

104 YEARS OF THE CARPATHIAN-BALKAN GEOLOGICAL ASSOCIATION



**XXIII International Congress
of the Carpathian-Balkan Geological Association
CBGA**

ABSTRACTS VOLUME

**Sergiu Drăgușanu, George Pleș, Călin Gabriel Tămaș
(EDITORS)**

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Babeş-Bolyai University, Cluj-Napoca, Romania

September 9-11, 2026

ISBN 978-606-37-3109-9

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E-mail: editura@ubbcluj.ro
editura.ubbcluj.ro | biblioteca.ubbcluj.ro

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Preface

Welcome to the 23rd Congress of the Carpathian-Balkan Geological Association (CBGA2026), to be held on September 9–11, 2026, at Babeş-Bolyai University in Cluj-Napoca, Romania. Building upon the success of previous congresses, including those held in Plovdiv (2022) and Salzburg (2018), CBGA2026 aims to provide an international forum for geoscientists from Southeastern and Central Europe and beyond to meet, exchange knowledge, and foster scientific collaboration. The Congress will bring together researchers, academics, and professionals from across the world to share recent advances, discuss emerging challenges, and promote fruitful scientific exchanges across the broad spectrum of Earth Sciences.

The Carpathian-Balkan Geological Association (CBGA) is a non-governmental, international scientific, non-political, and non-profit-making union of geoscientists working in the Carpathian-Balkan region and surrounding areas. It is affiliated with the International Union of Geological Sciences (IUGS) as a regional organization. The Carpathian-Balkan Geological Association (CBGA) aims to promote and encourage collaborative cross-border fundamental and applied geological research, as well as training and specialization in the Carpathian-Balkan realm. This concerns all the fields of geoscience, their environmental implications, and other related disciplines. To accomplish its aims, CBGA organizes a congress every four years by one or several country members, establishes Working Groups focused on joint projects of specific scientific interest, stimulates and runs discussions on crucial geological issues (geological processes, nomenclature, terminology, methodology, etc.), and publishes various scientific materials (congress proceedings, maps, monographs, etc.).

This Abstracts Volume comprises all scientific contributions, including both oral presentations and posters, presented at the Congress across its plenary, general, and special sessions. The editors wish to express their gratitude to the session conveners for their assistance during the peer-review process. The publication of this volume was made possible through the financial support of the Romanian Ministry of Education and Research, via the Fund for Financing Special Situations (FSS), alongside the generous sponsorships from the corporate partners of the CBGA 2026 Congress, including Geologic Site S.R.L., DPM Metals, Romcim S.A., Saint-Gobain Construction Products Romania S.R.L., Holcim (Romania) S.A., Grandemar S.A., MDPI Open Access Publishing Romania S.R.L., Fodina Target S.R.L., Geiger Transilvania S.R.L., S.C. Geogam Test & Drill S.R.L., GEOSD Consulting S.R.L., S.C. Carl Zeiss Instruments S.R.L., Geosoil Solutions S.R.L., and S.C. ARC Geostudies S.R.L.

The Romanian Consortium for the organization of the CBGA 2026 consists of Babeş-Bolyai University Cluj-Napoca, Romanian Academy, University of Bucharest, “Alexandru Ioan Cuza” University Iaşi, Geological Institute of Romania, Geological Society of Romania, National Institute for Research and Development on Marine Geology and Geo-ecology GeoEcoMar, “Victor Gorduza” Mineralogy Museum Baia Mare, and Romanian Society of Paleontologists.

We extend our sincere gratitude to all participants attending the CBGA 2026 Congress. The organizing committee is fully committed to delivering a high-caliber, engaging scientific meeting that fosters new academic collaborations while providing a memorable opportunity to explore the rich cultural heritage of Cluj-Napoca and the Transylvania region of Romania.

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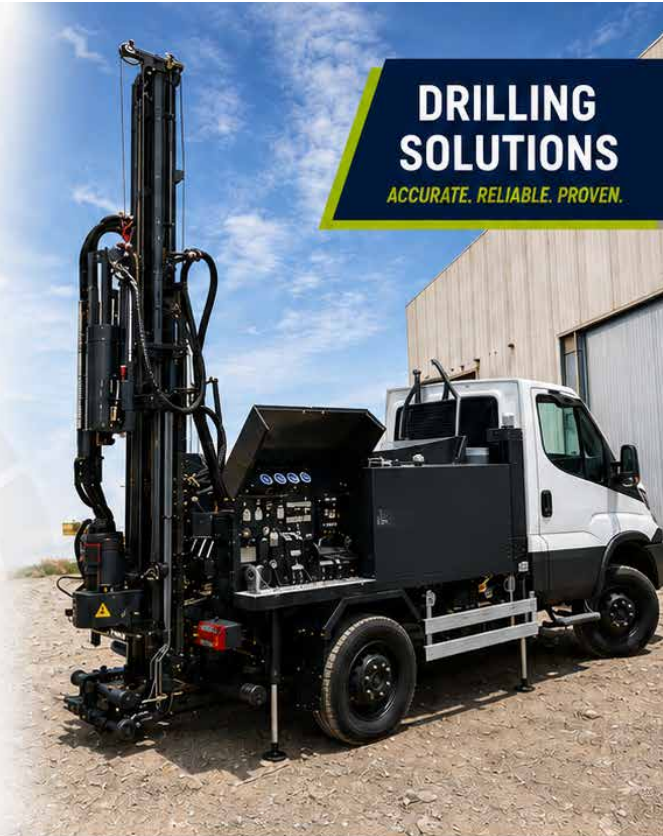
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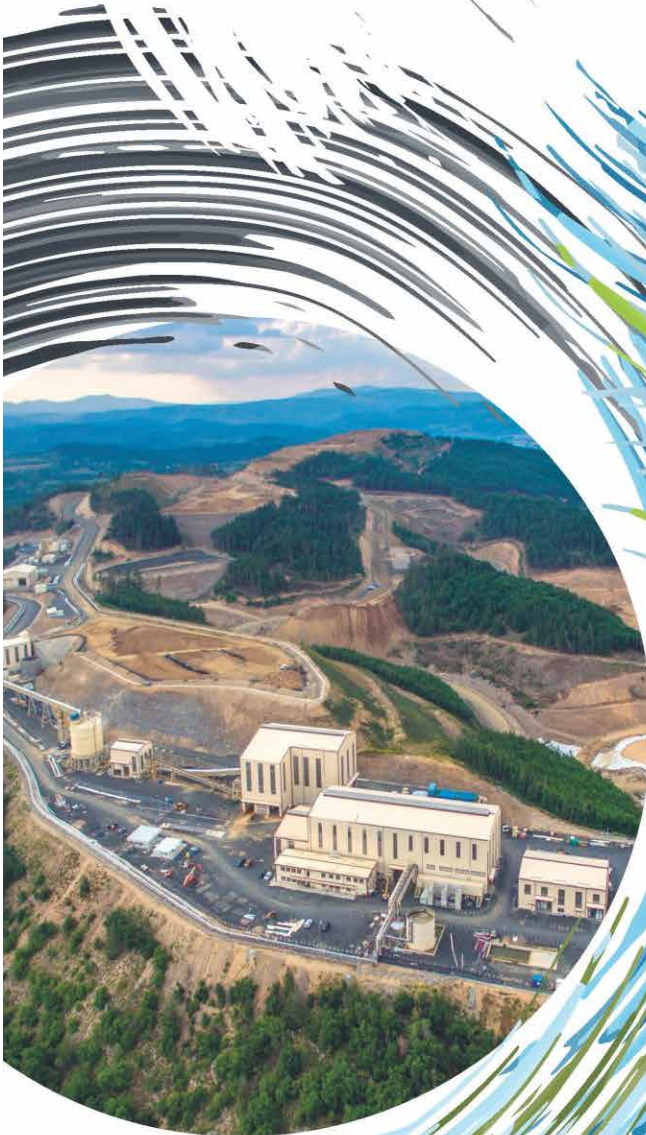


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Contents

Invited plenary speakers

<i>Mihai Ducea</i> : Gigantic Cold Magmatic Blankets Under Continental Plateaus and Their Relevance to the Evolving Continental Crust	26
<i>Szabolcs Harangi, Ioan Seghedi, Réka Lukács</i> : The Neogene to Quaternary Volcanism of the Carpathian–Pannonian Region: from initial plate tectonic models to quantitative petrogenetic explanations.....	27
<i>Liviu Matenco</i> : Tectonics and structural geology, from fundamental concepts to societal applications	28
<i>Alida Timar and PROGRESS team members</i> : The Geological Memory of Quartz: From Geochronology to Provenance	29

Session GS1 Archaeometry, Conveners: *Valentina Cetean, Dan Ștefan*

<i>Sandrine Baron</i> : The Provenance of Non-Ferrous Metals: The Case of Gold.....	31
<i>Dimitri A. G. Vandenberghe, Nasrin Karimi Moayed, Jef Heyndrickx, Arne Verbrugge, Jan-Pieter Buylaert, Stéphane Pirson, Possum Pincé, Alida Timar, Johan De Grave</i> : Dating in the dark (... and sometimes getting it right): practical progress of luminescence dating in (geo)archaeological research ...	32
<i>Robert-Csaba Begy, Anita Bozsik, Farkas-Aron Balint, Alida Timar</i> : Tracing Environmental Changes Using Lead-210 Geochronology	33
<i>Valentina Cetean, Marius Gheorghe Barbu, Eduard Ghinescu, Gică Băeștean, George Dincă</i> : Stone Projectiles for Roman Artillery from Ulpia Traiana Sarmizegetusa: Archaeometric Investigations	34
<i>Valentina Cetean, Ciprian Danciu, Aurora Pețan, Daniel Anca</i> : From Quarry to Sanctuary: Archaeometric Investigations of the Pietroasa-Deva Andesite Used at Sarmizegetusa Regia	35
<i>Delia-Georgeta Dumitraș, Ștefan Marincea, Frederic Hatert, Octavian G. Dului, Ana Emandi, Doina-Smaranda Sirbu-Radasanu, Ana-Voica Bojar</i> : Application of X-ray powder diffractometry in the study of crystallographic transformations of malachite used as a pigment in traditional paintings.....	36
<i>Bilyana Kostova, Boyan Dumanov, Katerina Mihaylova, Ralitza Berberova</i> : Archaeometric study of building materials—mortar and ceramics—from the Late Antique and Medieval fortress of Koζίακος, Obzor, Eastern Bulgaria.	37
<i>István Viczián, Tibor Németh, Péter Szabó</i> : Tokaj earth, a historical mineral medicine	38

Session GS2 Climate Change, Conveners: *Nikola Botoucharov*

<i>Eniko Katalin Magyari, Inger Alsos, Jon Camuera, Aneta Formackova, János Korponai, Gusztáv Jakab, Daniel Veres, Aritina Haliuc, Alfred Vespremeanu-Stroe, Diana Hanganu, Laurentiu Țuțuianu, Luminita Preoteasa, Heikki Seppä</i> : Late Glacial and Holocene climate dynamics of the Carpathian Mountain zone: tipping points and sedaDNA based species level vegetation responses.....	40
<i>László Palcsu</i> : Natural tritium variability and the solar cycle imprint: insights from ice caps, ice fields, and ice caves	41

Dániel Kovács: The Integrated Geodynamic Station: Field-Based Infrared Laboratory for Gas Monitoring in the Southeastern Carpathians (Covasna)42

Agnes Ruskal, Roxana Grindean, Andrei Diaconu, Andrei Panait, Ioan Tanțău: Reconstructing Holocene hydroclimate from peatland archives: a multi-proxy study from Romanian peatlands43

Daniel Veres, Ulrich Hambach, Frank Lehmkuhl, Christian Zeeden, Alida Timar-Gabor: The Danube loess: a high-resolution record of past millennial-scale climate dynamics in continental Europe.44

Session GS3 Geoheritage, Geoeducation, and Geoparks, Conveners: *Marinel Kovacs, Alexandru Andrășanu, János Szepesi*

Károly Németh: Volcanic geoheritage as an engine for volcanic hazard-resilient society from Saudi perspective46

Alexandru Andrășanu, Cristina Toma Ungureanu, Izabela Mariș: Geoconservation and Institutional Development47

Alexandru Andrășanu: The Romanian Model for UNESCO Global Geoparks: Operational Elements for Bridging Geological Heritage and Socio-Economic Resilience.....48

Valentina Cetean, Delia Cristina Papp: Total Tourism Value of Geosites in Romania: A County-Level Spatial and Socio-Economic Analysis.....49

Alexandros Chatzipetros, Christos Stergiou, Haritakis Papaioannou: Multimodal geoeducation in the Global UNESCO Vikos-Aoos Geopark Summer School series (Greece).....50

Ciprian Danciu, Valentina Cetean, Daniel Anca: Rușchița Marble: Integrating Heritage Values and Engineering Properties.51

Ioan Denuț, Anca Cocioță, Alexandra Sîngeorzan: Mineral heritage of Maramureș (NW Romania).....52

Ioan Denuț, Teodora Ruskal, Ioan Bereș, Alexandra Sîngeorzan, Marinel Kovacs: The Gutâi–Maramureș UNESCO Geopark Project (NW Romania): a framework for implementing geoeducational projects53

Mátyás Hencz, Tamás Spránitz, Károly Németh, Thomas Pieter Lange, Csaba Szabó, István János Kovács, Levente Patkó, Kálmán Török, Márta Berkesi: Deep-Earth Geoheritage: assessing xenoliths and fluid inclusions as lithospheric archives54

Marinel Kovacs, Alexandru Szakács, Ioan Denuț, Ágnes Gál: Geoheritage in the new Gutâi–Maramureș UNESCO Geopark project, East Carpathians (NW Romania).....55

Monica Macovei, Dan Grigore, Valentina Cetean: Playful learning at the National Geological Museum (Romania).56

Antoneta Seghedi, Alexandru Andrășanu, Andrei Briceag: The Cimmerian Dobrogea Geopark Project, Romania – 5 years of development towards a UNESCO Global Geopark57

Eubomír Štrba: From Geoheritage Values, Through Geodiversity Assessment to Geotourism Development: A Conceptual Approach58

János Szepesi, Zsuzsanna Ésik: Historical mining heritage as a georesource in the Tokaj Mountains (NE Hungary).....59

<i>Cristina Toma Ungureanu, Cristian Ciobanu, Adina Popa, Dan Popa, Mihai Tănăsescu: From Geological Research to Territorial Development: Interpretation as the Link between Science and Society in the Hațeg Country UNESCO Global Geopark</i>	60
---	----

Session GS4 Geophysics and Seismology, Conveners: Ioan Munteanu

<i>Stanisław Mazur, Christian Schiffer, Tanishka Soni: Receiver Function Imaging Reveals Pyrenean-Style Crustal Wedging and Continental Underthrusting in the Western Carpathians</i>	62
---	----

<i>Asimopolos Laurentiu, Asimopolos Natalia-Silvia, Dinu Luminita: Multiresolution Analysis of Geomagnetic Disturbances in 2026</i>	63
---	----

<i>Asimopolos Natalia-Silvia, Asimopolos Laurentiu, Francovschi Ion: Geomagnetism and Space Weather Website Design</i>	64
--	----

<i>Gabriel Cellier, Avish Kumar, Ioan Sanislav, Alex McCoy-West, Alkis Kontonikas-Charos, Elena Belousova: Mineral chemistry of sulfides from the ISCG Mount Colin deposit, Australia: Constraints on a multistage ore forming system</i>	65
---	----

<i>Alexandra Gereaa, Dragoș Tătaru, Bogdan Grecu, Andreea Tolea, Natalia Poiata, Andrei-Emilian Mihai, Alexandru Codreanu, Adriano Matteo, Alexandru Macovei: Integrated Multi-Geophysical Monitoring of Urban Evaporite Karst Hazards: Lessons from the GEOMONITOR Project in Slănic, Romania</i>	66
--	----

<i>Balázs Rácz, Alexandra Tămaș: Application of Seismic Attributes for Detecting Subsurface Channel Systems within the Chalk Group: A Case Study from Poole Bay, Southern UK.</i>	67
---	----

<i>Liliana-Irina Stoian, Anca Margareta Isac, Elena Aurelia Tudor, Antonio Ulmeanu, Avram Ovidiu, Ioan Scutelnicu, Adrian Tătaru: Integrated Geophysical Investigations for Seismic-Induced Landslide Hazard Assessment: A Case Study from Gornet, Romania</i>	68
--	----

Session GS5 Economic Geology, Conveners: Sibila Borojević Šoštarić, Marian Munteanu

<i>István Márton, Stefan Metodiev, Ivan Krumov, Kuncho Kunchev, Jelena Živanović, Nuțu Groza, Kalin Kouzmanov, Paul Ivășcanu: Unlocking an exceptional copper–gold endowment: New discoveries in the Late Cretaceous Timok–Srednogorie belt segment in Serbia and Bulgaria</i>	70
--	----

<i>Ioan V. Sanislav: How to form a world-class mineral province: the mineral systems of the Mount Isa Inlier, Australia</i>	71
---	----

<i>Nikoleta Aleksić, Bojana Đorđević: Organic matter in black shales from the Krčedin succession (Northern Serbia): preliminary observations.</i>	72
---	----

<i>Sibila Borojević Šoštarić, Tomislav Brenko, Marta Mileusnić: Degree of graphitization in the Slavonian Mountains (Croatia).</i>	73
--	----

<i>Andrea Čobić, Sabina Strmić Palinkaš, Matea Marenković, Ladislav A. Palinkaš, Irena Jurina Tokić, Vladimir Bermanec: Evolution of ore-forming fluids in the carbonate-hosted Pb-Zn Mežica deposit, Slovenia</i>	75
--	----

<i>George Dincă, Gheorghe C. Popescu, Gavril Săbău, Dimitrina Dimitrova, Andra-Elena Filiuță, Violeta-Monica Radu, Alexandru Anton Ivanov: Thallium Enrichment in the Săcărâmb Epithermal System: Evidence from Pyrite and Rare Sulfosalt Assemblages.</i>	76
--	----

<i>Alica Höss, Manuel Keith, Saeed Alirezaei, Karsten M. Haase: Tracing Tectono-Magmatic Controls on the Formation of Large Porphyry Cu Deposits in Long-Lived Arc Systems</i>	77
<i>Stoyan Klimentov, Kalin Rouskov, Rositsa Apostolova: Geochemical Associations and 3D Spatial Distribution of PCA Factors at the Momchil Deposit – Obichnik Section, Eastern Rhodopes.....</i>	78
<i>Jonghyun Lee, Ioan Sanislav, Avish Kumar, Helen McCoy-West: Porphyry Cu Fertility and Tectono-magmatic Evolution of Permian Granitoids in the Georgetown Region, Northeastern Queensland.....</i>	79
<i>Irina Marinova, Aleksandar Gadzhalov: The East Rhodopean low-sulfidation gold-silver metallogenic province, SE Bulgaria: a synthesis of existing and new data with emphasis on the Krumovgrad Goldfield</i>	80
<i>Lavinia Mihălțan, Sergiu Drăgușanu, Călin G. Tămaș: Morphology and chemical composition of alluvial gold from the Mureș Valley, România.</i>	81
<i>Georgi Milenkov, Hristiana Georgieva, Tzvetomila Vladinova, Radoslav Kalchev, Milen Stavrev: Geochemical characteristics of skarns from the Elatsite porphyry copper deposit, Bulgaria: Preliminary data.</i>	82
<i>Catherine Nyakecho, Avish Kumar, Ioan Sanislav, Melanie Finch, Helen McCoy-West: Deformation-enhanced fluid evolution and skarn–IOCG transition in the Paleoproterozoic Elaine Dorothy Cu–Au system, Mount Isa Inlier, Australia.....</i>	83
<i>Hugo Serra, Ioan Sanislav, Daniel Wiemer, Gregg Morrison, Steve Harper: Genesis of the world-class Ravenswood Gold Deposit, NE Queensland (Australia).....</i>	84
<i>Jasmin Sivčević, Siniša Glišić, Marko Matić, Admir Omerhodžić: Integrated Exploration of the Rupice Polymetallic Deposit, Vareš, Bosnia and Herzegovina</i>	85
<i>Milen Stavrev, Robert Creaser, Mihail Tarassov, Silvia Chavdarova, Irena Peytchava, Sergiy Curylo: Middle Eocene fertile magmatism in the central Rila–Western Rhodopes batholith constrained by Re–Os geochronology</i>	86
<i>Radule Tošović: Expert Economic Evaluation of Mineral Reserves in Enhancing the Business Environment of Serbia’s Mineral Sector.....</i>	87
<i>Radule Tošović: Modern Economic Geology and Management of the Mineral Sector in the Transitional Conditions of Mineral Production in Serbia.....</i>	88
<i>Stefan Velez, Kalin Rouskov, Alexandar Radulov, Kamelia Marinova, Kamen Bogdanov, Kamen Popov, Tsveta Stanimirova, Marlena Yaneva, Stefka Pristavova: Remote Sensing and Mineral Detection Tool Applications for Regional- to Local-Scale Targeting of Porphyry Copper Mineralisation in the Western Srednogorie, Bulgaria.....</i>	90

Session GS6 Energy Resources (Hydrocarbon, Geothermal), Conveners:
Cristian-Victor Mircescu, Nikola Botoucharov

<i>Cristian Victor Mircescu: Geothermal waters from the Pannonian Basin (Western Romania).....</i>	92
<i>Nikola Botoucharov, Hristo Dimitrov, Rositsa Pehlivanova, Eva Marinovska: Reevaluation of the conventional hydrocarbon potential in Northeast Bulgaria – overview and first steps</i>	93

Kitchka Alexander, Olshanetskyi Marian, Tyshchenko Andrii, Vyzhva Andrii, Zhadan Anatoliy, Makovets Oleg, Fenota Petro, Melnyk Leonid: Geology and HC potential of the Maikopian and Messinian channels exploration asset within the Dolphin E&P special permits offshore Ukraine94

Oltjon Koleci, Bardhyl Muceku, Laurent Truche, Ana Fociro: Three-Dimensional Gas Mapping in the Bulqizë Chromite Mine (Albania): Hydrogen, Methane, Oxygen and Structural Controls95

Lili Ladányi, Sándor Körmös, Félix Schubert: Evolution of fluid flow and hydrocarbon migration in a fractured Triassic carbonate system (North Hungarian Paleogene Basin).96

Gatien L. F. Morin, Svetoslav V. Georgiev, Lora Bidzhova, Emiliya Raeva, Nikola Botoucharov, Eva Marinovska, Ciprian Chelariu, Daniel Tabără: Geochemical characterization of crude oils and condensates from Romania and Bulgaria: new insights from carbon, hydrogen, and sulfur contents and trace element data97

Session GS7 Engineering Geology and Urban Geology, Conveners: Vasile Fărcaș

Ferenc Deák: Dynamic loading of rock masses in deep geological repository (DGR) projects99

Miroslav Krastanov, Rosen Nankin, Plamen Ivanov, Nikolai Dobrev, Boyko Berov, Antoaneta Frantzova: Engineering geological assessment of the rocks forming the Stone Mushrooms, Eastern Rhodopes, Bulgaria.100

Miroslav Krastanov, Rosen Nankin, Plamen Ivanov, Nikolai Dobrev, Boyko Berov, Antoaneta Frantzova, Ivan Tsvetanov: Engineering geological assessment of the rocks forming the Stone Wedding, Eastern Rhodopes, Bulgaria.101

Liliana-Irina Stoian, Anca Margareta Isac, Mircea Țicleanu, Elena Aurelia Tudor, Antonio Ulmeanu, Avram Ovidiu, Ioan Scutelnicu, Adrian Tătaru: Electrical Resistivity Tomography as a Decision Support Tool for Borehole Positioning and Geological Monitoring in the Slănic Area (Romania).102

Session GS8 Environmental Geochemistry - Exploring new frontiers in past metal pollution and environmental research, Conveners: Daniel Veres, Gabriel Ovidiu Iancu

Mateja Gosar: Geochemical Backgrounds and Anomalies: Linking Environmental and Resource Geochemistry with Geological Complexity in Slovenia104

Jack Longman: Anthropogenic lead in peat archives: reconstructing ancient metal pollution and societal complexity in the Carpathian-Balkan region and beyond105

Călin Baci, Moritz Kirsch, Călin Tămaș, Dan Costin, Dan-Constantin Niță, Anna-Hajnalka Kerekes, Andrei Radovici: A multiscale approach for environmental monitoring in mining areas106

Delia-Georgeta Dumitraș, Peter Istvan Luffi, Octavian G. Dului, Ștefan Marincea, Doina-Smaranda Sirbu-Rădășanu, Aurora-Maruta Iancu, Essaid Billal: New geochemical and mineralogical data on phosphogypsum from Turnu Măgurele, Romania.107

Ramona Huzum, Doina-Smaranda Sirbu-Radasanu, Delia-Georgeta Dumitraș: Assessing Soil Contamination and Potentially Toxic Elements Enrichment in an Urban-Adjacent Vineyard Soil, Iași, Romania.108

Ovidiu Gabriel Iancu, Nicușor Necula, Valentin Nicolae Coțac: Geochemical assessment of alluvial sediments from Ditrău Alkaline Massif, Eastern Carpathians, Romania109

Zlatka Milakovska, Millena Vetseva, Irena Peytcheva, Atanas Hikov, Petyo Filipov, Radoslav Kalchev: Heavy metal sources assessment in the sediments of Topolnitsa River basin (Bulgaria) using advanced SIMONA sediment quality protocols according to the EU Water Framework Directive.110

Irena Peytcheva, Petyo Filipov, Atanas Hikov, Milena Vetseva, Zlatka Milakovska: U-Pb detrital zircon geochronology of sediments from Danube river tributaries in Bulgaria: a contribution to understanding of sediment sources.....111

Doina-Smaranda Sirbu-Radasanu, Ramona Huzum, Delia-Georgeta Dumitraș: Manganese in natural soil and Technosol from Dealu Rusului – Bistrița Mountains112

Violeta-Monica Radu, Alexandru Anton Ivanov, Mario Rivaldo Paraschiv, Ioana Alexandra Avram, George Dincă, Andra-Elena Filiuță: Reducing Waste and Environmental Impact by Recovering Li, Co and Ni from Li-ion Batteries Using Green Alternatives113

Laura Tîrlă, Yunus Baykal, Silviu Constantin, Marian Cosac, Altug Hasözbeek, Marius Kenesz, Ionuț Mirea, Oana Teodora Moldovan, George Murătoreanu, Alexandru Petculescu, Marius Robu, Laurențiu Țuțuianu, Ștefan Vasile, Daniel Veres: Elemental-ratio signatures of Quaternary environmental change archived in selected cave sediment sequences from Romania114

Daniel Veres, Jack Longman, Calin G. Tamas, Eniko K. Magyari, Florin Gogaltan: Resolving the timing and impacts of early metallurgical pollution from the Balkans to central Europe116

Session GS9 Hydrogeology, Conveners: Boglarka-Mercedesz Kis

Judit Mádl-Szőnyi, Miklós Vincze, Ildikó Erhardt, Szilvia Simon, Brigitta Czauner, Márk Szijártó, Tímea Havril: How is the Water Cycle of the Carpathian Basin changing? What do we see, What do we not see, and What can we do?118

Dragoljub Bajić: Forensic geoscience approach to expert hydrogeological assessment in legal disputes.119

Fidan Bilalli, Aida Bode: Groundwater Hydrogeological Assessment Using Integrated Geophysical Methods (ERT and VES): A Case Study of the White Drin Basin, Kosovo.....120

Aurela Jahja, Katarzyna Wątor, Arjan Beqiraj, Piotr Rusiniak: Geochemical Insights into the Origin of Geothermal Waters in Albania121

Milan Kresojević, Aleksandar Tanasković, Veljko Marinović, Dušan Polomčić, Boris Vakanjac, Vesna Ristić Vakanjac: Baseflow Index as a Function of Changes in River Recharge Regime: The Case Study of the Velika Morava River, Serbia122

Jovana Nikolić, Aleksandar Tanasković, Jugoslav Nikolić, Samir Čatović, Veljko Marinović, Vesna Ristić Vakanjac: Conditions of Runoff Formation of the Resava River, Eastern Serbia123

Milan Pavličić, Dragoljub Bajić: Hydrogeological assessment of the groundwater quantity and quality regime at the Drugovac water supply source near Smederevo, Republic of Serbia.....124

Hristina Petrova, Katarzyna Wątor, Ewa Kmiecik, Piotr Rusiniak, Vesna Ristić Vakanjac, Jana Štrbački, Ana Vranješ, Boris Vakanjac: Chemical composition of groundwater in the Republic of North Macedonia: a geotectonic survey125

<i>Milica Šikman, Dragoljub Bajić: An Integrated Fuzzy VIKOR-TOPSIS Approach for Sustainable Protection Management of the Groundwater Source.</i>	126
<i>Brisilda Stafa, Arjan Beqiraj: Employing Hydrochemical and Isotopic Tracers to Characterize the Hydrogeological System of the Prespa–Ohrid Lakes.</i>	127
<i>Matija Stojanović, Dragoljub Bajić: Integrated Groundwater Resources Management for the Water Supply of Loznica, Republic of Serbia.</i>	128
<i>Balázs Varga, Botond Bodor, Boglárka-Mercedesz Kis: Tracing Geological Processes at Csiszár Bath (Covasna County, Romania).</i>	129
<i>Sava Vuković, Dragoljub Bajić: From spring to formula: Hydrogeological foundations for the safe and effective dermocosmetic use of thermomineral waters.</i>	130

Session GS10 Magmatism and Volcanism/Igneous Geology, Conveners: Ioan Seghedi, Marinel Kovacs

<i>Razvan Caracas: Atomic structure and degassing of silicate magmas</i>	133
<i>Ivan P. Savov & IODP Expedition 399 Science Party: Deepest mantle and gabbro section ever drilled: insights from petrology and geochemistry of rocks and fluids from IODP Hole U1601C, Atlantis Massif</i>	134
<i>Selim Berisha, Bardhyl Muceku, Festim Kutllovci: Oligocene–Miocene volcanic and subvolcanic magmatism of the Vardar Zone in Kosovo: preliminary petrography, spatial distribution and metallogenic significance</i>	135
<i>Igor Broska, Stoyan Georgiev, Sergii Kurylo, Pavel Uher, Anna Lazarova, Ľubica Puškelová: Garnet as indicator of origin and evolution of Variscan pegmatitic granite, the Bratislava pegmatite field (Western Carpathians)</i>	136
<i>Dariana Chivulescu, Mihai N. Ducea: Primitive magmatic compositions at collisional settings.</i>	137
<i>Stoyan Georgiev, Eleonora Balkanska: Characteristic features of the subaqueous volcanic activity in the Eastern Srednogorie Zone, Bulgaria</i>	138
<i>Stoyan Georgiev, Anna Lazarova, Eleonora Balkanska, Tzvetomila Vladinova, Igor Broska, Sergii Kurylo: Shifting from post-collisional (late Carboniferous–early Permian) to rift-related (late Permian–Early Triassic) magmatism: example from the External Balkanides, Bulgaria.</i>	139
<i>Artur Ionescu and Efthymia Efsthathiou: Deep Carbon and Water–Gas–Rock Interaction in the Harghita–Perșani Volcanic Region</i>	140
<i>Hristo Kiselinov, Polina Andreeva, Petyo Philipov, Stoyan Georgiev, Tsvetomila Vladinova, Valeri Sachanski, Dimitar Dimitrov: Metabasites of the Sredogriv Metamorphics (western Fore-Balkan, Bulgaria): petrography, geochemistry and tectonic settings – preliminary results.</i>	141
<i>Marinel Kovacs, Alexandru Szakács, Ákos Kővágó: Composite dykes in the Miocene Gutâi Volcanic Zone (East Carpathians, Romania). Petrogenesis and emplacement model</i>	142
<i>Ákos Kővágó, Marinel Kovacs, Alexandru Szakács, Csaba Szabó, István János Kovács: Magmatic ‘water’ content study of the Miocene Gutâi Volcanic Zone (East Carpathians, Romania) using FTIR methodology on Nominally Anhydrous Minerals</i>	143

Philip Machev, Momchil Dyulgerov, Felix Kaufmann, Lutz Hecht, Mariya Stifeeva: Sveti Nicola pluton (NW Bulgaria) – petrology and auto metasomatic alterations.144

Ioan Seghedi, Viorel M. Mirea, Péter I. Luffi: Volcanic Debris Avalanches Triggered by Basement Tectonic Activity: Case Studies from the Southern Apuseni Mts. and the Călimani–Gurghiu–Harghita Volcanic Range.....145

Stefan Velev, Kristian Kirilov: Application of Remote Sensing Methods for the Study of Pillow Lavas from the Western Srednogorie Magmatic Zone, Bulgaria.146

Session GS11 Metamorphism, Conveners: Franz Neubauer, Jaroslaw Majka, Philip Machev, Gavril Sabau

Lyubomirka Macheva, Irena Peytcheva, Albrecht von Quadt: The Cambrian Kolarovo Metaplagiogrinites in the Ograzhden Complex (Belasitsa Mt.): Insights into the Earliest Supra-Subduction Evolution of the Proto-Gondwana Margin148

Emilia Mosony, Ferenc L. Forray, Lucian Barbu: Cr-Muscovite from the Rodna Mountains (East Carpathians).....149

Session GS12 Mineralogy and Applied Mineralogy, Conveners: Gheorghe Ilinca

Ferenc Kristály: A plastic world built on minerals151

Radostina Atanassova, Martin Dimitrov, Stela Atanasova-Vladimirova: Growth mechanism of Fe-rich lamellae in rutile from the Kanarata deposit, SE Bulgaria.152

Ecaterina Bica-Biru, Robert-Csaba Begy, Alida Timar-Gabor: FTIR characterization of structural defects and internal features in natural quartz crystals.153

Daniela Brezeanu, Daniela Constantin, Șerban-Constantin Grecu, Zsejke-Réka Tóth, Johan De Grave, Alida Timar: Investigating the influence of apatite fission-track rock cooling ages on quartz luminescence and electron spin resonance properties: implications for provenance studies.154

Daniela Constantin, Monika Devi, Șerban-Constantin Grecu, Zsejke-Réka Tóth, Daniela Brezeanu, Anca Barla, Ion Nesterovschi, Simona Cînta-Pinzaru, Mihai N. Ducea, Stephen J. Mojzsis, Alida Timar: Multi-spectroscopic characterisation of quartz from igneous, volcanic and sandstone rocks worldwide. Insights for provenance studies based on OSL sensitivity155

Martin Dimitrov, Radostina Atanassova: Chemical peculiarities of the amphibole minerals from the Kanarata deposit, SE Bulgaria.....156

Dimitrina Dimitrova, Vassilka Mladenova: Microchemical characteristics of pyrite, arsenopyrite, and sphalerite from the Govezhda Au-base metal deposit, Western Balkan Mountains, Bulgaria.....157

Dimitrina Dimitrova, Victoria Vangelova, Milen Stavrev: Mineral associations of gold in the Martinovo and Chiprovtsi deposits, northwestern Bulgaria.158

George Dincă, Andra-Elena Filiuță, Violeta-Monica Radu, Alexandru Anton Ivanov, Valentina Cetean: Trace Mineralogy and Micro-textural Features of the Brucite Marbles from Dealul Pițigușului, Budureasa: A SEM-EDS Study.....159

<i>Hristiana Georgieva, Tzvetomila Vladinova, Georgi Milenkov, Radoslav Kalchev, Milen Stavrev</i> : New data on the mineral assemblage of skarn alteration within the contact-metamorphic halo of the Vezhen pluton, Central Stara Planina Mts., Bulgaria.	160
<i>Sylvina Georgieva, Rossitsa D. Vassileva, Georgi Milenkov, Margarita Ivanova</i> : Major and trace element composition and geothermometry of chlorites in the Djurkovo and Govedarnika Pb-Zn deposits, Central Rhodopes, Bulgaria.	161
<i>Yana Georgieva, Rossitsa D. Vassileva, Sylvina Georgieva, Georgi Milenkov, Valeri Dospatski, Istvan Marton, Stefan Metodiev</i> : Trace-element signatures of accessory minerals in the metamorphic rocks of the Kimi-Krumovitsa Unit, Chernichino area, Eastern Rhodopes, Bulgaria.	162
<i>Paulina Hîrtopanu, Elena Luisa Iatan-Codrean, Sorin Silviu Udubaşa, Nicolae Călin</i> : Mineralogical characteristics of rare earth carbonates from Ditrău Alkaline-Carbonatite Complex, Eastern Carpathians, Romania.	163
<i>Katerina Mihaylova, Sofia Panova, Vilma Petkova</i> : Effect of mechanochemical processing on the mineral composition of Moroccan and Egyptian phosphorite ores.	164
<i>Kiara Prendi, Ana Fociro, Katerina Schöepfer</i> : Bridging the Tethyan Gap: The First Localized Theoretical Model for Carbonate-Phosphate Formations in Albania Based on Comparative SEM-EDS Constraints	165
<i>Alexander Rizea, Dóra-Annamária Birtalan, Cristina Montana Puşcaş, Árpád-Olivér Vida, Enikő-Csilla Barabás, Orsolya Mártha, Lucian Barbu-Tudoran, Ágnes Gál</i> : The mineralogy of kidney stones and their related bacterial cultures.....	166
<i>Rositsa Titorenkova, Yana Tzvetanova, Margarita Goranova, Svetlana Encheva</i> : Crystal chemistry and Raman spectroscopic characterisation of pumpellyite from low-grade metamorphosed alkaline basaltoids in the vicinity of the Izvor village, Eastern Srednogorie, Bulgaria.	167
<i>Ákos Tóth, Ervin Hrabovszki, Krisztián Fintor, Máté Szemerédi, Elemér Pál-Molnár</i> : Petrographic and spectroscopic evidence for multi-stage alkali metasomatism in the felsic rocks of the Ditrău Alkaline Massif (Eastern Carpathians, Romania).	168
<i>Yana Tzvetanova, Elena Tacheva, Iskra Piroeva</i> : Kalsilite-leucite mineralisation in monzonite rocks from the Zvezdel pluton, Eastern Rhodopes, Bulgaria.	169
<i>Sorin Silviu Udubaşa, Elena-Luisa Iatan-Codrean</i> : Occurrences of Platinum and Platinum Group Elements in Romania.	170
<i>Codruţa Valea, Tudor Tămaş</i> : Authigenic phosphates in a bat guano deposit from Şura Mare Cave (Romania).	171
<i>Rossitsa D. Vassileva, Sylvina Georgieva, Valentin Grozdev</i> : Mineralogy and trace-element geochemistry of rhythmically banded quartz/calc-silicate rocks from the Malyovitsa Lithotectonic Unit (NW Rila Mountains, Bulgaria).	172

Session GS13 (Micro)Paleontology Paleocyanography, and Paleogeography, Conveners: Ioan I. Bucur, Lóránd Silye

<i>Péter Ozsvárt</i> : Cosmic genesis – Galactic forcing increases origination of marine microplankton.	174
<i>Dumitru-Daniel Badea, Mihai Brânzilă</i> : Late Miocene paleoenvironmental reconstruction of north-eastern Romania based on fossil microvertebrate assemblages.....	175

<i>Rebeka Bartos, Lóránd Silye, Lajos Katona: Mammoth findings from the Quaternary of Cluj-Napoca.</i>	176
<i>Dániel-Viktor Bencze, Gellért Dósa, Lóránd Silye: Miocene foraminifera in the Transylvanian Basin: how many are they?</i>	177
<i>Raluca Bindiu-Haitonic, Sabina Ungureanu: Refining the Late Cretaceous Foraminiferal Record of the Northern Eastern Carpathians (Romania).</i>	178
<i>Botond Bodor, Lóránd Silye: Foraminiferal Study of the Oligocene Sedimentary Record of Southern Albania.</i>	179
<i>Mara-Krisztina Boldan, Raluca Bindiu-Haitonic, Mirela-Violetta Popa, Ionuț Andreica: Biostratigraphy and Paleoecology of Priabonian Deposits from the Treznea and Jibou Areas (NW Transylvanian Basin, Romania).</i>	180
<i>Andrei Briceag, Mihaela Melinte-Dobrinescu, Gabriel Ion, Marius Stoica: Sea-level oscillations and environmental changes on the Romanian Black Sea shelf since the Last glacial Maximum.</i>	181
<i>Ioan I. Bucur, George Pleș, Milan Sudar, Hans-Jürgen Gawlick: Upper Triassic dasycladalean algae from southwestern Serbia.</i>	182
<i>Vladimir-Lucian Crăciun, Ioan I. Bucur, Iuliana Lazăr: Cretaceous calcareous red algae from Enisala (Northern Dobrogea).</i>	183
<i>Zoltán Csiki-Sava, János Magyar, Gergő Konecsni, Máté Szegszárdi, Soma Budai, Felix J. Augustin, László Makádi, Gábor Botfalvai: A river ran through it – A remarkable new Upper Cretaceous vertebrate locality from Vălioara (Hațeg Basin, Romania).</i>	184
<i>Cristian Cudalbu, Bianca Cudalbu, Mihaela Melinte-Dobrinescu: Calcareous nannofossils across the Neoeuxinian–Holocene transition of the NW Black Sea.</i>	186
<i>Darja Dankina, Sébastien Olive: From collection drawer to digital skeleton: CT reconstruction of a Devonian bony fish from Siberia.</i>	187
<i>Vilma-Ioana Daro, Cristina Mărioara Tănase (Călugărean): Micropaleontological Study of Eocene Formations from the Buzău Valley Profile (Siriu Dam Area): Paleoenvironmental and Paleogeographic Implications.</i>	188
<i>Bojana Djordjević, Hans-Jürgen Gawlick, Nevenka Djerić, Daniela Reháková, Alfred Uchman, George Pleș: Microfacies Characteristics of Late Jurassic Carbonate Clasts in the Krčedin Section (Fruška Gora Mts., Northern Serbia).</i>	189
<i>Dávid Dobri, Szabolcs-Attila Kövecsi, Cristian Victor Mircescu, György Less, Ramona Bălc, Virgil Drăgușin, Lóránd Silye: The early Eocene nummulitic limestones of Southern Dobrogea: a biostratigraphic, micropaleontological and paleoenvironmental approach.</i>	190
<i>Flora-Claudia Erbinucci, Carmen Mariana Chira, Raluca Bindiu-Haitonic: The Paleogene-Neogene biostratigraphy and paleoecology of the Botiza area (Maramureș, Romania).</i>	191
<i>Karmen Fio Firi, Frane Marković, Katarina Gobo, Jasenka Sremac, Marija Horvat: Lower Triassic deposits in Southern Croatia: gaining a better insight into the paleoenvironmental conditions by combining petrographic and paleontological methods.</i>	192
<i>Karmen Fio Firi, Frane Marković, Armin Zeh, Šimun Ašćić, Valerije Makarun: The Middle Triassic volcanic events, example from the Žumberak Mt. (Croatia).</i>	193

<i>Andreea-Georgiana Florea, Marius Stoica, A. I. Avrithis</i> : Biostratigraphic and Micropaleontological Investigation of the Sarmatian s.l. deposits in the Sâmnicele Valley (Middle Miocene, Romania).	194
<i>Ana Fociro, Bogusław Kołodziej</i> : Paleogene bauxites of the Mediterranean region: a case study from Albania.	195
<i>Sena Altınbilek Köylü, Fadime Suata Alpaslan, Peter Joniak, Florentin Cailleux, Pablo Peláez-Campomanes, Lars W. van den Hoek Ostende</i> : Another Piece in the Puzzle of Late Miocene Small Mammal Biochronological Mosaic of Anatolia: The Sütluce Locality.	196
<i>Alexandra Daniela Lăcătuș (Ene), M. Balini, I. Lazăr</i> : Aegean ammonoids from Deșli Caira Section (GSSP candidate for the base of the Anisian Stage), North Dobrogea, Romania.	197
<i>Milica Mrdak, Hans-Jürgen Gawlick, Milan Sudar, Nevenka Djerić, Martin Đaković</i> : Demise of the Ravni Carbonate Ramp and Wetterstein Carbonate Platform preserved in a far-travelled nappe in northern Montenegro (Čehotina River section).	198
<i>Emilia-Elena Nedelea</i> : What radiolarians reveal about a changing Paratethys Sea: Insights from the Getic Depression (Romania).	199
<i>Mariusz Paszkowski, Bogusław Kołodziej</i> : Redeposited corals from the Paleocene flysch of the Outer Carpathians (Czech Republic and Poland).	200
<i>Florin Pitea, Iuliana Lazăr</i> : Taxonomy of Lower Cenomanian corals of Grădișteța Muncelului – Cioclovina.	201
<i>Michael R. Sandy</i> : “Curiouser and curiouser!” — bivalves within a large Cretaceous ammonite (Santonian) from the Shumen Formation, Bulgaria.	202
<i>Ottília Szives, B. Szinger, P. Ozsvárt, Zs. Vallner, M. Velki, Z. Lantos, S. Józsa, R. Lukács, B. Cserép, L. Makádi, J. Haas</i> : Late Jurassic climate-change-induced reorganization of marine microplankton assemblages in the Transdanubian Range (Hungary).	203
<i>Alexia Vaida, Raluca Bindu-Haitonic, Ramona Bălc, George Gabor, Emanoil Sășăran, Lóránd Silye, Sorin Filipescu, Radu Crăiță</i> : Integrated micropaleontological study of a continuous Badenian succession in the Făget Basin (Transylvania, Romania).	204
<i>Marija Vuletić, Elżbieta Machaniec, Hans-Jürgen Gawlick, Nevenka Djerić, Martin Đaković</i> : Foraminiferal response to the oceanic anoxic events OAE1b and OAE1d in Aptian–Albian successions of the Budva Zone (Montenegro).	205
<i>İsmail Ömer Yılmaz, Emine Şeker Zor, Doğan Özcan, Mine Sezgül Kayseri Özer, Funda Akgün, Atike Nazik, Ayşe Özdemir, Osman Parlak, Emrah Şimşek, Elif Şimşek, Mehmet Namık Yalçın</i> : Cyclostratigraphical, stable isotopic and elemental analysis of the global Devonian–Carboniferous boundary in the Hakkâri–Şırnak area, Arabian Platform (Southeast Türkiye).	206

Session GS14 Stratigraphy, Sedimentology, and Facies Analysis, Conveners: *Iuliana Lazăr, George Pleş*

<i>Hans-Jürgen Gawlick</i> : Triassic intraplatform basins? What is written in the Triassic–Jurassic sedimentary successions of the Western Tethys Realm?	209
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<i>Ayman Agharabi, Nicolae Har, Ahmed Ntarmouchant, Forray Lazar Ferenc, Constantin Balica, Cristian Victor Mircescu, Horea Bedelan, El Mehdi Jeddi, Omar Ait Haddou, Mohamed Lahtani, Abdelmouiz Echcharef</i> : Mineralogical and petrographic analysis of thermal travertines in Banpotoc–Cărpiniș quarries (Hunedoara country, Romania).	210
<i>Polina Andreeva, Valeri Sachanski, Hristo Kiselinov, Dimitar Dimitrov, Tsvetomila Vladinova, Stoyan Georgiev, Petyo Filipov, Anna Pencheva</i> : Lower Devonian cherts of the Vrabcha Formation (Morava Unit, SW Bulgaria): petrography, geochemistry and depositional settings.....	211
<i>Vlad Apotrosoaei, Relu-Dumitru Roban, Mihaela Melinte-Dobrinescu</i> : Mid-Cretaceous successions in the Eastern Carpathians: Micropalaeontological, geochemical, and sedimentological studies.....	212
<i>Lora Bidzhova, Valeri Sachanski, Svetoslav Georgiev, Emiliya Raeva, Gatien Morin, Dimitar Dimitrov, Christophe Cloquet</i> : Mercury anomalies and mercury isotopes in Silurian sediments from Asaritsa, western Balkan, Bulgaria.	213
<i>Bujar Bilalli, Hans-Jürgen Gawlick, Mensi Prela, George Pleș, Andrea Uta</i> : Tithonian “Paraflysch” above obducted ophiolites (East/Main Vardar) in Gjilan Area, SE Kosovo with reworked material from a carbonate platform to the west: are the ophiolites all the same and derive from the Neo-Tethys?	214
<i>Carmen Mariana Chira, Carlo Aroldi, Andrei Smeu, Raluca Bindiu-Haitonic, Flora Erbinucci</i> : Integrated biostratigraphy and sedimentology of the Paleogene–Neogene deposits from Bârsana (Maramureș, northern Romania)	215
<i>Mircea-Alexandru Ciuclea, Emanoil Săsăran, Constantin Balica, Mihai Emilian Popa, Artur Kedzior, Karol Jewula</i> : The Lower Permian red beds of Sirinia Basin, South Carpathians.....	216
<i>Dimitar Dimitrov, Polina Andreeva, Valeri Sachanski, Hristo Kiselinov, Anna Pencheva</i> : New biostratigraphic and microfacies data on the Lower Devonian siliceous-carbonate sequence of Vrabcha Formation near the village of Mureno (Morava Unit, SW Bulgaria).	218
<i>Nevenka Djerić, Renata Jach, Špela Goričan, Daniela Reháková, Alfred Uchman, Hans-Jürgen Gawlick, Ján Schlögl, Uroš Stojadinović</i> : Jurassic–Early Cretaceous evolution of the easternmost Alpine–Atlantic realm: facies and biostratigraphic record from the Serbian Carpathians.....	219
<i>Daria Dohan, Annamária Hegedüs, George Pleș, Ioan I. Bucur, Sergiu Drăgușanu</i> : New occurrence of Upper Jurassic limestones in the Padiș Karst Plateau (Bihor Mountains). Microfacies and Biostratigraphy	220
<i>Katarina Gobo, Vlasta Čosović, Roko Ramov, Karla Vlatković</i> : Preserved against the odds: shallow-marine mass-transport deposits (MTDs) from the Eocene of Croatia	221
<i>Dan Grigore, Delia-Georgeta Dumitraș, Simona Rusu, Ștefan Marincea, Monica Macovei, Paul Condrat</i> : Mineralogical considerations on the Upper Cretaceous matrix of a unique assemblage of ammonites from the Babadag Basin (Romania).	222
<i>Annamária Hegedüs, George Pleș, Hans-Jürgen Gawlick, Viktor Karádi, Milica Mrdak, Daria Dohan</i> : The Late Triassic sedimentary evolution of the carbonate sequence from Merișor Hill (Codru-Moma Mountains, Romania).	223
<i>Jan Hejnar, Aneta Wronka, Krzysztof Starzec, Wojciech Schnabel, Michał Wojtowicz, Jan Barmuta, Kamil Kobylinski</i> : Application of XRF geochemical logging of geological samples for correlation between field sections and oil&gas exploration wells drilled in Outer Carpathians (Poland).....	225
<i>Dr Tamas Jasko</i> : Statistical distribution of holes in holy stones (Hühnergötter).....	226

<i>Viktor Karádi, Hans-Jürgen Gawlick</i> : Revision of the Triassic evolution of the Bükk Mts. (northeast Hungary).....	227
<i>Georgia Kostaki, Hans-Jürgen Gawlick, Adamantios Kilias, Emmanouil Katrivanos</i> : Triassic Hallstatt exotic blocks in the Avdella and Koziakas mélanges (Hellenides): Provenance and geodynamic implications for Neo-Tethyan ophiolite emplacement	228
<i>Piotr Łapcik, Jeff Peakall</i> : Diversity of turbidite architecture of Lhoty Formation (Albian–middle Cenomanian) recorded in Kozy quarry (Carpathians, Silesian Nappe, Poland).....	229
<i>I. Lazăr, C. Balica, C. V. Mircescu, T. Tămaș, A. Lăcătuș (Ene), V. Răuță, M. Stoica, M. Balini, M. Horacek</i> : Microfacies and mineralogy of the Deșli Caira carbonate succession across the Olenekian-Anisian Boundary (North Dobrogea Orogen, Romania)	230
<i>Andreea Mârza-Ene, Delia Lazăr, Cornel Olariu, Ioan Munteanu, Eugen Tudor</i> : Foreland lower plate evolution under the influence of two compressional systems. Case study: Eastern Moesian Platform during Badenian – Early Sarmatian.	231
<i>Khatuna Mikadze, Nino Lapachishvili, Zviadi Chkhaidze, Khatuna Avaliani, Rati Rachvelishvili</i> : Litological and biostratigraphic characteristic of the Cenomanian-Turonian deposits at the Ananuri section (eastern Georgia)	232
<i>Cristian Victor Mircescu, Ioan I. Bucur, George Pleș</i> : Microfacies and microfossils identified in the Upper Jurassic–Lower Cretaceous limestones of the Vălani Nappe (Bihor and Pădurea Craiului Mountains) ..	234
<i>Matej Pavlović, Katarina Gobo, Šimun Aščić</i> : Sedimentary characteristics of calciclastic offshore-transition deposits in the Ostrovica piggyback basin (North Dalmatian foreland basin, Croatia)	235
<i>Andreea Pinticaru, Tomasz Krzykowski, Doina Smaranda Sirbu-Radasanu, Sergiu Loghin</i> : Mineralogical and geochemical approach of argillaceous sediments from Manolea (Moldavian Platform).	236
<i>George Pleș, Hans-Jürgen Gawlick, Viktor Karádi, Annamária Hegedüs, Ioan I. Bucur, Milica Mrdak, Daria Dohan</i> : The Carnian sedimentary evolution of the Strâmtura Valley section (Apuseni Mountains, Romania)	237
<i>Silviu Rădan</i> : Sedimentological implications of mineralogy and origin of clay minerals assemblages in the Miocene salt deposits of Romania.....	238
<i>Emiliya Raeva, Rositsa Pehlivanova, Nikola Botoucharov, Gatién Morin, Lora Bidzhova, Svetoslav Georgiev</i> : Depositional Environment of the Paleogene Ruslar Formation, NE Moesian Platform (NE Bulgaria): Evidence from Bulk-Rock Elemental Data.	239
<i>Béla Raucsik, Andrea Varga, Olga Piros, Andrea Szuromi Korecz, Viktor Granyák, Elemér Pál-Molnár</i> : Microfacies and stratigraphic data from the Bulz Dolomite Formation (Anisian; Apuseni Mountains, Romania): implications for paleoenvironment, diagenesis, and correlation.	240
<i>V. Răuță, I. Lazăr</i> : Oxfordian sponge-microbial carbonates from Cehirgea -Veriga area (Central Dobrogea, Romania)	241
<i>R. D. Roban, M. N. Ducea, V. Schuller, D. Bunea, V. Cosmescu, G. Suman, R. A. Stoian, D. Stroe, M. Pârlea, V. Ene</i> : Interfingering of different Eocene basin floor fans in the remnant subducted ocean.....	242
<i>Valeri Sachanski, Dimitar Dimitrov, Polina Andreeva, Hristo Kiselinov</i> : Recognition of the Proposed Jarovian and Radotinian Stages within the Přídolí Series in Bulgaria.	243

Fatma Sinaj, Agim Sinojmeri, Irena Brunarska: Preliminary Insights into Jurassic Phosphorites of Albania: An Integrated Multi-Analytical Study.....244

Maya Stefanova, Zlatka Milakovska: Polar constituents in mudstones of Maritsa Iztok Basin, Bulgaria: a geochemical study on OM floral progenitors and diagenetic changes.245

