its sediments, further detailed geophysical and paleomagnetic studies, as well as absolute U/Th dating of speleothem samples, are necessary.

Anthropogenic deposits in Vienna

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The rising anthropogenic influence on the Earth System and its geological processes is strongly related to the Anthropocene concept. Potential Anthropocene geological units are thin, but distinct and globally widespread, connected changes are long-lived or irreversible. Caused by a combination of human and geological forces, the deposits under cities such as Vienna are stretched from pre-historic and historic to recent times. Financed by the WWTF (Vienna Science and Technology Fund), a new project is researching the growth of the Anthropocene signal in the urban environments of Vienna. As a unique interdisciplinary project “The Anthropocene Surge” (ESR17-040) combines natural sciences, humanities and art, and is regarded as an outstanding chance for a holistic view on the Anthropocene, its stratigraphy and perception.

The Anthropocene surge is the key hypothesis of the project. This term describes the accelerating and propagating wave of human influence on the environments and urban geology. The research will mainly focus on the evolution of the Anthropocene deposits in the urban environments of Vienna and identifying potential anthropogenic markers.

Firstly, the project aims to make a genetic classification of anthropogenic sediments to develop the stratigraphy of Vienna’s Anthropocene growth. Geochemical methods such as X-ray fluorescence will be used to detect a trace metal contamination, to investigate the record of the Anthropocene surge in the sedimentary archive.

Secondly, the geometry and topography of anthropogenic units and horizons will be incorporated into a GIS and will build the basis for a 3D model of the anthropogenic units, showing not only their present form but also their evolution in time. Historical maps, as *e.g.*, published in 1862 by Eduard Suess, will be added to the model to implement and review the mid-19th century growth of Vienna.

Thirdly, an essay, a film will be created accompanying the research and reflecting on the trajectories of the Anthropocene within different fields and methods. By recording the flow of scientific samples from humanly modified ground to a 3D modelled landscape, the points of contact between analogue and digital stratifications and their potential interactions will be traced.

Catastrophic landslide in Tbilisi (Georgia, Caucasus) and the way of its engineering solution aftermath

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The consequences of the catastrophic landslide in Tbilisi (Georgia, Caucasus) in 2015 are described. The main results of geological, geophysical and hydrogeological investigations of the landslide region are presented. The engineering solution of the problem of road rehabilitation is presented, including works to strengthen the slopes of the site, the construction of supporting walls, creation of a groundwater drain system and surface water, etc. A list of measures for prevention of natural disasters is presented.

Determination of positions and dimensions of the fallen blocks in the Kargabedir Rockfall Area using "Multi-View Stereo-Photogrammetry" method

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Using GIS data is a practical and frequently used method in the rockfall hazard assessment. It makes possible to estimate potential source areas and run-out zones in a rockfall region. The areas with a certain slope can be determined as potential source areas by using the slope maps generated from DEM (Digital Elevation Model). Additionally, as the resolution of DEM increases, the slope maps also become more representative of the topography. However, using topographic maps as a base for generating a high resolution DEM is not always possible due to the lack of 1:1000 scale topographic maps. On the other hand, Structure from Motion–Multi-view stereo-photogrammetry (SfM-MVS) method is a good alternative to acquire a high-resolution DEM and orthorectified aerial photographs. In this study, a lightweight UAV (drone) was used to obtain high resolution aerial photographs of the Kargabedir Hill, chosen as a pilot rockfall area. Thus, a high-resolution (0.4 m/pixel) DEM and a very high resolution (0.05 m/pixel) orthorectified aerial image were generated for the area by using the SfM-MVS method. The slope and propagation zone maps were prepared for the Kargabedir rockfall area using high-resolution DEM. In addition, the dimensions and positions of the fallen blocks were determined from the orthophoto and measured in situ. It has been observed that width-length-height measurements of the fallen blocks acquired from the field and orthophoto are compatible.

Burial dating of cave sediments reveal an uplift/incision at the Carpathian-Alpine border (Hainburg Hills)

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The Hainburg Hills are located in the east of Austria, where they form an elevated range that separates the Vienna Basin from the small Hungarian plain or Danube basin. They are part of the Internal West Carpathians and consist of Variscan magmatic and metamorphic rocks covered by weakly metamorphic Mesozoic sediments – mainly Triassic limestone and dolomite as well as Jurassic in age breccia.

Bad Deutsch Altenburg is a village west of Hainburg Hills, well-known for its thermal sulfuric spa since Roman times. Some 30 karst caves are mapped in the area, most of them were opened during quarrying and show signs of a hydrothermal or sulphuric acid speleogenesis. One, more than 15 m wide and 20 m high, cave chamber was recently excavated in an active quarry. It was completely filled with sediment that contains large well-rounded quartz cobbles in a flashy red matrix. The fine-grained matrix is poorly sorted with more than 30% clay (<2 µm) and consists of quartz, muscovite, and albite. In addition, analysis of the clay fraction identifies kaolinite, illite, and smectite. The occurrence of smectite in combination with the fine grain size most likely indicates soi-forming processes that resulted in an increase in fine material due to formation of new minerals in the B-horizon. Therefore, we concluded that the fluvial gravels, which are similar to modern ones of the Danube River, were transported into the cave together with a matrix, originating from a soil cover.

In-situ produced cosmogenic ^{10}Be and ^{26}Al in quartz can be used to calculate the time of the shielding from cosmic radiation (burial age dating) in an age range between 0.1 and 5 Ma. This method was performed on five quartz cobbles to determine the time when the sediment and matrix were deposited in the cave – most probably when the cave chamber was opened by surface erosion.

We assume that at the time of gravel emplacement, the cave level was at or close to the river level. Today the base of the cavity is 150 m above the Danube, thus the relative incision/uplift at the Hainburg hills may be calculated. In addition, so-called calcite rafts that form only at the surface of cave pools were sampled at a lower cave level and dated using the U/Th disequilibrium method.

Age calculations using the isochron method give an age of 3.8±0.4 Ma of gravel deposition, thus an incision/uplift rate of 36–44 m/Ma.

Protecting infrastructure from landslides and mudflows in Disaster Control Operations in Styria, Austria

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Almost every year is a disaster control operations in a district in Styria, caused by heavy storms, heavy precipitation and unfavorable geological conditions. The latest and most significant disaster control operations are summarized as follows. In 2016, heavy rain showers caused a disaster with > 1000 landslides in the district of Bruck-Mürzzuschlag, in particular in the municipalities of Stanz and Breitenau. In summer 2017, heavy rain showers caused a disaster with hundreds of landslides, mudflows and floods in the districts Liezen, Murau and Murtal.

Experience from the field, from the geologist of the "Straßenerhaltungsdienst" how to secure and protect infrastructure with different types of geotechnical methods from mudflow barriers to timber constructions.

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Geological significance of the Dinaridic fast velocity anomaly on the basis of the seismic modelling

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Shallow fast velocity anomaly in the northern Dinarides was for the first time discovered by Šumanovac and Dudjak (2016), and the teleseismic model of a high resolution in the area of the Dinarides and southwestern Pannonian basin, published by Šumanovac *et al.* (2017), revealed that the fast anomaly extends along entire Dinaridic mountain range. The anomaly was interpreted as a separation of the lower Adriatic lithosphere, which is detached from the crust, and steeply sinks beneath the Dinarides.

Teleseismic tomography can efficiently discover lithospheric slabs sinking in the asthenosphere on the basis of fast velocity anomalies that point to cold, solid rocks. Teleseismic events are used and incident rays at receivers are sub-vertical and steeply inclined, therefore horizontal velocity changes can be easily detected, while vertical cannot. Consequently, the method has a good horizontal and a poor vertical resolution, and interpretation of fast anomalies should be carried out very cautiously. In that sense the seismic modelling can significantly improve a reliability of the interpretation.

The shallow fast anomaly beneath the northern Dinarides clearly points to shallow descending Adriatic slab in the area. But, the deep fast anomaly (up to 450 km) in the southern Dinarides could not be unambiguously interpreted, because of the poor vertical resolution of the method. Besides, in the model of Šumanovac *et al.* (2017) the fast anomaly is partially attenuated in the area of the northern Dinarides and gives an impression about the break in the lithospheric slab between the northern and southern Dinarides.

The forward seismic modelling was carried out and a set of synthetic models was constructed, and obtained inverse models were compared with the inverse model for observed data. The analysis has showed there is no slab breakage beneath the Dinarides and the Adriatic lithospheric slab stretches continuously in the entire mountain range, which means the discontinuation in the part of the northern Dinarides is apparent. The shallow Adriatic lithospheric slab in the northern Dinarides has been validated, but the seismic modelling has shown that a cause of the deep southern fast anomaly does not have to be continuous deep Adriatic slab. A better fit of synthetic and observed inverse models has been obtained if the southern Adriatic slab has been considered as a discontinuous lithospheric slab, which has consisted of shallow and deep parts. In that case we should consider a new geological model of the southern Dinarides. The shallow Adriatic slab, stretching beneath the entire Dinaridic mountain range, is a consequence of the recent Adriatic subduction, and the deep part of the Adriatic slab in the southern Dinarides could be remnants of an older Adriatic subduction.

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Crustal structure and Moho depth in the area of Dinarides and SW Pannonian basin

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The research was performed in the area of Dinarides and south-western Pannonian basin with the aim to determine the crustal structure and Moho depths in the entire area. The Dinarides are located at the contact of the Adriatic microplate and southern part of European plate. Collision zone between them encompasses several different tectonic units. Accordingly, the crustal structure in this area is very complex. Deeper, mantle relationships are determined through recent teleseismic tomography investigations and fast velocity anomaly beneath Dinarides has been discovered which points to the Adriatic lithosphere slab steeply sinking in the asthenosphere (Šumanovac *et al.*, 2017). But crustal structure for entire area is not resolved yet, although there are some 2D-models.

The crustal characteristics are defined by different sets of geophysical data. The basic data are results of receiver functions (RF) analysis and 1D forward modelling of RF at about 40 seismic stations located in the research area. Those results are compiled with available models from active source seismic project ALP2002 along several profiles extending across this area and with gravity models (Šumanovac, 2010). The receiver functions are mainly used to map the velocity discontinuities. The Moho can be usually easy identified, but forward modelling enabled also determination of discontinuities in the crust and sedimentary basement, namely the crustal structure.

The Moho depths obtained by RF method are compared with the depths from other methods and existing Moho maps which partly cover the research area. Receiver functions analysis at the stations in the Dinarides show thickening of the crust and Moho depths is 10-15% greater than obtained by other geophysical methods (gravity and active seismic prospecting). In the Pannonian basin the Moho depths are about 25 km, which are similar to results of other data. In the transitional zone from the Dinarides to Pannonian basin which is a suture zone between Eurasia and Africa the crustal thickness is like in the Pannonian part but the structure is more complex. The reason for that are ophiolite zones (Dinaridic and Sava zones). Based on different datasets high-resolution Moho depth map and model of the crustal structure in this area is constructed. The final Moho topography is average of the Moho as result of gravity modelling and active seismic data and the one obtained by receiver functions analysis.

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Case study: Horizontal Loop Electromagnetic (HLEM) survey in the vicinity of Bátaapáti, Hungary

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A HLEM survey was carried out with a HLEM-400-GG instrument in the vicinity of Bátaapáti, Hungary. The subject of the survey was to delineate fractured zones and faults which affect the National Radioactive Waste Repository (NRWR). Fractures located in the Paleozoic monzogranite (the host rock of the NRWR) are sometimes filled with clay which has 3–4 orders of magnitude higher conductivity than the host rock. This physical property allows us mapping of clayey fracture zones as conductive bodies with electromagnetic technique just like in ore exploration.

The HLEM-400-GG instrument, developed by the Geogold Kárpátia Ltd., is a multi-frequency and multi-separation geophysical instrument which works based on the HLEM method. A horizontal coil with 1.4 m diameter transmits a sinusoidal EM field (vertical magnetic dipole, transmitter). Another horizontal coil (receiver) is placed at specified distances from the transmitter. The two coils are connected with a reference cable which used for communication and synchronisation between the units. The transmitter and receiver coils traverse along the survey profile, from station to station, with the specified distance kept between the coils.

The HLEM survey was conducted along nine parallel profiles with a constant profile distance of 100 m and with a station distance of 23.75 m. Profiles have different lengths between 1200–1300 m. In-phase and out-phase components of the secondary electromagnetic field were registered at seven different frequencies between 122 Hz and 6.510 Hz and four distinct coil distances from 47.5 m to 380 m. After careful data process, grid maps derived from the measured out-phase values can be used to determine clayey fracture zones in the monzogranite.

The Intramoesian Fault: tectonic contact at crustal and lithospheric depths

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The Intramoesian Fault, a crustal fault trending NW-SE, was considered since the early 1970s (Dumitrescu and Sandulescu, 1970) to separate two compartments within the Moesian Platform, which experienced different palaeogeographic evolution till the Jurassic time: *a*) westward, the Vallachian-Prebalkan compartment; *b*) eastward, the Dobrogean compartment (Sandulescu, 1984). Recently, it is mostly considered as a deep regional tectonic contact (Ioane and Caragea, 2015).

The Moesian Platform is located between the Carpathians and the Balkans, W–E elongated foreland tectonic unit having its eastern end on the Black Sea shelf. The geological mapping of the Intramoesian Fault was not possible due to the thick Quaternary sediments covering the Moesian Platform north of Danube, traces of regional faulting being totally hidden. A number of geophysical studies attempted during the last decades to locate and characterize the Intramoesian Fault using gravity, magnetics, refraction and reflection seismics (*e.g.*, Tarapoanca, 1996; Caragea and Ioane, 2015).

Recent interpretations of satellite magnetic and gravity stripping maps postulated an East European Platform affinity for the Moesian eastern compartment, due to contrasting magnetic properties and density at lithospheric depths along the Intramoesian Fault (Ioane and Caragea, 2015). When analyzing the crustal seismicity of the Moesian Platform, it was observed that the geometry of the tectonic contact suggests a soft collision, the western compartment advancing eastward at lower crustal depths (Stanciu and Ioane, 2017).

Seismic tomography studies (Piromallo and Morelli, 1997; van der Meer *et al*., 2018) illustrate crustal and lithospheric relationships between the East European Platform and superjacent terranes. A recent geotectonic model (Ioane and Stanciu, 2018) considers a westward displacement of East European Platform at lithospheric depths along a transcurrent fault till the Intramoesian fault.

Integrating available geological information and recent interpretations of geophysical data, the Intramoesian Fault is hereby considered a tectonic contact at both crustal and lithospheric depths.

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An attempt to apply space-borne monitoring of recent tectonics in the Southern Carpathians

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Satellite radar interferometry (InSAR – Interferometric Synthetic Aperture Radar) is an active remote sensing technique in microwave frequency domain. This space-based geodetic technique is proved to be an efficient tool to determine surface deformations in the satellite line-of-sight direction by exploiting the change of phase information of time-separated SAR scenes of the same area. With the Sentinel-1 twin satellites of the Copernicus Earth Observation Programme of the European Space Agency (ESA) a new era has started in mapping and understanding active tectonics. The mission started in 2014 provides coordinated observations for the whole globe with unprecedented time and moderate spatial resolution for the next 20 years. InSAR is frequently used for detecting ground deformation either from natural origin (volcanic eruption monitoring, crustal deformation studies, landslide monitoring, etc.) or anthropogenic source (dam monitoring, monitoring surface deformations due to induced seismicity), mostly in arid regions where temporal coherence between SAR scenes is ensured.

However, for small-scale geodynamic processes where several other sources (propagation through atmosphere, satellite orbital errors, digital elevation model errors, other error sources) overprint the deformation phase, therefore a long time series of backscatters with stable phase are required to discriminate the different phase contributions. This cannot be ensured by natural backscatters in vegetated regions, where the geometric and electromagnetic properties of the surface are rapidly changing. In this contribution we present a development of artificial backscatters which ensures the long-term observation of geodynamic processes based on the characteristics of Sentinel-1 satellites. The electromagnetic and geodynamic considerations of designing radar corner reflectors (RCR) are shortly presented. The twin RCR for ascending and descending satellite passes ensures the decomposition of the displacement fields to horizontal and vertical deformations. We also present our first results of RCR networks in landslide monitoring along the high loess bank of River Danube in Hungary. Comparison with independent GNSS observations shows that the developed technique is capable to map deformations with geodetic precision.

Our future aims include the deployment of such RCR networks in the Carpathian bend zone, where several endeavours have been performed to characterise the on-going active tectonics by measuring surface deformations with GNSS but inconsistent results were achieved. We identified three test sites with different but related geodynamic processes for long-term monitoring. One is the Vrancea seismic zone where the progressive delamination of the soft coupled vertical slab is still an open question. The internal part of the bend is interesting for the recent volcanic and post-volcanic activities. Several independent studies confirmed that the Ciomadul volcano, not far from Vrancea, is not extinct. We also intend to monitor the salt tectonics and its relation to seismic activities of the Vrancea zone in Praid, where the largest salt extrusion of the area is located.

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Trend evaluation of magnetic anomalies from Assarel copper mine

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We have evaluated the trend of magnetic anomalies by filtering and smoothing the magnetic data. We calculated the regional effect, based on the magnetic data, which we lowered from the initial data and obtained the residual effect. The filtering methods used, for which we have developed computational programs, are based on mobile averages with windows of different sizes and the calculation of the analytical expressions of polynomial surfaces of different degrees. The results of these types of filters were compared with spectral filters, in the context of existing knowledge data and their geological significance.

The methodology used has provided us with qualitative information, with varying degrees of rationality and from different depths, but which cannot be quantified by themselves. These filters can provide information about local and surface effects (residual maps, “high pass filters”), medium depth structures (through “band pass filters”), and deep structures (“low pass filters”). Principles of trend surface analysis are also applicable to hyper-surfaces in any dimensions.

A surface occupying a three-dimensional space is a mathematical function with a dependent variable and two independent variables. We can operate mathematically with four or more variables that are of major importance in applications where we want to investigate more geological or geophysical parameters.

Viewing spatial relationships in a three-dimensional space is very difficult. The best method is to assign a constant value to an independent parameter and to represent the parameter that depends only on two independent parameters, as in the case of trending surfaces. This type of representation is the general trend of the parameter dependent on two independent parameters. Typically, the dependent parameter is a geological or geophysical parameter and the two independent parameters are latitude and longitude.

Also, are presented the results of the mobile averages with different windows compared to the trend surfaces with different degrees, for Assarel area. The analytical expressions of the polynomial trends surface from geomagnetic data were calculated with the least squares method, highlighting the regional trend caused by the deep structures.

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Organizing and multi-criteria's analysis of database from Surlari Geomagnetic Observatory

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In this paper we designed a way of organizing the data base of the Surlari Observatory in order to analyse geomagnetic field's morphology. We have the geomagnetic data base for the entire period of activity from 1943 to the present for observatory. The scanned magnetograms from the analogue acquisition period have been digitized and reviewed, identifying all types of variations with different periodicities. From the entire dataset resulting from the processing of the geomagnetic field component records, several time series with different sampling rates were selected to be subjected to statistical and spectral studies. The sampling rates were chosen based on the maximum resolution of the acquisition systems and the length of the time series that have been analysed. In the case of analogue magnetograms recorded between 1943 and 1999, the maximum temporary resolution that can be reached is 3 minutes, but because the need to standardize the processing requires either the processing of the average values per minute or of the hourly averages, for these records we used the average hourly values of the components recorded.

Digital records during the period 1999-2009 have a sampling rate of 0.2 Hz and after this date to present day the rate was 2 Hz for the three-axial components and 0.2 Hz for the scalar value of the total field F. These sampling rates allow the average values to be calculated per minute for this period.

Thus, the data used to study the variations of the geomagnetic field with large periodicities are presented in the form of a series of average hourly values covering 1958–2006. These were calculated annually on the basis of definitive data for both analogue and digital recordings. Was processed, providing a long, almost continuous series of information (about four solar cycles).

For studying of diurnal, semi-diurnal and aperiodic variations (geomagnetic storms, SSC or SFE phenomena), a series of average values per minute were used for the entire period of digital recording in our observatory. In order to study periodic frequencies with higher frequencies we used records of the gross values of the components of the geomagnetic field with a sampling rate of 2 Hz covering generally periods of up to 24 hours. For all three components there is an ascending trend that is observable for the whole period. This trend represents the secular variation of the analysed components.

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Regional macroseismic field of the May 24, 2017, Bulqiza earthquake in Albania

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Reported effects for some earthquakes were statistically analyzed to extrapolate European Macroseismic Scale intensities (EMS-98) (Grünthal, 1998). Data were collected through an internet macroseismic questionnaire available at the website managed by IGEWE. A macroseismic investigation of the May 24, 2017, Ms=4.7 Bulqiza earthquake, in northeastern Albania, were carried out through an online web survey. The procedures are still in development and require refinement. A statistical analysis is applied to the data collected in order to investigate the spatial distribution of intensity of Bulqiza earthquake. The macroseismic intensity field (I) was described by identifying three main components: an isotropic component, a regional anisotropic component and a local random variations parameter (De Rubeis *et al.*, 2016). Map of macroseismic intensity for May 24, 2017 earthquake is compiled and later is continuously updated from others information. The final result is the definition of a particular intensity degree. Results of medium-low magnitude earthquakes are here presented showing the ability of the method in giving fast and interesting results. Effects reported in questionnaires coming from towns and villages are analyzed in deep. The attenuation of Intensity from the epicentre of May 24, 2017, Bulqiza earthquake show high attenuation in the north and south of the Bulqiza as opposed to a low attenuation on the other side in the east and west due to different crust properties (Ormeni, 2013). The attenuation or amplification anomalies receive, from web-based surveys, an enhanced possibility to be detected. The aim of this paper is to give insight into the concept of a community-based map creation process in the context of earthquake intensity estimation. This paper give a fast way for assessment of intensity, of attenuation function for intensity of this earthquakes, intensity isoseismic map and will be a proposal for the basis of an automatic system for assigning EMS-98 intensity values to questionnaire data gathered from a web page. From a technical point of view, the whole system is relatively straightforward to establish and use and therefore gives a good foundation for integrating community data into the scientific research.

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Some main aspects of seismic activity during the year 2017

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Albania is situated in Alpine-Mediterranean seismic belt comprising the zone of contact between lithosphere plates of Africa and Eurasia (Aliaj *et al.*, 2010). We present here the results of the analysis in parameters of events and some features of the seismicity, which have occurred in Albania and its surrounding area during 2017. In 2017 the seismicity of Albania is characterized by intense seismic microactivity (1.0 <M=3.0), many small earthquakes (3.0 <M=5.0), and two medium earthquakes (5.0 <M=7). On that territory (39.0–43.0N - 18.5–21.5E), 660 earthquakes were located, 6 of them were felt by population of Albania and three of them caused light damages in epicentre zones. The most of the local earthquakes (~97%) are distributed in depth between 0 km and 25 km. The upper and middle crusts are the most seismoactive layers in the lithosphere beneath Albania (Ormeni, 2010). The earthquake foci are concentrated mostly along the active faults and low velocity zones, as follows:

The Vlora-Lushnje-Elbasan-Dibra transversal fault Zone. It belongs to a complex faulting environment and low velocity layers (Ormeni *et al.*, 3013). In this transversal fault zone were located 187 earthquakes with magnitude ranging from 1.1 to 4.8 (Richter), one of them (ML 4.8) was felt and caused slight damages in the epicentre zone.

The Himara-Borshi- Kardhiq seismogenic Zone. There are faults and flexures, expressed with contrasts in relief (Aliaj *et al.*, 2010). In this fault zone were located 26 earthquakes with ranging magnitude from 1.8 to 4.1 (Richter), and one of them was felt.

The Kurbnesh-Skavica seismogenic Zone. It lies in the area of inner Albanides, along a digressional zone of faults. There were located 35 earthquakes with magnitude ranging from 1.5 to 5.1 (Richter). A moderate earthquake M=5.1 occurred in 3 km NE of Kurbneshi, with Intensity I0 = VII degree EMS-98. The latter was felt along northern and middle Albania and caused slight damages in the epicentre zone.

Significant increasing of seismic activity was registered in southeastern Albania on the F.Y.R.O.M territory. A moderate earthquake M=5.1 occurred in Ohrid Lake area, around the F.Y.R.O.M/Albania political border, on Saturday 3th of July, 2017. The main shock was followed by a series of aftershocks to magnitude ranging 1.5–4.1 (Richter), with Intensity I0 = VII degree EMS-98, and these were felt along southern and middle Albania.

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The subsurface structure of the Osterhorn Mountains: How to create a large-scale flat-lying nappe complex in a mountain belt?

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Fold-and-thrust belts form within a variety of structural settings in terms of their geometry, basement architecture and nappe thickness. Most of them are showing a classical anticlinal and synclinal structure, with a distinct pattern of thrust faults. Major portions of virtually undeformed flat-lying nappes are rare in mountain belts and would need, as a conceptual model, very special conditions for its formation in contrast to classical thin-skinned fold-thrust belts.

The Osterhorn Mountains within the Northern Calcareous Alps represent an example for such a flat-lying structure. It shows a largely subhorizontal and undisturbed bedding of the Triassic and Jurassic limestone formations and thus represents a special feature within the highly folded and imbricated Northern Calcareous Alps. Due to its geological structure, the Osterhorn Mts. were an area of intense seismic exploration of OMV AG in the late Seventies and early Eighties of the last century with the goal to find potential oil traps and reservoirs along the migration routes at the base of the alpine nappe units. The exploration campaign gathered a dense network of seismic profiles in the area of the Osterhorn Mts., which reaches a depth of more than 10,000 meters and provides an insight down to the autochthonous basement and autochthonous Cenozoic Molasse cover overridden by the alpine nappe stack.

In our study we assume a causal link between the subhorizontal bedding of the Osterhorn-Tirolic nappe and the underlying Bajuvaric nappe as well as the autochthonous and thrusted allochtonous Molasse basin. On the basis of the seismic data, we create a conceptual three-dimensional underground model to figure out the deep structure of the Osterhorn Tirolic-nappe and the subjacent formations. The interpretation of the area between the Bajuvaric nappe and the crystalline basement is considered as a key zone in the structural geological development of the Osterhorn Mountains. As a result of the proximity of these layers to the décollement of the Alpidic thrust unit, the assignment of the seismic structures to a realistic geological bedrock model requires a complex interpretative work. This three-dimensional model is used to determine the special conditions for the subhorizontal bedding like a stiff undeformable backbone, an extremely weak zone of shearing at the base of the thrust sheet and potentially a subhorizontal underground.

Comparative analyses of data recorded in different planetary geomagnetic observatory

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In this paper we present several applications, examples and results of the statistical and spectral methods of analysis of the geomagnetic data. For this purpose, we used methods and algorithms as numerical derivation in time, polynomial regression, correlation factor determination, spectral analysis and wavelet analysis. With these algorithms we have been developed work's program sequences in MatLab and AutoSignal to study the geomagnetic field morphology and to determine the spectrum of geomagnetic phenomena at different time intervals.

In the comparative analyses we used the definitive geomagnetic data recorded in six observatories located at different latitudes and longitudes, in periods of geomagnetic perturbations. Also, we used the data recorded at the Surlari Observatory at a frequency of 2Hz to identify correlations occurring between the high frequency oscillations of the geomagnetic field components over a 24-hour period (172800 samples).

Through derivation on time, the removal of periodic components is achieved and geomagnetic disruptions are clearly highlighted. Another way to analyse the signal is by correlating multiple sets of data using the correlation factor for a two-dimensional series of data. The correlation factor was calculated for a mobile window containing 10 pairs of values (xi,yi). This mobile window was moves step by step on the entire signal, with the one sample. Thus, the correlation factor can be calculated for each sample, in the middle of the window.

The correlation factor shows significant increases when there are causal relationships between two time series as in case of geomagnetic storms. If we have n recorded parameters, as time series, we can calculate correlation indices for n*(n-1)/2 two-dimensional pairs. A geomagnetic storm occurs simultaneously in observatories spread all over the world but with different amplitudes. The increase of the correlation factor is observed between the components of the geomagnetic field, recorded in different observatories.

Another way of processing the data we used was spectral analysis of the signals. Through spectral analysis performed with Fast Fourier Transform, a temporal signal is decomposed into real and complexes parts. This transform provides a complete spectre of the frequencies that make up the signal, but it does not keep any information as to when these occur. Also, we performed a wavelet analysis that gives us additional information about relation between frequency and time of occurrence.

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The density of lithostratigraphic formations of the Western Carpathian tectonic units (Slovakia case study)

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The nature density value of the geological objects is an essential premise in 2D and 3D gravimetric interpretation. Geological structure of the Slovakia is divided into the External Western Carpathians (EWC) and the Internal Western Carpathians (IWC). EWC represent the Flysh Belt and the Pieniny Klippen Belt units. IWC includes of the Lower Group of nappes (Vahicum and Tatricum tectonic units), Middle Group of nappes (Hronicum, Fatricum and Veporikum units) and Upper Group of nappes (Gemerikum, Meliatikum, Turnaikum and Silicikum units). Overstep complexes are represented by the Cainozoic sediments and volcanics. Collected available data are processed in the lithostratigraphic columns of relevant tectonic units with represent natural, matrix and dried sample densities for particular lithostratigraphic formations. The final output is the map of the tectonic units of the Western Carpathians with the values of the natural densities of the individual tectonic units. The presented map can serve as the principal background in geosciences interpretations.

Early to middle Pleistocene glaciofluvial terraces along the North Alpine Foreland: What do they tell us about glacial and mountain range dynamics?

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Remnants of glaciofluvial sediments in the North Alpine Foreland may host first order information on glaciofluvial processes of Quaternary climatic change. Outwash formation and preservation in the foreland region of the Alpine mountain range are not only a function of (factors related to) climatic variabilities. Other factors relate to the elevation distribution of the drainage basins (*i.e.*, the hypsometry), controlling for example: i) the volume of glaciers and thus the extension of outwash or, during times of relative glacier absence; ii) the fluvial stream power which in turn impacts the preservation potential of terrace bodies. While major climatic deteriorations (*e.g.*, glacial maxima) impact the northern Alps and its foreland rather in a uniform way (some west – east precipitation gradient), major hypsometric variations appear more distinct along the belt.

Since the ground-breaking work of Penck and Brückner (1909) almost no further studies attempted to establish a model where site-specific observations are fitted in a range-scale model. It turned out that the original model, suggesting a four-fold glacial model where ice advances in the North Alpine Foreland, cannot explain various local records. For example, while glacial and glaciofluvial deposits seem to cover the Early Pleistocene or even Pliocene in the West Alpine Foreland but without connection to glacial landforms, the situation is different in the eastern part. Ice marginal deposits of not only the LGM, but two to three earlier glacial maxima can often well tied to outwash deposits (the older the higher), but evidence of Early Pleistocene glaciofluvial deposits (or even older) is sparse or not existing – including absolute age information. Most studies therefore tend to develop models from a local perspective, neglecting Quaternary variations in glacial advance along the belt. The development of ideas to integrate local findings and relative age constraints into a regional model is therefore highly needed to better understand factors and feedbacks acting on Quaternary glacial advance and retreat cycles on a regional scale. The lack of absolute age data is a further major issue in most stratigraphic studies (dealing with deposits exceeding the feasible luminescence age range) but local depositional characteristics generally allow establishing relative age models (*e.g.*, through biostratigraphy, terrace elevation range, degree of weathering).

In this study we aim to compile data of pre-LGM outwash (*i.e.*, terraces) of the entire North Alpine Foreland to provide a discussion basis for an overall stratigraphic model and to better evaluate larger forcing scenarios (i.e. better understand driving factors/mechanisms). In this context the study also aims to suggest key areas for future dating campaigns. For this study we establish a database including the available glaciofluvial outwash deposits from different Swiss, German and Austrian sources. Mapped surfaces are cross-checked against (high-resolution) DEM data and, if available, supported by outwash base data. Terrace remnants serve as constraints to establish palaeosurfaces and evaluated regarding its distribution across the foreland. Moreover, processed data allows better evaluating the role of non-climatic factors in terrace distribution, like the role of base level variations (Danube *vs*. Rhine), ranging specific characteristics in topography and tectonics (Eastern *vs*. Western Alps) or shifts in the (tributary) drainage systems.

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Burial dating of cave sediments reveal uplift/incision at the Carpathian-Alpine border (Hainburg Hills)

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The Hainburg Hills are located in the East of Austria where they form an elevated range that separates the Vienna Basin from the small Hungarian plain or Danube basin. They are part of the Internal West Carpathians and consist of Variscan magmatic and metamorphic rocks covered with weakly metamorphic Mesozoic sediments - mainly Triassic limestone and dolomite as well as breccia of Jurassic age.

Bad Deutsch Altenburg is a village west of Hainburg Hills that is well-known for its thermal sulfuric spa since Roman times. Some 30 karst caves are mapped in the area, most of them were opened during quarrying and show signs of a hydrothermal or sulphuric acid speleogenesis. One more than 15 m wide and 20 m high cave chamber was excavated in an active quarry recently. It was completely filled with sediment that contains large well-rounded quartz cobbles in a flashy red matrix. The fine-grained matrix is poorly sorted with more than 30% clay (<2 µm) and consists of quartz, muscovite, and albite. In addition, analysis of the clay fraction identifies kaolinite, illite, and smectite. The occurrence of smectite in combination with the fine grain size most likely indicates soil forming processes that result in an increase in fine material due to formation of new minerals in the B-horizon. Therefore, we conclude that the fluvial gravels – which are similar to modern ones of the Danube River - were transported into the cave together with a matrix originating from a soil cover.

In-situ produced cosmogenic ^{10}Be and ^{26}Al in quartz can be used to calculate the time of shielding from cosmic radiation (burial age dating) in an age range between 0.1 and 5 Mio years. This method was performed on five Quartz cobbles to determine the time when the sediment and the matrix were deposited in the cave – most probably when the cave chamber was opened by surface erosion.

We assume that at the time of gravel emplacement, the cave level was at or close to the river level. Today the base of the cavity is 150 m above the Danube, thus the relative incision/uplift at the Hainburg Hills may be calculated. In addition, so-called calcite rafts that form only at the surface of cave pools were sampled at a lower cave level and dated using the U/Th disequilibrium method. Age calculations using the isochron method give an age of 3.8±0.4 Ma of gravel deposition, thus an incision/uplift rate of 36–44 m/Ma.

Session GT10-1

Mineral Deposits in the ABCD Region

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The Poldasht magnesite (W Azerbaijan, NW Iran) – a new type of magnesite deposit

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The Holocene magnesite deposit NW of Poldasht (W Azerbaijan, Iran) includes up to 12 m thick fine-grained, less consolidated magnesite covering basalt flows from Mt. Little Ararat. The surface of the basalt flows thereby forms two shallow basins (about 1 km^2), which are characterized by magnesite and small playa lakes. Sedimentation of magnesite started 5342±21 years BP, constrained by C^{14} age determination. Field observations indicate ongoing or modern magnesite precipitation. Magnesite, basalt and water samples were collected in order to unravel the mineralogical and (isotope) geochemical composition, and thus the type of magnesite deposit.