Mateusz Szczęch, Anna Waškowska, František Teták, Maciej Kania: The Farony Member – new Upper Cretaceous lithostratigraphic unit of the Ropianka Formation in the Magura Nappe (Outer Western Carpathians).....246

Mircea Țicleanu, Alexandru Szakács, Flori Culescu, Monica Ghenciu, Veronica Alexe: The real age, Lower Badenian, of the Slănic Tuff (Prahova, Romania).....247

Aleksandar Tričković, Dejan Radivojević: High-resolution sequence stratigraphy of Negotin area, Dacian Basin (Eastern Serbia).248

Session GS15 Tectonics and Structural Geology, Conveners: Liviu Matenco, Alexandra Tămaș

Dave McCarthy: The Role of Structural Geology in the Energy Transition.....250

Arjan de Leeuw, Anton Matoshko, Marion Roger, Stephen Vincent, Andrew Morton, Peter van der Beek, Laurent Husson, Oleg Mandic, Marius Stoica, Wout Krijgsman: Evolution of the Carpathian Foreland Basin and its link with collision and slab detachment.....251

Ion Gheuca, Viorica Iancu: Correlation of the Alpine polyphase/polystage tectonic units from the East and South Carpathians involving the pre-Mesozoic basement and related sedimentary covers252

Ervin Hrabovszki, Gyula Maros, Amadé Halász, Elemér Pál-Molnár, Félix Schubert: Vein mineralogy and fracture reactivation potential in the Boda Claystone Formation (SW Hungary): integrating vein evolution with the present-day stress field.253

Boris Ivanov, Yana Georgieva, Neli Hadzhieva, Nikolay Mihaylov, Nikolay Zhivkov, István Márton, Stefan Metodiev, Neven Georgiev: Tectonostratigraphic evolution of Paleogene supradetachment basins and its control on epithermal gold mineralization: case study from the Krumovgrad region, Bulgaria254

Maciej Kania, Mateusz Szczęch, Dawid Golda: Application of UAV photogrammetry in structural analysis of the Klikuszowa Quarry (Outer Western Carpathians, Poland).255

Vaso Kitanovic, Jelena Živanović, Mladen Zdravković, Ivan Strmbanović, Dragan Milošević, Vuk Milić, Ivana Suzić, Olivera Dukić-Mijucić, Danijela Sušić, Tijana Mitić, Ana Zekovic, Lazar Kotlajić, Vladimir Kovačević, Aleksandar Šestak, Nutu Groza, Stefan Metodiev, Ivan Krumov, Istvan Marton, Kuncho Kunchev, Paul Ivascanu: Conjugate fracture systems as indicators of regional stress, Valja Saka prospect, Eastern Serbia.256

Alexander Kitchka, Marian Olshanetskyi, Andrii Tyshchenko, Andrii Vyzhva, Anatoliy Zhadan, Oleg Makovets, Petro Fenota, and Leonid Melnyk: Challenging issues to reveal the geological structure, tectonic evolution of the Odessa Shelf, Ukraine257

Andreea Mârza-Ene, Liviu Matenco, Vlad Victor Ene: Core-complex in the wrong tectonic position? Towards solving the puzzle of Altân Tepe unit.....258

Bardhyl Muceku, Peter van der Beek, Georges Mascle and Artan Tashko: Thermochronological constraints on the thickening-to-extension transition in the eastern Albanides: an Oligocene volcanic marker in the Albanian-Thessalian Basin.....259

Gavril Săbău, Adriana Mariana Ion: Cimmerian medium grade metamorphic reworking in the Central Dobrogean basement: structural implications260

Balázs Soós, Péter Mucsi, Szabolcs Harangi, Réka Lukács, László Csontos: Continuous palinspastic reconstruction of the Pannonian Basin from nowadays to Oligocene261

Döme Zsombor Szabó, Elemér Pál-Molnár, Ervin Hrabovszki: Microstructural records of fluid migration and deformation in the Juhodályvölgy Marble (Ófalu, Hungary).262

Alexandra Tămaş, Ioana S. M. Tocariu, Bianca Copoş, Alexandru Lăpădat, Zsolt Schléder, Csaba Krézsek, Aimee Guida, Dan M. Tămaş: Insights into the role of mobile shales in the Romanian Eastern Carpathians fold-and-thrust belt263

Cristina Mărioara Tănase (Călugărean), Ioan Munteanu, Vilma-Ioana Daro: Late Pliocene – Quaternary structures of the Western Black Sea shelf.264

M. Țicleanu, S. Rădan, F. Culescu, O. Marina, M. Ghenciu, L. Asimopolos: New structural data in the area of the Badenian salt deposit from Slănic Prahova (Romania).265

Regina Zatykó, Elemér Pál-Molnár, Ervin Hrabovszki: Petrography and evolution of tectonic veins from the Bkf-5 borehole of the Mórágý Metagranite Complex, Hungary.266

Session GS16 Geochronology and isotope geochemistry, Conveners: Réka Lukács, Alida Gabor, Constantin Balica

Irka Hajdas: Radiocarbon dating of climatic and environmental records — applications and prospects for the development of preparation methods268

Catinca Mihaela Asoltanie, Mihai Alexandru Bunea, Vlad Victor Ene: Geochronology and geochemistry of alkaline intrusive rocks from Poiana Mărului – Șinca Nouă.269

Eleonora Balkanska, Stoyan Georgiev, István Márton, Alexandre Kounov, Irena Peytcheva, Milorad Antić, Takahiro Tagami, Shigeru Sueoka, Jan Wijbrans: Low-temperature thermochronology on magmatic rocks associated with Chelopech Cu-Au deposit, Bulgaria270

Dariana Chivulescu, Eszter-Ágota Pál, Gábor Vremir, Emanoil Săsăran, Constantin Balica, Mihai N. Ducea, Zoltán Csiki-Sava: Detrital zircon evidence for improved age constraints and sediment provenance changes during the marine-to-continental transition in the Upper Cretaceous Bozeș and Sebeș formations, southwestern Transylvanian Basin (Romania)271

Monika Devi, Zsejke-Réka Tóth, Alida Timar-Gabor: Optical bleaching of ESR centres in natural quartz: implications for ESR dating272

Petyo Filipov, Lyubomirka Macheva, Holly Stein, Aaron Zimmerman, Svetoslav Georgiev, Nikolay Bonev, Neno Todorov, Tzvetomila Vladinova: Re-Os geochronology and provenance of graphitized carbonaceous clasts from Middle Permian conglomerates, Ochindol Formation, West Balkan Zone, Bulgaria.273

Șerban-Constantin Grecu, Stephen J. Mojzsis, Mihai Ducea, Johan De Grave and Alida Timar-Gabor: Electron-beam dose dependence of the non-bridging oxygen hole centre in quartz across diverse rocks and sediments revealed by scanning electron microscopy: potential implications for provenance and thermochronology274

Boglárka Mercedesz Kis, Réka Szalay, Antonio Caracausi, Paolo Randazzo, Tivadar M. Tóth, László Palcsu, Judit Orsovski, Alessandro Aiuppa, Fausto Grassa, Szabolcs Harangi: Geochemistry of CO₂-rich gas emissions in the Carpathians: multiscale geological sources and implications for orogenic degassing275

Bogdan-Leontin Marti, Șerban-Constantin Grecu, Daniela Brezeanu, Daniela Constantin, Alida Timar: Evaluation of conventional quartz extraction protocols for optically stimulated luminescence (OSL) dating by scanning electron microscopy (SEM) coupled with energy dispersive X-ray (EDX) spectroscopy.276

Fırat Şengün, Viktor Bertrandsson Erlandsson, Johan Hogmalm, Thomas Zack: The age of the Akçaabat gold deposit in the Menderes Massif, western Anatolia, Türkiye: evidence from in situ Rb-Sr dating of K-bearing minerals277

Fırat Şengün, Petyo Filipov, Tzvetomila Vladinova: Provenance of the Jurassic Bayırköy Formation in the western Sakarya Zone, NW Türkiye: trace element composition and U-Pb ages of detrital rutiles.278

Ciprian Stremțan, Cristina Pușcaș, Aurel Perșoiu, Lukas Schlatt: High-resolution laser ablation mapping and stable isotope analysis of cryogenic cave carbonates from Scărișoara Ice Cave, Romania279

Tzvetomila Vladinova, Petyo Filipov, Nikolay Bonev, Lyubomirka Macheva: New U-Pb detrital zircon geochronology of the Late Paleozoic Ochindol and Vranska Formations in the vicinity of Zverino Village, West Balkan Zone, NW Bulgaria.280

Ryota Wako, Hideko Takayanagi, Katsuhiko Suzuki, Norifumi Morita, Takuto Ando, Svetoslav V. Georgiev, Yasufumi Iryu: Modification of crude oil Re-Os isotope system by basin-scale fluids from Miocene volcanic successions in the Niigata Basin, Central Japan.....281

Session GS17 Open Session

Ferenc L. Forray, Emilia Mosonyi, Ágnes Gál: Pan-European Database of Geological Sites283

Marija Horvat: GEOLAB project – Infrastructure reconstruction and procurement of instruments at the Croatian Geological Survey284

Miloš Markič: Some outstanding geochemical characteristics of coals in Slovenia (SW Pannonian Basin, NW Dinarides, Istria)285

Elemér Pál-Molnár, Tamás Vári, Nóra Czirbus, Andrea Varga, Béla Raucsik, Máté Szemerédi, Gábor Bozsó: From bedrock, through soil, to the grapevine: geochemistry and nutrient transfer in the Miniș–Măderat area (Carpathian–Pannonian Region, Romania).286

Elemér Pál-Molnár, Tamás Vári, János Szepesi, Andrea Varga, Béla Raucsik, Éva Kosztolányi, Máté Szemerédi: Lithology-controlled Vineyard Geological Identities in the Miniș–Măderat area (Carpathian–Pannonian Region, Romania).287

Special session SS1 Come together: Tracing explosive silicic volcanism and its impact across the Alpine-Mediterranean region during the Paleogene and Neogene, Conveners: Réka Lukács, Mihovil Brlek

Arjan de Leeuw, Klaudia Kuiper, Wout Krijgsman, Oleg Mandic, Krzysztof Bukowski, Marius Stoica, Sorin Filipescu, Liviu Matenco, Reinhard Roetzel, Iuliana Vasiliev: Explosive volcanism coming to the rescue in stratigraphy: $^{40}\text{Ar}/^{39}\text{Ar}$ dating of Early-Middle Miocene volcanic ashes in the Carpathian-Balkan area..289

Mihovil Brlek, Réka Lukács, Sean P. Gaynor, Francisco Apen, Sava Markovic, Federico Farina, Nina Trinajstić, Vlatko Brčić, Artur Kuligiewicz, Blanca Bauluz, Lorenzo Tavazzani, Marcel Guillon, Eric Lyu, Marko Špelić, Duje Kukoč, Ivan Mišur, Elena Watts, Elizabeth Niespolo, Blair Schoene, Elisa Laita, Alfonso Yuste, Madelyn Percy, Ivan Boev, Steffen Kutterolf, Julie Christin Belo, Dejan Prelević, Gabriella Obbágy-Arató, Katarina Gobo, Bruno Tomljenović, Andrea Di Capua, Róbert Arató, Vlasta Čosović:

External Dinaridic residual record of regional silicic volcanism, intense chemical weathering and tectono-stratigraphic evolution intertwined during Oligo-Miocene (Alpine-Mediterranean region).....290

Péter Gál, Réka Lukács, Péter Pecsmány, László Fodor, Maxim Portnyagin, Szabolcs Harangi: Detailed mapping of the 14.9 Ma Demjén Ignimbrite (northeastern Hungary): thickness and lithofacial variations in the eruptive sequence292

Réka Lukács, Mihovil Brlek, Razvan Bercea, Sorin Filipescu, Samuel Rybár, Katarína Šarinová, Slavomír Nehyba, Jörn-Frederik Wotzlaw, Marcel Guillong, Dawid Szymanowski, H. Albert Gilg, Olivier Bachmann, Szabolcs Harangi: Large-volume Miocene silicic volcanism in the Pannonian Basin: geochronological and geochemical correlation across central and southern Europe293

Péter Mucsi, Balázs Soós, Margaréta Gazsi, Péter Gál, János Szepesi, Dániel Botka, Réka Lukács, Szabolcs Harangi: Miocene silicic volcanism of the Nyírség Sub-basin (Pannonian Basin): insights from deep drill cores294

Special session SS2 Critical and strategic raw materials in the Alpine-Balkan-Carpathian-Dinaridic region: exploration, EU policy implementation, circular economy, and societal challenges, Conveners: Sibila Borojević Šoštarić, Vasilios Melfos, Irena Peytcheva, Marian Munteanu

Tobias C. Kampmann: Critical Raw Materials for Europe's Green and Digital Transition: The RAMP Partnership and the Policy Landscape for the Balkan-Carpathian Region.....296

Polina Andreeva, Hristo Kiselinov, Kristalina Stoykova, Zlatka Milakovska, Valeri Sachanski: Celestine mineralizations in Bulgaria – a review.....297

Sibila Borojević Šoštarić, Marta Mileusnić, Vječislav Bohanek: ADRIA region – beyond conventional mining.....298

Silvia Chavdarova, George Kamenov, Milen Stavrev, Irena Peytcheva, Atanas Hikov: Mineralogy, geochemistry and origin of manganese mineralization in the Srednogorie Zone, Bulgaria.....300

Silvia Chavdarova, Milen Stavrev: Bismuth-bearing mineralization in Bulgaria: new mineralogical and geochemical data from the Western Rhodopes.301

Svetoslav V. Georgiev: Bulgaria's National Scientific Program for Critical Raw Materials302

Sylvina Georgieva, Rossitsa D. Vassileva, Georgi Milenkov: Gallium distribution in silicate minerals from pegmatites of the Madan and Arda lithotectonic units, Rhodope metamorphic complex, Bulgaria.303

Sorin Halga: Rovina Project, Hunedoara County, Romania – from exploration to operation: challenges for the implementation of an EU strategic project304

Atanas Hikov: Potential for rare earth element (REE) deposits in Bulgaria and license areas.305

Pablo Martin-Cocher: Building a machine-friendly, geologically-contextualized dataset for the Carpathian–Balkan region: integrating lithostratigraphic lexicons, survey data, and mineral project records.306

Zlatka Milakovska: Manganese – a critical element of great potential in Bulgarian deposits and geological exploration areas.307

Marian Munteanu: The Romanian Programme for General Exploration: the burden of an early start308

Marius Mureșanu, Alexandra Orban, Alexandru-Iulian Lupulescu, Călin Baci, Giuseppe Etiope: Geological framework of high helium concentration in the Eastern Transylvanian Basin (Romania).309

Irena Peytcheva, Elitsa Stefanova, Dimitrina Dimitrova, Atanas Hikov, Desislava Sabeva: Critical raw material potential of porphyry copper systems from the ore to the tailing: a case study of the Chelopech high-sulfidation Cu–Au epithermal deposit, Bulgaria.....310

Eugenia Tarassova, Mihail Tarassov, Milen Stavrev: (Fe,Mn)-(Nb,Ta,Ti) and (Y,REE,U,Th)-(Nb,Ta,Ti) oxide minerals in heavy fractions of soils and river sediments in the area of the Grantcharitsa tungsten deposit, Western Rhodopes, Bulgaria.....311

Rossitsa D. Vassileva, Sylvina Georgieva, Tzvetomila Vladinova, Georgi Milenkov, Margarita Ivanova: Staurolite as the principal Li-concentrator in amphibolite-facies metapelites: evidence from the Sakar Mountain, Bulgaria.....312

Millena Vetseva, Nikolay Mihaylov, Yavor Stefanov: Petrography, geochemistry and maturity of glauconite across Upper Cretaceous formations from the SE Moesian Platform and Eastern Balkanide Zone (Eastern Bulgaria).313

Mariana Yossifova, Dimitrina Dimitrova, Svetoslav Georgiev, Rositsa Mihaleva, Emilia Raeva, Milen Stavrev, Lora Bidzova: Assessment of critical element concentrations in waste products from Thermal Power Plant Maritsa East 2, Bulgaria.314

Mariana Yossifova, Dimitrina Dimitrova, Marlena Yaneva, Milen Stavrev, Yordanka Donkova: Preliminary data on critical element concentrations in lignite from the Stanyantsi coal basin, Bulgaria. 315

Special session SS3 Exploring the Paratethys and Euxine Basins: Recent Advances and Novel Research Directions, Conveners: Dan Palcu, Mihaela Melinte

Gabriel Ion, Constantin Lazăr, Adrian Popa, Mihaela Melinte-Dobrinescu: Modern sedimentary structures bearing shallow gas – organic matter in an anoxic basin – Black Sea317

Sergiu Loghin: The late Volhynian depositional environments of the inner foredeep (Eastern Carpathian Foreland Basin) revealed by Bogata and Seaca brooks.....318

Mihaela Melinte-Dobrinescu, Teodora Baboș, Gabriel Ion, Constantin Lazăr, Dan Palcu-Rolier: Insights global and regional changes within the Late Eocene to Early Oligocene interval: The record of the Eastern Carpathians319

Cristian Mihalcea, Mihaela Melinte-Dobrinescu, Ioan Munteanu: Architecture of folds and thrust belt of the Eastern Carpathians: Case study Moinești–Târgu-Ocna.320

Dan V. Palcu Rolier, Mihaela Melinte-Dobrinescu, Marius Stoica, Milos Bartol, Sergiu Loghin, Sergey Popov: Documenting the demise of an ocean by multi-proxy basin-state reconstructions in the northern Tethys–Paratethys records.....321

Relu-Dumitru Roban, Mihai Ducea, Andrei Vasilache, Mihaela Melinte-Dobrinescu: Sedimentary record of Miocene forebulge migration in the East Carpathians: Insights from the Green-to-Grey Formation transition.....322

Marko Špelić, Michal Šujan, David Rukavina, Matija Vukovski, Tomislav Kurečić, Adriano Banak, Andrej Chyba, Kishan Aherwar, Koraljka Bakrač, Viktória Barany: From the Drava to the Sava Basin: Lake Pannon regression and tectonic inversion in the SW part of the Pannonian Basin System, Croatia.....323

Special session SS4 From crystal archives through magmatic processes to geodynamic evolution, Conveners: Vlad-Victor Ene, Szabolcs Harangi, Mihai Ducea

Barbara Cserép, Szabolcs Harangi, Saskia Erdmann, Krisztina Hajdu, Réka Lukács: Reprocessing and re-equilibration in a crystal mush: Insights from the Ciomadul dacite.....325

Vlad-Victor Ene, Maria Pârlea, Adriana Mihaela Stoica: Zircon Geochemistry of High Sr/Y and Calc-Alkaline Magmas from the South Apuseni Mountains326

Krisztina Hajdu, Szabolcs Harangi, Razvan-Gabriel Popa, Marcel Guillong, Olivier Bachmann, Barbara Cserép, Réka Lukács: Mixing Matters: Insights into Magma Evolution from Apatite Geochemistry327

Szabolcs Harangi, Emese Pánczél, Kende Szűcs, Patrik Konečný, Réka Lukács: Message from the upper mantle: origin of the alkali basalt magmas in the Pannonian Basin.....328

Péter Luffi, Mihai Ducea: Making arclogites: constraints from phase equilibria and trace element modeling.....329

Emese Pánczél, Szabolcs Harangi, Kata Molnár, György Czuppon, Patrik Konečný, Réka Lukács: Major, trace element and noble gas isotope composition of olivine from the alkaline basalts of the Perşani Volcanic Field, Romania: constraints on the magma source region.....330

Maria Pârlea, Mihai Ducea, Vlad Ene: Zircon Trace-Element Characterization of a Thin-Crust End-Member: Insights from the Aegean Arc.....331

Adriana Mihaela Stoica, Vlad-Victor Ene, G.C. Popescu, Maria Pârlea: Crystal mushes as cryptic zircon factories: Evidence from magmatic enclaves in andesites from South Apuseni Mountains, Romania.....332

Special session SS5 Granites in the Carpathian-Balkan area from pre- to post-collision, Conveners: Ciprian Stremţan, Constantin Balica

Maëlys Bévan, Martin Ondrejka: Alpine Late Cretaceous magmatism in the Western Carpathians (Slovakia)334

Momchil Dyulgerov, Dimitrina Dimitrova, Filip Machev, Yulia Plotkina: Geochemical characteristic of Sveti Nikola I-type granitoid (West Balkan zone, Bulgaria).....335

Milan Kohút, Igor Broska: The Western Carpathians granitic rocks evolution over the Variscan subduction/collision processes336

Máté Szemerédi, István Dunkl, Réka Lukács, Andrea Varga, Zoltán Kovács, Dóra Georgina Miklós, Krisztina Sebe, Árpád Máthé, Zoltán Máthé, Marija Horvat, Béla Raucsik, Zsolt Benkó, János Szepesi, Szabolcs Harangi, Elemér Pál-Molnár: From Variscan continental collision to post-collisional rifting: local and regional correlations of granitoids in the basement of the Tisza Mega-unit and the Apuseni Mts337

Special session SS6 Isotopes and Multiproxy in the Earth System: reconstructing climatic events at various time scales, Conveners: Ana-Voica Bojar, Franz Neubauer, Victor Barbu, Gottfried Tichy, Hans-Peter Bojar, Octavian G. Duliu

<i>Roxana Elena Ionete, Diana Costinel, Marius Gheorghe Miricioiu, Oana Romina Botoran: The Climate Signature of Wines: Insights from Romanian Isotope Records.....</i>	340
<i>Natalia Piotrowska, Alicja Ustrzycka, Alicja Bonk, Wojciech Tylmann: Tracing climate signals in lake systems: insights from modern isotope monitoring and sedimentary carbonates</i>	341
<i>Ana-Voica Bojar, Christophe Lécuyer, Hans-Peter Bojar, Claudia Antoniadu, Victor Barbu, François Fourel, Arnould Vinçon-Laugier: The Middle Miocene Climatic Transition (MMCT) at Muntele Piatra Verde, Eastern Carpathians, Romania.....</i>	342
<i>Ana-Voica Bojar, Victor Barbu, Natalia Piotrowska, Hans-Peter Bojar, Andrei Smeu, Fatima Pawelczyk, Ovidiu Guja: Relationship between climatic fluctuations, Homo sapiens, and Ursus spelaeus (Rosenmüller, 1794) during MIS 3.</i>	343
<i>Octavian G. Dulu, Tatjana Trtić-Petrović, Otilia A. Culicov, Ana-Voica Bojar, Delia-Georgeta Dumitraş, Pavel S. Nekhoroshkov, Ramona Visalom, Veronica Alexe, Lidia Manac, Hans-Peter Bojar: New data concerning the unconsolidated sediments in the Serbian Danube sector and its main tributaries utilizing X-ray diffraction, instrumental neutron activation analysis, X-ray fluorescence, and optical microscopy ...</i>	344
<i>Octavian G. Dulu, Cristiana Radulescu, Delia-Georgeta Dumitraş, George Dincă, Romul-Mircea Mărgineanu, Călin Ricman, Ana-Maria Blebea-Apostu, Claudia Gomoiu, Ioana-Daniela Dulamă, Claudia Stihl, Ion-Alin Bucurică, Ştefan Marincea, Doina-Smaranda Sîrbu-Rădăşeanu: New mineralogical, geochemical and isotopic data for the characterization of a fragment of the Mundrabilla (Australia) meteorite from the National Geological Museum collection</i>	345
<i>Delia-Georgeta Dumitraş, Ştefan Marincea, Frédéric Hatert, Octavian G. Dulu, Hans-Peter Bojar, Ana-Voica Bojar, Doina-Smaranda Sîrbu-Rădăşeanu, Ana Emandi: Application of X-ray powder diffractometry in the study of crystallographic transformations of malachite used as a pigment in traditional paintings</i>	346
<i>Ciprian Stremţan, Cristina Puşcaş, Elina Sahlstedt, Jan Woźniak, Magdalena Hoffman, Katja Rinne-Garmston: Laser-based approaches to tree-ring isotope analysis: assessing LA-CRDS versus LA-IRMS.</i>	347

Special session SS7 Mineralogy as a modern interdisciplinary science for the 21st century, Conveners: Razvan Caracas

<i>Zi-Yue Gao, Razvan Caracas, Kun-Feng Qiu: Gold in Pyrite: Atomic-Scale Insights from Ab Initio Simulations.....</i>	349
<i>Thomas Pieter Lange, Mihály Pósai, Márta Berkesi, Péter Pekker, Péter Vancsó, Zakhar Popov, Csaba Szabó, István János Kovács: The influence of solid-fluid interaction on fluid composition and computational approach.....</i>	350

Special session SS8 Salt systems across scales: Deposition, Deformation, Geohazards and Subsurface Applications, Conveners: Dan Mircea Tamas , Marta Adamuszek, Piotr Krzywicz

<i>Jessica Barabasch, Marta Adamuszek, Alexandra Tămaş, Mark G. Rowan, Zsolt Schléder, Dan Tămaş: Microstructures and rock salt rheology at geological timescales – examples from Romanian salt microtectonics.....</i>	352
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Oscar Fernandez, Szilvia Köver, László Fodor, Tomáš Potočný, Lajos Adam Csicssek, Hugo Ortner, Diethard Sanders, Marina Molčan-Matejová, Dušan Plašienka, Stanisław Mazur, Tanishka Soni, Mark G. Rowan, Josep Anton Muñoz, Gianreto Manatschal, Bernhard Grasemann: Pre-orogenic salt and rift inheritance: New perspectives on the evolution of the Eastern Alps and Western Carpathians354

Alexandru-Cosmin Codreanu, Daniel Scrădeanu, Bogdan Grecu, Marin Palcu, Iulian Popa, Adrian Iurkiewicz, Marius Mocuța, Mihaela Roca, Alexandra Petrescu, Adriano Matteo, David Decu, Dragoș Tătaru: Toward an Integrated Hydrogeological Model of the Slănic Prahova Salt–Sedimentary System355

Nicola Adriana Debrenti, Jessica Barabasch, Alexandra Tămaș, Dan Mircea Tămaș: The Role of Subgrain Piezometry in Understanding Salt Deformation: Examples from the Mânzălești Salt Diapir.356

Adrian Iurkiewicz, Mihaela Roca, Iulian Popa, Marius Mocuța, Ioan Munteanu: Tracing an active antropo-saline karst system in Slănic (Prahova) area – alternative hypotheses and supporting data/information .357
Adriano Matteo, Alexandra Gereu, David Decu, Alexandru-Cosmin Codreanu, Ilie Eduard Năstase, Bogdan Grecu, Dragoș Tătaru: Methodological Insights from Initial FullWaver ERT Test Surveys in the Slănic Prahova Evaporitic Environment (Romania)358

Ioan Munteanu, Ionelia Panea, Mihaela Roca, Valentin Nistor: Salt diapir morphology, the interaction between erosion and salt migration, Slănic Prahova, Romania.....359

Ilie Eduard Năstase, Alexandru Tigănescu, Bogdan Uritescu, Alexandra Petrescu, Nicusor Necula, Ioana Vizireanu, George Stoica, Georgiana Grigoraș, Alexandra Muntean, David Decu, Dragoș Tătaru: Integrated Multi-Temporal and Multi-Scale Monitoring of Ground and Building Deformation in the Slănic Salt-Karst Area (Romania).....360

Iulian Popa, Marius Mocuța, Adrian Iurkiewicz, Mihaela Roca, Ioan Munteanu: Outcomes of surface and groundwater monitoring activities in salt exploitation areas (relevant case studies: Ocna Șugatag, Ocna Mureș, Slănic-Prahova).....361

Mihaela Roca, Adrian Iurkiewicz, Ioan Munteanu, Marius Mocuța, Iulian Popa: Assessment of salt dissolution processes based on periodic video (CCTV) investigation of an observation borehole.....362

Dan Mircea Tămaș, Nicola Adriana Debrenti, Alexandra Tămaș: One Salt, Two Salts, Three Salts, More? Insights into the Miocene evaporitic history of the Romanian Carpathians.....363

Dragoș Tătaru and GEOMONITOR Project Team: Multidisciplinary Characterization of a Complex Urban Salt-Karst System: Insights and Results from the GEOMONITOR Project (Slănic Prahova, Romania).364

Alexandru Țiganescu, Ilie Eduard Năstase, Cristian Neagoe, Bogdan Grecu, Natalia Poiată, Alexandra Muntean, Constantin Ionescu, Dragoș Tătaru: Multi-Scale Monitoring of Ground Deformation and Structural Response in the Slănic Salt-Karst Area (Romania): Real-Time Assessment and Early Warning Framework365

Special session SS10 Tracing mineralization vectors for the magmatic-hydrothermal systems of the Carpathian-Balkan Area, Conveners: Gabriella B. Kiss, Ștefan Metodiev, Istvan Marton

Kalin Kouzmanov, István Márton, Jelena Živanović, Mladen Zdravković, Ana Zeković, Vuk Milić, Ivana Sužić, Nuțu Groza, Ivan Krumov, Kuncho Kunchev, Aleksandar Pačevski, Paul Ivascanu, Ștefan Metodiev: Architecture of an exceptionally high-grade Au skarn system at Čoka Rakita, eastern Serbia: Mineral and geochemical constraints367

<i>Sabina Strmic Palinkas, Todor Serafimovski, Blažo Boev, Goran Tasev, Ivan Boev, Lazar Gorgiev, Andrea Cobic: Geochemical vectoring within post-collisional magmatic-hydrothermal systems: A case study from North Macedonia</i>	368
<i>Beatrix-Boglárka Balázs, István Márton, Szabolcs Orbán, Árpád Ádámcsik, Gabriella B. Kiss: Barite (-polymetallic) mineralisations in the Tulgheș Group (Eastern Carpathians, Romania)</i>	369
<i>Zsolt Benkó, Adrienn Tatár, Ivett Kovács, Tibor Németh, László Rinyu, Christoph A. Hauzenberger, Marjan Temovski, Attila Csík, Boglárka Dönczö, Szilvia Simon: Unusual late Miocene glauconitic alteration in an early Miocene buried volcanic sequence near Paks, Hungary</i>	370
<i>Kincső Emődy, Gabriella B. Kiss: Genesis of a Cu ore occurrence on the NE Darnó Hill (NE Hungary).</i>	371
<i>Hristiana Georgieva, Tzvetomila Vladinova, Stoyan Georgiev, Rossen Nedialkov: Geochemical features of chlorite from propylitic alteration associated with Elatsite porphyry copper deposit.</i>	372
<i>Danijel Ivanišević, Ivan Mišur, Andreas Kronz, Marija Horvat, Damir Slovenec, Matija Vukovski, Jasmina Martinčević-Lazar: A compositional perturbation model of hydrothermal biotite-to-chlorite transformation in Variscan peraluminous granitoids from Mt. Papuk, north-eastern Croatia</i>	373
<i>Georgi Ivanov, Viktor Stoychev, Alexander Al-beeyni, Anastasiya Stoyanova, Aneta Aleksieva, Anton Vasilev, Betina Petkova, Beyhan Chaush, Brenda Hernandez, Ilian Atanasov, Ivan Petrov, Istvan Marton, Kuncho Kunchev, Mariana Trifonova, Miglena Grigorova, Miroslav Kavarimov, Paul Ivascanu, Ross Overall, Stefan Metodiev, Strahil Terziyski, Ivan Krumov: Wedge Zone Deep: a newly delineated high-grade mineralized zone at the Chelopech high-sulphidation Au–Cu deposit, Bulgaria</i>	374
<i>Radoslav Kalchev, Irena Peytcheva, Atanas Hikov: Mobility of trace elements in accessory minerals and its impact on whole-rock geochemistry: a case study from the Sharlo Dere area, Chelopech deposit</i>	375
<i>Gabriella B. Kiss, Harvey Reascos, Zsuzsa Molnár: Silver in some Pb-Zn mineralisations along the Periadriatic-Balaton Lineament: implications of mineral chemistry</i>	376
<i>Betina Petkova, Alexander Al-beeyni, Anastasiya Stoyanova, Aneta Aleksieva, Anton Vasilev, Beyhan Chaush, Brenda Hernandez, Georgi Ivanov, Ilian Atanasov, Ivan Krumov, Ivan Petrov, Kuncho Kunchev, Mariana Trifonova, Miglena Grigorova, Miroslav Kavarimov, Nutu Groza, Paul Ivascanu, Ross Overall, Stefan Metodiev, Strahil Terziyski, Viktor Stoychev, Istvan Marton: The Brevene South Porphyry: a newly discovered high-grade Au–Cu occurrence within the Chelopech magmatic-hydrothermal system.....</i>	377
<i>Mariana Segovia-More, Kalin Kouzmanov, Alexandra Tsay, Massimo Chiaradia, Elitsa Stefanova, Jelena Živanović, Mladen Zdravković, Vuk Milić, Ivana Suzić, Ivan Krumov, István Márton, Stefan Metodiev: Enigmatic deep secondary enrichment mineralization at Dumitru Potok, eastern Serbia.....</i>	378
<i>Ivana Suzić, Vuk Milić, Jelena Živanović, Mladen Zdravković, Dragan Milošević, Ivan Strmbanović, Ana Zeković, Tijana Mitić, Olivera Dukić-Mijucić, Vaso Kitanović, Danijela Sušić, Lazar Kotlajić, Vladimir Kovačević, Aleksandar Šestak, Nušu Groza, István Márton, Ivan Krumov, Stefan Metodiev, Kuncho Kunchev, Paul Ivāšcanu: Dumitru Potok Cu-Au Skarn Mineralization within a Larger Porphyry-Skarn-Carbonate Replacement System, NW Timok Magmatic Complex, Serbia.....</i>	379
<i>Mladen Zdravković, István Márton, Vladica Cvetković, Jelena Živanović, Ivan Strmbanović, Nušu Groza, Olivera Dukić-Mijucić, Vuk Milić, Vaso Kitanović, Tijana Mitić, Ana Zeković, Ivana Suzić, Kuncho Kunchev, Stefan Metodiev, Ivan Krumov, Irena Peytcheva, Stoyan Georgiev, Elitsa Stefanova, Radoslav Kalchev, Kalin Kouzmanov, Maria Ovtcharova, Paul Ivāšcanu: New U-Pb zircon and Re-Os molybdenite age constraints on the magmatic-hydrothermal systems at the Čoka Rakita – Dumitru Potok – Frasen ore cluster, NW Timok, Serbia.....</i>	380

Ana Zeković, Jelena Živanović, Mladen Zdravković, Ivan Strmbanović, Dragan Milošević, Vuk Milić, Ivana Suzić, Vaso Kitanović, Olivera Đukić-Mijčić, Danijela Sušić, Tijana Mitić, Lazar Kotlajić, Vladimir Kovačević, Aleksandar Šestak, Stefan Metodiev, Ivan Krumov, Istvan Marton, Kuncho Kunchev, Nutu Groza, Kalin Kouzmanov, Paul Ivascanu: Mineralization types in the Čoka Rakita deposit, Eastern Serbia381

Kristina Žigrović, Barbara Britvić, Andrea Čobić, Todor Serafimovski, Goran Tasev, Lazar Gorgiev, Sabina Strmić Palinkaš: Insights into Ore-Forming Fluids from Fluid Inclusion Studies in the Buchim–Borov Dol Porphyry Copper System, Republic of North Macedonia382

Special session SS11 Tracing Tethyan Oceans from Europe to Southeast Asia, Conveners: Franz Neubauer, Shuyun Cao, Yongjiang Liu

Shuyun Cao, Lirong Tao, Franz Neubauer, Johann Genser, Christoph von Hagke, Lefan Zhan: Closure of the oceanic Meliata basin: Implications from detrital U-Pb zircon data from Lower Cretaceous trench deposits in the Eastern Alps384

Ruihong Chang, Franz Neubauer, Yongjiang Liu, Qianwen Huang, Sihua Yuan, Qingbin Guan: Depositional and Metamorphic Framework of the Saualpe–Koralpe Complex: Tracking European Tethyan Evolution.385

Qianwen Huang, Yongjiang Liu, Johann Genser, Franz Neubauer, Sihua Yuan, Qingbin Guan, Boran Liu, Ruihong Chang: Petrogenesis of high-silica granites in the Eastern Alpine Schladming Complex: Implications for the Proto-Tethyan tectonic evolution.386

Qingsong Li, Shuyun Cao, Franz Neubauer, Christoph von Hagke, Johann Genser, Lirong Tao: On the multi-stage emplacement mode of the Neo-Tethyan accretionary wedge in southern Crete, Aegean Sea: insights from zircon U-Pb geochronology and geochemistry387

Yongjiang Liu, Franz Neubauer, Qingbin Guan, Ruihong Chang, Boran Liu, Johann Genser, Qianwen Huang, Sihua Yuan: The Plankogel Complex in the Eastern Alpine basement: an ophiolitic mélange ...388

Franz Neubauer, Shuyun Cao, Johann Genser, Yongjiang Liu, Sihua Yuan: The Early Alpine (“Austrian/Cimmerian”) orogeny between Eastern Alps and Iran explained by the closure of the Paleotethys Ocean.....389

Iva Olić Peco, Bojan Matoš, Dejan Prelević, Zorica Petrinc, Kristijan Sokol, Anja Kocjančič, Alan Moro, Borna Lužar-Oberiter: Upper Cretaceous volcano-sedimentary complex of the Kostajnica area: Insights from the westernmost Sava Suture Zone.....390

Sanja Šuica, Borna Lužar-Oberiter, Armin Zeh, Jan Schönig, Iva Olić-Peco, Šimun Aščić, Krešimir Petrinjak, Adriano Banak, Duje Kukoč, Marija Bjelogrić, Stjepan Čorić, Matej Plavac: Refining Cretaceous post-obduction convergence in the Dinarides based on detrital zircon geochronology and garnet chemistry391

Lirong Tao, Shuyun Cao, Franz Neubauer, Christoph von Hagke, Johann Genser, Lefan Zhan, Jianfeng Hu: Detrital zircon U–Pb ages and provenance of Upper Cretaceous and Triassic sedimentary rocks in the Central Srednogie and Sakar–Strandja zones: implications for Variscan and Tethyan tectonic evolution392

Sihua Yuan, Franz Neubauer, Yongjiang Liu, Johann Genser, Qingbin Guan, Boran Liu, Qianwen Huang, Ruihong Chang: On Triassic migmatization, Variscan metamorphism and paleogeographic origin of the Raabalpen Complex, Eastern Alps (Europe).....393

Special session SS12 Basement and cover rocks of the South Carpathians. A session celebrating the extraordinary career of Dr. Viorica Iancu of the Romanian Geologic Institute, Conveners: Mihai Ducea

Mihai Ducea, Mihai Ignatescu: The origin and evolution of the Sebeş-Lotru terrane, South Carpathians (Romania).....395

Andra-Elena Filiuță, Denisa Jianu, George Dincă, Violeta-Monica Radu, Alexandru Anton Ivanov: New Data on the Ultramafic Rocks from the Valea Muntelui Complex, Cindrel Mountains, Southern Carpathians.....396

Viorica Iancu: Tectono-metamorphic zonation and simple shear zones in the prealpine basement of the South Carpathians as result of mapping, petrological observation and integrated analytical data.....397

Viorica Iancu, Antoneta Seghedi: The South Carpathians: relative timing of the Alpine polyphase nappe stacking, basement-cover relationships and magmatic markers as documented by geological mapping and research.....398

Denisa-Laura Jianu, George Dincă, Andra-Elena Filiuță, Dragoș Panaitescu: Eclogites of the Cozia Formation: a new occurrence in the Southern Carpathians399

Boglárka-Mercedesz Kis: A tribute to Dr. Viorica Iancu's Scientific Contribution in Mineral-Water exploration.....400

Gavril Săbău: Lithologic sequence, markers, apparent lateral transitions and monazite U-Th-Pb^T metamorphic age constraints in the Lotru Metamorphic Suite, South Carpathians401

Errata

Session GS5 Economic Geology

Viktor Jäger, György Falus, Zsuzsanna Beke, Anikó Besnyi, László Szikszay, Anita Szabóné Kulati, Péter Kónya, Tivadar M. Tóth: Assessment of the Critical Element Potential of the Helesfa and Gyód Serpentinities, Southeastern Hungary.....404

Evdokia Papadopoulou, Alexandros Chatzipetros: High-resolution morphotectonic analysis for assessing fault activity: case studies from northern Greece405

Bálint Polonkai, Árpád Máthé, Attila Bálint, László Sőrés, Zoltán Horváth: Europe's First UNFC-Based Critical Raw Materials Map: Data Harmonisation and EGDI Integration in the GSEU Project.....406

Invited plenary speakers

Gigantic Cold Magmatic Blankets Under Continental Plateaus and Their Relevance to the Evolving Continental Crust

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Orogenic plateaus are low relief / high elevation continental zones forming near compressive plate margins. Their development remains controversial, yet they are critical to continental tectonics. More surface area near convergent boundaries is of plateau type than high relief mountainous terrains. Here I propose to investigate the development of magmatism under plateaus. I will address, from atom to outcrop to continental scale, the mass balance, physical mechanisms and duration of these unique magmatic systems developing at hundreds of kilometres horizontal scales. I use field observations of volcanic rocks from modern plateaus and exposed mid crustal sections of defunct plateau regions, molecular dynamic simulations and physical models of cold stored mush (melt and solid) systems under ductile deformation. Porous flow due to addition of mafic melts from the mantle and partial melting of the local crust gives way to conduit flow and accumulation of sill-like bodies of silicic nature, a small fraction of which further escapes and erupts at the surface as highly aluminous rhyolites. Contrary to more typical views of magma chambers, these elusive magmatic systems are predicted to evolve over millions to over ten million years, and represent a very important and yet to be elucidated, paradigm changing mode of forming-storing-erupting magma on Earth. These large blanket magmatic systems are probably the fundamental cause of the very development of low relief plateau zones. Plateau sills also represent the most important Earth factories of magmatically enriching elements such as Li, Cs, Rb or B, thus being of great interest to our modern industrial revolution. The salient contribution of this project is to quantify the life of sub-plateau, long lived, relatively magma horizontal bodies, often missed in plain sight in the geologic record and to calibrate the various boundary conditions of these systems against exceptionally preserved natural examples.

The Neogene to Quaternary Volcanism of the Carpathian–Pannonian Region: from initial plate tectonic models to quantitative petrogenetic explanations

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The Neogene to Quaternary volcanic activity associated with the formation and evolution of the Carpathian–Pannonian Region (CPR) produced a great diversity of magmatic rocks. Ideas about the origin of these magmas were incorporated into early plate tectonic models of the region. Plate tectonic theory provides a general view about regional distributions of volcanoes and the chemical composition of their erupted magmas, but cannot be readily applied to the CPR. Instead, the development of volcanoes and the closely associated deep magmatic processes can be better understood using the ‘source-to-surface’ philosophy, i.e., by evaluation of magma generation processes, the emplacement of magma in the crust, the processes and their timescale in the magma reservoir system, the reason for magma withdrawal, and the mechanisms of volcanic eruptions.

Four main groups of volcanic rocks formed during the last 20 million years are distinguished in the CPR: (1) silicic volcanic rocks (high-SiO₂ rhyolites and rhyodacites); (2) calc-alkaline-type suites (basalt–andesite–dacite–rhyolite and adakitic rocks); (3) potassic and ultrapotassic rocks (shoshonites, latites, leucitites, lamproites); (4) sodic alkaline volcanic rocks (various basalts, trachyandesites and trachytes). In the last two decades, major progress has been achieved in understanding the origins of this diverse volcanism and its relations to tectonic processes.

New zircon dating results revised the eruption ages and provided a robust chronological framework for the Miocene volcanism and the Paratethys sedimentary sequences. Integration of eruption ages with zircon trace element and isotope compositions helped in correlating distal ash occurrences with proximal deposits. The 18.1–14.4 Ma silicic ignimbrite flare-up volcanism occurred coeval with lithosphere thinning and had a major thermal impact on the continental crust. The calc-alkaline nature of the volcanic rocks does not necessarily mean an origin due to active subduction. Instead, they were generated partly due to lithospheric extension during the syn-rift phase of the Pannonian Basin and partly in a post-collisional setting. Thus, there is no classic volcanic arc in the CPR and the term ‘back-arc basin’ can be used for the Pannonian Basin only in structural point of view. Miocene and Quaternary ultrapotassic magmas were formed either by decompression melting during the syn-rift phase or by heating of upwelling asthenosphere, particularly in the south-southeast CPR. Alkali basalt volcanism formed distinct volcanic fields mostly in the peripheral areas of the Pannonian Basin. Each batch of magma corresponded to a unique melt generation event in the upper mantle. The compositional diversity of the basalts even within a volcanic field implies that the primary magma batches were formed by various degrees (1–3 %) of partial melting dominantly of garnet–peridotite in the heterogeneous asthenospheric mantle. The youngest volcanism in the CPR was basaltic (100–500 ka) and dacitic (30–160 ka), the latter with an adakitic nature.

After 50 years of intense research in the CPR, there are still many open questions. Mutual understanding of the results of different disciplines is crucial to better interpret the evolution of this tectonically complex area with a highly extended continental crust, to reveal its resources, and to assess its potential natural hazards.

Tectonics and structural geology, from fundamental concepts to societal applications

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Tectonics and structural geology are inherent multi-disciplinary research directions, spanning their impact from fundamental process-oriented analysis to practical societal application. Observations in sedimentary basins and orogenic areas affected by a significant amount of deformation show that the resulting geometry and rock characteristics control the key understanding required for applications in the sustainable use of the subsurface and renewable earth materials. In sedimentary basins, deformation-induced depositional space and associated diagenesis, at various spatial and temporal scales, is closely linked to the basin kinematics. The sediment infill and related diagenetic processes reflect the history of deepening and shoaling facies controlled by the activation and changes in the fault's offset rates. The deposition of associated tectonic successions is characterized by significant mass-wasting during enhanced periods of tectonic activity, while the interplay with other autogenic and allogenic effects becomes more obvious during tectonic quiescence. This approach is significantly genetic and applicable at all spatial and temporal scales, illustrated by examples from extensional, contractional, and strike-slip basins. The evolution of tectonic successions is correlated with fluid-rock interactions and diagenetic evolution, which is of particular importance in understanding lateral prediction in reservoirs and their changes during exploitation. The attributes of these successions are equally relevant for the large-scale screening and quantification of all subsurface geo-resources, conventional and particularly important for the sustainable ones (e.g., geothermal energy), geological storage (e.g., CO₂, hydrogen or other energy) and associated geo-hazards (e.g., induced seismicity), which are associated with enhanced fluid-rock interaction processes. In orogenic areas, tectonics and associated kinematic features are responsible for exhumation of deeply metamorphosed rocks, the association with syn- to post-kinematic fluid circulation impacting the formation of ore-deposits and the subsurface distribution of sediments during significant deformation and strain-partitioning. The regional tectonic and rheological inheritance is particularly important, which is critical to understand the patterns and magnitudes of strain-partitioning controlling the local distribution of metamorphism, magmatism, and the prediction of subsurface reservoirs. The importance of such multi-scale tectonic and structural geology features is illustrated by process-oriented concepts and their societal-relevant application, with focus on relevant examples in Central and SE Europe.

The Geological Memory of Quartz: From Geochronology to Provenance

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Quartz is the most widely used mineral in trapped-charge geochronology and has played a central role in establishing chronologies for Quaternary environmental, archaeological, and sedimentary archives. Luminescence dating methods, including thermoluminescence (TL) and optically stimulated luminescence (OSL), are based on the accumulation of trapped electrons and holes generated by natural ionizing radiation and released through thermal or optical stimulation. Similarly, electron spin resonance (ESR) dating exploits radiation-induced paramagnetic centres that accumulate through time. Together, these techniques have provided powerful tools for determining the timing of sediment deposition and landscape evolution over Quaternary timescales.

The success of these methods relies on a diverse suite of intrinsic and impurity-related defects within the quartz lattice. Traditionally, these defects have been viewed primarily as charge traps and recombination centres governing dosimetric behaviour. Increasing evidence, however, suggests that they represent a much richer geological archive, and may preserve information on crystallization history, source lithology, radiation exposure, sediment transport, burial, and recycling.

This lecture explores recent advances in the characterization of quartz defects and their implications for both geochronology and provenance studies. By integrating optically stimulated luminescence, thermoluminescence, electron paramagnetic resonance, and hyperspectrally resolved cathodoluminescence, it is now possible to investigate defect evolution across a wide range of geological settings and timescales. Particular attention will be given to oxygen-related defects and impurity-associated centres involving Al, Ti, and Ge, which provide insights into both luminescence sensitivity and the geological history of quartz grains.

Studies of quartz from source rocks and sediments of independently constrained age, including some of the oldest preserved terrestrial materials, reveal systematic changes in defect inventories that reflect prolonged exposure to geological processes. These observations indicate that the evolution of quartz cannot be explained solely by trapped-charge accumulation and recombination. Instead, long-term modification of the crystal lattice, potentially involving defect transformation, redistribution, and ionic mobility, appears to play a fundamental role in shaping the signals observed in nature.

The emerging picture is that quartz contains a geological memory that extends far beyond its established use as a geochronometer. Defect signatures inherited from source rocks and modified during transport and burial provide new opportunities for tracing sediment pathways as well as identifying provenance. Understanding how this memory is acquired and preserved not only contributes to a more complete physical model of luminescence and ESR phenomena but also opens new avenues for linking mineral-scale processes with crustal-scale sediment dynamics and Earth-surface evolution.

Acknowledgements. This research is funded by the European Research Council, ERC grant PROGRESS-CoG “Reading provenance from ubiquitous quartz: understanding the changes occurring in its lattice defects in its journey in time and space by physical methods”.

Session GS1

Archaeometry

Conveners:

Valentina Cetea, Dan Ștefan

The Provenance of Non-Ferrous Metals: The Case of Gold

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Identifying the source of the ores used in the production of archaeological metallic materials provides insights into ancient trade networks and exchange systems. However, this research remains challenging even today, despite increasingly innovative instrumentation and analytical tools. Indeed, factors such as the geochemical signatures of mineral deposits and the chemical-physical and anthropogenic processes involved in the *chaîne opératoire* - from ore extraction to metal production - limit the chemical tracing from ores to heritage objects.

In response to these persistent challenges, three interdisciplinary methodological approaches can optimize the reconstruction of ancient exchange networks: i) the establishment of relevant mining and metallurgical reference databases, achieved by integrating data from paleo-metallurgy, geology, and geochemistry; ii) the use of isotopic tracers tailored to the specific *chaîne opératoire* under study; and iii) the development of robust and comparable tracers applicable to all materials along a given same *chaîne opératoire*.

Three examples of gold *chaîne opératoire* are considered, i.e., gold mining and production during the Protohistoric period in France and the Roman era in Romania, and the still-unresolved question of the diffusion of West African gold during the medieval period, particularly in the context of the trans-Saharan trade connecting the Sahelian and Euro-Mediterranean worlds.

Through these case studies, conducted in contexts documented by archaeology or historical texts is demonstrated the value of these methodological approaches in generating high-value results. These examples also show how such data can challenge or support the re-examination of historical and archaeological narratives in a meaningful way.

Dating in the dark (... and sometimes getting it right): practical progress of luminescence dating in (geo)archaeological research

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While luminescence dating finds its origin in archeologically driven research questions, developments from the 1980's onwards rapidly led to a shift towards applications in earth sciences. Over the past 20-30 years, the method has undergone major technological and methodological advances, resulting in significant improvements in precision and accuracy on the one hand, and a considerably broadened scope and substantially increased number of publications reporting luminescence ages on the other.

To our experience, these advances have remained relatively unknown to, or untapped by, the broader archaeological community. It is difficult to assess the extent to which this still (partially) reflects a disillusion in the method during the first 20 years of luminescence dating development and application. Possibly along with the subsequent move towards more focus and applications in earth sciences, it might partially have resulted in fewer luminescence dating studies being published in archaeology-based journals from the 1980's onwards. In addition, luminescence dating is labour-intensive and hence relatively expensive and complex, making it generally less accessible to the non-specialist users. All taken together, use of luminescence dating in archaeology has been limited compared to that of other, better-known numerical dating methods, such as radiocarbon dating.

Nevertheless, luminescence dating did deliver major contributions to archaeology, especially beyond the range of radiocarbon dating. For example, with respect to improving our understanding of human migration and occupation throughout the Palaeolithic, or related to post 1600 CE events. Several of the main developments in luminescence dating, in their turn, would not have been triggered and accomplished without archaeochronological questions.

This lecture does not seek to present yet another historical review of these developments and accomplishments, the occasional success stories, exotic applications, or outcomes from large-scaled high-risk and high-visibility research. Comprehensive overviews and key papers on these matters have already been published.

Instead, this lecture aims at developing a critical understanding of what state-of-the-art routine luminescence dating techniques can and cannot contribute to resolving chronometric research questions encountered in archaeology. Several case studies which are mainly drawn from smaller-scaled local and regional archaeological research initiatives, with a minimum of technical detail, will be explored. A brief overview of some examples of more recent and future developments in luminescence dating, with their likely relevance to mainstream archaeology, will be given. We extend this towards the potential of using luminescence observations for material characterisation, provenancing and understanding formation and preservation processes in relation to historical context and current practical feasibility.

We illustrate how and motivate why luminescence chronometric research was, still is, and will hopefully continue to be, essentially driven by archaeological research questions. And vice versa. In general, it aims at broadening horizons and revitalizing one aspect of transdisciplinary scientific thought, knowledge and practice.

Tracing Environmental Changes Using Lead-210 Geochronology

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Lead-210 (^{210}Pb) dating has become a widely used tool for reconstructing recent environmental changes recorded in natural archives such as lake sediments and peatlands. This method is particularly valuable for establishing chronologies covering the last 100–150 years, a period that coincides with increasing anthropogenic influence on terrestrial and aquatic ecosystems. By applying ^{210}Pb -based geochronology, a wide range of environmental processes can be quantified and interpreted, including sediment accumulation rates, pollutant deposition histories, and watershed erosion dynamics.

Lake sediments act as continuous recorders of environmental conditions, capturing both natural and human-induced changes within their layered structure. In Romania, ^{210}Pb dating has been successfully applied to numerous lake ecosystems, providing insights into sedimentation processes and environmental contamination. By determining sediment accumulation rates, researchers can track lake-basin evolution and pinpoint periods of rapid deposition tied to land-use change or climate shifts. The method also enables detailed reconstructions of heavy-metal pollution, showing the onset, peak, and decline of contamination from industrial and agricultural activity.

The application of ^{210}Pb chronologies can be complemented by the use of artificial radionuclides, particularly ^{137}Cs , which is deposited across catchment surfaces. In this context, ^{137}Cs was used to investigate erosion processes within the watershed, as its spatial redistribution reflects soil movement and sediment transport. These erosion dynamics were subsequently placed into a chronological framework using ^{210}Pb -dated sediment cores. By integrating the catchment-scale information provided by ^{137}Cs with the temporal resolution of ^{210}Pb dating, it became possible to reconstruct the timing and intensity of erosion processes affecting the lake system. As a result, shifts in erosion intensity can be correlated with anthropogenic disturbances, including deforestation, agriculture, and urban development.

Peatlands represent another critical natural archive where ^{210}Pb dating plays a significant role. These ecosystems are essential components of the global carbon cycle, acting both as carbon sinks and sources of greenhouse gases. Understanding the dynamics of carbon accumulation and release in peat deposits requires precise chronological control, which can be achieved through ^{210}Pb -based dating methods for recent layers. Establishing an accurate timeline for peat stratigraphy allows researchers to quantify carbon sequestration rates and to assess changes in ecosystem functioning over time.

In European peatlands, including those studied in Romania, the integration of ^{210}Pb dating with other chronological approaches has enabled the reconstruction of carbon dynamics over extended timescales, reaching back several millennia. Such studies provide valuable data on both long-term carbon storage and periods of enhanced greenhouse gas emissions. These reconstructions contribute to a better understanding of how peatland ecosystems respond to climatic shifts and human activity, offering essential insights for predicting future environmental change and for informing climate mitigation strategies.

In conclusion, ^{210}Pb dating is a robust and versatile method for analyzing environmental processes recorded in natural archives. Its application in lake sediments and peatlands has significantly advanced our understanding of sedimentation, pollution history, erosion dynamics, and carbon cycling.

Stone Projectiles for Roman Artillery from Ulpia Traiana Sarmizegetusa: Archaeometric Investigations

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Among the military artifacts recovered during the 2008–2009 archaeological excavations at Ulpia Traiana Sarmizegetusa, the Roman colonia founded shortly after the Second Dacian War (AD 108–112), eight quasi-spherical stone projectiles were identified. Their morphology and dimensions indicate their use as ammunition for Roman artillery engines.

The present study aims to characterize these artifacts through a combination of non-destructive archaeometric methods, focusing on raw material identification, morphometric parameters, physical properties, and elemental composition.

Petrographic examination was performed under a binocular microscope in order to assess lithology, surface preservation, and weathering features. Dimensions were measured with a calliper along four axes, while masses were determined using a precision balance. Volumes were obtained by water-displacement measurements, allowing the calculation of apparent densities. Elemental compositions were investigated using portable X-ray fluorescence spectroscopy (pXRF), with particular attention given to the concentrations of Si, Al, Fe, Ca, and K.

The projectiles were shaped by pecking and grinding and fall into three size categories. Five specimens have average diameters between 58 and 63 mm, two measure 68 mm and 69.5 mm respectively, and the largest specimen reaches 83 mm. Their masses range from 238 g to 873 g. Apparent density values vary between 2.16 and 2.82 g/cm³, reflecting differences in lithology and internal structure. Most specimens cluster within the intervals 2.45–2.50 g/cm³ and 2.64–2.75 g/cm³.

The combined petrographic and geochemical data indicate that the projectiles were manufactured from quartz-rich sandstones, quartz-feldspathic rocks, andesite and microconglomerates. In several cases, intense surface alteration complicated macroscopic lithological identification, making pXRF analysis particularly useful for supporting petrographic interpretation. The raw material could have been obtained from naturally rounded river pebbles collected from watercourses in the broader region surrounding the site, whose morphology reduced the amount of shaping required to produce quasi-spherical projectiles.

The relatively small dimensions of the projectiles are consistent with their use in light and portable artillery engines, a type of equipment commonly employed by Roman military units during the Early Imperial period. The study provides new archaeometric data on Roman stone artillery projectiles from Ulpia Traiana Sarmizegetusa and contributes to a better understanding of raw-material selection and ammunition manufacture in Roman Dacia.

Acknowledgements. This research work is partially supported by the Romanian Ministry of Research, Innovation, and Digitization through the Core Program (project PN 23 39 03 01).

From Quarry to Sanctuary: Archaeometric Investigations of the Pietroasa-Deva Andesite Used at Sarmizegetusa Regia

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The historical significance of the Pietroasa-Deva andesite, recently included among the Romanian stones recognized for their heritage value, derives from its close connection with the sacred structures of Sarmizegetusa Regia, the capital of the Dacian Kingdom established in the Şureanu Mountains during the 1st century BC. The stone was extensively used for large architectural elements, including slabs, bases, discs, column drums, channels, vessels, and pillars. Similar andesite has also been identified at Feţele Albe and at the Dacian settlements of Pustiosu and Anineş, although the extent of its distribution remains insufficiently documented.

Geologically, the Pietroasa deposit belongs to the third cycle of Neogene volcanism in the Southern Apuseni Mountains and is associated with the massive subvolcanic stock known as the Măgura Andesite. Historical observations and subsequent petrographic investigations demonstrated a clear compositional and textural correspondence between the Pietroasa rocks and the andesite employed in the sacred constructions at Sarmizegetusa Regia, supporting a local provenance model. Petrographically, the rock is a porphyritic amphibole-, pyroxene-, and biotite-bearing andesite (classified as trachyte in some studies), consisting of a microcrystalline groundmass (50–60%) and phenocrysts (40–50%) represented mainly by plagioclase, hornblende, pyroxene, and biotite.

This study introduces, in an archaeometric framework, physical and mechanical recent data obtained from the Pietroasa quarry during the extraction of ornamental stone blocks. The investigated rock displays an average real density of 2.65–2.69 kg/m³, water absorption values of 2.32–2.55%, open porosity of 5.68–6.26%, uniaxial compressive strength of 95–110 MPa, and tensile breaking strength of about 11 MPa. These characteristics indicate high durability, excellent resistance to weathering, and a strong suitability for the production of large structural and architectural elements.

Although the analyses were performed on quarry material rather than on archaeological artefacts, the results provide new evidence supporting the selection of Pietroasa andesite by Dacian builders and contribute to a better understanding of the relationship between geological resources and monumental architecture in the Orăştie–Şureanu Mountains region. By integrating geological provenance, petrographic characteristics, and physical-mechanical properties, the study further strengthens the heritage stone status of the Pietroasa-Deva andesite provides new insights into ancient stone selection practices and the material foundations of Dacian sacred architecture.

Acknowledgements. This research work was supported by Romanian Ministry of Research through the Core Program (project PN 23 39 03 01) and the Research Grant 06/08.06.2026 - Marmosim Simeria.

Application of X-ray powder diffractometry in the study of crystallographic transformations of malachite used as a pigment in traditional paintings

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Malachite is one of the oldest known green pigments, which was widely used in the European and Asian arts, particularly in medieval paintings from the 15th and 16th centuries. In order to analyze the behavior of malachite pigment during the acidic weathering and meteoric alteration, a natural malachite sample from Congo was subjected to treatment with CO₂, NO₂ and SO₄, then analyzed by XRD, in order to gain new insights upon the crystallographic transformations.

The unit-cell parameters refined for the initial malachite sample are $a = 9.503(3)$ Å, $b = 11.982(8)$ Å, $c = 3.239(1)$ Å, $\beta = 97.75(2)^\circ$ and $V = 364.45(1)$ Å³. The structure of malachite consists of ribbons of edge-sharing CuO₆ octahedra running along the c -axis; they are linked together through corner-sharing, resulting in corrugated layers parallel to (010) that are interconnected through carbonate trigonal groups that assure an interlayer linkage. The carbonate groups are located in the (100) plane, so as the substitution of the C⁴⁺ cations by smaller or bigger cations will mainly influence the a and b cell dimensions.

The treatment with NO₂ caused the replacement of part of the C⁴⁺ ions with N⁵⁺, inducing slight distortions of the structural blocks due to the contraction or the expansion of part of the (XO₃) groups in the structure. As a result, in the N-substituted malachite, both a and b parameters are smaller than those in the untreated one, whereas the c unit-cell parameter remains, in the limit of errors, practically constant. The shrinkage of the unit-cell volume is also visible. For the SO₂-treated malachite, the unit-cell parameters show practically no changes considering the limit of errors. A slight decrease of the sample crystallinity is due to a reaction producing a copper sulfate and explains the “lose” of some small reflections from the malachite pattern. No changes in the malachite structure could occur, since the regular coordination number of the S⁶⁺ cation remains 4. Thus the replacement of three-fold coordinated C in the carbonate groups is precluded. In contrast, the CO₂ treated malachite shows a visible change in unit-cell parameters explained only by structural changes. The malachite sample used for the study is more hydrous than expected for assuring the stoichiometry based on the ideal formula. The only possible way to accommodate more water than in the ideal formula involves partial substitution of the (OH)⁻ by H₂O molecules, accompanied by vacancies in the octahedral sites. By consuming water, the gas treatment reduced these vacancies, resulting in a more “monoclinic” cell, with smaller β angle. Specifically to the CO₂-treated sample, it seems that the octahedral distortion of the two independent Cu²⁺ sites in the malachite structure, attributed to the Jahn-Teller effect of Cu²⁺ increased, which is normal considering that the initial vacancies in the octahedral sites were occupied by copper cations. As a result, the Jahn-Teller elongated axes of CuO₆ octahedra expanded, determining a normal increase of the a and decrease of the b unit-cell parameters. As in previous cases, the c unit-cell parameter remains practically constant.

Archaeometric study of building materials—mortar and ceramics—from the Late Antique and Medieval fortress of Κοζιάκος, Obzor, Eastern Bulgaria

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The Late Antique and Medieval fortress of Κοζιάκος is located in the Kaleto area, 2.2 km west of the town of Obzor in Eastern Bulgaria. The fortress originated as a Late Antique castellum, which existed until the early 7th century, and was known as an important religious, commercial, and military center. According to written records from the 13th and 14th centuries, Κοζιάκος holds prominent significance in the area's history between the Northern and Southern Black Sea coasts—its geographical location suggests a connection to maritime trade and traffic via the ancient port of Templum Iovis (?) in present-day Obzor (Gözken). Its semi-mountainous location, approximately 2.5 km from the coast, also suggests its importance for overland trade in the Eastern Stara Planina region (Soustal, 1991).

The fortress wall was constructed using the Opus emplectum technique on a foundation of limestone and marl blocks bonded with mortar. The wall has been built up—the courses consist of broken stones, aligned with standard Late Antique mortar-bonded bricks, and a Byzantine superstructure of limestone and marl blocks, also bonded with mortar.

The present research investigates the technologies used in the production of bricks (Late Antiquity) and mortar (Late Antiquity and the Middle Ages) based on the face and core of the masonry, as well as Byzantine bricks, roof tiles, and mortar from a structure located in the center of the Late Antique fortification.

The archaeometric study utilized X-ray fluorescence analysis, powder X-ray diffraction (PXRD) measurements, Fourier-transform infrared spectroscopy, and thermal analysis. To trace the phase changes in the ceramics, PXRD analyses were also performed on samples heated to 900°C. The archaeological (kilns near the site and wasters) and geological (clay, limestone, and marl in the area (Kunchev and Gercheva, 1992)) background suggest the local production of the building ceramics and a possible local quicklime production as well.

It has been determined that the bricks and roof tiles from both periods were made from clay with a similar mineral composition—montmorillonite-illite. The ceramics were fired at two different temperature ranges: Late Antique and Byzantine bricks—from calcite's decomposition temperature to ~850°C, Byzantine roof tiles—between 850 and 950°C. Two mortar types were used: lime mortar and mortar with ceramic fragments. The former was used during the Middle Ages, while the latter was used in both periods. Studies of mortar with ceramic fragments have established that it does not possess hydraulic properties, as the clay used exhibits pozzolanic activity within a very narrow temperature range (Keppert et al., 2024), which for this specific ceramic lies between 850 and 900°C. The results show continuity in the raw materials and construction techniques used, but also the addition of white mortar, typical of the Byzantine period.

Acknowledgements. This research was funded by the National Science Fund of Bulgaria under grant KP-06-N80/5 (B.K., B.D.). The authors gratefully acknowledge New Bulgarian University, the Department of Natural Sciences and the Geology laboratory – BF.

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Tokaj earth, a historical mineral medicine

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A natural clay variety called “Tokaj Earth” was mined for healing purposes on the Nagy Hill at Tokaj in the 16th to 18th centuries. Similar materials were widely applied since the ancient times, their name was *bolus* or *terra sigillata* (sealed earth), a variety from localities in Silesia was called *terra Silesiaca*. The Tokaj material was called “*terra medicinalis Tokayensis*”, i.e., Tokaj earth. The historical aspects were discussed in detail by Viczián (2017). Mineralogy was described by Viczián and Németh (2021).

For the present study, two historical samples preserved in mineralogical collections were taken. The first one was collected by József Szabó in 1863 from the Patkó Quarry, on the northern end of the town Tokaj, on the NE side of Nagy Hill. The sample is now preserved in the Museum of Sárospatak Reformed College. The other one comes from the Mineral Collection of Debrecen University and was collected by Péter Rózsa, 1980. The locality is Tarcál Quarry, on the W flanks of Nagy Hill. In both cases, the material fills fissures in fresh dacite rock. The samples are of light brown colour with some reddish shade, homogeneous, relatively hard with conchoidal fracture. They are porous, strongly adhering to the tongue.

XRD and thermal analysis of the samples were carried out in the Department of Mineralogy, Eötvös Loránd University, by Tibor Németh. XRD and thermal analyses show that the main minerals are disordered kaolinite (about 65-70 %), silica minerals (quartz, cristobalite, and amorphous, 15-20 %), and goethite (15 %). Kaolinite minerals were characterised by X-ray parameters like H_i : Hinckley Index, and $\Delta 001$: width of 001 basal reflection in $^\circ 2\theta$ units, and by thermal parameters like T_{corr} : corrected dehydroxilation temperature, T_d : difference of T_{corr} from standard, T_{ex} : temperature of exothermic reaction in $^\circ\text{C}$ (Földvári 2008).

Electron microscopic analysis of the samples was carried out in Pécs University, by Péter Szabó. SEM pictures show an aggregate of platelets of irregular, sometimes hexagonal-like shape. There are no tubes of laths. The grain size is in the range of 1 to 0.1 μm , in Tokaj, Patkó-bánya is much higher than at Tarcál. Chemical composition measured by Tibor Németh corresponds to the association kaolinite + silica mineral + iron oxide. Kaolinite of the Tarcál *bolus* sample is extremely disordered. In contrast, the kaolinite from the Tokaj, Patkós Quarry sample is transitional between the ordered, hydrothermal type and disordered weathered kaolinites.

Measured parameters were compared with parameters characterising various genetic groups of Upper Sarmatian kaolinite occurrences in the Tokaj Mts. and surrounding areas; however, all are different. The material of “Tokaj earth” may have been altered and transported to the present place by very low-temperature hydrothermal solutions.

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Session GS2

Climate Change

Convener:

Nikola Botoucharov

Late Glacial and Holocene climate dynamics of the Carpathian Mountain zone: tipping points and sedaDNA based species level vegetation responses

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Using alpine lake sediments, this talk synthesizes new pollen-based seasonal temperature reconstructions and high-alpine sedimentary ancient DNA evidence to examine Holocene temperature progression and the Mid-Holocene transition reshaping mountain vegetation at species-level resolution. Quantitative pollen-based reconstructions from five mid-altitude Carpathian sites show that Holocene climate evolution was strongly seasonal. Summer and winter temperatures both increased during the Early Holocene, but their trajectories diverged after the Middle Holocene. Summer temperatures reached a maximum at ~7.2 ka and declined gradually after ~6.1 ka, whereas winter temperatures continued to rise into the Late Holocene. This divergence indicates a progressive reduction in continentality across East-Central Europe during the last six millennia. The Mid-Holocene transition therefore marks a key climatic threshold, when decreasing summer warmth and changing seasonal moisture regimes began to reorganize vegetation across the Carpathian elevational belts.

The high-alpine sedaDNA record from Lake Bălea, situated at 2035 m in the Southern Carpathians, reveals how this regional climatic transition was translated into local, species-level ecosystem change. Plant metabarcoding identified 273 vascular plant taxa, 63 bryophyte taxa and 6 algae, with the great majority of inferred plant taxa resolved to species level. This taxonomic resolution made it possible to derive quantitative ecological indicators, including plant richness, elevational group composition, life-form spectra, grazing-indicator taxa and species-level ecological affinity to pH, humidity and light conditions. These indicators show that the Early to Mid-Holocene was characterised by productive alpine vegetation, extensive dwarf-shrub heaths, vascular cryptogams and the upslope signal of mesophilous woody taxa, consistent with warmer summers, enhanced chemical weathering and improved soil development. Around ~5600 cal yr BP, however, the onset of Neoglacial cooling triggered a major ecological turnover. Subalpine and thermophilous elements declined, dwarf-shrub and snowbed communities reorganized, nival taxa expanded, and sedaDNA-based plant richness decreased between ~5600 and 4650 cal yr BP. Redundancy analyses indicate that Early to Mid-Holocene plant composition was associated with calcium input, suggesting that warmer conditions and substrate development structured the high-alpine vegetation before the later shift toward precipitation- and disturbance-related controls. Overall, the Carpathian record shows that the Mid-Holocene transition was not simply a gradual cooling trend, but a tipping interval during which reduced summer warmth, altered seasonality and changing soil–hydrological conditions reorganized alpine plant communities, richness patterns and life-form structure. High alpine vegetation was shaped by seasonal alpine grazing since the Bronze Age that resulted in the development of alpine grassland with *Carex curvula* and the uphill and downhill movement of several grazing-adapted herbs. The talk also discusses phases of intensified alpine grazing many of which can be connected to migration events.

Acknowledgements. The research was supported by the NKFI Frontier Research Excellence Program (KKP-144209) led by Enikő K. Magyari and the National Multidisciplinary Laboratory for Climate Change (RRF-2.3.1-21-2022-00014) project.

Natural tritium variability and the solar cycle imprint: insights from ice caps, ice fields, and ice caves

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The 11-year solar activity cycle modulates the production rate of cosmogenic isotopes. Our previous research was among the first to demonstrate the link between the solar cycle and tritium – the radioactive isotope of hydrogen – in precipitation (Palcsu et al., 2018). Additionally, tritium ice core time series extending beyond the era of thermonuclear weapon testing confirmed that tritium is indeed influenced by solar activity (Palcsu et al., 2025). Moreover, analyses of low level tritium in ice help constrain the natural background level of tritium in precipitation, thereby providing a basis for validating isotope-enabled atmospheric general circulation models. The presentation will showcase examples of tritium time series from shallow ice cores recovered in Europe, Greenland, and Asia (Kyrgyzstan and Tibet) as well as from the Bortig ice cave, Romania.

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The Integrated Geodynamic Station: Field-Based Infrared Laboratory for Gas Monitoring in the Southeastern Carpathians (Covasna)

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Accurate quantification of diffuse geological gas emissions in non-volcanic areas is frequently overlooked in global carbon budgets (Gerlach, 2011). Furthermore, continuous monitoring of subsurface fluid migration is essential for advancing early leak-detection in underground CO₂ and H₂ storage facilities, as well as for identifying potential seismic precursors (Szakács, 2021). To address these climate, energy, and geohazard challenges, the TopoTransylvania community has initiated a multidisciplinary collaboration in the Southeastern Carpathians, centered on the Vrancea Seismogenic Zone. This highly active geodynamic region is characterized by frequent intermediate-depth earthquakes and significant natural gas emissions through mineral water springs and mofettas. The geochemical signatures of these fluid emissions confirm their non-volcanic origin, identifying them as surface expressions of deep, mantle-derived fluids released under lithospheric stress (Lange et al., 2023). Consequently, Covasna (Romania), known as the "city of a thousand mineral springs," serves as a key natural laboratory for exploring relationships between gas emanations and regional geodynamics.

At the core of this international collaboration is an innovative Integrated Geodynamic Station (IGS), established by the HUN-REN Institute of Earth Physics and Space Science at Covasna. Functioning as a field-based infrared laboratory, the IGS is currently equipped with a Fourier-Transform Infrared (FTIR) gas analyzing unit, a seismometer, and a meteorological station. The gas analyzing unit provides continuous monitoring of soil gas emanations (at 0.8 m depth) and atmospheric compositions with a temporal resolution of 5–10 minutes and ppm-level precision. The system utilizes a dual-cell pneumatic sampling approach: a short-path cell (SPC) for high concentrations and a long-path cell (LPC) for lower concentrations, both optimized for measuring infrared-active gases such as CO₂, CH₄, N₂O and other sulfur species in the spectral region from 4000 to 600 cm⁻¹.

By correlating high-precision gas flux data with seismic, meteorological and other geophysical observations provided by the National Institute of Earth Physics (NIEP, Romania), this research aims to establish a robust methodological framework to address the geohazard, environmental, and energy transition challenges.

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Reconstructing Holocene hydroclimate from peatland archives: a multi-proxy study from Romanian peatlands

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Peatlands represent highly sensitive terrestrial archives that preserve long-term records of hydroclimatic variability and ecosystem responses to environmental change. In this study, we reconstruct Holocene hydrological dynamics from five Romanian peatlands: Mlaca Tătarilor (S Transylvania), Tinovul Mohoş (CE Romania), Tăul fără Fund (N Transylvania), Iaz peatland (NW Romania) and Poiana Ştiol (N Romania), using quantitative depth-to-water-table (DWT) reconstructions derived from testate amoebae (TA) assemblages. To provide a broader environmental context, the DWT records were integrated with radiocarbon-based chronologies, lithological observations, peat physical properties inferred from loss-on-ignition (LOI), and pollen-based reconstructions of mean annual precipitation (P_{ann}) and mean annual temperature (T_{ann}).

Despite differences in local setting and peatland development trajectories, coherent patterns among the three records suggest a common hydroclimatic signal at regional scale.

Our results demonstrate the value of testate amoebae-based DWT reconstructions for identifying long-term hydroclimatic trends and highlight the importance of integrating biological and sedimentological proxies to improve understanding of peatland sensitivity to both natural climate variability and human impact throughout the Holocene.

The Danube loess: a high-resolution record of past millennial-scale climate dynamics in continental Europe

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High-resolution sedimentological, geochemical, and chronological investigations carried out on loess-paleosol sequences from the Danube region show distinct trends in data that correlate well with other Northern Hemisphere paleoclimate records covering the last glacial cycle. These features in loess data, most prominent in the magnetic susceptibility and grain-size data, are complemented by information from geochemical and isotopic proxies and provide important insights into the nature of the depositional environments during Greenland Interstadials (GI) and Stadials (GS).

To fully assess the paleoclimatic significance of loess proxies, results are further compared with regionally representative lake, speleothem, and marine stacks from the Black Sea, Mediterranean and the Northern Hemisphere. The comparison reveals consistent millennial-scale variability (e.g., fluctuations that track GI vs GS) archived within the proxy data that allow for the synchronization of records over the last glacial cycle. Such chronological synchronization (aided also by tephrochronology) of the loess records with other paleoclimate archives with high confidence on millennial timescales further allowed revealing some less pronounced but intriguing differences during Marine Isotope Stages 2 and 3. The results illustrate the value of a multiproxy multi-site approach in understanding sediment dynamics and variations in processes influencing/controlling loess-paleosol formation during rapid climate changes of MIS 3. Hence, loess-paleosol sequences so far widely underestimated are in many aspects directly comparable to well established paleoclimate archives and significantly improve the spatial resolution of Eurasian-wide paleoclimatic data.

Acknowledgements. This research is carried out and financed within the framework of the second Swiss Contribution MAPS, LOEs-CLIMBE project № IZ11Z0_230102.

Session GS3

Geoheritage, Geoeducation, and Geoparks

Conveners:

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Volcanic geoheritage as an engine for volcanic hazard-resilient society from Saudi perspective

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The volcanic geoheritage enhances resilience to volcanic hazards primarily by transforming volcanic landscapes into educational and participatory spaces for memory, learning, and governance. The strongest evidence indicates that geosites, outcrops, museums, trails, visitor centers, heritage stones, geocollections, and digital mapping tools help people understand eruption history, recognize hazards, explore evacuation options, and engage in meaningful local-level risk discussions. (McGuire and Fearnley, 2018; Németh *et al.*, 2021; Mafuko-Nyandwi *et al.*, 2024). Its most important roles are fourfold. First, it enhances hazard awareness and evacuation literacy through localized interpretation and education. Second, it builds community trust and preparedness by incorporating local knowledge, cultural memory, and participation into planning. Third, it facilitates risk-informed tourism and site management, if access, zoning, and warnings are actively overseen. Fourth, it contributes to recovery and adaptation since volcanic landscapes and livelihoods are often reinterpreted after eruptions, even when some heritage is lost. However, volcanic geoheritage does not automatically guarantee protection. While the sites that draw attention, recognition, investment, and visitors can boost awareness, they may also become more vulnerable if not managed properly through land-use controls, visitor management, emergency plans, and hazard mapping. Thus, volcanic geoheritage should be seen primarily as a social and governance resource to enhance resilience, rather than a replacement for formal risk mitigation strategies. Saudi Arabia hosts one of the world's largest interconnected distributed volcanic fields along the western edge of the Arabian Shield, located slightly off the axis of the Red Sea Rift (Németh, 2026). Since the Pleistocene, approximately 5,000 vents have formed in this area, with eruptions roughly every few centuries to millennia. This slow recurrence rate is too infrequent for human society to remember as a common natural event, making volcanic hazards less salient. The recent Saudi Quaternary Volcano Model, which identified the main hazard types linked to monogenetic volcanism in the western Arabian Peninsula, found that although volcanic hazard is notable, internal and external factors are impactful but manageable. In this context, volcanic geoheritage offers an excellent way to sustain collective awareness and preparedness, serving as an effective tool to develop a society resilient to volcanic hazards.

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Geoconservation and Institutional Development

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Geoconservation has matured into an integrative geoscience bridging scientific knowledge, management, and societal engagement, with geo-education functioning not merely as an outreach tool but as a foundational pillar of geoconservation itself. Together, they form a synergistic framework encompassing geodiversity, geological heritage, geotourism, and UNESCO Global Geoparks (UGGps). However, the institutional conditions required to sustain integrated geoconservation and geo-education capacity within academic settings remain underexplored. This paper analyzes the 25-year trajectory of geoconservation and geo-education activities developed within the Faculty of Geology and Geophysics, University of Bucharest, to extract a replicable institutional model.

Our methodology employs a longitudinal synthesis of institutional activities undertaken since 2000, analyzing over 100 national and international projects, two UNESCO Global Geoparks (Hațeg Country, 2005; Buzău Land, 2022), and a comprehensive portfolio of educational programmes — including the Master's in Applied Geobiology (2009), the European Virtual Seminar (2004–2023), and the CIVIS Civic Engagement course — to identify the structural pillars enabling sustained impact.

The results reveal five interconnected pillars: (1) continuous academic research and student training, embedding geo-education within geoconservation science; (2) active geopark management, where geoparks serve as living laboratories for geo-education; (3) international networking, exemplified by the ProGEO active involvement; (4) multi-level educational outreach across all audiences — pre-university curricula (Erasmus+ EMME), teacher training (Măgurele Summer School), student engagement (Research Night, Science Summer School, scientific caravans STEAM), and artistic interpretation (Creative Europe — The Big Green Project); and (5) strategic project acquisition across Erasmus+, Interreg, Horizon Europe, Creative Europe, and UNESCO frameworks. These pillars have delivered Romania's first two UGGps, initiated new geopark projects — Cimmerian Dobrogea and Gutâi–Maramureș, and earned national and international awards.

We conclude that the University of Bucharest, Faculty of Geology and Geophysics and their partners have developed a transferable institutional model demonstrating that continuous academic commitment, strategic funding, and international partnerships can integrate geoconservation and geo-education into a durable engine for research, teaching, and sustainable territorial development, offering a blueprint for universities worldwide.

The Romanian Model for UNESCO Global Geoparks: Operational Elements for Bridging Geological Heritage and Socio-Economic Resilience

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The UNESCO Global Geopark (UGGp) concept has evolved over the past 35 years from a niche scientific initiative into a mainstream instrument for sustainable territorial development. However, the application of this international framework often conflicts with heterogeneous local socio-economic conditions. This paper analyzes the 25-year trajectory of geopark development in Romania to extract a replicable operational model adapted to national and international contexts.

Our methodology employs a longitudinal case-study analysis of two Romanian UGGps — Hațeg Country (recognized 2005) and Buzău Land (recognized 2022) — both developed through multi-stakeholder partnerships coordinated by the University of Bucharest, which remains the only Romanian academic institution actively managing a UNESCO Global Geopark. We synthesized project-management approaches across these territories, focusing on the balance between international certification requirements and local capacity-building.

The results reveal that successful implementation in the Romanian context relies on the systematic application of five mandatory operational elements: (1) optimum territory delineation, (2) multi-level partnerships, (3) adaptive governance, (4) active networking, and (5) integrated interpretation of the research results for education and tourism. Crucially, the synergistic application of these five elements serves a dual final purpose: first, it drives tangible socio-economic development by stimulating local entrepreneurship, creating geo-tourism products, and attracting external funding; second, it consolidates a distinct international geological brand that elevates the territory's visibility on the global stage. The implementation of these pillars proved essential for advancing geoeducation, developing local geo-products, and securing the international recognition that defines a sustainable UNESCO designation. The absence of any single element correlates with project stagnation, whereas their simultaneous application facilitated 17-year (Hațeg) and 15-year (Buzău) trajectories from conception to UNESCO recognition, attracting significant EU and national co-funding.

We conclude that the Romanian model offers a pragmatic, replicable framework for emerging geopark initiatives, including the two new projects such as Cimmerian Dobrogea and Gutâi–Maramureș. By explicitly linking operational management to both local economic growth and global branding, this model demonstrates that geological heritage is not merely a scientific asset, but a strategic catalyst for integrated rural development. This paper provides a strategic blueprint for researchers and policymakers aiming to translate global heritage designations into measurable local outcomes and geosciences promotion.

Total Tourism Value of Geosites in Romania: A County-Level Spatial and Socio-Economic Analysis

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When integrated into territorial development strategies, geosites represent important geological heritage resources with potential to support regional economic development through geotourism.

This study, conducted within the framework of the national project PN 23-39-03-01, is based on a Romanian geosite database compiled using the official list of protected areas provided by the National Agency for Environmental Protection (ANPM). The database includes information on location, administrative unit, protection status, geological age, and content type. Each geosite is quantitatively assessed using the methodology of Brilha (2016), considering scientific, educational, and tourism values. The main parameter analyzed is the Total Tourism Value (TTV), defined as the sum of Tourism Value scores assigned to all geosites within each county. This indicator provides an aggregated measure of geotourism potential at regional scale. TTV values were correlated with socio-economic indicators for 2022, including population size, population density, and average household income, based on data from the National Institute of Statistics.

The analysis reveals significant disparities in geotourism potential among Romanian counties. The highest concentrations of geosites and TTV values are recorded in Alba County (75 geosites; 20,050 TTV points), followed by Bihor (46 geosites; 12,770 points) and Caraș-Severin (41 geosites; 10,640 points). At the opposite end of the spectrum, the lowest values are observed in Timiș (1 geosite; 195 points), Botoșani (2 geosites; 370 points), and Vaslui (2 geosites; 410 points). Other counties with notable geotourism potential include Argeș, Gorj, Hunedoara, and Vâlcea.

In terms of geological age, Romanian geosites are predominantly associated with Jurassic–Cretaceous formations (46%), followed by Miocene units (16%). A significant proportion of geosites in Alba and Bihor counties are located within the Apuseni Mountains and are related to karst geomorphology developed on carbonate rocks of Jurassic–Cretaceous age. These include gorges, cliffs, dolines, caves, avens, karst plateaus, and springs. Many of these geosites are situated within protected areas, particularly the Apuseni Natural Park, benefiting from formal protection and promotion frameworks.

Regarding socio-economic parameters, counties such as Alba and Bihor show values close to national averages. For example, in Alba County, 24 geosites are located in areas characterized by average household income, while 49 are in lower-income areas. In Bihor County, 11 geosites correspond to average-income areas and 34 to lower-income areas. In contrast, Timiș County, despite higher socio-economic indicators, shows the lowest geotourism potential among all analyzed counties.

Correlation analysis suggests that the relationship between geological heritage and economic development is not linear, but strongly influenced by infrastructure and broader socio-economic conditions, including accessibility and regional development levels. While geosites represent important assets for geotourism, their effective exploitation depends on the capacity of regions to integrate them into development and tourism strategies. Overall, the results highlight strong spatial disparities in geotourism potential across Romania and emphasize the importance of integrating geological heritage into regional planning and sustainable tourism development.

Acknowledgements. This work is supported by the Romanian Ministry of Research, Innovation, and Digitization through the Core Program (project PN 23 39 03 01).

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Multimodal geoeducation in the Global UNESCO Vikos-Aoos Geopark Summer School series (Greece)

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Geoeducation is a foundational pillar of the UNESCO Global Geoparks initiative, helping connect geoscientific knowledge with society and promoting sustainable development through education, research, and geoheritage. It also builds observational and collaborative skills and a deeper understanding of how geological environments, biodiversity, culture, and local communities interact. Within this framework, the Vikos–Aoos UNESCO Global Geopark has run a series of annual Summer Schools since 2022, in partnership with the Department of Geology at the Aristotle University of Thessaloniki. These Summer Schools are being organized in Konitsa (Ioannina, NE Greece) and have grown into an established institution of applied geoeducation.

This paper reviews the first five editions of the program (2022–2026), examining how its educational focus evolved, participation levels, and evaluation outcomes. The thematic scope broadened progressively: starting with the Geopark’s geology and geological features, then expanding to geohazards, natural disasters, and climate change, then to geodiversity and modern field research methods, and finally to the links between geology, cultural heritage, and the human-shaped landscape.

The teaching model rests on three complementary components: theoretical lectures, outdoor educational field trips at selected geosites, and group projects with public presentations of results. This approach strengthens experiential learning and connects theoretical knowledge with field observation. Over the five years, 170 young scientists participated, mostly graduate students and final-year undergraduates, selected from 215 applications submitted. The five editions also involved 47 instructors from universities, research institutions, and management bodies. The program included a total of 45 thematic lectures, 15 field exercises, 27 group presentations, and 7 parallel educational activities, reflecting the program’s continuous development.

Analysis of evaluation questionnaires indicates high levels of participant satisfaction. Field exercises were identified as the most valuable part of the learning experience, and the scientific quality of instructors, interdisciplinary collaboration, and teamwork also received particularly positive ratings. Suggestions for improvement mainly centered on increasing time spent in the field, confirming that the program’s hands-on, experiential nature is its main comparative strength.

The experience of the first five editions suggests that the Vikos–Aoos Geopark Summer Schools represent a successful geoeducation model; one that deepens understanding of geoheritage, fosters interdisciplinary learning, and builds meaningful ties between universities, management bodies, and local communities. During 2026, the program entered the next stage by being incorporated into the activities of the Aristotle University of Thessaloniki’s Center for Continuing Education and Lifelong Learning; this is expected to strengthen its institutional standing further.

Acknowledgements. The authors would like to thank the Municipality of Konitsa for its continuing support throughout the Summer School series.

Ruşchiţa Marble: Integrating Heritage Values and Engineering Properties

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Ruşchiţa marble is one of Romania's most renowned ornamental stones, distinguished by its long exploitation history, extensive architectural use, and strong cultural significance. Official quarrying began in 1884 and has continued, with interruptions and technological changes, for more than 140 years. The marble extracted from the Ruşchiţa deposit in the Poiana Ruscă Mountains has been widely used in public and private buildings, monuments, decorative architecture, and restoration projects both in Romania and abroad. Its historical significance, aesthetic qualities, and architectural legacy have established Ruşchiţa marble as one of Romania's most representative heritage stones, recognized for its national and international geoheritage value.

From a geological perspective, the Ruşchiţa deposit belongs to the metamorphic formations of the Poiana Ruscă Massif, where crystalline limestones were transformed into marble under regional metamorphic conditions. The deposit includes several ornamental varieties, particularly white, grey, and pink marbles, distinguished by their colour, texture, and mineralogical composition. Beyond its aesthetic appeal, the long-term success of Ruşchiţa marble as a building and decorative stone is closely related to its physical and mechanical characteristics.

This contribution integrates published information with recent engineering investigations carried out in the active quarry. Historical data are complemented by new measurements obtained from drill-core samples collected in the Top Nord sector of the Ruşchiţa Old Quarry. The results indicate a volumetric density of approximately 2.70–2.71 g/cm³, uniaxial compressive strength values ranging between 51 and 68 MPa, tensile strength values of 5.57–6.62 MPa, and shear strength values of 11.67–14.31 MPa. These properties confirm the good mechanical behaviour of the rock and help explain its durability and suitability for architectural applications, while also highlighting performance limitations and informing conservation strategies for environments subjected to intensive wear and repeated freeze–thaw cycles.

By integrating heritage significance with geological and engineering characteristics, the study provides a holistic perspective on Ruşchiţa marble as both a valuable construction stone and a geoheritage resource. The combination of historical importance, architectural legacy, and favourable material properties demonstrates how scientific, cultural, and engineering values converge to support the conservation, interpretation, and promotion of this exceptional natural stone. The Ruşchiţa case illustrates the importance of integrating historical, geological, cultural, and engineering evidence in assessing and promoting stone heritage within the broader geoheritage framework.

Acknowledgements. This research work was supported by Marmosim S.A. in Research Grant 1336/2020 and by the Romanian Ministry of Research through the Core Program (project PN 23 39 03 01).

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Mineral heritage of Maramureş (NW Romania)

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Of the 6,220 mineral species recognized worldwide by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association, published in May 2026, approximately 1,000 have been described in the geological formations of Romania.

The paper aims to carry out a statistical evaluation of the minerals identified in the geological formations of northwestern Romania (Maramureş County). The minerals will be categorized according to the genetic processes and the geological bodies to which they belong, with the intention of extracting and highlighting the mineral species that are of particular importance and that may acquire heritage status.

Thus, we propose the separation of the following categories: (1) petrogenic minerals — which are components of rocks and which will be divided into igneous, metamorphic and sedimentary; (2) metallogenic minerals — which are found in mineral associations corresponding to mineral deposits and will be divided into hydrothermal and metamorphic.

Minerals from the category of petrogenic ones are much smaller in number and, in certain situations, mineral species are not described as individual mineral species, but only as groups or series. Metallogenic minerals and especially those forming hydrothermal, polymetallic and gold-silver deposits, associated with Neogene volcanism, are much more numerous.

Some of the minerals described and especially those of hydrothermal genesis present special characteristics, such as: they represent mineralogical priorities at a global level, are very rare mineral species or exhibit distinctive characteristics in some of their properties. The 10 minerals described for the first time in the world, in the so-called Baia Mare mining area, are (Denuţ et al., 2015): andorite, semseyite, dietrichite, szmikite, felsöbányt and klebersbergite — at Baia Sprie, fizélyite — at Herja, fülöppit — at Dealul Crucii, rhodochrosite — at Cavnic and baiamareite — at Săsar. Among the minerals with particular properties — the so-called mine flowers — we mention (Denuţ & Sîngeorzan, 2016): cubic pyrite crystals from Țibleş, dark green prismatic vivianite from Ilba, purple amethyst from Valea Roşie, spheroidal calcite concretions, semseyite rosettes and acicular-flattened stibine crystals from Herja, red tabular barite and acicular stibine crystals from Baia Sprie, the various morphological forms of gold, transparent prismatic-pyramidal quartz crystals, decametric gypsum crystals, barite of various colors, cubic fluorite crystals, pink rhombohedral rhodochrosite crystals and red prismatic realgar crystals from Cavnic, prismatic stibine from Băiut or calcite in a variety of shapes and colors originating from various deposits.

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The Gutâi–Maramureş UNESCO Geopark Project (NW Romania): a framework for implementing geoeducational projects

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The Gutâi–Maramureş Geopark Project is an initiative dedicated to protecting, promoting, and interpreting the geological, natural, mining and cultural heritage of the Maramureş County (north-western Romania), through education, conservation, and sustainable development. After its first year of implementation, the project has established a strong foundation for geoeducation and public engagement.

Geoeducation is one of the project’s main priorities, aiming to increase public awareness of geodiversity and geological heritage through interactive learning experiences designed for children, students, teachers, and the general public. During the first year, the Maramureş County Museum of Mineralogy “Victor Gorduza” in Baia Mare, together with its partners, organized a wide range of educational activities that combined museum learning, school outreach, and outdoor experiences.

Museum-based educational workshops were regularly organized as part of public outreach activities and local cultural events, offering visitors the opportunity to examine mineral samples under stereomicroscopes and explore crystal structures, textures, and other microscopic features that are not visible without magnification. These interactive activities encouraged scientific curiosity while introducing participants to the diversity and importance of mineral resources.

Another component of the geoeducational programme consisted of outreach initiatives carried out beyond the museum setting, in schools and outdoor environments, where museum educators engaged directly with local communities. Specialists from the Museum used portable teaching collections of minerals, allowing participants to examine and handle authentic specimens. These hands-on experiences transformed theoretical geological concepts into engaging educational experiences.

Outdoor learning represents a key element of the Gutâi–Maramureş Geopark Project. A central component of this programme is the five-day Summer School “Geodiversitate în Maramureş” (“Geodiversity in Maramureş”), an annual field-based educational initiative that brings together students interested in geology, nature, and environmental protection. Through field excursions, practical activities, and direct observation at representative geosites, participants explore geological processes and the relationships between geodiversity, biodiversity, landscape evolution, and local communities. The camp also includes informal educational activities that encourage teamwork and environmental awareness.

Beyond the activities dedicated to students, the project actively engages the wider community through guided geological hikes organized on special occasions, like International Geodiversity Day, World Environment Day and other public events. These excursions to sites such as Creasta Cocosului (Rooster’s Crest) in Gutâi volcano and top of the Igriş volcano provide participants with the opportunity to discover volcanic landscapes, unique geological formations, local biodiversity, and the close relationship between geological heritage and traditional cultural landscapes.

The first year of the Gutâi–Maramureş Geopark Project demonstrates that integrated geoeducation, combining formal, non-formal, and outdoor learning, enhances public understanding of Earth sciences and geoconservation while strengthening community engagement through accessible experiences linked to geological heritage.

Deep-Earth Geoheritage: assessing xenoliths and fluid inclusions as lithospheric archives

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Deeply originated geological materials provide rare and direct evidence of processes operating in otherwise inaccessible parts of the Earth. This contribution introduces the concept of Deep-Earth Geoheritage, with particular emphasis on mantle- and lower-crustal xenoliths and their fluid inclusions as natural archives of lithospheric structure, composition, evolution and volatile cycling. Although geoheritage frameworks commonly focus on surface or near-surface geological features, xenolith-bearing volcanic rocks preserve time-constrained snapshots of the deep lithosphere, transported to the surface by rapidly ascending magmas. Their mineral assemblages, deformation fabrics, geochemical signatures and enclosed fluid and melt inclusions record processes such as metasomatism, melt–rock interaction, lithospheric modification and deep volatile transfer.

We argue that xenoliths and their associated fluid inclusions should be regarded not only as scientific samples, but also as vulnerable geoheritage objects. Their rarity, restricted occurrence, non-renewability and scientific irreplaceability make them highly significant elements of geodiversity. Many xenolith-bearing outcrops are small, fragile, exposed to erosion, quarrying or uncontrolled sampling, and are often insufficiently recognized in geosite inventories and conservation strategies.

To support the recognition and comparison of such sites, we propose a semi-quantitative evaluation framework, the Deep-Earth Geoheritage Score (DEGS). The method adapts established geoheritage criteria to deep-origin geological archives and evaluates xenolith-bearing localities using criteria such as rarity, representativeness, scientific significance, temporal value, integrity, fluid-inclusion archive value, non-renewability, vulnerability, educational potential and conservation suitability. The approach provides a transparent and reproducible basis for prioritizing xenolith-bearing geosites and integrating them into geoheritage assessment, geopark interpretation and conservation planning.

The framework is being tested through a case study from the Bakony–Balaton Highland Volcanic Field in western Hungary, within the UNESCO Bakony–Balaton Global Geopark. This volcanic field is one of the best-studied xenolith-bearing areas of the Carpathian–Pannonian region and contains several mantle- and lower-crustal xenolith localities suitable for DEGS-based evaluation.

By linking deep Earth science with geoheritage and geoconservation, this study provides a conceptual and methodological foundation for recognizing xenolith-bearing volcanic sites as Deep-Earth Geoheritage and for communicating otherwise hidden processes of the Earth's interior to both scientific and public audiences.

Acknowledgements. This work was supported by the MTA FI FluidsByDepth Lendület (Momentum) project, provided by the Hungarian Academy of Sciences (grant no. LP2022-2/2022; PI: Márta Berkesi).

Geoheritage in the new Gutâi–Maramureş UNESCO Geopark project, East Carpathians (NW Romania)

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A new UNESCO Geopark project is developing in the Gutâi Volcanic Zone (GVZ), NW Romania, in the framework of a partnership between local authorities, Earth Science institutions and NGOs involved in sustainable development and tourism promotion. The GVZ belongs to the East Carpathian Neogene-Quaternary volcanic range, built up during the Cenozoic geotectonic evolution of the Carpathian-Pannonian Region (CPR). It is one of the most complex volcanic areas in the CPR, where Miocene volcanic activity took place during a long time-interval, between 15.4–7.0 Ma. The region is well known for its richness in precious and polymetallic hydrothermal ore deposits mined along centuries-long intervals. In the area of the future Geopark there are numerous geological sites mostly located in areas dominated by volcanic rocks. The volcanic sites — volcanic structures, shallow intrusive bodies, rhyolite ignimbrites, lava cooling textures, volcanoclastic deposits, erosional volcanic landforms, together with other site types related to minerals, fossils, stratigraphy and tectonics — are all part of the rich geological heritage of the future Geopark. Some of them have official protection status at the national level. They are of the petrological, mineralogical, stratigraphic, paleontological, structural, geomorphological and hydrogeological types according to Brilha (2016).

Twenty-five sites were quantitatively assessed using Brilha's methodology. All the sites have high Scientific Values (SV = 300–370 out of 400) certifying that they can be classified as geosites. Several volcanic geosites are very rare or unique in the East Carpathians volcanic range, such as the Ilba “Stone Rosette”, the “Lespezi” andesite columns, “Rooster's Crest”, “Tătaru Gorges” or in the whole CPR (e.g., the “White Tulipe” and “Vlaicu's Church” composite dykes). The Mine Hill in Baia Sprie town is a unique geosite, hosting one of the most representative hydrothermal ore deposits in Europe, with six minerals first described in the world, representing Romania's proposal for The Third 100 IUGS Geological Heritage Sites. Among the many fossil-bearing sites of the area, the most representative is the Chiuzbaia paleontological reserve with official protection status (IV IUCN). It is a fossil flora type locality, where some of its palaeobotanical species were described for the first time in the world.

One of the most significant geological patrimonial values is represented by the mineralogical heritage. More than 150 mineral species (the vast majority related to the hydrothermal ore deposits) were described in the area of the future Geopark, ten of these for the first time in the world. The Mineralogical Museum in Baia Mare city hosts all these minerals within its amazing collection representing an important ex-situ type geoheritage site. The high values of the Potential Educational Use (PEU) and Potential Touristic Use (PTU) parameters of the majority of the geosites (> 250) besides high Scientific Values justifies their inclusion in geoeducational trails and geotouristic routes as well as their promotion in accordance with the geoeducation and geotourism concepts at local, national and international levels.

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Playful learning at the National Geological Museum (Romania)

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This contribution explores alternative approaches to teaching geological science adapted for school-age students. At the National Geological Museum (a department of the Geological Institute of Romania), the museum's educators aim to make geology, a vast and highly technical field, more accessible and engaging. Traditional teaching methods (explanation and demonstration) are combined with interactive activities (experiments and crafts). Here we present a selection of playful teaching activities through examples from lessons and special guided tours.

Each lesson aligned with the school curriculum includes at least one experiment or an opportunity for children to learn through play. When presenting soil types, we use shovels to dig in the museum courtyard. We observe the soil layers and the organisms they contain, and we conduct simple geochemical tests, such as measuring pH. The children complete an “Earth Detective” worksheet and, at the end, identify the soil type they have examined. We have also adapted this activity for bad weather by bringing a transparent container with intact soil layers and their contents into the educational workshop.

We also run programmes for children outside school groups. For example, “GeoAltfel” (GeoDifferent) includes a Minecraft-based lesson in which children explore in-game materials by handling real samples, examining them under a microscope, and discussing why some materials cannot exist. Sometimes, when we learn about a sustainable way of reusing the plastic, we use plastic lids to build dinosaurs or improvise a table-football game. Children enjoy handling stones, feeling their textures, and comparing their weights; whenever possible, we incorporate teaching specimens into our explanations.

The playful learning activities are engaging and may be remembered better than conventional explanations. Active participation encourages attention and learning by doing. Children have different learning needs, and using a variety of teaching methods increases the chances that each one will learn something. These concepts are not new but their implementation at the National Geological Museum is adapted to meet the needs of the target groups and available resources. Understanding why dinosaurs went extinct requires a lot of other knowledge (such as fossilization, the evolution of species, or the effects of a meteorite impact) that can be explained in a simple way using accessible examples: recent bones altered by heat or bacteria, and a stone impacting layers made of flour and cocoa.

Acknowledgements. This work contributes to project ProGeo-RO - PN 23-39-03-01— Contract no. 34N/2023, funded by the Romanian Ministry of Education and Research.

The Cimmerian Dobrogea Geopark Project, Romania – 5 years of development towards a UNESCO Global Geopark

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The area of the Cimmerian Dobrogea Geopark has a rich geodiversity, reflecting its Hercynian roots, Cimmerian history, and Late Cretaceous opening of the West Black Sea Basin. The biostratigraphy of the Mesozoic successions is based on a rich macro- and microfauna. Triassic deposits are dated by ammonoids, bivalves, and microfossil assemblages of foraminifera, conodonts, and ostracods. The Jurassic turbidites, locally rich in trace fossils, contain ammonites and bivalves. The Late Cretaceous sandstones and limestones are dated by large inoceramid bivalves, ammonites, and microfossil assemblages rich in foraminifera and nannoplankton. Although the Paleozoic fauna is scarce, the Lower Devonian brachiopod-rich locality at Bujorul Bulgăresc is protected as a nature reserve.

The most important geosites are found in the Agighiol Hills Natura 2000 site, and in the Casimcea nature reserve. The Deșli Caira site in the Agighiol Hills is one of three international GSSP candidate sections for the base of the Anisian (Olenekian-Anisian boundary). The international workshop in May 2026, organized jointly by the Universities of Bucharest and Milan and the Subcommittee on Triassic Stratigraphy, concluded in its minutes that the Romanian proposal is excellent, given its rich ammonoid fauna and continuous succession of limestones. Agighiol geological reserve in the same Natura 2000 site is a rich fossil site for Lower to Upper Triassic ammonoids, with both adult and juvenile individuals enabling studies of ontogeny and species evolution. In the Casimcea reserve (the Moesian Platform part of the Geopark), two outcrops with Ediacaran fauna were identified in Late Neoproterozoic turbidites, containing species *Aspidella* and *Palaeopascichnus*, known in famous localities with Ediacaran fauna, like Charnwood Forest (England) and respectively Mistaken Point (Newfoundland, Canada).

The Geopark project is initiated by the University of Bucharest, NRD GeoEcoMar, Tulcea County EPA and two NGOs. A small team of volunteers from these institutions is working on inventories of natural and cultural heritage, on defining the territory and developing its infrastructure. An information point was created in 2024, followed by two thematic trails (*Treasures of Agighiol* and *Casimcea, a petrified garden*). An ongoing project, *The Consulate of Mount Consul*, is a well-developed educational and community initiative linked to the centennial of Mount Consul Nature Reserve and the development of the Cimmerian Dobrogea Geopark project, which represents a strong cooperation between schools, local communities, conservation actors, and geopark development partners. This project will continue next year, expanding the partnership to mark the centenary of Romania's first nature reserve. Another project, scheduled to start in autumn 2026, involves a new thematic trail — “*Mahomencea Valley: Geology and Hidden Archaeology*” — and an information kiosk for the four nature reserves in Casimcea. All these projects involve workshops, educational activities and summer camps with local schools, many organized in the European Geoparks Week or in the schools' Green Week. The Fossil Festival is in its third edition in 2026, as is Researchers' Night. In 2026, the Geopark organized the International Volcano Day for the first time.

Our main short-term goal is forming a local management team and ensuring its functioning for the next 5 years, essential requirements for submitting the application for the UNESCO status.

Acknowledgements. Financial support from Core Project PN 23 30 04 01 of NRD GeoEcoMar is gratefully acknowledged.

From Geoheritage Values, Through Geodiversity Assessment to Geotourism Development: A Conceptual Approach

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Geoheritage, geodiversity, and geotourism represent three closely related but often independently developed research domains within geosciences and heritage studies. Despite their conceptual affinity, the relationships among these domains remain insufficiently articulated, resulting in a fragmented understanding of how geological values are identified, how they are embedded within broader landscape systems, and how they are translated into sustainable geotourism development. Based on previous work (Štrba et al., 2023), which identified limitations in geoheritage assessment approaches in relation to geotourism applications, this paper addresses the need for a more integrated conceptual understanding by proposing a framework that links geoheritage values, geodiversity, and geotourism development into a unified interpretative structure.

Within the proposed framework, geoheritage is defined as the value-based dimension of geodiversity, encompassing geological features and phenomena of scientific, educational, aesthetic, cultural, and functional significance. It represents the selective recognition of elements considered meaningful within a broader abiotic environment. Geodiversity is conceptualised as the overarching diversity of abiotic elements and processes within the landscape, providing both the contextual framework in which geoheritage acquires meaning and its operational expression through established assessment approaches. In this sense, geodiversity functions as a bridging concept that connects individual geoheritage values with the wider spatial and relational structure of the landscape.

Geotourism constitutes the application-oriented dimension of this relationship, translating integrated geoheritage and geodiversity knowledge into interpretation, educational activities, visitor experience design, and sustainable regional development strategies. Rather than treating geosites as isolated attractions, the framework emphasises that geotourism potential emerges from the interaction between significant geological features and the structure, diversity, and interpretative capacity of the surrounding landscape. This interaction enables the development of coherent narratives, supports visitor engagement, and strengthens awareness of geological heritage within broader environmental systems.

By explicitly connecting value-based (geoheritage), contextual-structural (geodiversity), and application-oriented (geotourism) perspectives, the paper contributes to a more holistic conceptual understanding of geological heritage systems. The framework extends previous findings on geoheritage–tourism linkages as indicated by Štrba et al. (2023) and integrates advances in geodiversity conceptualisation and assessment. It provides a theoretical basis for more coherent future research and supports the development of integrated approaches to the sustainable management, interpretation, and use of geological heritage in geotourism contexts.

Acknowledgements. This work was supported by the Slovak Research and Development Agency under the project no. APVV-24-0554.

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Historical mining heritage as a georesource in the Tokaj Mountains (NE Hungary)

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The Tokaj Mountains in NE Hungary preserve a diverse volcanic geoheritage that significantly influenced regional development for centuries. The geological framework is defined by Miocene silicic and intermediate volcanism (13.2–9.6 Ma), producing extensive effusive and pyroclastic sequences, and hydrothermal alteration. The southern extent forms the Tokaj Wine Region Historic Cultural Landscape, inscribed as a UNESCO World Heritage site (UNESCO TWR) in 2002. Historical quarries represent secondary geodiversity and anthropogenic geoheritage, offering significant scientific, cultural, and geotourism value (Ésik, 2021; Szepesi et al., 2020, 2024).

Based on historic cadastres and geological mapping, recent comprehensive field surveys (Szepesi et al., 2020, 2024; Ésik, 2021) identified 101 historical mining objects: 56 in the North Zemplén area and 45 within the UNESCO TWR.