Mineralogical investigations revealed that the deposit mainly contains magnesite together with montmorillonite, dolomite and albite. Organic matter of plants and angular lithoclasts – reworked basaltic and pre-Quaternary metamorphic and volcanoclastic material from the hinterland – are disseminated within the fine-grained magnesite. Major element analyses of the magnesite sediment yield MgO and CaO contents between 35.1 to 44.4 wt.% and 0.9 to 9.4 wt.%, respectively. Distinct contributions from silicates are indicated by SiO_2 (3.2–19.3 wt.%), Al_2O_3 (0.3–3.4 wt.%) and Fe_2O_3 (0.1–1.5 wt.%) contents. Stable isotopes of the Mg carbonates span wide $\delta^{18}O_{V\text{-}PDB}$ and $\delta^{13}C_{V\text{-}PDB}$ range from –6.79 to +1.01‰ and from 0.99 to +5.06 ‰, respectively. The obtained Mg isotope values ($\delta^{26}Mg_{DSM3}$) range from –1.04 to +1.01‰ for the magnesite, and between +0.55 and +2.59‰ for ambient waters.

The comparison of the mineralogical and (isotope) geochemical data with well-known global types of magnesite (*e.g.*, Veitsch, Kraubath, Bela Stena type) highlights Poldasht to be an until now unknown type of a magnesite deposit characterized by (i) its Holocene age, (ii) basalt related Mg source of the mineralizing fluids, and (iii) its formation in a evaporation-controlled playa environment. This setting of magnesite formation is likely triggered by seasonal and/or climatic changes, which influence water conflux, evaporation and thus precipitation.

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Olivine-spinel re-equilibration in chromitites from the Alpine-Dinaride region

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The crystal structure of spinels allows a wide range of cation substitutions, both in tetrahedral and in octahedral sites. In particular, when chromite is associated with olivine, these two minerals exchange Mg and Fe^{2+} ions under sub-solidus conditions. The exchange is temperature-pressure dependent. The dependence from T and (to a lesser extent) P, was used for the calibration of the olivine-spinel geothermometer (Ballhaus *et al*., 1991), for the calculation of the re-equilibration temperature of the system.

The application of this method depends on sub-solidus ions diffusivity, and in particular the possibility to reach equilibrium compositions. Usually, it is assumed that the equilibrium compositions of chromites and olivines are those analyzed close to intergranular borders. In order to better understand the spatial distribution of Mg and Fe^{2+} within these two minerals, we investigated their diffusion as a function of the distance from intergranular limits, with the aim of extending geothermometer applications to rocks with variable chromite to olivine ratios.

For the evaluation of Mg-Fe^{2+} diffusion, we selected chromitite ores from two different geological contexts, characterized by fresh chromitites and dunites. The first area is located in the Finero Complex, Northern Italy, where sub-continental mantle peridotites host fresh chromitite bodies enveloped by dunites. The second area is the Iballe chromite mine, Northern Albania, where fresh chromitite bodies are hosted in the mantle section of the Mirdita Ophiolite.

Mg and Fe^{2+} distribution between chromites and olivines was investigated through grids of EMP analyses (usually 7 × 7 or 9 × 9 with a mesh size of 0.1 or 0.2 mm) at variable chromite to olivine ratios. The simplest configuration, a tiny euhedral chromite grain surrounded by olivine, was used to model the ion diffusion curve in olivine. The Mg and Fe^{2+} concentrations are constrained by two boundary conditions: their values at the boundary and for a distance that tends to infinity. The best fit was attained using two curves: a hyperbole far from the boundary and an exponential close to the grain boundary, which can be used to infer re-equilibrated compositions, and hence temperatures. The same mathematical model, applied to chromitites, allows extrapolating two different compositions, re-equilibrated and primary (magmatic?).

This statistical methodology provides a way to derive re-equilibration compositions, and subsequently temperatures of accessory spinel-bearing rocks more reliable than the usual approach based on analyses close to the boundary. It can be applied also to rocks that underwent widespread serpentinization, a common feature in podiform bodies within ophiolites. Finally, when applied to chromitites, it also returns primary compositions of both spinel and olivine allowing to deduce a primary, possibly magmatic, temperature.

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Metallogenic features of chromitite mineralization related to ophiolitic assemblages, Western Balkan

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Western Balkan ophiolites represent a very important geological feature of southeastern segment of folded Mediterranean region, being part of the Late Jurassic Tethyan ophiolitic belt. They extend from near Zagreb in the northwest through Central Serbia, Kosovo, Albania, Macedonia to South Greece, along about 1000 km. Some ophiolitic belts are composed of several massifs of variable size, ranging from several to more than 500 km^2. Their composition varies from mostly lherzolite in the northwestern area (Zlatibor, Maljen massifs), through lherzolite-harzburgite in the south-eastern areas (Troglav, Ibar massifs) up to hartzburgite-dunite (Brezovica, Rahovec, Tropoj-Gjakova, Luboten-Radusa, Lojane, Kukesi, Bulqiza, Shebenik-Pogradeci massifs; Pindus, Vourinos and Othris in Greece). The lherzolite and lherzolite-hartzburgite massifs are distinguished by higher content of Al_2O_3 (3–5 wt%) and low content of MgO, while in the hartzburgite-dunite massifs the content of Al_2O_3 is low (0.3–0.6 wt%). The latter are composed of Mg-rich forsteritic olivine (Fo_{90}) 75–85% and enstatitic (En_{90}) orthopyroxene. This compositional variation is conditioned by the different melting degree of the upper mantle, from very low (close to primitive mantle composition) up to high and very high (20–25%), which is characteristic for hartzburgite-dunite massifs that represent extremely depleted peridotites.

In addition, the Western Balkan ophiolites are also distinguished by chromite mineralization. In particular, the chromite concentration is very high in southern Kosovo, Albania and northern Greece (Çina, 2010, Economou *et al*., 1986). The distribution of chromite mineralization, its relation with different ultramafic formations, the morphology, size and grade of the ore bodies, and the chromite composition correlate with variation of the composition of ultramafic massifs. Thus, chromite mineralization is absent or scarce in lherzolitic massifs and belongs to the Al-rich-type, while it is abundant in the hartzburgite-dunite massifs and where it belongs to the Cr-rich-type (Cr/Cr+Al = 0.78–0.82). The eastern ophiolitic belt of Albania is an exception among the Tethyan ophiolitic belts due to its very high abundance of chromite mineralization. There hundreds of occurrences and deposits are known, some of them having only about 1 million tons, while the Bulqiza-Batra deposit represents the bigest one; about 25 million tons of chromite ore were mined from this deposit (Alliu *et al*., 1996).

The chromite mineralization is situated in upper mantle hartzburgite-dunite, in dunite-hartzburgite of the transition zone and in dunite of the supra MOHO zone. Only limited chromite (Al-rich and Fe-rich type) mineralization is hosted in the ultramafic cumulate sequence. The ore bodies have typical podiform shape, as long known for Alpine type ophiolites (Thayer, 1960). In general, many ore bodies are tabular, often folded, pencil-like to even vein shape. The ores have massive, dense disseminated and nodular textures and are high grade (40 up to 50% Cr_2O_3) while the chromite is Cr-rich and of the metallurgical type. The ore bodies hosted in the dunitic cumulate section are “pseudostratified” and composed of disseminated, thin banded and schlieren textured chromite, while the ores are of low (15–25% Cr_2O_3) grade.

Another particular mineralization that is not characteristic for Alpine type ophiolities is PGE. Some occurrences and small deposits are known in the Albanian ophiolitic belt. One type chiefly of Pt-Fe alloy is related to pyroxenite dikes and Fe-rich chromite, the other one is related to disseminated Ni-sulfides in supra MOHO dunites, while the third type is found in chromitite in ultramafic-mafic cumulates. The PGE content ranges from 2000–3000 to 10000 ppb.

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Trace elements of the Aleksinac oil shale, Serbia

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Apart from conventional petroleum reserves in the Pannonian Basin, Serbia has significant oil shale resources in a number of small Cenozoic basins. They are situated in the central and south part of the country, including Carpatho-Balkanides. All oil shales are of lamosite type, deposited in lacustrine environment from Paleogene to Miocene. Due to its excellent quality, thickness and significant resources, Lower Miocene "Aleksinac" oil shale deposit is the primary one considered for exploitation and petroleum production processing.

Since oil shale retorting for petroleum production is not only an economic but also an environmental issue, we have analyzed, by ICP-MS, concentration of 56 trace elements and sulfur in the surface samples of Aleksinac oil shale, including all potentially toxic (As, Be, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Se) and radioactive elements (U, Th). We have also performed Rock Eval 6 pyrolysis of the samples to obtain total organic carbon content (TOC), mineral carbon content (MinC) and carbonates type. Diagrams mostly show that calcite is the predominant carbonate mineral with decay temperatures between 763 and 843 °C.

Trace elements were divided into several groups, according to ICP-MS results, and then studied in detail to check correlation with TOC (organic matter) and MinC (carbonates). The results for all elements were finally compared to average and reference values of various globally occurring oil shales, black shales and argillites. It is concluded that there is no abnormal concentration of any potentially toxic trace elements, and that sulfur content in analyzed samples is very low (< 0.13 wt.%). Average concentration of Th (9.24 ppm) and of several other trace elements are higher than average global values for oil shales, but not above those in argillites or black shales. Based on the first ICP-MS results presented here, it can be concluded that surface exploitation and processing of the Aleksinac oil shale would not impose higher environmental risks compared with those of the reference oil shales, especially concerning average concentrations of As (25.47 ppm) and U (4.25 ppm).

TOC of analyzed samples is up to 13.1 wt.%, while MinC is in the range between 0.36 and 7.33 wt.% (3.0– 61.1 wt.% of calcite equivalent). Concerning the correlation of trace elements with TOC, only Ca and Mg show strong positive correlation with organic matter. Most other trace elements show either no correlation or negative correlation with carbonates. Strong negative correlation with MinC was found for Cu, Pb, Zn, V, Ba and Ag. Radioactive elements U and Th show no correlation with both TOC and MinC.

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Geochemical characteristics of prograde Pb-Zn distal skarns in the Madan ore field, Bulgaria

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The chemical evolution of the Pb-Zn mineralization in the Madan ore field has been associated with the onset of early Oligocene extension-related magmatism in the Central Rhodopes of southern Bulgaria (Marchev *et al.*, 2005). The primary ore occurs as sulfide replacement of distal skarn bodies that formed at the intersection of regional scale mineralized normal faults with marble horizons in metamorphic basement rocks. Skarn formation has been constrained between 29.95 and 31.22 Ma (Kaiser-Rohrmeier *et al.*, 2013; Hantsche *et al.*, 2017).

The prograde assemblage of the distal skarns in Madan is dominated by Mn-rich pyroxene aggregates. These skarn bodies developed outward from the mineralized faults, extending irregularly into marble lenses at the decametric scale. At the Petrovitsa deposit, such a skarn-vein relationship was mapped and sampled to study the geochemical evolution of the distal skarn system with distance from the local source of fluid and heat. Sections of preserved prograde skarn were sampled for bulk rock chemical analysis, petrography, and silicate geochemistry to better understand local chemical evolution that occurs during formation of distal skarn systems.

Concentric growth bands in the radial pyroxene aggregates are observed at the hand sample and microscopic scale, and result from variations in grain size and chemistry. Data from Electron Microprobe Analysis (EMPA) are presented to show variations in major element silicate geochemistry both at the thin-section and outcrop scale away from the vein. Results indicate alternating chemical compositions in the bands, cycling between Fe-rich pyroxenes, which are typically fine-grained (~1mm), and coarser, Mn-rich pyroxenes (~0.5 to 5 cm). Calcium data from the EMPA have been used as an internal standard for LA-ICP-MS trace element analysis.

Preliminary trace element data on pyroxenes suggest decrease in Zn with distance outward from the core of the pyroxene spheroids (Bovay *et al.*, 2015). Ongoing studies of the trace element composition of pyroxenes from the Petrovitsa Pb-Zn skarns will be presented here, with a focus on chemical changes at the outcrop scale. Continued study of the variations in major and trace element geochemistry will unlock new insights on element distribution and ore mineralization in distal skarn systems.

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Stanniferous W-(Sn) skarn mineralisation near to Felbertal tungsten mine, Tauern Window, Eastern Alps

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The scheelite exploration target Messelingscharte (Eastern Tyrol, Austria) is located about 8 km SSE of the world-class Felbertal tungsten deposit. The W-(Sn) mineralisation occurs in Early Palaeozoic amphibolites (Basal Amphibolite unit; Basisamphibolit) close to the contact with the overlying Basal Schist (Basisschiefer) in the central Tauern Window of the Eastern Alps. Variscan orthogneisses of different age and source are exposed nearby; *i.e.* Felbertal augengneiss, 338.5±1.3 Ma, εHf_t –6.8 to –5.3; Granatspitz gneiss, 314±18 Ma; εHf_t –3.1 to +2.5 (Kozlik *et al*., 2016b).

Geological mapping and regional geochemical sampling including re-evaluation of work undertaken during the 1970s identified three types of scheelite mineralisation: (1) Sn-bearing clinozoisite-scheelite skarn; (2) Deformed scheelite-quartz veins; (3) Scheelite in mylonitic quartz-amphibolite layers. The most important mineralisation type is the Sn-bearing clinozoisite-scheelite skarn of pre-Alpine (Variscan?) age. It occurs as metre-sized irregular pods within amphibolites and amphibole schists. The skarn-like rock is composed of major clinozoisite, quartz, and plagioclase with minor/accessory scheelite, titanite and chlorite. Analyses of random pick sample reveal high concentrations of the granitophile elements W (up to 7.7 mass% WO_3), Sn (up to 1250 ppm SnO_2), Be (up to 41 ppm) and base metals (Cu, Pb, Zn; $\sum \leq 2500$ ppm) in the skarn rock. Compared to the amphibolite host rocks Ca and LIL elements are enriched whereas less mobile Mg, HFS elements (Ti, Nb, Zr, Hf). The flat REE patterns show LREE depletion, a marked positive Eu anomaly and flat to increasing HREE.

The unique feature of the investigated W-(Sn) skarn is the association of scheelite with Sn-bearing silicates. Stanniferous clinozoisite and stanniferous titanite were identified as the main Sn carriers (clinozoisite ≤3.00 mass% SnO_2; titanite ≤6.48 mass% SnO_2). Substitution of tin is controlled by the following substitution: $2(Al,Fe)^{3+} = (Sn,Ti)^{4+} + (Fe,Mg,Mn)^{2+}$. Clinozoisite as well as titanite were affected by metamorphic re-crystallisation; *i.e.*, they are of pre-metamorphic origin. Three scheelite types are distinguished based on micro-textures, zoning, Mo-content and UV fluorescence. They show intriguing similarities to scheelites of Felbertal deposit where pre-Alpine Mo-bearing scheelite of magmatic hydrothermal origin was apparently overprinted by two stages of metamorphism (Kozlik *et al*. 2016a).

The W-(Sn) skarn formed by interaction of water-rich fluids of likely magmatic-hydrothermal origin with metabasite host rocks. The clinozoisite-dominated calc-silicate rocks are interpreted as a metamorphosed distal W-(Sn) skarn, a mineralisation type that has not been reported from the Eastern Alps before but is known as a rare skarn type *e.g.*, from some Cornish Sn skarns (van Marcke de Lummen, 1986).

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Exploration of lithium and borates in the area of the Valjevo – Mionica basin (Serbia)

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The preliminary results of exploration of lithium and borates in the area of the Valjevo – Mionica basin in western Serbia indicate that Li-B mineralization there occurs in roughly east-west trending structural troughs/basins associated with the Vardar zone. The target basins are host to Neogene aged, layered lacustrine sediments. Locally the basins contain significant lithium and borate mineralization. Lithium was so far only detected in clay minerals, while boron occurs in searlesite and probertite and/or pseudomorphs after other borate minerals. The basins of potential economic interest are those that contain continental lacustrine sediments of Neogene age. The Lithium zone is located below the Borate zone in the "Bela Stena" formation (claystone, marl, dolostone).

However, these targeted strata are typically covered by younger sediments, thus making exploration more challenging. Most of the central parts of these basins were mapped as Miocene sediments of the upper, middle and lower M_2 zone. Stratigraphic units, as described, are composed mainly of pelitic sediments, sandy clays and, subordinately, coarse clastic rocks. Targeted horizons are tuffaceous sediments ranging from claystone to siltstone to fine sandstone. These horizons are dolomitic and contain intercalations of marl and coarser sands. Thin ash fall tuffs are noted within the prospective section and are used as marker horizons to correlate drill holes. The section immediately overlying the targeted mineralized strata in the Valjevo-Mionica basin is also comprised of mostly pelitic lacustrine sediments that coarsen eastward as based upon the results of the two holes drilled to date in the adjoining Ljig basin. Mineralised strata are again mostly covered by younger sands, silts and clays.

Acknowledgements. Our company Euro Lithium (GeoMin Consulting) is currently exploring lithium and borate resources of this basin and so far we had positive results.

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Mineral chemistry of sulphides from the produced concentrates of the Olympias-Stratoni mines (Chalkidiki, Greece)

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The Kassandra mines are located in the Chalkidiki peninsula, Northern Greece. Presently, production is being held in Olympias mine and Stratoni mines comprising of two deposits; Madem Lakkos and Mavres Petres. There is a long history of mining in the Kassandra area. It has been estimated, from the volume of ancient slags, that about 1 million tonnes of ore were extracted during the classical Greek period and that the Stratoni mine continued production through the Roman, Byzantine and Turkish periods. Currently, the Kassandra mines produce mineral concentrates of pyrite/arsenopyrite, galena and sphalerite.

Sulphide mineralization occurs within amphibolite facies metamorphic rocks of the Kerdylia assemblage. The assemblage represents a metamorphosed marine sedimentary-volcanic sequence of probable Mesozoic or older age. Eocene and Oligocene granitic intrusions occur throughout the Kerdylia sequence, mainly as pegmatite and granite dykes of several generations that were emplaced syn- to post-metamorphic. The Kerdylia sequence was affected by syn-peak metamorphic penetrative deformation, which is manifested by a dominant, shallow dipping layer-parallel foliation. At least two other foliation-forming events affect the sequence with progressively less strain, as well as significant late extensional faulting.

Mineralization at Olympias and Stratoni is of the carbonate replacement type. It occurs in association with a marble horizon. Mineralization is structurally late and is superimposed on the metamorphic fabrics in the area. It is associated with an extensional, brittle to semi-brittle fault network that was likely active coevally with the ore-hosting Stratoni Fault to the south.

Back-scattered electron (BSE) images and microprobe analyses of minerals were made by a JEOL 8200 electron probe micro-analyzer (EPMA) equipped with a wavelength dispersive spectrometer (WDS) at the University of Milan, Italy.

The chemical formulae of the minerals in their relevant concentrates were calculated as following: galena (Stratoni Mine): $Pb_{0.975–0.990}Zn_{0.000–0.004}Mn_{0.000–0.002}As_{0.000–0.001}S$; sphalerite (Stratoni Mine): $Zn_{0.788–0.845}Fe_{0.118–0.167}Mn_{0.006–0.010}Pb_{0.000–0.001}S$, pyrite (Olympias Mine): $Fe_{1.019–1.051}As_{0.000–0.033}Pb_{0.000–0.001}Zn_{0.000–0.001}S_2$, arsenopyrite (Olympias Mine): $FeAs_{0.848–0.878}S_{1.065–1.131.}$ Also, boulangerite was detected in the pyrite/arsenopyrite concentrate, with microprobe analyses revealing the following chemical formula: $Pb_{5.182–5.253}Sb_{4.214–4.449}As_{0.058–0.154}Fe_{0.040–0.154}Zn_{0.000–0.063}Mn_{0.010–0.020}S_{11}$.

Ongoing research is targeting the determination of trace element concentrations focusing on the those elements that are considered as critical raw materials (CRM) by the EU (Godelitsas *et al*., 2015).

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Au-Ag-Bi mineralization at the Assarel porphyry copper deposit (Srednogorie metallogenic zone, Bulgaria)

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The Assarel porphyry copper deposit is located in the Panagyurishte ore district of the Srednogorie structural-metallogenic zone of Bulgaria, part of the Late Cretaceous Apuseni – Banat – Timok – Srednogorie magmatic and metallogenic belt. This metallogenic belt contains several porphyry Cu and epithermal Au-Cu deposits characterized by anomalous Bi-Se-Te-Au signatures with Bi- and Se-bearing trace minerals and Au- and Ag-tellurides most abundant in the main Cu-stage bornite and chalcopyrite paragenesis (Bogdanov *et al*., 2004), and in the quartz-pyrite-chalcopyrite±molybdenite mineral association (Popov *et al*., 2000). The Assarel porphyry Cu deposit is related to Late Cretaceous granodioritic subvolcanic rocks that intrude Palaeozoic granitoid basement and Late Cretaceous volcanic deposits. The mineralization is present as impregnations and veinlets of chalcopyrite, bornite and pyrite ± magnetite, molybdenite, bornite and enargite and involves both the dioritic subvolcanic and granitoidic rocks (Bogdanov, 1980).

Several samples (most of them intensely mineralized), taken from drill cores performed in the area of Assarel ore deposit, were investigated by optical and electron microscopy, while mineral composition was measured using energy-dispersive spectroscopy (SEM-EDS). Most samples show alteration dominated by silicification (quartz-pyrite and quartz-hematite-magnetite mineral assemblages) and phyllic alteration (sericite-chlorite-quartz-pyrite mineral assemblage). Argillic alteration overlaps phyllic alteration in several samples or is dominant when kaolinite-alunite is well-developed (advanced argillic alteration). The main ore minerals are dominated by chalcopyrite (fine-grained impregnations and veinlets, stockwork infill) and covellite-chalcocite-bornite (in supergene alterated samples). Galena, idaite, sorosite, greenokite, Au-bearing minerals (gold, nagyagite), Ag-bearing minerals (native silver, acanthite, aguilarite, hessite, naumannite, empressite), Bi-bearing minerals (bismuthinite), and selenide minerals (naumannite, chlausthalite) are present, as micro-inclusions within pyrite, chalcopyrite and in the groundmass. Gold grains commonly show low Ag concentrations (up to 8 wt.%), occasionally higher (up to 36 wt.%). Native copper and copper-tin alloys (up to 9 wt.% Sn) are also present as micro-grains in several sericitized samples. Our study reports the occurrence of several new minerals (acanthite, aguilarite, bismuthinite, greenokite nagyagite, sorosite) for Assarel deposit, and provides indications that precious and rare metals (Au, Ag, Bi, Se, Te) precipitated since the early stages of porphyry type mineralization.

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Geology and ore mineralization at Babyak deposit, Western Rhodope (Bulgaria)

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New data on ore mineralogy, alteration of host rocks and structural analyses are presented for Babyak Ag-Mo-Au deposit in this contribution. They allow distinguishing several tectonic, magmatic and hydrothermal events to which the ore-forming processes are linked. Two main mineralization stages are distinguished that are related to distinct structural events. The early Mo-Bi-Ag mineralization is related to QSP alteration and it is controlled by semi-brittle moderately dipping normal faults, most likely linked to regional detachment faults. The later Au-Pb-Zn-Cu mineralization accompanied by greisen-like host rock alteration is controlled by steep dextral strike-slip and normal faults, probably related to the activity of the regional Ribnovo fault zone and Babyak-Grashevo shear zone. Based on the new data obtained in this study a granitic relationship of ore mineralization is proposed for of the Babyak deposit.

Hydrothermal alteration assemblages and patterns in porphyry copper systems in Romania

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It is well known that hydrothermal alteration assemblages are very important for identification and exploration of porphyry copper deposits. On the Romanian territory, this type of ore deposits is associated with magmatic rocks of Late Cretaceous (in the Banat region) as well as Neogene age (in the South Apuseni Mountains), respectively; both are localised in the western part of the country. Our work provides an overview of the characteristics of porphyry Cu ± Mo ± Au deposits and occurrences from these two regions.

Over the years, different authors (*e.g.*, Boştinescu, 1984; Cioflica and Vlad, 1984; Vlad and Borcoş, 1997), based on metallogenic models, grouped these deposits differently; often a group was named after the most representative deposit or prospect. In some cases, this praxis led to misplacing porphyry copper systems with quite different characteristics into the same class.

Starting with reviewing the features of these ore deposits and occurrences (including the relatively recent explored ones) and focussing on hydrothermal alteration assemblages and patterns, we present data allowing us some considerations on the common features and particularities of these deposits.

Hydrothermal alteration zones have been identified in most of the porphyry Cu systems; alteration mineral assemblages are zoned spatially and temporally. The following hydrothermal alteration types have been distinguished: a) potassic; b) phyllic; c) argillic (intermediate argillic); d) advanced argillic; e) propylitic; f) skarn. Propylitic alteration assemblages occur (more or less well developed) in all the porphyry systems. Skarns are associated with some of the Late Cretaceous porphyry copper systems; they are insignificant in the Neogene belts. It is to note that porphyry-epithermal systems are well represented in the South Apuseni Mountains. Mineralization occurs as dissemination in pervasively altered rocks and within stockwork veins. Chalcopyrite is the dominant hypogene copper-mineral.

The study compares hydrothermal alteration patterns of porphyry Cu deposits in the Late Cretaceous Banat region and the Neogene South Apuseni Mountains. A table summarizing the characteristics of the alterations and mineralizations of these porphyry Cu systems is presented.

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Trace elements in tetrahedrite from Polish Tatra Mountains (Tatric Unit, Western Carpathians): results of EMPA and LA-ICP-MS analysis

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In the Polish part of the Tatra Mountains, tetrahedrite is the most common sulphosalt in hydrothermal ores; it is associated with other subordinate base-metal sulphides (BMS), such as chalcopyrite, pyrite and galena. The hydrothermal siderite-quartz-sulphide mineralization formed during the final stage of the crystallization of granitic magmas from solutions circulating in shear zones (Gawęda *et al*., 2007). EMPA and LA-ICP-MS techniques were used to analyse major and trace element concentrations in tetrahedrite from three locations: Pyszniańska Valley, Ornak slope – "Pod Banie Gully" and Ornak slope – "Piekło Gully".

Chemical analysis of tetrahedrite confirms major variations in As and Sb (As:Sb = 38:62). Small scale variations of these elements were observed as distinct oscillatory zoning visible in back-scattered-electron (BSE) images. Bismuth (up to 1500 ppm of Bi) substitutes Sb/As in the tetrahedrite structure. Contents of Zn and Fe correlate very well with each other. The small deficit of these divalent metals, limited to two atoms per formula unit, is complemented mainly by Hg substitution (up to 1845 ppm). Cobalt and cadmium, also detected by LA-ICP-MS, are present at concentrations less than 500 and 150 ppm, respectively. Other trace elements detected are: Ge, Ga, Mo and Sn are less than 10 pmm; Au and In are less than 1 ppm. According to George *et al*. (2017) these trace elements preferentially partition into the co-crystallising BMS phases. The contents of major and trace elements of tetrahedrite from these three locations in the Tatra Mountains do not differ significantly. Trace elements can be used for assessing co-crystallisation of ore minerals, and thus provide important information for their potential use as sulphide geothermometers (George *et al*., 2016).

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Mineralogical analysis of REE-Zr-Nb mineralized rocks in the Bükk Mts, NE Hungary

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The low grade metamorphic rocks of the Bükk Mts host a recently discovered metasomatic REE-Zr-Nb mineralization. Host rocks are layered metavolcanics and metasediments embedded in limestone. The REE-Zr-Nb mineralization overprints the synmetamorphic deformation features. The characteristic minerals are zircon, REE phosphates and Nb-containing Ti-oxides in sizes smaller than 10 micrometers, associated with potassic feldspars and phyllosilicates. The paragenesis and the enrichment of the high field strength elements corresponds to the mineralizations attached to alkaline magmatism, although there is no any known magmatic source in this case.

The small grain size limits the possibility of optical investigations, therefore we used electron microscopy, EPMA and XRD to determine the mineralogical composition. Heavy HFSE minerals and clay minerals were separated by settling of pulverised subsamples. We used samples of host rock types not affected by the REE-Zr-Nb mineralization for comparison. Mineralogical investigations included diagnostic clay mineral identification and heavy mineral fraction analysis by XRD and EPMA beyond whole rock XRD analysis.

Most abundant alteration minerals of the matrix are phengitic muscovite (1M and 2M1 polytypes) and illite in all host rock types, also potassic feldspars in metavolcanics. Smectite (Mg or Fe-saponite) and iron oxide minerals are present as replacement tipically. The HFSE minerals are disseminated in the matrix. The mineralogy indicates a low temperature potassic metasomatism by an alkaline fluid.

Links between the neotectonic regime and the Tertiary mineralization of the Vertiskos and Kerdylion Units, N. Greece

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Throughout the Vertiskos and Kerdylion Units in northern Greece a wide range of Oligocene–Miocene ore deposits are documented including porphyry, epithermal, skarn, carbonate replacement and intrusion-related vein type mineralisation. Metallogenesis in this region has been strictly related to extension in a back-arc environment operating since the Tertiary.

The area of interest is monitored by a network of 20 permanently installed GPS stations. The processing of the primary geodetic data is based on the triangulation of the GPS stations. In particular, the total of 20 different GPS stations was combined to different sets of three stations. Each set leads to a triangle formation, while each station is located on a triangle vertex. The recorded geodetic data of each GPS station is combined with geodetic data of two other stations, allowing to calculate the maximum horizontal extension and rotation of the triangle centroid, representing the triangle. Based on this procedure, 399 different triangles were constructed within the study area, providing 399 maximum horizontal extension and rotation values.

Based on the extracted maximum horizontal extension values, an interpolation method was applied, leading to the construction of a map including 50 nano-strain step contours, while the maximum and minimum values are 543.5029 and 2.1114 nano-strains, respectively. The exact locations of ore deposits were highlighted onto the aforementioned map in order to examine their possible relationship to the maximum extension values. The results show that the locations of the majority of ore deposits coincide with areas of medium to maximum horizontal extension. Especially, the southern part of the study area exhibits remarkably high maximum horizontal extension values, as a result of the active fault zones of Stratoni-Varvara, Megali Panaghia-Gomati, Sochos and Mygdonia that are active since the Oligocene. Finally, the presented GPS rotational data are in agreement with the published palaeomagnetic data for the study area. In particular, counter-clockwise and clockwise rotations appear in the northern and the southern parts, respectively. A transition zone of zero rotation values is observed inbetween separating the counter-clockwise and clockwise rotation blocks.

Spodumene pegmatites, pegmatites and leucogranites from the Austroalpine Unit (Eastern Alps)

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In the Austroalpine Unit spodumene-bearing pegmatites occur heterogeneously distributed over an E-W distance of more than 400 km. They are usually associated with barren pegmatites which crystallized in Permian time.

There a two schools of thought about the genesis of the spodumene bearing pegmatites: Economic geologists bring forward the argument that these pegmatites only develop by fractionation of granitic parent plutons, whereas metamorphic petrologists consider that the barren pegmatites and even some highly fractionated pegmatites are products of anatexis of metapelitic country rocks. In the first case the virtual absence of co-genetic fertile granites in the Austroalpine units render the model problematic, whereas in the second case the formation of suitable Li-enriched pegmatitic melts is not yet understood.

A new understanding of the Austroalpine basement through geological mapping and geochronological and geochemical investigations during the past few years gives the opportunity to reinvestigate this problem: In Permian time the Austroalpine unit was affected by lithospheric extension, causing basaltic underplating, high temperature/low pressure metamorphism and intense magmatic activity (Schuster and Stüwe, 2008). The Permian P-T-t path is characterized by heating at slightly decreasing pressure.

Sm/Nd garnet ages on barren pegmatites are in the range of 247 to 288 Ma (*e.g.*, Thöni and Miller, 2000). New age data on three spodumene pegmatites yielded 263±8, 265±3 and 268±2 Ma whereas for leucogranites ages of 259 to 287 Ma were determined.

Muscovites from more than 450 samples of barren pegmatites, spodumene pegmatites and leucogranites and migmatic mica schist were investigated with respect to their chemical composition. With respect to the pegmatite classification diagrams of Černý and Burt (1984) muscovites from barren pegmatites and migmatitic mica schist mostly plot in fields of muscovite bearing (MSC) and muscovite barren (MSCB) pegmatite classes. Leucogranites plot together with higher evolved barren pegmatites, whereas spodumene pegmatites reach the fields of moderately evolved pegmatites. Even though the spodumene pegmatites are far away from highly fractionated pegmatites.

All in all, pegmatitic melts formed by regional anatexis during the Permian event. Melt accumulation and fractionation via crystallization of barren pegmatites and leucogranites lead to the formation of spodumene pegmatites.

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Session GT10-2

From subduction to post-collision: tectonics, magmatism and ore deposit controls along the Anatolian-Caucasian-Iranian segment of the Tethys belt

Conveners:

Hervé Rezeau, Marc Hässig and Robert Moritz

Subduction-related to post-collision porphyry and epithermal systems: Lessons from the SE European-Anatolian-Caucasian segment of the Tethys belt

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The Tethys belt results from the convergence of the African, Arabian and Eurasian plates. Adequate conditions for porphyry and epithermal ore deposit formation were provided by successive Mesozoic and Cenozoic magmatic and tectonic settings along the southeast European, Anatolian and Caucasian segments of the Tethyan belt.

Typical subduction-related porphyry and epithermal deposits were formed during the Cretaceous. They were related to subduction of the northern Neotethys branch and thickening of calc-alkaline magmatic arcs along the Lesser Caucasus, the Pontides and the Balkans, and to subduction of the southern Neotethys branch along the calc-alkaline southeastern Anatolian belt.

Subsequent diachronous accretion of Gondwana-derived plates and Arabia to the Eurasian margin initiated a diversity of geodynamic environments. One of the consequences was a jump of the active Paleogene Neotethys subduction to the south of the Tauride-Anatolian block, and local subduction-related Eocene calk-alkaline magmatism with associated porphyry-epithermal systems, such as in the southernmost Lesser Caucasus. By contrast in other locations, such as the Aegean region, the Eastern Pontides and the southeastern Anatolian belt, Late Cretaceous to Paleogene post-orogenic geodynamic evolution resulted in calc-alkaline, high-K calc-alkaline and shoshonitic magmatism and collisional to post-collisional porphyry and epithermal systems.

After final accretion of Arabia and Eurasia and closure of the southern Neotethys branch, post-collisional Neogene geodynamic evolution prevailed, however resulting in distinctly different tectonic settings. For instance, the Aegean region evolved into a highly extensional domain, whereas transpressional strike-slip tectonics dominated in the Lesser Caucasus. Porphyry and epithermal systems were emplaced in both geodynamic environments.

Mesozoic to Early Cenozoic evolution of the Somkheto-Karabagh and Pontides Arcs: a regional study across Armenia, Georgia and Anatolia

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During the Mesozoic, the southern margin of the Eurasian continent recorded the closure of the Paleotethys and opening of the northern Neotethys oceanic domains. From the Jurassic to the Eocene, this region experienced subduction, obduction, and micro-plate accretion events, and final Eurasia-Arabia collision and closure of Neotethys oceans.

Three main domains are distinguished in the Lesser Caucasus and NE Anatolia, including from South to North: (1) the South Armenian Block (SAB) and the Tauride-Anatolide Platform (TAP), Gondwanian-derived continental terranes; (2) scattered outcrops of ophiolite bodies along the Sevan-Akera and Ankara-Erzincan suture zones; and (3) the Eurasian plate, represented by the Eastern Pontides margin and the Somkheto-Karabagh Arc. The Eastern Pontides and the Somkheto-Karabagh belts represent magmatic arcs formed during north-dipping Tethyan subduction under the southern Eurasian Margin followed by collision throughout Mesozoic and Early Cenozoic times. The onset of the north-dipping subduction is not well constrained. However, studies conducted in the Caucasus, Georgia and the Pontides reveal coeval calc-alkaline magmatic activity since the Early or Middle Jurassic. Yet, Cenomanian to Santonian ages have been proposed as well.

The source of the dispute concerning onset of subduction lies in the lack of evidence of it, particularly evidence for subduction-related magmatism. Our study has yielded new observations, radiometric dating and geochemical data of magmatic rocks of the Lesser Caucasus region, including the Alaverdi district in NE Armenia and the Bolnisi district in southern Georgia, which allow a better reconstruction of the evolution of magmatism along the southern Eurasian margin. Analyses show calc-alkaline to high-k magmatic arc activity during Late Jurassic times (158–148 Ma) in the Alaverdi district and in the Bolnisi district calc-alkaline to shoshonitic magmatic arc activity during Campanian times (83–81 Ma). These data are complemented by previously published data pertaining to the Eastern Pontides and the Black Sea region of Georgia. We argue that subduction under the margin started during the earliest Jurassic and continued throughout the Mesozoic until collision between SAB-TAP and Eurasia during early Eocene times. The various magmatic ages previously discussed rather reflect magmatic pulses corresponding to particular configurations in the subduction setting.

In light of the implications of their geochemical characteristics, we can constrain the source and petrogenesis of the subduction-related magmatic rocks. In light of the complexity of the regional geological and magmatic evolution along the southern Eurasian margin, our multi-disciplinary approach allows us to constrain the plate tectonic and geodynamic evolution of the Pontides-Lesser Caucasus segment of the Tethyan belt.

Link between Cenozoic magmatism and porphyry-epithermal systems in the Lesser Caucasus, Armenia: new temporal and geochemical constraints

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The Lesser Caucasus is a major segment along the central Tethyan metallogenic belt, located between the Anatolian and Iranian orogenic belts. It resulted from the successive subduction and closure events of the northern and southern branches of the Neotethys during the Late Cretaceous and the Cenozoic as a consequence of NNE-verging convergence of Arabia and Gondwana-derived terranes with Eurasia. The collision between the Arabian and Eurasian plate occurred in the Late Eocene to Oligocene. This convergent movement has initiated dextral strike-slip tectonics in the South Armenian Block of the Lesser Caucasus, which in turn controlled the magma ascent and associated ore deposits during the Cenozoic. A recent study in the southernmost part of the belt, at the Meghri-Ordubad pluton, revealed a 30 m.y.-long subduction to post collisional magmatic evolution with sporadic porphyry Cu-Mo and epithermal ore formation.

This follow-up project investigates the Cenozoic magmatic and metallogenic setting at a broader scale, along the entire South Armenian Block. It focuses on three different areas where economic ore districts are associated with Cenozoic magmatic rocks, including from north to south: the Meghradzor epithermal Au deposit in the Tejsar area, the Amulsar epithermal Au deposit and spatially associated intrusions, and the Dastakert porphyry Cu-Mo deposit in the Bargushat pluton.

On a regional scale, the Cenozoic rocks of the South Armenian block have heterogeneous geochemical characteristics as revealed by calc-alkaline, shoshonitic and alkaline magmatism, but homogeneous isotopic mantle-derived signatures. The latter is best illustrated by zircon isotope geochemistry, such as median initial εHf values ranging from +8.0 to +11.3 for Eocene to Miocene magmatic intrusions from the different study areas. These Cenozoic magmatic rocks display whole-rock trace element patterns characterized by Nb, Ta and Ti negative anomalies, which is typical of a convergent margin context.

On a local scale, new geochronological data and whole-rock geochemistry of intrusions from the northern and the central Lesser Caucasus present magmatic histories that are diachronous when compared to the Meghri-Ordubad pluton. In the northern part, the Tejsar area is characterized by two major magmatic pulses spatially and temporally associated with mineralizing events. An early shoshonitic to alkaline magmatic pulse at ca. 41 Ma is associated with an epithermal Au deposit of the same age, and a second "adakitic-like" calc-alkaline magmatic pulse at ca. 28 Ma is linked to porphyry Mo mineralization (Hankavan prospect). The central part at Amulsar is characterized by a ca. 34 Ma-old high-K calc-alkaline to shoshonitic magmatism, spatially associated with a high-sulfidation epithermal Au deposit. Alunite crystals from the hydrothermally altered zone of the deposit yielded a $\delta^{34}S$ value of 26.3±0.3‰, and support its magmatic-hydrothermal origin. The exact timing for the magmatic-hydrothermal relationship is still unknown, but $^{40}Ar/^{39}Ar$ dating on alunite crystals is ongoing.

These new insights support the existence of a metallogenic belt of regional extent during the Cenozoic. Constraining the temporal and genetic link between the Cenozoic magmatism and associated ore deposit in the South Armenian Block of the Lesser Caucasus certainly represents an important contribution to improve mineral exploration in this region.

Lithological control and facies architecture of the Late Cretaceous Kvemo Bolnisi Cu-Au prospect, Bolnisi mining district, Lesser Caucasus, Georgia

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The Bolnisi mining district is a major metallogenic province in the eastern part of the Western Lesser Caucasus, where numerous prospects and ore deposits are located. Exploration in this region is very active, with the discovery of new promising occurences and ore deposits. The region consists of Late Cretaceous volcanic and volcano-sedimentary rocks emplaced between Paleozoic rocks of the Khrami and Loki basement. Pyroclastic rocks are dominant within the Bolnisi district. Rhyodacitic ignimbrite, ash fall and density current deposits have a phreatomagmatic origin (Popkhadze *et al*., 2017). Rhyolitic to basaltic lava domes and extrusions are preserved in this region, which questions the existence of a caldera structure. The mineralizations are associated with Late Cretaceous volcanic events at different stratigraphic levels (early Turonian-early Santonian and late Campanian), and are located mostly at contact zones with rhyolitic to dacitic domes and extrusions. The copper-gold Kvemo Bolnisi prospect and the currently producing Madneuli copper-gold polymetallic deposits are hosted by the Mashavera Suite and all ages are consistent with a Coniacian to Santonian stratigraphic age of the Madneuli deposit (Moritz *et al*., 2016). The distance between both deposits is about 6–7 km. Our investigations, based on physical volcanology and facies oriented analyses at Kvemo Bolnisi allow us to distinguish the following facies types: lithic-pumice-rich tuff, non-welded ignimbrite, fine-grained tuff, columnar-jointed dacite dome, polymictic breccia, a bedded volcano-sedimentary sequence, and welded ignimbrite. According to the detailed drill core investigations combined with field observations, it is possible to constrain the stratigraphy of the host rocks in the Kvemo Bolnisi area, and to reconstruct their depositional environment, and in addition understand their association with volcanic events and the time relationship with mineralization. The upper stratigraphic levels consist of lithic-pumice tuff, fine-grained tuff and non-welded ignimbrite, which are strongly altered and oxidized, and host shallow, supergene Au mineralization. During the petrographic investigation, it is difficult to recognize pumice or lithic clasts in tuffs, as they are affected by argillic alteration. In some places, remnants of pumice clasts were identified. The sequence is strongly fractured. In the deeper parts, bellow the base of the oxidation zone, the welded ignimbrite has a classical fiamme structure, mainly hosting Cu-rich ore. The mineralized polymictic breccia pipe is cross-cutting all host rock sequences. A columnar-jointed post-ore dacite dome is the last volcanic event in Kvemo Bolnisi area.

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Jurassic magmatic evolution of the Somkheto-Karabagh tectonic zone, Lesser Caucasus

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Jurassic series of the Somkheto-Karabagh (SK) zone is one of the main tectonic units of the Lesser Caucasus. Meanwhile comparing with the same type and coeval Jurassic igneous manifestations of SK belt through southwestern Georgia to the Pontides (in Turkey) and towards southeast (in Iran) has an important regional significance in the field of geodynamic constructions of the central part of the Alpine-Himalayan orogenic belt. The intermediate part of the SK belt is located in western Azerbaijan that is why new data about it are unavailable to us. In the studied area magmatism took place in the Early(?)–Middle and Late Jurassic epochs, and volcanism has mainly had submarine nature in the Paleotethyan basin.

Investigated volcanic rocks are variably metamorphosed to prehnite-pumpellyite and lower greenschist facies, typical of seafloor alterations. The existence of a powerful andesite series (1500–2600 m) indicates that a considerable amount of water has penetrated in the magma chamber as a result of the absorption of the oceanic crust. All the magmatic members of the SK zone are subalkaline (tholeiitic and, mainly calc-alkaline), some boninites are also encountered. Boninites and boninitic andesites, dacites, and rhyolites belong to low-Ca boninitic series of rocks. Low-Ca boninites exhibit high concentration of SiO_2 (average 58.07 wt.%; range 50.03–63.35 wt.%), and MgO (average 10.43 wt.%; range 6.01–16.88 wt.%). The Cr, Co, and Ni concentrations are higher (average Cr 550 ppm; average Co 42 ppm; average Ni 155 ppm).

Normalized to N-MORB trace element concentrations of Jurassic rock samples show enrichment in large-ion lithophile elements (LILE) and partly light rare earth elements (REE) relative to high field strength elements (HFSE) with the clear negative anomalies in Nb, Ta, P and Ti. Trace element distributions are the characteristics of ensimatic island-arc magmas generated in subduction zones. While the spectra of Chondrite normalized REE plots of Middle Jurassic volcanic and plutonic (plagiogranite) series are flat and parallel ($(La/Yb)_N$ = 0.4–2.4), the spectra of Upper Jurassic granitoids (diorite, tonalite, granite etc.) show huge enrichment of light REE relative to heavy REE ($(La/Yb)_N$ = 2.2–17.3).

These differences of the behavior between trace elements of two various aged series support the idea, that they are petrogenetically unrelated. According to our geochemical results the partial melting of the depleted mantle source, consisting of spinel lherzolite, is responsible for derivation of Lower–Middle Jurassic volcanic rocks, and the fractional crystallization of that melt leads to the formation of plagiogranite plutons. As an alternative to the prevailing north-dipping subduction models, it is suggested that the Paleotethyan lithosphere was sinking to the south beneath the SK zone during Jurassic.

Petrology and Zircon U-Pb Dating of the Vakijvari Ore-Bearing Pluton, Lesser Caucasus, Georgia

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The Vakijvari ore field is formed in the central part of Paleogene the Achara-Trialeti fold-thrust belt, in the SW part of the Lesser Caucasus. The ore bearing pluton of the vakijvari ore field is considered as the largest igneous body of the region, which cuts through the Middle Eocenic volcano-sedimentary formations of mostly andesitic composition. There are investigated eight outcrop sections of the plutonic body along the Vakijvari ore field and covers nearly 70 km².

Vakijvari ore-bearing pluton is mostly composed of coarse-grained rocks of subalkaline and syenetic composition with pyroxene-biotite and hornblende-bearing varieties, biotite-pyroxene bearing monzonites are dominated as well. Their basic chemical composition of rocks varies between the following limits: SiO_2 = 56.5–61.5%, Al_2O_3 = 16.2–17.7%, Fe_2O_3 = 2.5–4.3%, FeO = 2.2–4.8%, CaO = 4.2–6.7%, Na_2O = 3.3–5.3%, K_2O = 3.8–5.9%.

In the contact area between volcano-sedimentary rocks and Vakijvari pluton, strong post-magmatic hydrothermal alteration zones have been developed, among them 10 gold-bearing ore occurrences have been identified, which are genetically related to the plutonic body. These occurrences are presented at the following ore associations: quartz-low sulfidic, quartz-copper-polymetallic, iron ore-pegmatite, sulphur-pyrite and copper-molybdenum-porphyry.

The U-Pb radioisotope dating of zircons from the Vakijvari syenite pluton were conducted by means of a New Wave laser ablation (LA) UP213 system coupled to an Agilent 7500s ICP-MS in the Department of Geosciences, National Taiwan University, the analytical procedures has been carried out by Chiu *et al*. (2009). The dated sample (#12Geo13) has been provided from the central part of the intrusive body and it is identified as hornblende-syenite (SiO_2 = 59.7%). During the research, 24 zircon grains have been separated and dated from this sample.

The Th/U index is always >0.4 for all zircon grains, which demonstrates the typical igneous origin of these formation (Wu and Zheng, 2004). The weigh mean U-Pb age of zircons has been dated to be 43.26±0.72 Ma (MSWD = 0.74, Probability = 0.030), which corresponds to Middle Eocene Epoch (Lutetian Stage), the period of volcanic activity.

Based on the research conducted, it should be concluded that the intrusion in the Vakijvari ore field has been immediately followed by the plutonic injection and therefor, the volcano-sedimentary and plutonic deposits should be considered as the products of synchronous formation.

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Syn-Collisional Porphyry and Epithermal Deposits along the Eastern Anatolian Magmatic Belt, Turkey

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The indentation of the Arabian platform into Eurasia caused cessation of subduction and subsequent segmentation of the Southern Neotethyan oceanic slab since the late Oligocene. Those tectonic events resulted in the production of widespread magmatism in central and eastern Anatolia that formed the Eastern Anatolian Magmatic Belt during the late Cenozoic. Mineral deposit discoveries along that Belt reveal that the syn-collisional Oligocene to Miocene magmatic complexes are prospective for gold-rich porphyry- and epithermal-style mineralization. Our field-based study provides new temporal, spatial and geochemical constraints for the causative magmas. Central Anatolia is dominated by high-sulfidation epithermal Au prospects and deposits (10–3 Ma) that are clustered in the Konya, Niğde and Kayseri mineral districts and centered on stratovolcanoes. In contrast, the eastern Anatolian region contains porphyry-, high-sulfidation epithermal- and Carlin-style precious and base metal mineralization (25–17 Ma) such as at the Tunceli and Ağrı districts and the isolated Hasançelebi high-sulfidation epithermal Au-Ag prospect. Those hydrothermal systems and associated igneous host rocks emplaced at extensional sites at fault intersections and along pull-apart basins in a context of crustal compression. Magma was fertile at the beginning of the regional magmatic cycles at 25 and 12 Ma in eastern and central Anatolia, respectively. Geochemical features of Anatolian magmatism gradually evolved towards less hydrous, less oxidized, shallowly-produced and mantle-dominant magmas. Taken all together, we interpret that the steepening of Southern Neotethyan oceanic slab at the onset of the Arabia – Eurasia continental collision in the Oligocene resulted in a brief pulse of magmatism and porphyry mineralization in the Tunceli district. Subsequently, the slab broke off beneath eastern Anatolia in the early Miocene. The resulting sub-horizontal rupture propagated westwards to central Anatolia from the early to middle Miocene, followed by the slab gap opening, which continued to the present. This event was accompanied by the westward migration of the magmatic activity and associated porphyry and high-sulfidation epithermal mineralization from the easterly Ağrı district, Hasançelebi high-sulfidation epithermal prospect to the westerly Kayseri and Niğde districts along the Eastern Anatolian Magmatic Belt. The long-lived asthenospheric heating beneath Anatolia was responsible for the progressive loss of the metasomatized, metal-bearing sub-continental lithospheric mantle, and thus the increasing production of barren volcanism that formed the widespread late Miocene to Quaternary Erzurum – Kars volcanic plateau in eastern Anatolia.

Tectonics, magmatic and metallogenic evolution of Georgia and adjacent areas

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The lithosphere of Georgia and the Caucasus represents a collage of lithospheric fragments of the Tethys Ocean and its Eurasian and Africa-Arabian margins. Available data allow tracing the geodynamic evolution of the Black Sea – Caspian Sea region in Neoproterozoic–Phanerozoic time. Two stages of development are distinct: precollisional – Neoproterozoic-Early Cenozoic, and syn-postcollisional – Late Cenozoic. Within the precollisional complexes, there are revealed fragments of the Prototethys, Paleotethys and Neotethys as well as lithospheric rock complexes of microcontinents and island-arc systems.

An interpretation in favor of a Gondwanan origin of Late Proterozoic-Middle Paleozoic Transcaucasian basement rocks was proposed by Zakariadze *et al*. (1998). During the Early–Middle Paleozoic, in the wake of northward migrating Gondwanan fragments the Paleotethyan basin was formed. Northward migration of the Transcaucasian massif throughout the Paleozoic caused narrowing of the Prototethys and its transformation into a back-arc basin. The crystalline basement of the fold-and-thrust belt of the Cavcasioni consists of various Paleozoic metamorphic and magmatic rocks. The southernmost strip of the crystalline core is represented by thrust slices of metaophiolites.

In the Late Paleozoic-Early Mesozoic, the oceanic basin separating the Africa-Arabian continent from the Taurus-Anatolian-Iranian platform was gradually extending. However, at that time, only the Central Iranian terrain (CIT) separated from Gondwana. The Taurus-Anatolian Terrains (TAT) broke from Gondwana in the Middle Jurassic. The Neotethys was formed in the Middle-Late Mesozoic. Northward displacement of TAT resulted in its gradual nearing with the Pontian-Transcaucasian-Iranian active continental margin, narrowing of the Paleotethys-Tethys, formation of the suture belt between the TAT and CIT. The suture belt, apparently, is marked by fragments of ophiolite mélange of the Lakes Van-Urumiyeh and Khoy.

Suprasubduction-type magmatic activity was repeatedly recurring in the region in Neoproterozoic-Early Paleozoic (Pan-African orogeny), Middle Paleozoic (Caledonian orogeny), Late Paleozoic (Variscan orogeny), Mesozoic-Early Cenozoic (Alpine orogeny). Precious and base-metal deposits of Georgia, Somkhit-Garabagh (Armenia, Azerbaijan), Eastern Pontides (Turkey) and Iranian Garadagh are genetically associated with the Jurassic and Cretaceous-Eocene suprasubduction magmatic activity.

During the Oligocene, marine basins were replaced by euxinic-type basins, which are considered as the beginning of syncollisional development. Subaerial volcanic eruptions that occurred simultaneously with molasse formation in the foreland basins and produced calc-alkaline series of basalt-andesite-dacite-rhyolitic composition began in the late Miocene-Pliocene. Formation of some deposits and ore manifestations of precious and rare metals in Georgia (Cavcasioni) and adjacent countries is associated with syn- and postcollisional metallogenic epoch (Daralagöz, Iranian Garadagh, Urumiyeh-Dakhtar, etc.). Mineralisations are related to syn- and postcollisional magmatic and postmagmatic hydrothermal processes and have close relationships with main tectonic lineaments, such as ophiolitic suture belts).

On the example of formation of precious, base and rare metals deposits in Georgia and adjacent countries, it is possible to make assertion concerning genetic relationships of pre-collisional, syn- and postcollisional magmatic activity with metallogeny and geodynamic evolution of the region.

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Geodynamic control of the regional metamorphism, volcanism and metallogeny in the Caucasus at Phanerozoic subduction and collision of Tethys Ocean

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The regional metamorphism, volcanism, hydrothermal alteration and metallogeny in the Caucasus and adjacent regions of Eurasian active margin are controlled by Phanerozoic geodynamic development. The various stages of pre-collision and post-collision development were related to subduction of the Tethys ocean slab beneath the Eurasian margin during the convergence of Gondwana and Eurasia continents. The initial stage of subduction revealed in regional metamorphism and smelting of granite magma from the lithosphere at temperatures of 350–750 °C. It is manifested at the Fore Range of Caucasus and Intermountain block of Transcaucasus, where occurred Paleozoic granite-metamorphic complexes. Later, with increasing temperature up to 1000–1100 °C the andesite magma was smelted from subducting slab and calc-alkaline andesite-dacite volcanic activity of island arc setting took place at Late Paleozoic and Early Jurassic in Fore Range and Transcaucasus exemplified by andesite-dacite series of Bechsin zone and “Lower Tuffite” (Chiatura series). The subduction was continuing in Cretaceous. The first stage was steady state subduction revealed in the island arc setting, calc-alkaline volcanism and gold-copper-base metal mineralization with Au, Pb, Zn, Cu association. In the zone of volcanic activity and mineralization here participate the sialic crust (source of Au and Pb), basaltic crust source of Zn and mantle (source of Cu). It is exemplified in Madneuli cluster of Bolnisi ore district (Transcaucasus). Age of mineralization here is Tironian–Santonian (87–90 Ma).

The steepening (transformation) of subducting slab (roll back, break off, detachment and delamination) stipulated incursion of mantle diapir on high levels of the lithosphere revealed the interarc rifting in the Fore Range of Caucasus in Paleozoic–Late Jurassic, after the steady state subduction of Bechasin Zone with calc-alkaline volcanism of island arc setting. At this stage sialic crust source of Au and Pb was spread out from zone of volcanism and mineralization. The intensive rifting here is manifested in tholeiite volcanic activity and copper-zinc-pyrite mineralization forming the Khudes group of deposits (Khudes, Urup, Daud). The volcanic activity and mineralization here precede the Early Paleozoic regional metamorphism of amphibolite and granulate facies. Therefore, with the steady state subduction related calc-alkaline volcanism as volcanological indicator and gold-copper-base metal mineralization associated with Au, Pb, Zn and Cu as metallogenic indicators of island arc setting. Whereas the incursion of mantle diapir caused interarc rifting revealed in tholeiite volcanism, as volcanological indicator and copper-zinc mineraslization as metallogenic indicator of interarc setting. At the same time abovementioned setting in the Fore Range of Caucasus, confirm by ratio of Sr and Pb isotopes the REE and chondrite elements contention, as geochemical criteria.

The further strengthen of transformation of subducting slab the incursion of mantle diapir at highest level and intensive spreading. At this stage the sialic as well as basaltic crust are spread out from the zone of volcanism and mine ralization and inter-backarc rifting trancferred in the minor ocean setting. It is exemplified by transferring Achara-Trialeti interarc zone of Lesser Caucasus in the Black Sea minor ocean and Talish back-arc rift in Caspean sea minor ocean. The most distinct minor ocean setting is described in Küre Complex of Central Pontides (Turkey), where minor ocean setting revealed in the ophiolite volcanism, dunite-peridotite magmatism and serpentinization – volcanologic and petrological indicators and copper-pyrite Cyprus type mineralization lack of Au, Pb and Zn where metallogenic indicator is only Cu, sourced from mantle.

The pre-collision development temporally and spacially caused by subduction occurred as along deeping and steepening of subducting slab, so laterally to deeping, as well as way-up succession revealed in alternation of steady state subduction, related to island arc setting, its transformation with incursion of the mantle diapir at various levels, recorded in inter-arc-backarc rifting and minor ocean setting. Every setting arc manifested by described distinct volcanological, petrological, metallogenic indicators, confirmed by geochemical criteria.

In Oligocene-Miocene the Tethys ocean was closed and transforming pre-collision development transformed in the post-collision stipulated by convergence of Gondwana and Eurasia continents. At post-collision stage process of subduction is terminated, however the steepening of subducted slab was continuing.

It stipulated ascending stream of fluids and incursion of mantle material in thick lithosphere. The first post-collision stage revealed in orogenesis, fold-thrust structuring and synorogenic smelting granitoid magma. The fluid stream leaching the gold and trace metals Sb, W, Mo and HG from thick lithosphere and forming porphyry and low sulfidation quartz-antimonate, quartz-sheelite and quartz-wolframite gold-bearing veins and stockworks. The gold-bearing lower sulfide mineralization are known in the Zopkhito, Lukhumi, Okrila and Natsarula deposits of Caucasus (Georgia), as well in Iran and Turkey regions. The trace metals association Sb-W-Mo-Hg widespread in ore wall altered rocks, so widely penetrated in ore-bearing rocks. The first of post-collision process in the Caucasus, dated of Oligocene–Miocene, are substituted the rocks of pre-collision setting characterized of high geochemical backgroung of mentioned trace metals, so they are geochemical and metallogenic indicators of post-collision activity in the pre-collision rocks. The second stage dated by Pleistocene-Quaternary is presented by shoshonite-alkalibasalt volcanic activity, characterized the geochemical criteria of the same rocks of pre-collision setting, such as Sr and Pb isotopes, REE and chondrite elements and lack of described trace metals characterized the first stage of post-collision development.

Magmatizm and ore occurrences of the Kakheti and Tusheti regions, Greater Caucasus, Georgia

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The Greater Caucasus represents a Phanerozoic collisional orogen, which is accreted to the south margin of the Eurasian continent, from the Caspian to the Black Sea and extends for more than 1200 km. The two major sequences resulting from its construction are distinguished as the pre-Mesozoic crystalline basement and Mesozoic-Cenozoic sedimentary and volcanic-sedimentary cover (Okrostsvaridze and Tormay, 2011).

Kakheti and Tusheti regions are located on the Eastern Greater Caucasus. Kakheti region is located in the Southern slope of this range and Tusheti - in the North slope. This segment of the Greater Caucasus orogen is mainly underlain by highly deformed Lower-Middle Jurassic shales, sandstones, and volcaniclastic rocks, intruded by numerous intrusive bodies of various compositions. All units contain a variety of ore occurrences and their surrounding zones of hydrothermal alteration (Akimideze, 2010). However, small relics of pre-Mesozoic crystalline basement are also exposed in the South slope of this ridge, which are in active tectonic contact with the Jurassic formations. These rocks are presented by crushed plagiogranite porphyries, zircons U-Pb isotopic age of which are 313±8 Ma (Makhvali river outfall) and 312±3 Ma (Stori river source). Continued magmatic and metallogenic research, in the past 30 years have led to important new information regarding the construction of these regions. Three main stages of magmatic activity are now clearly identified in Jurassic period. The first magmatic activity is revealed in Early Jurassic (in Sinemurian), related to extensional tectonism, which ranged from rhyolitic, through dacitic and andesitic, and to basaltic magma. Additional extensional processes (in Bajocian) were characterized by intrusion of a gabbro/diorite dike system into recently deposited late Early Jurassic-Early Middle Jurassic sedimentary formations. The third magmatic event was associated with Middle Jurassic folding (in Bathonian) and uplift during which multiphase diorite plutons were emplaced. Related intense hydrothermal activity was responsible for principal polymetallic mineralization, with more than 100 recognized outcrops (Gagnidze and Okrostsvaridze, 2015). A detailed study of 11 of these ore occurrences has indicated anomalous concentrations of gold, thorium, yttrium, cobalt, cadmium, and bismuth. In addition, several new and potentially significant ore mineral occurrences were discovered.

In conclusion, we note that it is necessary to undertake more detailed metallogenic research in the Kakheti and Tusheti regions, because many significant problems still exist and important copper-polymetallic deposits, such as those in neighbouring Azerbaijan (Filizchay) and Dagestan (Kizil-Dere), may be present, but concealed, in areas of shallow cover.

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Structural control of the Cenozoic porphyry and epithermal deposits during Tethyan subduction to post-collision evolution of the Lesser Caucasus

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Cenozoic subduction to post-collision evolution of the central Tethyan belt was highly favorable for the formation of porphyry Cu-Mo and epithermal Au mineralization along the Lesser Caucasus. The Cenozoic mining districts are located mainly along the regional active NW-oriented Pambak-Sevan-Sunik dextral strike-slip fault system, which coincides with the major collision zone between the Gondwana-derived South Armenian block and the Eurasian margin.

Major Cenozoic porphyry Cu-Mo and epithermal Au systems are located in the southernmost Lesser Caucasus in the Zangezur-Ordubad mining district, and are hosted by the composite Meghri-Ordubad pluton and associated volcanic rocks. The majority of the ore-hosting structures and the emplacement of magmatic intrusions were controlled by N-S, E-W and NE-oriented faults, which are predominantly confined to a central N-S oriented corridor, located between two regional NNW-oriented dextral strike-slip faults, named Khustup-Giratagh and Salvard-Ordubad faults.

During the Eocene, NE-oriented principal stresses created the essentially dextral strike-slip tectonic regime along the major N-S-oriented strike-slip faults, concomitantly with the late stage subduction of the Neotethys. These faults controlled the emplacement of the main porphyry Cu-Mo and epithermal Au and base metal deposits and prospects, including the Dastakert, Hanqasar, Aygedzor and Agarak porphyry Cu-Mo and the Tey-Lichkvaz and Terterasar epithermal Au systems.

The Eocene structures were repeatedly reactivated during the subsequent Neogene tectonic evolution of the Zangezur-Ordubad mining district, as the region evolved from a subduction to a post-collision geodynamic setting. The world-class Kadjaran porphyry Cu-Mo deposit was formed during the late Oligocene and subsequently overprinted by an epithermal event during the early Miocene concomitant with the early Miocene Lichk porphyry-epithermal system. Both mineralizing events were also controlled by dextral strike-slip tectonics. This is triggered by the NE- to NNE-oriented regional compression related to the Paleogene Eurasia-Arabia convergence and subsequent Neogene post-collision evolution.

Since the early Miocene, the paleostress reconstruction indicates N-S to NW-oriented principal stresses and resulted in left-lateral reactivation of faults and mineralized structures, which are linked to the tectonic plate re-organization during the late Neogene post- collision geodynamic evolution.

This study underscores the importance of regional strike-slip tectonics as a fundamental control on the formation of Cenozoic porphyry-epithermal systems and associated magmatism within the Lesser Caucasus, and is comparable to other major porphyry-epithermal metallogenic belts.

Distribution pattern of PGEs and PGMs in chromitites from Abdasht and Soghan mafic-ultramafic complexes (Haji Abad-Esfandagheh district, Southern Iran)

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It is well-established that PGEs of ophiolite chromitites mainly from PGMs. Understanding of PGM composition and their microstructural position in chromitites can be used to get information about crystallization processes, physicochemical conditions of chromitites, post-magmatic evolution of chromitites as well as their geodynamic environments.

Abdasht and Soghan mafic-ultramafic complexes host major chromite ores that are part of the Haji Abad-Esfandagheh district, the second most important chromite producing area in Iran. They are situated in an E-W trending area 60 km long and 5–10 km wide within a very tectonically active zone, composed of Sanandaj – Sirjan/Bajgan – Durkan highly deformed metamorphic rocks. The Abdasht complex is mainly composed of variably serpentinized dunite, harzburgite, websterite and minor wherlite and lherzolite. Chromitite ore bodies are included in mantle harzburgite tectonite and dunites and follow three distinct pseudostratigraphic levels for a length of more than 3 km. Soghan complex is located about 3 km East of Abdasht. Minor chromitites are hosted within the Gechin unit, composed of strongly serpentinized dunite and harzburgite. Major chromitite ores are found in the Main Soghan unit, composed of an alternation of dunites and harzburgites. Soghan complex also comprise a Transition Zone and Layered Gabbros.

Chromitite samples from 4 different mines (3 in Soghan and 1 in Abdasht) were collected and studied for their metallic mineral assemblages. Of the primary BMS assemblage only few pentlandite relict grains and one bornite were detected in both complexes. The secondary assemblage comprises both low-S sulfides (heazlewoodite) and metallic phases (awaruite, native Ni and Cu) that are indicative of low-S fugacity conditions. PGMs are much more abundant in Abdasht than in Soghan. PGMs are dominated by euhedral laurite inclusions within chromite grains, while PGE alloys show more variable compositions and are usually associated to hydrate silicate phases like amphibole and chlorite.

PGE whole rock contents share for all samples a strong depletion in Pt and Pd. PGE_{tot} is higher in Abdasht (173 ppb average and 421 ppb maximum) than in Soghan (97 ppb average and 164 ppb maximum) chromitites. PGE chondritic patterns form two distinct groups of samples. Type I has higher PGE_{tot} values (174 ppb average) and distinct negative Ir anomaly. Type II patterns show much lower PGE_{tot} (20 ppb average) and a flat Os to Rh trend. These two types are equally shared between the two complexes. The whole set of data is consistent with metallic assemblages that can be found in ophiolite mantle sections but in Abdasht and Soghan the secondary transformation of the BMS and PGM assemblages is particularly strong. The main event, probably due to serpentinization, is a strong desulfurization that affected the silicate-hosted BMS more than the mainly chromite-hosted PGMs. This event can be responsible also for a re-distribution of PGEs. Type II PGE patterns are consistent with a stronger desulfurization that in the PGM assemblage mainly affected laurite. Dissolution of laurite flattened PGE patterns and decreased whole rock PGE contents.

Analysis of magmatic processes of the Paleogene Adjara-Trialeti fold-rift zone, Lesser Caucasus: Implication from zircon U-Pb geochronology

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Adjara-Trialeti was formed in the Lesser Caucasus collisional orogeny as a rift zone by the end of the Cretaceous, developed during the Paleogene, by the end of which it underwent folding (Gamkrelidze, 1986). It is mainly constructed of trachytic and trachyte-andesitic volcano-sedimentary formation, though plutonic bodies also play an important role in the structure and are mainly represented by ore-bearing syenite and monzonite (Okrostsvaridze and Bluashvili, 2014). According to paleontological data, the volcano-sedimentary formation is dated as Middle Eocene, though there is no information on isotopic age of the plutonic bodies. Some researchers think that these bodies of Adjara-Trialeti zone are coeval with volcanic activity, while others think they belong to the Upper Eocene (Lordkipanidze and Nadareishvili, 1964).

More than two hundred zircon crystals of the major ore-bearing plutons of the Adjara-Trialeti fold- rift zone were dated by the U-Pb method using the Laser Ablation ICP-MS Technique of the isotope laboratory at the National Taiwan University. The results are as follows: Merisi (diorite), sample #12Ge-03 = 43.42±0.61 Ma; Merisi (syenite), sample #12Ge-04 = 42.78±0.65 Ma; Namonastrali (diorite), sample #12Ge-05 = 42.42±0.5 Ma; Namonastrali (diorite), sample #12Ge-06 = 42.03±0.83 Ma; Vakijvari (syenite) sample, #12Ge-13 = 43.26±0.74 Ma; Zoti (syenite), sample #12Ge-0 = 43.86±0.43 Ma; Zoti (gabbro) sample #12Ge-16 = 46.77±0.81 Ma; Okros-Gele (syenite), sample #12Ge = 19-44.34±0.55 Ma; Rkviana (gabbro), sample #12Ge-21 = 44.85±0.59 Ma.