Over 40 historic open-pit quarries provided rhyolitic tuff for local masonry, ornamental carving, and subterranean wine cellars. Intense hydrothermal silicification supported the production of high-quality millstones, while the medieval area of Telkibánya exploited epithermal low-sulphidation gold-silver mineralization. Most historical quarries are now inactive. Current operations extract andesite and dacite (e.g., Colas Északkő), perlite at Pálháza, and rhyolite tuff in the Mád-Bodrogkeresztúr-Rátka area. Evaluations classify abandoned quarries from very attractive (e.g., Old Millstone quarry – Megyer Hill) to unattractive, based on vertical differentiation, preservation state, and natural succession (Szepesi et al., 2024).

Despite their value, these sites face anthropogenic and natural vulnerabilities. They lack specific administrative protection, organized management, and public awareness. Furthermore, uncontrolled mineral collecting (e.g., at Telkibánya) severely degrades primary mineralogical elements and secondary mining landforms (Szepesi et al., 2020).

Integrating these objects into geo-education initiatives provides a framework for protecting vulnerable georesources. Safeguarding their heritage requires quarry industry partnerships to rescue materials and prioritize geodiversity during site restoration. Open-managed collecting strategies and public outreach will secure this anthropogenic geoheritage for future generations.

Acknowledgements. This research was supported by the European Union and the State of Hungary, financed by the European Regional Development Fund in the project GINOP-2.3.2-15-2016-00009 ‘ICER’. This work is also supported by the MTA–HUN-REN CSFK Lendület “Momentum” Pannonian Volcano Research Group (LP2024-9).

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From Geological Research to Territorial Development: Interpretation as the Link between Science and Society in the Hațeg Country UNESCO Global Geopark

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UNESCO Global Geoparks demonstrate how geological heritage can become a driver of sustainable territorial development when scientific knowledge is translated into meaningful experiences for local communities and visitors. This paper analyses the evolution of the Hațeg Country UNESCO Global Geopark during its 2022–2026 revalidation cycle, focusing on the relationship between geological research, heritage interpretation and territorial development.

During the four-year period, scientific research substantially expanded the knowledge of the geopark's geological heritage through the description of four new dinosaur species, updated geological mapping, revised stratigraphic interpretations, volcanological studies and the reassessment of twenty geosites. These scientific advances provided the foundation for new conservation priorities, visitor experiences and educational programmes.

Rather than communicating geology as isolated scientific information, the geopark employed an integrated interpretation framework that connects the “Time of Earth” with the “Time of Humans” through the concept “Journey through Ages”. New thematic trails, artistic interpretation projects, community storytelling, comics-based interpretation and climate change education translated complex geological research into accessible narratives relevant to local identity and contemporary societal challenges. This approach also strengthened partnerships with schools, municipalities, researchers, artists and tourism stakeholders.

The results demonstrate that interpretation functions as an effective knowledge-transfer mechanism, transforming scientific research into educational opportunities, sustainable tourism products and community participation. The experience of the Hațeg Country UNESCO Global Geopark suggests that geological interpretation should be regarded not only as a communication tool but also as a strategic instrument for territorial development, capable of connecting scientific excellence with local development objectives and the Sustainable Development Goals.

Session GS4

Geophysics and Seismology

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Receiver Function Imaging Reveals Pyrenean-Style Crustal Wedging and Continental Underthrusting in the Western Carpathians

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The Western Carpathians preserve the record of closure of the Alpine Tethys Ocean and subsequent collision between the northern European passive margin and the Adria-derived Alps–Carpathians–Pannonian (AlCaPa) tectonic unit. Despite decades of geological and geophysical investigations, the deep lithospheric architecture of the Europe–AlCaPa boundary remains poorly constrained. Existing tectonic models commonly invoke complex paleogeographic scenarios involving multiple oceanic basins and the presence of a buried microcontinental fragment represented by the Czorsztyn Ridge. However, direct geophysical evidence supporting these interpretations has remained limited.

Here we present new lithospheric-scale images derived from joint inversion of Receiver Functions (RFs), Rayleigh wave dispersion curves and P-wave polarisation and Common Conversion Point (CCP) migration along a dense north–south passive seismic transect crossing the Western Carpathians. The dataset comprises 27 broadband seismic stations, including 18 stations deployed specifically for this project as part of a three-year passive seismic experiment. Receiver Functions were calculated from teleseismic earthquake waveforms. The station-wise joint inversion yielded a 2D velocity model of the crust and uppermost mantle to a depth of 75 km. This model was then used to migrate the RFs to produce structural CCP images of the subsurface. The resulting models provide new constraints on crustal and upper-mantle discontinuities beneath the Europe–AlCaPa collision zone.

The structural sections image the Moho at depths of approximately 30–35 km and reveal two major crustal offsets beneath the Pieniny Klippen Belt and the eastern extension of the Hurbanovo-Diósjenő Fault. Integration of all CCP images into a geological interpretation indicates a previously unrecognized double-wedge architecture in which the European upper and lower crust are independently underthrust beneath their AlCaPa counterparts. The lower-crustal Europe–AlCaPa boundary evolves upward into a blind mid-crustal detachment zone that accommodates differential shortening and crustal imbrication during continental collision.

A second key observation is a south-dipping positive conversion in the upper mantle that is directly connected to the European Moho. This structure is interpreted as the base of attenuated European lower crust that remained attached to the underthrust European lithosphere during the final stages of collision. The geometry closely resembles the continental double-wedge system documented in the Pyrenean–Cantabrian Belt, suggesting that similar mechanisms of continental underthrusting and crustal stacking operated in both orogens. The inferred density structure of the lower crust may explain the absence of widespread exhumed high-pressure metamorphic rocks within the Western Carpathians.

Importantly, the RF images do not provide any seismic evidence for the existence of the hypothesized Czorsztyn Ridge, although the resolution of the method does not allow its complete exclusion. Instead, the results support a model in which the Europe–AlCaPa boundary is a broad zone of crustal-scale imbrication and continental underthrusting rather than a simple narrow suture. These findings contribute to a broader understanding of lithospheric processes operating during Alpine-type continental collision.

Acknowledgements. This work is sponsored by the National Science Centre (Poland) grant number 2021/43/B/ST10/02312. We would also like to acknowledge AdriaArray effort with which the passive seismic experiment of this project was conducted.

Multiresolution Analysis of Geomagnetic Disturbances in 2026

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An important direction within the core project of the Geological Institute of Romania, entitled "Geomagnetism, a modern tool in space weather forecasting and rapid response to associated natural hazards for the protection of critical infrastructures and national air traffic security", is the study of geomagnetic storms and the methodology for complex analysis of these phenomena. In the present work, we used data from the geomagnetic observatories of the INTERMAGNET network, sampled at 1 minute, for two geomagnetic storm occurred in this year, periods January 19-21 and March 21-23. The geomagnetic field varies in time and space, being a signal composed of periodic and non-periodic elements and is monitored in a triaxial system. In the paper, based on these data, we use spectral evaluation (Fourier, wavelet, signal decompositions into approximations and details with various functions on different levels, etc.) to analyze various geomagnetic phenomena (such as: geomagnetic storms, disturbances, etc.) and their degree of occurrence. The superiority of the wavelet methodology over Fourier consists in obtaining information in the form of a three-dimensional graph (time, frequency, amplitude). The precise specification of the time duration of a geomagnetic signal decreases the accuracy of its spectral information and vice versa, according to the Heisenberg uncertainty principle. Thus, we obtain good temporal accuracy for high-frequency phenomena (at the expense of the accuracy of the amplitude of these frequencies), respectively, we will be able to know with greater accuracy the amplitude of the low-frequency components existing in the signal, without strictly localizing the moments in which they appear. The wavelet technique allowed us to analyze the local components of the magnetic field through variable frequency windows and different functions. Windows with longer time intervals allowed us to extract low-frequency information, average window times led us to extract medium-frequency information, and very narrow windows highlight high frequencies or details of the analyzed signals. The model of the disturbed geomagnetic field is composed of periodic oscillations plus non-periodic oscillations given by the impact of the solar wind on the terrestrial magnetosphere. Wavelet coherence is applicable to the analysis of non-stationary signals and uses the analytical Morlet wavelet, being able to detect events such as geomagnetic field anomalies, change points and transitions. The arrows in the coherence plot indicate the phase relationship between the two signals at each time point and frequency (or period). The phase angle of the cross-spectrum is the same as the phase difference between the signals. The direction of the arrows in regions of high coherence can help to understand the phase relationship. From the data analyzed from geomagnetic observatories for the three triaxial components and the total field, very good wavelet correlation and coherence were found during the geomagnetic storm.

Acknowledgements. This paper was supported by Installation and Special Objective of National Interest (IOSIN) – Surlari National Geomagnetic Observatory and Core Program PN23390401/2023-2026. Also, we thank the national institutes that support them and INTERMAGNET for promoting high standards of magnetic observatory practice.

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Geomagnetism and Space Weather Website Design

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Within the core project of the Geological Institute of Romania entitled Geomagnetism, a modern tool in space weather forecasting and rapid response to associated natural hazards for the protection of critical infrastructures and the security of national air traffic, we designed a website dedicated to geomagnetism and space weather. In this website, we included both the results of the project and the Surlari Geomagnetic Observatory, which is part of the INTERMAGNET planetary network. Links to geomagnetic databases, presented in the bibliographic references, with the triad indices K and Kp, the geomagnetic field perturbation index Dst, as well as solar wind parameters such as speed, density and solar radiation flux, can also be found. On the specialized websites in the links in the bibliography, we also find interactive, graphical and tabular information regarding the forecast of geomagnetic storms, polar auroras and solar activity. Another component of the website we designed is the interactive map (ArcGIS/Esri + OpenStreetMap via Leaflet.js) centered on the coordinates of the Surlari Observatory (44.6797 N, 26.2517 E, altitude 83m), with markers and metadata.

Declination plays a particularly important role for civil aircraft navigation, as it can differ depending on the variations in the magnetic field. The determination of the declination is done with the absolute magnetometer and is calculated at each point of interest in accordance with the position of the geographic and magnetic meridians of the measuring station and the declination of the Sun at the exact moment of determining the position of the Sun, expressed in sexagesimal degrees.

The measurements of declination, inclination and total field that we performed were based on the measuring station in the vicinity of the airport, which was selected as a magnetic field area without anomalies, at a sufficiently large distance from sources of major industrial disturbances, high-voltage lines, roads and urban spaces.

The values of the mean declination of the Sun and the equation of time are found in the astronomical yearbook, being calculated based on the ephemeris equations. The values thus measured were corrected for the diurnal variation and then reduced to the mid-year level, based on the values from the Surlari National Geomagnetic Observatory. To obtain the updated value of the declination, the annual average value given by the international geomagnetic field reference model (IGRF) and the absolute values measured at the Surlari National Geomagnetic Observatory were used. In this way, the declinations of airport surfaces in Romania were calculated and the respective data were represented in ArcGIS. The declination values can be viewed interactively within the created site. Also, published works and those presented at specialized conferences are presented.

Acknowledgements. This paper was supported by Installation and Special Objective of National Interest (IOSIN) – Surlari National Geomagnetic Observatory and Core Program PN23390401/2023-2026. Also, we thank the national institutes that support them and INTERMAGNET for promoting high standards of magnetic observatory practice.

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Mineral chemistry of sulfides from the ISCG Mount Colin deposit, Australia: Constraints on a multistage ore forming system

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Deposits from the Iron-Oxide Copper Gold (IOCG) family have traditionally been associated with the production of copper, gold and iron; however, they are also known to be potentially enriched in a wide range of elements, including critical metals. In this context, advances in in-situ analytical techniques allow detailed investigation of complex hydrothermal mineral systems through the composition of sulfides, which are widely associated with mineralization stages in IOCG and similar systems. Cu-Fe sulfides can host relevant concentrations of numerous elements, and when coupled with an understanding of their textures, timing of formation and mineral associations, can provide key insights into the evolution of a hydrothermal system. However, application of these systematics remains limited in the Cloncurry Province, limiting the understanding of fluid evolution and hindering the potential to investigate critical metal endowments. In this study, we use a combination of petrography, SEM, EPMA and LA-ICP-MS to investigate the distribution and composition of multiple generations of pyrite, pyrrhotite and chalcopyrite, the main sulfides in the system, to constrain the composition and evolution of the mineralizing fluid at the Mount Colin deposit, Cloncurry Province, Australia.

A complex arrangement of the sulfides is observed, including a spatial zonation in prevalence from pyrite to pyrrhotite to chalcopyrite towards the ore zone. Significant concentrations of cobalt and nickel are measured in the Fe-sulfides, despite some variation, pyrites are often Co-rich and Ni-poor, with one type containing concentrations exceeding 32,000 ppm. Ni, on the other hand, is commonly associated with pyrrhotite, with multiple analyses exceeding 15,000 ppm; however, low-Ni pyrrhotite and, conversely, high-Ni, low-Co pyrites are also described. Chalcopyrite, while not notably enriched in either element, consistently shows higher concentrations in samples from high-grade areas, likely reflecting its dominance over other sulfides in those zones. Negative correlation between Co and Ni with Fe (wt.%) and flat time-resolved signals suggest crystal lattice substitution between Co^{2+} and Ni^{2+} for Fe^{2+} . Simultaneous peaks in time-resolved signals indicate the likely presence of micro inclusions of other sulfides, including sphalerite, galena and cobaltite, evidenced by co-occurring peaks in Zn-Cd, Pb-Bi and Co-As, respectively. Multigeneration of sulfides are reinforced by elemental mapping which revealed distinct zonation patterns among the sulfides, most notably in pyrites. For instance, one texture observed in highly altered zones associated with likely late Fe-enriched quartz $\pm$ calcite injections, shows earlier pyrite grains overgrown by euhedral pyrite; these later zones are enriched in Ni and display strong Ni zonation relative to the Ni-poor cores.

The textural and compositional findings suggest multistage sulfide paragenesis, likely including formation of late-stage types that, while minor, evidence a complex evolution of the system. Element distribution also helps constrain the evolution of the deposit; despite some variation, Co appears to be linked with earlier and more distal sulfides, whereas Ni and other mobile elements are often associated with later sulfide generations. Finally, the anomalous concentrations of these elements are an important feature of this deposit, evidencing a potential critical metal endowment worthy of further investigation.

Integrated Multi-Geophysical Monitoring of Urban Evaporite Karst Hazards: Lessons from the GEOMONITOR Project in Slănic, Romania

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In April 2024, a sudden sinkhole appeared in Slănic, Romania, a town underlain by a massive Badenian salt deposit and shaped by historical mining. The event damaged infrastructure and revealed complex interactions between subsurface dissolution, hydrogeology, and anthropogenic disturbance. In response, the multidisciplinary GEOMONITOR project was initiated to develop integrated subsurface models and support operational risk mitigation.

The geophysical component combines several complementary methods adapted to the constraints of an urban salt-collapse setting, including limited survey access, cable-layout restrictions, electromagnetic and anthropogenic seismic noise, and reduced ground-penetrating radar (GPR) penetration in saturated clay-rich deposits. Surveys cover multiple regions inside the town as well as the mining outskirts. Seismic data collection was concentrated in the central part of the town. Local GPR, gravimetry, and 4D time-lapse electrical resistivity tomography (ERT) track active deformations close to the center, targeting a new instability discovered during project development. Gravimetric stations were deployed outwards in concentric rectangles, whereas airborne magnetic data was collected in the outskirts, and GPR data sampled road networks showing visible surface deformations.

Several 4D time-lapse ERT profiles tracked subsurface changes in a nearby area to locate the underground void over time and better understand what led to the partial collapse of the house near a borehole. The data showed very low resistivity values ($<10\text{ohm}\cdot\text{m}$), highlighting clay layer saturation near collapsing houses and potential brine infiltration. The gravity survey showed patterns outlining broader subsurface trends potentially related to the salt diapir and geological heterogeneities. GPR profiles using low frequency antennas mapped shallow stratification to complement ERT datasets, highlighting structural deformations beneath the asphalt road.

Active and passive seismic surveys were carried out to provide a better image of the mechanical properties of the subsurface like stiffness contrasts, resonance behaviour and spatial variability of ground conditions in investigated areas. The Multichannel Analysis of Surface Waves (MASW) and passive Microtremor Array Measurements (MAM), provided shear-wave velocity profiles with depths. These profiles show that the central suffosion zone features a low V_{s30} dropping to 184 m/s, classifying it as ground class C (intermediate ground), according to Romanian Seismic Design Code P100-1/2013, prone to high seismic wave amplification. The Horizontal-to-Vertical Spectral Ratio (HVSr) was applied to determine the fundamental resonance frequency (f_0), providing a useful proxy for identifying lateral changes in impedance contrast, which may reflect variations in sediment thickness and, indirectly, changes in the depth to the top of the salt formation. The f_0 mapping shows low values (1.3–3 Hz) across thick, uncompacted central sediments to high frequencies (>7 Hz) where salt bedrock rises near the surface.

Ultimately, the GEOMONITOR system structures these methods into two operational levels: Package A for immediate emergency anomaly triage and Package B for long-term 4D prediction, providing local authorities with the diagnostic data required to manage active urban risks.

Acknowledgements. This work was carried out within the project No.28Sol(T28)2025, funded by the Ministry of Education and Research, through UEFISCDI (Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding).

Application of Seismic Attributes for Detecting Subsurface Channel Systems within the Chalk Group: A Case Study from Poole Bay, Southern UK

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The geological interpretation of seismic data is an essential step in the stratigraphic and structural analysis of the subsurface. To enhance certain geological features in seismic data, a widely used geophysical method is the application of seismic attributes. These seismic attributes combine information from multiple elements of the seismic data (such as amplitude and frequency) in order to highlight certain features in the structure of the subsurface (Chopra and Marfurt, 2008).

For the present case study, we have identified a subsurface channel system in the Chalk Group, in Poole Bay area (southern coast of the United Kingdom). To reveal the channel system, we have used seismic attributes in conjunction with data analysis and visualization tools (such as a horizon probe).

The Chalk Group is a lithostratigraphic unit made up predominantly of coccolith biomicrite, formed between the Cenomanian and Danian times. (Charnock et al., 2016; Gale, 2005).

During our geological interpretation of the seismic data, we have identified features in the seismic data that might indicate structural or lithological changes. In order to highlight these zones, we have used the seismic attributes such as sweetness and variance, along with spectral decomposition techniques. Sweetness is a seismic attribute derived from the frequency and amplitude of the signal, while variance measures the continuity of the signal between neighboring traces (Chopra and Marfurt, 2018; Li et al., 2017). Spectral decomposition is a time-frequency analysis that improves the detection of thin features through the careful selection of appropriate frequency components, that are then blended together in order to illuminate lithological or/and structural features (Chopra and Marfurt, 2007, 2016).

Using these seismic attributes, we have identified a complex depositional system in the Chalk Group, formed by meandering channels, point bars, and crevasse splays.

Acknowledgements. Contains information provided by the North Sea Transition Authority and/or other third parties.

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Integrated Geophysical Investigations for Seismic-Induced Landslide Hazard Assessment: A Case Study from Gornet, Romania

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Earthquakes represents one of the major triggering factors for slope instability in geologically complex regions, particularly where favourable lithological, hydrogeological and geomorphological conditions coexist. Improving the assessment of seismic-induced landslide hazard requires an integrated approach capable of combining direct investigations with geophysical imaging and site response analysis.

This study presents a multidisciplinary methodology developed within a doctoral research programme and applied in the Gornet area (Prahova County, Romania). Geological mapping, geotechnical investigations and complementary geophysical surveys were integrated with seismic site response analyses to characterize subsurface conditions and evaluate their influence on slope stability. Electrical and seismic geophysical methods provided information on the spatial distribution of geological units and the physical properties controlling ground behaviour during seismic loading. These datasets were combined with geomorphological observations, hydrogeological information and hazard assessment procedures to develop an integrated interpretation of slope instability.

The proposed methodology enabled the identification of sectors with increased susceptibility to seismic-induced landslides by correlating subsurface geological conditions with local site response characteristics. Integrating multiple investigation techniques reduced uncertainties associated with individual datasets and improved the reliability of hazard assessment. In addition to identifying potentially unstable areas, the study provides a framework for evaluating the interaction between geological structure, groundwater conditions and seismic amplification effects.

Results demonstrate that multidisciplinary investigations significantly improve the understanding of landslide-prone environments and provide a robust basis for hazard assessment, territorial planning and long-term risk reduction. The proposed workflow may be applied to other areas affected by similar geological and seismic conditions, supporting sustainable land management and disaster risk mitigation.

Acknowledgements. This study was developed as part of the first author's doctoral research. The authors gratefully acknowledge the Geological Institute of Romania for providing technical support, access to geophysical equipment and logistical assistance during the field investigations.

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Session GS5

Economic Geology

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Unlocking an exceptional copper–gold endowment: New discoveries in the Late Cretaceous Timok–Srednogorie belt segment in Serbia and Bulgaria

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The Late Cretaceous Apuseni–Banat–Timok–Srednogorie (ABTS) belt is a major Cu–Au metallogenic province in southeast Europe, developed during Neotethyan subduction, slab rollback, and upper-plate extension. Over the past 15 years, exceptional copper–gold discoveries have been made in relatively mature districts of the Serbian and Bulgarian segments of this belt, already totalling more than 20 Mt of Cu and 20 Moz of Au in new metal resources. Recent exploration reports suggest that these resource figures may soon double. The newly discovered deposits represent various parts of magmatic-hydrothermal systems, including porphyry Cu–Au (Čukaru Peki Lower Zone, Brevene South Porphyry at Chelopech, Frasen), high-grade Au manto-skarn (Čoka Rakita), skarn and carbonate-replacement Cu–Au–Ag-polymetallic (Dumitru Potok, Frasen, Rakita Deep, Malka Golaja), high-sulfidation type epithermal Au–Cu (Čukaru Peki Upper Zone, Wedge Deep Zone at Chelopech) and distal sedimentary rock-hosted Au (Bigar Hill, Korkan, Kraku Pešter) mineralization. This contribution aims to synthesize new exploration results and geological models, with the aim to gain better insights in the exceptional Cu–Au fertility of the belt, review common controls on ore formation and criteria for concealed resources.

The emerging target-generation model prioritizes: 1) magma-fertility indicators reflecting highly oxidized magmas and magma hybridization; 2) long-lived, basement-inherited structures that acted as feeders for silicate melts and hydrothermal fluids; 3) reactive host-rock contacts, permeability contrasts, and carbonate reaction fronts; 4) vertical telescoping between high-sulfidation epithermal and porphyry Cu–Au mineralization, capable of forming ultra-large and exceptionally high-grade copper–gold systems; 5) carbonate dissolution and karstic processes that may enhance deposit-scale hypogene and supergene remobilization and enrichment; 6) system-scale alteration and metal zoning, depth extensions, and coincident geochemical and geophysical vectors toward blind, high-grade porphyry, epithermal, and skarn mineralization; and 7) late tectonostratigraphic evolution that favoured preservation and exhumation of previously formed copper–gold mineralization.

The new findings refine the predictive framework for the ABTS belt and demonstrate its continued potential for world-class copper and gold resources beneath syn- and post-mineral volcanic, sedimentary, tectonic, and mine-cover environments. This exploration potential is particularly notable in the relatively underexplored Romanian segments of the Late Cretaceous belt, including the Apuseni, Poiana Rusca, and Banat districts.

Acknowledgements. The authors gratefully acknowledge the collaborative teamwork of the creative and talented geoscientists at DPM Metals and various other exploration and mining companies active in the belt, whose efforts contributed to these exceptional new discoveries in the Timok and Srednogorie districts.

How to form a world-class mineral province: the mineral systems of the Mount Isa Inlier, Australia

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The Palaeo- to Mesoproterozoic Mount Isa Inlier of northwest Queensland is one of Earth's pre-eminent metallogenic provinces and a global benchmark for Proterozoic base- and precious-metal endowment. It hosts a remarkable diversity of giant ore systems: stratiform and shear-hosted Zn–Pb–Ag (Mount Isa, George Fisher, Century, Cannington, Dugald River); sediment hosted, structurally controlled epigenetic Cu and iron-oxide–copper–gold (Mount Isa copper, Ernest Henry, Osborne, Eloise); the world's highest-grade Mo–Re deposit (Merlin); REEs and significant U and Georgina Basin phosphate. Why did so much metal, of such varied character, accumulate in one terrane? Drawing on the mineral-systems framework, this presentation argues that world-class endowment reflects not a single exceptional factor but the repeated coincidence, in space and time, of the essential ingredients of fertile mineral systems on a long-lived, repeatedly reactivated lithosphere.

Four ingredients are emphasised. First, a fertile but repeatedly reworked basin system: rather than a simple layer-cake of rift-related superbasins, the inlier records ~400 million years (ca. 1890–1490 Ma) of discontinuous, diachronous basin development, its stratigraphy increasingly shown to be laterally variable and broken by major depositional gaps, that sourced metals, oxidised and evaporite-buffered brines, and reduced, carbonate-rich host rocks. Second, a crustal-scale structural framework of basement-penetrating faults and lineaments that repeatedly plumbed fluids from source to trap. Third, a recurring tectonic driver: basin growth was punctuated by orogenesis — the ~1880–1850 Ma Barramundi, the ~1750–1710 Ma Wonga, and the ~1650–1490 Ma Isan orogenies — with belt-like, calc-alkaline I-type magmatism indicating convergent-margin influence along the eastern North Australian Craton rather than purely intracontinental extension; each cycle of shortening, inversion and magmatism (including ~1550–1490 Ma Williams–Naraku intrusions) mobilised fluids and refreshed chemical gradients. Fourth, abundant, efficient traps, reduced and carbonaceous horizons, redox fronts, carbonate-replacement sites and zones of structural complexity, across a protracted Pb–Zn to Cu–Au continuum.

Viewed this way, the Inlier's contrasting deposit styles emerge as expressions of one fertile, polyphase, repeatedly reworked lithosphere rather than unrelated accidents. Recognising the true, discontinuous basin architecture, and which ingredients are common to all systems versus those that discriminate between styles, both explains the province's endowment and sharpens the search for deposits beneath cover, offering a transferable template for assessing the fertility of other Proterozoic provinces.

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Organic matter in black shales from the Krčedin succession (Northern Serbia): preliminary observations

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Black shales represent valuable records of paleoenvironmental conditions and organic matter preservation and are commonly used to assess thermal maturity and hydrocarbon generation potential. The Krčedin succession is a mixed carbonate–siliciclastic deposit of Upper Jurassic–Lower Cretaceous age. Marlstone deposits in the upper part of the succession are associated with pyrite-rich and organic-rich intervals, including black shale horizons and trace fossils. Dark gray to black, fine-grained, laminated organic-rich shale horizons, approximately 30 cm thick, are interbedded within the marlstone succession and were selected for geochemical and organic-petrological analyses. The study aims to determine the quantity and characteristics of organic matter, evaluate its preservation state and hydrocarbon generation potential, and reconstruct the depositional paleoenvironmental conditions that controlled organic matter accumulation and preservation.

Selected black shale samples from the Krčedin succession were analyzed using Rock-Eval pyrolysis to assess organic matter abundance, thermal maturity, and hydrocarbon generation potential. Organic-petrological analyses were additionally performed to characterize organic matter and pyrite distribution within the studied horizons. The black shales are characterized by low hydrogen index values (~450–500 mg HC/g TOC) and organic matter in the early stage of diagenesis, dominated by Type III kerogen. Geochemical parameters indicate low TOC contents (up to 0.5 wt.%) and very low S₂ yields (≤2 mg HC/g rock), while T_{max} values (~420°C) suggest thermally immature organic matter. Organic-petrological observations reveal a very low abundance of vitrinite particles unsuitable for reflectance measurements, minor inertinite-group macerals, and abundant pyrite.

The obtained data suggest a limited hydrocarbon generation potential of the studied black shales. Nevertheless, the presence of organic matter and pyrite indicates episodic preservation under dysoxic conditions during the evolution of the Krčedin succession. Further studies will focus on the spatial distribution and depositional controls of the organic-rich intervals.

Acknowledgements. The study was supported by the Ministry of Education, Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-34/2026-03/200126).

Degree of graphitization in the Slavonian Mountains (Croatia)

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Natural graphite is classified by the European Union as both a Critical and Strategic Raw Material because of its indispensable role in lithium-ion batteries, electric vehicles and low-carbon technologies (European Commission, 2023). Despite its strategic importance, the EU produces only negligible quantities of natural graphite and remains highly dependent on imports, primarily from China (European Commission, 2024). Croatia hosts several historical graphite occurrences but currently has neither active graphite mines nor economically defined graphite reserves (Marković, 2002).

Graphite occurrences in Croatia were first described by Kišpatić (1892), who recognized graphite, graphite phyllites and graphite schists in the Slavonian Mountains of eastern Croatia. These occurrences belong to the Tisza Unit, representing the exposed Variscan basement of the Pannonian Basin (Pamić & Jurković, 2002; Pamić et al., 2002; Schmid et al., 2008). Graphite mineralisation is hosted by Devonian–Carboniferous graphitic schists and metagreywackes, occurring as irregular lenses and layers containing typically 40–60 wt.% C or as disseminated graphite within the host rocks (Marković, 2002). Mining was active between 1947 and 1971 at Brusnik, Sivornica and Brezovo Polje.

Three principal graphite-bearing zones are recognised in the Psunj Mountains (Marković, 2002). The Brusnik zone extends for ~10 km and contains graphitic schists with 53–64 wt.% C, while graphite lenses locally reach 32 wt.% C. The Omanovac–Rašaška zone hosts discontinuous lenses containing 22–48 wt.% C. The Brezovo Polje–Sivornica zone contains the highest-grade mineralisation, with crystalline graphite from Sivornica reaching 71–77 wt.% C, whereas cryptocrystalline graphite at Brezovo Polje contains 50–55 wt.% C. Additional occurrences in southern Papuk (Stražeman, Golo Brdo, Kaptol, Vetovo and Bistri Potok) comprise disseminated graphite, fracture coatings and irregular graphite-rich lenses within graphitic schists and metagreywackes (Marković, 2002).

Graphite formed through progressive metamorphic transformation of organic-rich sedimentary rocks. Graphitization was initiated during Variscan regional metamorphism and subsequently modified by a low-grade Cretaceous eo-Alpine overprint affecting the Tisza Unit (Biševac et al., 2009, 2010, 2013). Illite crystallinity (Kübler and Árkai indices), b_0 parameters and vitrinite reflectance indicate metamorphic conditions of 190–300 °C and 2–3 kbar, corresponding to anchizonal–epizonal conditions (Biševac et al., 2009, 2010, 2013; Petričević, 2012). These conditions enhanced the structural ordering of carbonaceous material but were insufficient to produce highly crystalline graphite. New X-ray diffraction analyses confirm a low degree of graphitization, with $d_{002} = 3.533$ Å and $\beta_{002} = 0.125^\circ$, indicating poorly ordered graphite. These results are consistent with the low-grade metamorphic conditions inferred from illite crystallinity and vitrinite reflectance.

Although the Croatian graphite occurrences are too small and discontinuous to represent a significant future source of natural graphite, they preserve an important record of the Variscan and Alpine metamorphic evolution of the Tisza Unit. Recent studies have suggested a possible link between graphite occurrences in the Slavonian Mountains and La Tène graphite pottery found in the region, while the technological use of graphite in La Tène pottery is well documented across Central Europe. Although the exact source of the graphite remains uncertain, these links connect critical raw materials with archaeological heritage and provide a basis for future interdisciplinary research integrating geology, archaeometry, experimental archaeology and geotourism.

Acknowledgements. This work was supported by NPOO GeoCritical project, UNIZG-RGNF.

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Evolution of ore-forming fluids in the carbonate-hosted Pb-Zn Mežica deposit, Slovenia

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The Mežica Pb-Zn ore deposit, located in Slovenia within the Northern Karavanke geotectonic unit of the Eastern Alps, has generally been classified as a Mississippi Valley-Type (MVT) deposit hosted by Triassic platform carbonates. Numerous Pb-Zn occurrences are known from Triassic sedimentary sequences of the Eastern and Southern Alps and along the Periadriatic Lineament, and their genetic models remain a matter of the ongoing debate. The Mežica deposit is no exception; although it has been classified as a Mississippi Valley-Type (MVT) deposit, several aspects of its genesis, including the origin of the ore-forming fluids and the processes responsible for ore precipitation, are still not fully understood. The mineralization is hosted predominantly by dolomite and consists mainly of sphalerite and galena, with minor pyrite. Common gangue minerals include dolomite, calcite, anglesite, ankerite, and rhodochrosite. Several ore textures observed in the deposit provide evidence for the processes responsible for mineralization, including replacement textures, colloform textures, open-space filling, and brecciation.

Fluid inclusion studies indicate that the mineralizing fluids were relatively low-temperature, acidic, high-salinity brines, with salinities ranging from 16.4 to 23.1 wt% NaCl equiv. and homogenization temperatures between 100 and 170°C. These data are consistent with observations from MVT deposits globally.

The Mežica deposit formed during the Late Triassic to Early Jurassic as a result of thermally driven fluid circulation associated with regional crustal extension. During the extensional phase, a hydrothermal convection system developed, allowing fluids to circulate through faults and fractures. The main mechanism of ore formation involved the mixing of metal-bearing brines, interpreted as modified Triassic seawater, with meteoric fluids. The brines transported lead and zinc as chloride complexes, while organic matter within the carbonate platform promoted sulfate reduction and the generation of sulfide. Mixing with meteoric water caused a decrease in fluid salinity, destabilizing metal-chloride complexes and reducing the ability of the fluid to transport metals. As a result, sphalerite and galena precipitated. Ore deposition was further enhanced by cooling during fluid mixing and by chemical interaction with the dolomitic host rock. These processes are reflected in the development of colloform and replacement textures.

Brecciation occurred during the late stages of mineralization. Subsequent fluid circulation through the brecciated rock resulted in recrystallization of sphalerite and the development of pyrite reaction rims around some ore fragments, indicating continued hydrothermal activity after brecciation. Post-ore carbonates (11.1–23.41 wt% NaCl eq.; Th = 108–250°C) which cemented breccia clasts indicate as well continued hydrothermal activity following the main stage of ore formation.

The final stage in the evolution of the deposit involved the circulation of heated oxygen-rich meteoric waters. Fluid inclusion data from wulfenite and supergene carbonates show salinities close to 0 wt% NaCl equiv., and homogenization temperatures between 60 and 250°C, indicating that these late fluids were diluted hot waters.

Thallium Enrichment in the Săcărâmb Epithermal System: Evidence from Pyrite and Rare Sulfosalt Assemblages

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The Săcărâmb Au-Ag-Te deposit, situated in the Metaliferi Mountains of Romania, exemplifies a remarkably intricate intermediate sulfidation epithermal system. Pyrite precipitates across all five paragenetic stages of the deposit, thereby serving as a robust proxy for tracking fluid chemistry over time. This study utilizes LA-ICP-MS to quantify trace element concentrations in pyrite across these stages, with a focus on the temporal evolution of thallium (Tl) and its correlation with metalloid elements. The results indicate a significant, stage-dependent fluctuation in Tl concentrations. In the early to intermediate stage of pyrite (Stages 1–3), associated with higher-temperature base-metal sulfides and initial telluride deposition, there is evidence of highly depleted Tl levels (medians < 2 ppm). In contrast, late-stage pyrite (Stages 4 and 5) defined by colloform textures (melnikovite) exhibits a substantial increase in thallium, reaching median concentrations of approximately 190 ppm. Furthermore, LA-ICP-MS data reveals a distinct positive correlation between Tl and Sb ($r \approx 0.65$) in the late-stage pyrite. This late-stage geochemical spike provides substantial evidence that corroborates the first-ever discovery of Tl-sulfosalts in the Săcărâmb system (Dincă, 2019; Dincă et al., 2025). These include boscardinite ($\text{AgTl}_2\text{Pb}_6(\text{Sb}_{15}\text{As}_4)_{19}\text{S}_{36}$), pierrotite ($\text{Tl}_2(\text{Sb},\text{As})_{10}\text{S}_{16}$), its dimorph parapierrrotite (TlSb_5S_8), and two previously unidentified Tl-rich homologues of the andorite series Mineral W and Mineral Y. Additionally, EPMA data reveals that several other late-stage sulfosalts incorporate Tl as trace impurities during this specific hydrothermal pulse, including bernarlottiite (0.15–0.75 wt%), baumhauerite (0.07–0.3 wt%), senandorite (0.07–0.2 wt%), and the geocronite-jordanite series (up to 0.54 wt%). These sulfosalts crystallized synchronously with highly enriched colloform pyrite, thus confirming an influx of thallium into the system. It is hypothesized that this late-stage thallium is not magmatic in origin; rather, it is the result of fluids leaching metals from the surrounding sedimentary and metamorphic lithologies during the terminal cooling phases of the Săcărâmb stratovolcano system.

Acknowledgements. Authors are thankful for the funding to the COFUND-ERAMIN-3-PEGMAT and the national projects: RESET, PN-III-P2-2.1-PED-2019-453, PN 23-39-02-02, PN23-39-02-03 and PN 23-39-02-05. We thank the GeoEcoLab Laboratory, Geological Institute of Romania, for access to SEM-EDS. We also thank PhD Topa Dan from Central Laboratory at the Natural History Museum, Vienna, Austria for electron microprobe measurements and BSE images. The authors would like to acknowledge the Geological Institute of the Bulgarian Academy of Sciences for facilitating the LA-ICP-MS analysis.

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Tracing Tectono-Magmatic Controls on the Formation of Large Porphyry Cu Deposits in Long-Lived Arc Systems

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Large to giant porphyry Cu deposits are rare and often concentrate within specific arc segments, but it remains unclear why certain arc segments are economically mineralized, while others are sub-economic or barren. The Urumieh-Dokhtar magmatic arc in Iran hosts numerous porphyry Cu deposits, including the large Miduk and Sarcheshmeh deposits. However, porphyry Cu formation is largely confined to the southeastern arc segment and occurs relatively late in arc evolution. New drill core geochemical and isotopic data from Miduk and Sarcheshmeh are compared to a compiled database of barren rocks across the Urumieh-Dokhtar magmatic arc to investigate the influence of magmatic processes and arc dynamics on porphyry formation. Magmatic rocks from Miduk and Sarcheshmeh show felsic, adakite-like (e.g., $\text{La/Yb} > 20$) signatures. This was previously attributed to extensive crustal thickening, which is, however, not supported by our data. Instead, the fertile magmas show amphibole fractionation reflecting elevated H_2O contents. By contrast, the barren arc magmas exhibit calc-alkaline, normal arc signatures ($\text{La/Yb} < 20$) that are indicative of plagioclase-dominated crystallization. Sr-Nd-Pb isotopes reveal a relatively homogeneous mantle source across the arc, but elevated $^{87}\text{Sr}/^{86}\text{Sr}$, $^{206}\text{Pb}/^{204}\text{Pb}$ and trace elements (e.g., $\text{Th/Nd} > 0.2$, $\text{Ce/Pb} < 10$) indicate a contribution of sediment melts to the mantle wedge. Furthermore, non-modal batch melting modelling and REE systematics ($\text{La/Yb} > 20$, $(\text{Dy/Yb})_{\text{CN}} > 1.2$) at Miduk and Sarcheshmeh suggest a change in the sediment composition affecting the source of the fertile porphyry magmas. We attribute a primary control on the formation of large porphyry Cu deposits to the prolonged, focused and static magmatism in the southeastern arc segment. We suggest that collision-related compression promoted crustal thermal maturation, long-lived magma accumulation and the generation of fertile H_2O -rich felsic magmas, which were likely emplaced at shallow crustal levels during waning compression. By contrast, arc migration in the central segment prevented the formation of economic porphyry deposits. The proposed model therefore contributes to a better understanding of magmatic processes related to porphyry formation and highlights the control of regional stress linked to arc evolution and migration.

Geochemical Associations and 3D Spatial Distribution of PCA Factors at the Momchil Deposit – Obichnik Section, Eastern Rhodopes

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The Momchil deposit – Obichnik section is an intermediate-sulfidation epithermal Au–Pb–Zn occurrence situated in the northern part of the Zvezdel–Pcheloyad ore field, Eastern Rhodopes, southern Bulgaria, associated to the Oligocene Zvezdel volcano-plutonic complex. The deposit is hosted by andesitic volcanics and pyroclastics, with adularia–sericite type gold mineralization hosted by quartz–sulfide veins and quartz–sericite–pyrite altered epiclastic breccias within an east–west trending hydrothermal alteration zone. The principal ore minerals are pyrite, sphalerite, galena, chalcopyrite and tennantite–tetrahedrite, with gold distributed within sulfides and associated to quartz, sericite, kaolinite, and adularia. A multivariate statistical analysis was conducted on geochemical data from 11,563–13,461 samples, encompassing 30 chemical elements, integrating descriptive statistics, Pearson correlation analysis, and Principal Component Analysis (PCA) with Varimax rotation.

Descriptive statistics and Pearson correlation analysis confirm log-normal distributions typical of hydrothermal systems and delineate three principal geochemical groupings: a sulfide ore association (Zn–Cd: $r = 0.795$; Zn–Pb: $r = 0.658$), a mafic lithogeochemical background (Fe–Co: $r = 0.502$; Fe–Sc: $r = 0.571$), and a hydrothermal pathfinder assemblage (As–Sb: $r = 0.626$).

PCA with Varimax rotation resolved seven interpretable factors: Factor 1 (Fe, Co, Mn, Sc, V, P) reflects a mafic lithogeochemical background. Factor 2 (Ca, Sr, Mg, Be) represents a carbonate-alkaline earth assemblage. Factor 3 (Zn, Cd, Pb, Au, Cu, S) captures the principal sulfide ore association and constitutes the dominant economic component. Factor 4 (As, Sb, Mo, Ag) corresponds to a hydrothermal-epithermal pathfinder suite. Factor 5 (Ti, V, Al, Na) defines an aluminosilicate host-rock signature. Factor 6 (Cr, Ni) indicates an ultramafic-mafic contribution. Factor 7 (Ba, Hg) represents a minor dispersed component.

Factor scores were interpolated and rendered as three-dimensional volumetric models and compared against a reference $\text{Au} > 0.5$ g/t envelope. Factor 3 shows the closest spatial correspondence with the gold-anomalous body, confirming that gold mineralization is geochemically integrated within the polymetallic sulfide assemblage. Factor 4 displays a partially offset distribution, with high-score zones extending into peripheral portions of the deposit – consistent with the distal character of As–Sb–Mo mineralization in epithermal systems and defining a geochemical halo around the economic core. Factor 1 encompasses the gold-bearing volume within a broader host-rock anomaly, while Factors 2 and 5 show no systematic spatial association with the $\text{Au} > 0.5$ g/t envelope. The spatial decoupling between Factors 3 and 4 suggests zonation consistent with a telescoped hydrothermal regime, providing a quantitative basis for refining ore volume criteria and targeting zones of highest economic potential in subsequent resource modelling.

Acknowledgements. National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria, Task: I.1.5. Clarification of geological regions with high potential for new discoveries of critical and strategic raw materials.

Porphyry Cu Fertility and Tectono-magmatic Evolution of Permian Granitoids in the Georgetown Region, Northeastern Queensland

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Two pulses of Permo–Carboniferous magmatism have been recognised in the Kennedy Igneous Association (KIA) around the Georgetown region, northeastern Queensland, Australia. Some Permian granitoids, mainly granodiorite and tonalite, display distinctive high Sr/Y and La/Yb ratios, steep LREE/HREE patterns, and absent to weak negative Eu anomalies. These adakitic or adakite-like characteristics suggest a potential association with porphyry Cu(–Au) systems and distinguish them from KIA granitoids in other provinces, which are more commonly linked to W and/or Sn mineralisation. Discrimination diagrams for adakitic sources indicate that these Permian granitoids were generated by partial melting of thickened lower continental crust, with or without delamination, rather than by slab melting. This interpretation is supported by zircon Hf isotope data from the Georgetown region, which show uniformly negative $\epsilon\text{Hf}(t)$ values below CHUR, consistent with derivation from continental crustal sources. In addition, $\epsilon\text{Hf}(t)$ values become progressively less radiogenic from the Carboniferous to the Permian, suggesting increasing crustal thickening and/or greater involvement of continental crustal melting through time. In contrast, granitoids from the Hodgkinson Province show a different temporal trend: $\epsilon\text{Hf}(t)$ values decrease until ca. 325 Ma and then increase thereafter, indicating a tectonic shift from crustal thickening to crustal thinning and/or enhanced mantle input. These contrasting isotopic trends suggest that the Georgetown and Hodgkinson provinces initially experienced a similar Early Carboniferous regime of continental crustal thickening but subsequently evolved under different tectono-magmatic conditions.

Permian granitoids in the Georgetown region can be further divided into less-fractionated and more-fractionated groups based on whole-rock geochemistry, including SiO_2 contents and adakitic signatures. Zircon trace-element data show that the less-fractionated group is clearly distinguished from the more-fractionated and Carboniferous granitoids by more oxidised and hydrated conditions, as indicated by higher $(\text{Ce}/\text{Nd})/\text{Y}$ and Eu/Eu^* . Apatite geochemistry from the less-fractionated Permian granitoids also records more oxidised signatures, including steeper LREE/HREE patterns and higher Eu/Eu^* , consistent with the zircon results. These features indicate stronger fertility for hydrothermal mineralisation, particularly porphyry Cu systems. Two Permian mineralisation corridors containing Cu, Au, Ag, and base metals occur in close spatial association with the less fractionated granitoids, supporting their exploration significance. As a case study, the Yataga pluton complex, one of the Permian less-fractionated intrusions, comprises diorite, monzonite, granodiorite, granite, and aplite. Zircon data indicate generally oxidised and hydrated conditions across the pluton, particularly in the more felsic samples. However, apatite geochemistry reveals two felsic groups that are interpreted to reflect different stages of fluid exsolution. For example, Granite 69 has higher La/Sm, Yb/Sm, and Arsenic contents in apatite, suggesting crystallisation before or during the early stage of fluid exsolution, whereas Granite 136 and aplite record more evolved post-exsolution signatures. Granite 69 may therefore represent a particularly important exploration target for hydrothermal mineralisation.

The East Rhodopean low-sulfidation gold-silver metallogenic province, SE Bulgaria: a synthesis of existing and new data with emphasis on the Krumovgrad Goldfield

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The low-sulfidation Au–Ag prospects of the Eastern Rhodope Mountains, SE Bulgaria are distributed across an area of approximately 2,000 km². They are of late Eocene to early Oligocene age, are hosted predominantly by supradetachment sedimentary rocks, are generally characterized by low abundances of base-metal sulfides, and belong to the adularia–sericite class. Despite extensive study, their genesis remains incompletely understood. Available geochronological data (⁴⁰Ar/³⁹Ar ages of hydrothermal adularia) indicate that they clearly predate the Late Eocene–Oligocene volcanic activity by at least 0.6 and up to 2 Ma. Field relationships provide additional evidence for their pre-magmatic origin. At some prospects, clasts of epithermal mineralization occur as xenoliths within the Oligocene Reseda ash tuff of the First Acid Volcanic Phase. Thus, these Au–Ag prospects appear older than the numerous adjacent Late Eocene–Oligocene magmatic-related Pb–Zn deposits. Consequently, they are regarded as a distinct group of epithermal Au–Ag prospects and grouped into a separate low-sulfidation gold–silver metallogenic province.

Most researchers have emphasized the close temporal relationship between the formation of these prospects and the development of metamorphic core complexes, the associated detachment faults, and the overlying supradetachment sedimentary basins. Accordingly, because the exhumation of the metamorphic core complexes and the formation of supradetachment basins broadly coincided with the voluminous Late Eocene–Oligocene magmatism in the Eastern Rhodopes over a period of approximately 5 Ma, some authors have proposed that magmatism may have contributed heat and, possibly, fluids and gold to the hydrothermal systems.

Since these hypotheses were first advanced, substantial new data have become available, which provide stronger support for a non-magmatic origin of this distinctive class of economically significant gold deposits in the Eastern Rhodopes, SE Bulgaria.

We propose that the low-sulfidation gold-silver prospects were formed in response to the Cenozoic crustal extension, slab rollback, and associated asthenospheric mantle upwelling. In this model, heat was transferred from the upwelling asthenosphere into the crust, establishing very high geothermal gradients and driving large-scale hydrothermal circulation. Descending meteoric waters were heated at depth and subsequently ascended along permeable structural pathways, leaching metals and ligands from the metamorphic basement and the overlying sedimentary succession during their migration.

Detachment faults likely served as the principal conduits for fluid flow. In the Krumovgrad goldfield, the pervasive silicification developed along the detachment fault system, including both the major low-angle fault and the associated low-angle-to-steep listric faults, provides evidence of the sustained circulation of hot hydrothermal fluids. These observations indicate that the detachment fault system acted as a major zone of focused upward fluid flow and hydrothermal alteration.

Within this framework, the low-sulfidation Au–Ag systems, spatially associated with metamorphic core complexes and detachment fault systems, represent a hydrothermal response to regional extension and mantle upwelling, predating the onset of widespread magmatism. The subsequent development of the Late Eocene–Early Oligocene volcanism in the Balkans, and in the Eastern Rhodope Massif, in particular, may therefore be viewed as a later manifestation of the same geodynamic processes.

Acknowledgements. The authors thank DPM Metals, Bulgaria, for granting permission to sample and for providing geological information. This research has been funded by the Bulgarian National Science Fund (contract KP-06-N54/6) and by the Bulgarian Ministry of Education and Science (National Science Program "Critical and strategic raw materials for a green transition and sustainable development", approved by the Resolution of the Council of Ministers no. 508/18.07.2024).

Morphology and chemical composition of alluvial gold from the Mureş Valley, România

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The fieldwork took place at a ballast pit in the Mureş Valley near the city of Alba Iulia, where heavy minerals were collected by panning. Native gold was isolated in the laboratory using a ZEISS Stemi binocular microscope, and its chemical composition was determined by electron probe microanalysis (EPMA) with a CAMECA SXFive instrument at the Department of Geology, Babeş-Bolyai University, Romania.

Morphological analyses of the gold grains followed the methodology described by Barrios et al. (2015). The grains are mostly sub-discoidal, with less frequent elongated forms, and their sizes generally remain below 1 mm. Geochemical analyses indicate that most native gold grains have a uniform chemical composition. Nevertheless, some grains show chemical heterogeneity, with higher Au concentrations occurring along their margins.

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Geochemical characteristics of skarns from the Elatsite porphyry copper deposit, Bulgaria: Preliminary data

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The Elatsite porphyry copper deposit is situated within the Apuseni-Banat-Timok-Srednogorie magmatic and metallogenic belt (Popov et al., 2002). Skarn occurrences are associated with the contact between the Carboniferous Vezhen pluton and the basement rocks (Lazarova, 2008). The metasedimentary sequence includes phyllites, chlorite-sericite schists, chlorite-sericite-calcite schists and calcareous schists. Skarns occur within the contact-metamorphic halo around the pluton, forming thin bands and discontinuous levels preferentially developed in carbonate-rich horizons of the basement sequence (Georgieva et al., 2024).

Exoskarns prevail over endoskarns, which are restricted to small zones transitional towards the pluton. In drill cores, the exoskarns form small bodies, commonly less than 50 cm thick and rarely up to 1 m, alternating with schists and hornfelses. Their mineral assemblage includes garnet, pyroxene, titanite, magnetite, epidote and carbonate, with variable sulphide mineralization. Relative to the surrounding country rocks, the exoskarns have higher CaO and Sr contents, higher total Fe ($\text{Fe}_2\text{O}_3 + \text{FeO}$) and MgO, and lower SiO_2 , Al_2O_3 , Cr, Rb, Ba, Pb, Th and U. These features reflect the carbonate-rich protolith and the formation of calc-silicate and Fe-bearing minerals during skarn development.

The alteration index (AI) and chlorite-carbonate-pyrite index (CCPI) also separate the exoskarns from their host rocks. Lower AI values are controlled by high CaO contents and reduced proportions of alkali-bearing components. The relatively lower CCPI values, compared with carbonate-rich schists, suggest that this index is strongly affected by the primary lithology and carbonate abundance, rather than only by hydrothermal alteration intensity. Elevated Cu contents are related to chalcopyrite mineralization, indicating that the exoskarns acted as favorable sites for sulphide deposition.

The REE patterns of the exoskarns resemble those of the carbonate-rich host lithologies, especially the chlorite-sericite-calcite schists. Chondrite-normalized patterns are variable, but generally show relative LREE enrichment over HREE, with LaN/YbN ratios of 0.67–6.35. However, total REE contents are lower in the skarns, averaging 122 ppm, compared with 212 ppm in the precursor rocks. This may reflect dilution by newly formed calc-silicate minerals and/or partial REE redistribution during skarn formation.

Overall, the major-, trace- and rare earth element characteristics of the Elatsite exoskarns indicate strong geochemical inheritance from the sedimentary-derived protoliths in which they developed. The enrichment in Ca, Sr, Fe, Mg and Cu, however, points to localized fluid-rock interaction and sulphide introduction. Thus, the exoskarns record a dominantly protolith-controlled evolution, modified by limited but significant hydrothermal overprinting.

Acknowledgements. This study was supported by project KP-06-M84/2, funded by the National Science Fund, Bulgaria.

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Deformation-enhanced fluid evolution and skarn–IOCG transition in the Paleoproterozoic Elaine Dorothy Cu–Au system, Mount Isa Inlier, Australia

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The Elaine Dorothy Cu–Au±REE deposit, located in the Mary Kathleen Domain of the Mount Isa Inlier, NW Queensland, records multi-stage Paleoproterozoic skarn development coupled with progressive deformation and evolving hydrothermal fluid chemistry. Copper–gold mineralisation is hosted by garnet–diopside–amphibole–carbonate calc–silicate skarns within the Corella Formation (~1750–1742 Ma). Early hydrothermal activity is linked to emplacement of the calc–alkaline Burstall Granite and Lunch Creek Gabbro at ~1740 Ma during the Wonga Orogeny. Petrography and mineral paragenesis indicate an initial high-temperature stage characterised by sulphide vein infill within scapolite–feldspar–diopside and garnet–diopside–amphibole skarn assemblages formed during prograde metasomatism. This stage was followed by amphibole–biotite–quartz–calcite retrograde alteration and deformation-assisted sulphide remobilisation.

In situ LA-ICP-MS trace element analyses of pyrite, pyrrhotite, chalcopyrite, and magnetite constrain fluid evolution and redox–sulphur fugacity conditions. Selenium concentrations in early pyrite (Py1) yield formation temperatures of 544 ± 36 °C for magmatic fluids and 323–417 °C for hydrothermal fluids active during sulphide mineralisation. Early pyrite exhibits elevated Co/Ni ratios consistent with a magmatic–hydrothermal origin, whereas later pyrite generations define mixing trends indicative of progressive interaction with crustal wall rocks. Textural transitions from disseminated sulphides to stringer zones and locally massive sulphide lenses reflect structurally focused fluid flow along fractures and shear zones. Strong positive Bi–Pb correlations in pyrite, pyrrhotite, and chalcopyrite record coupled metal transport and evolving redox conditions during cooling and deformation.