It can be seen from the results that the ore-bearing plutons of the folded rift zone of Ajara-Trialeti intruded the volcanic-sedimentary rocks within a short time interval, between 46–42 Ma. It should be noted that the peak of the volcanic activity in the Ajara-Trialeti zone was similarly dated as the Middle Eocene. If we trust these data and accept the results of the plutons dating by above method of U-Pb on zircons, we should assume that the volcanic activities in the region were shortly followed by the plutonic intrusions. Proceeding from the above and the petrological-geochemical analysis of volcanic and plutonic rocks, we assert that their formation is not significantly separated in time and they are connected to a common magmatic source.

From the conducted survey, we can also conclude that within the Adjara-Trialeti fold rift zone, the ore-bearing plutons are of the Middle Eocene (46–42 Ma) age. It is clear therefore, that new ore occurrences, in the region, need to be explored in the contact zone of the plutonic injections of this age.

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Session GT10-4

Geochronology, whole rock and mineral chemistry as assessment tools for magma fertility and ore formation in magmatic-hydrothermal systems

Conveners:

Kalin Kouzmanov, Albrecht von Quadt, Irena Peytcheva and Istvan Marton

Factors Influencing the Au-Cu Endowment and Deposit Diversity in the Cenozoic West Tethyan Magmatic Belt, SE Europe

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Gold enrichment in magmatic-hydrothermal settings may be due to a number of factors ranging from regional-scale tectono-magmatic processes to local-scale emplacement controls. Factors may include: (1) melting of pre-enriched subcontinental lithospheric mantle; (2) preferential partitioning of Cu and Au in silicate and sulfide melt phases; (3) oxidation-fractionation variations controlling metal behaviour in magmas such as preferential Au-transport in S-rich reduced mantle-derived mafic melts; (5) partitioning of Au and Cu in shallowly emplaced magmatic-hydrothermal systems. In the Western Tethyan magmatic belt both regional and local factors likely influenced Au-endowment. Gold-copper mineralization developed in two main periods of Cretaceous and Cenozoic magmatism. The Cretaceous deposits are dominantly Cu-Au porphyry, high sulfidation epithermal and volcanic massive sulfide deposits, whereas in the Cenozoic Cu is significant only in porphyry systems. However, the Cenozoic contains approximately three times greater total Au endowment (for Au-deposits >0.5 Moz), and also has a greater deposit diversity including porphyry Au-Cu and Au-only deposits, high, intermediate and low sulfidation epithermal Au systems, and Au-rich skarn, carbonate replacement and sediment-hosted styles. The Cu ± Au endowment of the Cretaceous is consistent with focussed fertile subduction related arc magmatism and generation of calc-alkaline porphyry to HS epithermal systems, whereas Au-enrichment related to Cenozoic magmatism appears to be related to more alkalic compositions (commonly high-K calc-alkalic to shoshonitic) formed in a widespread back-arc or post-collisional extensional settings. In many of the Au-rich Cenozoic magmatic belts there is geochemical evidence for sourcing subcontinental lithospheric mantle that was previously enriched by Cretaceous subduction-related metasomatism. At the deposit scale recent research and exploration at three significant Au-rich Cenozoic systems, namely Kisladag, KMC and Bolcana, suggest that Au-enrichment may have been triggered by rapid late injection of alkaline mafic melts into cooling felsic systems.

Geochemistry of massive sulfide orebodies at Bor (Serbia)

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Genetic connection between porphyry and epithermal type of mineralization has been demonstrated for many deposits, from classic examples of Far Southeast – Lepanto (Arribas *et al*., 1995, Mancano and Campbell, 1995; Hedenquist, 1998) and Butte, Montana (Rusk *et al*., 2008; Reed, 2013) to more recent ones of Chelopech (Chambefort and Moritz, 2014) and Zijinshan (So *et al*., 1998). Veins with high-sulfidation epithermal mineral assemblage are ubiquitous in paired porphyry Cu and high sulfidation epithermal Cu-Au systems, but high-grade massive sulfide orebodies with sharp ore gradients are less common and require a special set of conditions in terms of sulfur and oxygen fugacity and Cu/Fe ratio of the fluid. The explanation of the mechanism that could lead to the formation of massive sulfide ore from the host rock is still being debated; replacement and open-space infill are common arguments based on textural evidence, and an alternative is the direct condensation of sulfide melts from magmatic vapor. Mixing of hydrothermal fluid with seawater could cause a significant drop of solubility. We present textural and geochemical evidence supporting the hypothesis that isovolumetric replacement under high sulfur fugacity conditions is required to form the massive sulfide orebody lenses like T orebody at Bor, and compare the geochemistry of epithermal veins from the transitional porphyry-epithermal zone to massive sulfide orebodies. We use thermodynamic modelling of key sulfide assemblages to pinpoint the required temperature and fO_2/fS_2 levels. We have performed leaching experiments in the clean lab environment to perform mass balance calculations and show what elements are truly refractory compared to the least altered protolith.

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The oldest northern magmatic-hydrothermal systems in the Late Cretaceous Srednogorie zone of Bulgaria: scales of processes and magma fertility

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The formation of ore deposits results from a chain of process, related to the interaction of lithosphere and crust, regional and local tectonics, magmatism and geochemistry, which eventually lead to fluid focusing and metal precipitation. Deciphering of successive relatively "short" processes leading to the formation of (sometimes giant) deposits requires the application of reliable geochronological methods and the three runners among them are the U-Pb, Re-Os and Ar-Ar isotope methods. As the ore deposits are usually structurally controlled, and the porphyry-copper deposits (PCDs) are shallow (<4 km deep) systems, the Ar-Ar and Rb-Sr on potassium rich minerals and FT and (U-Th)/He thermochronology are complimentary applied to date faults and time of exhumation.

Recent application of the high-precision CA-ID-TIMS U-Pb zircon method helped refining the age of Elatsite PCD. The main mineralization is confined by the individually dated igneous events between 92.329±0.021 Ma and 92.050±0.019 Ma, thus the entire time span for ore-forming magmatism and high-temperature hydrothermal activity extended over a maximum duration of 0.31 Ma. A thermal anomaly at ~81 Ma is suggested by the new FT and (U-Th)/He dating of zircons (similar to published Ar/Ar sericite age of 79.9±1.4 Ma). It is not supported by the published Re/Os molybdenite ages (92.4±0.3 to 91.88±0.5 Ma) and Ar/Ar or Rb/Sr ages of amphibole, biotite and K-feldspar (91.7±1.4 Ma to 90.55±0.8 Ma). Therefore, we can conclude that the main magmatic-hydrothermal activities ceased at ~90–91 Ma, whereas ascription of ages ~80 Ma to distinct events needs further studies. The age of Elatsite PCD can be distinguished from that of the adjacent occurrences and deposits (all dated with U-Pb method on CA-treated zircons): 93.11±0.76 Ma Ma (Praveshka Lakavitsa), 92.76±0.12 Ma (Etropole) and 92.14±0.06 Ma and 91.784±0.092 Ma (Chelopech). Consequently, we suggest different magmatic-hydrothermal systems in the northern (Balkan) parts of the Srednogorie zone as part of the ABTSB.

Strontium isotope system of the magmatic-hydrothermal minerals in Elatsite is affected by magmatic and fluid-rock interaction. Most initial strontium ratios of the alteration minerals lie on a mixture line between the Late Cretaceous and basement rocks. Sulfur isotopes argue for primary magmatic source of fluids and sulfur.

The Turonian magmatism at Elatsite and its region reveals characteristic geochemical features as high Sr/Y of whole rocks and plagioclase, high potassium content and V/Sc ratios in amphibole and WR. They suggest higher water content and oxidation state of magma.

The preservation of the Late Cretaceous Elatsite PCD might be explained by the Paleocene-Eocene compression in the Balkan belt that lead to the tectonic burial and consequent preservation of the deposits. In Late Eocene-Oligocene time (U-Th/He apatite ages of 39.3±3.0 Ma) the region was cooled down to temperatures below 75 °C and afterward exhumed to the surface uncovering the 3–4 km deep porphyry system.

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Petrology and geochronology of pre- to post-ore igneous rocks from Asarel porphyry copper deposit, Central Srednogorie, Bulgaria

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The Panagyurishte strip of Central Srednogorie Zone, Bulgaria is a part of the Upper Cretaceous Apuseni-Banat-Timok-Srednogorie magmatic-metalogenic arc belt. Asarel porphyry copper deposit is one of the biggest operating mines in the area. The ore formation is related to subsequent intrusion of pre-, syn- to post-ore shallow intrusions. The present study provides new data for the petrology and geochronology of these magmatic rocks in order to constrain better the time of magma generation and the magma sources.

During the present study we analyzed rocks related to pre-syn ore stages and post-ore dykes cross-cutting the mineralization. The first ones constitute larger subvolcanic bodies of granodiorites to granodiorite porphyries intruded mainly in the Carboniferous Smilovene pluton. The rocks are usually intensely metasomatically altered (propylitic, sericitic to argillic and advanced argillic) and contain sub-economic to economic copper concentrations. The second ones form small subvolcanic bodies and dykes, usually with propylitic alteration to almost non-altered. They cross-cut mineralized rocks with high economic concentrations. In both phases can be observed melanocratic cognate enclaves, which are evidence for mingling and magma chamber dynamics.

The analyzed samples from the less altered rocks (both stages) show relatively close SiO_2 contents ranging from 58 to 62.5 wt.%. The rocks are high-K calc-alkaline with total alkalis in the range of 5.36–6.79 wt.%. On the diagram for immobile elements Nb/Y vs Zr/Ti they fall in the field of granodiorites. On a primitive-mantle normalized diagram, the rocks show peaks in LILE (U, Th, Pb) and troughs in Nb, Ta, Ti and P. They show high contents of LILE and steep LREE and MREE chondrite-normalized patterns and almost flat HREE normalized patterns. Weak negative Eu anomaly and La_N/Yb_N (10 to 13) is observed. Some of the analyses are adakite-like, showing relatively high Sr (570–760 ppm) and low Y (15–18.7) which probably is due to amphibole fractionation during suppressed plagioclase crystallization.

The petrography of the pre- to syn-ore subvolcanic bodies usually is difficult because of the more intense metasomatic alterations. The rock forming minerals are presented by relicts of plagioclase, biotite and amphibole. The rock forming minerals of the post-ore dykes are presented predominantly by plagioclase ($An_{37–57}$) and amphibole (magnesio-hornblende to pargasite) with accessories of apatite, zircon, titanite, allanite and magnetite. The groundmass is fine-grained. The calculated depths of crystallization of the hornblende are 7.5–6 km and temperature of 840–880 °C.

The zircon U-Pb geochronology clearly distinguish the both phases (CA-ID-TIMS method; pre-syn-ore 90.35±0.18 Ma and syn-post-ore 89.6±0.03), showing that the time of ore formation is not exceeding 0.75 Ma. The LAICP-MS dating gives similar results and shows that the inherited component is limited. The Ce* anomaly of the pre- to syn-ore magmatics are higher than that in the post-ore ones, also with slightly higher Ti in zircon temperatures. This probably is due to higher oxy-reduction conditions (fO_2) of the magma source at the beginning of mineralization formation.

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Geochemical indicators for discrimination of hydrothermal alterations associated with epithermal and porphyry deposits

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Hydrothermal alterations are between the most important criteria for prospecting for ore deposits because of close connection of alteration and ore mineralization being parts of the same magmatic-hydrothermal system. Analysis of mineralogy and geochemistry of advanced argillic alteration (AAA) and related hydrothermal alterations gives reason to propose some elements as geochemical indicators. They can be used for separation of AAA zones and would give vectoring for exploration.

Our previous investigations of AAA in Bulgarian deposits from the Srednogorie zone and the Rhodopes show that AAA zones characterize with geochemical features which are result of formation in extremely acid conditions and specific mineral composition – alunite, kaolinite, dickite, diaspore, pyrophyllite, APS minerals, zunyite, rutile, etc. Most of chemical elements are very mobile and are extracted. Other like Sr, to a lesser extent P, Pb, LREE, concentrate due to their including in alunite and APS minerals (mainly svanbergite-woodhouseite, rarely florencite) while Ti, V, Zr, Nb, Ta, etc. are inert in these zones and take part in rutile and residual zirconium phases. All these minerals remain stable during weathering and allow trace elements to be used for geochemical prospecting. On the other hand the alunite geochemistry is known as a vector to the mineralized center.

It was established that the significant enrichment of Sr concentration is characteristic feature of advanced argillic alteration of volcanic rocks. At the same time Sr contents in transitional alteration zones (propylite, intermediate argillic, sericite) are low. Thus Sr can be used for separation of AAA zones from the other hydrothermal alterations. This is very important in cases with similar mineral composition such as intermediate argillic and kaolinite AAA rocks especially if there were not found other typomorphic minerals. Differentiation of sericitic rocks from pyrophylitic AAA rocks is also difficult due to similar optic features of the two minerals. In these cases, Sr concentrations can be used as a “strontium criterion”.

Independent geochemical indicator is Rb/Sr ratio. It allows precise separation of sericitic from AAA rocks because of contrasting values in the two alteration types. Anomalously low values of Rb/Sr ratio are typical of AAA zones and suggest high-sulphidation epithermal environment, while high values are characteristic of sericitic rocks and could be perspective for prospecting of porphyry copper or low-sulphidation epithermal mineralization.

In some cases the REE patterns can be used as geochemical indicator. REE patters of AAA rocks are characteristic and different from that of other alteration types: comparatively inert behavior of LREE (sometimes with slight enrichment) while MREE and HREE become mobile and are extracted. Different are the REE patterns of monoquartz rocks (massive silica, vuggy quartz) which show strong depletion of all REE. These most altered rocks contain only inert elements, mark the central parts of hydrothermal systems and may concentrate Au mineralization.

Proposed geochemical indicators are a contribution to the known models of geochemical dispersion around porphyry copper deposits at their upper levels. They should be used for precise mapping of metasomatic zoning, making correct model of magmatic-hydrothermal system and would give prospective for exploration.

The Karavansalija ore center (KMC) in SW Serbia (SE Europe): 1.7 Ma magma evolution, skarn formation and about 140 Ka timespan of economic ore mineralization

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The Karavansalija Mineralized Center (KMC) with its porphyry Au skarn mineralization within the Rogozna Mt. magmatic suite in southwestern Serbia belongs to the Oligocene Serbo-Mazedonian-Magmatic and Metallogenic Belt. The belt is represented by Pb–Zn–Ag (± Sb ± Cu ± Au ± W) veined hydrothermal and/or skarn replacement mineralization. A few of the empiric base metal deposits situated within the Rogozna Mt. and its surrounding areas are Trepca, Crnac, Belo Brdo and Leskova Glava.

The KMC Au skarn deposit proved to be the result of multiphase hydrothermal activity caused by discrete magmatic pulses. Zircon LA-ICP-MS and ID-TIMS dating together with zircon trace element and Hf isotope measurements suggest that magmatism starts around 29.3 Ma with andesitic to trachy-andesitic extrusives and shallow intrusive volcanics. It is followed by a more evolved trachy-andesitic shallow intrusion into Cretaceous limestone at ca. 29.0 Ma (prograde exoskarn). The fluids in excess show 550 °C and 55 wt.% NaCl equivalent, indicating a magmatic fluid source. During cooling of the hydrothermal system, the exoskarns entered a retrograde phase that leads to incomplete reaction of garnet to hydrous phases like chlorite and epidote.

During a period of quiescence of about 1.2 Ma, a lamproite melt was injected the increased heat and fluid pressure lead to the expulsion of a crowded porphyritic stock at ca. 27.76 Ma, strongly interacting with the skarns and establishing/reactivating the hydrothermal system which leads to an enrichment of valuable ore minerals (arsenian pyrite, chalcopyrite, sphalerite and galena). During the retrograde stage the gold bearing minerals precipitated. Soon after an unmineralized second pulse of porphyry dykes cut the previous crowded porphyries and skarns at ca. 27.62 Ma, thus bracketing the maximum timespan of economic ore mineralization to about 140 Ka.

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Genetic study of gabbro hosted copper mineralisations in the Albanian Mirdita Zone

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Albania has a great variety of ore deposits, where 20% of the Cu resources belong to a deposit type of unknown genesis. The focus of this work is on this "enigmatic" stockwork quartz-sulphide mineralisation, appearing in the ophiolite unit of the Dinarides. The Albanian Mirdita Zone represents the Jurassic oceanic basement and can be grouped in two distinct geotectonic environments: the western MOR- and the eastern SSZ-type (Robertson and Shallo, 2000). The deposit of Puka-Kçira is located in the MOR-, while Thirra is found in the SSZ-type geological environment. The deposits have not yet been examined with modern analytical methods, therefore this work contains beyond the classic petrographical analysis, the evaluation of the formation processes using a wide range of analytical methods (XRD, SEM-EDS, EPMA, fluid inclusion microthermometry, Raman spectroscopy, stable- and noble gas isotope analyses, whole rock geochemistry). The completed and the ongoing analyses help us to understand the ore forming processes, the deposits' genetics and these can be used in the future explorations and exploitations as well.

The thickness of the veins is between a few centimetres to twenty metres. We analysed samples representing the barren quartz and calcite veins, the sulphide-containing veins and their alteration halo in the gabbroic host rocks. According to the petrographical analysis, the gabbroic host rock suffered propylitic/greenschist and prehnite-pumpellyte facies alteration. Two types of stockwork mineralisations can be distinguished in Thirra: (1) chalcopyrite, pyrrhotite, cobaltite, pyrite and sphalerite bearing; (2) arsenopyrite, scorodite, chalcopyrite, pyrite and sphalerite bearing assemblages. The ore mineral assemblage is composed of chalcopyrite, pyrite and a minor amount of native tellurium, Ni- and Ag-Au-tellurides in Puka-Kçira, occurring in massive to disseminated texture. Mineral chemistry of pyrite, chalcopyrite and epidote suggests a VMS related origin, more precisely, the deeper part of its feeder zone. Based on whole-rock geochemical analyses, the mineralisations can be classified as mafic, Cyprus-type VMS deposits. However, higher amount of Ag, As, Co and Zn in Thirra, as well as more Cr, Ni, V and Cu in Puka-Kçira make a distinction between the different geotectonic positions (MOR vs. SSZ).

Based on fluid inclusion study, the minimum formation temperature of the late stage calcite is between 180–260 °C at both locations, while the minimum ore forming temperature is 330–370 °C in Puka-Kçira and 270–350 °C in Thirra, as suggested by inclusions of coeval quartz. The hydrothermal fluids are of evolved seawater origin, though besides the fluid-rock interaction in the crust, a minor mantle component is also detectable, as suggested by the noble gas isotope (He, Ne, Ar) and H stable isotope analyses of the quartz and sulphide hosted fluid inclusions. These are supported by the C and O stable isotopes of late stage calcite as well.

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Investigation of the platinum group elements contents in some mafic and ultramafic rocks from the Romanian Carpathians

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A set of 25 samples from several mafic and ultramafic rocks in Romania have been analysed for Ni, Cu and PGE contents. The samples were collected from Tisoviţa-Iuţi mafic-ultramafic complex (harzburgite, podiform chromitite and listvenitized gabbro) and Răşinari (peridotite) in the Southern Carpathians, Breaza ultramafic body (lherzolite) in the Transylvanian Nappes of the Eastern Carpathians, Gialacuta (serpentinite), Roşia Nouă (peridotite) and Ciungani (gabbro) in the South Apuseni Mountains.

Some samples from the Tisoviţa-Iuţi complex showed relative PGE enrichment (up to 3 g/t PGE in podiform chromitites) while the samples from the other locations have lower PGE contents (less than 0,04 g/t). The Cu/Pd ratios in most ultramafic rocks of the Tisoviţa-Iuţi complex and of the Transylvanian Nappes of the Eastern Carpathians are either within the field of the PGE-enrichment or in the mantle range, while the Răşinari peridotites and the sulfide-rich gabbros from Ciungani show Cu-Pd ratio in the PGE-depletion range. Mantle-normalized values of the chalcophile metals also suggest PGE-enrichment in the Tişoviţa-Iuţi complex. These rocks show Cu depletion, reflected by the scarcity of Cu minerals as compared with the varied Ni sulfides and arsenides (*e.g.*, heazlewoodite, pentlandite ± altaite inclusions, millerite, orcelite). Similar PGE trends but at much lower PGE contents are shown by the ultramafic rocks at Breaza, where the reducing environment during the serpentinization induced the formation of Ni-Fe alloys on pentlandite. The sulfide-rich gabbros from Ciungani and the Răşinari peridotites display distributions of the chalcophile metals typical for PGE-depleted magmas. The Ciungani gabbros exhibit negative anomaly of platinum, which is almost as low as Ir and Ru. Such low Pt contents could be explained by Pt retention in the refractory mantle residue, probably as alloys with Os, Ir, Ru or Fe.

With the exception of Răşinari body, all sampled rocks are part of ophiolitic complexes. The rocks from the South Apuseni Mountains are the most PGE-depleted, probably because of sulfide saturation events that occurred before the emplacement of their parental magmas. The samples from Breaza (ophiolites from the Transylvanian Nappes of the Eastern Carpathians) do not show significant PGE depletion or enrichment, while the ultramafics from Tisoviţa-Iuţi show local PGE enrichment. PGE contents similar to those in this study (as high as 3 g/t) have been mentioned in several unpublished reports on the Tisoviţa-Iuţi complex. Despite their high PGE contents, no PGE mineral has been reported from these rocks, so far, which we would explain by the highly heterogeneous character of PGE mineralization.

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Geochronology and geochemistry of zircons from the Rovina Valley Project and the Stanija Prospect – Apuseni Mountains (Romania): constraints from LA-ICPMS/TIMS dating, trace and REE geochemistry of zircons and whole rock studies

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Most of the calc-alkaline and alkaline magmatic rocks in the Southern Apuseni Mountains crop out along graben-like structures and were emplaced, based on the K/Ar dating method, between 14.7 and 7.4 Ma (Roşu *et al*., 2004). Being situated about 200 km away from the East Carpathian volcanic arc, active subduction in the Miocene can be excluded, even though some magmas show an adakite-like character. Authors like Harris *et al*. (2013) therefore suggest decompression melting of a previous metasomatized mantle and later asthenosphere upwelling to be the reason for the found magmatic suite. A correlation of the magmatic activity with the opening of the graben structures due to rotation in the region could explain the decompression, and as a consequence create a pathway for a facilitated rise of the magma through the crust (Roşu *et al*., 2004).

Besides the geodynamic evolution on regional scale, the formation of several Cu-Au porphyry deposits that are abundant in the so called ”Golden Quadrilateral” is linked to the Miocene volcanism (Harris *et al*., 2013). Inside the Rovina Valley Project and the Stanija Prospect areas, both owned by the Euro Sun Mining Inc., at least four porphyry deposits are located within a few kilometers distance. Our goal is a better understanding of the relationship between the different intrusions and their mineralization potential. Additionally, we try to characterize differences in the magma composition and thereby hopefully unravel heterogeneities in the magma source region. Samples were collected from several outcrops in the two Project/Prospect areas, but also include drill cores from the three Rovina Valley Project deposits. Zircons were analyzed by LA-ICPMS to obtain reliable U/Pb ages, as well as trace element compositions, REE and Hf-isotopes. The most adequate zircons were selected based on these results to conduct measurements with TIMS on them, as some of the intrusion ages on deposit scale were too similar to be resolved with LA-ICPMS. First result from LA-ICPMS showed that three of the sampled deposits are were similar in age and are about 12.3 Ma old, while the last deposit is significantly younger (about 11.3 Ma).

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New geodynamic model of the Miocene magmatism of the Apuseni Mountains (Romania): constraints from LA-ICPMS/TIMS dating, trace and REE geochemistry of zircons and whole rock studies

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Most of the calc-alkaline and alkaline magmatic rocks in the Southern Apuseni Mountains (SAM) crop out along two graben-like structures that are oriented WNW-ESE, respectively NNE-SSW. Based on the K/Ar method, their emplacement was dated to between 14.7 and 7.4 Ma (Roşu *et al*., 2004). Being situated about 200 km away from the East Carpathian volcanic arc, active subduction in the Miocene can be excluded, even though some magmas show an adakite-like character. Harris *et al*. (2013) therefore suggest decompression melting of a previous metasomatized mantle and later asthenosphere upwelling to be the reason for the found magmatic suite. A correlation of the magmatic activity with the opening of the graben structures due to rotation in the region could explain the decompression. This rotation could in addition create a pathway for a facilitated rise of the magma through the crust (Roşu *et al*., 2004).

Besides the geodynamic evolution on regional scale, the formation of several Cu-Au porphyry deposits that are abundant in the so called “Golden Quadrilateral” is linked to the Miocene volcanism. (Harris *et al*., 2013). Our goal is a better understanding of the relationship between the different intrusions and their correlation with the proposed opening of the graben structures, as this relationship is of great importance for the mineral exploration in the region.

Samples were collected in and around the basin, covering eight sample positions of Roşu *et al*. (2004), and also including drill cores from the active exploration sites at the Rovina Valley- and the Certej project. Zircons were analyzed by LA-ICPMS to obtain reliable U/Pb ages. Also trace elements, REE and Hf-isotopes were measured to unravel the origin of the magmas and the postulated mantle contribution. As some of the intrusion ages on deposit scale are too similar to see a trend in the area, we additionally dated some of the intrusive events by thermal ionization mass spectrometry (TIMS).

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New U-Pb LA-ICP-MS and ID-TIMS zircon dates for Erdenet Porphyry Cu-Mo deposit and constraining its relation to the Tsagaan Chuluut lithocap in Northern Mongolia

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The formation of the Central Asian Orogenic Belt (CAOB), located north of the Tethyan tectonic domain, is a result of multiple complex oceanic subduction events and collisions (Liu *et al*., 2015). It is host to the Erdenet porphyry Cu-Mo deposit, approximately 240 km NW of Ulaanbaatar, which is related to arc-magmatism driven by the subduction of the Mongol-Okhotsk Ocean. The deposit is the second largest copper producer in Mongolia (26 million tons of ore per year) and is middle to late Triassic in age (~240 Ma, Watanabe and Stein, 2000; Kavalieris *et al*., 2017). Erdenet is spatially related to the Tsagaan Chuluut lithocap approximately 2 km NW of Erdenet open pit, however, recent $^{40}Ar/^{39}Ar$ dating on alunite from the lithocap suggests it is 16 Ma younger than the porphyry system (224±2 Ma, Kavalieris *et al*., 2017). The possibility that the lithocap is related to either the adjacent Erdenet deposit or subjacent, still undiscovered porphyry mineralization is discussed using new zircon U-Pb LA-ICP-MS, high precision ID-TIMS age data, and trace element geochemistry. Ages were obtained on pre-mineralization granodiorite host rocks, syn-mineralization porphyritic granodiorite, post-mineralization cross-cutting trachyandesite dikes in the open pit, and cross-cutting porphyritic andesite dikes in the lithocap.

Preliminary $^{238}U/^{206}Pb$ LA-ICP-MS results show that pre-mineralization host rocks vary in age but are generally >250 Ma. Syn-mineralization data indicate protracted zircon crystallization growth, with a weighted average age corresponding to ~237 Ma, within error of previously published zircon and Ar/Ar dates (see poster for complete reference list), but contrasting with precise Re-Os data from molybdenite (240.4±0.8 Ma, Watanabe and Stein, 2000). Cross-cutting dikes from the lithocap give a weighted average $^{238}U/^{206}Pb$ age of 229.4±1.3 Ma, marking an age discrepancy between the $^{40}Ar/^{39}Ar$ alunite age from the lithocap and the timing of sub-volcanic cross-cutting andesitic dikes in the area. Synthesis of the published age and trace data will be discussed.

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U/Pb zircon dating of Miocene magmatism in the Apuseni Mountains (Romania) and time relationship of intrusive events at the Certej Deposit

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The Southern Apuseni Mountains (SAM) in the inner Carpathians of Romania are hosting some of Europe's biggest porphyry Cu-Au and epithermal Au-Ag deposits. The source magmas of these deposits are Miocene in age and calc-alkaline in composition. Most of the magmatic rocks in the SAM crop out along two graben-like structures that are oriented NW-SE. Based on the K/Ar method, their emplacement was dated to between 14.7 and 7.4 Ma (Roşu *et al*., 2004). Being situated about 200 km away from the East Carpathian volcanic arc, active subduction in the Miocene can be excluded. Harris *et al*. (2013) therefore suggest decompression melting of a previous metasomatized mantle and later asthenosphere upwelling to be the reason for the found magmatic suite. A correlation of the magmatic activity with the opening of the graben structures due to rotation in the region could explain the decompression (Roşu *et al*., 2004). The Certej project is an epithermal Au-Ag deposit and is situated in the South of the SAM inside the NW-SE orientated Brad-Zlatna basin. The mineralization occurred along the contact of three porphyritic andesite intrusions and the Cretaceous and Neogene basin sediments.

Our goal is a better understanding of the relationship between the different intrusions and their correlation with the proposed opening of the graben structures, as this relationship is of great importance for the mineral exploration in the SAM. This study will also try to resolve the emplacement timing of the three, so far not U-Pb dated, major intrusions at the Certej Deposit.

Samples were collected in and around the basin, covering eight sample positions of Roşu *et al*. (2004), and from drill core sections of several intrusive bodies at the Certej project. Zircons were analyzed by LA-ICPMS to obtain reliable U/Pb ages of 12.5 Ma. As some of the intrusion ages on deposit scale are too similar to see a trend, the major intrusions were also dated by thermal ionization mass spectrometry (TIMS). XRF measurements of bulk rock and trace elements, REE and Hf-isotopes in zircons were measured to unravel the origin of the magmas and the postulated mantle contribution.

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Zircon morphology, composition and age dating as prospector of the fertile magmatism in the Paleogene Ruen zone, Bulgaria

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In present study we provide data for the chemical composition, crystal morphology and ages of zircons from Paleogene igneous rocks from the Ruen zone, SW Bulgaria, which is part of the bigger Cenozoic magmatic and metallogenic belt in Serbia, FYR-Macedonia, Bulgaria and Greece. The morphology and zircon composition provide significant information about the magma evolution and its fertility in terms of water content and oxidation state. The NW-SE oriented Ruen magmatotectonic zone (Harkovska, 1984) spreads out about 120 km on the territory of SE Serbia, E FYR-Macedonia and SW Bulgaria. We focused only on samples on the Bulgarian side comprising fresh volcanic rocks (V13) and slightly altered subvolcanic rocks (V169), hosting the Pb-Zn ore mineralization, determined respectively as trachyrhyodacites to porphyrites (Osogovo mountain). They evolved with significant crustal input (about 50 %) according to their Sr isotope composition. The analysis of the zircon population yields ~50 % inheritance of older zircons.

The autocrystic zircons of the Paleogene trachyrhyodacites (1/3 of all) are presented by predominantly stubby short prismatic crystals, whereas relatively elongated crystals are subordinate. They reveal thick to fine oscillatory zoning patterns. The rest of the Paleogene ages are recorded in zircon rims enveloping older zircon grains with age clusters at ~205 and ~250 Ma. The Paleogene zircons show lower Zr and Hf content in the short prismatic (pyramidal habit) crystals in comparison to long prismatic ones, as well as increased Y and REE concentration, which might be due to slow growth rates. The zircon population of the porphyrites has similar morphology but with bigger and broad short prismatic crystals. In this altered rock zircons reveal lower U and Th content combined with extremely increased Pb values. Characteristic feature of zircons from both samples is the development of the basal pinacoid faces, very common for silicified rocks (Kostov, 1973).

The chemical composition of the zircons from the volcanic and porphyritic trachyrhyodacites shows the following characteristics: i) Relatively well defined negative Eu-anomaly in the volcanic rock and weak Eu-anomaly in the subvolcanic analogue with almost flat M-HREE chondrite normalized pattern; ii) Eu/Eu* ratio above 0.3 and (Ce/Nd)/Y above 0.01 pointing to magmatism with high magmatic water content or high oxidation state, or both (Lu *et al*., 2016); iii) Dy/Yb ratio less than 0.3. These features suggest fertile magmatism in term of water content and oxidation state.

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Geochemical features of the magmatic-hydrothermal system near village of Babyak, Western Rhodopes (Bulgaria): links between the hydrothermal alterations and related ore mineralization

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The Babyak base-metal deposit is located in Western Rhodopes, about 180 km SE of Sofia. It is part of the Western Rhodopes ore region that belongs to the Eocene-Miocene Serbomacedonian-Rhodope Pb-Zn and Cu-Au metallogenic belt of the Western Tethys in SE Europe.

The deposit is related to the granites and pegmatites (± aplites) of the Rila-West Rhodope batholith, intruded into the metamorphics of the Sarnitsa lithotectonic Unit (chiefly gneisses, schists and marbles). Ore-bearing zones are hosted predominantly in the brittle contacts between different lithologies or cross-cut the rocks, which are affected by moderate to strong wall-rock alterations. The close relationships to the granites, as well as the type of the mineralization show some specific characteristics of the intrusion-related gold systems (IRGS).

Ore mineralization (Mo-Cu-Pb-Zn-As-Bi-Ag-Au) occurs mainly as sulfide and sulfosalt veinlets, disseminations and nests in quartz veins. The main ore minerals are pyrite, molybdenite, sphalerite, galena, chalcopyrite and some sulfosalts (tennantite, lillianite). About 10 big zones with many apophyses are distinguished, with width ranging from few cm up to 5–10 m, length between 300 and 1500 m and depth about 350–400 m. The main hydrothermal alteration types are phyllic, argillic and greisen-like, locally also propylithic alteration. Silicification is often observed around the veins and veinlets, whereas exo- and endoskarns are formed on the contact between the granites and the host marbles.

EPMA and LA-ICP-MS methods are used to study the major and trace element chemistry of some alteration minerals (white micas, chlorite, epidote and rutile), and pyrites. The chemical composition of alteration and ore minerals could be used as a vector to the mineralized core of the magmatic-hydrothermal system near Babyak and could help for development of a well constrained model of the deposit. That model will be of great importance for the future exploration activities in the area. Based on the mineral associations (parageneses), morphology and chemical composition of the minerals, as well as mineral inclusions we distinguished five stages of hydrothermal mineralization and alteration: (1) a high-temperature stage represented by grossular-andradite skarns that contain also epidote, diopside, vesuvianite, plagioclase, potassic feldspar, ± magnetite; (2) quartz, muscovite, fluorite, pyrite, molybdenite, chalcopyrite, ± rutile, scarce bismuth- and tungsten bearing phases in microcracks, veinlets and impregnations; (3) quartz, sericite, chlorite, calcite, pyrite, molybdenite, ± rutile, ± hematite, ± epidote, ± clay minerals as veinlets, massive nests or filling cracks; (4) precipitation of the main gold and silver-bearing ore minerals (pyrite, sphalerite, galena, ± chalcopyrite, ± sulfosalts) in quartz veins (± sericite, ± calcite) with variable thickness; (5) low-temperature stage of quartz, calcite, zeolites, ± sericite, ± pyrite veins or veinlets.

Typical minor and trace elements in the analyzed pyrites are Ti, Cr, Mn, Co, Ni, Cu, Pb, As, Ag, Au, Sb, Bi, etc., with distinct distribution in the pyrites from different hydrothermal stages. The main difference is established between pyrites from stages 2 and 3 (enriched in Cr, Ni, Co and depleted in As) and stage 4 (mainly As-bearing with low Cr, Ni and Co content). Geochemistry of white micas of stages 2 and 3 indicate enrichment in Sn, W and Ti.

Session GT11-1

Petroleum systems and hydrocarbon exploration in the Carpathian-Balkan region

Conveners:

Reinhard Sachsenhofer and Gabor Tari

Polish Carpathians south of Kraków: geology and unconventional hydrocarbons potential

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The Outer Carpathians are built up of a stack of nappes and thrust-sheets showing a different lithostratigraphy and tectonic structures. The Outer Carpathians nappes are thrust over other each other and on the North European Platform and its Miocene–Paleocene cover. The rocks represent a time span between the Late Jurassic and the Early Miocene. They correspond to more or less separate sedimentary basins and every basin generally displays a different lithostratigraphic development. During the overthrusting movements the tectonic units became uprooted and generally only the central parts of the basins are preserved. The following Outer Carpathian nappes have been distinguished: Magura Nappe, Fore-Magura group of nappes, Silesian, Subsilesian and Skole nappes. The Outer Carpathians contain organic-rich rocks, deposited in the basins belonging to the Tethys realm during Jurassic–Late Cretaceous and to the Paratethys realm during Oligocene times. The Protosilesian Basin, which constitutes the northern part of the Western Tethys, developed as back-arc basin north of the Alpine Tethys during Late Jurassic times. The Lower Cretaceous anoxic black clayey shales and mudstones of Spas and Veřovice formations were deposited in this basin. The value of Total Organic Carbon (TOC) is up to 11.86% on the Spas Formation. The Oligocene Menilite Formation was deposited in the Krosno Basin, which belonged to the Paratethys. This basin originated in front of the advanced accretionary prism. TOC content of Menilite Formation ranges of from 0.18 to 17.25%. The high organic productivity was caused by restricted conditions as well as by symmetric and circular upwelling. The major processes responsible for organic richness are: high biologic productivity, non-dilution of organic richness by clastic sedimentation, and preservation of organic matter within its depositional environment. Today organic-rich rocks belong to the Silesian and Skole nappes. Parts of the anoxic shales have been hidden at the depth of few thousand meters during the folding and overthrusting movements. Locally, the sequence of a single thrust sheet is undisturbed and monoclinally dipping to the south, hiding under structurally higher units. In such areas the anoxic shales, both older ones deposited during Early Cretaceous, as well as the younger formed during Oligocene times, can represent unconventional resources known as shale-gas and shale-oil as they occur at the depth of few thousand meters in a form of continuous, horizontally lying beds.

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Unconventional petroleum systems of the Polish Outer Carpathians and their Miocene Foredeep Basin

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The North Carpathian petroleum province includes the Outer Carpathians (OC) fold-and-thrust belt and their Miocene Foredeep Basin (MFB), both being very mature with exploration and production. The OC are producing oil and gas since the mid of XIX century, while in the MFB gas is produced since 1950s of XX century. Remaining proven conventional hydrocarbon resources of the province are very low, however new unconventional concepts upscale potential of yet-to-find resources significantly.

The MFB at present produces gas at a rate of 1.5 Bcm/y, and the remaining proven gas resources of the basin are to a large extend exhausted (contingent resources – 32 Bcm; reserves – 8 Bcm). Low burial depth, thus low drilling costs, and high quality of biogenic gas (>95 % Methane) makes the production economically prolific, and creates desire for further exploration. The sedimentary fill of the MFB is predominantly fine-grained, therefore conventional sandstone reservoir are uncommon.

Recently a new exploration approach is applied to the MFB, with attempt to produce gas from shallow mudstone-dominated heterolithic formation. The play is regarded as unconventional tight gas or hybrid system. Low burial (1500–2000 m) implies low consolidation of unconventional reservoir, therefore hydraulic fracturing cannot be effective. However, laminas of siltstone or fine-grained sandstone within the mudstone reservoir increase its cumulative lateral permeability. Gas is produced with by drilling deviated wells to the reservoir interval being 100–200 m thick without stimulation. In the southern part of the MFB, buried beneath Carpathian overthrust to higher depth (3000–3500 m) the Miocene sandstones become consolidated and fracturing stimulation of tight reservoir is applied. The both approaches give commercial gas flows – among 30 wells drilled so far 25 were positive. Initial gas flows from individual wells are usually at the level of 40–80 Mcm/d. New unconventional gas contingent resources of this basin are estimated to 400 Bcm of recoverable gas.

In the OC further south conventional reserves are nearly depleted. However, at present shale oil/gas potential is identified in the Menilite Shale (Lower Oligocene). The shale is characterized by very high average TOC (up to 10%), high thickness (~100 m), and thermal maturity laterally and vertically (tectonic multiplication) varying from immature, through oil and wet gas window, to dry gas window. Oil and gas saturation of the shale is confirmed by HC shows and results of frac jobs. The other unconventional play in this province is a tight gas/oil in Cretaceous and Paleogene sandstone reservoir. Tight reservoir development is observed as a rule at burial depths higher than ~2000 m. Moreover, geological constraints indicate presence of deep gas/oil in the Outer Carpathians. In this case a challenge for exploration is low quality of deep seismic image, resulting from complex structure of the orogen. In a case of the OC a new yet-to-find unconventional potential so far remains not quantified.

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Unconventional geological play concept of southwestern part of Neogene Pannonian basin (Croatia)

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Sava and Drava Neogene basin sedimentary infill was submitted to fracking campaign in 2015/2016 on 5 vertical wells. Results gave crucial input data for start of an integrated, multidisciplinary study of unconventional play potential in Croatia. Exploration approach to unconventional reservoirs with knowhow transfer was established with engagement of experienced consulting company. Research focused on regional present source rocks and over-pressured oil and gas accumulations in low permeability reservoirs. Complete in-deep analysis from database, basin scale, play and prospect based analysis to the final drilling location was performed in one-year joint project. Composite dataset analyzed archive studies, published articles, well data (mud logging, TOC (Rock-Eval), core data, well tests, vitrinite reflectance – Ro), wirelogs, basin modeling data and seismics (two 3D cubes, >400 2D seismic lines, full TWT interpretation coverage, full coverage of structural depth maps and fault polygons interpretation). Two major unconventional plays were identified, shale and tight oil/gas plays. Further analysis characterized 6 main regional plays: Panonian low permeability play, Panonian shale oil play, Badenian low permeability play/tight carbonates, Badenian shale play, Karpatian low permeability play and Lower Miocene shale play. Altogether 20 potential locations were analyzed on play level while only 5 top-most ranked were upgraded to prospect level – two shale and three tight plays. Ranking was performed by implementing following criteria: stratigraphy, target depth, depositional environment/sedimentology, area extent, thickness, TOC, trapping, HC shows, maturity and migration, porosity and data quality. Unconventional shale prospect analysis revealed that the gas/oil content per rock unit is very low, which predominantly relates to the low TOC content in the interlayered shale/marls. “Sweet spot” pilot area analysis reached best well recovery of 0.018 BCM which is significantly lower than required well economic cut-off. The studied shale plays are regarded as a poor unconventional play and at present day conditions the economic exploitation is unlikely. The most prolific prospects identified in the study areas are tight gas plays regarded as moderate prolific and moderate risk prospects. For these plays an appraisal concept was developed together with multistage stimulation/fracking designs and development scenarios. Review of drilling and stimulation technologies for low permeability reservoirs and develop alternative cost schemes can make potential “game changers” out of tight gas plays in mature Pannonian basin petroleum system.

Petroleum system analysis of small scale Miocene troughs in the Pannonian Basin, results of a 3D basin modeling case study from Southern Hungary

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The role of the Early to Late Miocene age source rocks in the Late Neogene petroleum system of the Pannonian Basin is undoubtedly significant, but less investigated as it would be necessary. Only few general publications exist which describes these sediments and their importance. We focused on the understanding of the Neogene tectono-stratigraphic development and petroleum systems of these small-scale syn-rift grabens in southern Hungary. We have developed a workflow for the organic geochemical, seismic and facies interpretation, basin subsidence and finally 3D basin modelling to better understand the Miocene–Pliocene age hydrocarbon system in a 1620 km^2 study area. This area covers two, small scale (less than 200–400 km^2 each) troughs fulfilled with syn- and post-rift deposits with large thickness but significantly different structural evolution. During our investigation six source rock beds were identified and built into the model. Thousands of meters of Early-to-Middle Miocene, (Karpatian age) sediment was accumulated in the “pull apart”, but later structurally partly inverted Kiskunhalas Trough in the south, where four moderate-to-good quality (2 wt.% estimated original total organic carbon [TOC], 200 HI), dominantly gas-prone, immature to wet gas mature source rock beds were identified. In the overlying Middle Miocene (Badenian age) sediments, a younger, generally good quality (2 wt.% estimated original [TOC], 300–500 HI, Type II and II-S), oil-prone, dominantly oil mature source bed was identified. This layer as the regional Miocene source rock plays the main role of the known hydrocarbon accumulations. The 3D basin and petroleum system modelling helped understanding the hydrocarbon migration into the already discovered fields as well as identified possible future exploration objects.

LBr-1 structure for pilot CCS in the Vienna basin: lithological and tectonic 3D model

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The LBr-1 is an abandoned oil and gas field Lanzhot – Brodske located at the Czech and Slovak border in the Vienna basin. The Lanžhot block forms a southern part of the Hodonín – Gbely horst in the Czech part of the Vienna Basin, adjacent to the Moravian Central Depression on the W and Kúty Depression on the SE. This area has been recently revisited with an effort to evaluate potential CO_2 storage (CCS) and EOR. The well log data along with the seismics, petrophysics and stratigraphy served as basis for construction of a new 3D/2D model of the Badenian to Pannonian and younger strata. The oil and gas field LBr-1 was explored and exploited from 1956 to 1976. The new well log correlations introduced marker horizons, sequence stratigraphic features, such as upward coarsening or fining, pinchouts and transgressive phenomena. The well log data are tied up with the 3D seismics and principal surfaces are interpreted with lithological patterns and petrophysical properties in maps and profiles in addition to the previous works (Prochac *et al*., 2012). The key intervals include 4 partial sand horizons within the Lab reservoir, top of the Middle Badenian regional seal and base of the reservoir. Faults are mapped in the seismic lines and modeled in 3D. They are situated mainly outside the reservoir and do not represent a major risk for the storage integrity. The overburden model includes top of the Sarmatian, Pannonian coal seam strata, and the base of the Quaternary. Compartmentalization and reservoir continuity is shown in 3D and provides basis for improved understanding of the porosity and permeability distribution in the storage complex. The modeling results of the 3D structure within the geological context of the northern Vienna basin are used in the dynamic reservoir model simulating the CO_2 storage.

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Development of Early-Middle Jurassic hydrocarbon bearing basins in western part of Northern Bulgaria

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After discovering in 1975 the first two in Bulgaria economic oil-gas fields in the Lower Jurassic basal terrigenous sediments, named Dolni Lukovit and Bardarski Geran, the exploration strategy in NW Bulgaria has been changed to Lower Jurassic basal clastics. However, in spite of the large volume exploration (seismic and drilling), only few smaller oil and gas-condensate fields of this type have been found. The main obstacle during the exploration has been the unpredicted irregularity in the spreading of the Lower Jurassic basal clastics. Often they pinch out quickly, or became predominantly shally, or manifest serious compaction changes.

The hydrocarbons in these accumulations have been generated by some source intervals in thicker above 250 m Lower–Middle Jurassic sedimentary succession, related mainly with lower-middle part of the Ozirovo Formation (Dolni Lukovit and Bukorovtsi members) and lower part of the Etropole Formation (Stefanets Member) (Georgiev, 1997, 2000; Georgiev and Ilieva, 2007).

The main aim of our study is to localize the complicated system of small and deeper sedimentary basins, which development is controlled often by reverse faults, as well to clarify their subsidence history and depositional environment. The study is based on all data from exploration (seismic and drilling) and literature. The source hydrocarbon kitchens are related with deeper zones of these basins, where the thickness of the Lower–Middle Jurassic sediments is above 400–500 m.

The productive Lower Jurassic basal deposits have thickness usually no more than 30–50 m. They are presented mainly by bright colored fine to middle grained quartzitic sandstones and siltstones, slightly cemented with calcareous matrix, well-marked by PS log. The lower part of the section is more shally (Bachiishte Fm.), while the upper one is more terrigenous (Kostina Fm.). By relevant seismic facial and paleo-geomorphological analysis and interpretations are marked the probable zones of Lower Jurassic basal deposits spreading, which are the most promising for exploration.

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Tectonic setting and hydrocarbon potential of the Albanides fold-and-thrust belts

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The Albanides are part of the Dinaric-Albanic-Hellenic thrust belt that resulted from the tectonic sedimentary evolution of the Adria microplate during the Alpine orogeny from Triassic to the present. The studies on tectonic setting and hydrocarbon potential of the Albanides thrust belts started with regional geological mappings as well as seismic and gravimetric surveys considered as very important data to understand the tectonic and structural models, tectonic history, identification of the possible prospects, as well as for a better orientation of the exploration works.

Now, after 100 years activity, the integration of numerous geological-geophysical data clearly show the presence of a westward thrusted tectonic model of each tectonic zones and belts.

As part of the Dinaric-Hellenic arc of the Alpine chain, based on their stratigraphy and tectonic evolution, the Albanides are subdivided into Internal and External Albanides. The Internal Albanides are characterized by the occurrence of Jurassic ophiolites and include Mirdita, Korabi and Gashi tectonic zones. The External Albanides comprise complex tectonic assemblages, carbonate-flysch westward thrusted units, identified as Krasta-Cukali, Kruja, Ionian and Sazani tectonic zones.

Oil and gas accumulations discovered up to now are located only in the Ionian tectonic zone. They occur in both carbonates of the Ionian zone and in the clastic formation of Peri-Adriatic Depression. The carbonate reservoirs range in age from Cretaceous to Eocene and essentially consist of pelagic facies of the Ionian tectonic zone. They are lithologically represented by micritic and clastic fractured limestones. In general, carbonate reservoirs have low matrix porosity but open fractures are present. Clastic reservoirs belong to the Periadriatic depression and occur in the sandstones of the Messinian–Pliocene interval.

Considering still unclear the story of filling or not of all the traps with hydrocarbons, this paper deals with the finding of relationships between tectonic models and discovered oil field models. Such proposed models can help in discovering the same oil field models discovered to date, but also can help in discovery of the new hidden subthrust traps.

Deepwater petroleum play types of the Black Sea

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Deepwater hydrocarbon exploration drilling began in the Black Sea less than twenty years ago, primarily because of the economical/technological challenges associated with mobilizing suitable drilling rigs through the Bosporus. To date, however, approximately 20 deepwater wells have now been drilled, targeting a large variety of plays in this very large underexplored basin complex.

The numerous deepwater Black Sea play types can be subdivided into pre-, syn- and post-rift/sag plays. The sag/post-rift play types have proven to be more successful, finding either biogenic gas in Miocene to Pliocene reservoirs associated with the Palaeo-Danube and Palaeo-Dniper/Dnestr, or oil in Oligocene deepwater siliciclastic systems. Syn-rift or early post-rift plays, in contrast, assumed mostly shallow water carbonate reservoir targets. Just one well has targeted the pre-rift stratigraphy.

The largest targets are syn-rift fault blocks, such as the Andrusov and Tetyaev highs in the center of the Black Sea. Although their internal stratigraphy is still very poorly constrained (*i.e.*, proportion of pre-rift and syn-rift versus pre-rift basement), this translates to not only reservoir presence risk, but also to reservoir quality risk. The trap sizes are very large. In addition, the assumed lateral charge from the Miocene-Oligocene Maykop Formation and from the Middle Eocene Kuma Formation makes these structures attractive.

The overall structure of the Shatsky Ridge in the Russian sector of the basin is not as clear because it includes elements of a large Jurassic carbonate platform on top. The Polshkov High is unique in the sense that it represents a large rotated syn-rift fault block along the lower plate edge of the Western Black Sea in Bulgaria. On the conjugate upper plate margin, very large inverted syn-rift structures, such as the Kozlu Anticline, are recognized in the Turkish sector. On top of some of these syn-rift highs, various carbonate geometries were interpreted on seismic data, which turned out to be associated with Cretaceous volcanism.

In the post-rift and sag basin fill, several intra-Cenozoic reservoirs are being targeted in the compactional anticlines above the large syn-rift highs. Another play associated with deepwater sands of the Maykop sequence is the deepwater extension of the Subbotina discovery offshore Crimea. The Subbotina structure is just one compressional anticline among many others situated in a dominantly Miocene, south-vergent folded belt offshore Kerch Peninsula. Similar thrust-fold belts are also known in the Russian (Tuapse), Georgian (Gurian), Turkish (Pontides), and Bulgarian (Balkans) sectors of the Black Sea. However, reservoir presence and quality will remain a definite risk for the Cenozoic reservoir intervals in certain segments of the Black Sea as the function of intermittent sedimentary entry points and the corresponding provenance areas.

Shelf collapse, tilting and hydrocarbon trap formation on deltaic to slope deposits (Újfalu and Algyő Formations), Battonya-high, Late Miocene Pannonian Basin

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The Late Miocene of the Pannonian Basin is a well known hydrocarbon system, including source rocks, reservoirs and seals, particularly in the vicinity of basement highs. Large volume of reservoir quality sandstones were deposited as: 1) basin-center confined turbidite lobes pinching out towards the highs; 2) unconfined turbidite lobes related directly to progradation of the shelf-slope; and 3) mouth bar on delta fronts and delta-channel fills. All types are both temporally and spatially widespread and my form stratigraphic traps with lateral and top seals at many locations. However, even if other necessary factors (*e.g.*, charge) are present, only those sandstone bodies act as reservoirs which are also in structurally suitable position. Here two examples are presented from the Mezőkovácsháza 3D seismic dataset (Battonya-high, Southeast Hungary). The sedimentary succession above basement rocks is comprises of thin basal abrasional conglomerates, ca. 75 m of profundal marls overlain by slope siltstones (Algyő Formation) up to a thickness of 200 m. Generally turbidites are thin isolated sheets or missing indicating that bypass may have been common during deposition. The slope is overlain by 30–50 m coarsening up deltaic suits (Újfalu Formation) up to an overall thickness of 500 m. Some of the delta lobes reached not only the shelf edge, but got extended to the uppermost slope. The lacustrine sediments above the high formed a gentle compactional anticline enhanced by the Pliocene inversion. Therefore delta-front to upper slope strata on the upstream side of the high are now tilted to a small scale antiform, while opposite tilt of the same type of geometry did not generate closure.

Based on interpretation of five successive clinoforms, *i.e.*, delta-to-slope-to-basin floor horizons, the shelf progradation has been reconstructed both on maps and 3D blocks. The specialty of the area is that two main sediment input directions are indentified: there was a self-slope prograding from northwest and another from southeast. The intensity of the progradation appeared to be highly asymmetric: the progradation from the northwest (*i.e.*, Palaeo-Danube) was about twice as fast than that from the southeast. As the roughly 250 m deep lake rapidly filled, a major slope collapse occurred manifested by several listric faults, tilting of 200 m high slope slabs in the extensional realm and folds to reverse faults at the compressional part. Very rapid deposition of deltaic sands induced further deformation, which in turn made a small anticline of the sands. This 3D closure was necessary to develop the trap.

Although above the Battonya-high, the Late Miocene sediments have not been affected by major structural deformation, the observed Pliocene tilt and the self-slope collapse, played significant roles in hydrocarbon trapping.

Conventional and unconventional petroleum systems in the Ukrainian Dniepr-Donets-Basin: A comprehensive source rock study

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In Ukraine hydrocarbons are produced mainly in the Dniepr-Donets Basin (DDB). While reservoirs are predominantly located in the Upper Visean and Lower Permian, a multitude of potential source rock units exists in the Devonian and especially the Carboniferous succession (*e.g.*, Upper Visean “Rudov Beds“). In an attempt to evaluate their contribution to the charging of conventional oil and gas deposits, oil/gas-source rock correlation was performed based on biomarker and carbon stable isotope data. Furthermore, pyrolysis gas chromatography was used to define the hydrocarbon potential of the potential source rock intervals. The majority of investigated oil and gas/condensate samples could be correlated either to a (Upper) Visean or a Serpukhovian source, while Devonian rocks were not identified as a major source in the NW DDB, despite their relative importance in the neighbouring Pripyat Trough. Furthermore, organic geochemical data clearly points to mixing of different oil families in the NW DDB. Additional contributions of Tournaisian, as well as Bashkirian and Moscovian (partly coaly) units were determined especially for the central and SE DDB (*e.g.*, giant Shebelinka field). Due to their proven importance as a source for conventional oil/gas deposits in the NW DDB, Upper Visean Rudov Beds might also be considered a target for shale gas/oil production. Unconventional production requires certain quality parameters to be met, and preferably lateral continuity. Clearly, Rudov Beds show sufficient TOC contents and thickness over a wide lateral area, including main parts of the NW and central DDB. Nevertheless, organic petrographical and organic geochemical data point to a facies zonation with the oil-prone facies being restricted to the so-called Srebnen Bay in the NW part of the basin, whereas a strong terrestrial input at the basin margins and in the central part clearly reduces the generation potential for liquid hydrocarbons in these areas. Target maturity for shale oil (>0.8 %Rr) and shale gas (>1.2 %Rr) production is reached at great depths only (>4.5 km and >5.5 km, respectively), and kinetic experiments do not point to earlier generation, *e.g.*, due to the presence of type II S kerogen. The low thermal maturity, confirmed by the presence of expandable clay minerals to depths >5 km, is referred to a low Mesozoic heat flow that also agrees with 1/2-D thermal modelling results. The mineralogical composition of Rudov Beds varies strongly in both lateral and vertical directions, challenging the previously established facies zone concept. A substantial fraction of samples from the basinal (siliceous), as well as the majority of samples from transitional (calcareous) and marginal (clayey) facies zones do not meet the desired cut-off of >60 wt.% brittle minerals (quartz, feldspar, pyrite, etc.), due to high clay mineral contents. Kaolinite contents up to 80 wt.% where determined even for samples from the basinal facies. Furthermore, a strong diagenetic overprint resulting in authigenic (carbonate) cement phases was observed for many samples. These are considered to have an important influence on the overall mechanical properties, limiting their predictability by bulk mineralogical data.

Reservoir quality assessment for hydrocarbon-bearing rocks using MICP tests

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Reservoir Quality assessment is one of the most important issues in the oil and gas industry. It can be achieved through several technical methods based on the pore volume, connectivity and conductivity. Reservoir Quality index (RQI), Reservoir Flow Indicator (FZI) and Reservoir Potential Index (RPI) are among the most important parameters used for this assessment. In addition, Winland equation (r35) is one of these important techniques that are mostly based on the pore throat distribution. Recently many trials have been introduced to assess and rank the reservoir quality based on the pore throat distribution curves obtained from the Mercury Injection Capillary Pressure (MICP) tests for sandstone reservoirs. These studies ranked the reservoir quality into six ranks based on the pore throat radius which has been classified into five sizes: mega, macro, meso, micro and nanopores. The present study is a further trial to rank the sandstone reservoirs based on the MICP studies and to compare its efficiency with the other common techniques, *e.g.*, Winland equation, RQI, FZI and RPI. A total of more than 200 sandstone samples were collected and their petrophysical properties were studied including, bulk and grain densities, porosity and permeability. In addition, their pore throat distributions were studied using the MICP tests up to 30.000 psi. The obtained curves were then ranked after digitization into mega, macro, meso, micro- and nanopore sizes. Integration between the capillary curves and the pore sizes enables accurate assessment for the reservoir quality. Extension of the present study to the carbonate and shale reservoirs has been tested for some published data. It is achieved that, the present procedure can be applied to heterogeneous reservoirs (carbonates) and nanopore size reservoirs (shales) but with further discrimination into sub-ranks for shales and more complicated curves due to heterogeneity of carbonates. Therefore, the MICP tests are successful procedure for ranking the prospective reservoirs into six ranks with the homogeneous first quality reservoirs having the best rank and the sixth quality highly heterogeneous and nanopore reservoirs have the worst rank.

Rift sequence stratigraphy and its contribution to source rock understanding – Serbian part of Pannonian Basin

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The Pannonian basin is classical back-arc basin formed during the Miocene times. The recent studies of south-eastern part of Pannonian Basin showed that rifting took place along asymmetric simple shear extensional mechanism (Matenco and Radivojević, 2012). The analysis of syn-kinematic reflectors demonstrates that normal faulting migrates in time and space and took place on a wide Miocene time interval (roughly 20–5.5 Ma) (Matenco and Radivojević, 2012).

The most prolific source rocks in Serbian part of Pannonian Basin are marls and limestones of the Sarmatian and Pannonian (Kostić, 2012). Besides this sequence, source rocks are also to a lesser extent represented by shales of the Badenian and Pre-Badenian Tertiary, while the Lower Pontian shales were found to contain only gas-prone source rocks (Kostić, 2012). Since the Sarmatian sediments are mostly missing or have very restricted thickness in depressions close to the biggest oil and gas fields in Serbia (Ivanišević and Radivojević, 2018; Radivojević and Rundić, 2016) one can conclude that the main source rock is of Pannonian age. Those rocks correspond to the Endrőd formation hemipelagic marls, one of the source rocks at the largest hydrocarbon field in Hungary – Algyő field (Magyar *et al*., 2006). The marly limestones and limy marls of Lower Miocene are most contributing source rocks in Croatian part of Pannonian Basin (Lučić *et al*., 2001). Those sediments are absent in vicinity of biggest Serbian oil fields, since the rifting of major depressions appeared later.

The different timing of rifting affects the age (Lower Miocene to Pontian) and depositional environment (marine to lacustrine) of hydrocarbon generation. Because of that it is important to use the rift sequence stratigraphy approach which should led to better understanding of the petroleum system elements.

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Thermal maturity of Miocene organic matter from the Carpathian Foredeep in the Czech Republic

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The aim of the research was to determine the thermal maturity of the Miocene sedimentary rocks with the vitrinite reflectance. Based on this information, it is possible to characterize the expected paleo-geothermal gradient within the Carpathian Foredeep in the area of Czech Republic.

The Carpathian Foredeep represents a peripheral foreland basin formed due to the tectonic emplacement and crustal loading of the Alpine-Carpathian Thrust Wedge onto the passive margin of the Bohemian Massif. The lithological and stratigraphical content and basin architecture changes in different parts of the basin. Local and regional unconformities are developed due to varying intensity and orientation of flexural loading and different geologic and tectonic histories of the basement, along with a polyphase nature of the active basin margin and gradual change of its position. The basin continues north into the Polish part of the Carpathian Foredeep Basin and south into the North Alpine Foreland Basin. Twenty-five samples from 13 boreholes from the central part of the Carpathian Foredeep were collected. For all those samples, random vitrinite reflectance (Rr) was measured and maceral analysis was performed. Additionally, in order to evaluate regional distribution and depth trends for all of the Carpathian Foredeep, an archive data of vitrinite reflectance from 31 samples from 20 boreholes and results of RockEval pyrolysis (RE) from 107 samples were used.

The vitrinite reflectance values (% Rr) in boreholes Got 1, Got 2, Tl 1 and Luk 1 are continuously increasing with the depth from 0.36% Rr to 0.58% Rr. In samples from Koryčany 9 and 13 boreholes, the vitrinite reflectance ranges from 0.26% Rr to 0.28% Rr, and from Mouchnice 1, 2 boreholes, vitrinite reflectance ranges from 0.27 % Rr to 0.29 % Rr. The vitrinite reflectance of organic matter from the boreholes of Ždánice 135, 147, and 175, Snovídky 1 and Žarošice 2 shows significantly lower values (0.22–0.3% Rr) compared to other parts of the Carpathian Foredeep. Samples also contain a high ratio of organic matter in which liptinite is significantly represented.

Maceral analysis of dispersed organic matter in the sediments of the Carpathian Foredeep enabled to determine dominant maceral composition. The analysis showed that the decisive parameter is the ratio of the liptinite component.

Source rock potential, geochemical characteristic and thermal maturity of the Oligocene Menilite Formation within the Loučka outcrop (Silesian Unit, Czech Republic)

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The Oligocene Menilite Formation is regarded as one of the most prolific source rocks of hydrocarbons within the Paratethys. The formation is in the territory of the Czech Republic subdivided into the Subchert Member (NP22), Chert Member (uppermost NP22 to NP23), Dynow Marlstone (NP23) and Šitbořice Member (uppermost NP23 to lowermost NP25). Our research represents the results of bulk geochemical analysis and Rock-Eval pyrolysis. The geochemical evaluation, source rock potential, kerogen type and thermal maturity of the Menilite Formation were studied using 37 samples originated from the Loučka outcrop, where the Subchert Member, Chert Member, Dynow Marlstones and lowermost part of the Šitbořice Member are exposed. Studied outcrop (GPS coordinates of N 49° 26' 39.1"; E 17° 51' 46.3") is situated only about 7 km SE from the original Glocker's (1844) type area of several small (up to 2 m) isolated outcrops, where the Menilite Formation has been first recognized.

Within the studied outcrop the TOC ranges from 0.72 to 13.48 wt.% with the average of 3.81 wt.%. The Chert Member samples show the highest average TOC of 5.13 wt.% among the members. The HI of all studied samples ranges between 55 and 721 mg HC/g TOC (with the average and median of 435 and 434 mg HC/g TOC, respectively). The average reaches 367 mg HC/g TOC within the Subchert Member, 636 mg HC/g TOC in Chert Member, 447 mg HC/g TOC on samples of Dynow Marlstone and 254 mg HC/g TOC on samples from Šitbořice Member. The free hydrocarbons content (S1 peak) range from 0.03 to 0.99 mg HC/g rock with the average of 0.24 mg HC/g rock only, while the residual hydrocarbon content (S2 peak) range from 0.90 to 71.86 mg HC/g rock with the average of 18.26 mg HC/g rock. The whole studied succession has mostly "Good" source rock potential according to petroleum potential of S1+S2 peaks (23 of total 37 samples) and even "Very Good" source rock potential according to TOC (30 of total 37 samples) based on the classification of Peters (1986). Kerogen type II with admixtures of kerogen type I (mostly of the Chert Member) and type III was indicated based on the Rock-Eval data (HI versus Tmax) and TOC versus S2 peak relationship. Presumed immaturity indicated by Rock-Eval Tmax (from 406 to 433 °C) was confirmed by random vitrinite reflectance (Rr).

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An alternative technique to determine source layers without direct geochemical measurements – case study from the Pannonian Basin, southern Hungary

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The role of the Early Miocene Karpatian age source rocks in the Late Neogene petroleum system of the Pannonian Basin could be locally significant, but less investigated as it would be necessary so far. Only few general publications exist which describes these sediments and their local importance. Identification and understanding of their role in the active petroleum system are challenging because these rocks generally have restricted areal distribution under various geological setting, and are deeply buried under HPHT condition. Because of the Karpatian age sediments were rarely in the focus of the mainstream of the hydrocarbon exploration, only few wells are existing in Hungary which penetrated its sediments and are properly investigated. Looking the facts above, it is crucial to use all the available data with the best interpretation technique to gather every possible information about these source rocks. In this work an alternative technique is presented for the identification and delineation of possible source rock layer/s in the investigated Karpatian sediment package of the Kiskunhalas Trough, located on the southern part of the Great Hungarian Plain, Hungary. The workflow was executed on two wells, but the data background of them was rather different. The technique was figured out for the well with the modern dataset and controlled by the older well in which direct geochemical measurements were taken in the 1980s. The results look reasonable for the thermally matured source rocks under the given geological and physical setting. With the application of the work flow a new, so far unknown source layer was identified and helped to understand better the lateral variation of the source rock facies. Last but not least, the results of this study was built into our regional scale basin modelling work what gave us more precise estimations about the hydrocarbon potential of the area. Despite of the technique was developed for a special condition (matured source rocks, HPHT), but probably could be applied for source rocks identification under different conditions as well.

The Lower Paleozoic oil/gas shale plays in the Central Europe

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During the last decade shale oil/gas potential was analyzed for a number of European petroleum basins. The major exploration efforts were concentrated on the European Lower Paleozoic organic-rich shale. Such shale formations are developed on the western slope of the East European Craton (EEC) within Caledonian foredeep basins, *i.e.*, Baltic Basin (BB), Lublin-Podlasie Basin (LPB), and Volyn-Podillya-Moldavia Basin (VPMB), as well as on other adjacent tectonic blocks, *i.e.*, the Malopolska and Moesia (MP).

Within the EEC a diachronism in deposition of organic-rich shale is observed – in the southwest BB it begun during the Middle/Upper Cambrian, in the central BB during the Caradoc, in the Eastern BB and northern LPB during the Llandovery, while in the southern LPB and in the VPMB during Wenlock time. On the ECC flexural basin, the belt of organic-rich shale deposition was replaced to the east, *i.e.*, towards shallower part of the basin, by sedimentation of carbonates, while in the west it was limited by the influx of detritus derived from Caledonian collision zone.

TOC contents of the analyzed shale formations is highly variable both laterally and vertically. Within the EEC the highest average TOC in observed in the central BB (Caradoc and Llandovery), and in the western BB (Alum Shale), where is riches 3–5% and 5–10%, respectively. In the LPB and VPMB the TOC contents is lower (mostly in a range of 1–1.5%), while in the MP (Tandarei Fm) it ranges from 0.1 to 3.5%. Net reservoir thickness, defined only for the BB and LPB, is the highest also in the central BB and is equal to 20–40 m. Gross thickness of organic-rich shale in the whole analyzed is in a range of a few to several tens of meters. High thickness of TOC-lean shale is characteristic for the Wenlock in the eastern BB, LPB, and VPMB.

On the western slope of the EEC the burial depth to the Lower Paleozoic shale reservoir increases from the east and northeast towards west and southwest, while within the MP burial depth increases towards the north. The same direction thermal maturity of the reservoir changes. In the major part of the study area the shale reservoir is matured to the oil or liquids window. Gas window is limited and restricted to the deep part of the basin (>3500–4000 m). Due to early hydrocarbon generation and subsequent significant uplift, at the major part of the study area no overpressure is observed. Degree of tectonic deformation is low in the BB, and moderate in the remaining area.