Late-stage shearing localised sulphide concentration within amphibole–biotite–quartz–feldspar–calcite–epidote–chlorite alteration assemblages, demonstrating deformation-enhanced metasomatism under retrograde conditions. The integrated lithological, structural, and mineral–chemical dataset indicates that sulphide mineralisation at Elaine Dorothy evolved from high-temperature magmatic skarn processes to structurally focused hydrothermal remobilisation during Paleoproterozoic crustal reworking. Mixed Fe–Cu–Co geochemical signatures, magnetite development, and deformation-controlled fluid flow collectively support interpretation of Elaine Dorothy as a transitional skarn–IOCG system, highlighting the critical role of structural permeability and fluid mixing in Cu–Au enrichment within Paleoproterozoic terranes.

Genesis of the world-class Ravenswood Gold Deposit, NE Queensland (Australia)

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In magmatic–hydrothermal gold systems, world-class endowment is favoured where a fertile source reservoir, sustained metal-bearing fluid flux and (re-)activation of permeable structural pathways are repeatedly coupled during favourable tectonic triggers. Such triggers commonly involve far-field stress switches that reactivate inherited networks, a feature of long-lived accretionary margins. The northeastern Australian Tasmanides exemplify this along the Gondwana margin, where slab advance–rollback, ribbon detachment–recollision and inversion repeatedly reworked crustal architecture (Betts et al., 2012). In the Charters Towers Province, Early Devonian granite-hosted orogenic gold and Carboniferous–Permian intrusion-related gold systems (IRGS) are linked to transtensional and extensional regimes, respectively (Betts et al., 2012; Evans, 2024). However, the magmatic, structural and spatiotemporal controls on Queensland’s largest gold mine, Ravenswood, remain incompletely constrained. Ravenswood is an IRGS hosted in the eastern Ravenswood Batholith, which records Ordovician Macrossan, Late Silurian–Early Devonian Pama and Carboniferous–Permian Kennedy magmatism. Mineralisation occurs within the Pama-age Jessop Creek Tonalite. Subvertical early-formed structures partly controlled gold distribution, but most mineralisation occurs as shallow-dipping conjugate quartz-sulphide vein arrays of the ca. 310 Ma event (Evans, 2024).

This study integrates U–Pb zircon geochronology with bulk-rock geochemistry to reassess Ravenswood district magmatic architecture and evolution. Pama-stage construction is dominated by ca. 429–421 Ma ages, with a ca. 421–416 Ma tail, rather than the ca. 415–400 Ma envelope inferred from published mica and whole-rock ages. The ca. 415–400 Ma ages may instead reflect isotopic resetting during Early Devonian tectono-hydrothermal activity. Geochemical data indicate a hydrous continental-arc Pama framework characterised by coupled hornblende–plagioclase fractionation. Mafic–ultramafic cumulate end-members suggest layered hydrous arc-cumulate architecture linked to a cogenetic gabbro–tonalite–granodiorite differentiation trend. Two Kennedy-age mafic dykes hosted in the early-formed Area 4 and Nolans structures define a critical magmatic–structural component. These dykes yield ca. 336 Ma U–Pb zircon ages, contain zircon populations texturally distinct from older Pama inheritance, and show LILE–LREE enrichment with negative Nb–Ta–Ti anomalies, consistent with an enriched, arc-modified mafic source. Only these dykes exceed 0.05 ppm Au, and Au is associated with enriched magmatic signatures and hydrothermal alteration proxies, suggesting combined magmatic-fertility and hydrothermal-upgrading control.

We interpret the hydrous Pama calc-alkaline system as having preconditioned a fertile deep-seated reservoir later tapped through inherited plumbing pathways during Early Devonian and/or Kennedy-age tectonic events. The ca. 336 Ma dykes are interpreted as mineralisation precursors recording fertile structural pathways tapping an enriched, arc-modified mafic source, not the final ore-forming event. The ca. 310 Ma event overprinted this architecture, enhancing permeability through movement-sense changes, linkage and rheological contrast. Ravenswood’s world-class endowment reflects the superposition of fertile Pama batholithic architecture, structural permeability enhancement, Kennedy-age mafic plumbing and late magmatic-hydrothermal overprint.

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Integrated Exploration of the Rupice Polymetallic Deposit, Vareš, Bosnia and Herzegovina

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The Rupice polymetallic deposit is a SEDEX-type deposit with significant concentrations of Pb, Zn, Ag, Au, and barite, and subordinate Cu and Sb. It is located in the Borovica-Vareš-Čevljanovići metallogenic zone, within a complex tectonic setting of the Internal Dinarides and the wider regional framework of the Durmitor thrust. The geological setting comprises Triassic predominantly carbonate rocks, with subordinate clastic and volcanic-magmatic rocks, as well as Paleozoic low-grade metamorphic schists, metasediments, and subordinate metavolcanic units. Mineralization in this area has been known since ancient times, while modern exploration continued intermittently until 1989, when reserves of 1.5 Mt were calculated in categories B+C1, with average grades of Pb+Zn = 6.8% and BaSO₄ = 51.43%.

A new exploration cycle began in 2017 and included drilling, geophysical surveys, soil geochemistry, chemical analyses, mineralogical investigations, and underground mining works. The current Mineral Resource Estimate is based on 469 diamond drillholes, including 49 historical drillholes totaling 5,691 m and 420 recent surface diamond drillholes totaling 101,162 m. Geophysical surveys covered more than 4 km² and included induced polarization, gravimetry, magnetometry, and reflection seismics, while mineralogical studies included PLM, XRD, and SEM.

Rupice comprises two principal ore zones, Rupice Main and Rupice North West. The mineralization forms a stratabound, breccia-hosted, folded lensoid sulphide-barite body with pinch-and-swell geometry, originally deposited as conformable lenses within the enclosing stratigraphy and subsequently modified by thrusting and folding. The host succession includes Middle Triassic interbedded dolomite, tuff, and shale, underlain by Lower Triassic siliciclastic units. The ore bodies dip moderately toward the northeast and remain open to the northwest at depth. Their combined strike extent exceeds 900 m, width reaches up to 350 m, and maximum thickness is about 65 m. Structural control is expressed through strata-parallel thrusts, steeper linking faults, and imbricate ramps that influenced orebody geometry. Mineralization is dominated by sphalerite, galena, chalcopyrite, pyrite, tetrahedrite-tennantite, and barite, with silver mainly associated with galena and gold occurring as fine inclusions in sulphides.

As of 1 April 2025, the Mineral Resource Estimate comprises an Indicated Mineral Resource of 10.7 Mt grading 264 g/t Ag, 7.4% Zn, 4.8% Pb, 1.9 g/t Au, 0.65% Cu, and 0.22% Sb, and an Inferred Mineral Resource of 0.9 Mt grading 150 g/t Ag, 3.5% Zn, 2.8% Pb, 0.8 g/t Au, 0.37% Cu, and 0.15% Sb. The integrated exploration methodology proved effective for ore body characterization and confirms the economic significance of the Rupice deposit.

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Middle Eocene fertile magmatism in the central Rila–Western Rhodopes batholith constrained by Re–Os geochronology

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The Rila–Western Rhodopes Batholith (RWRB) is one of the largest Late Cretaceous–Paleogene magmatic complexes in the Balkan Peninsula and represents a major metallogenic center hosting numerous occurrences and deposits enriched in W, Mo, Bi, Au, Ag and other critical metals. Previous geochronological studies have demonstrated that the batholith is a composite magmatic body formed through multiple intrusive stages, including Late Cretaceous granitoid intrusions (~71–68 Ma) and Paleogene granitoids emplaced during the Early and Middle Eocene. However, the direct temporal constraints on the relationship between fertile magmatism and hydrothermal ore formation remain unclear.

This study presents the first Re–Os molybdenite age from the Grancharitsa tungsten deposit, located in the central part of the RWRB. Grancharitsa is a hydrothermal quartz-feldspar vein-type tungsten deposit hosted by Late Cretaceous granitoids with scheelite and pyrite as the main ore minerals with a subordinated role of molybdenite, bismuthinite, chalcopyrite, sphalerite, galena, arsenopyrite, pyrrhotite and marcasite. Replicate Re–Os analyses of a molybdenite separate yielded model ages of 39.56 ± 0.23 Ma and 39.37 ± 0.22 Ma, providing the first direct age constraint on the mineralization. These results constrain a Middle Eocene fertile magmatic-hydrothermal event associated with the youngest Paleogene magmatic phase in the batholith.

Electron-microprobe and LA-ICP-MS analyses indicate that molybdenite is chemically homogeneous and close to ideal MoS_2 stoichiometry. Trace-element concentrations are characterized by low Re abundances and enrichment in W, Bi and Te. Tungsten concentrations locally reach several thousand ppm, consistent with the tungsten specialization of the deposit. The enrichment in Bi and Te indicates crystallization from evolved magmatic-hydrothermal fluids and distinguishes the Grancharitsa molybdenite from other Mo-bearing systems within the RWRB.

Comparison with the nearby Babyak Mo–Ag–Au–W–Bi deposit reveals significant temporal and geochemical differences. Previously published Re–Os ages of molybdenite from Babyak (~53 Ma) record an Early Eocene mineralization event, whereas the Grancharitsa molybdenite formed approximately 13 Ma later. In addition, Babyak molybdenite is enriched in Re, Pb and Ag, whereas the Grancharitsa molybdenite is characterized by W–Te enrichment. Significant Bi concentrations occur in molybdenite from both deposits, suggesting broadly similar metal associations but contrasting ore-fluid evolution during successive stages of Paleogene magmatism.

The combined geochronological evidence from granitoids, pegmatites and ore minerals indicates that the central RWRB underwent a prolonged Early- to Middle-Eocene period of fertile magmatism and associated hydrothermal activity between ca. 53 and 39 Ma. The new Re–Os age from Grancharitsa is indistinguishable from the crystallization age of the youngest Paleogene granitoids of the batholith (~39 Ma) and provides the first direct temporal link between tungsten mineralization and fertile post-collisional magmatism in the region. Together with the Early Eocene mineralization at Babyak and the Eocene magmatic record documented elsewhere in the batholith, these data provide evidence for long-lived ore-forming processes and incremental Paleogene growth of the RWRB.

Acknowledgements. The research was supported by the Bulgarian National Science Fund under project KP-06-M84/1 and the National Science Program “Critical and Strategic Raw Materials for a Green Transition and Sustainable Development” funded by the Ministry of Education and Science of Bulgaria.

Expert Economic Evaluation of Mineral Reserves in Enhancing the Business Environment of Serbia's Mineral Sector

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The strategic, economic, and technological guidelines for Serbia's future economic development, particularly in the context of European integration, require significant progress in the production of basic materials. Within this development framework, the mineral sector plays a particularly important economic and material role through the production of metallic, non-metallic, and energy mineral raw materials required by various industries. Traditional methods of economic evaluation, however, have proven insufficient for addressing the complex, multifactorial challenges of the modern mineral economy. This paper presents a comprehensive and practically applicable framework for the expert economic evaluation of mineral reserves as an essential basis for strategic planning and investment decision-making in Serbia's future development. With more than 2,000 deposits of different mineral commodities, Serbia possesses a significant mineral resource base; however, unlocking its full economic potential requires the application of a modern, integrated methodology for economic evaluation.

Based on systematized data for three major categories of mineral raw materials—metallic, non-metallic, and energy—an expert economic evaluation model was applied by integrating five key analytical aspects: (a) geological, (b) mining, (c) economic, (d) ecological, and (e) management. The current operating environment of Serbia's mineral sector is shaped by four dominant groups of factors: (i) transitional economic conditions; (ii) the application of sustainable development principles to mineral exploration and exploitation; (iii) the intensification of environmental protection requirements; and (iv) the growing presence of foreign companies holding mineral exploration and exploitation rights. In accordance with the established methodology, the expert economic evaluation incorporated nine factors and three sets of indicators—natural, value-based, and synthetic—which together enable a multidimensional economic evaluation of individual deposits and the determination of their market value for planning and implementing mineral production.

The geological aspect involved defining the economic types of minerals, ores, and deposits and quantifying reserve categories. The mining aspect enabled the determination of appropriate exploitation methods, production capacities, and mine life. The economic aspect, in addition to estimating capital and operating costs, was crucial for evaluating the contribution of the mineral sector to national GDP and examining new development opportunities, particularly the potential for valorizing lithium and boron in advanced battery production. The economic analysis also addressed copper and gold reserves as important components of mineral production in the forthcoming development period. Given the ongoing energy crisis, the expert economic evaluation of existing oil and gas reserves and their potential for future production represented a distinct analytical component. The ecological aspect incorporated growing environmental concerns through the analysis of individual geo-ecological factors to assess the feasibility of economically and environmentally sustainable mineral exploitation, including the application of modern technologies for preventing water, soil, and air pollution. Finally, the management aspect is particularly important because it incorporates expert economic evaluation into strategically important decision-making and security considerations related to the functioning of the mineral sector and associated mineral production, thereby providing a foundation for further economic development.

The applied multifactor expert economic evaluation demonstrated the substantial importance of the effective functioning of Serbia's mineral sector for future economic development, particularly with regard to copper and gold reserves, oil and gas reserves, and the environmentally constrained economic potential of boron and lithium reserves. By providing a structured, quantifiable, and robust methodology for the expert economic evaluation of mineral reserves, the proposed approach improves the practical applicability and reliability of reserve valuation, supports risk mitigation, and enhances the competitiveness of Serbia's mineral sector. The findings and methodological framework of the analysis also provide valuable strategic guidance for domestic and foreign investors, as well as for mineral policy-makers, in formulating a sustainable national mineral strategy for the exploration, exploitation, and economic utilization of Serbia's mineral reserves.

Acknowledgement. This paper is the result of a scientific research project financed by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, under Contract no. 451-03-34/2026-03/200126.

Modern Economic Geology and Management of the Mineral Sector in the Transitional Conditions of Mineral Production in Serbia

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Mineral resources and reserves represent a finite but strategically important material basis for mineral production in Serbia. Their significance extends beyond the mining sector and directly affects the functioning of numerous economic branches, ranging from construction and metallurgy to high-tech industries such as the automotive and battery sectors. Given the economic principle of finite resources and the practically unlimited needs of modern society, this paper addresses the economic and managerial imperative of their rational, efficient, and sustainable use throughout the entire mineral production process in Serbia.

Starting from the contemporary role and significance of economic geology in Serbia as the fundamental research issue addressed in this paper, the study identifies the absence of an integrated management model for mineral enterprises operating under the conditions of Serbia's transitional economy. This deficiency consequently leads to suboptimal business decisions, inadequate resource allocation, and reduced competitiveness of the Serbian mineral sector. The aim of the research was to recognize, identify, and define the key success factors of mineral enterprises operating under transitional conditions in Serbia through the application of economic geology methods and modern management concepts. The findings are intended to provide an analytical basis for developing a framework for business improvement in accordance with contemporary market conditions and European standards.

From a methodological perspective, economic geology represents an important applied discipline that, based on fundamental geological-economic analyses—including the evaluation of the quantity and quality of mineral reserves, analysis of exploitation conditions, and evaluation of market potential—enables objective and informed business decision-making relevant to mineral production. Based on the research-based classification of mineral enterprises in Serbia according to various criteria, including the number of employees, type of activity, market role, economic value of production, and ownership structure, a direct impact on contemporary organizational structures and managerial practices was identified.

At the same time, under the current transitional conditions of mineral production in Serbia, particular analytical attention should be given to critical mineral raw materials, including lithium, rare earth elements, cobalt, and boron. These resources are of strategic importance for the development of technological, energy, and defense systems, as well as for the green transition of the European Union. Given Serbia's significant potential in these mineral resources, they provide important opportunities for economic development. However, their exploitation requires a high level of managerial expertise, the application of modern technologies, and compliance with relevant environmental standards.

The methodological framework of the analysis presented in this paper is based on an integrated evaluation of the geological, economic, and managerial parameters of mineral enterprises in Serbia. To achieve the stated research objective, comparative analysis, multi-criteria evaluation, and qualitative research methods were applied, complemented by triangulation. This methodological approach enables a comprehensive economic and managerial evaluation and validation of findings related to mineral production.

Analysis of the collected primary data showed that the success of mineral enterprises primarily depends on five factors: (a) the type, quality, and economic value of mineral raw materials; (b) production performance; (c) the degree of implementation of the production plan; (d) the level of operating costs; and (e) market prices of mineral raw materials. In addition, managerial competencies have a significant impact, particularly in the areas of strategic planning, risk management, and stakeholder communication within the mineral sector.

Comprehensive geological-economic research into mineral production in Serbia indicates four key segments of the mineral economy that require particular managerial attention: (a) mineral production; (b) mineral distribution; (c) mineral trade; and (d) mineral consumption. At the same time, strategic priority in Serbia should be given to mineral production, particularly the production of critical mineral raw materials, since other technological and processing activities depend on this fundamental form of material production. The analysis indicates that a successful transition of the mineral sector requires the parallel improvement of all segments of the mineral economy, together with stronger integration of mineral production with research, development, and innovation.

In this way, the paper establishes a comprehensive framework for improving the management of Serbia's mineral sector through an integrated approach combining economic geology and modern management concepts. The proposed framework can serve as a basis for developing a national mineral resource management strategy aligned with relevant EU policies and standards, including the Critical Raw Materials Act and the European Green Deal. This approach can contribute to a more efficient transition process, increased competitiveness, greater investment attractiveness, and the long-term sustainability of mineral production in Serbia, while simultaneously creating opportunities for further research into modern technologies, digitalization, and the application of artificial intelligence in the mineral sector.

Acknowledgement. This paper is the result of a scientific research project financed by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, under Contract no. 451-03-34/2026-03/200126.

Remote Sensing and Mineral Detection Tool Applications for Regional- to Local-Scale Targeting of Porphyry Copper Mineralisation in the Western Srednogie, Bulgaria

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The increasing global demand for critical and strategic raw materials requires rapid, cost-effective, and environmentally sustainable mineral exploration approaches. This study presents an integrated multi-scale exploration workflow combining regional-scale ASTER remote sensing and digital elevation model (DEM)-based structural analysis with electrical resistivity tomography (ERT), induced polarization (IP), portable X-ray fluorescence (pXRF), X-ray diffraction (XRD) and drone-based photogrammetry. This combined methodology is demonstrated at the Radulovtsi porphyry copper occurrence in the Burel ore field, Western Srednogie, Bulgaria, addressing an important exploration gap within the western segment of the Tethyan–Eurasian Metallogenic Belt. Regional structural interpretation identified a dominant NW–SE (320–330°) dextral strike-slip fault system with subparallel en échelon fault segments and associated NE–SW (60–70°) antithetic P' shears. The Krusha, Zlatusha, Radulovtsi, Gurguliat, and Klisura lithocaps, together with Cu–Au mineralisation, are concentrated at fault intersections and releasing bends, where transtensional deformation promoted hydrothermal fluid circulation and ore deposition. Portable XRF screening was used to optimise geophysical survey design along a 160 m ERT/IP profile acquired using an ABEM Terrameter SAS 1000 multi-electrode system. Co-located pXRF measurements were collected at 2 m intervals with a Bruker S1 Titan 800 spectrometer. A high-resolution drone-derived photogrammetric model and TIR survey enabled remote mapping of supergene copper minerals (malachite and azurite) and the fault–fracture network controlling mineralisation. The strong spectral and visual contrast between these minerals and the host rocks facilitated rapid delineation of mineralized zones and supported efficient field planning. The Radulovtsi occurrence is hosted by a Late Cretaceous subvolcanic quartz diorite porphyry intrusion. XRD analyses confirmed clinocllore–albite alteration associated with chalcopyrite and magnetite mineralisation. ERT imaging delineated a shallow low-resistivity zone interpreted as hydrothermally altered and supergene-weathered material, while a pronounced IP chargeability anomaly (>80 ms) coincides with surface copper mineralisation and indicates disseminated sulphides at depth. Portable XRF analyses identified Cu concentrations of 0.30–0.80 wt.%, corresponding to a secondary geochemical dispersion halo. Moderate positive correlations between Cu concentration and both resistivity ($r = 0.49$) and chargeability ($r = 0.41$) demonstrate the complementary value of integrating geophysical and geochemical datasets.

The proposed workflow enhances exploration targeting, supports rapid field decision-making, and provides a transferable methodology for porphyry copper systems and other structurally controlled mineral deposits.

Acknowledgements. This research was supported by the European Union–NextGenerationEU, CleanExplore project No BG-RRP-2.017-0035 and КП-06-H74/6, National Science Fund of Bulgaria.

Session GS6

Energy Resources (Hydrocarbon, Geothermal)

Conveners:

Cristian-Victor Mircescu, Nikola Botoucharov

Geothermal waters from the Pannonian Basin (Western Romania)

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The Pannonian Basin is a Neogene post-tectonic basin characterized by a generalized subsidence in the Badenian. From a geological point of view, the Romanian sector of the Pannonian Basin is divided in the northern, central and southern parts.

The northern part comprises the Satu Mare-Carei and Carei-Oradea sectors.

In the Satu Mare-Carei sector, metamorphic formations and Cretaceous sedimentary units are covered by up to 3000 m thick Eocene-Pliocene sediments. The Miocene formations comprise Badenian and Sarmatian siliciclastic deposits. The Pliocene succession consists of up to 2100 m thick marls, clays and sands (Țenu 1981). The geothermism of the entire area is determined by a regional geothermic anomaly. The thermic flux has a medium value of $2,0 \mu\text{cal}/\text{cm}^2$, with temperature gradients exceeding $50^\circ\text{C}/\text{km}$ (Airinei 1977). In the Oradea-Carei sector, the basement of the Pannonian Basin consists of metamorphic and sedimentary formations belonging to the Bihor Unit and Upper Cretaceous formations. They are covered by up to 1400 m thick Miocene-Pliocene sediments.

In the Carei-Satu Mare sector, geothermal aquifers are generated in the fracture networks affecting the Miocene sandstones and conglomerates or the Pliocene sands and poorly cemented sandstones. Recent data has shown that flowrates range between 0.85 and 21 l/s. Hydrostatic levels range between -32.2 and +32.5 meters. Temperatures range between 60 and 70°C .

Geothermal aquifers are present in the Oradea-Carei sector in altered metamorphic rocks, karstified Mesozoic carbonates, Cretaceous sandstones and Miocene-Pliocene conglomerates, sandstones and sands (Țenu 1981). Data from 1980 has shown that flowrates ranged between 2.2 and 35 l/s. Temperatures ranged between 48 and 82°C . The potential of these aquifers is strongly diminished at the moment.

The central part is defined by the Oradea-Băile Felix-Băile 1 Mai-Sântandrei geothermal system. At Oradea, geothermal water is produced from Middle Triassic limestones and dolomites, at depths of 2000-3440 m. Flowrates range between 3 l/s and 40 l/s. Temperatures range between 72°C and 102°C .

At Băile Felix-Băile 1 Mai, therapeutic mineral water is produced from Lower Cretaceous carbonate formations of the Bihor Unit, at depths of 42-500 m. Flowrates range between 7 l/s and 27 l/s. Temperatures range between 34°C and 45°C .

The southern part comprises the following sectors: Crișul Repede-Crișul Negru, Crișul Negru-Mureș and south of Mureș.

In the Crișul Negru-Mureș sector, the basement of the Pannonian basin consists of metamorphic rocks and Upper Cretaceous-Paleogene sandstones. The sedimentary cover contains Miocene and Pliocene conglomerates, sandstones, limestones, sands, and marls.

Geothermal waters are exploited from weathered metamorphic rocks, Upper Cretaceous sandstones and conglomerates, and Miocene or Pliocene sandstones.

South of Mureș, the basement of the basin contains metamorphic and volcanic rocks. They are covered by Miocene siliciclastic rocks and Pliocene clays, sands and marls. Geothermal waters are produced from weathered metamorphic rocks, Miocene limestones and sandstones or Pliocene sands.

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Reevaluation of the conventional hydrocarbon potential in Northeast Bulgaria – overview and first steps

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Crude oil and natural gas maintain their status as resources of fundamental importance for global and regional energy security. The present study aims to synthesize the available geological, geophysical and geochemical data to reevaluate the conventional hydrocarbon potential of Northeast Bulgaria. This is based on a comprehensive analysis and interpretation of hydrocarbon perspectives.

Northeast Bulgaria and the adjacent Black Sea offshore are characterized by proven petroleum potential with the Tyulenovo petroleum field, as well as the offshore gas fields Galata, Kavarna, and Kaliakra. Several local hydrocarbon accumulations have been also established: onshore (Durankulak, Krapets, Balgarevo, Priseltsi, and Novo Oryahovo) and offshore (Samotino more). Numerous exploration wells drilled for oil and gas within the South Moesian periplatform zone and the Dolna Kamchia depression have recorded hydrocarbon findings.

Significant part of Northeast Bulgaria remains poorly explored, and the existing interpretational models are insufficient for a detailed elucidation of its hydrocarbon potential. A number of prospective zones have not been the subject of modern detailed analysis, while a part of the data requires revision in the context of the new geological concepts.

The poorly explored zones are of particular interest within the following structural units: the North Bulgarian arch, the Varna monocline, the South Moesian periplatform zone east of the Yantra River, and the Dolna Kamchia depression.

The criteria for evaluating the hydrocarbon potential encompass a detailed analysis of the elements and processes that determine the functioning of the petroleum systems. The potential source rocks, the degree of thermal maturity of the organic matter, the spatial distribution of reservoirs and seals, as well as the localization of tectonic and stratigraphic traps, have been analyzed. All crucial hydrocarbon prerequisites have been systematized, which resulted in the oil and gas accumulations.

In the South Moesian platform margin, the main stratigraphic intervals with hydrocarbon potential are associated with thick Mesozoic sequences, which include source rocks, reservoirs, and seals, namely the Middle Triassic carbonate sediments (Doirentsi Fm.), the Upper Triassic dolomites (Russinovdel Fm.), the Lower-Middle Jurassic argillaceous-terrigenous-carbonate deposits (Ozirovo Fm. and Etropole Fm.), as well as the Lower Cretaceous carbonates (Ticha Fm. and Kaspichan Fm.).

In the offshore area of the Western Black Sea basin and the Dolna Kamchia depression, the hydrocarbon potential is primarily associated with the Paleogene and, to a lesser extent, the Mesozoic complexes. The Middle-Upper Eocene terrigenous deposits of the Avren Fm. and the Oligocene terrigenous-argillaceous sediments of the Ruslar Fm. meet the criteria for reservoirs and seals. The prospective Mesozoic sequences are associated with the Lower Cretaceous terrigenous-carbonate deposits of the Kamchia Fm. and Kaspichan Fm.

The investigated targets in Northeast Bulgaria are classified into four categories according to the degree of their hydrocarbon potential: highly prospective, prospective, low-prospective, and non-prospective or with undetermined potential.

Acknowledgements. This work has been carried out in the framework of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers № 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria.

Geology and HC potential of the Maikopian and Messinian channels exploration asset within the Dolphin E&P special permits offshore Ukraine

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The area of study, the conjugation zone between the slope of Precambrian EEP, Paleozoic-Cimmerian Scythian platform and younger Meso-Cenozoic Black Sea basin, is surprisingly complex in terms of tectonic structure and evolution of the whole region that is making it simultaneously as the most interesting area from the geological point of view, despite of the relatively moderate hydrocarbon resources. In 2021, PGS Exploration ASA, under a contract with NJSC Naftogaz of Ukraine, conducted high-resolution 3D seismic acquisition coupled with detail bathymetric mapping in a shallow water area of 5000 square kilometres in the Far Northwestern Inner shelf of the Black Sea of Ukraine.

Based on the interpretation of the latest 3D seismic data and relying on the industrial “standard” for the identification of oil and gas plays, seven promising hydrocarbon plays within the perimeter of Dolphin 01-10 special permits were identified (Kitchka et al., 2025). Amongst these plays we recognized and studied in detail two of the youngest ones that are the most important for the main Black Sea basin hydrocarbon potential, namely the Maikopian and Messinian ones. The last one incorporates rather enigmatic seaway between the Dacian and contemporaneous Black Sea, this in fact the northern branch of late Neogene Danube deflected to the north by stable crustal block of the North Dobrogea Promontory. It was run west-east sinusoidally along the Sassyk thrust-slip fault then turned right to join rather deep Odessa canyon traversing continental shelf break of the Marginal Terrace (Kitchka & Tyshchenko, 2019).

There are many braided (and sometimes temporary) channels and tributaries with oxbow lakes and internal islands along its route. It should be mentioned that there are no evident amplitude bright spots along the feature, so the most probable traps are related to closures along main course of the channel created by differential compaction and local tectonics. The most promising entrapment area is located towards northern tributary uphill general slope. The drainage feature has a typical river-like V-shaped cut of 2-3.5 km wide filled with stacked sandstone reservoir units of 300 m total depth.

The Maikopian channels differ from the above though they occur at several different stratigraphic levels and are more streamlined upon their appearance and also marking the peak of orogenic stage (subsidence of the basins and simultaneous rising the cordilleras) so it is clearly seen how Maikopian (mostly early Neogene, stage) have bypassed the rising Kiliya-Zmiiny Uplift inside the Parathetian sedimentary realm. We have mapped one anticlinal closure traversing the valley on the east side of the cube and several fault-related traps attributed to the Sassyk thrust-slip fault. Maikopian drainage features are usually twice as wide as Messinian ones and have less sinuosity along the stream.

Except for these two prominent drainage systems there are other ones in the deeper sequences, but it is quite another story. It is well known the Black Sea basin lacks reservoir rocks and their spatial development is very uncertain; to find high quality reservoir is quite equal to discover a commercial hydrocarbon field.

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Three-Dimensional Gas Mapping in the Bulqizë Chromite Mine (Albania): Hydrogen, Methane, Oxygen and Structural Controls

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The Bulqizë chromite mine, hosted within the Eastern Albanian ophiolite belt, provides exceptional underground access to an active natural hydrogen system at depths exceeding 1 km. As part of an ongoing PhD project, approximately 7,500 gas measurements were carried out in mine anchors across four underground levels. The surveyed levels range in length from approximately 900 to 1,900 m and are separated vertically by about 40 m.

Hydrogen (H₂), methane (CH₄), oxygen (O₂), and carbon dioxide (CO₂) concentrations were integrated into a three-dimensional model of the underground galleries. Because the measurements were performed in a deep underground mine, the spatial model should be considered as a relative 3D reconstruction of the gallery network rather than an absolute georeferenced coordinate system.

The results reveal a highly heterogeneous gas distribution. Methane concentrations locally exceed 13 vol.% and are concentrated in restricted sectors, while hydrogen anomalies follow the same spatial pattern. Oxygen decreases strongly in gas-rich zones, whereas CO₂ is systematically absent or close to detection limits. The spatial organization of the anomalies indicates that gas migration is controlled by fracture and fault corridors intersecting the chromite-bearing ultramafic sequence.

Preliminary structural measurements, mostly from Level 21, support the interpretation of fault-controlled gas drainage. Although the available lineation dataset is still limited, it suggests that the main gas anomalies are associated with preferentially oriented fracture planes acting as migration pathways. Further structural measurements are underway to better characterize the fracture network controlling gas migration.

This study highlights the importance of combining 3D underground mapping, systematic gas measurements and structural observations to characterize active fluid circulation in ophiolitic hydrogen systems.

Evolution of fluid flow and hydrocarbon migration in a fractured Triassic carbonate system (North Hungarian Paleogene Basin)

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The faulted and fractured rock assemblages of the North Hungarian Paleogene Basin are primary exploration targets for the hydrocarbon and geothermal energy industries in Hungary. This study investigates a deep borehole intersecting a fractured and brecciated rock succession through detailed petrographic and geochemical analyses. These data are used to reconstructs the history of paleofluid migration within the studied fault zone.

The material investigated originates from Well-A, which intersected a fault zone developed within a Triassic carbonate succession. The studied core interval comprises a fault breccia dominated by calcite cement, while the wall rock is preserved only as isolated clasts. To distinguish individual cement generations and associated fluid migration events, conventional petrography and cathodoluminescence microscopy were used. These investigations were complemented by fluid inclusion petrography and microthermometry. Primary aqueous fluid inclusion assemblages hosted by the different calcite cement phases exhibit distinct homogenization temperature ranges, indicating that the calcite cement precipitation under different physicochemical conditions. Hydrocarbon-bearing inclusions were further characterized using UV-fluorescence spectroscopy and fluorescence lifetime imaging microscopy (FLIM).

Based on the combined petrographic and fluid inclusion dataset, five calcite cement generations were identified, three of which are associated with hydrocarbon-bearing fluid migration. In addition, the morphology, distribution, and size of wall rock clasts indicate multiple successive fracturing events, each followed by episodes of calcite cementation.

The composition of fluid-inclusion assemblages preserved within the various cement phases allows reconstruction of temporal variations in hydrocarbon charge within the fault zone. The results suggest that the early stages of fault-zone evolution were characterized by intensive hydrocarbon migration, followed by a progressive decline in hydrocarbon saturation. However, hydrocarbons reappeared in the system after precipitation of the youngest calcite cement phase, indicating a subsequent hydrocarbon migration event. These observations highlight the importance of repeated fault activity in controlling fluid-flow pathways and hydrocarbon migration within fractured carbonate reservoir of the North Hungarian Paleogene Basin.

Acknowledgements. This work was sponsored by the National Research, Development and Innovation Fund, University Research Scholarship Programme (EKÖP), Cooperative Doctoral Programme and Hungarian Scientific Research Fund (grant No. K-138919) Ministry of Culture and Innovation, Hungary.

Geochemical characterization of crude oils and condensates from Romania and Bulgaria: new insights from carbon, hydrogen, and sulfur contents and trace element data

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The major and trace metal composition of crude oil, bitumen and their source rocks provides insight into the paleoenvironmental conditions during source-rock deposition and ultimately the processes of oil generation, migration and secondary modification, as well as the basis for chemical classification of petroleum products (e.g., Georgiev and Hurtig, 2025). Here we present the first published C and H contents for 43 petroleum samples from two eastern European petroleum provinces: 12 crude oils and 7 condensates from the Moesian Platform in Bulgaria and 24 crude oils sampling various basins across Romania. These data are complemented by new, as well as previously published (Georgiev et al., 2024) trace element compositions and S contents.

The crude oils from Romania exhibit a broad range of C (67.70 to 85.66 wt%) and H (8.55 to 14.40 wt%) contents, with atomic H/C ratios within 1.28–2.05. In contrast, the Bulgarian crude oils show narrower C (80.96–84.68 wt%) and H (11.22–13.59 wt%) content ranges, as well as atomic H/C ratios (1.66–1.95). The Bulgarian condensates have even smaller variations of C (83.24–84.07 wt%) and H (13.64–14.65 wt%) contents and exhibit the highest atomic H/C ratios (1.97–2.09), which is consistent with a dominantly paraffinic composition. Sulphur content is generally low (<0.5 wt%), except for one Romanian sample (ST05) from the Eastern Carpathians with 4.63 wt%. Trace element concentrations are overall low (<1–2 ppm) in most samples. However, two Romanian crude oils have elevated Fe (172.30–244.58 ppm), Ti (10.70–15.14 ppm), and Cr (5.87–6.08 ppm), most likely reflecting entrapped detrital minerals or contamination from pipeline corrosion rather than indigenous petroleum geochemistry. Furthermore, the crude oils from Gigen and Selanovtsi (Bulgaria) have substantially higher V (11.85–10.67 ppm), Ni (12.98–9.62 ppm), and Ca (134.76–41.59 ppm) concentrations compared with the rest of the Bulgarian samples.

Low V/(V+Ni) ratios (<0.15) in most Romanian crude oils, as well as the Bulgarian Tyulenovo crude oil and Butan and Dolni Dabnik condensates indicate lacustrine origin for the source rocks and deposition under predominantly oxic bottom-water conditions. By contrast, the remaining Bulgarian samples mostly have V/(V+Ni) ratios of ~0.5 indicative of suboxic conditions, which is consistent with published palaeoenvironmental reconstructions pointing to Lower-Middle Jurassic source rocks from the Moesian Platform (Georgiev et al., 2024). Conversely, the elevated V/(V+Ni) ratio (0.59) and high S content (4.63 wt%) of the Romanian sample “ST05” from the Eastern Carpathians suggest a more anoxic-euxinic depositional setting for the source rock of this crude oil.

Acknowledgements. This work is supported by grant KII-06-DB/6 of the Bulgarian National Science Fund.

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Session GS7

Engineering Geology and Urban Geology

Convener:

Vasile Fărcaș

Dynamic loading of rock masses in deep geological repository (DGR) projects

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As of 2022, there are 437 operable power reactors in the world, with a combined electrical capacity of 393 GW. Additionally, there are 57 reactors under construction and 102 reactors planned, with a combined capacity of 58 GW and 108 GW, respectively, while 325 more reactors are proposed. High-level waste from these reactors is currently estimated to exceed 300,000 tonnes, while low- and intermediate-level waste is many times that value. Suitable sites for disposal and isolation from the surrounding natural environment of this waste, which must be stored for hundreds of thousands of years, must be found.

Underground construction creates a damage zone around excavation. The depth away from the excavation surface of the damage zone depends on the rock mass properties, the stress field, and the construction method. This presentation investigates the fracture development process in the magmatic rock masses and evaluates continuum modelling methods to predict the damage zone dimensions under static and dynamic loading. The fractured characteristics also affect the behaviour of the rock mass.

By presenting a case study started from the laboratory scale, a complete investigation has been carried out by using the conventional rock mechanical measurements, but with concentrated focus on the uniaxial compressive strength measurements for detailed description of the brittle fracturing behaviour. This procedure was followed by investigating of the in-situ large scale rock mass using the information from the underground facility (tunnel mapping, in-situ geotechnical, geophysical measurements). This allowed for the assembly of rock mechanical behaviour from the microscopic scale to large scale.

Using a continuum based static and dynamic modelling approach, a set of predictive damage depth curves were developed for the different excavation damage zones. This approach was found to be sensitive to the tensile strength used as an input in case of static approach and further results shown the sensitivity of the previously induced excavation damage zone depths using the method for brittle rocks due to the dynamic loads. These approaches are handling the dynamic loads of the drilling and blasting excavation method and the earthquakes. Back analysis of a DGR radioactive waste repository project and forward prediction of the excavation damage around its underground cavities in granitic rock mass are used to illustrate the importance of this presentation.

Engineering geological assessment of the rocks forming the Stone Mushrooms, Eastern Rhodopes, Bulgaria

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The Stone Mushrooms are a rock phenomenon near the village of Beli Plast in Bulgaria, on the road between Haskovo and Kardzhali. The present study examines the natural phenomenon of the Stone Mushrooms by conducting an engineering-geological assessment of the rocks and the area in which they are located.

The rocks are a variegated set of acidic (rhyolitic) volcanic tuffs with accessory medium-acid lapilli. They were formed by volcanic activity from the Paleogene period and subsequent erosion. White to pale pink at the base (stump) to slightly darker or grayish-greenish at the cap of the mushroom. The pink color is due to the mineral clinoptilolite, and the blue and black spots are from manganese concretions. The greenish color comes from the mineral celadonite. The rocks themselves are up to 2.5–3 m high.

Geological hazards in the area that may affect the rock phenomenon are (Krastanov et al., 2025a, b): erosion, weathering, earthquakes, climatic impact, human activities (human impact), etc. This determines the vulnerability of the rock monument to these geological processes.

A number of studies have been carried out on rock samples. LIDAR and radiometric thermal camera imaging was performed using a drone. Results of the studied samples of the rocks that make up the Stone Mushrooms are characterized by the following indicators: bulk density, water absorption, point load strength (PLT), compressive strength of rock types (Schmidt hammer), and dynamic deformation modulus (Deflectometer Terratest 8000) (Krastanov et al., 2024, 2025a).

Namely: bulk density on average in an air-dry state 1.53 g/cm³ (1.16–1.76 g/cm³); in a water-saturated state 1.80 g/cm³ (1.62–1.95 g/cm³). Water absorption on average 18.75% (10.04–40.60%). The average value of the corrected point load index $I_{s(50)}$ is 0.46 MPa for the stronger (cap of the mushroom) and 0.21 MPa for the weaker (base of the mushroom) rock varieties.

Acknowledgements. This study was conducted under the project “Geological risk assessment on rock cultural monuments on the territory of the Eastern Rhodopes”, funded by the Scientific Research Fund (contract KPI-06-H84/2 of 09.12.2024).

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Engineering geological assessment of the rocks forming the Stone Wedding, Eastern Rhodopes, Bulgaria

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The Stone Wedding is a rock phenomenon near the village of Zimzelen in Bulgaria, about 3.2 km northwest of the city of Kardzhali. The present study examines the natural phenomenon of the Stone Wedding by conducting an engineering-geological assessment of zeolitized rhyolite pyroclastics from the Beli Plast complex, over an area of 5.0 ha. The stone sculptures were formed as a result of differential weathering and erosion processes. This is due to the varying hardness and mineral composition of the pyroclastic layers, where softer tuffs eroded faster than the more resistant parts.

Geological hazards in the area that may affect the rock phenomenon are (Krastanov et al., 2025a, b): erosion, weathering, earthquakes, climatic impact, human activities (human impact), etc. This determines the vulnerability of the rock monument to these geological processes.

A number of studies have been carried out on rock samples. LIDAR and radiometric thermal camera imaging was performed using a drone. Results of the studied samples of the rocks that make up the Stone Wedding are characterized by the following indicators: bulk density, water absorption, point load strength (PLT), compressive strength (Schmidt hammer) and dynamic deformation modulus (Deflectometer Terratest 8000) of rock types (Krastanov et al., 2024, 2025a).

Namely: bulk density on average in an air-dry state 1.74 g/cm³ (1.59–1.86 g/cm³); in a water-saturated state 1.96 g/cm³ (1.84–2.05 g/cm³). Water absorption on average 12.69% (9.54–16.62%). The average value of the corrected point load index $I_{s(50)}$ is 0.08 MPa (0.01–0.41 MPa).

Acknowledgements. This study was conducted under the project “Geological risk assessment on rock cultural monuments on the territory of the Eastern Rhodopes”, funded by the Scientific Research Fund (contract KII-06-H84/2 of 09.12.2024).

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Electrical Resistivity Tomography as a Decision Support Tool for Borehole Positioning and Geological Monitoring in the Slănic Area (Romania)

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Electrical Resistivity Tomography (ERT) is widely applied in near-surface investigations due to its ability to provide continuous imaging of subsurface electrical resistivity and to complement information obtained from direct geological investigations. Integrating geophysical and borehole data represents an effective approach for reducing uncertainties associated with the characterization of complex geological and hydrogeological environments.

Within the GEOMONITOR project, ERT investigations were performed in the Slănic area alongside a drilling programme comprising three geological and three hydrogeological boreholes. Two-dimensional resistivity models were interpreted in conjunction with lithological descriptions and hydrogeological observations obtained during drilling, allowing a comprehensive assessment of subsurface conditions.

Resistivity distributions revealed marked lateral and vertical variations related to changes in lithology, weathering degree and groundwater occurrence. Correlation with borehole information facilitated the identification of geoelectrical units and improved the interpretation of subsurface heterogeneity between investigation points. Integrating geophysical and geological datasets also contributed to refining the local geological and hydrogeological model, highlighting the spatial continuity of geological features that cannot be resolved using borehole information alone.

The study demonstrates the benefits of combining Electrical Resistivity Tomography with conventional geological investigations for subsurface characterization and geological monitoring. Continuous geophysical imaging, supported by direct borehole observations, provides a more reliable basis for interpreting geological and hydrogeological conditions and contributes to the development of integrated monitoring strategies in areas characterized by complex subsurface conditions.

Acknowledgements. This work was carried out within the GEOMONITOR project. The authors gratefully acknowledge the Geological Institute of Romania for providing technical support, access to geophysical equipment and logistical assistance during the field investigations conducted in the Slănic area.

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Session GS8

**Environmental Geochemistry -
Exploring new frontiers in past metal pollution
and environmental research**

Conveners:

Daniel Veres, Gabriel Ovidiu Iancu

Geochemical Backgrounds and Anomalies: Linking Environmental and Resource Geochemistry with Geological Complexity in Slovenia

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Environmental geochemistry focuses on the distribution and behavior of inorganic and organic contaminants in the environment. Chemical elements occur naturally in the environment, and elevated concentrations may result from mineralization, specific lithologies, or human activities such as mining, industry, urbanization, traffic, and agriculture. Geochemical background and threshold are two fundamental concepts in environmental geochemistry. Geochemical background represents the normal, expected concentration range of an element in soil, sediment, or water of a given area. It reflects natural geological settings. However, due to long-term human impacts, even concentrations measured in remote areas may include diffuse anthropogenic influence. As a result, the term ambient background was introduced. A threshold differentiates between background and anomaly.

Understanding the geochemical background range is essential for distinguishing natural variation from pollution or mineralization, setting environmental quality standards, identifying contamination sources, and interpreting geochemical anomalies in environmental and mineral exploration studies. The presentation will synthesize current research with the historical development of the field, demonstrate the integration of geochemical background and threshold concepts in environmental assessments and mineral resource exploration, and present case studies from Slovenia and Europe.

Slovenia is situated at the junction of four major tectonic units — the Dinarides, the Southern and the Eastern Alps, and the Pannonian Basin. The Dinarides and the Southern Alps cover nearly 60% of the territory and are composed mainly of sedimentary rocks, with carbonates predominating, forming an extensive karst landscape. The Eastern Alps consist predominantly of metamorphic and magmatic rocks, while the Pannonian Basin is filled with a thick sedimentary sequence. These natural features determine the baseline geochemistry, while a long history of human activity has further shaped the geochemical characteristics of Slovenia. Centuries of intensive mining, industry, and urban development have left regional and local signatures in the distribution of potentially toxic elements (PTEs).

The influence of long-term mining and ore-processing activities on PTE accumulation in various environmental media, including different types of dust in mining and urban areas (city dust), has been studied for more than 30 years by the geochemistry research group of the Geological Survey of Slovenia. It has been established that, in Slovenia, mining and ore processing are the most important anthropogenic sources of metals in the environment. Two of the most affected areas are the regions surrounding the Mežica and Idrija closed mines. In urban areas, interactions between chemical elements and their compounds of both natural and anthropogenic origin are common. Extreme weather events, including episodes of intense precipitation and flooding, present significant environmental challenges by triggering the mobilization of contaminants that were previously stable. These events can alter the spatial distribution of pollutants and transform their physicochemical properties, thereby complicating efforts to assess and manage environmental quality. Understanding these mechanisms and their implications for environmental quality is becoming increasingly important in the context of global environmental change.

Acknowledgements. This Invited Lecture was supported by the Slovenian Research and Innovation Agency (ARIS) through the research projects ExtremEarth (J7-60124), CityDust (N1-0440) and the research programme Groundwater and Geochemistry (P1-0020).

Anthropogenic lead in peat archives: reconstructing ancient metal pollution and societal complexity in the Carpathian-Balkan region and beyond

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Atmospheric lead (Pb) deposited in natural archives is one of the most widely used proxies for reconstructing past human impacts on the environment. Because atmospheric Pb arises mostly from human activity (e.g., mining, smelting, and later leaded petrol), and is transported and deposited efficiently via the atmosphere, the flux of anthropogenic Pb accumulating in an archive provides a direct measure of past pollution intensity. Ombrotrophic peat bogs, archives that receive inputs solely from atmospheric deposition, offer high-resolution, well-dated records of this anthropogenic Pb flux, allowing changes in metal pollution to be reconstructed over millennia. When combined with Pb isotope analysis, these records can identify the sources of contamination, offering a powerful tool for linking environmental archives to historical patterns of resource extraction, trade, and conflict.

In this talk I will review our previous work applying this approach in the Carpathian-Balkan region, a landscape with a long and rich history of metal extraction, to reconstruct ancient metal pollution. This includes our study identifying pre-Roman and subsequent mining and metallurgical pollution signals in peat archives from a bog in Serbia and our subsequent work extending this framework to archaeological questions of production and provenance in the Medieval period covering the whole Balkan.

Looking ahead, I will outline three key directions for our future research in this field. First, how a new large-scale synthesis of Pb records from lakes and peat bogs across Europe aims to produce a global-scale picture of historical pollution trends. Second, I will present a new method for the application of Pb isotopes to identify ancient pollution sources, using subtraction of the lithogenic background signal followed by source-mixture modelling in MixSIAR to better constrain the provenance of atmospherically deposited Pb. Finally I will discuss an investigation into whether peat-derived Pb pollution levels can serve as a proxy for societal complexity, through comparison with quantitative measures of social organisation from the Seshat: Global History Databank. Collectively, these directions aim to extend the utility of peat Pb records from tracing pollution history to informing broader questions about human societal development.

A multiscale approach for environmental monitoring in mining areas

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The growing rate of mineral extraction imposes increasing pressure on the environment in mining areas.

The expansion of mining operations, coupled with progressively stricter environmental requirements, renders environmental monitoring increasingly complex and financially burdensome for operators.

Conventional ground-level assessment techniques frequently fail to deliver the requisite spatial-temporal resolution for extensive, intricate mining terrains, especially in monitoring acid mine drainage, heavy metal dispersion, land use and landscape alterations, ecological changes, and impact on the communities and ecosystems. The project “*Multiscale observation services for mining-related deposits – MOSMIN*” aims to develop an innovative array of tools and services for geotechnical and environmental monitoring, along with the valorisation of mining-related deposits. MOSMIN integrates ground-based measurements with aerial and satellite data to achieve a more accurate and comprehensive assessment of the environmental conditions in mining regions.

Acid mine drainage (AMD) is among the most harmful environmental impacts in mining areas. A thorough comprehension of AMD formation, together with the identification of its pathways and accumulation zones, is essential for successful mitigation and impact reduction. The concept has been tested at Roşia Poieni porphyry copper mine, a medium-size open pit operation in the Apuseni Mountains – Romania.

Combined mineralogical analyses and hyperspectral satellite data from PRISMA and EnMAP platforms allowed the identification of alteration types and secondary minerals assemblages responsible for the AMD generation. Multispectral satellite data, particularly from Sentinel-2, were shown to be essential for spatial and temporal scaling of hyperspectral results. At the local scale, UAV-based multispectral and hyperspectral imaging proved critical for resolving contaminant distributions in narrow drainage corridors and near-field impact zones that are not adequately captured by satellite sensors. The tailings storage facility (TSF) acts as a sink for acid water and transported particulates.

The integration of these space-air-ground observation methods effectively addresses the limitations of individual investigation modalities, thus contributing to more effective environmental monitoring and cleaner mining operations. The EO-derived indicators proved to be useful tools for the assessment of contaminant generation, mobility, and persistence in mining environments.

Acknowledgements. This work was financially supported by the European Union Agency for the Space Programme under Project 101131740—MOSMIN—HORIZON-EUSPA-2022-SPACE.

New geochemical and mineralogical data on phosphogypsum from Turnu Măgurele, Romania

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Following the global trend towards reducing the consumption of primary raw materials, the circular economy is increasingly focusing on industrial wastes, technological by-products and mining wastes. Phosphogypsum is a by-product of phosphate fertilizer production and is produced in large quantities. Over 3 billion tons of phosphogypsum are stored worldwide in dumps covering hundreds of hectares. Their recycling in order to obtain raw or construction materials needed for various branches of industry is a scientific challenge. In this context, the accurate knowledge of the chemical composition of phosphogypsum deposits, as well as of geochemical processes that affect the wastes plays an important role. Phosphogypsum is mainly composed of gypsum (up to 95%) and minor proportions of quartz, brushite-ardealite, celestite, fluorite and clay minerals. The content in elements other than Ca and P varies depending on the nature of the raw phosphates used in the manufacture of phosphoric acid for chemical fertilizers and on the type of process used.

As part of the efforts to increase the knowledge on phosphogypsum from one of the six case studies selected by the FIC-FIGHTERS project (this project is funded by the European Union under grant agreement N° 101135157), four phosphogypsum samples collected from different areas of the Turnu Măgurele dumps were analyzed by XRD, SEM and LA-ICP-MS on pressed pellets. The chemical compositions of all four samples are quite similar, the minor differences reflecting differences in the origin of the raw phosphate rock (phosphorite) used by the dihydrate process employed to obtain phosphoric acid.

The measured Sr/Ca ratios indicate that the Turnu Măgurele phosphogypsum originates from phosphorites formed in sedimentary (Sr/Ca < 0.0057, one sample) as well as in magmatic (Sr/Ca > 0.0057, three samples) conditions. The phosphogypsum from Turnu Măgurele contains a series of chemical elements, i.e., Presumably Contaminating Elements (PCE), light and heavy REE, U and Th. that are considered toxic by the Environmental Protection Agency of the United States. Another element identified in all the analyzed samples is Ba; it appears in very small quantities (up to 209 ppm), but always Sr (up to 6715 ppm) > Ba. Both Sr and Ba readily substitute Ca in the gypsum structure. Other PCE are represented by Ta, Cu, Zn, Co, Ni, V, Ti, Nb, Cr and Pb, among which Ti is the most abundant (up to 842 ppm). The presence of V, Ni, Co, Ti, Fe and Mn, as well as the sum of LREE, which is always higher than the sum of HREE, reflects the capacity of phosphogypsum to preserve element patterns of its source rock. PG from Turnu Măgurele preserves a negative Eu anomaly, which is characteristic for all the phosphorites used as raw materials, reflecting that a reductive environment persisted both during the generation of phosphorites and during the technological process.

High mobility of the PCE elements is expected under the acidic pH conditions typical of phosphogypsum waste dumps; this could increase the risk of toxicity by rainwater drainage reaching the groundwater level and increases the importance of this study.

Assessing Soil Contamination and Potentially Toxic Elements Enrichment in an Urban-Adjacent Vineyard Soil, Iași, Romania

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Effective monitoring and management of soil quality depend critically on distinguishing between natural geochemical baselines and anthropogenic inputs. Vineyard soils are highly susceptible to accumulating potentially toxic elements (PTE) due to long-term agrochemical treatments applied for fertility and plant disease prevention. This study presents preliminary data evaluating eight PTE (Cr, Co, Ni, Cu, Zn, Cd, Pb, and As) to highlight the extent of anthropogenic degradation in a vineyard plot located in the southern part of Iași city, Romania. For a comprehensive assessment, 15 topsoil samples (~1.5 kg each) were collected, alongside profile samples and samples from the middle of the vine rows at a depth of 50 cm. The total PTE content was determined using Energy-Dispersive X-ray Fluorescence (ED-XRF). Environmental indices, specifically the geoaccumulation index (I_{geo}) and contamination factor (CF), were calculated to quantify human-induced pollution using background values determined from uncontaminated deep soil in a control area.

The preliminary findings demonstrate a clear anthropogenic fingerprint, as all analyzed elements, with the exception of Cd, exceed natural background levels. Furthermore, Cr, Ni, Cu, and Pb concentrations surpass normal soil baseline levels, with Cu significantly exceeding the alert threshold of 100 mg/kg as stated by the Romanian legislation in force. While computed I_{geo} values characterize the soil conditions as unpolluted to moderately polluted, the individual CF values reveal distinct and varying pollution levels: low contamination for Cr, Co, and Cd; moderate for Ni; significant for Cu and Pb; and very high contamination levels for Zn and As. Complementary mineralogical analysis on the 63 μ m soil fraction showed a relatively homogenous composition consisting of quartz, muscovite, albite, K-feldspar, and secondary minerals such as illite, illite-smectite, montmorillonite, kaolinite, and calcite. Except for quartz, these minerals can accommodate PTE only at the trace level, confirming they are not the primary source of contamination. Consequently, the elevated PTE budget is attributed to anthropogenic inputs, predominantly intensive agricultural practices coupled with urban traffic pressures. Under the identified slightly alkaline pH conditions, PTE mobility is reduced, as Fe- and Mn-oxy-hydroxide compounds or carbonate precipitation are likely involved in their retention. Therefore, the grapevines are not currently exposed to excessive PTE uptake, and the toxicity risk remains diminished as long as the soil physico-chemical parameters do not significantly change.