The highest exploration activity so far took place in the BB and LPB, where ~70 wells were drilled. However, there was only 5 wells with representative production test results. None of these wells was located in the dry gas window, easier for production. So far no commercial flow was obtained. The key challenge for flow rate improvement remains joint fracturing at a given location of at least two individual reservoir formations (*e.g.*, Caradoc and Llandovery) simultaneously.

Source rock potential and thermal maturity of the Oligocene Šitbořice Member (Menilite Formation) in the Ždánice Unit (Czech Republic)

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Rocks deposited within the Oligocene Paratethys are recognised as hydrocarbon sources. Those strata are one of the most important source rocks in the Flysch Carpathians among others. The Šitbořice Member (uppermost NP23 to lowermost NP25 zone) represents the upper part of the Menilite Formation in the Outer Flysch Carpathians of the Czech Republic. The Šitbořice Member is composed of brown and green non-calcareous shales, occasionally with bodies of mudstones or concretions of carbonates. Our research represents the results of bulk geochemical analysis and Rock-Eval pyrolysis. The geochemical evaluation, source rock potential, kerogen type and thermal maturity of the Šitbořice Member were studied using borehole cores. Based on the boreholes gamma logs, the continuous profile of the Menilite Formation in the area has been reconstructed.

TOC and Rock-Eval pyrolysis data were used for the primary assessment of the source rock potential and determination of the predominant type of organic matter. TOC ranges from 0.63 to 6.87 wt.%, with the average of 2.90 wt.%. The HI ranges from 53 to 541 mg HC/g TOC (with the average of 196 and median of 153 mg HC/g TOC). The TOC and Rock-Eval data show that Šitbořice Member holds mostly "very good" source rock potential according to TOC, however, "poor" according to petroleum potential (Peters, 1986). Nevertheless, 12 of total 37 samples are classified as "good" and 3 samples as "very good" source rock according to petroleum potential. The equal distribution between kerogen type II and III has been indicated by HI. However, the "true" HI based on the relationship of the residual hydrocarbon potential versus TOC according to Dahl *et al.* (2004) corresponds to kerogen type II. Presumed immaturity was confirmed by Rock-Eval Tmax. All studied samples reach narrow Tmax range from 400 to 424 °C. These values indicate low thermal maturity and the presence of a large portion of unconverted original organic matter. This fact is reflected in the kerogen type determination and the evaluation of its source rock potential.

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A new technology for oil and gas exploration and the evaluation of productive zones in Ukraine

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The methodology of combined geological-structural-thermo-atmo-geochemical exploration (further GSTAGE) is based on a complex approach to understand the spatiotemporal distribution of fluid-transmitting hydrocarbon systems combined with the development of fluid dynamic models, as well as optimizing the oil and gas exploration and searching hydrocarbons at shallow and significant depths in the sedimentary cover and in the basement. In the frame of this methodology, an ensemble of near-surface explorational techniques for land and marine areas was developed. It is based on the implementation of structural-thermo-atmo methods to predict highly permeable fault zones and to search for hydrocarbons in the crystalline basement and Phanerozoic deposits of the Carpatho-Crimean, Azov-Black Sea sectors of the Ukrainian Tethyan province. The difference between GSTAGE and other surveys, in addition to its systematic and complex approach, lies in its patented specially designed and high-quality express equipment that provides high-level exploration on-land and in marine conditions and analytical processing of the data.

Following criteria are analyzed in the frame of GSTAGE exploration: structures, tectonics, lithology, stratigraphy, facies, correlations, geochemistry and temperature gradients. The spatial distribution of thermo-atmo-geochemical anomalies is determined on the basis of a thorough analysis of the geological information from the research locations. In contrast to the hydrocarbon near-surface exploration methods, which were used in Ukraine earlier and were aimed at "direct" signs of hydrocarbon deposits such as methane anomalies, GSTAGE focuses on a systematic analysis, which includes thorough structural mapping and modeling of the fault-block frame, as well as detecting the highly permeable neotectonically active zones, that determine the modern near-surface discharge of fluid-gas streams and the most active hydrocarbon migration pathways.

The most characteristic near-surface mapping features of hydrocarbon industrial deposits are the following: a) the confinement to geodynamically passive and weakly fluid-permeable blocks that are favorable for trap formation and hydrocarbon deposits preservation; b) the presence of weak diffusive halos of methane and its horologes, which are surrounded by their local maxima at the peripheries; c) an increase of the temperature index above the hydrocarbon deposits.

Mapping these near-surface thermo-atmo-geochemical features, combined with geological and structural investigations of promising areas, is crucial for oil and gas prospect evaluation. Cartographic models are developed based on the distribution of sediment temperature indexes, the sum of the methane homologues, the integral coefficient corresponding to the indices of geodynamic activity and the permeability of geological and tectonic disturbances.

Using the methodology of GSTAGE we confirmed the spatiotemporal range of productivity; evaluated the potential of local structures; specified the search criteria for oil and gas deposits within the Carpathian region, the Ukrainian sector of the northwest and Kerch shelves, the continental slopes of the West and East Black Sea basins and the Sea of Azov.

Hydrocarbon generative – accumulative system of deep-seated sediments of the north of Western Siberia

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The current practice of geological and exploration works on increasing hydrocarbon resources is aimed in many countries for non-traditional objects, among which deep-seated deposits (below 4–5 km) play an important role. So, one of the promising targets for the search for hydrocarbons is the Triassic deflections in the north of Western Siberia, discovered by the Tyumen superdeep well (btm is the 7502 m) (the Korotchaevsky deflection), the Yen-Yakhinsk superdeep well (8250 m) (the Yen-Yakhinsky deflection), and the Jarudey Parametric well (5010 m) (the Jarudean deflection). According to the data of drilling, it was found out that the thickness of the Triassic terrigenous strata reaches to 1,350 m in which the oil and gas reservoirs have been identified. The density of the C_{org} content is the highest in the petroleum bearing strata of the Jarudei deflection, Triassic deposits according to the Rock Eval pyrolysis data are in the main oil formation zone. The petroleum bearing strata in the Korotchaevsky and the Yen-Yakhinsky deflections experienced a high catagenesis (AK3) and are in the main gas formation zone, having passed the main oil formation zone in the Middle Jurassic-Early Cretaceous time (Meshcheriakov and Karaseva, 2010).The results of the tests confirm that the development of reservoirs at great depths below 5.5 km. Core porosity and geophysical exploration of wells reach 16% in the Triassic sandstones of the Korotchaevsky deflection, and 14% – in the Yen-Yakhinsky deflection.The ideas of the continuous compaction of terrigenous rocks with depth and the absence of reservoirs at great depths were refuted. The reservoirs of different types below 4–5 km are recorded both in sedimentary and in volcanic strata of the Triassic. The reservoirs with relatively low values of porosity and permeability at great depths under conditions of abnormally high reservoir pressures are favorable for the development of migration and the formation of zones of gaseous hydrocarbons accumulation.

Based on the results of the tests in the conditions of high temperatures (more than 150 °C) and anomalous pressures (Ka > 1.7), the inflows of hydrocarbon gas enriched with methane in the depth interval of 5700–7100 m were obtained in the Korotchaevsky and the Yen-Yakhinsky deflections. Intense oil manifestations in the Triassic sediments of the Yaroudey deflection is marked (Karaseva *et al.*, 2012). The generative - accumulative system of hydrocarbons in the Yaroudey deflection contributed to the development of oil accumulations, whereas in the Yen-Yakhinsky and the Korotchaevsky deflections – the formation of gas deposits.

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Session GT12-1

Hydrogeology

Conveners:

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Karst aquifers of Southeast Europe – The greatest water resource for potable water supply

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Southeast Europe (SEE) is known worldwide as the "classic karst" where a new scientific discipline karstology was also born. In the Alpine orogenic belt and its branches Dinarides, Apennines, Carpathians, Balkans, and Hellenides the karstified carbonate rocks are widely distributed, and karst aquifers represent the main water resource for potable water supply. The six capitals and many large cities depend on water supply from karst aquifers (Stevanović, 2010; Stevanović and Eftimi, 2010). Among them are Rome (spring Peschiera, 18–21 m^3/s), Vienna (Kaiserbrunn, Kläffer, 4.5 m^3/s), Sarajevo (Vrelo Bosne, 1.4–24 m^3/s), Tirana (> 1.5 m^3/s), Podgorica (Mareza, 2–10 m^3/s), and Skopje (Rašče, 2.5 m^3/s). The tapping of large springs was the traditional method of water supply in the region since the Roman times and most cities along the shores of the Adriatic and Ionian seas were founded near large springs (*e.g.*, Rijeka, Split, Dubrovnik, and Kotor). Regional waterworks from the sources that drain the southern Apennine karst lead to Campania (Naples) and Puglia (Bari, Taranto). The most recent intake Bolje sestre of karstic sublacustrine spring (Q_{min} = 2.3 m^3/s) at the Skadar Lake basin ensures stable potable water delivery to entire coastal area of Montenegro (Radulović, 2000; Stevanović *et al.*, 2008; Stevanović, 2010).

The percentage of participation of karst water in the public supply varies from one country to the next, the highest being in Montenegro, where it exceeds 80%. The six SEE countries have more than 25% of their territories covered by karst, and all utilise less than 10% of their internal renewable water resources. In these countries (Montenegro, Bosnia and Herzegovina, Albania, Slovenia, Croatia and Austria), each citizen has more than 5,000 m^3 of water available annually (FAO-Aquastat, 2014). In an average hydrological year, each inhabitant of Montenegro has 21 m^3 of water available, but utilises just 1.2% of this volume. In Bosnia and Herzegovina the utilisation rate is even lower, below 1%. Citizens of other two "karst countries" Croatia and Albania use less than 5% of annually available water.

SEE is one of the most water-rich regions in the world, but ensuring regular water supply is not an easy task for the engineers for two reasons: the unstable regime of karst aquifers, which often results in reduced springs' discharge during the summer/autumn months, and the high vulnerability to pollution (limited attenuation capacity of the aquifers).

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Hydrochemistry and isotopes in risk assessment for coastal aquifers in Albania

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Albania has large coastal aquifers, in part in sediments, and in part karstic. This review will deal with the sedimentary aquifers, notably in the Drin, Mati and Vjosa deltas. Albania is an active tectonic area and this, in connection with sea water level variations, has meant that the coastline has moved considerably during the last millennia. Another factor is the gradual loss of vegetation, which has increased erosion and extended the coastal plains. Albania has erosion amounting to about 27 tons/ha.

Threats to the coastal aquifers are salt water intrusion, gravel extraction and pollution from mining upstreams, as well as the local pollution from agriculture and habitation on the coastal plains. In a perspective, the increase of the sea water level is another risk. Isotopes are useful in interpretation, ^{18}O, and D can show whether the water is of atmospheric origin or from intrusion of the sea water. The ^{34}S can, in this case, distinguish between sea water sulphate, sulphate from sulphide oxidation (mine tailings) and tracking of the recharge. In the thick Mati aquifer dating by ^{14}C was useful as part of the 200 m-thick sediments could contain fossil water.

There are elevated levels of chloride, especially in the Mati and Vjosa coastal aquifers. Plotting water isotopes versus chloride concentration show that this is not due to sea water intrusion. However, there are notably in the thick Mati plain sediments intercalated clay layers that leak chloride the age of these phenomena is in the order of 6000 years and date back to the Flandrian transgression, when the sea shore reached up to the coastal highlands. The ^{34}S indicate that sulphate has, especially in the Mati aquifer, sulphide oxidation origin coming from the active cooper mine and the numerous old mines in the Fani tributary to the main Mati River. The low ^{34}S values in the Mati aquifers, mirroring the sulphide oxidation in mine tailings along the Mati River, indicate that the recharge of the aquifers comes from the river.

As the metals leaching from mine tailings is a potential risk this was studied in the Fani River, a tributary to the main Mati River. The *in situ* dialysis showed that the metals were predominantly in colloidal and suspended form and sedimented within a few kilometers downstream from the point source. Metals were in the Drin and Vjosa rivers studied by speciation with the Visual MINTEQ speciation programme. Nowhere were the permissible levels of nickel and zinc surpassed. Locally, nitrate is elevated, thus indicating an influence from agriculture and habitations.

The risks for the studied aquifer seem to be limited as per present. Gravel extraction along the Mati River should be abandoned to avoid clogging and decrease in recharge. Monitoring of groundwater chemistry should be continued with the good ongoing programme. Groundwater level monitoring, especially along the sea shore, should be done in wells of different depths. Some of the old mine tailings deposits should be supplied with sedimentation ponds before the drainage reaches the rivers.

Hydraulic mechanism of discharge of Seljašnica karst spring (SW Serbia)

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Identification of karst aquifer characteristics is one of the main prerequisites in order to protect and use karst groundwater in a sustainable way. First information about the functioning of a karst hydrogeological system can be given by analyzing the karst spring discharge data, having in mind that karst springs are actually the only visible and often easily accessible part of a karst aquifer. Therefore, it is important to set up a monitoring network for continuous measurement of the karst spring discharge in order to determine the geometry and hydraulic features of a karst aquifer. Insight into the functioning of a karst hydrogeological system can be provided by analyzing behaviour of karst aquifer discharging in recession conditions, *i.e.*, in the period when karst aquifer has no recharge. Such an approach has been applied to the Seljašnica karst aquifer. This karst aquifer is part of a larger karst system – the Babine karst plateau, which is located in southwestern Serbia at the very border with Montenegro. The Babine karst plateau belongs to the Dinaric karst region, and it is built of Middle Triassic limestones, which thickness varies from 150 m to 750 m, in some parts possibly up to 1200 m. The ophiolites of Jurassic age and Triassic porphyrite igneous rocks define the boundaries of the Babine karst plateau. This karst plateau is drained by three large karst springs: Seljašnica and Bučje, in Serbia, and Breznica in Montenegro, and several other smaller springs. Systematic records of daily karst spring discharge of Seljašnica karst spring have been measured since May 2015. Characterization of Seljašnica karst aquifer and determination of hydraulic mechanism of discharge was carried out by analyzing the Seljašnica karst spring hydrograph and applying recession analysis in the period with no recharge. The analysis of the karst spring hydrographs has showed that the maximum discharge, Q_{max}, was 1.5 m^3/s, while Q_{min} was 0.14 m^3/s in period May – December 2015. Next year (2016), the maximum discharge was 7 m^3/s, while Q_{min} was 0.2 m^3/s. At the end, in 2017, Q_{max} was 5.5 m^3/s, while Q_{min} was 0.15 m^3/s. The maximal discharge rates occurred in springtime, when the effective infiltration from rainfalls and melted show is intensive, while the minimal occurred in summertime. The recession analysis was separately applied for 2015, 2016 and 2017 by using the Maillet's exponential equation. The analysis has shown the existence of 4 micro-regimes of discharging in 2015, which lasted for 98 days, 2 micro-regimes in 2016 (lasted 120 days), and 3 micro-regimes in 2017 (lasted 144 days). It was noticed that order of magnitude of recession coefficients (10-2) went up in 2015 after 35 days and in 2017 after 103 days, which indicates the existence of two dominant karst channels, probably at different levels, which are activated depending on current groundwater level. Otherwise, lower order of magnitude of recession coefficients (10-3) indicates that karst aquifer discharging occurs only as baseflow from the matrix porosity, when the higher and/or lower karst conduit is dried out.

Using hydrogeological and geophysical studies to evaluate the groundwater potentiality at Beni-Suef District, Egypt

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This work is aimed to the using of the electrical resistivity and hydrochemistry studies to evaluate the groundwater potentiality and assessment it for different uses. Thirty two vertical electrical resistivity soundings were carried out for detecting the groundwater potentiality. Forty two groundwater samples were collected from the studied area (Quaternary and Eocene aquifers) and chemically analyzed for major cations and anions. The result of analysis has been used to evaluate the collected groundwater for drinking and irrigation purposes, by comparing those parameters with the World Health Organization (WHO) and the Egyptian standards. The calculated electrical resistivities were calibrated with borehole data to assign the different lithological formations. Based on these, a subsurface resistivity map and an aquifer thickness map were prepared. The results indicate that the eastern and northern parts of the study area have low groundwater potentiality to meet the demands of water for irrigation and domestic purposes, where as the southern region has medium groundwater potential zones. Seventy-one percent of the collected Quaternary samples are suitable for drinking, and 80% of the Eocene samples are unsuitable due to their high levels of salinity. All the collected groundwater samples are unsuitable for domestic uses due to the high level of hardness. The majority of the collected groundwater samples are safe for irrigation based on SAR and US salinity diagram, RSC, KR and permeability index.

Geochemical long-term monitoring of heavy metals and arsenic in sediments from the Pannonian Basin in the Province of Vojvodina (Northern Serbia)

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Long-term monitoring (from 2013 to 2017) was carried out of selected surface sediments (0–50 cm) at four locations along Vojvodina (Northern Serbia): Bosut River, Nadel River and specific systems like Krivaja River and Begej Canal that are associated with the Danube–Tisa–Danube Canal (DTD). After digesting with cc. nitric acid, sediment samples were analyzed. Measurements of Ni, Zn, Cd, Cr, Cu and Pb were carried out by flame atomic absorption spectrometry (FAAS). The arsenic was measured by graphite furnace atomic absorption spectrometry (GFAAS) and Hg, by cold vapour atomic absorption spectrometry (AAS).

The average values of investigated substances, including priority substances (Ni, Cd, Pb and Hg) from four investigated locations, are: 70.28 mg/kg for Ni; 354.43 mg/kg for Zn; 9.38 mg/kg for Cd; 201.56 mg/kg for Cr; 108.34 mg/kg for Cu; 61.41 mg/kg for Pb; 51.24 mg/kg for As; and 0.53 mg/kg for Hg, dominantly higher than the average of the upper continental crust (*e.g.*, McLennan, 2001). Ni, Cd and As have also concentrations above prescribed national legislation (Serbian Official Gazette RS 50/2012, 2012) values that was created mostly based on the Dutch regulatory standard (Ministry of Housing, 39, 2000). The following mean concentrations of Ni in the sediment were detected: Bosut River (76.8 mg/kg); Krivaja River (51.18 mg/kg); Nadel River (55.15 mg/kg); and the Begej Canal (98 mg/kg). Based on prescribed national legislation, the values of Ni are showing elevated concentrations at investigated sites and indicate classification of sediments above maximum tolerable concentration.

In order to additionally process the concentration data, the geo-accumulation index (Igeo) was used to evaluate the quality of the sediments and to determine the potential ecological risks. Except Ni, all other substances have geological index values above concern, implying influence on biota. Interestingly, the geo-accumulation index for Ni varies in the low range 0.27–1.14 at the research sites, classifying these as unpolluted to moderately polluted, mostly due to possible periodical variations in seasonal water regime suggestions its geogenic origin.

A comparison of the results based on different criteria for the sediment quality assessment shows that they are sometimes contradictory. Therefore, a single approach to quality assessment may be insufficient. The combinations of the prescribed values, geological and ecological indices shifts the focus to establish a more complex methodology for the analysis of the impact on sediment, also for sediments from other similar nearby located and wider regions.

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Quality assessment of mineral and underground water from an old spa resort from Romania (Sângeorz-Băi locality)

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Water quality from Sângeorz-Băi locality (Northern Romania) was investigated. The latter locality is a well-known spa situated on the banks of the Someșul Mare River, at the base of the Rodnei Mountains (Eastern Carpathians), at 56 km away from the town of Bistrița. The mineral springs are known for their curative properties since the 17^{th} century. The mineralized aquifers are located between 55.20 m and 160.20 m depth, being quartered in Eocene sandstones and calcareous tuffs. The underground waters are situated at 8–18 meters in depth.

Thirty water samples have been collected (mineral waters – 8; public supply waters – 7; and well waters – 15) in two seasons – October 2017 and May 2018. The hydrochemical facies of the analyzed waters have been investigated using the Piper and Chada diagrams. The dominant water types are Na-Cl, for mineral waters, and Ca-Cl for underground waters. Based on the total hardness value and total dissolved solids (TDS), the investigated waters are falling into very hard brackish category (mineral waters), moderately soft-fresh and moderately hard-fresh water category (public supply waters), and moderately soft-fresh to moderately hard-fresh water category (well waters).

The assessment of underground waters quality was focused on the suitability of these waters for agricultural purposes (irrigation) using the sodium percentage (%Na) and sodium adsorption ratio (SAR) indices. The obtained results indicate that all the investigated waters are suitable for irrigations showing a low and very low hazard from this point of view. This is due to the intrusion of fresh waters into the aquifers.

Heavy metals concentration is extremely low, except one sample from water supply, where the copper content is exceeding the maximum limit allowed (MLA) by the national legislation, and three well waters, where the content of lead is exceeding the MLA. The dominant heavy metal in every analyzed water category is as follows: in mineral waters – Fe (98.50% of the samples), in well waters – Fe (in 51.49%) and in water supply – Cu (in 53.66%).

The results showed radon concentrations within the range of 5.36–24.28 Bq/l with an average value of 13.07 Bq/l, whereas radium concentration varied between 0.07 and 0.282 Bq/l with an average value of 0.16 Bq/l for all types of water covered within this survey. The corresponding annual effective ingestion dose due to radon and radium from water was determined from drinking water used by the population inhabiting the area. The results of this study clearly indicate that the radon and radium concentrations in drinking water samples are mostly low and below the proposed reference level of the EU Commission Recommendation.

The results certify the good quality of all the investigated water categories from the Sângeorz-Băi locality. The mineral waters represent an important resource for the area that can be capitalized at national and international levels as curative waters. Starting to this point, the tourism development should be an important priority, not negligible in the context of an increasing level of pollution of surface and underground waters in the world.

Quality of karst waters in Bulgaria – condition and problems

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The natural conditions in Bulgaria predetermine the occurrence of two major types of karstic waters (Antonov and Danchev, 1980; Pentchev *et al.*, 2004). The first type is related to the aquifers typical to Northern Bulgaria. These cover vast areas and occur at different depths. The water is being abstracted mostly through boreholes. In Central and Southern Bulgaria the karstifiable rocks are distributed irregularly and form individual karst massifs where the groundwater flows generally in channel networks. Often these are highly vulnerable. The water is being abstracted through tapped springs.

Following the adoption of WFD 2000 and the introduction of the principle of catchment management for the individual aquifer bodies, a systematic sampling of water sources was undertaken, including more than 200 karst sources. The results of the chemical analyses are collected by the River Basin Directorates. The objective of the present research is to investigate the condition of the karst water in the terms of hydrochemistry and the main causes for exceedances of certain indicators that were observed in approximately 1/3 of the tested sources. Most widespread is the NO_3 contamination – exceedances were recorded in 29% of the samples. These occur in wells in the topmost aquifers in Northern Bulgaria, in regions of dynamic agriculture. Approximately the same are the exceedances of Mn (29%) and Fe (24%), which in most instances were detected in water sources related to reducing conditions in the saturated zone. From the saturated zone are also the water sources of elevated ammonium concentrations (18%). In deeper aquifers, as well as in karst basins, in the conditions of slower and prolonged groundwater flow, there are higher concentrations of Ca, Mg, total hardness, and electrical conductivity as a result of dissolution of the karstic rocks. Elevated Na and Cl concentrations and increasing values of electrical conductivity were recorded in a limited area of the Sarmatian Karst Aquifer as a result of sea water intrusion. Elevated concentrations of some heavy metals were recorded in individual samples (Pb, Cr, Zn, Ni, Hg), regardless of the absence of anthropogenic sources of those elements. The increasing As concentration in the karst spring of Kobilyak is an interesting example of the combined effect of natural and anthropogenic factors.

The analysis indicates that the exceedances of quality standards for most of the parameters are caused by geogenic factors and to a lesser extent by contamination.

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Geochemical and isotopic evidence of seawater intrusion in the Fushe-Kuqe (Northwestern Albania) confined aquifer

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The Fushe-Kuqe costal aquifer is a typical confined alluvial aquifer, located in northwestern Albania. The aquifer medium consists of alternating and discontinuous layers of water-bearing gravel and sand with silt-clay impermeable layers giving to aquifer a multilayer character. Along the Mat River the aquifer seems to be continuous, whereas at distances 1.5–2 km from the river two to four or more aquifer layers appear separated by clayey layers. The transmissibility of the aquifer is generally high in the central part of the plain, on both sides of Mat River, where it is about 4000 to 8000 m^2/d, and gradually decreases to about 500–1000 m^2/d at the northern and southern periphery of the aquifer (Eftimi, 2003). The aquifer recharge occurs mainly through water infiltration from the River Mat gravelly bed in the North, and from Drojariver in the South, while its natural discharge proceeds to the Adriatic Sea.

Based on chloride and TDS content in groundwater, an advancement of sea water intrusion into aquifer fresh water was revealed. The direction of sea water wedge from coastal southwestern sectors towards Gorre and Fushe-Kuqe, where pumping station are located (Cenameri and Beqiraj, 2016), favours the opinion that it was caused by a decrease of groundwater pressure due to the high groundwater pumping. An increase of chloride content in groundwater through time was found, which means that sea water intrusion towards the fresh aquifer water is still advancing and is caused by both intensification of groundwater pumping for public water supply and by the private drilling of artesian private wells (Cenameri and Beqiraj, 2016).

By using Simpson ratio (SR) (Todd, 1959) and Jones ratio (JR) (Jones *et al.*, 1999) for investigating seawater intrusion in Fushe-Kuqe aquifer, it was recently found that most of groundwater sample fall in the fresh water (SR<0.5; JR>0.86) category as it could be expected for shallow wells (<50 m deep) which tap the first aquifer (Eftimi, 2003). Only two wells that tap the second (90 m deep) and third aquifer (>150 m deep) in the near shore line, show high (3.8 and 7.55) SR values and low (1.0 and 0.8) JR values, respectively.

The $\delta^{18}O$ and $\delta^{2}H$ values vary within a narrow (–6.78 to –7.96, and –41.86 to –50.53, for ^{18}O and ^{2}H, respectively) range and do not correlate with salinity as it could be expected when a single source of TDS and Cl exists. The lack of correlation between chloride and $\delta^{18}O$ indicates that the brackish groundwater is not formed by the mixing in of sea water (Kumanova *et al.*, 2014). In fact, the $\delta^{18}O$ and $\delta^{2}H$ values do not indicate any enrichment toward sea water isotopic composition.

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Geo-ecology of magisterial pipeline corridors – an example from the Kazbegi-Red Bridge section (Caucasus)

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At present, the main pipelines represent the most profitable economic means in terms of transportation, supply and exploitation of energy resources. Since their laying is associated with a change in the natural environment, the ecological study of these corridors is a prerequisite.

Geo-ecological study of the main pipelines is divided into three stages. This is the study of the pipeline route, to establish the existing background before the work begins. The second stage is the establishment of environmental impact during the laying of the pipeline. The third step is to monitor the environmental problems encountered during exploitation.

The presented article gives a geo-ecological study of the corridors of gas pipelines in the section 1200 m, 1000 m and 700 mm on the Kazbegi-Red Bridge (North-South) section. Carried out works represents the first stage of the study, and we have identified the physical and biological characteristics of the pipeline corridors. It was determined the purity of air, noise, chemical composition of soil, water and vegetation cover, as well as engineering and geological conditions of gas pipeline corridors.

The results obtained do not exceed the values of the maximum permissible concentrations adopted in Georgia and in European countries, although Pl, Co, Ni and Cd show increased values directly near the gas pipeline.

Session GT15

Cultural geology: Composition, technology and provenance of archaeological artifacts

Conveners:

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Mica schists – principal raw materials for early medieval Slavic rotary querns in Moravia and Silesia (Czech Republic)

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Raw materials for milling equipment have always been an object of the due attention in the past. Local rocks (especially granites, rhyolites, various clastic sediments) were used for crushers and saddle querns in the Neolithic to Hallstatt period. Rotary querns started to be widely used in the La Tène period and their appearance was accompanied by the origin of important production centres sometimes with large distribution areas. We know such workshops for Celtic rotary querns also in Bohemia, for example at the Kunětická hora Hill in eastern Bohemia (Tertiary tephritic phonolite), Žernoseky in northern Bohemia (Permian rhyolite ignimbrite) and around Přílepy in western Bohemia (Permian arcose). Lower Carboniferous greywackes of the Moravo-Silesian Paleozoic or sandstones from the Carpathian flysch belt were popular in Moravia. Occurrence of metamorphic rocks like gneiss or mica schist among raw materials for saddle querns or rotary querns is only exceptional. Similarly, especially various igneous (plutonic and volcanic) rocks were used in the following Roman and Migration periods.

Surprisingly, the Slavic rotary querns from the Early Middle Ages in Moravia were made prevalently from totally different raw material – mica schist in spite of it the rock seems to be rather unsuitable for such purpose. At all important Slavic fortified settlements from the period of Great Moravian Empire, *i.e.*, Mikulčice near Hodonín, Břeclav-Pohansko, Brno-Líšeň, Uherské Hradiště-Staré Město, mica schists form prevalent raw materials (roughly about 47% to 63%). They are followed by Slovakian rhyolites (up to 40%), gneisses (up to 20%), Carpathian flysch sandstones (up to 20 %), Miocene limestones, Permian arcoses, Culmian conglomerates. From archaeological literature it is evident that mica schist represents prevalent or substantially used raw material for Slavic rotary querns also in Lower Austria, Bohemia, Czech and Polish Silesia.

Detailed petrographic studies revealed only a part of those raw materials can be classified as typical mica schist. Some of them correspond to macroscopically similar two-mica gneiss because of a higher content of feldspars. To distinguish individual mica schists from various natural resources it is necessary to determine composition of accessory minerals, which may be represented by garnet rich in aluminium (almandine), tourmaline, staurolite, and kyanite. Using microprobe the author with his students has investigated chemical composition of garnet and tourmaline of rotary querns from a few Slavic hillforts: Chotěbuz-Podobora near Český Těšín (Czech Silesia), Staré Zámky in Brno-Líšeň and Hradiště in Znojmo. The results were compared with composition of accessory minerals of mica schists or two-mica gneisses from already described early medieval workshops for rotary querns at Altenhof near Gars am Kamp (Lower Austria), Čučice near Oslavany (western Moravia), Kamieniec Ząbkowicki near Kłodsko (Polish Lower Silesia) and a potential source Švédské šance at Svojanov (western Moravia) to determine the provenance of Slavic rotary querns.

Mineralogical and petrological characteristics of igneous rocks used for making polished stone tools from the Eneolithic archaeological site Masinske Njive (Serbia)

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In this study we report results of mineralogical and petrological investigations of 12 samples, which represent raw material used for making polished stone tools from the Eneolithic archaeological site Masinske Njive (Serbia). It is located about 45 km southwest from Belgrade, within the largest Serbian coal mining field called "Kolubara", in the close vicinity to the Starčevo and Eneolithic archaeological site Jaričište. The applied methods – optical transmitted light microscopy and SEM-EDS analyses – provided data about the composition and rock classification of the raw material and enabled important constraints on its possible origin.

Although the entire collection contains different rock types, we focus here only on igneous rocks. Two different rock facies of magmatic origin were found at Masinske Njive: hydrothermally altered volcaniclastics and facies of coherent quartzlatites. The main petrographic feature of the hydrothermally altered volcaniclastics is the presence of pumice. This characteristic implies that part of the raw material derived from rocks that were formed exclusively during explosive volcanic episodes. The facies of coherent quartzlatites can be divided into two varieties: mica-bearing quartzlatites, and pyroxene-bearing quartzlatites. The mica-bearing quartzlatites contain sieved plagioclases and display evidence of phlogopitization of biotite. The phlogopitized parts of biotites show higher SiO_2 and MgO contents and lower FeO(t), and Al_2O_3 concentrations compared to fresh biotites. The pyroxene-bearing quartzlatites do not possess any of the mentioned characteristics typical of the mica quartzlatites.

According to the information known from the local geology, we can emphasize that the pumice-bearing facies, along with the rocks which displaying effects of biotite phlogoptization are typical for volcanic successions of the Cenozoic igneous complexes of Serbia (Rudnik-Borač-Kotlenik, Kopaonik, Golija, Rogozna). Although all these complexes may be proper candidates for the origin of this raw material, the closest area to Masinske Njive is the volcanic complex of the Rudnik Mts, which strongly suggest that this was the area of origin of the studied raw material. The pyroxene-bearing quartzlatites differ from the mica-bearing varieties both in their petrography and presumably in petrogenesis, therefore, we suppose that the former represent a raw material of different provenance.

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Archaeopetrological studies nowadays: knowing the provenance of lithic tools by applying multidisciplinary analysis, from mineralogy to geochemistry

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In the last decades the successful application of some geological analytical methods to the study of archaeological lithic raw materials has allowed the development of a new discipline, the Archaeopetrology. The combination of mineralogical, chemical and physical methods from geology to social sciences as archaeology goes beyond the research on sourcing the lithic raw materials in prehistory and provides accurate archaeological responses. Furthermore, the addition of geochemical techniques to the archaeopetrological method generates quantifiable data, helping us to complete the previous mineralogical analysis.

This study regards the lithic industry at two Paleolithic rockshelters, l'Hort de la Boquera (Margalef de Montsant, Tarragona) dated from 12.250±60 BP to 11.775±45 BP, and La Roureda (Vilafranca, Castelló) dated to 11.350±50 BP both located in the north-eastern part of Iberia (Spain). A total of 28.412 flint artifacts and 35 geological samples from the surrounding area were investigated by a combination of techniques, such as macroscopy, polarized light optical microscopy, scanning electron microscopy, micro-Raman, X-ray diffraction and laser ablation inductively coupled plasma mass spectrometry.

Based on the comparison of lithic tools and geological samples it has been possible to identify the flint categories. For the l'Hort of Boquera site, three types of flint were distinguished: Type 1 – coming from the Cenozoic Ulldemolins Complex, Type 2 – collected from Quaternary terraces of Ebro River and Type 3 – originating from the Oligocene La Serra Llarga Formation. At the La Roureda site, four types of flint were distinguished: Type A (collected from an anthropogenic outcrop "Mas del Pinar", the Maastrichtian–Paleocene Fortanete Sinclyne and the Eocene–Oligocene Font de la Salut Formation); Type B (from the Turonian Mas del Quinyó Formation); Type C (with an unknown origin so far); and Type D (coming from the Quaternary terraces of Guadalope and Montlleó Rivers).

This work is an example of the great potential of the archaeopetrological approach and the study of provenance of the lithic raw materials in addressing the archaeological concepts of territory, taking into account the geographical space exploited by the prehistoric communities. An outgoing research of lithic tools found at several Palaeolithic and Neolithic settlements in Transylvania (Romania) will benefit of the applications of these methods in order to answer to the archaeological questions such as the economy of the prehistoric communities. Finally, the reasons for certain human behavior in prehistory will be better understood.

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Petrography and mineralogy of metabasite-artefacts from the Neolithic settlement at Brno-Holásky and comparison with rocks from source region near Želešice, South Moravian Region, Czech Republic

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Rocks from two different sources were studied petrographically and mineralogically using optical microscopy and electron microprobe analyses – metabasites used for manufacturing of polished stone artefacts found in the Neolithic settlement at Brno-Holásky (Trnová, 2017) and rocks from Želešice-metabasite body (Veverka, 2016). The comparison of these two different rock collections could be helpful to determine the source area of Neolithic mining within the Želešice source region and specify the rock variety preferred for production of polished stone industry during the Neolithic period. Želešice area is situated in the metabasite zone of the Brno batholith south of Brno and approximately 8 km WSW of the Brno-Holásky Neolithic settlement.

Metabasites from the Brno-Holásky settlement are characteristic by gray-green color, distinctive metamorphic foliation and common presence of tiny veinlets. Fine-grained amphibole predominates in the rocks along with plagioclase. Magnetite is common accessory mineral compared to somewhat rarer ilmenite, apatite and chlorite and secondary titanite. All the studied rocks were described as amphibole-rich greenschists to amphibolites (Trnová, 2017).

Most of the rocks from the Želešice-metabasite body were described by Veverka (2016). Amphibole and plagioclase predominate but common epidote, chlorite, biotite and quartz occur in some rock-varieties, along with titanite, ilmenite, magnetite, apatite and rare tourmaline and sericite. The rocks from the Želešice-metabasite body were described as chloritic greenschist, metadiorites and epidote-rich amphibolites with rare occurrence of biotite-gneiss with tourmaline. Amphiboles from the artefacts have composition of actinolite to magnesiohornblende with some transitions to tschermakite, ferrotschermakite, ferrohornblend and ferropargasite. In the rocks from Želešice, actinolite to magnesiohornblende prevail and pargasite to edenite were determined exceptionally.

Plagioclases from the artefacts are more basic, show wider range of basicity and have elevated contents of Fe^{3+} (up to 0.018 a.p.f.u.) compared to plagioclases from Želešice-rocks (up to 0.009 a.p.f.u.). Magnetite shows the composition of the end-member only with traces of Al and Mg in the both rocks from Brno-Holásky and Želešice area, while ilmenite is enriched significantly in Mn in the rocks from Želešice area. Chlorite is Mg-rich in both collections, as well as biotite in the rocks from Želešice. Tourmaline from the biotite gneiss in Želešice corresponds to Fe-rich dravite.

Amphibolites to greenschists from the source area near Želešice are very close in their petrography and mineral-composition to the raw material used for production of polished stone artefacts at the Neolithic settlement near Brno-Holásky. However, the rocks from Želešice area differ from the raw material in higher contents of epidote especially. The sample determined as chloritic greenschist, which was considered as the most similar rock to the raw material of the stone artefacts, comes from the vicinity of the contact of the metabasite body with granitoids of the Brno batholith where the metabasites were influenced by contact metamorphism and rheological properties of metabasites have improved therefore.

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Provenance of the Carpathian obsidians – View of geologist

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Obsidian is instantaneously solidified (quenched) igneous – volcanic rock, originated mainly from the acid rhyolitic (rarely basic basaltic) melt, often referred to as "natural glass", with typical glassy lustre and usually dark jet-black, grey or brown colour. Generally, it is dominantly composed of amorphous, dark (opaque) volcanic glass (≥95 volume %), with addition of various minerals, like biotite, plagioclase, alkali feldspar, quartz, pyroxenes, amphiboles, magnetite, Fe-Ti oxides, pyrrhotite, pyrite, chalcopyrite, olivine, zircon, apatite, monazite, uraninite, ilmenite, hercynite and garnet. Obsidian was widely used for tool-making (stone industry) during prehistoric times, and played significant role in the evolution of Humankind. Volcanic glass was geologically known since the end of the 18th Century, and it was archeologically documented in the 19th century in the Zemplín – Tokaj area (on the both sides of the present boundary between SE Slovakia and NE Hungary), the only natural volcanic glass region in Central Europe. The Carpathian obsidians from the studied Zemplín-Tokaj area belong to the Eastern Slovakian Neovolcanic Field (ESNF) in the SE Slovakia/NE Hungary, where the isolated Sarmatian volcanoes penetrate the Miocene strata and pre-Cainozoic basement. Surprisingly, modern geological research in the second half of the 20th century was more or less absent, and the archaeologists have been making basic research there. The pioneer work of Williams-Thorpe *et al.* (1984) brought the first provenance study of the Carpathian obsidians from the archaeological point of view. Authors recognized major provenance zones for obsidian samples from the Zemplín-Tokaj area, using the INAA analysis, and determined sources such as: "Carpathian-1", originating from the Viničky and Malá Tŕňa localities and "Carpathian-2a and 2b", coming from the occurrences at Csepegő Forrás, Tolcsva, Olaszliszka and Erdőbénye, located in the southern Hungarian sector. Revised provenance study (Rosania *et al.*, 2008) recommended distinguishing of Viničky obsidians (Carpathian 1a) from Cejkov obsidians (Carpathian 1b). Noteworthy is that the archaeologist's chemical analyses of obsidians comprise rather eclectic collection of determined elements that cannot be used for real geological genetic purposes. Our study is focused on the origin of obsidians in samples from the localities Viničky, Cejkov, Brehov and Hraň. Methods used include: LA-ICP-MS from spots and WR; dating (FT glass, K/Ar on WR, Ar/Ar – glass + biotite); EMPA – glass + minerals; µCT; Raman, Mössbauer, Rtg spectroscopy; positron annihilation lifetime spectroscopy (PALS); DTA (thermogravimetric analysis), magnetic susceptibility + thermomagnetic curves; radiogenic (Sr, Nd, Pb +Hf) and stable isotopes (O, H, Li + B). However, our complex study does not support an exact discrimination between samples from studied localities, and we recommend categorizing these obsidians by common label "Carpathian 1" only. Naturally, there exist some small mutual differences among the samples from these localities. Indeed, these variations are often statistically overlapping. Noteworthy, there exist common differences within one hand specimen in microdomains, *e.g.*, presence or absence of oriented flow fabric, presence of various microlites, dominance of the Fe-Ti oxides and/or pyroxenes trichites, their specific gravity etc., albeit glass composition of these obsidians is generally comparable. Nevertheless, there is known criticism of using handheld portable XRF data without calibration, and general compatibility bias of older INNA and XRF data to modern ones produced by mass spectrometry (LA-ICP-MS).

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Culture geology – Salzburg to Japan

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Culture geology – that was originally proposed by Prof. Wolfgang Vetters, University of Salzburg, as Kulturgeologie in the journal "Mitteilungen der Österreichischen Geologischen Gesellschaft", volume 93 (2003). In his article he defined culture geology as the interactive field of geology with cultural sciences. He mentioned also that culture geology is not a new discipline of geosciences, but it gives attractive presentation of geosciences to the public.

My first experience of culture geology is the attendance of the conference in Gmunden (Beiträge zur Geologie des Salkammerguts: Weidinger *et al.*, 2003) in August 2003. In this conference such culture-geological presentations were made: geoturism in Salzkammergut, geographical park of Dachstein, geotrail projects of Henndorf and Wolfgangsee, etc. I have been fascinated by new trend of geosciences as well as the radiolarian biostratigraphy of the Northern Calcareous Alps, and tried to incorporate it to Japan. First I have made a geotrail in the children park on small granitic hill, Okayama city, Japan (Suzuki *et al.*, 2009). This geotrail project was just a copy of Austrian geotrails like Wolfgangsee, Kapfenstaein etc. At that time I was satisfied with making copy of the Austrian culture geology.

On the March 11. 2011, however, northeast Japan was strongly shaken and its pacific coast was attacked by too high wave of tsunami. Although the catastrophe was caused by geological phenomena, Japanese geology could not help even one of victims. Under the consideration of the situation of geological academia in Japan, it was needed a new research field to connect geology and the public. So I have tried to introduce the concept of culture geology, the link between geology and human beings. In the year 2014, the first session of culture geology was held in the meeting of the Geological Society of Japan in Kagoshima. After 2015 to present, the Kakenhi-project of culture geology is supported by JSPS (Japan Society for the Promotion of Science). And in 2018 we have founded the Society of Culture Geology on the March 10. with 48 members in Kyoto. Now a new journal "Geology and Culture" is editing. The society is open not only for Japanese but also for anyone having interest to culture geology all the world.

In my talk the features of Japanese culture geology are introduced, especially with animistic point of view, in comparison with European geocultures.

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The use of handheld XRF and LA-QICP-MS in the analysis of the late Roman Seuso Treasure – implications on composition, provenance and technology

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The Seuso Treasure is one of the most significant silver treasures of Late Roman Imperial Age, dated to the 4^{th} century AD. It consists of 14 large silver vessels used for dining and washing (Mráv and Dági, 2014). The objects can be grouped based on their decoration, function, and manufacturing technique and can be linked to different workshops and/or different silversmiths. The major objectives of the archaeometric research performed on the treasure are the determination of the elemental composition of the objects, the mapping of their chemical homogeneity as well as the comparison and classification of the objects based on their chemical composition in combination with archaeological considerations. X-ray fluorescence, a widely used technique in the analysis of archaeological and historical metal objects, was applied to analyse the objects non-destructively as in the case of other late Roman silver finds (Lang *et al.*, 1984; Cowell and Hook, 2010; Lang and Hughes, 2016). The hXRF measurements were performed systematically along a pre-designed grid at several points, in contrast to other studies, in which objects were measured only at a few points. In order to determine the bulk elemental composition of the vessels and to verify the hXRF results, very small metal samples taken from the different parts of the objects were analysed by using LA-QICP-MS. Our results are compared with the elemental composition of other significant silver treasures of Late Roman Imperial Age.

The analysed objects consist of rather pure silver (88–98 mass% Ag) intentionally alloyed with copper. The copper content in the objects and in the various parts of the composite objects (ewers, situlas, amphora, and toilet casket) is not the same. Bases, handles, thumb-pieces, and rims, which are more exposed to mechanical impact, have higher copper content in order to increase the strength and hardness of soft silver. Gold, lead and bismuth, the most important trace elements detected in the silver objects, also show various concentrations among the artefacts, suggesting the use of different raw materials. Gold and lead contents of the objects indicate that not reused or remelted, but primary, cupelled silver was used for manufacturing the artefacts. The objects are classified into several groups based on their Bi/Pb ratios indicating the use of silver-lead raw materials with different Bi contents. The LA-QICP-MS measurements verified the results of the hXRF analyses. However, the effect of the corrosion can also be well traced, namely enrichment of silver and gold and depletion of copper on the surface.

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Understanding Roman Potters' technology at Fanum Martis, Northern France, using a compositional approach

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The Roman town of Fanum Martis, Valenciennes, is known to have become an important centre of pottery production with 15 kilns already identified. Five kilns were found scattered in the southern part of the town during the 1970s and 1990s, whereas recent excavations yielded another 10 kilns in the south-eastern part. All the kilns were dispersed, and operated between the end of the 1st century AD and the beginning of the 4th century AD. Examination of the waster dumps of the kilns that were excavated between 1970s and 1990s revealed a wealth of information on the typo-morphology of the local ceramic products; combined with the results of the recent excavations, this research examines Roman potters' technology at the centre of Famars, and change therein through time.

Inter-and intra-kiln variability among the waster vessels has been examined in detail, using both petrographic and chemical analyses. The scientific analyses have made significant contributions to different aspects of potters' technology at the town of Famars, and permitted to reconstruct consistent traditions. Several compositional patterns have been identified among the ceramic vessels, and they appear to be correlated to different phases in the operation of the kilns, and to changes in potters' selection of raw materials and manipulation. Close correspondence between the mineralogical and chemical characterisation of the ceramic samples provides several well-defined compositional reference groups for this production centre. They permit the identification of local products from Famars at other sites in Northern France, Belgium and the Netherlands, and provide a firm basis for infering the trade and distribution patterns in this northern region of the Roman Empire.

Fe-gehlenite formation in ancient ceramics: a firing or a primary composition indicator?

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Recently, in the ruins of Roman Napoca city (present day Cluj-Napoca, in Romania), dated back to 2^{nd} century A.D., more than one hundred sherds of fine and semifine household pottery were found. In the voids left by the decomposition of carbonate aggregates and foraminifera tests, various firing phases such as glass, 'ceramic melilite', clinopyroxene and Fe-gehlenite were identified. The latter is an important marker for the temperature reached when producing ancient ceramics. Due to usually low amount and very fine grains, its presence is generally difficult to document. Most of the proofs are provided by X-ray powder diffraction (XRPD), electron microprobe analysis (EMPA) and classical scanning electron microscopy coupled with energy dispersive X-ray spectrometry (SEM-EDX). The overwhelming strong X-ray diffraction peak of quartz masks the weak peaks which may be assigned to Fe-gehlenite. Additionally, the solid solution among gehlenite and åkermanite may change the position of the indicative XRPD lines. The EMPA and SEM-EDX chemical data are biased by the diameter of the electron beam, much larger than the individual grains/crystals.

We describe here in greater details Fe-gehlenite formed in the Roman sherds having a vitreous matrix, based on the analyses provided by cold field emission scanning microscope coupled with an energy dispersive X-ray spectrometer (CFE-SEM-EDX). With a very fine focused electron beam, CFE-SEM-EDX enables to visualize phases ~10 nm in size, and to measure a surface as small as 100 nm^2. The aim of the study is to find how Fe-gehlenite looks like, its chemistry and its relation with firing temperature.

Fe-gehlenite forms flat, leaf-like dendrites, maximum a few µm in length and 50 to 100 nm in width, showing often a divergent 'blow-up' orientation. The arms of the dendrites are polycrystalline and consist of 10 nm-sized tabular grains arranged in a rod-like manner. The chemistry is variable, with ~45 to 57 mass% CaO, ~15 to 27 mass% SiO_2, ~6 to 29 mass% FeO_{TOT}, and ~6 to 9 mass% Al_2O_3. Only K_2O and MgO show a constant and low amount, around 2 mass%. Fe-gehlenite contains a significant amount of Fe-åkermanite, as part of a solid solution.

The Fe-gehlenite dendrites have formed by the reaction between the Fe-rich illite-like groundmass and lime resulting from calcite decomposition. Its highly variable composition reflects mainly the local inhomogeneity of the ceramic paste and the time too short to reach a chemically balanced material. The mixed environment, both vitreous and crystalline, in the Roman ceramics indicates the formation of Fe-gehlenite between ~850 °C and ~950 °C, with a maximum around 900 °C.

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Chemical composition and colourants of Early Sarmatian mosaic (millefiori) face and checker beads found at Dunakeszi (Hungary)

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Among the archaeological finds in an Early Sarmatian woman grave excavated at Dunakeszi-Székesdűlő (Hungary), dated to the end of 1st century – beginning of 2nd century AD, various jewels, including several glassy beads were found. Mosaic (millefiori) beads with chessboard and face motifs, so-called checker and face beads, were uncovered in the region of the right wrist. Three of the four, disc-shaped face beads of Selling I type are uniform in terms of the used colours and the portray: the inner face was made of yellow, red and black glasses, framed by black and red glass bands, and finally by a thick green glass rim. In the fourth bead the face was made of white, black and red glasses, surrounded by black and white glass bands, and a light green glass rim. Two of the three checker beads are similar regarding the used colours (red, yellow, white and black), whereas the third one was made of two colours, namely red and white.

The archaeometric research aims to reveal the material characteristics of the mosaic beads in order to get data for the material usage (basic glass composition and colourants) and the production technology. The chemical composition of the beads was first analysed non-destructively by using micro-XRF (X-ray fluorescence) technique. In addition, quantitative chemical composition of tiny glass samples detached from the beads was determined together with the study of the microstructure by using an electron microprobe coupled with an energy-dispersive X-ray spectrometer. Colouring and opacifying inclusions were also analysed by Raman microspectroscopy.

All glasses of the face and checker beads are sodic glasses, although different colours have different basic glass compositions. For the checker beads red glass was produced from plant ash alkali flux (plant ash-silica glass), white and yellow glasses were made of mineral soda flux (soda-lime-silica glass), whereas black glass forms a distinct group suggesting the possible use of plant ash added for some of the alkali along with mineral soda flux. Plant ash-silica and soda-lime-silica glass types are also characteristic for red and yellow glasses of the face beads, respectively, whereas with exception of one of the beads green glass is of plant ash-silica type and black glass is of soda-lime-silica type. The limited numbers of earlier published compositional data about mosaic face and checker beads also showed the use of plant ashes for red glass compared to white and yellow glasses (Stout, 1985). Therefore, it seems probable that the workshop(s) producing mosaic (millefiori) beads systematically used different types of sodic glass.

Green glass was coloured with copper and contains antimony-based opacifiers. Red glass with tiny, sub-micron to micron sized copper crystallites is chemically of low-lead, low-copper type. Calcium antimonate is the colourant and opacifier in white glass, whereas lead-(tin) antimonate was added to yellow glass. Black glass contains copper-iron-sulphur-bearing inclusions.

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World-class mineral type localities in Romania

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Mineral type localities are geographically well-defined sites where mineral species were identified and described for the first time and their names originate from. Being largely used in the relevant literature and common geological practice, and validated by IMA's CNMMN, those mineral names, together with their type localities, have an intrinsic scientific and cultural value. Museums and collections, where type locality mineral specimens are available for professionals, students and the general public, can also be considered as parts of the same cultural heritage. The Carpathian-Pannonian Region, including Romania, hosts a large number of geological – among them mineralogical – type localities. Currently, 37 CNMMN-validated minerals originate from 15 Romanian type localities, two of them among the richest mineral type localities in the world: Săcărâmb (Nagyág) in the Southern Apuseni Mts. (9 new minerals), and Baia Sprie (Felsőbánya) in the Gutâi Mts, Eastern Carpathians (7 new minerals). Other prominent type localities, where at least 2 new mineral species were described for the first time, include Băița Bihor (Rézbánya), Fața Băii (Facebánya), Ocna de Fier (Vaskő), Cavnic (Kapnikbánya), and Baia Mare (Nagybánya). Some very common minerals, such as wollastonite and rhodochrosite have Romanian type-localities. The chemical element and the native element group mineral tellurium was identified and described at Fața Băii. Merrihueite is a new mineral found in a piece of meteorite fallen at Mădăraș in the Transylvanian Basin. The most recently CNMMN-validated minerals are museumite (collected at Săcărâmb and hosted in a museum in Florence, Italy), magnesio-fluoro-hastingsite from Uroi, alburnite from Roșia Montană and grațianite from Băiţa Bihor. Most of the Romanian type-locality minerals belong to the group of sulphosalts and are related to Neogene hydrothermal ore deposits. A few minerals, such as nagyágite and felsőbányaite, are named after their type-localities, others (*e.g.*, krennerite, semseyite, andorite, fülöppite) wear the names of geologists or amateur mineralogists, themselves discoverers of new minerals. Type locality mineral specimens are preserved and exposed in the Mineralogical Museum in Baia Mare, in the Geological Museum of the Geological Institute of Romania in Bucharest, as wella as in the Mineralogical Museum of the Babeș-Bolyai University in Cluj-Napoca (with a unique collection of meteorites). The Gold Museum in Brad has a world-class collection of native gold specimens originating from the richest European gold-province. Despite their world-fame, rarity and scientific relevance, these mineral type localities and museums are not included in the list of the 49 protected "geological reserves" in Romania. We propose that at least three mineral type localities – Săcărâmb (9 new minerals), Baia Sprie (7 new minerals) and Fața Băii (for the chemical element and the native element mineral tellurium) – to be promoted and protected as geosites of outstanding scientific relevance and as parts of the geological and cultural world heritage. More investigation is needed to fully document and promote these mineral type localities in the context of the widely accepted criteria (*i.e.*, representativeness, integrity, rarity, and scientific knowledge) to be considered when recognizing and qualifying objectives of geoheritage relevance.

Speleothems stored in the "Earth and Man" National Museum, Sofia, Bulgaria

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Various speleothems are formed in the karst caves. They are presented by stalagmites, stalactites and coralloids, although stalactite-stalagmite columns and stalactite-helictites are also widespread. Speleothems grow in response to specific physical and chemical processes within the caves and every cave is characterized by its individual set and characteristics of speleothems and minerals. A rich collection of cave formations from 49 caves from Bulgaria and 14 from abroad is stored in the "Earth and Man" National Museum. The collection mainly includes cave formations from caverns and mining excavations discovered during mining activities and rarely from private collections. In the present work, the speleothems from now-defunct small karst cave called "Obrechenata" is presented. Because of the impossibility of preserving the cave in the limestone quarry, all speleothems – 296 samples were carefully taken from the cave – before it was destroyed, and then became the first exhibits of the collection of cave formations in the "Earth and Man" National Museum. Stalactites, coralloids and helictites are the most widespread in the cave, while stalagmites and crystallictites are rare.

Mineralogical investigations have been carried out on coralloids with the specific tower-type morphology, covering the bottom of a small sinter pool, which were found to have grown over earlier formed fragments of cave rafts and spherulites. EPMA of differently colored parts of coralloids shows that the calcium is a prevailing chemical element (CaO 51.7–55.3 wt.%). The content of MgO is to 0.3 wt.%. The coloring in brawn correlates with amounts of Si, Al and Fe – their maximal contents are detected in the spherulite cores (in wt.%): SiO_2 to 1.69, Al_2O_3 to 0.9 and Fe_2O_3 to 0.41. Other minor elements as K and S well correlate with Fe being (in wt.%) to 0.05 (K_2O) and to 0.20 (SO_3). XRD analysis shows that calcite is an absolutely dominant mineral. The XRD analysis reveals traces of jarosite. This finding although correlated with the chemical composition of the spherulite cores intensively colored in brawn, raises a question about the physicochemical conditions of mineral deposition in the cave. Jarosite is a mineral stable in strongly acid media ($pH<3$) and this mineral is found in aggressive alkaline carbonate surrounding. Most probably the observed intensive coloring of the spherulites cores is due to the replacement of initial jarosite by ferric iron oxides as is expected to be in alkaline media.

The "Earth and Man" National Museum is a cultural and scientific institution, where mineral collections, including that of cave formations, are stored, systematized and studied. Although the "Obrechenata" cave is a bitter example of destruction of natural phenomena by humans, the preserved collection of all the speleothems from this cave is also an example of positive thinking and concern for the future generations.

The study of the effects of temperature changes on archaeological marble from Jordan

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In this study the effects of temperature changes on marble samples from some archaeological sites in Jordan is thoroughly studied. The aim is to fully understand the behavior of archaeological marble in response to the daily and seasonal changes of temperature so as to help develop suitable conservation policies and measures for the protection of cultural heritage made of marble. The studied marble samples were characterized by microscopic examination, traditional testing methods and non-destructive ultrasonic technique to determine their microstructure and physico-mechanical properties. The samples were, then, subject to accelerated aging tests by a set of elaborate thermal cycling simulating diurnal and seasonal temperature fluctuations in Jordan. Afterwards, the samples were tested again and the induced changes in their microstructure and physical and mechanical properties were determined and studied. The results indicate that the thermal stresses resulting from such temperature variations can be sufficiently large to produce microcracks in marble and negatively affect its physical and mechanical properties. Consequently, suitable conservation measures were proposed to protect archaeological marble objects, particularly those exposed outdoor, and reduce the danger of their damage by temperature variations.

Geoconservation significance of natural building stones in a cultural landscape, a case study of rhyolite tuff, Tokaj Wine Region UNESCO World Heritage Site

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Natural stones are common products of cultural landscapes. These stones well represent the impact of the geology on the society and well illustrate how the culture may influence the geoheritage perception, utilization and management through centuries. The utilization is depending on the physical properties (hardness, colour) stone aesthetics and transportation possibilities. The rhyolite tuffs are one of the most common stones worldwide. These materials are directly produced by volcanic eruptions and the freshly deposited volcaniclastic sediments went through variable scale diagenesis and/or hydrothermal alteration. The non-welded or poorly welded massive ignimbrite deposits are commonly used throughout the world in the architecture (Italy, Mexico, Hungary).

The Tokaj Wine Region (TWR) Historic Cultural Landscape is situated in NE Hungary and inscribed on the World Heritage List in 2002 as a cultural site. Due to special geological impact on the land use and the specialized viticultural traditions the landscape is characterized by exceptionally high geodiversity. The widespread rhyolite tuffs of the TWR deposited during the Middle to Late Miocene (13.5–11.3 Ma) and connected to terminating of back-arc extension in the Pannonian basin. The hydrothermal activity cased intensive silicification and usually elevated the hardness of ignimbrite. Sometimes argillic alteration occurred. The link between TWR geoheritage and culture is multiple. The numerous historical buildings are part of the UNESCO World Heritage. Many churches, castle walls and local buildings, the frontage of the heritage cellars are also using these natural stones. The religious sculptures and gravestones of these stones were also important. The utilization of rhyolite tuff originated in the medieval ages. The quarries are scattered throughout the wine region. The common, regionally transported variety is the white to pale yellow coloured “Bodrogkeresztúr” tuff. Other yellowish colored varieties quarried in Abaújszántó and Mád region. Some quarries used underground carving (Szegi) in the loose, non welded pumiceous deposits for making rock grist. The hardest, silicified varieties were carved for quality millstones from the 15th century (Mád, Sárospatak). The products of the old millstone quarry of Megyer Hill (Sárospatak) won first order medal of 1862 world expo in London.

The geoconservation value of the historical quarries is well illustrated by the exposed special geological features providing key localities of volcanic formations. Successful geoconservation activities were achieved in the Megyer Hillm Sárospatak. The amazing quarry yard was declared as nature conservation area of national interest in 1997. The renewed nature trail presents the local geology and the millstone production. The famous wine cellars in the Szegi underground mine is also special link between culture, land use and geodiversity. Unfortunately, several historical quarry (Fehérkő–Abaújszántó, Nyilazó–Sárospatak) are abandoned and many problems arisen because of the lack restoration. The main and most common problems include the quarry wall instability, illegal dumping and pollution and dense vegetation cover hiding the geological interests of the quarries. The quarries in Mád and Bodrogkeresztúr region are still operating and there are restricted possibilities for active geoconservation.

Although, the geodiversity, especially the natural stones have a special role in the land use of UNESCO World Heritage cultural site, but it needs particular efforts to demonstrate that geological values could have significant additional elements of the destination brand enhancing the related geotourism activities.

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Prospects of the use of volcanic geosites from the Carpathian areas of Romania for informal geological education and awareness

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The mobilization of knowledge from the academic communities to their diverse audiences is one of the chief objectives of the present scientific research. At the level of earth sciences, this ends up in more coherent environmental, educational and sustainable development policies, practices, and programs. In this context, due to their unique cognitive and aesthetic values, the volcanic geosites have high potential for geological education, geoconservation awareness, as well as for geotourism.

The present work focuses on the Neogene–Quaternary magmatic and post-magmatic processes in the East Carpathians and the Apuseni Mountains. The geological heritage in the two areas includes: different rock types (*e.g*., dacite, andesites, basalts), well preserved volcanic structures (*e.g*., Ciomad caldera); landscapes (*e.g*., rock formations, cliffs, volcanic caves, volcanic lakes and bogs), and a wide range of postvolcanic phenomena (*e.g*., mineral and thermal water springs, dry and wet mofettes, CO_2 and H_2S exhalations, sulfur deposits, caverns with intense native sulfur and alums encrustations on walls). An important metallogenic activity is related to the Neogene magmatism. Base metal and gold deposits occur especially in the Oaș – Gutâi Mountains (East Carpathians) and the Metaliferi Mountains (Apuseni Mountains). Both regions are well known for a long mining tradition. Some historical underground mining works are conveniently preserved and can be visited (*e.g*., Roșia Montană).

The study areas have been evaluated in order to identify the objectives that meet one or more criteria for a geosite, based on their scientific, educational and touristic value. The following criteria have been applied: to expose a unique or critical record of natural history; to be scientifically important; to contribute to understanding the natural history of the region; to be of significant educational utility; to offer distinct aesthetic and/or cultural values. For the proposed geosites the risk factors for degradation were assessed based on several factors: deterioration of geological elements, proximity to areas/activities with harmful potential, legal protection, accessibility, and density of population near the site. Subsequently, we have elaborated a presentation model for the selected geosites in order to provide the geological information in an accessible format for the wider public. The presentation model contains information regarding the general geological framework, details emphasizing the importance of the geosite, as well as other morphological, ecological and/or cultural/historical aspects.

Presently ignored or considered scars on the landscape, post-mining areas may become an interesting component of geological education and geotourism if appropriately developed. Documentation sites showing the formation, distribution and exploitation of ore deposits, exhibitions and open-air museums of geology and mineralogy can be arranged on site. Selected zones can be used to exemplify acid mine drainage formation and other mining effects on the environment.

Further detailed studies are needed in order to promote areas for being integrated in the European Network of Geoparks (*e.g*., Tușnad – Ciomad volcano – Bálványos area).

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The emblematical stone monuments of Cluj-Napoca, Romania

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Stone monuments (*e.g.*, buildings, statues, art objects) represent an important part of our European cultural heritage. Cluj-Napoca (Kolozsvár, Klausenburg), used to be for a while the capital city of Transylvania, is the largest settlement of this region hosting well-known stone monuments of regional importance. For this study several historical buildings, including churches, monuments and statues from the historical central part of the town were chosen. All of them are shortly described referring to the name, type, builder, construction history, building techniques, architectonic style, type and origin of building materials. In particular, we focused on the petrographic features of the building materials, and our results could improve the restoration and preservation activities of the studied. Buildings: the Art Museum (Bánffy Palace), the main building of the Babeş–Bolyai University, the Etnographic Museum of Transylvania (The Redoute Palace), the Cluj County Prefect's Headquarter, the Cluj-Napoca City Hall, the Central University Library, the Fortress Hill (Cetăţuia), the Roman–Catholic Palace (Status-ul romano-catolic), the Romanian National Theatre and Opera, the Toldalagi–Korda Palace, the Matthias Corvinus House, the middle-age bastions and towers (the Bridge Tower, the Monastery Tower, the Tailors' Tower, the Stoneworkers' Tower). Historic churches: the Bob Church, the Calvin–Reformed Church of the Lower Town (the Church with Two Towers), the St. Trinity Roman–Catholic Church (the church of the Piarists'), the Evangelical Lutheran Church, the Franciscan Church and Monastery, the Transfiguration Greek–Catholic Church (the church of the Minorits), the Orthodox Metropolitan Cathedral, the Reformed Church, the Saint Michael Roman–Catholic Church, The Unitarian Church. Statues and monuments: the Mathias Corvinus Monument, the Mihai Viteazul Equestrian Statue, the Carolina Obelisk, the Transylvanian School Statuary Group, the Statue of Saint George killing the Dragon, the Avram Iancu Monument, Lupa Capitolina, the Memorandum Monument. Regarding the building materials, most of the monuments are made of different types of limestones and calcareous sandstones, some of them being still quarried. The Paleogene limestones could be originated from the old quarries of Baciu, Viştea and, Suceag. Jurassic *Ammonitico rosso* type limestones known in the Carpathians were also identified. The travertine blocks could be transported from Geoagiu, Cărpiniş and/or Borsec. The magmatic rocks found in the old buildings can be Neogene Pietroasa andesites.

Microstructural and compositional study of Late Iron Age (La Tène) pottery from the Mureș Valley (Transylvania, Romania)

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At Orosia and Cuci villages, located along the Mureş River in Transylvania (Romania), Late Iron Age (La Tène) pottery sherds stamped with a 'double-lyre' motif were discovered. At Orosia there was a small settlement, whereas at Cuci only a two-chamber kiln (containing also pottery) was found. To compare the composition, technology and raw materials, 23 sherds (15 from Orosia and 8 from Cuci) were investigated by polarized light optical microscopy, X-ray powder diffraction and scanning electron microscopy coupled with energy dispersive spectrometry.

The sherds have a dark brown to dark grey colour and are coated with a dark grey or black slip. The texture is more or less oriented, and the structure varies from semifine to coarse. The clasts are basically the same for all samples: quartz, K-feldspar, plagioclase, muscovite, carbonate, pyroxene, amphibole, as well as ceramoclasts, lithoclasts (andesite, basalt, micaschists, quartzite, silicastone, limestone, rare volcanic tuff) and Fe-concretions. Chemically, the matrix is Si-Al-rich, with variable amount of K, Fe, ±Ca.

The sherds from Orosia consist of a carbonate-rich illitic matrix (type A) or an illitic matrix without carbonate (type B). Optically, the matrix is highly birefringent. The carbonate inclusions are partly decomposed. The 1 and 0.45 nm X-ray diffraction peaks of illite/muscovite are strong and narrow for all type A and for a part of type B sherds. A sintered ceramic body but no vitreous phase is seen in the secondary electron images.

There are two types of Cuci sherds: type A (carbonatic, highly birefringent, similar to the Orosia type A samples) and type C (non-carbonate, with an opaque matrix, due to a high content of Fe-phases, most likely spinel). The X-ray diffraction peaks of illite/muscovite are very weak. A vitreous mass with some minerals relics is seen in the secondary electron images.

The thermal changes e.g. the sinterization, the incomplete destruction of the clay minerals and muscovite crystalline structure, and the partial decomposition of carbonate indicate ~800–850 °C firing temperature for the sherds of type A (Orosia and Cuci) and B (Orosia). A higher temperature (~900 °C) is inferred for the type C sherds (Cuci), based on the extensive vitrification of the matrix, the destruction of the clay minerals and muscovite structure and the formation of spinel.

The composition of the matrix in the sherds of type A indicates carbonate-rich illitic clay (mudstone) as a raw material, for which the Neogene (Sarmatian and Pannonian) marly clay and clay cropping out nearby would be a good candidate. For the type B and C of sherds, it is possible that small occurrences were quarried. The local alluvia of the Mureș River could have served as tempering material for all samples.

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Lavrion: one great territorry with unique geoheritage as a prospective geopark

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The boarder territory of Lavrion, also called Lavereotiki, is located SE of Attica, at a distance of 55 km from Athens, and covers a surface of approximately 200 km^2. Its morphology is hilly and the highest altitude is approximately at 372 m. The area is dry, partly covered by pine trees, crossed by numerous valleys and surrounding area of Lavrion, with the natural Sounion National Park, is a remarkable center of cultural tourism and leisure. Access to Lavrion is normally through paved roads, which are relatively easy to travel. The history of the area, its sights, natural beauty, and proximity to Athens, as well as its hotel infrastructures make Lavrion peninsula an ideal spot for bried or longer visits.