Acknowledgements. First author acknowledges the support provided by the project “Integrated interdisciplinary system for the implementation of sustainable development activities in the North-East Region of Romania – SIDNER” (Cod SMIS: 337821).

Geochemical assessment of alluvial sediments from Ditrău Alkaline Massif, Eastern Carpathians, Romania

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In the present study we investigated alluvial sediments from two rivers draining the Ditrău Alkaline Massif in the Romanian Eastern Carpathians: 10 samples from the Ditrău River and 10 from the Jolotca River. Twelve potentially toxic chemical elements (As, Cd, Pb, Zn, Cu, Ni, Cr, Hg, Co, V, Mn, Fe) were analyzed in a certified lab (ALS Minerals Loughrea, Ireland), applying the ME-MS61L™ method (Super Trace Lowest DL 4A by ICP-MS). The geochemical background values were determined by the iterative Median + 2×MAD method (Reimann et al., 2005).

Moreover, ten pollution indices were calculated: Enrichment Factor (EF), Geoaccumulation Index (I_{geo} ; Müller, 1969), Contamination Factor (CF), Pollution Load Index (PLI; Tomlinson et al., 1980), Ecological Risk Index (RI; Håkanson, 1980), Modified Nemerow Index (mCd), Toxicity Risk Index (TRI), ERM Quotient (mERMQ), Sediment Index (CSI), and Modified Hazard Quotient (mHQ); UCC from Rudnick & Gao (2014).

The results for Jolotca River indicate a mean PLI of 0.987; four samples slightly polluted (1J, 4J, 8J, 20J; PLI 1.02–1.27); mean RI 117.7; sample 20J at moderate risk (RI 167.5); mCd 1.78; TRI 5.66; mERMQ 0.213; CSI 0.353; mHQ 0.886. As enrichment reflects post-magmatic hydrothermal REE–Ti–Fe–Nb mineralisation (Fintor et al., 2025), Zn is above UCC.

For Ditrău River, all PLI values are < 1 (which suggests an unpolluted area, with a mean of 0.783); mean RI 76.8 (all low risk); mCd 0.889; TRI 3.61; mERMQ 0.157; CSI 0.249; mHQ 0.635. Enrichment in Cr, Ni, Co, and V reflects ultrabasic/mafic rocks of the Ditrău Massif.

EF values indicate predominantly minimal to moderate enrichment ($EF < 2$), consistent with a lithogenic source. I_{geo} classifies all samples as Class 0 (unpolluted).

Both rivers show natural geochemical signatures of the Ditrău Alkaline Massif. Elevated As in Jolotca River sediments is consistent with post-magmatic hydrothermal REE–Ti–Fe–Nb mineralisation of the Jolotca ore field (Fintor et al., 2025), while the Ditrău River reflects ultrabasic/mafic contributions. No anthropogenic impact or ecological risk was identified.

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Heavy metal sources assessment in the sediments of Topolnitsa River basin (Bulgaria) using advanced SIMONA sediment quality protocols according to the EU Water Framework Directive

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Topolnitsa River basin is an area of economically significant historic and recent mining, ore processing and agricultural activities. Present study is a follow-up on a previous river sediment quality assessment in the Topolnitsa River basin, expanding its scope and tracing potential sources of heavy metals and arsenic in the river sediments with further tributaries and adjacent arable land.

Systematic sediment sampling, analysis, and quality assessment were carried out following and advancing EU Water Framework Directive–aligned Interreg DTP SIMONA methodologies. Twenty-two bottom river sediments and 16 floodplain sediments were collected from 11 strategic locations in Topolnitsa River Basin (Dushantsi-Petrich section), along with four arable soil samples (top and bottom layers) from the Zlatitsa and Chavdar–Chelopech areas. We analyzed the heavy metal and As content of the <0.063 mm, and selectively <2 mm fractions, on fused pellets applying XRF and LA-ICP-MS analyses at Faculty of Geology and Geography, Sofia University and Geological Institute, Bulgarian Academy of Sciences. Due to lack of environment quality standards for river sediments in Bulgaria, we compared our data with the Serbian Regulation on limit values of pollutants in surface and ground waters and sediments; the Dutch Target values and soil remediation intervention values, and background concentrations for metals in soil/sediment and groundwater legislation 2000; the USEPA Threshold Effect Concentrations (TEC) and Probable Effect Concentrations (PEC). Bulgarian background and intervention threshold values for soils were used for comparison with the collected soil samples.

Arsenic content in all sediment samples varies around the USEPA TEC values, with the notable exception of the samples from the Pirdopska and Zlatishka Rivers where As is around USEPA PEC, with one floodplain sample from Pirdopska even exceeding the Dutch intervention value. Copper contents in bottom sediments from Topolnitsa after Medet Tailings and from Medetska River, and in floodplain sediments from Medetska, Pirdopska and Zlatishka Rivers also exceed the Dutch intervention value. Zinc and Pb values in all samples are close to USEPA TEC values. Nickel is close to but below USEPA TEC, while chromium contents are around USEPA PEC values. Zlatitsa top soil sample stands out with As value higher than the Bulgarian intervention value for soil, and Co, Pb and Zn values lower than the Bulgarian intervention value, but higher than local background values.

In line with the main results for the heavy metal and As spatial distribution in the investigated area we can outline the following heavy metal and As potential sources: Pirdopska and Zlatishka Rivers – for As; the area of the Topolnitsa catchment between Medet and Chelopech Tailings – for Cu and probably Cr. The significantly elevated Cu, As and Cr contents in all Topolnitsa river sediment samples indicate ongoing and/or remobilized pollution, highlight the need for mitigation measures and the necessity for systematic sediment monitoring.

Acknowledgements. The study was supported by BG-RRP-2.011-0040-C01/02 REXPro Project, financed by NewGenerationEU Recovery and resilience mechanism, investment C2.I2 „Increasing the innovation potential of the Bulgarian Academy of Sciences in the field of green and digital technologies”.

U-Pb detrital zircon geochronology of sediments from Danube river tributaries in Bulgaria: a contribution to understanding of sediment sources

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Sediments are important components of the river systems. They can be considered the hidden key for healthy rivers, as their quantity and quality (Q&Q) control environmental, social-economic, geographic and cultural aspects. The Danube River Basin is facing significant challenges related to the Q&Q of the sediments and the two main are (i) the severely disrupted sediment continuity by the river regulation, dams, and bank stabilization; and (ii) the sediment quality monitoring remains fragmented and non-harmonized. In response to these sediment-related problems, a five-year EU project has been started in late 2024, called iNNOSED: “iNNOvative SEDiment management in the Danube River Basin”. The project aims to establish a Knowledge Center that will introduce innovative methods for monitoring and modeling the Q&Q, provide innovative sediment management practices, demonstrate new measures and evaluate their socio-economic and environmental aspects. The better understanding of the Q&Q involves studies on their geological sources. Here we present the U-Pb LA-ICP-MS detrital zircon (DZ) geochronological data on sediments from Danube river tributaries in Bulgaria and compare them with the already studied Romanian tributaries (Ducea et al., 2018) down-stream Iron Gate Dam, as the latter acts as significant sink for sediments and contaminants.

Bottom sediment samples were taken in the lower streams of Ogosta, Iskar and Yantra Rivers. Zircons were separated using conventional water and heavy liquids techniques, randomly chosen, mounted and CL-imaged. The LA-ICP-MS analyses were performed at the Geological Institute, Bulgarian Academy of Sciences in Sofia.

Three different age distribution patterns are obtained. In Ogosta River sample, more than 90% of the DZ are Variscan. They spread from rare Early Carboniferous (only 3 grains at 350–358 Ma) through a peak of 320–330 Ma and a less pronounced but clear Late Carboniferous–Early Permian signal. Only four out of 105 analyzed grains are Late Cretaceous (78–81 Ma), whereas Ordovician and Cadomian–Neoproterozoic DZ are rare, and one grain is approx. 2050 Ma. The DZ of Iskar River sediments yield ages mostly within 75–89 Ma (>90%) and rare Variscan (4 out of 104 with an age 305–330 Ma) and Ordovician grains (approx. 460 Ma, 4 grains). In Yantra River the sediments are carrying >40% DZs of Late Cretaceous age (75–88 Ma), >50% Variscan zircons (280–345 Ma), a few Cadomian to Neoproterozoic (555–640 Ma) and single Ordovician and Proterozoic grains.

The DZ data for the three Danube tributaries suggest sediment sources from outcropped rock successions in the Balkan and Getic Units in Bulgaria (the Variscan peaks of Ogosta and Yantra Rivers). They also may answer the 320–340 Ma peaks in the Danube Delta sediments that do not have their sources in the Southern Carpathians. However, the Late Cretaceous peaks from Iskar and Yantra Rivers are not clear enough in the Danube Delta sediments and ask for further studies. The future work will also include additional tributaries from the southern part of the Lower Danube basin, as well as historical sediments from flood plains to better interpret information on sediment sources and transport of DZ.

Acknowledgements. The study is supported by iNNOSED Horizon Europe project, grant 101157360.

Manganese in natural soil and Technosol from Dealu Rusului – Bistrița Mountains

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Generally, the soil inherits the mineralogical fingerprint from the parent material. When the soil developed on barren and ore-bearing rocks, its geochemistry is more diverse and can be used for raw material exploration.

In Dealu Rusului two soil categories are found. The natural soil places on mountain slope and small highlands, whereas Technosol has been generated around former waste hard material or on tailing from ore-roasting furnaces. The mineralogical differences between these two soil categories consist in the Mn-bearing mineral abundance and also pH values. The natural soil, with a dominant acid pH (<6.5) is enriched in rock-forming minerals typical of Tg2 lithogroup and in some cases, preserved ‘exotic’ Mn minerals (e.g. sonolite/jerrygibbsite, hodgkinsonite, bustamite/johannsenite, braunite, ardenite and pyrosmalite) near secondary minerals like birnessite. Technosol is enriched in mafic phases such as pyroxenes (e.g. diopside, enstatite, augite), amphiboles (e.g. hornblende, cummingtonite–grunerite, richterite, riebeckite) or other rare silicates (e.g. ilvaite, ardenite, hodgkinsonite) and its neutral to slightly alkaline pH favored the secondary todorokite development and the preservation of these mafic minerals. The mineralogy is reflected by the soil geochemical composition. Thus, in natural soil Mn concentration does not exceed the level of minor element (592–4810 mg/kg), whereas in Technosol the level of accumulation placed between 1–4% Mn. For this soil category the contamination exists. It was evaluated on the base of manganese background (400–4454 mg/kg) and contamination factor. The impact upon ecosystem was also followed by the means of potential ecological risk. The results show that the risk is low and that, as long as soil is contaminated but the conditions remain neutral, manganese bioavailability is low and no negative ecological impact could occur. Another soil feature which supports the limited environmental risk is connected to by the soil maturation degree evaluated by chemical index of weathering (CIA and modified MIA). Thus, the intermediate development stage for both soil categories (e.g. 76% CIA and 70% mMIA for natural soil; 73% CIA and 68% mMIA for Technosol) infers that the risk associated with the increase in manganese mobility is limited.

All the applied investigations show atypical soil mineralogy and Mn contents in both soil categories, which reflect the mineralogical and compositional characteristics of beneath parent material. These features can serve as geochemical tools for further ore exploration in light of the demand for manganese in the high-tech market.

Reducing Waste and Environmental Impact by Recovering Li, Co and Ni from Li-ion Batteries Using Green Alternatives

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Recovery of critical raw materials (CRMs) from waste is essential to mitigate environmental pollution and enable circular-economy strategies. In this context, extracting CRMs from spent lithium-ion batteries (LIBs) is a key step toward sustainability. Conventional approaches for CRM recovery from end-of-life batteries rely primarily on chemical leaching, which typically requires large acid quantities and raises environmental concerns. Here, a sustainable process using oxalic acid was investigated for the recovery of CRMs, including lithium (Li), cobalt (Co), and nickel (Ni), from spent LIBs. Oxalic acid is a biodegradable organic acid that has been proposed as an eco-friendly alternative to conventional inorganic acids, providing high selectivity with a reduced environmental impact.

Experiments were conducted using Type 18650 cells recovered from an e-scooter battery. Discharge was performed in two stages: first using an electrical load, followed by immersion in a saline solution (3.5% NaCl) for more than 24 h. After mechanical dismantling, the cathode materials were treated with a dilute oxalic acid solution (0.05 M) to separate them from the current collector composed of aluminum and PVDF. The cathode-material suspension (BM) was then supplemented with solid oxalic acid to reach a concentration of 1.0 M. The mixture was refluxed at 95 °C under stirring for at least 12 h. After cooling, the pH of the filtered liquid was adjusted to 12 by gradually adding concentrated sodium hydroxide under agitation, with the goal of precipitating transitional and other metals (Al, Mn, Co, Ni, Fe, and Cu). Following filtration, the residual sodium content in the clarified solution was reduced by acidifying to pH 1 using oxalic acid, which promoted sodium oxalate precipitation. The resulting clear filtrate was dehydrated, and the crystalline salts were subjected to two-step thermal decomposition: heating at 250 °C for 1 h, followed by heating at 650 °C for 1 h. This thermal treatment was intended to remove unreacted oxalic acid and convert lithium oxalate into lithium carbonate.

By demonstrating applicability across different cathode compositions, the proposed approach provides a sustainable and efficient route for LIB recycling. Overall, CRM recovery from spent LIBs supports the recycling of valuable resources and thereby contributes to the advancement of a circular economy.

Acknowledgements. Authors are thankful for the funding from the PN 23-39-02-02 project. We thank the GeoEcoLab Laboratory from Geological Institute of Romania

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Elemental-ratio signatures of Quaternary environmental change archived in selected cave sediment sequences from Romania

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Cave sediments host a wide range of geochemical proxies that record high-resolution environmental variability. Here, we investigate the elemental-ratio signatures of five sedimentary sequences in the Romanian Carpathians to reconstruct Quaternary environmental changes at well-documented archaeological sites and caves with confirmed human presence during the Late Pleistocene. The investigated caves are distributed across the major mountain regions – the Eastern Carpathians (Vârghiș caves – Lublinit, Ursului, and Peștera Mare), SW Southern Carpathians (Livadița Cave), and Apuseni Mountains (Biserița Cave), capturing a broad range of geological and environmental settings and providing a basis for evaluating the diagnostic potential of geochemical signatures in cave sediments.

High-resolution X-ray fluorescence (μ -XRF) spectroscopy was performed using an Itrax core scanner on individual sediment samples collected at 2-cm resolution from each section. Elemental ratios and relative variations of major and minor elements are integrated with stratigraphy, grain-size analysis, magnetic susceptibility, and chronological constraints into a multi-proxy interpretative framework of context-dependent geochemical associations. Based on these associations, we identified the geochemical signals of the main processes controlling sediment deposition and diagenetic evolution in each cave, including carbonate, detrital, hydrological, weathering, aeolian, biogenic, and volcanic signals.

We evaluated a total of 20–25 elemental ratios, of which 8–10 are the most relevant for each site. The data show that the geochemical signatures differ among the studied caves, reflecting differences in the dominant depositional and post-depositional processes, except for the carbonate system, which dominates all sites, as reflected by high Ca/Ti and Ca/Al values. Detrital signals indicate changes in sediment source (Mg/Ca, Sr/Ca, Ti/K, Ti/Zr), grain size and transport mechanisms (Zr/Al, Si/Al), with a distinct aeolian

input at Vârghiș and Livadița. The Mg/Ca and Sr/Ca ratios effectively constrain a felsic tephra layer at Ursului, whereas at Bisericuța, very high Sr/Rb, Sr/Ti, Ca/Ti and S/Ti ratios, together with moderately elevated Mn/Fe values, suggest diagenetic overprinting of a reworked cryptotephra horizon. Biogenic signals associated with fossil-rich layers or possible human occupation are reflected by P/Ti and P/Ca ratios, particularly at Vârghiș and Bisericuța, the latter functioning as a sediment trap. The integrated interpretation of elemental-ratio associations strongly constrains the observed stratigraphic units and occasionally captures the signatures of short-lived events, including volcanic eruptions and episodic gravitational and fluvial inputs.

The results demonstrate that elemental ratios are inherently site-specific, and their selection and interpretation should be guided by the geochemical context of individual cave sedimentary systems. The proposed framework strengthens the interpretation of μ -XRF datasets and is complementary to further investigations, including petrography, micromorphology, SEM-EDS analyses, and mineralogical characterization.

Acknowledgements. This work used research equipment from the LifeWatch Project (POC/448/1/1/ Large R&D infrastructures), contract no. 327/390003/06-11-2020, and it was financially supported by grants no. PN-IV-P2-2.1-TE-2023-0654 (to LT) and PN-IV-PCBRO-MD2024-0067 (to MR), funded by UEFISCDI; grant no. F-RO-CH-2024-0161/IZ11Z0_230102 (to DV), funded by the Swiss National Science Foundation and UEFISCDI; and EEA grant SEE-RO-NO-2018-0126/2018 (to SC).

Resolving the timing and impacts of early metallurgical pollution from the Balkans to central Europe

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Archaeological data document early cultural traits in southeastern Europe linked to ancient metalworking, but lack of data precluded a precise understanding of their long-term environmental impact. Here we report geochemical results from several Carpathian peat profiles showing evidence of lead (Pb) excess denoting anthropogenic metal pollution already by ca. 5200–4300 BCE. Our find directly corroborates the archaeological evidence, as the dazzling array of early metal artifacts considerably exceeds evidence from elsewhere making this a phenomenon largely exclusive to southeastern Europe. Using also Pb isotopic constraints and calculations of Pb accumulation, we conclude that the rise in Pb by ca. 5200–4300 BCE represents a direct record of environmental pollution during this era of primitive but widespread smelting and protometallurgical experimentation in the Balkans. We also observe another period of anthropogenic Pb pollution during the Late Copper/Early Bronze Age ca. 3,600 years BCE, to date one of the earliest such evidence documented in European environmental records. By 1000 BCE the environmental signal of excess Pb became ubiquitous in the Balkans, peaking during the Iron Age and the Roman period. A steady, almost linear increase in Pb concentration after 600 BCE, until ca. 700 CE is observed, documenting the development in both sophistication and extent of southeastern European metallurgical activity throughout Antiquity and the Roman period. A sustained medieval Pb pollution spanning 10th to 16th centuries AD reached pollution levels and a Pb flux comparable to the modern period.

Our reconstruction of environmental pollution contrasts and complements evidence from western Europe. We advocate this reflects regional variability in metal pollution output linked to developments attained by the different European societies for last millennia. Our results add crucial evidence to the long-range and long-lasting legacy cast upon the environment by past metal processing in Europe already from the Late Neolithic, c. 7000 years ago.

Acknowledgements. This research is carried out and financed within the framework of the second Swiss Contribution MAPS, LOEs-CLIMBE project № IZ11Z0_230102.

Session GS9

Hydrogeology

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How is the Water Cycle of the Carpathian Basin changing? What do we see, what do we not see, and what can we do?

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The water cycle of the Carpathian Basin is undergoing a profound transformation. Following the historic drought of 2024, large parts of the region have again experienced extreme heat and severe water scarcity. Snowmelt-driven spring floods of the River Tisza have been largely absent for years, while record-low water levels on the Danube affect navigation, aquatic ecosystems, energy production, and bank-filtration drinking water supplies. Concerns are also growing about the future of Lake Velence, and declining water levels in Lake Balaton are already impacting tourism and local economies. Across parts of the Hungarian Great Plain, sustaining traditional agriculture is becoming increasingly difficult. These developments raise an important question: has the Carpathian Basin entered a process of aridification?

This lecture explores the drivers behind these changes and explains why they cannot be understood by looking only at rivers, lakes, and canals. Beyond climatic factors, the region's water balance is strongly influenced underground water determined by regional groundwater flow systems that connect uplands, lowlands, river valleys, ecosystems. These largely invisible connections play a fundamental role in sustaining water resources and ecological functions. Drawing on research carried out by the József and Erzsébet Tóth Endowed Hydrogeology Group at ELTE, the lecture presents examples from different regions of Hungary, discusses future changes projected by climate scenarios, and reviews adaptation options, including groundwater replenishment, nature-based solutions. Special attention is given to the Nature-Based Managed Aquifer Recharge (NaBa-MAR[®]) concept, developed by the research group, which combines managed aquifer recharge with landscape-scale hydrogeological analysis to support effective and sustainable water retention. The central message is simple: the aridification of the Carpathian Basin is no longer a future risk but an ongoing process. Successful adaptation will require a better understanding of groundwater systems and their integration into water management, decision-making, and public awareness.

Acknowledgements. The research was implemented by the National Multidisciplinary Laboratory for Climate Change (RRF-2.3.1-21-2022-00014) under Hungary's National Recovery and Resilience Plan. Additionally supported by the 2023-1.2.2-HE PARTNERSEG-2023-00005, the European Partnership 101060874 – Water4All project, and the ELTE Excellence Fund.

Forensic geoscience approach to expert hydrogeological assessment in legal disputes

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Forensic hydrogeology represents a specialized application of hydrogeological knowledge, methods, and evidence in legal, administrative, and expert-assessment contexts. Unlike the narrower understanding of forensic geology commonly associated with criminal investigations, this research is focused on the objective interpretation of groundwater-related evidence, technical documentation, field observations, and professional standards in cases where hydrogeological issues become the subject of legal dispute. This paper examines the role of forensic hydrogeology in the expert assessment of groundwater intake structures, with particular emphasis on wells used for the abstraction of thermal and groundwater resources. The study is based on the premise that hydrogeological systems are naturally heterogeneous, spatially variable, and often characterized by uncertainty, which must be carefully considered when evaluating the technical adequacy and performance of tapping objects. In this context, differences in well yield, drawdown, water temperature, hydrochemical characteristics, and exploitation regime cannot be interpreted solely through the assumption of technical deficiency, but must be assessed in relation to the natural variability of the aquifer system. The methodological framework includes the analysis of technical and project documentation, review of hydrogeological reports, interpretation of lithostratigraphic and well-construction data, field inspection of the site, spatial verification of tapping objects, and synthesis of all available hydrogeological evidence. Special attention is given to distinguishing between variations caused by natural geological and hydrogeological conditions and those potentially resulting from inadequate design, construction, or execution of works. The expected results highlight the importance of a structured forensic hydrogeological approach in supporting objective expert opinion in legal disputes. Such an approach enables a scientifically grounded evaluation of whether tapping objects function within the expected range of natural hydrogeological variability and whether performed works comply with professional standards and regulatory requirements. The paper contributes to the development of forensic hydrogeology as an applied geoscientific discipline by demonstrating its relevance beyond criminal investigation, particularly in civil, commercial, and technical disputes involving groundwater resources. The proposed approach may improve the reliability of expert assessments, reduce methodological errors, and strengthen the role of hydrogeological evidence in legal decision-making.

Acknowledgements. This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia. The authors gratefully acknowledge the Ministry's support of scientific research as an essential contribution to the advancement of a knowledge-based society. This work was carried out under the Contract on the Realization and Financing of Scientific Research at the Faculty of Mining and Geology in 2026, No. 451-03-34/2026-03/200126.

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Groundwater Hydrogeological Assessment Using Integrated Geophysical Methods (ERT and VES): A Case Study of the White Drin Basin, Kosovo

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Sustainable management of groundwater resources requires accurate hydrogeological characterization and identification of aquifer structures in the groundwater. This study presents the integrated application of two geophysical methods – Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) – for the identification and characterization of aquifers in the Drin i Bardhë River Basin in Kosovo.

The research was conducted at 11 hydrogeological sites, including alluvial sediment environments, pro alluvial deposits and flysch formations. A total of 37.49 km of ERT profiles and 126 VES measurements were conducted, using the ARES and ARES II geophysical systems. Data analysis showed significant variations in electrical resistivity, with values <30–50 Ωm representing water-saturated clayey sediments, while the range 80–200 Ωm identifies sandy and gravelly aquifers with high permeability.

The results show that about 63% of the studied localities present high aquifer potential, while 27% present medium potential, mainly in areas with conglomerates and heterogeneous deposits. Only 10% of the localities resulted unproductive, due to the presence of shallow bedrock or flysch formations with low permeability. The thickness of the identified aquifers varies from 15 to 40 m, while in some sedimentary areas it reaches up to 60–70 m depth.

The integration of ERT and VES methods enabled the identification of buried fluvial structures (paleo-channels) and the determination of optimal areas for monitoring drilling. Based on the geophysical interpretation, 14 locations for monitoring wells were proposed, significantly reducing the risk of unproductive drilling.

The results demonstrate that the integrated use of geoelectrical methods constitutes a reliable and cost-effective approach for the hydrogeological characterization of sedimentary basins and for sustainable groundwater resource planning in regions with high geological complexity.

Geochemical Insights into the Origin of Geothermal Waters in Albania

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Albania hosts low-enthalpy geothermal systems distributed across four thermal provinces: Kruja, Peshkopia, Peri-Adriatic Depression, and South Ionian. This study integrates major and trace element geochemistry, mineral saturation modelling, solute geothermometry, and multivariate statistics to characterise the origin and geothermal. Thirteen samples (11 natural springs, 2 deep wells) collected during two campaigns (May–June 2023; January–February 2024) were analysed for field parameters (T, pH, EC, EH) and 30 elements quantified by ICP-OES and ICP-MS.

Piper diagram classification of the geothermal waters reveals diverse water facies: Na-Ca-Cl-SO₄ Ca-Na-Cl-SO₄, Ca-Na-Cl in Kruja province, Ca-SO₄ in Peshkopia, and Ca-HCO₃ and Ca-Mg-HCO₃-SO₄ Ca-Na-Cl-HCO₃ water types in cooler springs from the southern provinces, reflecting differences in the hydrogeological features between geothermal provinces. Ion ratios identify carbonate and silicate dissolution, gypsum weathering, halite dissolution, and cation exchange with secondary clay minerals as dominant hydrogeochemical processes. Elevated concentrations of As (≤ 1.74 mg/L), B (≤ 20.0 mg/L), Li (≤ 7.89 mg/L), and Sr (≤ 25.95 mg/L) confirm deep water–rock interaction, while low B and Li values indicate negligible magmatic fluid input.

Silica (quartz: 35–104 °C; chalcedony: 17–73 °C) and cation-ratio (K/Mg: 28–114 °C; Na/Li: 30–79 °C) geothermometers are consistent with low-enthalpy conditions; Na/K estimates were excluded due to overestimation in Ca-rich waters. PHREEQC saturation modelling constrains equilibrium reservoir conditions to 35–75 °C, with CO₂ degassing driving carbonate supersaturation.

Three principal components with eigenvalues above 1 were retained by applying the PCA which accounts for 83.74% of the total variance. They allow to discriminate three geothermal water clusters: hot saline deep-circulating waters (PC1, 50.3%), Ca-SO₄-enriched evaporitic waters (PC2, 24.6%), and shallow oxidising Mg-rich waters (PC3, 8.9%). The results support a multi-stage genetic model, meteoric infiltration at elevation, progressive heating and mineral dissolution, and variable mixing with shallow groundwater during ascent, providing a geochemical baseline for sustainable development of Albania's geothermal resources.

Acknowledgements. The authors thank the Hydrogeochemical Laboratory of AGH University of Kraków for chemical analyses and the Earth Sciences Department, Polytechnic University of Tirana, for fieldwork support.

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Baseflow Index as a Function of Changes in River Recharge Regime: The Case Study of the Velika Morava River, Serbia

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The Baseflow Index (BFI) is a quantitative indicator of the contribution of baseflow to total river discharge, defined for a gauging profile that controls a specific catchment area. It represents the ratio between the volume of baseflow (discharge sustained by groundwater inflow) and the total runoff volume. The value of this parameter depends on the geological composition of the terrain and the hydrogeological characteristics of the basin. Aquifers that can store water and release part of their dynamic reserves to surface flow (when groundwater levels are higher than river levels) strongly influence BFI values, which typically range between 0.15 and 0.90. This study examines the impact of anthropogenic factors on BFI changes, focusing on the lower Velika Morava basin.

The Velika Morava River is the main surface watercourse that drains about 42.4% of the total area of the Republic of Serbia. Its flow is formed near Stalać by the confluence of the South Morava and West Morava rivers. Observations of water levels and discharge measurements on this river have been established at several gauging profiles, of which the Ljubičevski Bridge profile is of particular importance for this study. Monitoring at this profile began as early as 1923 and continues to this day. For the purposes of this study, daily discharge and water level values were available for the period 1948–2024. Based on the data obtained on daily water levels and absolute elevations of the water table, it was observed that during the 1990s the riverbed deepened by about 4 meters. The cause of this was uncontrolled and illegal gravel and sand extraction in the immediate vicinity of the hydrological profile. This deepening of the riverbed, because of anthropogenic factors, also influenced the change in the direction of groundwater movement. Before the 1990s, groundwater was recharged by the river during medium and high flows, while during extreme low flows the river was sustained by aquifers in its alluvium. After the riverbed deepening, groundwater recharge from the river occurs only during extreme floods. During medium and low flows, groundwater levels remain higher than the river, causing the river to be fed by groundwater instead. This shift directly influenced BFI values: the average BFI for 1948–1989 was 0.65, while for 1990–2024 it increased to 0.70. These results confirm that riverbed deepening led to greater groundwater contribution to river flow. The ultimate consequence is a reduction in groundwater reserves stored in the Velika Morava alluvium.

Conditions of Runoff Formation of the Resava River, Eastern Serbia

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The Resava River is the largest right tributary of the Velika Morava, joining it near Svilajnac. Its catchment covers about 685 km² and the river length is around 65 km. The basin consists of two distinct geomorphological and hydrogeological units: the upper part, built of karst terrains of the Kučaj–Beljanica massif (Lower Cretaceous and Upper Jurassic), and the lower part, characterized by fertile alluvium of the Velika Morava and Resava overlying Miocene lacustrine sediments.

To monitor discharge, the Republic Hydrometeorological Service of Serbia established two gauging stations: Manasija Monastery (controlling 358 km², about 55% of the basin) and Svilajnac (controlling the entire basin, 683 km²). This study used mean daily discharges from both profiles for 1961–2020.

Results show that the mean multiannual discharge at Manasija Monastery is 3.50 m³/s, while at Svilajnac it is 4.52 m³/s. During spring (March–May), about 50% of annual runoff volume passes through the Resava, whereas in autumn this share drops to 10%. Notably, 77% of water at Svilajnac originates from the upper basin. Runoff modules confirm this: the upper basin contributes on average 10 l/s/km², while the lower yields only 3.1 l/s/km², giving a basin average of 6.6 l/s/km². Compared to the national average of 5.83 l/s/km² (Jaroslav Černi Institute and RHMS, 2009), the upper basin is significantly more abundant, but the lower basin is below average, so the catchment as a whole is only slightly above Serbia's mean.

For defining runoff formation conditions, direct and baseflow components were separated at both profiles. The same procedure was applied to the immediate basin section, represented by the discharge difference between Svilajnac and Manasija. Groundwater contribution was assessed using the baseflow index. Given the long observation period (60 years), indices were calculated for three basin parts over two sub-periods (1961–1990 and 1991–2020), each 30 years long, to evaluate changes in runoff formation through time.

Acknowledgements. Contract on realization and financing of scientific research of SRI in 2026, No.451-03-34/2026-03/200126 and No.451-03-33/2026-03/200126, Ministry of Science, Technological Development and Innovation of Republic of Serbia

Hydrogeological assessment of the groundwater quantity and quality regime at the Drugovac water supply source near Smederevo, Republic of Serbia

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The Drugovac water supply source near Smederevo, formed within Neogene sandy sediments, represents an important local groundwater resource for public water supply. The hydrogeological characteristics of the aquifer and the relatively stable groundwater regime indicate the potential for reliable and sustainable exploitation of this source. The aim of this paper is to analyse the quantitative and qualitative groundwater regime, assess the exploitation potential of the source, and define the basic conditions for its rational use and protection. The research is based on the analysis of data collected during exploratory works conducted over one hydrological year. The applied methodology included groundwater level monitoring, pumping tests in wells, precipitation analysis, and hydrochemical analyses of groundwater samples. Based on these data, the hydrogeological characteristics of the aquifer, groundwater regime stability, hydrochemical composition, and possibilities for optimal exploitation were evaluated. The results indicate a relatively stable quantitative and qualitative groundwater regime, with estimated exploitation reserves of approximately 5.3 l/s, confirming the potential of the Drugovac source for local water supply. The findings provide a basis for defining guidelines for sustainable groundwater source management, including continuous monitoring of hydrogeological and hydrochemical parameters, controlled exploitation, and the implementation of protection measures aimed at preserving groundwater quality and quantity.

Acknowledgements. This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia. The authors gratefully acknowledge the Ministry's support of scientific research as an essential contribution to the advancement of a knowledge-based society. This work was carried out under the Contract on the Realization and Financing of Scientific Research at the Faculty of Mining and Geology in 2026, No. 451-03-34/2026-03/200126.

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Chemical composition of groundwater in the Republic of North Macedonia: a geotectonic survey

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The Republic of North Macedonia is located in the central part of the Balkan Peninsula. Despite its relatively limited areal extent, its territory is characterized by pronounced geological heterogeneity. Within the Macedonian territory, four distinct geotectonic units are recognized: the Western-Macedonian zone, the Pelagonian horst–anticlinorium, the Vardar Zone, and the Serbo-Macedonian Massif, each differing in lithology and geodynamic evolution.

During the period 2023–2024, groundwater occurrences of types thermal, thermomineral and mineral waters, were sampled at 66 locations distributed throughout the country. The sampling network encompassed both captured and uncaptured springs, as well as wells and boreholes, with the aim of determining their chemical composition, including macro- and microcomponents.

Analytical results indicate that in 68% of the investigated samples the bicarbonate anion (HCO_3^-) is predominant, meaning that the $\text{HCO}_3\text{--Ca--Mg}$ hydrochemical facies is the most widespread. In addition to the common type of water, there is a noticeable difference in the physicochemical characteristics of these waters. In the examined samples, the mineralisation values span the interval from 180,7 to 3892,1 mg/l, while the temperature rises in the interval from 12,5 to 28,0 °C. Furthermore, the pH scale encompasses values between 6,2 and 7,8 and the electrical conductivity indicator is recorded in the range of 64 to 4032 $\mu\text{S/cm}$. This water type occurs within a broad spectrum of lithologies, ranging from Quaternary alluvial sediments and fissured shale–carbonate sequences to chlorite–epidote–sericite schists, metadiabases, and calcareous limestones and limestones, as well as phyllitoid rocks, muscovite gneisses and oxyto–amygdaloid gneisses, a thick complex of phyllite shales, metasandstones, carbonate shales, metaconglomerates, marbleized limestones, quartzites, and related rock units.

An Integrated Fuzzy VIKOR-TOPSIS Approach for Sustainable Protection Management of the Groundwater Source

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Groundwater sources used for public water supply require protection strategies that integrate hydrogeological reliability, technical feasibility, environmental safety, economic efficiency, and social acceptability. This paper presents an integrated fuzzy multi-criteria decision-making approach for selecting the optimal protection management plan for the “Jagodica” groundwater source. The research is based on the assumption that conventional decision-making procedures are often insufficient for complex hydrogeological systems, particularly when decision criteria are mutually conflicting and partly defined by uncertain, imprecise, or expert-based information. The methodology combines hydrogeological analysis, hydrodynamic modelling, and fuzzy multi-criteria optimization. A calibrated hydrodynamic model was used to evaluate the effects of different protection measures under relevant groundwater flow conditions. Three alternative protection management plans were considered: drainage wells, an impermeable barrier, and a drainage canal. These alternatives were assessed using a set of technical, economic, environmental, and social criteria relevant to groundwater source protection. To account for uncertainty and linguistic expert judgement, the fuzzy VIKOR and fuzzy TOPSIS methods were applied, enabling compromise ranking and comparative evaluation of the proposed alternatives. The results provide a structured basis for identifying the most suitable protection strategy for the “Jagodica” groundwater source. The integrated fuzzy VIKOR–TOPSIS framework enables a more realistic evaluation of protection alternatives by incorporating both quantitative model outputs and qualitative expert assessments. Particular attention is given to the ability of the proposed protection measures to prevent groundwater inflow from the direction of the industrial zone while minimizing disturbance to the natural recharge conditions of the production wells. The proposed model contributes to the improvement of decision-making in sustainable groundwater management by offering a transparent, flexible, and reproducible procedure for ranking protection measures under conditions of uncertainty. The findings may serve as a methodological basis for the selection of optimal groundwater source protection strategies in other hydrogeological settings, especially where water supply systems are exposed to potential pollution risks and where decision-making requires the simultaneous consideration of technical, environmental, economic, and social factors.

Acknowledgements. This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia. The authors gratefully acknowledge the Ministry’s support of scientific research as an essential contribution to the advancement of a knowledge-based society. This work was carried out under the Contract on the Realization and Financing of Scientific Research at the Faculty of Mining and Geology in 2026, No. 451-03-34/2026-03/200126.

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Employing Hydrochemical and Isotopic Tracers to Characterize the Hydrogeological System of the Prespa–Ohrid Lakes

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The Lake Prespa–Lake Ohrid water region constitutes a common hydraulic system which is one of the oldest, ecologically significant and tectonically complex lake systems in Europe. Based on the chemical and isotopic data a tentatively time related hydraulic model, affected by recent climatic changes, was given.

Seventeen samples were collected during two sampling campaigns (June and October, 2024) of which 4 surface water and 13 groundwater. Chemical analyses were performed at the Chemical Laboratory of the Albanian Geological Survey, Tirana and Hydrogeochemical Laboratory of AGH University of Kraków, Poland, while isotopic analyses were conducted at the Laboratory of Chemical and Isotopic Analysis at the Institute of Geosciences and Georesources, Pisa, Italy.

The surface and groundwater of the Prespa–Ohrid system belong to two hydrochemical types: Ca-HCO₃ and Ca-Mg-HCO₃. Groundwater emerging from the western flank of the Mali i Thatë–Galičica massif consists of a mixture of karst and Big Prespa Lake water. Spring waters of the Ca-HCO₃ facies primarily relate to karstic limestones, whereas Lake Prespa serves as the primary source for the Ca-Mg-HCO₃ water type.

The water of Lake Prespa is the most isotopically enriched ($\delta D = -30.8$, $\delta^{18}O = -3.56$) due to intense evaporation, while the most impoverished water is the water of Biljana spring ($\delta D = -67.4$, $\delta^{18}O = -10.10$), emerging in North Macedonia, which can be considered as a “pure” karst spring. Isotopic analysis reveals that the waters of the Shën Naum, Kufi, Tushemisht, and Gurras springs plot between Lake Prespa and the Biljana spring, confirming a blend of lake and karst water components. A two-component mixing model was applied to evaluate the contribution of the karst and Lake Prespa water to the spring water, considering both the chloride content and isotopic composition of H-2 and O-18 in the water. Calculations based on the above two-component models showed that karst contributes over 50% of the mass to the water in the springs, according to the following decreasing trend: 95%, 85%, 65% and 55% for the Elshan, Lubanisht, Pojan, Shen Naum and Kufi-Tushemisht-Gurras, respectively.

Acknowledgements. The authors thank the Department of Earth Sciences and the Institute of Geosciences of the Polytechnic University of Tirana, for fieldwork support. Our gratitude goes to the Hydrogeochemical Laboratory of AGH University of Kraków for chemical analyses.

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Integrated Groundwater Resources Management for the Water Supply of Loznica, Republic of Serbia

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Groundwater resources represent a strategic basis for public water supply in the Loznica area, where the availability of water is closely related to the hydrogeological conditions of the Drina River alluvial plain. Sustainable use of these resources requires an integrated approach that combines knowledge of aquifer structure, groundwater regime, recharge conditions, well performance, and potential pressures on water quantity and quality. In this context, the management of groundwater resources for the water supply of Loznica should be based on the systematic interpretation of field data, continuous monitoring, and predictive modelling. The aim of this paper is to assess the main hydrogeological factors that control groundwater availability in the Loznica area and to define the basic principles for integrated groundwater resources management. The research focuses on the relationship between the alluvial aquifer, river influence, precipitation regime, groundwater abstraction, and the operational characteristics of water supply wells. Special attention is given to the role of hydrogeological modelling as a tool for analysing groundwater flow conditions, evaluating the effects of exploitation, and supporting long-term planning of the water supply system. The methodological framework includes the synthesis of geological, hydrogeological, hydrological, and operational data relevant to groundwater source management. This comprises the interpretation of aquifer geometry, lithological composition, hydraulic parameters, groundwater levels, river stage variations, precipitation input, and well discharge data. These elements are used to establish a conceptual understanding of the groundwater system and to support the development of a numerical model capable of simulating different management and exploitation scenarios. The expected results should contribute to a more reliable assessment of groundwater reserves, the identification of key factors controlling the aquifer regime, and the definition of measures for rational exploitation and protection of groundwater resources. The study also aims to provide a basis for optimizing monitoring activities, improving the resilience of the water supply system, and reducing potential risks related to overexploitation or water quality deterioration. The results of this research may support the development of a scientifically grounded management framework for groundwater resources in the Loznica area. Such an approach is essential for ensuring the long-term reliability of public water supply, preserving groundwater quantity and quality, and strengthening decision-making in accordance with the principles of sustainable water resources management.

Acknowledgements. This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia. The authors gratefully acknowledge the Ministry's support of scientific research as an essential contribution to the advancement of a knowledge-based society. This work was carried out under the Contract on the Realization and Financing of Scientific Research at the Faculty of Mining and Geology in 2026, No. 451-03-34/2026-03/200126.

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Tracing Geological Processes at Csiszár Bath (Covasna County, Romania)

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We carried out a geological and hydrogeological investigation in the Csiszár Bath area near Bálványos, focusing on carbon-dioxide emissions, the characteristics of the local mineral waters, and the geodynamic activity that marks the region. The study area lies within the youngest volcanic zone of the Eastern Carpathians and is directly linked to the Ciomadul volcanic system. Although Ciomadul's last eruption took place tens of thousands of years ago, the region is still marked by strong carbon-dioxide upflow and abundant mineral springs. These features clearly indicate that deep-seated geodynamic processes remain active beneath the surface. The main goal of the research was to document the mineral waters and gas emissions found in the Csiszár Bath area and to determine the spatial distribution and intensity of carbon-dioxide release. Our fieldwork, conducted in July 2025, included measurements of CO₂ flux emerging from soil and water, analysis of gas composition, and the recording of physical and chemical parameters of springs and pools. For carbon-dioxide flux measurements, we used a West System instrument equipped with infrared detectors. Gas composition was determined with a Multi-GAS device, while the physical-chemical properties of the waters were measured using a Thermo Fisher multiparameter instrument.

The results show that the mineral waters in the area display considerable chemical variability. The pH values were consistently in the acidic range, which reflects the presence of dissolved carbon dioxide. Electrical conductivity values varied widely, pointing to differences in water–rock interaction and mineral content across the study area.

Gas composition analyses revealed that carbon-dioxide is the dominant component at every measurement point, while methane appeared only in very small amounts. Hydrogen sulfide concentrations were particularly high in the Hamvas pool and in the mofetta. These findings support the conclusion that gas emissions in the region are primarily linked to deep geological processes rather than shallow, near-surface sources.

Carbon-dioxide flux measurements revealed an extremely heterogeneous distribution. The highest emissions occurred in the mofetta and around certain pools, where maximum values reached the order of hundreds of thousands of g/m²/day. Both interpolation and statistical analyses show that gas upflow is not uniform; instead, it is strongly controlled by fault zones and fracture networks. The distribution of flux values is skewed, reflecting the natural heterogeneity of the system and indicating that gas emissions concentrate in a few localized key spots.

The most important conclusion of the study is that the Csiszár Bath area can still be considered an active geodynamic system. The dominance of carbon-dioxide, the presence of acidic waters, and the structurally controlled gas emissions all point to ongoing deep geological processes that continue to influence the surface environment. These findings contribute to a better understanding of the origin of mofettas and mineral waters, and they highlight the geotouristic and scientific significance of the region.

From spring to formula: Hydrogeological foundations for the safe and effective dermocosmetic use of thermomineral waters

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Thermomineral waters represent an important natural resource traditionally associated with balneology, medicine, and rehabilitation. In recent years, increasing attention has been directed toward their potential application in dermocosmetics, where they are used as an active component of products intended for skin care, protection, and the maintenance of physiological skin balance. In many countries, thermal and thermomineral waters form the basis for the development of dermocosmetic products, with their use relying on specific chemical composition, the stability of physicochemical parameters, microbiological safety, and sustainable resource management. Such practice highlights the need for a detailed understanding of the hydrogeological conditions of formation, natural characteristics, and quality of these waters. This paper is based on the view that the thermomineral waters of Serbia, due to their diverse chemical composition, hydrogeological characteristics, and established spa tradition, may represent a significant but insufficiently utilized potential for dermocosmetic application. The aim of the paper is to analyse the basic hydrogeological and physicochemical parameters of thermomineral waters, examine the natural factors controlling their properties, and assess the possibilities for their safe and functional use in dermocosmetic products. The methodological approach includes a review and analysis of relevant professional and scientific literature, consideration of good-practice examples from countries where thermal waters are successfully used in the dermocosmetic industry, and evaluation of prospective localities in Serbia possessing this type of resource. Particular attention is given to parameters such as water temperature, total mineralization, pH value, ionic composition, presence of trace elements, stability of physicochemical characteristics, and conditions of emergence at the surface. In addition, the basic requirements for the safe use of thermomineral waters in dermocosmetic products are considered, including microbiological safety, quality control, sustainable exploitation, and compliance with applicable regulations and standards. The results are expected to highlight the importance of hydrogeological and physicochemical characteristics of thermomineral waters as key factors in assessing their applicability in dermocosmetics. In particular, the paper is expected to identify parameters that may be relevant to the potential beneficial effects of these waters on the skin, as well as localities in Serbia that could serve as a basis for further research and the development of products based on domestic natural resources. The findings should contribute to a better understanding of the possibilities for valorising Serbia's thermomineral waters beyond their traditional balneological use, while also emphasizing the need for additional hydrogeological, hydrochemical, microbiological, and dermatological investigations prior to their wider dermocosmetic application. The results of this paper may provide a basis for establishing a scientifically grounded approach to the selection, control, and sustainable use of Serbia's thermomineral waters for the development of innovative dermocosmetic products.

Acknowledgements. This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia. The authors gratefully acknowledge the Ministry's support of scientific research as an essential contribution to the advancement of a knowledge-based society. This work was carried out under the Contract on the Realization and Financing of Scientific Research at the Faculty of Mining and Geology in 2026, No. 451-03-34/2026-03/200126.

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Session GS10

Magmatism and Volcanism/Igneous Geology

Conveners:

Ioan Seghedi, Marinel Kovacs

Atomic structure and degassing of silicate magmas

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We investigate the atomic structure of various mafic melts rich in volatiles. For this we use computational techniques based on ab initio molecular dynamics simulations. We span a wide range of pressures, temperatures, and compositions.

We analyse the evolution of the structure of the liquids as a function of pressure and temperature. We find that the silicate melt structure is always formed on a backbone of polymerized silica and alumina polyhedra. The other cations, like Na, Mg, and Ca, freely float in between these large polymers. Iron plays a special role in that it may participate in the polymerization or may just lie in between these polymers. We show that a magma accommodates compression by the augmentation of the second-coordination Si-O sphere.

Then we investigate the dissolution of various volatiles in several magmas. We find that noble gases and CO₂ are profoundly incompatible in silicate melts. They easily degas under lower pressure conditions, particularly when they are present jointly in the melt. Hydrogen is highly soluble in silicate melts. Sulphur degassing is highly sensitive to its redox state, oxidized sulphur begin highly volatile, while reducing species are attached to the melt.

We relate the geochemical evolution of large magma volumes to the evolution of the atmosphere and the development of deep reservoirs of volatiles, which remained isolated from the surface throughout the entire evolution of our planet.

Acknowledgements: This research was supported by the European Research Council, via ERC Advanced Grant DAWN.

Deepest mantle and gabbro section ever drilled: insights from petrology and geochemistry of rocks and fluids from IODP Hole U1601C, Atlantis Massif

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We will present lithology and geochemistry results for the very depleted serpentinized peridotites and gabbro recovered from recently drilled (IODP Expedition 399, Mid-Atlantic Ridge 30°N) Site 1601C on the south wall of the Atlantis Massif (AM). These samples represent the deepest in situ gabbro/peridotite drill cores ever recovered from the ocean floor (Lissenberg et al., 2024). The downcore variation in alteration minerals, fluid mobile elements and the vast isotope fractionations highlight the important role of seawater infiltration and seawater–peridotite–gabbro interactions taking place at shallow depths. However, it appears that the role of H₂O-based fluids is gradually diminishing downcore from the ocean floor and away from the large scale detachment fault responsible for the emplacement of the AM. We will emphasize the importance of studying and understanding deformation during basaltic volcanism on the ocean floor and give examples of the complexity of the fluid–melt–rock interactions deep in the oceanic crust.

The isotope systematics of the fluids recovered from Site 1601C at depth > 1 km resemble the composition of the fluids emitted from the Lost City hydrothermal system (located only 800 m to the south). They are also similar to the pervasively altered gabbro samples from the same site. It appears that magma intrusions and active metamorphic (hydration) reactions involving rather unaltered lithologies may occur near and below the drill core basement (at 1268 mbsf).

We will attempt to evaluate the importance of variously hydrated oceanic mantle and crust as volumetrically important carriers of volatiles from the surface to the deep mantle. Extensive serpentinization of the deep peridotite reservoir of the lithospheric mantle may not be as common and voluminous as previously thought. Perhaps only in the case of abundant tectonic reworking and/or gabbro (sill) intrusions, the oceanic lithosphere may be penetrated by fluids and/or melts. The latter can greatly alter the original mineralogy and profoundly impact the isotope fractionations and volatile storage capacity of the oceanic crust.

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Oligocene–Miocene volcanic and subvolcanic magmatism of the Vardar Zone in Kosovo: preliminary petrography, spatial distribution and metallogenic significance

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The Vardar Zone hosts one of the most important belts of Cenozoic post-collisional magmatism in the central Balkan Peninsula, developed within the Dinaride–Hellenide orogen following the closure of the Western Vardar oceanic domain and the Paleocene–Eocene collision. Regional geochronology brackets this magmatism between the Oligocene (~32–27 Ma) and the Early–Middle Miocene (~21–17 Ma), with the magmatic-hydrothermal activity accompanying the Trepça Pb–Zn–Ag skarn dated at ~23 Ma.

This study presents the first results of a systematic field and petrographic reconnaissance of the volcanic and subvolcanic rocks exposed in the Kosovo segment of the Vardar Zone. Geological mapping and sampling were carried out in six magmatic complexes: Kopaonik (Leposavić), Bubës (Zubin Potok), Trepça (Mitrovica), Leçë (Podujevë), Janjevë (Prishtina) and Nosalë-Klllokot (Anamorava). Over 40 representative samples were collected, from which thin sections were prepared for petrographic characterisation.

Preliminary petrography reveals a dominantly intermediate-to-alkaline association of andesites, latites, quartz-latites, trachytes and trachyandesites, with subordinate dacites, basaltic/diabasic dykes and associated pyroclastic rocks (tuffs and breccias). These lithologies are consistent with a high-K calc-alkaline to shoshonitic affinity and exhibit magma-mixing textures documented in coeval complexes of the wider region. These features reflect partial melting of a metasomatized lithospheric mantle, followed by fractionation and crustal interaction during post-collisional convergence and subsequent extensional exhumation.

Pervasive hydrothermal alteration and disseminated sulphides (galena, pyrite), particularly in the Janjevë and Trepça complexes, highlight the close magmatic-metallogenic link expressed regionally by the Trepça and Crnac Pb–Zn–Ag deposits and by the emerging Miocene Li–B potential of the Western Vardar zone. The dataset establishes a petrographic and spatial framework for subsequent integrated studies, including whole-rock geochemistry, mineral chemistry, geochronology and fluid-inclusion analysis, aimed at constraining the petrogenesis, geodynamic evolution and metallogenic significance of Cenozoic magmatism in Kosovo.

Garnet as indicator of origin and evolution of Variscan pegmatitic granite, the Bratislava pegmatite field (Western Carpathians)

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Pegmatite dyke swarms and pegmatitic granite bodies are developed in the southern part of the Variscan Bratislava S-type granite massif (Tatric Superunit, Western Carpathians). Pegmatite dykes are several centimeters to meters wide and occur mainly either directly within the host granitic rocks or in the adjacent Paleozoic paragneisses. We studied in detail a pegmatitic granite body in the central part of the Bratislava pegmatite field at the Kamzík hill in Bratislava, along with its aplitic dykes. The garnet (almandine 46.7–55.5, spessartine 41.9–51.0, grossular 1.2–1.9 mol.%) in this pegmatitic granite was crystallized by precipitation from the residual melt at an age of 354 Ma, as yielded by LA-ICP-MS U-Pb dating. The obtained age is coeval with the ages of columbite-tantalite from the nearby pegmatites and zircon and monazite from the host granites of Bratislava Massif. However, the pegmatitic granite is slightly younger than the nearby diorite and granodiorite bodies (ca. 358 Ma). The garnets are arranged in lines and have been reprecipitated by Ostwald ripening, forming the larger crystals in the middle part of the garnet trains, as was shown by the micro CT tomography. The trace elements in garnet were measured by LA-ICP-MS, and the results show high P content (>1000 ppm) and elevated levels of Y, Zr, Ga, and Sn. The high P in garnets reflects a relatively high P concentration of the residual granite melt. Garnet is also primarily enriched in Li (>100 ppm) and in Sn. However, higher concentrations of Li and Sn are associated with muscovite, which also contains a relatively high Rb concentration (>1000 ppm). Li in pegmatitic micas (>100 ppm), a good tracer of fractionation, is significantly higher than in micas from parental granites. Pegmatite system in the Bratislava granite massif formed from S-(I-) granite type originated in the lower crustal zone after their intrusion into middle-crustal conditions. The fractionated low Li and Sn concentrations prevented the formation of Li- and Sn-dominant minerals, because they fractionated in melt derived from immature sedimentary crustal rocks, which represents insufficient protolith for the formation of Li-rich LCT pegmatites. The trace-element chemistry of the accessory minerals in the investigated pegmatitic body indicates their formation from a relatively slower cooling residual crustal granitic melt, accompanied by the gradual escape of residual magmatic volatiles. The overpressure of residual volatiles, which typically occurs in pegmatite systems, caused only weak brittle deformation, e.g., fragmentation and fracturing of albite, and kinking of micas. Residual volatiles caused the disintegration of only a small part of the plagioclase volume; e.g., microcline was not disintegrated, but after alteration by fluids, it became abundant in secondary apatite. In summary, the geochemical data indicate that the investigated pegmatitic granitic body formed from immature metasedimentary rocks during the time span of ca. 358–354 Ma, which is related to an early phase of Variscan granite formation in the Western Carpathians at the beginning of the Tournaisian extensional tectonics following collision.

Acknowledgements. This research was supported by the project SK-BG 23-0016.

Primitive magmatic compositions at collisional settings

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Approximately 30–50% of convergent margins that have undergone continental subduction and collision over the past 10 Ma are magmatic. Contrary to the common view that such magmas represent highly silicic mid-crustal melts generated by radiogenic heating (e.g., the canonical Himalayan leucogranites), collision-related volcanism closely resembles subduction volcanism. It is dominated by andesitic to dacitic compositions displaying negative High-Field-Strength Element anomalies and typically forms stratovolcanoes. Young volcanic systems in the Carpathians, Greater Caucasus, Lesser Caucasus, Eastern Anatolia, and Zagros exemplify this magmatic style. In these regions, oceanic slabs that preceded continental collision have largely been consumed, rendering classical models of slab dehydration insufficient without substantial modification of system boundary conditions. Nevertheless, collisional volcanic belts are widespread and commonly endowed with metals, in many cases exceeding the metallogenic potential of typical subduction systems. Despite this, they remain comparatively understudied, yet are essential for constraining global magmatic processes.

Here, we compile a dataset of ~400 of the most mafic compositions reported from collisional belts associated with the Neo-Tethys realm. These samples represent the least evolved magmatic products of their respective suites, with many corresponding to true basalts. The data indicate predominantly calc-alkaline affinities and, almost universally, pronounced negative Nb–Ta anomalies characteristic of arc magmas, underscoring their geochemical similarity to subduction-related melts. In addition, basaltic thermobarometric approaches used to estimate equilibration pressures and temperatures suggest P–T distributions comparable to those observed in modern oceanic subduction environments. Our preliminary conclusions are that mantle melting in collisional settings is fundamentally governed by processes analogous to subduction, although the nature of the downgoing lithosphere differs from that of a typical oceanic slab and varies among individual collisional belts.

Characteristic features of the subaqueous volcanic activity in the Eastern Srednogorie Zone, Bulgaria

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The Late Cretaceous magmatic activity of the Apuseni–Banat–Timok–Srednogorie magmatic (metallogenic) belt (ABTS) is considered as a continental margin arc, formed as a result of the northward oblique subduction of the Vardar-Izmir Ocean beneath Serbo-Macedonian and Rhodope massifs. The southward shifting of the magmatic activity (93 to 67 Ma) has been interpreted as a consequence of retreating subducted plate and slab roll-back. The evolution of the Eastern Srednogorie segment is related to the development of intra-arc rift (82–77 Ma), filled with thick (3000–4000 m) subaqueous volcano-sedimentary successions. Numerous paleovolcanic centers are found, including small eroded plutons (in their central parts), feeder dikes and ring plutons intruded in the caldera faults. The present contribution is focused on the subaqueous volcanic structures and textures and the interaction of the lava with the flysch-like sedimentation, formed along the paleovolcanic slopes. The studied subaqueous lava flows exhibit various structural features depending on diverse factors: rate of effusion, the composition of the lava, the slope of the underlying surface, the degree of solidification, the gas component, etc. Crucial to the overall structure of subaqueous lava flows is the rate of effusion. At higher effusion rates, in the near-vent parts, the lava movement is often carried out through lava tubes and followed by the formation of massive sheet flows. In distal sections, following a decrease in the effusion rate, the massive lava flow can transform into a pillow lava flow. In some cases, “pillows” of significantly larger sizes – up to several tens of meters, known as “megapillows”, are observed within the pillow lavas. As the lava solidifies, a radial prismatic jointing develops perpendicular to the outlines of the “pillow”. They represent important main conduits that fed the flow from the source to the advancing front and can be observed in the lower, middle or upper sections of the lava flow and often transit into massive lavas. Upon solidifying, the “pillows” are separated by chilled margins. Hyaloclastites and peperites are frequently observed in the peripheral parts of the subaqueous lava flows, near the water surface. They form as a result of autoclastic fragmentation and chilling of the lava upon its contact with seawater. The rock fragments of the hyaloclastic breccias have angular and irregular shapes. “Jig-saw fit” structures are frequent and the matrix consists of chilled and altered volcanic glass. When water-saturated sediments come into contact with the hot lava, they can be “sucked in” due to the temperature difference and fluidization effect, cross-cutting the volcanics in the form of clastic dikes. In this case, they are located directly within the margins of the lava body and are called in-situ peperites. Volcanic fragments can be dispersed within the sediments and an exo-peperite is also observed.

Acknowledgements. This work has been carried out in the framework of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers № 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria.

Shifting from post-collisional (late Carboniferous–early Permian) to rift-related (late Permian–Early Triassic) magmatism: example from the External Balkanides, Bulgaria

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The Variscan orogenic belt formed during the late Paleozoic, resulted from the convergence and subsequent collision of the two major paleocontinents Laurasia and Gondwana, including a number of smaller microplates and fragments of magmatic arcs. During the final stages of the Variscan orogeny, late- to post-collisional magmatism was broadly manifested with an emplacement of large granitoid plutons (with minor mafic component), which delineate a long and well-pronounced magmatic belt. Subsequently, at the transition from Permian to Triassic, Eurasia was a locus of a widespread mafic to acidic magmatism and rifting thus causing the Pangea breakup. In the External Balkanides (including Balkan and Sredna Gora), the syn-orogenic to post-orogenic Variscan magmatic stage generally follows the main stage of convergence and subsequent collision of the two major paleocontinents, Laurasia and fragments of Gondwana respectively. An important compressional ductile Variscan shear zone with an orogenic-scale significance probably marks a suture and traces the contact between the high- and low-grade metamorphic complexes along the southern foot of the Central Stara Planina Mountains in Bulgaria. The zone was initiated shortly after the thermal peak of the metamorphism in amphibolite facies in the Sredna Gora high-grade metamorphic complex (~337 Ma) and predated the stage of the late syn-tectonic to post-tectonic voluminous orogenic-scale magmatism in late Carboniferous to early Permian in the Balkan region. The initial high-K-alkaline magmatism, reflecting melting of an enriched mantle source, was revealed at 330 to 310 Ma, followed by a voluminous calc-alkaline to high-K calc-alkaline magmatism, evidenced by several plutonic bodies (with ages in the interval 309 to 306 Ma) and remnants of contemporaneous volcanic rocks (307.4±2.2 Ma). There are sporadic coeval K-alkaline events. The final stage of the late Variscan magmatic activity is marked by the intrusion of predominantly acid subvolcanic bodies and dikes in the interval of 288–286 Ma up to 260 Ma. In the Central Sredna Gora Mountain, two suits of granitoids are known – I-type (c. 312–304 Ma) and later S-type (c. 290 Ma). The I-type granodiorite-dominated plutons show many indicators of magma mixing and mingling processes as well as typical to I-type granites accessory minerals (e.g., titanite, low-Mn apatite, zircon and typical zoned allanite-(Ce)). This magmatic activity is finalized by the emplacement of S-type muscovite granites (Strelcha type granites), where mafic input is practically absent. The typical accessory minerals are apatite, zircon, and monazite. During the late Permian–Early Triassic, a new magmatic episode started with the emplacement of small granitoid bodies (Kalofer and Klissura/Rozino plutons) as well as numerous subvolcanic and volcanic bodies in the Central Balkan and Sinite kamani areas. All these rocks are formed in a close time span between 255 to 251 Ma. Geochemical data from several of the bodies show trends of A-type granitoids and can be classified as A₂-type granites formed as a result of crustal melting induced by mantle melts in a post-orogenic setting.

Acknowledgements. This study is funded by the National Science Fund, bilateral cooperation (Bulgaria–Slovakia) via contracts КП-06-Словакия/10 and SK-BG-23-0016.

Deep Carbon and Water–Gas–Rock Interaction in the Harghita–Perșani Volcanic Region

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This work investigates the relationship between igneous petrology, whole-rock geochemistry, water chemistry, gas geochemistry, and deep carbon sources in the Harghita Mountains and the neighboring Perșani volcanic field. By integrating published rock data with compiled water and gas geochemical databases, the study provides a combined interpretation of water–gas–rock interaction in one of the most important CO₂-rich mineral water provinces of the Eastern Carpathians.

From a geotectonic perspective, the Harghita volcanic chain represents the southern segment of the Călimani–Gurghiu–Harghita volcanic range and records the final stages of post-collisional magmatism in the Carpathian-Pannonian region. The southward migration of volcanism, together with the young age of South Harghita activity, reflects the combined influence of slab rollback, slab detachment, lithospheric delamination, asthenospheric upwelling, and regional faulting. These processes created favourable pathways for magma ascent and for the migration of deep CO₂-rich fluids toward the surface.

The petrological data show a clear contrast between Harghita and Perșani. Harghita is dominated by calc-alkaline, high-K calc-alkaline and shoshonitic rocks, with South Harghita showing more evolved dacitic to shoshonitic compositions. These features indicate a metasomatized, hydrous, volatile-rich mantle source affected by slab-derived fluids or melts and crustal processing. In contrast, the Perșani volcanic field is mainly composed of alkaline to trachybasaltic rocks derived from low-degree asthenospheric melting, with only minor inherited subduction-related signatures. This contrast helps explain why South Harghita is more closely associated with intense CO₂ degassing.

The compiled whole rock, water, and gas databases allow the comparison of rock composition, hydrochemical facies, dissolved gases, stable isotopes, noble gases, and carbon-source parameters. Co-occurrence network analysis separates the samples into basin-related, orogenic, and volcanic/post-volcanic environments, showing that the system is controlled by lithology, tectonic position, salinity, pCO₂, saturation state, water isotopes, and carbon source. Water geochemistry indicates that many samples are bicarbonate-rich due to CO₂ dissolution and interaction with carbonate and silicate rocks, while chloride-rich waters reflect halite dissolution and salt-diapir influence along the Transylvanian Basin margin. Sulfate-rich waters suggest interaction with H₂S, reduced sulfur species, sulfide oxidation, or sulfur-bearing deposits.

Stable isotopes indicate a predominantly meteoric origin for most waters, with local modification by evaporation, sedimentary basin fluids, evaporites, and diagenetic processes. Gas geochemistry confirms that the system is dominated by CO₂, with subordinate CH₄, N₂, H₂S, He, and minor hydrocarbons. Helium isotopes indicate minor mantle input, whereas methane isotopes suggest thermogenic, sedimentary, oxidized, microbial, or mixed origins. Carbon-source calculations show that dissolved inorganic carbon cannot be explained only by aquifer carbonate dissolution, confirming the importance of external CO₂.

Overall, the Harghita–Perșani region can be interpreted as an active post-volcanic water–gas–rock system. Present-day mineral waters and gas emissions preserve the combined imprint of mantle, slab, crustal, sedimentary, and aquifer-scale processes, with South Harghita representing the main zone of deep CO₂ transfer and surface degassing.

Metabasites of the Sredogriv Metamorphics (western Fore-Balkan, Bulgaria): petrography, geochemistry and tectonic settings – preliminary results

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The Lower Paleozoic Sredogriv metamorphics (Angelov et al., 2006) of the Montana Tectonic Unit (Ivanov, 2017) in the western Fore-Balkan, Bulgaria represent an alternation of different parametamorphites and polymict metaclastic rocks, all affected by green schist facies metamorphism. Various in size allochthonous bodies (exoclasts, olistoplaques and olistostromes) from metamorphosed magmatites (metagabbro, metadiabases, greenschists, albitophyres and metamorphosed granitoids) have been tectonically included among them (cf. Kiselinov, 2024).

The present work is focused on the allochthonous metabasites of the Sredogriv metamorphics and aims to investigate their petrography and tectonic settings, based on the obtained geochemical (major and trace elements) data.

The metabasites are grayish-green to greenish-black in color and medium- to fine-crystalline. They are characterized by massive to schistose structure and doleritic, porphyritic, glomeroblastic to blasto-ophitic texture. The primary magmatic mineral assemblage consists of plagioclase, pyroxene, olivine, amphibole, ilmenite, titanomagnetite, zircon, and apatite. The mafic minerals have been affected by intense chloritization and the formation of fine-grained aggregates of carbonate and titanite. The metamorphic mineral assemblage is represented by albite, chlorite, epidote, zoisite, amphibole, quartz, and carbonates.

The Harker diagrams reveal a clear clustering and strong similarity among the studied metabasites, as well as with other metabasites from the investigated area and the Berkovitsa Tectonic Unit (Ivanov, 2017). The analyzed rocks are classified as low-potassium basalts to basaltic andesites. On the TiO₂–MnO–P₂O₅ discrimination diagram, most samples plot within the MORB (middle ocean rift basalts) and OIT (oceanic island tholeiites) fields, whereas a smaller proportion falls within the CAB (calc-alkaline basalts) and OIA (oceanic-island alkali basalts) fields.

On the Th/Yb versus Ta/Yb diagram some of the analyzed samples plot within the field of oceanic island arcs, whereas the remaining samples fall within the fields of active continental margins and within-plate basalts (WPB). In contrast, on the Ti–V diagram, the samples are concentrated within the MORB and OIB (oceanic island basalts) fields. Furthermore, according to the TiO₂–Zr diagram, the metabasites plot within the MORB and WPB fields, while on the Zr/Y–Zr diagram they display values characteristic of within-plate basalts.

The obtained results suggest the allochthonous nature of the metabasites and highlight the need for further detailed studies.

Acknowledgements. The Bulgarian National Science Fund of the Ministry of Education and Science, Grant KP-06-N84/1, supported this study.

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Composite dykes in the Miocene Gutâi Volcanic Zone (East Carpathians, Romania). Petrogenesis and emplacement model

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The Gutâi Volcanic Zone (GVZ) belongs to the East Carpathian volcanic range developed in the north-western part of Romania. Intermediate/andesitic multiphase volcanism took place here during Miocene times (13.4–7.0 Ma). The Laleaua Albă magmatic complex in the central-southern part of the volcanic area represents the third volcanic stage of the intermediate volcanic activity (8.5–8.0 Ma) and mainly comprises two sub-parallel composite dykes, each composed of an external zone of aphyric andesite and an internal zone of macroporphyritic dacite. Complex mineralogy characterizes both rock-types: 1. sanidine macrocrysts (up to 5 cm), large-sized plagioclase, quartz and biotite phenocrysts and smaller-sized amphibole and pyroxene as xenocrysts in dacites, 2. much smaller-sized xenocrysts of plagioclase, amphibole and pyroxene and phenocrysts of plagioclase, quartz and biotite in andesites. Abundant microgranular gabbroic enclaves (MME) of various sizes (up to 90 cm) occur in the dacites. Chemical composition and texture of the mineral assemblages in both dacites, andesites and MME place constraints on the magma-mingling and -mixing rock-forming processes: multiple plagioclase populations with disequilibrium textures (sieve textures with resorption zones), resorption embayments in the large-sized sanidine crystals, clinopyroxene coronas on quartz phenocrysts, similarly high Mg# (70–89) clinopyroxene (as frequent crystal clusters in dacites and andesites) and high Mg# (71–84), high Al (11.6–15.5) amphibole (magnesian hastingsite, sadanagaite and pargasite) in the MME (as phenocrysts), dacites and andesites (as xenocrysts). The geochemical data also assert the involvement of magma-mingling and -mixing in the petrogenesis of the two rock-types of the composite dykes. A pathway of mixing processes between melts of basaltic composition, similar to that of the MME, and silicic composition, similar to that of the dacite is shown in geochemical diagrams (e.g., Rb-Rb/Sc, Th-Th/Sc). Large-sized low An (28–40) plagioclase, strongly Ba-zoned sanidine, large-sized quartz and biotite phenocrysts suggest an evolved magma source stalled in upper crustal reservoirs (probably a felsic crystal mush). Similar pressures (5–9 kbars) calculated for the high-Al, high-Mg amphibole and high-Mg clinopyroxene from all three lithologies (andesites, dacites and MMEs) suggest deep sources of crystallization (23–33 km) in mafic magmas. A multilevel magmatic plumbing system is considered for magma generation and evolution involved in the dyke injections. The assumed architecture of the magmatic plumbing system consisting of deep (lower crust) and shallow (upper crust) magma reservoirs is consistent with the observed magma-mingling and -mixing features involved in the petrogenesis of the Laleaua Albă magmatic complex. The deeper mafic magmas intruded in the shallow magma reservoir/felsic mush, generating the two rocks of the composite dykes. The changeable geometry of the two dykes, the complex relationships between the two rock-types, with different contact types (from sharp to transitional, from brittle to plastic), at various scales reflect a complex magma injection and emplacement history. The dacitic magma was subsequently injected along the same path into the central part of the earlier andesitic injection of the composite dyke.

Magmatic ‘water’ content study of the Miocene Gutâi Volcanic Zone (East Carpathians, Romania) using FTIR methodology on Nominally Anhydrous Minerals

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The Gutâi Volcanic Zone (GVZ) is located in the East Carpathian volcanic range in the north-western part of Romania. A multiphase post-collision intermediate/andesitic volcanism took place in GVZ during the Miocene (13.4–7.0 Ma). The calc-alkaline volcanism has a lithospheric mantle source modified by subduction components. The Fourier Transform Infrared (FTIR) spectrometry was used to study the Nominally Anhydrous Minerals (NAMs) phenocrysts found in the GVZ rocks to establish the ‘water’ content of the source melts. Among the NAMs, clinopyroxene was chosen as the most reliable mineral phase to understand the magmatic ‘water’ content, because it has a relatively slow diffusion rate of hydrogen in its structure as compared to other NAMs. Furthermore, it is a primary crystallizing phase in the studied rocks and not prone to weathering. To better understand the involved processes two benchmark magmatic complexes were selected: the Firiza basaltic complex (FBC) (8.1–7.0 Ma) and the Laleaua Albă magmatic complex (LA) (8.5–8.0 Ma). The FBC represents the final stage of volcanism in the area, it is the only calc-alkaline basalt in the GVZ and during its ascent it was not stalled at shallow depths or affected by significant mixing/mingling, assimilation or fractionation processes. The FTIR data obtained on clinopyroxene from the FBC basalts highlighted magmatic ‘water’ contents ranging from 1.85 to 3.91 wt.%, corresponding to calculated values of source water between 2200 and 5200 wt. ppm. The LA is a composite dyke system consisting of a dacitic core, which contains mafic microgranular enclaves (MME), enclosed in an andesitic envelope and containing the same type of clinopyroxenes early crystallized in a deep source basaltic magma. The FTIR data highlighted that the clinopyroxenes in the MMEs show a relatively uniform ‘water’ content representing the conditions at the source of the clinopyroxenes. On the other hand, the clinopyroxenes from the dacite show varying water contents as the result of magma mixing processes. The results obtained for these two magmatic complexes were compared with those of other volcanic phases of GVZ such as Mogoşa composite volcano (a sill at Şurdeşti, 11.3 Ma), Chicera-Budeşti composite volcano (lava flow, 10.5 Ma), Rotundu composite volcano (lava flow, 10.3 Ma), Igriş composite volcano (lava flow, 9.5–9.0 Ma), and Gutâi lava dome (9.3–9.0 Ma) representing the major evolution stages of the intermediate/andesite volcanism in the GVZ.

Sveti Nicola pluton (NW Bulgaria) – petrology and auto metasomatic alterations

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Sveti Nicola pluton crops out in NW Bulgaria and geographically belongs to Stara planina Mnt. The granitoid plutons from this area are united as „Stara planina calc-alkaline formation“. The pluton is elongated in east-west direction ($3\text{--}3.5 \times 16\text{--}17$ km), continuing in the west into Serbian territory. It was intruded in the rocks of the Cherni vrah ophiolite massif and the Berkovitsa Low-grade Metamorphic Complex. The Sveti Nicola pluton is composed of massive leuco- to mesocratic, coarse to very coarse grained rocks with granodiorite-granite composition. In some places the rocks are coarsely porphyric after feldspar, and rarely porphyric after quartz. Close to the SE contact the rocks are strongly deformed and converted to S-C mylonites. No aplite and pegmatite veins are observed but MME are common. The country rocks are partly amphibolized or converted into hornfelses or pyroxene-garnet skarns after marbles.

The major rock-forming minerals are: plagioclase, K-feldspar, amphibole, quartz, biotite and the accessories apatite, zircon, magnetite, titanite and allanite.

Plagioclase forms idiomorphic twinned crystals and shows well developed zonation ($\text{An}_{34\text{--}32}$ in the core and $\text{An}_{24\text{--}21}$ in the rim). All grains are partly or fully sericitised.

K-feldspar is perthitic microcline.

Amphibole forms idiomorphic crystals pleochroic in yellow-green colors and is magnesio-hornblende in composition.

Biotite is pleochroic in brown-yellow colors (phlogopite-annite in composition with $X_{\text{Fe}} = 0.48\text{--}0.52$ and $^{\text{IV}}\text{Al} = 1.05\text{--}1.15$ p.f.u.). Fresh unaltered grains are very rare, usually they are fully replaced by chlorite (clinocllore) and epidote. Along cleavage planes secondary hydrogarnet is observed.

The aim of the study is to describe the auto metasomatic alterations in the pluton. They can be described as sericitisation of plagioclase, chloritization of biotite and formation of epidote and hydrogarnet. Epidote forms idiomorphic single grains with growth zones clearly visible on SEM images. It is epidote-clinozoisite in composition ($\text{Ep} = 0.31\text{--}0.57\%$; $\text{Czo} = 0.69\text{--}0.43\%$). Hydrogarnet uses the cleavage planes of biotite as comfortable structural position. It is dominated by grossular-andradite ($\text{Gross} = 40\text{--}51\%$; $\text{And} = 41\text{--}50\%$). We interpret these changes as postmagmatic alteration caused by residual fluids genetically related to the magma of Sveti Nicola pluton. Such type of auto metasomatic mineralization is widespread in the plutons from this region of Bulgaria – prehnite formation in Belogradchik and Rzhana plutons. This process occurs at temperature $230\text{--}300$ °C (chlorite thermometer), i.e. under conditions of prehnite-pumpellyite facies.

Sveti Nicola pluton was intruded at hypabyssal level (max 0.5 GPa after Al_t in Amp). This is somewhat contradictory with the coarse grained texture of the rocks. The obtained temperature of crystallization is ~ 600 °C (Ti in Bt thermometer). The recent geochronological data obtained by means of the $^{207}\text{Pb}/^{235}\text{U}$ method after zircon (Carrigan et al., 2005) indicated isotopic age of the Sveti Nicola pluton of 311.9 ± 4.1 Ma, thus defining it as Late Carboniferous.

Acknowledgements. The investigations are financially supported by the Bulgarian scientific research fund – grant КП-06-H84/4.

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Volcanic Debris Avalanches Triggered by Basement Tectonic Activity: Case Studies from the Southern Apuseni Mts. and the Călimani–Gurghiu–Harghita Volcanic Range

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The fault systems developing in tectonically active regions, whether extensional, compressional or strike-slip, facilitate the transfer of magmas from their source region toward the surface and thus represent essential factors controlling the localization and formation of volcanoes. The same fault systems, however, may also contribute to the destabilization and collapse of the volcanic edifices, leading to the formation of large volcanic debris avalanche deposits (VDADs).

The Bontău volcanic complex (including the Bontău stratovolcano and surrounding individual domes) formed between 14 and 10 Ma in the western part of the Zărand graben of the Southern Apuseni Mts., an intra-continental oblique rift setting. The volcanic complex formed in two stages related to the evolution of the graben. The first effusive-explosive stage of the stratovolcano formation and the development of individual lava domes at 14–12 Ma coincided with the block-rotational extension of the graben. Then, after ~12 Ma, the second stage started with a Plinian eruption, which was followed by the formation of extrusive domes as well as widespread edifice collapses concomitantly with the development of E–W and NW–SE compressional/transpressional fault systems in the graben. First oriented westward and eastward, along the graben system, and then southward and northward, the sector collapses resulted in four massive VDAD units surrounding the complex.

In the Călimani–Gurghiu–Harghita Volcanic Range (CGHVR) the generation of magmas between ~10 and 0.03 Ma as well as active tectonic instabilities are linked to the progressive detachment of the subducted slab that followed the oblique collision between the East European Platform and the overriding Dacia Mega Unit in a post-collisional tectonic environment. As slab tearing and roll-back advanced along strike of the East Carpathians, post-collisional crustal deformations affected the Dacia Mega Unit, facilitating the progressive formation of a series of stratovolcanoes and domes along CGHVR, but also contributed to the destabilization and partial collapse of several volcanic edifices. The sector collapses of the four major volcanoes (Călimani, Fâncel-Lăpușna, Vârghiș, and Luci-Lazu) occurred successively at their southern flank and much of the generated debris avalanches ran out toward depocenters located in the south, suggesting they have resulted from a migrating topographic subsidence–uplift pattern, which accompanied the slab tearing along CGHVR. The fault-controlled opening of intra-mountain basins and subsidence on the eastern flank of the CGHVR likely contributed to the collapse of the eastern sector of the Ostoros and Ivo-Cocoizaș volcanoes.

These examples demonstrate that in addition to explosive volcanic eruptions and seismic activity, continuous “slow” basement deformation may also play an important role in triggering the collapse of volcanic edifices and the generation of the VDADs.

Acknowledgements. We acknowledge the support of CNCS–UEFISCDI grant PN-II-ID-PCE-2012-4-0137 of the Ministry of Education and Scientific Research and CNCS–UEFISCDI grant PN-III-P4-ID-PCCF-2016-4-0014 of the Ministry of Research and Innovation.

Application of Remote Sensing Methods for the Study of Pillow Lavas from the Western Srednogorie Magmatic Zone, Bulgaria

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Remote sensing methods offer extensive possibilities for collecting spatial data that enable geological outcrops to be documented with high resolution. The integration of these data into various software platforms allows the creation of realistic 3D models that can be effectively used for geological interpretation, visualization, and education. In this study, an Unmanned Aerial Vehicle (UAV) and a smartphone equipped with a LiDAR sensor were used to produce 3D and 2D geological models of pillow lava outcrops from the Western Srednogorie Magmatic Zone, Bulgaria.

The Western Srednogorie Magmatic Zone encompasses Upper Cretaceous volcanic, subvolcanic, and intrusive rocks subdivided into three volcano-sedimentary formations, the middle of which produced widespread submarine pillow lava flows from several subaqueous volcanic centers.

The study employs a hybrid remote sensing approach combining a DJI Mavic 3 Enterprise RTK unmanned aerial vehicle and a mobile device (Apple iPhone 15 Pro Max) equipped with an integrated LiDAR scanner. The UAV was fitted with a photogrammetric camera with mechanical shutter and an RTK module for enhanced positional accuracy. For detailed morphometric and structural analyses, the LiDAR scanner of the iPhone 15 Pro Max complemented the aerial data.

A photogrammetric 3D model of a pillow lava flow was produced, revealing the upper surface and cross-sections of the flow. The direction of lava movement was determined from elongation patterns and inter-lobe relationships. Hyaloclastites at the top of the pillow sequence were clearly distinguished, with tightly packed individual pillows characteristic of massive submarine eruptions. Paleoenvironmental parameters were estimated by integrating morphological and textural data from both LiDAR scanning and photogrammetry. Well-defined quench margins indicate relatively rapid cooling, while variations in quench zone thickness – thicker at the base and thinning upward – are consistent with accelerated cooling in the upper flow portions. The variable sizes of individual pillows, as quantified from digital models, preclude a reliable interpretation of paleoslope angle.

The study demonstrates the growing applicability of accessible remote sensing technologies in geological fieldwork. UAV-based models establish overall flow geometry, while smartphone-derived models provide detailed morphometry of individual structures. Once created, 3D models serve as permanent digital twins, enabling repeated measurements and analyses in a laboratory setting at any time.

Acknowledgements. This study is supported by project “Remote sensing and field studies of porphyry copper and epithermal ore systems from Western Srednogorie metallogenic region” KII-06-H74/6, National Science Fund of Bulgaria.

Session GS11

Metamorphism

Conveners:

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The Cambrian Kolarovo Metaplagiogranites in the Ograzhden Complex (Belasitsa Mt.): Insights into the Earliest Supra-Subduction Evolution of the Proto-Gondwana Margin

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Leucocratic orthogneisses from the lower high-grade unit (Vertiskos-Ograzhden Complex) of the Serbo-Macedonian Massif (SMM) in the Belasitsa Mountain (SW Bulgaria) are the focus of this study. In Bulgarian geological literature, these rocks are well-known as the "Kolarovo metaplagiogranites", a term coined during the state geological mapping in 1966.

Geotectonically, the SMM is thought of as the uppermost thrust sheet of the Alpine Rhodope nappe system. Although these equigranular, well-foliated plagioclase-quartz-garnet-mica orthogneisses appear completely texture-trivial under a strong amphibolite-facies metamorphic mask, trace-element geochemistry provides a unique and powerful window into their primary igneous signature.

The rocks form small sheet-like bodies and a larger, irregularly shaped 3-km² domain with metamorphic mineral composition dominated by plagioclase, quartz, garnet, biotite, and muscovite, along with localized hornblende related to tectonic metabasite contact zones. Although spatially closely associated with metabasites, a shared meta-ophiolitic genesis is ruled out by contrasting U-Pb zircon geochronology. The associated metabasites yield a younger Silurian age (434.9 ± 3.5 Ma), whereas the Kolarovo metaplagiogranites exhibit a Cambrian ²⁰⁶Pb/²³⁸U zircon age of 521.3 ± 9.7 Ma. The presence of inherited Cambrian zircon cores within the widespread, younger equigranular and porphyritic Ordovician metagranites proves that this high-grade tectonic slice is a coherent Gondwana-derived crustal fragment preserving an older crystalline basement framework rather than a random chaotic tectonic melange.

Whole-rock major element data confirm a highly felsic (SiO₂ = 71.02–73.91 wt.%), strongly sodic (Na₂O = 4.51–5.12 wt.%), and low-K₂O signature, with Na₂O/K₂O ratios > 4 unequivocally classifying them within the trondhjemitic magma series. Trace elements reveal low Rb (up to 20.85 ppm), Y (< 15.4 ppm), and Zr concentrations, coupled with elevated Sr (306–577 ppm) and Ba contents. Chondrite-normalized REE patterns exhibit pronounced heavy REE depletion and weak negative Eu anomalies (Eu/Eu* = 0.67–0.78) due to plagioclase fractionation, except for a distinct phase showing a strong positive Eu anomaly (1.45) and high Sr, marking localized plagioclase-cumulate differentiation within the feeding magma chamber.

The elevated Sr/Y ratios (25–50) impart a distinct adakite-like signature, definitively ruling out a shallow, low-pressure ophiolite-related origin. Instead, they conform to high-Al₂O₃ trondhjemitic generated via slab melting of young, subducted oceanic crust at medium- to high-pressure conditions. This genesis was heavily controlled by a stable amphibole-bearing residuum that effectively retained the heavy REE and Y, while plagioclase was preferentially consumed into the partial melt.

The Kolarovo metaplagiogranites reveal a striking geodynamic contrast to the synchronous Cambrian magmatism in the adjacent Struma Unit (Kraishte Zone). While the latter marks the main, shallower plutonic volumes of a regional island arc system, the investigated small bodies represent its deepest, adakitic roots, offering key insights into the deep architecture of this peri-Gondwanan realm. During the subsequent Paleozoic collision, these juvenile adakitic lenses (Rb/Sr = 0.02–0.04) were mechanically detached, imbricated, and spatially juxtaposed with the Ordovician oceanic crust and ancient Proterozoic sediments within a shared tectonic suture zone in the Balkans.

Acknowledgements. This study was partially funded by the National Science Fund (Bulgaria) via contract KP-06-N74/4.

Cr-Muscovite from the Rodna Mountains (East Carpathians)

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The chromium-rich dioctahedral micas are relatively rare metamorphic minerals, and this paper sought to characterize them through petrographic, mineralogical, and crystallographic analysis using techniques such as petrographic examination, X-ray diffraction (XRD), and scanning electron microscopy combined with energy dispersive X-ray spectroscopy (SEM+EDS).

The Eastern Carpathians Median Dacitic segment within the Rodna horst comprises Subbucovinian and Infrabucovinian Alpine (Austrian phase) tectonic units. In composition of every Alpine unit, there are few overthrust or imbricated Variscan (first metamorphism mainly Ordovician, Pană et al, 2002) Barrowian type in amphibolite facies conditions metamorphosed units, such as: Rebra, Negrișoara, Tulgheș and Bretila- Rarău terrane with few Paleozoic sedimentary and volcanic cover rocks of greenschist facies conditions (Mosonyi, 1999, Culshaw et. al., 2012, Mosonyi et al, 2018).

The studied rocks are outcropping in the carbonatic Rebra 2 (Voșlobeni) formation of Subbucovinian, which is consisting of alternating carbonate-schist ($\pm$ phlogopite, fuchsite, phengite), amphibolite ($\pm$ garnet, diopside, tremolite-actinolite, epidote) and tremolite-bearing – dolomitic or calcitic marble sequences.

The chromium bearing (~40 ppm) carbonate schists contain three main foliations (the crenulation type S_3 is transposed after over S_2 due to intrafolial folding) and three main mineral assemblages: calcite, dolomite, muscovite₁, tremolite 1, diopside, Zn-Pb- sulphides of peak conditions overprinted on ocean-floor volcano- sedimentary protolith, associated with bimetasomatic processes which penetrated the contrasting lithological contacts (reaction skarns) and resulting ankerite, phlogopite, fuchsite (Cr-bearing muscovite), diopside, pyrite and finally dynamic retromorphic assemblages due to Variscan and/or Alpine nappe stacking-related thick shear zones, with recrystallised quartz boudins, dolomitised calcite, muscovite 2 (dioctahedral mica with Fe, Mg, Na), tremolite 2. The studied micas possess $2V = 40-42^\circ$, are dioctahedral, with general crystallochemical formula $((K_{0.87}Na_{0.14})(Fe_{0.1}Mg_{0.1}Ti_{0.02}Cr_{0.02}Al_{1.7})[Al_{0.95}Si_{3.05}]_4O_{10}(O,OH,F)_2 - K(Fe_{0.14}Mg_{0.1}Ti_{0.06}Al_{1.63}Cr_{0.05})[Al_{0.83}Si_{3.17}]_4O_{10}(O,OH,F)_2$ outlining a Cr-bearing (0.44 to 0.9 wt% Cr_2O_3) muscovite into phengite (mariposite), containing paragonitic component due to dynamic retromorphism.

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Session GS12

Mineralogy and Applied Mineralogy

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A plastic world built on minerals

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Plastics, i.e. polymers, have become a primary cornerstone of the 21st century civilization, spreading from industrial applications to everyday – often unnecessary uses – like PET and LDPE products. Even if awareness has been raised on these products and legislation aims to their restriction, other major application materials are shaping the polymers future. Without PVC, PUR, HDPE, PTFE, PC, etc. today's construction, automotive and digital industries would collapse (probably reopening the option of a green and clean future). At the root of each molecule used for polymer production there stand a synthetic crystal which has been produced from minerals obtained still predominantly from mining, rather than recycling and reuse. These are the catalysts, required in plastic production starting from base material synthesis up to the production waste management, and even the neutralization or recycling of spent polymer products. Moreover, the catalysts require carriers or supports, mostly also manufactured from mineral resources.

Catalyst supports and carriers are ranging from simple oxides like alumina, titania and silica polymorphs up to more complex ceramics, like cordierite and mullite and even inorganic carbon, often processed from biomass. There is a point where the support and carrier needs to be differentiated, as the catalytic phase might be a doped product of the carrier, which further requires a support phase.

Catalysts for synthesis of base organics can be high purity PGE-s in sub- or nanocrystalline form, but transitional metals, their oxides or metal-organic complexes, but for some simple reactions e.g. nitrobenzene synthesis, concentrated sulfuric acid acts as a catalyst over nitric acid. In a further step, the industry requires catalysts for polymer synthesis, assembling the base molecules into the highly performing product.

Catalysts for waste gas and water management include red-ox materials able to decompose organic molecules in the presence or absence of external energy sources, like UV light for photocatalysis. However, it's not only the production chain relaying on catalysts, at the end of their life cycle, polymers should be neutralized or recycled. Both processes involve the decomposition of the polymer to simpler blocks, neutral for disposal or suitable for reuse in synthesis. Some of the simplest materials applied in solvolysis, like NaOH and KOH, are obtained exclusively from mineral resources.

Finally, it cannot be left unmentioned the case of aiding materials: without the acids of Cl, F, S, N, P and various organic acids, polymer synthesis is unfunctional, either lacking required components, or production chain parts (vessels, pipes, machine parts). These acids are obtained by consuming mineral resources, either as base products, or catalysts as for nitric acid. Furthermore, the plastic products often will become functional only after using mineral additives, fillers or conditioners, obtained from mining production.

The aim of present contribution is to offer a systematically summarized and statistically explained use of mineral resources in polymer industry, with a glimpse on the recycling status of spent polymers and water requirements of the whole polymer sector.

Growth mechanism of Fe-rich lamellae in rutile from the Kanarata deposit, SE Bulgaria

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The Kanarata albitized granite deposit is located on the NE periphery of the Sakar batholith, adjacent to the contact with the metamorphic framework. The granite batholith is well investigated during the years and a lot of information related to the mineralogy, petrology, structure features and geochemical specialisation has been published (Kamenov *et al.*, 2010, Pristavova *et al.* 2019, Yanev, 2023 and references therein).

Rutile is the most common naturally occurring titanium dioxide polymorph and is widely distributed as an accessory mineral. In nature, titanium dioxide mainly occurs in three structural states: rutile, anatase and brookite.

The formation of twins in natural rutiles is most often related to the intergrowths/overgrowths of rutile with structurally related minerals that crystallize in the corundum-type structures (Daneu *et al.* 2014). Rutile and corundum-like minerals as well as related oxyhydroxides, possess a common hexagonal close-packed oxygen sublattice, enabling fast and effective mineral replacement processes (Armbruster, 1981). The epitaxially induced twinning of rutile has been reported during the chemical leaching of ilmenite (Putnis 2009).

Using optical microscopy, energy-dispersive spectroscopy and x-ray diffractometry we identified thick interfacial lamellae of Fe-rich phase in rutile (101) twins. We distinguished several chemical compositional varieties with TiO₂ from 34.77 to 45.15 wt. % and FeO from 54.90 to 65.23 wt. %. The mineral phase is difficult to be identified because the lamellae sizes (under micrometer).

Exsolution is the term used to describe crystal growth occurring in a solid phase; it proceeds through nucleation and growth processes (Sunagawa, 2005). The observed exsolved phase from the Kanarata deposit appears as thin platelets parallel to a low-index face of the host rutile phase. Structurally oriented exsolution of Fe-rich lamellae most probably are controlled by the crystal structure of the host phase.

Acknowledgements. The authors are grateful to N. Gospodinov, for the support during fieldwork and the donated sample. L. Mihailov is acknowledged for the assistance with the XRD analysis.

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FTIR characterization of structural defects and internal features in natural quartz crystals

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This study evaluates the structural characteristics and defect distribution in natural quartz crystals using Fourier Transform Infrared (FTIR) spectroscopy. Structural imperfections and impurity-related defects in quartz influence its physical, optical, and structural properties. FTIR spectroscopy was utilised to investigate the variations in local structural order by analysing an FTIR-derived crystallinity index (CI) and the full width at half maximum (FWHM) of specific absorption bands.

The transmission FTIR spectra exhibit characteristic quartz absorption bands at 460, 692, 778, and 1080 cm^{-1} , corresponding to Si–O–Si framework vibrations (α -quartz). Additional bands at 1620 cm^{-1} indicate molecular water, while features at 1880 and 2000 cm^{-1} represent overtone and combination lattice modes. Bands near 3460–3470 cm^{-1} relate to structurally bound hydroxyl defects and Al–OH centers. Weak bands at 3858 and 3735 cm^{-1} correspond to isolated and free OH stretching vibrations from silanol groups.

The Si–O–Si framework bands at 692 and 778 cm^{-1} were selected for quantitative analysis. The ~778 cm^{-1} band reflects stretching modes of the ordered tetrahedral lattice, whereas the ~692 cm^{-1} band is sensitive to local structural distortions. A crystallinity index (CI) was calculated from the relative integrated areas of these two bands.

Combined evaluation of the CI and FWHM parameters reveals clear variations in structural order and homogeneity. Higher CI values and narrower absorption bands (lower FWHM) indicate a more organized, less defect-rich crystal structure, whereas broader bands reflect increased lattice disorder and higher defect concentrations.

These results demonstrate that FTIR spectroscopy is a robust, non-destructive technique for assessing structural quality, defect incorporation and crystal evolution in natural quartz, offering important insights for geological and materials science investigations.

Acknowledgements. This work was supported by ERC Consolidator Grant 101043356 - PROGRESS, Horizon Europe (2023-2027) and Premiere PROGRESS (PN-IV-P8-8.1-PRE-HE-ORG-2023-0118).

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Investigating the influence of apatite fission-track rock cooling ages on quartz luminescence and electron spin resonance properties: implications for provenance studies

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Although quartz is considered one of the purest minerals in terms of chemical impurities, it contains numerous intrinsic and extrinsic point defects that originate during crystallization and continue to evolve after the crystal becomes a closed system. These defects become thermally stable only below relatively low temperatures (<100°C). Continuous exposure to the natural ionizing radiation modifies pre-existing defects and promotes the formation of trapped-charge centers responsible for optically stimulated luminescence (OSL) and thermoluminescence (TL), as well as paramagnetic centers detectable by electron spin resonance (ESR). Recently, quartz OSL sensitivity and oxygen-related ESR signals (e.g., E₁ centers) have been proposed as provenance indicators.

This study tests the hypothesis that quartz from source rocks with older cooling ages and slower exhumation rates has experienced a longer post-closure exposure to natural ionizing radiation, particularly alpha particles, resulting in larger populations of radiation-induced defects. Consequently, quartz with older cooling ages is expected to exhibit higher OSL sensitivity and stronger ESR signal intensities than quartz with younger cooling ages.

To test this hypothesis, ten granite samples characterized by contrasting apatite fission-track (AFT) cooling ages and zircon U–Pb crystallization ages were selected. The samples were collected from four geographically and geologically distinct regions (Thailand, Brazil, Kyrgyzstan and India), spanning AFT ages from 8 to 250 Ma and zircon U–Pb crystallization ages from 68 Ma to 3 Ga. The AFT ages can be considered suitable proxies for quartz cooling ages because they record thermal conditions comparable to those at which trapped-charge systems become thermally stable (<120°C). Quartz extracts from granites were characterized using OSL, TL, ESR and cathodoluminescence (CL).

Preliminary luminescence results reveal pronounced sample-dependent characteristics. No clear correlation has yet been identified between OSL sensitivity or ESR signal intensity and AFT cooling age or zircon U–Pb crystallization age. Repeated irradiation and optical stimulation cycles produced either a weak or no measurable OSL sensitization.

Although no systematic relationships have yet emerged from our dataset, the observed sample-dependent behaviour suggests that rock cooling history may not exert a primary control on quartz luminescence and ESR properties. These preliminary findings highlight the complexity of the processes governing these signals and provide a basis for further evaluating their potential as quartz provenance indicators.

Acknowledgements. This research is funded by European Research Council ERC grant PROGRESS-CoG “Reading provenance from ubiquitous quartz: understanding the changes occurring in its lattice defects in its journey in time and space by physical methods”

Multi-spectroscopic characterisation of quartz from igneous, volcanic and sandstone rocks worldwide. Insights for provenance studies based on OSL sensitivity

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Quartz is a ubiquitous, durable mineral abundant in most lithologies and in sedimentary systems. Its stability during weathering and diagenesis makes it a robust provenance tracer. Quartz optically stimulated luminescence (OSL) sensitivity and electron spin resonance (ESR) signals have been empirically proposed as indicators for sediment provenance based on differences in quartz sensitivity. Sensitivity is defined as luminescence produced per unit dose (Gray: Gy) per unit mass (mg). The mechanisms driving OSL sensitisation during quartz weathering from source rock remain an open question in the luminescence community. While it is largely believed to be acquired by earth surface processes, recent studies bring evidence that sensitisation processes depend on source geology. Moreover, most studies focus on quartz grains deposited in the sink and infer possible source rock by clustering.

The present study investigated a diverse suite of source rocks a wide range of geological settings in Arizona, Romania and Australia, including granites, sandstones, volcanic and metamorphic rocks, and, where applicable, their derived sediments, independently dated from millions (Ma) to billions (Ga) of years. To understand the mechanism of OSL sensitivity we combined thermoluminescence (TL), OSL, ESR, cathodoluminescence (CL) and Raman spectroscopy measurements, with geochemical data obtained through laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). Only quartz samples exhibiting all three characteristics - the $[\text{TiO}_4\text{Li}^+]^0$ paramagnetic centre in ESR spectra, relatively high titanium and lithium concentration, and strong blue emission in SEM-CL - showed sensitisation following repeated cycles of laboratory dosing and bleaching. Samples lacking these centres did not show any laboratory OSL sensitisation by dosing and bleaching. We find a strong correlation of the degree of laboratory OSL sensitisation with the $[\text{TiO}_4\text{Li}^+]^0$ electron centre from ESR signal, and the titanium and lithium concentrations measured by LA-ICPMS. Our data on rocks of various ages and regions reinforce the idea that the potential for OSL sensitisation originates from specific lattice defect structures acquired by quartz during crystallisation. The results also highlight the role of Li^+ -ion impurities in forming paramagnetic centres such as $[\text{AlO}_4/\text{h}]^0$ and $[\text{TiO}_4\text{Li}^+]^0$, advancing our understanding of the interaction between radiation and specific defects in quartz.

Acknowledgements. This research is funded by European Research Council ERC grant PROGRESS-CoG “Reading provenance from ubiquitous quartz: understanding the changes occurring in its lattice defects in its journey in time and space by physical methods”

Chemical peculiarities of the amphibole minerals from the Kanarata deposit, SE Bulgaria

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The Kanarata deposit is located about 3 km north-northeast of Hlyabovo village, in southeastern Bulgaria. The deposit is hosted in the northeastern periphery of the Sakar granitic batholith, where they are affected by albitization. Cracks and caverns are often observed, filled with hydrothermal mineralizations represented by euhedral crystals of albite, amphibole, titanite, apatite, rutile and others (Kamenov *et al.*, 2010; Yanev, 2023 and references therein).

We studied amphibole supergroup minerals – their crystal morphology, chemical composition and nomenclature affiliation, according to Hawthorne *et al.* (2012). The morphology of the crystals is observed under optical stereo microscope. The chemical analyses are performed on SEM-EDS. For the mineral characterization a single-crystal X-ray diffraction is used.

A characteristic feature of the investigated crystals is their fine-fibred terminations. The main crystallographic forms are {110} and {010}. The habit is prismatic to long prismatic ($A^c_{(110)}$) and fibrous (A^c_f). The temperature is the main factor controlling the amphibole habit and this is an evidence for the fast crystallization (Kostov and Kostov, 1999). Szopa *et al.* (2020) established that the temperature of the hydrothermal activity in the deposit is in the range of 290–330 °C.

Values for $Fe^{3+}/(Fe^{2+} + Fe^{3+})$ can be calculated using assumed site-occupancy limitations and the electroneutrality principle, and although the values obtained are not very accurate (Hawthorne, 1983). The lack of H, Li, and Fe^{3+} distorts the amounts of other constituents and the problem is still present in that the formulas are still inaccurate. There are methods available to determine these components, and amphibole analysts should be acquiring or using these on a routine basis (Hawthorne, 2012). The obtained crystallochemical formulae reveal that all of the studied samples belong to the subgroup of the Ca amphiboles. The species are: tremolite, magnesio-hornblende and pargasite.

Acknowledgements. The authors appreciate the Magma-97 AD, Engineer S. Lyutskanov, N. Gospodinov for the fieldwork and the samples. Thanks are due to Professor R. Nikolova (Institute of Mineralogy and Crystallography) for the single-crystal X-ray diffraction.

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Microchemical characteristics of pyrite, arsenopyrite, and sphalerite from the Govezhda Au-base metal deposit, Western Balkan Mountains, Bulgaria

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The Govezhda gold-base metal deposit is located in NW Bulgaria. It comprises quartz-sulfide veins hosted in the low grade metamorphic rocks of Diabase-phyllitoid complex (Berkovitsa and Dalgi Del group), discovered in the vicinity of the villages of Govezhda, Kopilovtsi, and Diva Slatina. Source of ore-forming fluids is the presumed quartz-diorite, diorite porphyrite and granodiorite porphyrite dykes of the Late Carboniferous (Variscan) age. The ore mineralization includes pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, tetrahedrite, gold, scheelite, cassiterite, and rare sulfosalts. Ore minerals are formed through four main ore stages. Gold occurs mainly with galena and sphalerite from the second stage, but also as "invisible gold" within pyrite and arsenopyrite from the first stage (Mladenova et al. 2003).

The chemical composition of pyrite, arsenopyrite, and sphalerite was determined by EPMA and LA-ICP-MS in samples of quartz-sulfide veins from waste ores in the area of the villages of Kopilovtsi and Diva Slatina. The main structurally bound trace elements in pyrite and arsenopyrite are Co, Ni, Mn and Sb, as in pyrite and As, while in sphalerite they are Mn, Fe, Cd, Ga, In, Sn and Hg.

The trace element content of these minerals varies in the following ranges (in ppm): 1) pyrite - Co (0.28–95), Ni (2.1–290), Mn (18–85), As (25–39000), and Sb (less than 100, mostly detected as tetrahedrite-tennantite, arsenopyrite, galena, and Pb-Sb sulfosalts); 2) arsenopyrite - Co (0.37–146), Ni (5.6–380), Mn (11–57), and Sb (105–3087); 3) sphalerite - Mn (3.3–476), Fe (2364–32900), Cd (3242–7679), Ga (7.3–45), In (0.19–0.55), Sn (1.2–20), and Hg (32–76). Copper content is determined in all three minerals, but is associated with grains or inclusions of chalcopyrite and tetrahedrite-tennantite (pyrite and arsenopyrite) and blebs ("chalcopyrite disease") in sphalerite. For the same reason, Pb and Ag contents in pyrite and arsenopyrite, as well as Sb in pyrite, are also reported. Lead content is mostly associated with galena and sulfosalts such as bournonite, boulangerite, and owyheeite, while Ag content is associated with tetrahedrite-tennantite, pyrargyrite, and proustite. The Ag content in pyrite ranges from 0.21–1300 ppm, in arsenopyrite from 0.64–118 ppm, and in sphalerite from 9.8–180 ppm. Tin and In contents were determined by several analyses in pyrite, probably related to stannite or cassiterite inclusions.

The estimated gold contents for the host minerals analyzed (pyrite, arsenopyrite and sphalerite) vary widely. They are usually the result of tiny veins or inclusions of gold nugget ablated by laser downhole in pyrite, arsenopyrite, and sphalerite. The size of these gold particles is usually smaller than 2–3 µm, and some of them could be considered as "invisible" gold. The estimated gold contents in pyrite range from 0.05–43 ppm, in arsenopyrite - 1.8–606 ppm, and in sphalerite - 0.13–5.33 ppm.

Acknowledgements. This study is financially supported by the KP-06-N84/4 grant of the Bulgarian National Science Fund

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Mineral associations of gold in the Martinovo and Chiprovtsi deposits, northwestern Bulgaria

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The Martinovo and Chiprovtsi deposits, united by some authors in the so-called Chiprovtsi ore zone, are located in the western part of the Balkan Mountains. Their formation is believed to be related to the syntectonic emplacement of the Sveti Nikola granite intrusion (311.9 ± 4.1 Ma) and the Prekop quartz-diorite to monzodiorite intrusion into the low-metamorphic rocks of the so called Diabase-Phyllitoid Complex (DFC) in Bulgaria during the last Variscan collisional events. In the papers published so far, the Prekop intrusive body has been considered both as a relatively late intrusive phase of the granite and as a separate late intrusion related to the same evolved magmatic source. The mineralization types of the Martinovo and Chiprovtsi deposits show well defined lateral geochemical zonation from west to east, with gradual transition from skarn (Fe–Mo±W) and medium temperature (Pb–Zn–Ag) to low temperature hydrothermal mineral assemblages (Hg–Sb–fluorite). The ore mineralization is deposited in the following paragenetic assemblages: molybdenite-scheelite; magnetite; arsenopyrite-pyrite (arsenide-sulfide); pyrrhotite-chalcopryrite; polymetallic (Pb–Ag–Sb–Zn–Cu); baryte-ankerite; and fluorite-cinnabar-baryte. The deposits were operated for extraction of Fe and Mo (Martinovo), and Pb and Ag (Chiprovtsi).

Although gold has been described in both deposits, due to its rarity and insignificant content, its distribution has never been studied in detail. This study presents data on the mineral associations of gold and estimates the gold contents of host minerals spatially and temporally. Therefore, representative samples of different assemblages were studied using optical microscopy, SEM, EPMA and LA-ICP-MS. It is well known that main mineral hosts of gold are As-bearing pyrite and arsenopyrite, since in most cases As spatial presence promotes gold deposition. Our study has shown that gold indeed has spatial association with pyrite and arsenopyrite, but its occurrence is not always concurrent with the formation of these minerals. Most often it is deposited with late minerals such as chalcopryrite, native bismuth and other bismuth minerals from the pyrrhotite-chalcopryrite assemblage or with chalcopryrite and galena from the polymetallic assemblage. As a result, high Au contents (up to 15 ppm), due to gold particles, have been found in chalcopryrite associated with pyrrhotite. The earliest pyrite (molybdenite-scheelite assemblage) rarely contains gold. Low Au contents have been reported in pyrite from the pyrite-arsenopyrite assemblage (up to 2 ppm), while in arsenopyrite the Au content reaches 9 ppm. Pyrite from the polymetallic association contains 0.2–3.7 ppm Au. The latest deposition of gold is associated with colloform pyrite found in the easternmost part of the Chiprovtsi deposit. The gold content in this colloform pyrite (Velin dol and Lukina padina sections) (up to 2.7 ppm) and marcasite (Hlebarska chuka) (up to 150 ppm) is suggested to be the result of the presence of numerous nanoscale gold particles, as evidenced by the flat LA-ICP-MS intensities. The anomalously high gold content of this marcasite corresponds to a very high arsenic content (up to 10 wt%), which could even suggest the presence of chemically bound gold (Au(I)).

Acknowledgements. This study is supported by the KP-06-N84/4 grant of the Bulgarian National Science Fund.

Trace Mineralogy and Micro-textural Features of the Brucite Marbles from Dealul Pițigușului, Budureasa: A SEM-EDS Study

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The Dealul Pițigușului area (Budureasa, Romania) features a contact metamorphic aureole formed by Late Cretaceous–Early Paleogene magmatic intrusions into Mesozoic carbonates. This thermal event generated a distinct structural zoning, transitioning from proximal Mg-skarns to brucite-bearing dolomitic marbles (Marincea et al., 2022). While the Budureasa skarns are extensively documented, the accessory phases within the surrounding marbles remain less explored. This study uses SEM-EDS to investigate the micro-textural and mineralogical properties of brucite marbles and their calc-silicate transition zones. The samples display a predominantly granoblastic texture spanning from calcitic to dolomitic marbles. Submillimeter brucite nests are dispersed throughout the matrix, frequently associated with talc and clinocllore. Micro-textural evidence indicates that these nests are retrograde hydration products of primary periclase, marking a high-temperature prograde origin. Despite comprising less than 1% of the mineral composition, the trace mineral suite is diverse. Identified phases include disseminated chlorite, smectite, epidote-clinzoisite, phlogopite, apatite, and fluorite. Proximal zones preserve relict high-temperature phases such as diopside, forsterite, and spinel. Hydrothermal fluids mobilized base metals and metalloids, precipitating discrete grains of sphalerite, galena, chalcopyrite, arsenopyrite, and pyrite (locally altered to goethite). Furthermore, SEM-EDS analysis revealed rare trace phases hosted by the carbonate-brucite matrix, including Ti- and Mn-bearing minerals (geikielite, titanite, rutile, hollandite), secondary vanadates (mottamite), and unusual accessory phases such as baddeleyite, zircon, and uraninite. This mineralogical assemblage records a multi-stage metasomatic evolution. Following the primary high-temperature contact metamorphism, pervasive retrograde hydrothermal fluids acted as carriers for a distinctive array of metalliferous and radioactive trace elements, leaving a complex geochemical signature on the Budureasa aureole.