On the other hand, intense mining and metallurgical activity were developed in Lavrion and the wider area of Lavreotiki (Kamariza, Plaka, Thorikon, Botsaris Valley, Cavity Soureza Valley, Megala Pefka, Dimoliaki, etc.) in ancient times (from 3500 B.C.), reaching its peak in the 5th and 4th centuries B.C.). Consequently, that activity brought about economic and cultural development. In 1860, after 19 centuries of rest, the modern history of the exploitation of the deposits began, introducing innovative methods in mining-metallurgical activity (plants, machine shops, mining galleries, shafts, etc.).The monuments of the mining-metallurgical science and art which flourished twice in Laveotiki are heirlooms from our ancestors and we should protect, conserve and highlight them.

The natural environment, the long-term history and cultural heritage, as well as its valuable geological heritage, make Lavrion a great territory for the development of geotourism and the designation of the area as geopark.

In order to address the processes for Lavrion to become a Geopark, NCSD/IGME created a web-based interactive map (http://geoparks.igme.gr/lavrio/), where the overall natural, cultural and geological heritage are presented as map layers, together with numerous other operations for the end-user of the web map. The web map also comprises the Geosites of Lavrion, which include locations for the geology of the area as well as abundant mines and sites of mining activity. In addition, seven Georoutes are depicted which connect the Geosites and encourage the visitor to follow them and get to know Lavrion’s long history.

Determination of weathering in Pharax rock tombs (Karaman, Turkey) by non-destructive test methods (NDT)

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Anatolia located between Asia and Europe has hosted a lot of civilizations throughout the human history. The civilizations founded in the Anatolia benefited from the geological features of the region in the best way. According to the geological features of their living area, they sometimes made shelters or temples carved into soft rocks, sometimes the rock tombs carved into hard/medium hard rocks as a symbol of dominance. Within the scope of this study, Pharax rock tombs which ideally reflect the characteristics of the rock tomb art of the Isaura Civilization, have been investigated. For this purpose, firstly, mineralogical-petrographical, index and mechanical properties of the rock units which the rock tombs were carved in are determined. Then the mapping studies have been performed by the determination of the deterioration in these tombs with the help of non-destructive testing techniques (NDT) and the use of this obtained data. It was aimed to form a model base for conservation efforts by using of the obtained study data.

Differential use of flint varieties in prehistoric lithic industry: A case study

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This study is the first approach to the analysis of the raw materials through an archaeopetrological perspective and tries to deduce the relation between different flint tools recovered from the site and the four types of flint discriminated in its study. In addition, and as far as possible, it has been established a relationship between the type of tool and the variety of flint.

The Epimagdalenian rockshelter of "La Roureda", dated to 11,350 ± 50 BP, is located in the eastern part of the Iberian Peninsula (Spain). The stone tool assemblage from La Roureda contain a total amount of 3,059 pieces of flint, including 286 retouched tools, 20 cores and 2,753 flint remains.

The archaeopetrological method applied to the tools allowed to discriminate four types and five varieties of flint used for their manufacture. Two of the main types, Type A (with its two chromatic varieties, 1 and 2) and Type B, have a brackish/lacustrine origin. The next in order of importance, is Type D with a marine origin. The last one, Type C, has an unknown origin so far. According to the typological classification of archaeological materials the same type tools were quantified.

The relation between variety and typology shows that two predominant flint types have been used to manufacture a higher number of typological groups. The Type A variety 1 – of very high quality – has been used to manufacture burins, backed bladelets, notches and denticulates, backed bladelets and the only scraper found so far. Furthermore, the cortical analysis demonstrates that is the only type chipped at the site. The Type B, of lower quality than the Type A, has been used to manufacture the end scrapers, drills, side retouched tools, écaillées and the only microburin recovered from the rockshelter.

The Type C, despite less frequent, was almost exclusively used to manufacture the "blade supports" and the backed bladelets. Obviously, the type D is the most frequent material used for the side-retouched tools, composite tools and écaillées.

Thus the archaeopetrological analysis demonstrates that the human groups of hunter-gatherers from La Roureda established different patterns of exploitation and transport of siliceous raw materials. They were certainly conditioned by the characteristics and the unequal offer of emplaced mineral resources by their environments. Therefore, the sourcing strategies and behaviors were in line with territorial knowledge acquired through experience. Surely, they knew a number of primary and secondary outcrops available and therefore the mineral resources that could be exploited to their benefit along daily needs.

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Eneolithic pottery from Southern Carpathians (Romania): An archaeometric study

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The beginning of the Eneolithic in Banat and Transylvania (Romania) is marked by the so-called "Foeni Group" population, which has been described from more than twenty archaeological sites. The radiocarbon dating indicates a time span between 4,750 and 4,400 B.C. for this group. Burnished and black-topped pottery is characteristic. No remains of pits, surface clumps or kilns related to pottery production were found in the area.

The semifine to coarse ceramic sherds, included in this study, are assigned to the Foeni cultural group and were exhumed at the Great Cave of Cerișor, in Southern Carpathians (Romania). The sherds were investigated by polarized light optical microscopy (OM), X-ray powder diffraction (XRPD) and electron microprobe analysis (EMPA), in order to describe the ceramic composition and fabric, the type and origin of the raw materials as well as the technological knowledge of the potters.

The surface of the sherds is covered by a black or dark grey slip and has a shiny appearance due to burnishing. Two sherds seem to belong to black-topped pots, i.e. with the upper part black, and the lower part reddish-brown. Most of the sherds have a homogenous reddish-brown ceramic body, only a few show a sandwich or a bi-zonal structure. Generally, the sherds show mostly an anisotropic matrix, with rare isotropic areas. The aplastic components are fragments of quartz, muscovite, plagioclase, rarer potassic feldspar, biotite and heavy minerals. Lithoclasts (quartzite, micaschists and quartzo-feldspathic fragments), pedogenic concretions, ferruginous grains, clay pellets and ceramoclasts are found as well. The XRPD indicates a fairly uniform mineralogy, with quartz, illite/muscovite and feldspars as main phases. The intensity and width of illite/muscovite 1 nm peak is variable, with some samples producing intense and narrow peaks, others showing only small and wider peaks.

The secondary electron images and the EMPA data show an inhomogenous and porous ceramic body, affected mainly by sintering processes. The matrix, with SiO_2 ranging from 43.40 to 58.41 mass%, Al_2O_3 from 18.59 to 29.30 mass%, FeO_{TOT} from 2.15 to 9.39 mass%, CaO from 0.88 to 2.99 mass% and K_2O from 1.25 to 7.87 mass%, suggests that a Fe-rich illitic-muscovitic mudstone was used as main raw material. Mudstones of Miocene age, with a similar composition, crop out north of the cave. The mineralogy and petrography of the clasts indicate a silty to sandy material occurring in the vicinity of the cave, as temper.

The pottery was fired mostly in oxidizing conditions, a few (including the black-topped one) recording a variable atmosphere. The thermal transformations, restricted to sintering and reduced vitrification, suggest that the pottery was fired between ~800 °C and ~850 °C, most likely in temporary structures (*e.g.*, clamps, bonfire).

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Composition and microstructure of Late Roman-Early Byzantine pottery from (L)Ibida (Dobrudja, Romania)

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The town of (L)Ibida in Moesia Inferior (Scythia Minor) province (present day Slava Rusă, in Dobrudja, Romania) begun at the end of the 1st century AD as a Roman military camp, along the actual Slava River. The city was located along the right bank of the actual Slava River, on the trade route connecting Noviodunum (in north-west, on the Danube River) and Constantinopolis. The archaeological excavations revealed a high amount of pottery, tile and glass fragments, as well as various metal artefacts. In this study, twenty pottery sherds dated to the Late Roman (4^{th} century AD) to Early Byzantine (6^{th} century AD) period were investigated by several analytical methods in order to obtain a snapshot of the technology and production in a remote province of the Late Roman Empire. Optical microscopy (OM) and X-ray powder diffraction (XRPD) helped to identify the main mineral components and the thermal changes due to firing. The fresh surface of small chips broken from nine selected sherds were subject of cold field emission scanning electron microscopy coupled with energy dispersive X-ray spectrometry analysis provided compositional and microstructural information at small scale (~10 nm).

Most of the sherds have a mixed matrix, with both low birefringent and isotropic parts. The semifine to coarse aplastic inclusions consist of mostly angular fragments of quartz, plagioclase, potassic feldspar, amphibole, biotite and various lithoclasts. The latter are fragments of rhyolite, basalt, granite, sandstone, chert, limestone, greywacke, quartzite and micaschist. Most of samples contain Fe-rich concretions. Part of the samples contains discrete grains of carbonate, sometimes grouped in small clusters. Muscovite in significant amount was found in only two samples. The limestone clasts show partial thermal transformation. Only hematite, melilite, clinopyroxene and most likely part of feldspar were identified as firing phases by XRPD. The secondary electron images show also a mixed groundmass, with both sintered and vitreous areas. Chemically, the have mainly SiO_2, Al_2O_3, FeO_{TOT} and K_2O, with variable but low CaO. As firing phases, silica glass, Fe aluminosilicates, rare CaSiAl compounds (melilite), and clinopyroxene are characteristic.

In the studied ceramic shreds, the partial decomposition of the carbonates, the formation of the CaSiAl compounds and the diminishing of illite-muscovite XRPD peaks points to at least 850 °C temperature. On the other hand, the transitional character of the matrix, with a mix of sintered and vitreous parts, indicates a temperature below 900 °C.

In the areas there are no clays suitable for pottery. The Pleistocene loess is silt containing too much quartz to make a workable paste. The geological formation fitting to the matrix and clasts composition i.e. the Quaternary alluvial mud of the Slava River (collecting material from Proterozoic greywacke, micaschists and amphibolites, Paleozoic granites, Mesozoic rhyolites, basalts, limestones and cherts, and Pleistocene loess) supports the assumption of a local production of the pottery.

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Microfossils in ancient ceramics: tracing the firing temperature and the raw materials

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When studying archaeoceramics, several analytical methods are usually involved. Most basic information on composition comes from polarized light optical microscopy (OM), X-ray powder diffraction, scanning electron microscopy, electron microprobe analysis (EMPA) and inductively coupled plasma mass spectrometry. Other complementary methods, *e.g.*, Fourier transform infrared spectroscopy, electron paramagnetic resonance, and X-ray fluorescence, were used as well. The last decade witnessed a new approach of the archaeoceramic, connected to micropalaeontology (Quinn and Day, 2007; Quinn, 2008; Wilkinson *et al.*, 2017). It proved to be an important and reliable tool in studying archaeoceramics as it may offer important information not only on clayey raw materials used, but also on the firing temperature. Here we apply the micropalaeontological methods to investigate the provenance of 4^{th}–2^{nd} century B.C.E. terracotta figurines found near Durres (Albania). The study was performed on thin sections for OM and polished thin sections for EMPA.

The area consists of Miocene to Pliocene shales and mudstones, and Late Pleistocene to Early Holocene alluvial clayey deposits which might provide ceramic raw materials. The ceramic body of the terracotta figurines consists of an illite-like matrix, displaying a low anisotropy. There are only few small fragments of quartz, feldspars, muscovite, chloritized biotite and heavy minerals. Among lithoclasts, quartzite and basalt predominate. Framboidal pyrite and slightly thermally decomposed calcareous foraminifera tests are peculiar constituents. The latter still preserve the shape and internal details which allow their determination. Abundant planktonic species such as *Orbulina* spp. and *Globigerina* spp. have been identified. Firing in an oxidizing atmosphere and a temperature at over 850 °C but below 900 °C, is supported by the reddish colour of the sherd, the low birefringent matrix and the weak decomposition of the calcareous foraminifera tests.

To find whether the terracotta figurines were produced locally or have been imported, clayey rocks suitable for ceramics were micropaleontologically investigated. The Miocene to Pliocene shales and mudstones cropping out north-east of the site contain foraminifers similar to those found in the terracotta ceramic body. Even more, the shales are host of framboidal pyrite. Therefore, we may consider that these rocks were used as raw materials to produce locally the terracotta figurines.

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What glazes can add to the production technology studies? A case study on the medieval "Besztercebánya/Banská Bystrica" stove tiles

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A special collection of late Medieval stove tiles was found at several sites in the northern part of the Carpathian Basin. First findings were discovered in Besztercebánya/Banská Bystrica (present day Slovakia). The unique, high-quality stove tiles are decorated by circumstantial motives, and illustrate religious and profane topics. Most of them are glazed and apart from the dominant green glaze, yellow and rarely white, blue and black glazes also appear. Earlier archaeological and art historical studies classified these stove tiles into one group. However, to clarify whether these products were made in a single workshop at Besztercebánya/Banská Bystrica or in several workshops, detailed archaeometric analysis is required. In order to determine the material and production technique of the tiles, ceramic bodies and glazes are investigated using polarizing microscopy, X-ray diffraction and electron microprobe analyses.

Based on the detailed investigation of the ceramic body, the findings, which derive from six sites from Slovakia and Hungary, can be classified into four main groups. Samples from the Hungarian sites and Fülek/Fiľakovo – apart from one tile from Eger – are similar regarding their raw material (illitic+/-kaolinitic clay). In contrast, stove tiles from Besztercebánya/Banská Bystrica and the tiles from Csábrág/Čabraď form independent groups due to the presence of variable magmatic, metamorphic and limestone rock fragments. These results suggest that the tiles were made in several, at least three workshops.

All glazes applied on the tiles are single-layered high lead glazes (52.8–67.1 mass% PbO, 20.9–35 mass% SiO_2, 7–11.1 mass% total alkali) coloured with copper and iron, respectively. On the ceramic-glaze interface abundant tabular lead feldspar crystals were developed in situ. Among the green glazed ceramics, samples from Besztercebánya/Banská Bystrica show a unique characteristic with intentional addition of lead antimonate pigment to the green glaze. Yellow colour was produced by using various techniques, *e.g.*, changing the copper/iron concentration ratio within the glaze or with addition of lead antimonate pigment particles.

Using SEM-EDS for unveiling technology and provenance of Roman bricks and tiles in SE Romania

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The scanning electron microscopy coupled with energy dispersive spectrometry (SEM-EDS) provides basic information on composition and fabric of ancient ceramics and consequently supports the assumptions on the technology and provenance (Tite and Maniatis, 1975). By determining the changes of physical, mineralogical and chemical properties of the ceramic phases, the firing temperature can be inferred. The back-scattered electron (BSE) images are helpful in observing micro-texture features such as the degree of vitrification and the reaction between components. The energy dispersive spectrometry provides data on the chemistry of the matrix and non-plastic inclusions and therefore helps in finding the raw materials.

Ten samples of bricks and tiles recovered from the remnants of the Roman baths at Mălăieşti, located at 90 km N of Bucharest (SE Romania), were employed in the present study. The baths were built by the Roman soldiers during the Dacian wars, between 101 and 106 A.D. The baths were used for a short period of time and were already abandoned in 117 A.D.

The BSE images and the EDS analysis of the bricks and tiles revealed basically an illitic/muscovitic matrix. Fragments of quartz, feldspars and muscovite are frequent. Occasionally, fine-grained carbonate and framboidal pyrite may be found. Most of samples show sintering of the clay particles, i.e. illite and muscovite lamellae connected together by small bridges of molten material. The sintered matrix has a variable chemistry, with SiO_2 between ~50 and 62 mass%, Al_2O_3 between ~18 and ~30 mass%, CaO between 0 and 1.7 mass%, FeO_{TOT} between ~5 and ~24 mass%, K_2O between ~4 and ~10 mass% and MgO between 2 and 5 mass%.

Only one brick shows an increased amount of glass and advanced exfoliation of micas. The chemistry of the glass is variable and includes SiO_2 (~55 mass%); Al_2O_3 (~24 to 30 mass%); CaO (0 to~1 mass%); FeO_{TOT} (~7 to ~17 mass%); K_2O (~4 mass%); and MgO (~2 mass%). Crystals of Ca and Al with some Mg (melilite?) formed by firing were found grouped in a cluster. The small cubic crystals (~97 mass% SiO_2), occurring in some voids, may represent silica pseudomorphs.

The microstructural changes recorded by SEM indicate that most of the bricks and tiles were fired at temperatures which did not exceeded 850 °C. Only two samples, one showing extended vitrification and the other containing most likely melilite, reached a higher temperature, around 900 °C. The extremely variable chemistry of the matrix points to a raw material similar to the Miocene mudstone cropping out in the surroundings of the site. The bricks and tiles were manufactured and fired locally.

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Two decades of restored detail geological survey 1:25 000 in Moravian Carpathians (Czech Republic)

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After covering the entire territory of the Czech Republic by geological maps in scale 1:50 000, the Czech Geological Survey (CGS) focussed since 1996 to detail geological maps in scale 1:25 000. The concept of new map projects covered selected areas, like national parks, geoparks, agglomerations and geohazard areas instead of entire territory of the country.

Since 1996, the production of detail maps was supported by four consequent projects with duration between 5 and 7 years. Budget of these projects, previously covered from public sources is, in the present time, financed from internal sources of the CGS or based on contracts from industry (*e.g.*, geological maps for nuclear power plants). The map production supported by the GIS-technologies has fully digital outputs prepared for print or archiving. The detail geological survey follows CGS internal guidelines for construction of geological map, its graphic supplements (*i.e.*, legend, cross section, and stratigraphic chart) and explanatory booklet. Format and content requirements are defined by detail methodical manuals. Map reliability is supported by a database of reference points built on the Oracle platform. About 400 points is required for a map sheet. The database contains outcrop descriptions, petrographic, biostratigraphical and structural data.

The geological map is accompanied by a set of special maps: mineral-resources, hydrogeological, engineering-geological, and environmental factors. Detail geological survey retakes data on slope failures recorded and evaluated in frame of independent project. The special maps serve as a tool for consulting in land-use planning, utilizations of mineral resources, ground water protection, etc.

The detail geological survey is performed besides the Bohemian Massif also in Outer Carpathians in Moravia including the Carpathian Foredeep, Carpathian Flysch Belt and Vienna Basin. Up to now, the survey covered Brno agglomeration, Hodonín area, Olomouc city, Dukovany nuclear plant area, Hranice area, Vsetín area and Beskydy.

Within the Outer Carpathian domain, 39 geological map sheets from a total of 135 were finished or are still in progress, what makes 21% of a whole. Fifteen maps with explanatory booklets were printed. The CGS database of reference points contains 19 704 items for the Outer Carpathians, what makes 505 points per map sheet. Interactive geological maps are available online in open-access mode at: http://mapy.geology.cz/geocr_25/.

Detail geological survey brought many new observations, improved lithostratigraphy, biostratigraphical and structural data inspiring further research. Prospect for a continuation of the detail geological survey in the future is open and some interesting areas are waiting for coverage (*e.g.*, Bílé Karpaty and Beskydy) depending on society demand and financial support.

Effects of cement and fly ash on engineering properties of clayey soil

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Soil stabilization techniques through mixing with various binders, although popular in many countries, has found very limited application in Albania. This paper aims at looking into the stabilizing effects of cement and fly ash admixtures with marine clay from Durres, Albania, from the perspective of compaction properties and Atterberg limits. The chemical composition of the soil and binders was determined using the X-fluorescence method. The pH-method was employed for estimating the optimal content for the binders, and then the change occurring in the compaction curve of the soil, based on these values, was observed. Furthermore, various cement/fly ash ratios and curing periods, ranging from 1 hour to 24 hours, and 48 hours, or more, were considered in order to determine the effects on the plasticity index. The latter results obtained using the fall-cone test method were linked to other important properties of the soil, such as the unconfined compressive strength and swell potential, as suggested by literature. The test results showed that the use of cement and fly ash as binder agents with clayey soils plays a significant role in improving its strength parameters and lowering its swell potential.

An algorithm based on particle swarm optimization for determining grain size from digital images of sediment

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Particle swarm optimization (PSO) can be used for various reasons in different field of study. In this case we use this approach to determine the average grain size of sediment on the bed, grain-size distribution of bed sediment, and vertical profiles in grain size in a cross-sectional image throughout a bed. We assume that the particles are represented by the grain with similar size on the swarm (the whole sample). The difference between our approach and the standard PSO algorithm is the fact that we assume the particles static. After the optimization of the particles, we produce a representative determination of the size for the swarm. This approach is less accurate than the traditional grain size measurements (sieving) but it offers other advantages: it is faster than traditional techniques (around 110 times more); it is also appropriate for sampling *in situ* surficial sediments along river flow. The software obtained from this algorithm can be used with different kind of high resolution images. These images should be obtained using any source with sufficient resolution, including digital cameras, digital video, smartphones, or underwater digital microscopes, especially for real-time grain-size mapping of the bed.

(Re)used building materials as economic and cultural indicators along the Southwestern Black Sea area in Late Antiquity and bejond

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The study is focused on re-used building materials with Classical, Hellenistic, Roman and Early Byzantine origin from the Southwest Black Sea area – elements of the architectural order (marble bases, columns, capitals, friezes), interior decoration (marble ledges, door frames and windows, wall lining slabs, including of proconnesian marble) and the statuary marble plastic from Greek and Roman pagan temple and Byzantine Christian churches; stone slab and block from street pavement and tiling of fortifications; bipedal to ½ format bricks, some of which with a seal of imperial brickeries in the East Roman capital Constantinople, flat and arched tiles from public and private constructions.

In the selected case studies – Mesambria – Mesembria (city of Nessebar, Burgas municipality), colony of Doric Megara, and Deultum – Debeltos (Debelt village, Burgas municipality), a colony of veterans from Leg VIII Augusta, these spolia due to pragmatic and ideological, and/or spiritual motives, are reused for the construction of fortification walls, harbour facilities, street colonnades and pavements, churches, housing, and graves during the Late Antiquity, Middle Ages, and modern times.

Restored and socialized in the architectural ensembles from the Antiquity and Middle Ages from the national archaeological reservations “Old Nessebar” and “Deultum – Debelt”, the presented spoils, part of the historical heritage and the cultural tourism in the Bulgarian Black Sea area, have become mediators between generations, cultures, and civilizations in the region.

Rocklogger – can a smartphone replace a geological compass?

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The possibility of using a smartphone with the app “Rocklogger” instead of a geological compass was examined. For this purpose, around 350 pairs of geological measurements, each carried out by a geological compass and a smartphone, were collected. These values were compared by their means and directly by vector subtraction. In direct comparison, the digital data has a lower precision with a median deviation of 13°. There are of course also deviations at the mean values, but they are in most cases acceptable and the deviations get smaller if there are more measurements. Care has to be taken at dipping angles above 40°, and then the deviations of single measurements can get inacceptable high, so a mean value of several measurements is essential to obtain useable data. To sum up, smartphones can be used as geological compass if some extra measurements are taken to compensate for the lower precision and measuring speed or rather quantity are more important than high precision. If high precision is needed as common in most scientific settings, a traditional geological compass is still the way to go. To ensure a long life of the smartphone, it should be used in a waterproof cover to avoid scratches and penetration of moisture.

Carbonate biomineralization at the points of emergence of selected mineral waters in Serbia

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Places near the points of emergence of mineral waters are very often considered as a suitable habitat for extremophilic microorganisms, since nutrients and minerals that naturally occur in these waters play a vital role in stimulating their growth and development. During the four year research period, 17 different occurrences of mineral waters were examined. Mineral waters were categorized according to type (*i.e.*, bicarbonate, sulphate, chloride, fluoride, silicon, sodium, and magnesium waters), the pH value (alkaline, low alkaline, and neutral), and temperature (cold or acratothermal, *i.e.*, hypo-, homeo- or hypertherms). The pH value ranged from 6.9 to 9.6, the temperature from 11 °C to 93 °C, and total dissolved solids from 600 to 7000 mg/L.

Biomineralization was observed in biofilm that was developed near the points of emergence or on the metal construction of wells. The examination of biofilm samples using light and scanning electron microscopy revealed the presence of the following phototrophic microorganisms: Cyanobacteria, Chlorophyta and Bacillariophyta. Dominant biominerals were of carbonate origin, where $CaCO_3$ was dominant, but occasionally Mg was also found. On the other hand, the very low content of Mn, Al, Si, Fe, K, and Na were recorded. Biominerals were characterized with specific morphology and altered properties as a consequence of the presence of inorganic and organic substances.

During the biomineralization process, 60 different biominerals can be formed. Carbonate biominerals are among the most studied ones, and it is considered that they can have many applications, for example in biomedicine, construction, geotechnics, bioremediation of the environment and art. Mineral waters and biomineralization processes have not been the subject of research in Serbia so far. However, due to the specific habitats for extremophilic microorganisms, their ecology and physiology and potential applications of biominerals, mineral waters deserve special attention in the future.

The need for sustainable supply mix of aggregates in the City of Belgrade (Serbia)

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Establishing the sustainable supply of aggregates at any administrative level is an important challenge due to their vast economic importance, but also because of the potential ecological and societal influence of their production, particularly at the local level.

The City of Belgrade is the largest market for aggregates in Serbia but the production of natural aggregates on its territory is rather small, due to the geology dominated by Neogene and Quaternary sedimentary rocks (Simić *et al.*, 2016). The complex economic, environmental and societal challenges indicate the need to restructure the whole supply chain by using the concept of the Sustainable aggregates resource management (SARM) and Sustainable supply mix (SSM) principles in aggregates supply planning. SARM is efficient, low socio-environmental impact quarrying and waste management, while SSM uses multiple sources, including recycled wastes and industrial by-products that together maximize net benefits of aggregate supply across generations (SARMa Glossary, 2011).

The production of crushed rock, sand and gravel on the territory of Belgrade is almost equal, while majority of “imported” aggregates is sand and gravel from the Danube River due to lower price and much lower transportation costs because of barge shipments. Consumption of crushed rocks includes around 90% of limestone and dolostone, the rest being magmatic rocks. The main issue of using crushed rock on the territory of the City of Belgrade is the long transport routes, which are usually near or more than 100 km, creating more logistic problems and increasing cost of aggregates.

The analysis of the actual supply chain clearly shows that Belgrade cannot expect increased production of natural aggregates on its own territory due to the geological background and the environmental protection.

Considering recycling of aggregates, none of construction and demolition waste is currently being recycled, which is one of the important topics for the future. Another potential and rather important source of secondary aggregates is ash and slag from production of electricity in coal-fired thermal power plants Nikola Tesla.

Use of SSM of natural (primary) and manufactured (secondary) aggregates should be the strategic orientation of the city of Belgrade in order to achieve the goal of a sustainable supply and utilisation of aggregates.

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Brittle fault analysis in the Greywacke Zone (Iglsbach-, Sperl- and Fuxgraben/Salzburg/Austria) and associated deformation of overlaying Quaternary sediments

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Some characteristics of present-day land surface can be used to decipher the palaeotectonic record. Most of this information is derived from narrow zones centered on faults or immediately adjacent to them, because these are the sites where an unambiguous record of deformation can be obtained.

Several valleys in the Greywacke zone exhibit excellent natural and - due to newly constructed roads - artificial outcrops in bedrock and overlaying Quaternary sediments. Therefore, as a first step, the tectonic features of three small fault-controlled valleys in the Greywacke Zone (Iglsbach-, Sperl- and Fuxgraben), trending parallel to the prominent Salzach valley fault in N- to NE direction have been examined in outcrop scale. In a second step, overlaying ice-marginal terrace sediments and/or glaciofluvial sediments capped by basal till were studied in order to detect Holocene tectonic overprint and thus still ongoing tectonic activity until present.

Three small investigated valleys cut into metamorphic rocks of the Greywacke Zone, which mainly consists of dark phyllites and a few several meters thick metavolcanic layers. The valleys generally trend NE and appear to be the traces of steep, NE trending normal faults. First results of field work indicate that the meandering course of the valleys in map scale seems to be influenced by prominent vertical AC planes of W- to NW striking folds. These AC planes are dominant within the gneissic metavolcanics only and could well be the reason for meandering in the observed range.

Locally the bedrocks are overlain by horizontal Quaternary sediments of the last glaciation stage. The sediments originate from ice-marginal terraces or glaciofluvial processes more generally and are mainly medium- to fine-grained noncohesive sands with layers of loamy sands or clays.

Occasionally normal faults could be detected within the fine-grained sands, trending NE and dipping steeply SE. Vertical displacement along these normal faults is in the range of several centimeters. We are aware, that gravitational settling of the quaternary sediments could be the reason for these normal faults. However, the correspondence of orientation and displacing between the recent movements within the sediments and the faulting of the bedrocks clearly indicates a genetic connection and long lasting movements under a constant stress field.

Analysis of geological-seismological data in the region included in the geological map 1:50 000 Sheet 54 – Saranda

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The planes 54-Saranda region, geographically lies in southern Albania while geologically belongs to Ionian zone; more specific in Cika and Kurveleshi belts, which form an unbroken, elongated unit that extends continuously southwards into Greece.

This study area has a complicated geological construction, involving some carbonate and flysch deposits with abruption on the western side and the explosion of the diaphyric formation. In these deposits, the evaporitic formation, which is Triassic in age, is significant. Other entities that also take part of the region are the carbonate formation of Triassic to Eocene age, the flysch formation (Oligocene to Burdigalian), and the molasse formation (Pliocene) (Onuzi, 2005). According to Albanian Seismological Network database, which provides seismicity from 1968 to 2017, tens seismic events, mainly small earthquakes, are spread out the study area, although the northern part of the region appears to be more active. On this zone, between 39°73' and 39°99' N, and from 19°80' to 21°11' E, 156 earthquakes were located, with ML=1.0–4.5 (Richter), 59 of them have magnitude ML>3.0 and 8 of them with ML>=4.0. The most of local earthquakes, about 95%, are distributed in depth between 0 km and 25 km, with an average depth of 13 km. The upper and middle crusts are the most seismoactive layers in the lithosphere beneath Albania (Ormeni, 2010). By generalizing the data from the depths of earthquakes statements, it can be assumed that the seismoactive layer in Saranda region is the upper and the middle crust. According to the seismogenic models, the study area lies in a zone, which is characterized by Mmax=7.0 (Aliaj *et al.*, 2010). The Saranda region is a part of anticline chain (Shendelli-Saranda-Ksamil) that very gradually dips into the Quaternary deposits of the Butrinti area (Onuzi, 2005). The Saranda anticline is the outermost fold of the southern external Albanides, and is oriented NNW-SSE. The western part of the anticline forms the southern coastal area, where the events are distributed almost vertically in depth, showing a slight dip to the east with maximum depth of 104 km. The focal mechanisms indicate thrust and strike-slip faults in the area. According to Aliaj *et al.* (2010), the thrust faults are cut by strike-slip faults, trending NE and SE. Nevertheless, in this area, during the study period, significant seismic activity was not recorded. The evaporites were force to move towards lower pressure gradients when the normal faults were reactivated as thrust or strike-slip faults.

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The CEEPUS network "Earth-Science Studies in Central and South-Eastern Europe" – nineteen years of challenges and success

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Established in 1999 by Prof. Dr Voker Höck from Salzburg University (Austria), who served as network coordinator for one decade, the "Earth-Science Studies in Central and South-Eastern Europe" represents one of the oldest and largest networks within the Central European Exchange Program for University Studies (CEEPUS). It is aimed to improve the quality in teaching geosciences as the main objective, according to the general goals. There are several means, *i.e.*: *a*) diversifying teaching topics and methods; *b*) active collaboration among students and teachers; and *c*) increasing the scientific quality of both learning and teaching are involved in achieving the main objective of the network.

Eighteen universities from ten countries (Austria, Albania, Czech Republic, Croatia, Hungary, Poland, Romania, Serbia, Slovenia and Slovakia) are involved in the project: Babeş-Bolyai University Cluj-Napoca (network coordinator); University of Vienna, University of Innsbruck; Montanuniversität, Leoben; University of Salzburg; Polytechnic University, Tirana; University of Brno; University of Zagreb; Eötvös Lorand University, Budapest; Jagiellonian University in Krakow; University of Wroclaw; University of Warsaw; University of Silesia in Sosnowiec; Alexandru Ioan Cuza University, Iași; University of Belgrade; Ljubljana University; Comenius University Bratislava; and Technical University, Kosice. These universities are located within the Alpine-Carpathian-Balkan-Dinaride mountain belt. Its complex structure offers the possibility to study many geological domains, from mineralogy, petrology, paleontology, geophysics, to applied geology, archaeometry, oil geology, ore deposits, etc. Moreover, the area covered by CEEPUS countries underwent a similar economic, political, and most important, educational development in recent years, which facilitates the management of the whole organization.

The involvement of more than 1500 individuals in the network basic activities (mobility and teaching), during almost twenty years, proves a high interest and demonstrates the network feasibility. Thanks to the motilities, the students had the possibility to attend short courses, they could participate to field-courses and field excursions in terrains of highly geological complexity, and they could work together with teachers and colleagues.

A special significance is provided by the joint supervision of student projects, in which mentors from different universities are involved. The social aspect of the network, such as establishing the cooperation among students and teachers and giving them the opportunity for meeting various cultures and traditions, must not be neglected. Sustainability of the network is demonstrated by people who used the network first as students, and later as academic staff.

Although the network faced serious obstacles, mainly related to different legislation and rules, the lack of long term students for four-months' mobilities or the language barrier, the scopes of the network, its significance for the development of fundamental and applied geology in the participating countries as well as for the society in many aspects e.g., environmental problems, water and ore researches, geo-hazards etc., make this network an organization for the future. Join us!

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Diagenesis and Stadial Analysis of Jurassic Dolomite, Case Study: South-Setifian Shelf (NE Algeria)

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The carbonate series of the South-Setifian shelf provides a good example of the carbonate shelf sedimentation in the external zones of the Eastern Algerian Alpine Belt. It's about deposits, which by their vertical succession, lithology and their diagenetic evolution are similar to those of the recent Bahamian shelf. Detailed analysis of diagenesis has allowed the distinction of various petrographic types, as well as the retracement of paleogeography and dolomitisation model of the sedimentary succession.

Lithostratigraphic and sedimentological studies of the lower Senonian series of the Belezma Batna Mountains southern flank (NE Algeria)

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Located at the North-East of Algeria, the area of this study belongs to the Atlas Domain represented by the Batna-Belezma Mountains. The study of the Dj. Tuggurt Coniacian series, along two cross sections, shows the superposition of two informal lithological formations: *1*) limestone-dominated formation, which was referred at the base to the upper Turonian, and the remaining part was assigned to the lower Coniacian; *2*) marl/limestone-dominated formation, with early to middle Coniacian age. These lithological formations contain three facies associations archiving the paleoenvironmental evolution of the carbonate shelf: facies of the outer shelf characterized by the opening of the basin; facies of the middle shelf characterized by the installation of rudist bioconstructions; and facies of the inner shelf characterized by the abundance of benthic organisms.

From the diagenetic point of view, studied set of sediments has passed through three stages of diagenesis during its evolution: *1*) early diagenesis, dominated by biologic activity of organisms; *2*) burial diagenesis, characterized generally by physical and chemical phenomena; and *3*) late diagenesis represented by karstification and dissolution.

The concatenation of facies has allowed the distinguishing of three megasequences, the first two tend to be regressive and the last one tends to be transgressive.

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