Acknowledgements. This work was supported by the COFUND-ERAMIN-3-PEGMAT framework and national projects PN 23-39-02-02, PN23-39-02-03, and PN 23-39-02-05. We thank the GeoEcoLab Laboratory (Geological Institute of Romania) for SEM-EDS access. We also thank Alexandru Roșu, Gelu Agafiel Mărăcineanu, and Verde Magnesium SRL for providing the samples and permission to publish.

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New data on the mineral assemblage of skarn alteration within the contact-metamorphic halo of the Vezhen pluton, Central Stara Planina Mts., Bulgaria

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In the study area, the Vezhen (Vejen) pluton is described as a large intrusive body more than 20 km long and over 8 km wide, composed mainly of granodiorite locally including porphyritic varieties (e.g. Kamenov et al., 2002; Antonov et al., 2011). The samples studied are located at the Zlatitsa-Teteven part of the Stara planina mountains. The age of the pluton has been constrained at about 307 ± 0.85 Ma, using U–Pb age dating of zircons (e.g. Georgiev et al., 2020). The pluton intrudes a metasedimentary basement composed of various phyllites and schists (e.g. Lazarova, 2008). Along the contact between the pluton and the basement, a contact-metamorphic halo composed of hornfelses, spotted/knotted schists, etc, is formed (e.g. Lazarova, 2008). Skarn alteration is developed within this contact-metamorphic halo and is associated with epidote- and feldspar-bearing veins, some of which contain fine-grained garnet porphyroblasts (e.g. Lazarova, 2008; Antonov et al. 2011).

The skarns revealed in the studied area are exoskarns developed in knotted and chlorite-sericite-carbonate schists exposed as small zones, occasionally up to 50 cm in thickness. The rocks are moderately weathered with yellow-green-grey to yellow grey colours. The alteration assemblage consists of garnet, pyroxene, titanite, epidote, plagioclase and magnetite. At the macroscopic scale two garnet varieties can be distinguished, one occurring as brownish-red aggregates, stripes and nests up to 1 cm in size, and the other disseminated throughout the rock as smaller dark-coloured grains. Garnet is compositionally classified as grossular-andradite type, with variable components of $\text{And}_{48-54}\text{Grs}_{32-36}\text{Alm}_{4-6}\text{Sps}_1$. Pyroxene is abundant in the exoskarns, usually fine-grained, subhedral to anhedral, shows patchy zoning, classified as diopside with varying components $\text{Wo}_{49-53}\text{En}_{29-35}\text{Fs}_{14-19}$. Epidotes occur either as small inclusions in garnet, up to 10–15 μm in size, or as larger subhedral grains reaching up to 100 μm . Epidote inclusions are characterized by higher REE contents than the larger individual epidote grains. Plagioclase occurs intergrown with epidote or garnet, forming aggregates of small sized to micro-sized grains, described as albite with $\text{An}_{1-5}\text{Ab}_{94-97}\text{Or}_{<1-1}$.

Overall, the studied alteration is interpreted as a garnet-pyroxene exoskarn formed during the early stage of skarn formation with minor overprint by late-stage mineral assemblages represented by epidote and plagioclase.

Acknowledgements. This study was supported by project KP-06-M84/2, funded by the National Science Fund, Bulgaria.

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Major and trace element composition and geothermometry of chlorites in the Djurkovo and Govedarnika Pb-Zn deposits, Central Rhodopes, Bulgaria

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Chlorite minerals are widespread in various geological environments, and their composition reflects formation conditions. In the Central Rhodopean Pb–Zn deposits, chlorites occur as an alteration product of aluminosilicate rocks and as gangue, formed during the main ore stage (Vassileva, Bonev, 2003; Vassileva et al., 2021). The Djurkovo and Govedarnika Pb–Zn deposits (Laki ore district) are related to the Eocene–Oligocene evolution of the Rhodope Metamorphic Complex and show contrasting ore styles: vein and predominantly Mn-rich skarn-hosted respectively (Milenkov et al., 2026).

The studied chlorites from both deposits are part of the alteration assemblage comprising epidote-group minerals, sericite, adularia, quartz, kaolinite, carbonates ($\pm$ REE carbonates), hematite, and rarely xenotime. The chemical composition obtained by EPMA reveals chamosite-clinocllore series with variable Fe/Fe+Mg ratios from 0.392–0.895 (Djurkovo) and 0.468–0.990 (Govedarnika). The SiO₂ content in the studied chlorite ranges from 20.53 to 29.04 wt% in Djurkovo and from 22.52 to 27.71 wt% in Govedarnika. The corresponding ranges for FeO, Al₂O₃, MgO, MnO, and ZnO are 20.85–40.83, 17.87–20.72, 2.69–18.15, 1.08–6.40, and 0–0.55 wt% in Djurkovo, and 18.08–43.60, 11.61–21.06, 0.26–15.42, 1.32–13.19, and 0–2.07 wt% in Govedarnika, respectively. The V₂O₃ content in the studied chlorites for both deposits is $\leq$ 0.2, while TiO₂, NiO and Cr₂O₃ are $\leq$ 0.1 wt%.

LA-ICP-MS analyses of chlorite from both deposits reveal the presence of minor and trace elements, including Li, Rb, Sr, and Ba at concentrations reaching hundreds of ppm, and B, Co, Ga, Cs, and Pb occurring at tens of ppm.

Chlorite compositional variability reflects formation conditions and provides the basis for its widespread use as a geothermometer commonly based on the correlation between tetrahedral Al-occupancy and formation temperature. The studied chlorites from Djurkovo and Govedarnika indicate formation temperatures of 270–364°C and 210–370°C respectively.

Elevated Mn and Zn contents in Govedarnika chlorites highlight a stronger interaction with Mn- and Zn-rich ore-forming systems, whereas Djurkovo chlorites are comparatively Mg-richer. Nevertheless, chlorite geothermometry suggests that both deposits formed under similar hydrothermal conditions. The results emphasize the role of hydrothermal alteration assemblages as potential hosts of critical elements, including Li, B, Mn, Mg, Co, Ga.

Acknowledgements. The study is supported by the Bulgarian National Science Found project LiBeRE KP-06-N94/3 and contributes to the aims of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers № 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria.

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Trace-element signatures of accessory minerals in the metamorphic rocks of the Kimi-Krumovitsa Unit, Chernichino area, Eastern Rhodopes, Bulgaria

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The metamorphic sequence of the Kimi-Krumovitsa lithotectonic unit is lithologically heterogeneous and comprises irregularly interlayered gneisses, amphibolites, marbles, calcschists, metagabbros, and rare quartzites, together with ultramafic bodies. The present study focuses on the Chernichino and Karatepe prospects, located east of Chernichino village in the Eastern Rhodopes, and aims to characterize the major- and trace-element signatures of the accessory minerals in gneiss, amphibolite, and marble. Representative drill-core samples from two drillholes were examined by a complex approach involving optical petrography, cold-CL, EPMA and LA-ICP-MS.

Both drillholes intersect alternating gneiss, amphibolite, and marble, locally crosscut by ultramafic bodies and pegmatite dykes. The gneisses comprise plagioclase, quartz, K-feldspar, biotite, muscovite, chlorite, and garnet, with accessory titanite, apatite, and rutile. The amphibolites consist mainly of hornblende, plagioclase, quartz, epidote, and garnet, with accessory epidote-group minerals, apatite, titanite, and zircon. Locally, impure marbles contain epidote-group minerals, titanite, apatite, and zircon, overprinted by minor late pyrite-chalcopyrite mineralization. A mafic body emplaced in the marble is spatially associated with intense marble replacement.

Back-scattered electron imaging and mineral-chemical data indicate that epidote-group minerals in marbles record localized REE redistribution during fluid-assisted metasomatism. These minerals commonly exhibit irregular inhomogeneity and/or growth zoning, with brighter domains enriched in rare earth elements relative to darker domains. The light domains contain ~0.2 wt.% La₂O₃, compared with ~0.02 wt.% La₂O₃ in dark domains, whereas Ce₂O₃ ranges from 0.02 to 0.6 wt.% between dark and light domains. Thorium contents in epidote are only in tens of ppm range. REE-bearing clinozoisite is more strongly enriched, with average light-domain concentrations of 1.6 wt.% La₂O₃ and 4.1 wt.% Ce₂O₃, whereas the corresponding values in the dark domains are 1.4 wt.% La₂O₃ and 2.5 wt.% Ce₂O₃. Thorium incorporation ranges from 0.4 to 0.8 wt.%, whereas Sr occurs at hundreds of ppm levels. In the mafic dyke-related assemblage, epidote-group minerals contain higher average contents of La₂O₃ (1.7 wt.%), Ce₂O₃ (3.2 wt.%), ThO₂ (1 wt.%), and SrO (0.2 wt.%). Titanite from all lithologies contains elevated LREE relative to HREE together with Ta, Nb, Y, V, and Th, whereas Ga, Sn, and Ge occur only in the tens of ppm range. Fluorapatite likewise contains hundreds to thousands of ppm Sr, hundreds of ppm Σ REE, and tens of ppm B and Y.

Accessory mineral assemblages in the studied lithologies record localized trace-element redistribution during fluid-rock interaction within the metamorphic basement. Assemblages within impure marble intervals indicate LREE enrichment relative to HREE and localized trace-element redistribution during fluid-assisted alteration of reactive carbonate horizons. The observed zoning patterns and trace-element enrichments suggest multistage accessory mineral growth during fluid-rock interaction, reflecting localized metasomatic re-equilibration within the metamorphic basement in the Chernichino area, Eastern Rhodopes.

Acknowledgements. The field studies and samples are provided by DPM Metals Krumovgrad. Analytical procedures are financially supported by DPM Metals Inc. and Bulgarian National Science Fund project KP-06-N94/3 (LiBeRE).

Mineralogical characteristics of rare earth carbonates from Ditrău Alkaline-Carbonatite Complex, Eastern Carpathians, Romania

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The Ditrău Alkaline-Carbonatite Complex (DACC), emplaced within the Cambrian crystalline basement of the inner East Carpathians, comprises a succession of magmatic and post-magmatic events associated with Triassic extension and Jurassic rifting. Its magmatic evolution is interpreted to have culminated in the emplacement of a carbonatite intrusion following the alkaline silicate magmatism and exploiting the same structural pathways. The Jolotca and Belcina mineralized areas host abundant rare earth element (REE) mineralization, with REE carbonates representing one of the most important mineral groups.

Primary REE carbonates identified in the DACC include members of the bastnäsite-, parisite-, and synchysite-groups, röntgenite-(Ce), sahamalite-(Ce), ancylite-(Ce), and eisenkalkancylite (a carbonate of REE, Fe, and Ca). The secondary hydroxylbastnäsites (with Ce, La, and Nd, respectively) formed during late hydrothermal alteration of pre-existing REE phosphates, allanite-(Ce), and primary REE carbonates. For this study, the mineral assemblages were re-examined using a combination of optical microscopy, electron microprobe analysis (EPMA), and energy-dispersive X-ray spectroscopy (EDS).

The REE carbonates display pronounced micron-scale oscillatory zoning, reflecting fluctuations in the composition of carbothermal-hydrothermal fluids during crystal growth. The zoning is primarily controlled by variations in LREE and Ca contents and records repeated changes in fluid chemistry under near-constant physicochemical conditions. Textural evidence also documents replacement relationships among members of the REE fluorocarbonate group, together with widespread bastnäsitization of allanite-(Ce) and monazite-(Ce), indicating multiple episodes of fluid-mineral interaction.

Newly obtained textural and analytical evidence reveals a four-stage evolution of the REE mineralization in the DACC: (1) an early magmatic apatite-magnetite-Nb-rich rutile-monazite assemblage; (2) primary hydrothermal monazite-(Ce), allanite-(Ce), and primary REE carbonates formed during the carbothermal stage; (3) secondary REE carbonates and secondary allanite-(Ce) produced by late hydrothermal alteration; and (4) a late-stage assemblage of fergusonite, pyrochlore, sulfides, and molybdenite. Cross-cutting relationships demonstrate that primary REE carbonates postdate the magnetite-apatite association, marking a distinct carbothermal event. These findings refine the evolutionary model of the Ditrău alkaline-carbonatite complex and highlight the critical role of evolving carbothermal-hydrothermal fluids in controlling the formation and transformation of REE carbonate assemblages.

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Effect of mechanochemical processing on the mineral composition of Moroccan and Egyptian phosphorite ores

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The rise in global demand for mineral fertilizer production and the need for sustainable practices call for the development of acid-free methods in the processing of low- and medium-grade phosphorite ores. The manufacture of P-based fertilizers relies heavily on the exploitation of phosphate rock reserves, with Morocco holding the largest global reserves (50 Gt), followed by China (3.8 Gt) and Egypt (2.8 Gt) (U.S. Geological Survey, 2024).

Mechanochemical activation is a suitable processing method for phosphate rocks due to its effectiveness in increasing the assimilable forms of phosphorus without generating waste in the process. This is achieved by inducing structural defects and phase transformations in the main apatite mineral (Fang *et al.*, 2019).

The present study investigates the effect of mechanochemical treatment via a planetary ball mill on the mineral composition and structural characteristics of apatite and associated gangue minerals in Moroccan (MP) and Egyptian (EP) phosphorite ores. The main differences in the phosphorites' chemical composition are related to their SiO₂ (5.6% for EP vs. 1.9% for MP), P₂O₅ (22.4% for EP vs. 21.5% for MP), and CaO (31.6% for EP vs. 30.1% for MP) content. The ores were processed at varying times between 10 and 300 minutes with 20 mm Fe grinding bodies. The resulting changes in the mineral and chemical composition were characterized using Powder X-ray Diffraction (PXRD) combined with Rietveld refinement, Fourier-Transform Infrared Spectroscopy (FTIR), and Wavelength Dispersive X-ray Spectroscopy (WD-XRF).

Before activation, both ores exhibited a similar mineral composition consisting of francolite, calcite, and quartz, with the additional presence of dolomite in the Moroccan phosphorite. Upon processing, monetite formation was observed in both ores, accompanied by orthophosphates in the Moroccan phosphorite and pyrophosphates in the Egyptian one. Furthermore, two types of anionic isomorphism were observed in all activated samples: the substitution of fluoride ions (F⁻) with hydroxyl groups (OH⁻) along the hexagonal axis of francolite, forming fluor-hydroxylapatite, and the partial replacement of phosphate groups (PO₄³⁻) by carbonate (CO₃²⁻), resulting in B-type carbonate apatite.

The results obtained indicate that mechanochemical activation is a highly effective, acid-free method for the treatment of Moroccan and Egyptian phosphorite ores. By inducing structural defects, phase transformations, and solid-phase synthesis, the initial apatite is transformed into more reactive forms. The effect is more prominent in the Egyptian phosphorite, owing to the higher content of quartz, whose particles have an additional abrasive effect during activation.

Acknowledgements. This work was supported by European Regional Development Fund under "Research Innovation and Digitization for Smart Transformation" program 2021-2027 under the Project BG16RFPR002-1.014-0006 "National Centre of Excellence Mechatronics and Clean Technologies".

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Bridging the Tethyan Gap: The First Localized Theoretical Model for Carbonate-Phosphate Formations in Albania Based on Comparative SEM-EDS Constraints

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Regional models of Tethyan marine phosphogenesis emphasize broad processes such as upwelling, redox fluctuations, and nutrient cycling, yet they do not capture the localized structural and geochemical evolution of the small, tectonically disrupted basins that characterize the External Albanides. Although Albania represents one of the most structurally complex sectors of the former Tethyan margin, no framework has previously linked its carbonate–phosphate deposits to micro-scale mineralogical and chemical evidence. Here we propose a localized theoretical model for phosphatic formation in Albania, integrating legacy geological mapping with high-resolution SEM–EDS analyses from the Fushë-Bardhë and Bogaz sectors.

Cretaceous phosphatic horizons preserve a primary marine upwelling signature, with authigenic fluorapatite enriched in Fe–Ti–Al and REEs. Textural and chemical relationships indicate a multi-stage history involving initial phosphogenesis, subsequent deformation, paleokarst dissolution and reprecipitation, and later fluid overprinting. These observations suggest that an originally depositionally constrained system was modified by later fluid redistribution.

Jurassic carbonate formations display pervasive brittle fracturing and matrix brecciation. SEM–EDS mapping shows that fracture networks host K–Mg–Al silicate phases consistent with illite/smectite compositions, secondary iron-oxide pseudomorphs, and localized heavy-metal concentrations. The occurrence of nearly pure Si domains (90–98 wt%), Al-rich phases, and iron oxides within microscale fractures is compatible with high-temperature, oxidizing, Al–Si-rich fluid activity, although additional mineralogical confirmation is required. Discrete U-bearing grains associated with halide-rich micropockets (Cl–Na–K) and evaporitic salts suggest episodic interaction with saline, metal-bearing fluids; the mineralogical identity of these grains requires further verification.

Together, these contrasting micro-chemical signatures and historical geological data support a reconstruction of evolving fluid pathways, stress regimes, and chemical deposition along this portion of the Albanian margin. This localized framework refines regional Tethyan phosphogenesis models by illustrating how the tectonic architecture of the External Albanides produces heterogeneous mineralization patterns not predicted by basin-scale approaches.

Acknowledgements. This work was supported by CEEPUS mobilities 22/23 and 25/26 at the University of Vienna. The author thanks Peter Nagl, and Susanne Gier for their support.

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The mineralogy of kidney stones and their related bacterial cultures

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Many factors are culprits for kidney stone genesis: unbalanced diet, insufficient liquid consumption, hormonal issues, urinary postponement, etc. Mineralogical analysis on these biological “concretions” such as the morphological study and micromorphological study using thin section, isotope radio mass spectrometry (IRMS), X-ray diffraction (XRD), and electron microscopy images (SEM) give us new perspectives on the topic which could help us understand their genesis and find ways to prevent them.

Kidney stone formation follows a simple process and principle: something precipitates or crystallizes out of the urine, which serves as a starting point for other crystals to grow and consolidate into a potentially dangerous kidney stone.

The major components identified in kidney stones have been the oxalates weddellite and whewellite, the phosphates apatite and struvite and other minerals such as uricite.

Carbon stable isotope data holds information on food intake and is also influenced by geography.

The different characteristics and genesis of urinary tract-associated minerals can be used to our advantage in figuring out different ways to eradicate, corrode, or completely avoid these unpleasant outgrowths, in addition to identifying potential bacterial colonies that might flourish under the conditions in which the stones form or within the stones themselves—potentially leading to additional complications.

Bacterial colonies have been identified by first incubating them and then seeding them on various culture media. The formation of mineral precipitates within the urinary tract can create a very favorable environment for bacteria to develop. It's also important to distinguish between pathogenic and non-pathogenic bacteria, as this difference is crucial to the effect they have on the patient, the former having the ability to cause either mild or severe illnesses.

Additionally, we have conducted a statistical analysis using R studio with the intention of properly determining the observed correlations and finding the infection potential of a kidney stone.

In this presentation, we will discuss the results of mineralogical analyses performed on a set of 39 kidney stone samples, predominantly of oxalatic and phosphatic composition. These analyses determine the stones' composition and examine their structure, as well as their origin and the bacterial colonies that have been discovered to be developing inside or around them. We will also discuss possible connections between these different bacterial strains and the mineralogy of kidney stones.

Acknowledgements. The authors thank Assoc. Prof. Tudor Tămaș.

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Crystal chemistry and Raman spectroscopic characterisation of pumpellyite from low-grade metamorphosed alkaline basaltoids in the vicinity of the Izvor village, Eastern Srednogie, Bulgaria

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The pumpellyite-group members are low-grade metamorphic and hydrothermal minerals. Pumpellyite is a characteristic constituent of rocks metamorphosed at subgreenschist facies and it is also present in rocks formed under blueschist-metamorphism conditions.

The studied samples have been collected near the village of Izvor from Upper Cretaceous volcanic rocks metamorphosed at prehnite-pumpellyite facies. The volcanic rocks are represented by alkaline basaltoid lava flows, which belong to the Kartalkus Formation of the Burgas Group, Eastern Srednogie Zone. The secondary minerals are prehnite, pumpellyite, epidote, albite, chlorite, quartz, titanite and native copper. Special attention was paid to determine the type of pumpellyite. The chemical composition of pumpellyite is important for determining the metamorphic grade.

Pumpellyite was observed as radial aggregates of fine fibrous crystals together with prehnite, chlorite and albite. Usually it is present within the fillings of the amygdale cavities and veins and rarely as irregular replacements on the groundmass. Electron probe microanalyses (EPMA) of pumpellyite were calculated on the basis of 16 cations per 24.5 oxygens assuming a chemical formula of $W_4X_2Y_5Z_6O_{20+x}(OH)_{8-x}$. The calculation procedure assumes that all charge imbalance is compensated by oxidation of Fe^{2+} to Fe^{3+} and the proportion of Fe^{3+} and Fe^{2+} is adjusted so that all 16 cations are full. The substitutions of R^{3+} in the X site are compensated by substitutions of O^{2-} for OH^- and univalent for divalent cations in the W site.

The MgO content is approximately constant in all spot analyses, average 2.8 wt%. The Al_2O_3 content ranges from 16.05 to 21.40 wt% (3.12–4.06 apfu mainly at the Y-position). The Si content is generally close to the ideal six cations. The sum of Ca and Mn cations is invariably <4.0, so the W site contains some Fe^{2+} , Na, K and rarely Sr and Ba. The studied pumpellyite is rich in iron. The Fe^{2+} and Fe^{3+} contents at the X-position range from 0.28 to 0.748 apfu and 0.87 to 1.01 apfu, respectively. The Al content in X-position is negligibly low (0–0.1 apfu). The presence of Fe^{3+} in the Y-position (up to 0.85 apfu) indicates solid solution towards julgoldite (up to 21 mol% julgoldite component). The pumpellyite compositions are plotted in the $Al+Fe^{3+}-Fe^{2+}-Mg$ ternary diagram. This projection corresponds to the dominant cation in the X-site. According to Passaglia and Gottardi (1973) the predominance of Fe^{3+} in X-position gives us the reason to attribute the studied pumpellyite to the pumpellyite-(Fe^{3+}) end-member of the series.

Raman spectroscopy confirms the identification of pumpellyite by the presence of characteristic peaks at 118, 131, 226, 277, 291, 358, 371, 423, 481, 509, 601, 695, 816, 920, 984, 1012, 3469 and 3527 cm^{-1} . The most intense band at 695 cm^{-1} , assigned to bending vibrations of the Si_2O_7 sorosilicate groups, coincides with published spectra of pumpellyite-group minerals and exhibits no measurable shift despite the iron-rich composition and the presence of a significant julgoldite component. This observation indicates that Fe substitution has little effect on the sorosilicate framework.

Acknowledgements. We thank Stefanie Heidrich from University of Hamburg, Germany for electron probe microanalyses and BSE images.

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Petrographic and spectroscopic evidence for multi-stage alkali metasomatism in the felsic rocks of the Ditrău Alkaline Massif (Eastern Carpathians, Romania)

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The Ditrău Alkaline Massif represents one of the largest alkaline intrusive complexes in the Carpathian region and preserves extensive evidence of post-magmatic fluid-rock interaction. Although alkali metasomatism has been recognised in numerous alkaline complexes worldwide, the paragenetic evolution and textural relationships of metasomatic mineral assemblages remain incompletely constrained in many systems. This study aims to reconstruct the paragenetic evolution of metasomatic alteration in felsic rocks (e.g., syenites, quartz syenites, and alkali granites) of the Ditrău Alkaline Massif, Eastern Carpathians (Romania), a Triassic rift-related alkaline complex characterised by diverse lithologies and a complex structure (Pál-Molnár *et al.*, 2021).

Petrographic observations reveal extensive modification of the primary magmatic mineral assemblage by successive metasomatic reactions, particularly adjacent to albitite dykes cross-cutting the host rocks. Feldspar alteration is dominated by co-oriented and hetero-oriented replacement, commonly associated with myrmekite formation. Quartz is frequently consumed by reaction rims composed of clinopyroxene, blue amphibole, and iron oxides, while biotite occurs both as inclusion-rich relics of the primary magmatic crystals and as inclusion-poor intergranular crystals related to secondary, metasomatic processes. Mineral contact relationships, replacement textures, and cross-cutting features indicate a multi-stage history of metasomatic alteration. Raman spectroscopy was applied to confirm the identity of metasomatic mineral phases and investigate structural differences between feldspar generations. Cathodoluminescence imaging revealed multiple feldspar generations displaying contrasting luminescence colours and complex growth relationships. These colour variations are interpreted to reflect differences in trace-element distribution and defect structures rather than major differences in the structural state of feldspars detectable by Raman spectroscopy.

Integration of petrographic observations, textural relationships, mineral contact analysis, and spectroscopic data suggests a multi-stage alkali metasomatic evolution accompanied by progressive changes in fluid composition. Early albitisation and myrmekitisation were followed by biotitisation and the development of a fenite-like mineral assemblage characterised by blue amphibole, clinopyroxene, extensive feldspar replacement, and reaction rims developed at the expense of quartz. These observations demonstrate that fluid migration played a fundamental role in the mineralogical re-equilibration of the felsic rocks and highlight the importance of prolonged alkali metasomatism during the post-magmatic evolution within the Ditrău Alkaline Massif.

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Kalsilite-leucite mineralisation in monzonite rocks from the Zvezdel pluton, Eastern Rhodopes, Bulgaria

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In nature, kalsilite and leucite occur in K-rich and silica-undersaturated rocks of various origins: volcanic, intrusive, and metasomatic. In this study, both minerals were found in monzonite rocks from the second intrusive phase of the Oligocene-aged Zvezdel pluton (Nedialkov and Mavroudchiev, 1995), in close proximity to skarn contacts. The skarn xenoliths (nodules) are entirely hosted by the monzonite. They most likely represent carbonate xenoliths that were incorporated into the magma during its emplacement. The skarn mineral assemblage mainly consists of garnets from the grossular-andradite series, melanites with a TiO₂ content of 8–11 wt.%, fassaitic clinopyroxene, esseneite, clinopyroxene from the diopside-hedenbergite series, wollastonite-2M, plagioclase, and calcite, as well as the less abundant minerals quartz, epidote, prehnite, melilite, chlorite, thaumasite and zeolites. Titanite, apatite and magnetite occur as accessory minerals. The presence of wollastonite, garnet and Ca-rich clinopyroxene, and the absence of Mg-rich skarn minerals such as olivine or periclase suggests that the assimilated wall rock was Ca-rich limestone. This is consistent with the limestone found in the drill cores in the in this area.

Kalsilite grains occur as inclusions in a K-feldspar matrix and exhibit strongly corroded margins. They may reach a size of up to ~20 µm. Electron probe microanalysis reveals only slight variation in the chemical composition of the studied kalsilite grains. The SiO₂ content ranges from 38.20 to 38.42 wt%, the Al₂O₃ content from 28.93 to 31.30 wt%, and the K₂O content from 27.7 to 28.54 wt%. The crystal chemical formulae of kalsilite are calculated on the basis of four oxygen atoms. The Fe₂O₃ content (total iron was calculated as Fe₂O₃) varies from 0.77 to 3.52 wt% (0.02–0.08 apfu Fe³⁺). The chemical composition of the studied kalsilite is characterised by the absence of Na₂O and CaO. In the immediate vicinity of the contact zone with the skarn nodules, kalsilite is associated with K-feldspar containing 0.84–4.28 wt.% BaO (forming a celsian component of 1.85–8.49 mol%), as well as anorthoclase with the composition Ab_{60.0–78.8}Or_{16.1–32.2}An_{5.1–10.8}.

The leucite grains are irregularly shaped and either elongated or teardrop-shaped. Their size ranges from 10 to 20 µm. Leucite only occurs as inclusions in clinopyroxene crystals. All of the analysed leucites have a stoichiometric Si/Al ratio that closely approximates to 2:1. The replacement of K by Na is extremely low (0.02–0.03 apfu Na, calculated on the basis of six oxygens). The Fe₂O₃ content varies from 0.63 to 0.77 wt% (0.017 to 0.022 apfu Fe³⁺), indicating some Fe³⁺ substitution of Al in the tetrahedral site. Clinopyroxenes associated with leucite have compositions that fall within the Quad field (Morimoto et al., 1988).

The presence of kalsilite and leucite as relict minerals near the contact zone is probably the result of calcite reacting with the main intrusive body at the time of its emplacement. The assimilation of cold carbonate by hot magmas is an important open-system process that allows conditions favourable to the formation of kalsilite and leucite to be established. This process of carbonate assimilation results in desilication at the skarn contact and the early crystallisation of kalsilite and leucite. Their formation is considered to be the earliest stage of the metasomatic process.

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Occurrences of Platinum and Platinum Group Elements in Romania

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Platinum group elements (PGE) are critical raw materials and have strategic importance for green technologies, catalysis, and high-performance alloys. In Romania, PGE occurrences are rare and insufficiently documented, being reported mainly from placer deposits, Ni-Cu sulfide mineralizations, and chromite-bearing ultramafic bodies (Udubaşa et al., 2023). This contribution presents a review of the currently documented platinum and PGE occurrences in Romania and discusses their geological significance in the context of future critical raw material exploration.

The oldest documented occurrence is represented by the gold-bearing placers of the Pianu Valley, Sebeş Mountains. Historical records reported the presence of native platinum grains, subsequently confirmed by quantitative investigations. Electron microprobe analyses confirmed native platinum containing 91–94 wt.% Pt and 4–9 wt.% Fe, providing the first analytical confirmation of native platinum from Romania (Udubaşa et al., 2004; Udubaşa and Udubaşa, 2015).

Another important occurrence is located in the Vâlsan Valley, Făgăraş Mountains, where Cu-Ni(±Co) mineralization hosted by metamorphosed basic rocks contains mainly chalcopyrite, pyrrhotite, and pentlandite. Platinum occurs in association with cobaltpentlandite, pentlandite, and pyrrhotite. Micro-PIXE and SEM-EDS analyses confirmed platinum within the sulfide assemblages (Udubaşa et al., 2023).

Further occurrences are associated with the chromite-bearing serpentinites of the Tişoviţa-Iuţi area, Southern Banat. Platinum contents ranging between 1.4 and 5.4 g/t have been reported from serpentinitized ultramafic bodies. Mineralogical investigations identified platinum associated with cobaltpentlandite, chromite, and magnetite, while more recent studies documented PGE grains containing Pt and locally Pd, occurring together with oxide and sulfide minerals (Udubaşa et al., 2023).

Besides native platinum and PGEs, platinum-bearing minerals have also been reported. Sperrylite (PtAs₂) was described from the Holbav area, Făgăraş Mountains, where it occurs as microscopic inclusions in pyrrhotite associated with chalcopyrite within nickel-bearing ultrabasic bodies hosted by metamorphic rocks (Udubaşa et al., 2023).

All of these occurrences indicate that Romanian PGE mineralizations are associated with three main geological environments: placer deposits, Ni-Cu sulfide systems, and chromite-bearing ultramafic complexes. Although platinum and PGEs have been documented in these mineralization types, available data remain largely descriptive and locally constrained. Future mineralogical, geochemical, and isotopic studies are required to further evaluate their metallogenic significance and identify which occurrences present the highest economic potential.

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Authigenic phosphates in a bat guano deposit from Șura Mare Cave (Romania)

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Bat guano deposits in caves host diverse secondary phosphate assemblages resulting from the reactions of the acidic environment provided by the guano decay with the bedrock, speleothems and various detrital deposits they are in contact with. This study documents a 1.5 m bat guano deposit from Șura Mare Cave (Romania), a major roosting site for bats. Subsamples from the core were extracted at 0.5 cm intervals and the separated minerals were analyzed by means of X-ray powder diffraction, Raman and FTIR spectroscopy and scanning electron microscopy.

The secondary mineral assemblage comprises eight authigenic phosphates: ardealite, brushite, hannayite, hydroxylapatite, strengite, struvite, taranakite and whitlockite. The deposit shows a clear vertical zonation, in which Fe and Al phosphates are restricted to the basal sandy-silty substrate, Ca, Ca-Mg phosphates and struvite occur all along the core, while hannayite, associated with struvite, brushite and ardealite, occurs only in the top section, close to the surface of the deposit. Struvite and hannayite, the two Mg-NH₄ phosphates, are rarely found in karst environments, so this study also focuses on documenting their properties and their paragenetic relations.

Unit cell parameters refined via Rietveld analysis are consistent with the Pmn2₁ orthorhombic group for struvite and with the P-1 triclinic group for hannayite. Raman and FTIR spectroscopy revealed the presence of PO₄, NH₄, H₂O and Mg-O bending vibrations in both minerals, while FWHM analysis of $\nu_1(\text{PO}_4)$ and $\nu_1(\text{PO}_3\text{OH})$ provided a crystallinity proxy that can differentiate the two Mg-NH₄ phosphates. Hannayite exhibits well-developed crystals, precipitated under stable conditions, while struvite crystals suggest a rapid crystallization.

Mineralogy and trace-element geochemistry of rhythmically banded quartz/calc-silicate rocks from the Malyovitsa Lithotectonic Unit (NW Rila Mountains, Bulgaria)

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Pegmatite-related skarns are considerably less understood than intrusion-related skarn systems, particularly regarding the mechanisms of fluid transport, reaction-front propagation, and trace-element redistribution during carbonate metasomatism. The parametamorphic Malyovitsa lithotectonic unit hosts an unusual suite of rhythmically banded quartz/calc-silicate rocks formed during the Paleocene tectono-magmatic evolution of the Rhodope metamorphic complex in NW Rila Mountain, Bulgaria. An ongoing study combining field observations, petrography, mineral chemistry, trace-element geochemistry, and geochronological constraints aims to elucidate the origin and evolution of these rocks and assess the processes responsible for their distinctive internal architecture. This contribution presents mineralogical and geochemical results.

The investigated rocks differ from typical contact skarns by exhibiting centimetre- to decimetre-scale rhythmic banding composed of alternating smoky quartz ($\pm$ feldspar)-rich and calc-silicate layers. The smoky quartz-rich domains are interpreted as pegmatitic, whereas the intervening calc-silicate layers comprise assemblages dominated by grossular-andradite garnet and diopside, with later vesuvianite and zoisite recording subsequent stages of fluid evolution. Allanite-(Ce) and REE-bearing epidote-group minerals and accessory titanite, fluorapatite and zircon document redistribution of incompatible and rare-earth elements during metasomatism.

EPM analyses show that garnet compositions are strongly grossular-rich (Gr₈₀₋₉₈) with subordinate andradite and minor pyrospite components. Compositional variation is governed predominantly by Fe³⁺-Al³⁺ substitution. LA-ICP-MS analyses demonstrate systematic incorporation (in ppm) of B (50-65), V (50-145), Ga (22-48), Y (70-100), Σ REE (55-65) into garnet. Diopside is chemically enriched in Li (~50), Be (up to 44), B (70-100), Zn (500-620 ppm). Vesuvianite contains elevated Li (~220), Be (~750), B (~100), Zn (~210), Y (100-380), Bi (600-1000), U (reaching 265) and moderate contents of Σ REE (125-206). Allanite-(Ce) is the principal REE-bearing phase, characterized by very high LREE (La-Sm), Th, and U incorporation. Epidote displays intermediate REE-abundances with lower Th and U than allanite, while zoisite is depleted in most trace elements, except for B, Zn and Ga. Titanite is enriched in HFS elements (particularly Nb, Ta, Zr, and Hf) and contains elevated LREE and Y contents relative to the associated silicates.

The observed rhythmic mineralogical architecture is interpreted to reflect repeated infiltration of Si-rich pegmatite-derived fluids into reactive carbonate horizons, promoting the development of successive metasomatic reaction fronts rather than a single equilibrium reaction along a static pegmatite-marble contact. The inferred paragenetic sequence, from early diopside-grossular assemblages to F-rich vesuvianite and zoisite, records progressive cooling and the evolution of hydrous metasomatic fluids during continued fluid-rock interaction. The preferential incorporation of Li, Be, REE and HFSE into the skarn minerals reflects the evolving composition of pegmatite-derived metasomatic fluids, highlighting the fundamental influence of pegmatite emplacement on mineral assemblages and trace-element redistribution. The mineral data indicate that pegmatite emplacement and skarn formation were dynamically coupled processes involving multiple episodes of metasomatism. The studied occurrence in NW Rila therefore represents a distinctive example of pegmatite-related quartz-calc-silicate composite rocks and provides new insights into fluid evolution, trace-element mobility and mineral paragenesis during carbonate replacement in metamorphic terranes.

Acknowledgements. The study is financially supported by the Bulgarian National Science Fund - project LiBeRE KP-06-N94/3

Session GS13

**(Micro)Paleontology Paleooceanography,
and Paleogeography**

Conveners:

Ioan I. Bucur, Lóránd Silye

Cosmic genesis - Galactic forcing increases origination of marine microplankton

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The continuous flux of Galactic cosmic rays reaching Earth's atmosphere produces ionizing radiation capable of damaging the DNA of living organisms. Although the radiation dose at Earth's surface remains relatively stable on short timescales, theoretical models predict long-term fluctuations with a periodicity of approximately 32 million years. As the Solar System oscillates above and below the Galactic plane during its orbit around the Galactic center, the shielding effect of the Galactic magnetic field weakens, allowing an enhanced flux of cosmic rays to reach Earth and potentially increase mutation rates.

Here, we investigate whether these long-term Galactic cycles are reflected in the evolutionary history of marine microplankton, including Radiolaria, Calcareous Nannoplankton, Dinoflagellata, and Planktonic Foraminifera throughout the Phanerozoic. We identify a significant correlation between the Solar System's Galactic oscillations and the origination rates of marine zoo- and phytomicroplankton genera (weighted global p -value = 1.25×10^{-4} ; 3.72σ). Restricting the analysis to intervals during which all four microplankton groups coexisted further strengthens the relationship, yielding a post-trial significance of 4.52σ .

These results provide evidence that long-term Galactic forcing may have exerted a measurable influence on the evolutionary dynamics and biodiversity of marine microplankton over geological timescales, suggesting that extraterrestrial processes have contributed to shaping the history of life on Earth.

Late Miocene paleoenvironmental reconstruction of north-eastern Romania based on fossil microvertebrate assemblages

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The Upper Miocene deposits of the Eastern Carpathians Foreland represent an exceptionally valuable paleontological archive, distinguished by a high fossiliferous potential that encompasses both invertebrate faunas, well documented in the specialized literature, and vertebrate faunas of various sizes, including continental microvertebrates. The latter remain insufficiently studied both at a regional level within Romania and on the broader scale of Eastern Europe, and therefore represent a priority direction for paleontological research. Although continental microvertebrates are frequent in the Upper Miocene sediments of this region, the existing reports of their presence are only a starting point in the complex process of analyzing, classifying, and interpreting the available fossil material.

The present study focuses on the systematic analysis of the fossil microvertebrate assemblages recovered from these deposits. Taxonomic identification was carried out on the basis of dental morphology, a well-established and widely used method, given the high resistance of dental structures to diagenetic processes and their elevated degree of preservation in the geological record. Detailed analysis of the shape, size, and occlusal surface relief of the teeth allowed the studied specimens to be assigned to precise taxonomic categories and provided a solid foundation for the subsequent paleoecological interpretations. Fossil eggshells have also been identified, and their provenance can be established through specific methods.

The microvertebrate groups identified in this study include rodents, lagomorphs, and insectivores, all of which are valuable tools for the reconstruction of the continental paleoenvironments in which these organisms lived and evolved. The presence or absence of certain species within a fossil assemblage faithfully reflects the ecological characteristics of the respective environment, including the degree of humidity, dominant vegetation type, average temperature, and substrate nature. The composition of the faunal assemblages thus becomes a highly accurate paleoecological proxy, enabling a detailed reconstruction of environmental conditions from the geological past.

A central aspect of the study is the comparative analysis of the microvertebrate assemblages of two successive biostratigraphic stages of the Upper Miocene: the Vallesian and the Turolian. Concrete and well-documented arguments support significant differences between the paleoenvironments of the two stages, reflected in the distinct composition of their characteristic faunal assemblages. These differences are linked to the climatic and vegetation changes that occurred at both global and regional levels during the Late Miocene, offering a clearer picture of continental ecosystem dynamics during this period.

The proposed paleoecological interpretations are further supported and validated by comparing the local assemblages with those described in the specialized literature from Eastern Europe and Western Asia, thus providing a comprehensive regional perspective. This comparative approach allows the identification of faunal similarities and differences at a regional scale and the highlighting of possible faunal migration routes and diversification centres, contributing significantly to completing the paleontological and paleoecological picture of the European Upper Miocene.

Acknowledgements. For the specific methods of analyzing fossil eggshells, the author is grateful to the Karl Hirsch Memorial Grants 2025 and to the grant *Fossil eggshells from the Sarmatian (sensu lato), Late Miocene of Eastern Romania (2025)*, funded by WIPS.

Mammoth findings from the Quaternary of Cluj-Napoca

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The Paleontological and Stratigraphical Museum of the Babeş-Bolyai University (PSMBBU) holds many molars and other skeletal elements belonging to mammoth species, which originate from all across the country and some even from outside of it. Over the course of last year I have overviewed this collection and created a database containing every information found alongside each piece (place of origin, collector's name, date of collection etc.). The purpose of my research is to introduce a new mammoth remain consisting of several skeletal elements found at Cluj-Napoca into this collection. Radiocarbon dating was applied on the new remains in order to constrain its age. CT scanning and morphometrics was used to infer on the morphology of the skeletal elements found, and to constrain its taxonomical status. The sample collected at the site was studied using standard micropaleontological methods. So far, charophyta, gastropoda and ostracoda remains were recovered. These suggest the existence of a marsh environment at the time of the burial of the mammoth remains.

Acknowledgements. We thank István Major for helping with the radiocarbon dating.

Miocene foraminifera in the Transylvanian Basin: how many are they?

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The aim of this research is to establish a comprehensive publication-based foraminiferal database for the Miocene sedimentary record of the Transylvanian Basin in accordance with the most recent guidelines (see Jonkers et al., 2025). Doing so we challenge the known stratigraphic distribution of Miocene foraminiferal taxa recovered from the basin, as it might contain significant uncertainties, partly resulting from differing taxonomic approaches applied by various authors and partly due to the heterogeneous sampling and documentation practices of previous studies. These uncertainties hinder a more refined reconstruction of the basin's evolutionary history and limit the accuracy of regional biostratigraphic correlations.

The project involves the systematic collection and digitization of published Miocene foraminiferal occurrence data, which is standardized within a unified taxonomic framework and complemented with metadata, including stratigraphic position, locality, and paleoenvironmental interpretation. The resulting database will allow the investigation of spatial and temporal patterns in foraminiferal taxa and assemblages and facilitate comparisons among different biostratigraphic zonation schemes.

A major objective of the study is to identify and evaluate biostratigraphic uncertainties by recognizing inconsistencies among existing stratigraphic distribution data, clarifying the role of problematic taxa, and assessing the reliability of age determinations derived from published records. In addition, the main Miocene stratigraphic units of the Transylvanian Basin will be characterized based on their foraminiferal assemblages, with particular emphasis on environmental changes, basin-depth and sedimentary trends, and biogeographic patterns.

The database and subsequent analyses will contribute to a more accurate understanding of the Miocene evolution of the Transylvanian Basin and provide a foundation for future high-resolution stratigraphic and paleoecological investigations.

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Refining the Late Cretaceous Foraminiferal Record of the Northern Eastern Carpathians (Romania)

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The turbiditic successions of the Eastern Carpathians represent one of the most important sources for the study of Cretaceous–Paleogene agglutinated foraminiferal assemblages. The deposits from the northern area of the Eastern Carpathians were previously investigated from a micropaleontological perspective by Bindiu Haitonic (2018). One of the studied sections is located near Putna, where the deposits were assigned to the Maastrichtian–Priabonian interval. In order to cover a broad stratigraphic range, the sampling strategy adopted in the previous study was relatively sparse. To achieve a more detailed reconstruction of the evolution of foraminiferal assemblages, the Putna section was revisited and a 20 m thick sedimentary succession was sampled at high resolution. Every silty-clay intercalation within the turbiditic sequence was sampled and analyzed. The recovered foraminiferal assemblages are exceptionally well preserved and are dominated by coarsely agglutinated taxa. The most abundant genera include *Nothia*, *Reophax*, *Paratrochamminoides*, and *Recurvoides*, all characteristic components of classic „flysch-type” agglutinated foraminiferal assemblages. The occurrence of *Caudammina gigantea*, together with the presence of the trace fossils *Chondrites*, *Zoophycos*, and other deep-marine ichnotaxa, provides important biostratigraphic and paleoenvironmental constraints. These data support the assignment of the studied deposits to the latest Cretaceous and indicate their affiliation with the Hangu Formation of the Tarcău Nappe. The new high-resolution dataset contributes to a better understanding of the composition and distribution of agglutinated foraminiferal communities in the latest Cretaceous deep-water marine basin of the Northern Eastern Carpathians.

Acknowledgements. We thank Prof. Alfred Uchman for his assistance in the identification of trace fossils and Prof. Sorin Filipescu for his support in obtaining the foraminiferal photographs. The fieldwork was supported by S.N.G.N. Romgaz S.A., project No. 44533.

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Foraminiferal Study of the Oligocene Sedimentary Record of Southern Albania

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We have investigated the foraminiferal assemblages recovered from the Oligocene Bozdovec Formation occurring in the Albanian–Thessalian intramountain basin, southern Albania using both qualitative and quantitative methods. The examined samples were prepared using standard micropaleontological procedures applying a 63 µm mesh sieve. The dried >63 µm residue was analyzed for planktonic and benthic foraminiferal tests using two different size-fractions: the larger than 125 µm, and that above 63 µm.

The lack of prior foraminiferal studies forced us to use the age and paleoenvironmental results based on calcareous nannoplankton remains Kallanxhi et al. (2016) as the starting point of our investigation. According to this study, the depositional environment of the examined formation during the Oligocene (possibly Chattian) was characterized by a neritic, shallow marine setting with warm-temperate waters and significant continental sedimentary input.

Our results based on the planktonic foraminiferal analyses confirm the previous results of Kallanxhi et al. (2016), while data on benthic foraminiferal assemblages further constrain the paleoenvironmental conditions of the seafloor during the deposition of the Bozdovec Formation.

Acknowledgements. We gratefully acknowledge Mădălina Kallanxhi for generously providing the samples used in this study. Her support and collaboration were essential for completing the analytical work, and we sincerely appreciate her contribution to the project.

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Biostratigraphy and Paleoecology of Priabonian Deposits from the Treznea and Jibou Areas (NW Transylvanian Basin, Romania)

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The Paleogene successions of the Transylvanian Basin consist of alternating continental and marine deposits, reflecting successive changes in sedimentary conditions throughout the basin's evolution (Filipescu, 2011). The late Priabonian is characterized by the development of marine sedimentation, documented by the presence of foraminiferal assemblages that provide valuable paleoecological information regarding depositional environments. This study focuses on the analysis of foraminiferal assemblages identified in Priabonian deposits from the Treznea and Bodia areas, located within the Meseș sedimentary area. The main objectives are to reconstruct depositional conditions based on micropaleontological evidence and to integrate the results into a broader regional basin framework. The micropaleontological assemblages are dominated by calcareous benthic foraminifera, while agglutinated and planktonic forms occur in low proportions, supporting the interpretation of a shallow-marine depositional setting. The occurrence of the genera *Cibicidoides*, *Cibicides*, *Lobatula*, *Pararotalia*, and *Quinqueloculina* indicates environmental conditions favorable for the development of epifaunal benthic communities in relatively well-oxygenated waters. The presence of macrofossils, including *Campanile giganteum*, *Cepatia* sp., *Trochus* sp., and corals, further supports the interpretation of a shallow, relatively stable marine environment suitable for calcareous benthic fauna. Lithostratigraphically, the deposits belong to the upper part of the Cluj Limestone Formation (Bodia), transitioning into the lower part of the Brebi Formation (Treznea). This study contributes to the existing knowledge of the Priabonian succession in a region that remains comparatively underdocumented from a micropaleontological perspective and provides new data that can be integrated into a broader basin-scale paleoenvironmental framework.

Acknowledgements. The authors would like to thank technician George Gabor for his guidance and assistance in the Micropaleontological Sample Preparation Laboratory.

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Sea-level oscillations and environmental changes on the Romanian Black Sea shelf since the Last glacial Maximum

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The Black Sea is a semi-enclosed basin and the largest anoxic basin in the world. It is a vast, deep-water epicontinental sea linked to the eastern Mediterranean Basin and, consequently, to the world's oceans via a narrow and shallow series of corridors known as the Dardanelles–Marmara–Bosporus seaway. Currently, there is an exchange between warmer, saline Mediterranean water flowing in at lower levels and cooler, fresher Black Sea water flowing out at the surface. As a result, the Black Sea waters are heavily stratified and anoxic at greater depths, below 200m. The average salinity of the modern Black Sea is approximately 17‰ in most surface waters and can reach up to 23‰ in deeper areas. This salinity profile was established during the early Holocene. During the last major glacial phase, the Black Sea basin became isolated as the eastern Mediterranean's water level dropped below that of the connecting pathway due to glacio-eustatic sea-level changes. Later, as the global ice sheets released much of their water back into the oceans, there was a significant post-glacial rise in sea levels, leading to a reconnection between the Black Sea and the Mediterranean during the early Holocene, facilitating the exchange of waters. However, during the last glacial episode, the water level was controlled by regional climate and varied independently from global sea level (Ross et al., 1970).

Since the Last Glacial Maximum, the sedimentary record of the Black Sea displays three main lithological units (Ross and Degens, 1974): Unit 3 – lacustrine pelite (Late Glacial), comprises fine-grained clastic sediments that accumulated in an ‘lacustrine’ environment with well-oxygenated bottom waters, Unit 2 – sapropel muds (early to middle Holocene) consists of dark fine-grained sediments with high organic matter content that corresponds to the establishment of anoxic conditions in the basin, and the Unit 1 - the microlaminated coccolith ooze (middle Holocene to Recent) consists of microlamination with light and dark laminae accumulated under marine conditions. The light-colored layers consist almost entirely of coccolithophorid *Emiliania huxleyi*.

In this study we aim to make an overview of different depositional environments from the Black Sea shelf and to highlight some paleoecological aspects that shaped the transition from a ‘freshwater lake’ to the present-day marine basin, emphasizing the fauna's response to this process. Particular attention will be given to the co-occurrence of species originating from the Ponto-Caspian and Mediterranean regions on the shelf. The study also focusses on sediment lithology and geochemistry to understand the changes in the depositional environment during this transition.

Acknowledgements.

The research leading to these results was supported by the Ministry of Education and Research – NUCLEU Programme: PN 23 30 01 01 and PN 23 30 02 01.

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Upper Triassic dasycladalean algae from southwestern Serbia

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A kilometre-sized block of lagoonal Dachstein Limestone (Ilidža Limestone cf. Hips et al., 2011) crops out along the Sirogojno–Rožanstvo road near the Prištavica River bridge. This huge limestone block contains fissure fillings of ophiolitic mélangé material and represents part of the upper carbonate–clastic Sirogojno Mélangé, which in this area consists of diverse Upper Triassic blocks of various sizes (Zöhrer et al., 2021). The Sirogojno Mélangé, together with several underlying sedimentary mélanges beneath the ophiolitic nappe stack (Gawlick et al., 2017), are part of the Dinaridic Ophiolite Zone above the East Bosnian–Durmitor Unit.

Several samples from the Dachstein limestone block were found to be rich in dasycladalean algae. The rock is a medium to coarse-grained bioclastic grainstone, with peloids and micritic intraclasts, and with numerous remains of organisms: rare fragments of sponges and corals, bivalves, gastropods, echinoderms, benthic foraminifera, elianellaceae and dasycladalean algae. Some bioclasts are blackened (see Hips et al., 2011 for details). The age of the limestones is most likely Norian, judging by the presence of the foraminifer *Aulotortus sinuosus*. (see also Hips et al., 2011).

Dasycladalean algae are mainly represented by a species of the genus *Pseudodiplopora*, characterized by a slightly claviform thallus, with phloioiphorous laterals and ovoid reproductive organs (cysts), closely adjacent and forming a continuous cylinder at the edge of the axial cavity; between the cysts and the laterals there is an uncalcified space. The presence of cysts in the axial cavity (endospore type) has been assumed for most dasycladalean algae from the Paleozoic and Triassic. During the Triassic, however, there were only ten species in which the cysts were clearly preserved in the axial cavity. One of these (*Mizzia? toncii*) is known from the Middle Triassic (Ladinian). The others are known from the Late Triassic: *Pseudodiplopora ioanaletitiae* (early Carnian); *Diplopora decastroi*, *D. interiecta*, *D. phanerospora*, *D. tubispora*, *Kantia praecursor*, *Pseudodiplopora adnetensis*, *P. borzai* and *P. iranica* (Norian–Rhaetian).

The specimens from the limestones studied near Sirogojno are morphologically closest to *D. interiecta* and *D. iranica*, but the club-shaped thallus and some dimensional parameters indicate a separate species.

The Late Triassic represents a period of radical transformations in the reproductive evolution of dasycladales, with the appearance of cladospore–goniosporate and choristosporate species (Barattolo et al., 2021), and the diminution of the presence of endospore species.

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Cretaceous calcareous red algae from Enisala (Northern Dobrogea)

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The occurrences of Cretaceous carbonate successions bearing red algae in Romania were rarely mentioned from the post-tectonic sedimentary cover of the Carpathians areas (Bucur & Strutinski, 1983; Bucur & Urian, 1989; Săsăran et al., 2018) and of the North Dobrogea Orogen (Bucur & Baltres, 2002; Crăciun et al., 2026).

The aims of this research are to introduce the taxonomy of calcareous red algae identified in the Cretaceous carbonate succession from the Enisala area (Northern Dobrogea); to present the associated microfacies and based on microfacies analysis, to discuss the depositional environment and the paleoecology of the associated fossil assemblages.

The following red algae taxa were identified from the 240 thin sections studied from Enisala (uppermost Albian – lower Cenomanian): *Sporolithon rude* (Lemoine) Ghosh and Maithy, *Sporolithon phylloideum* (Bucur and Dragastan) Tomás et al., *Paraphyllum primaevum* Lemoine, ?*Lithophyllum* sp. and *Agardhiellopsis cretacea* Lemoine.

Four microfacies types have been identified from the studied section: transgressive basal carbonate breccia, bioclastic wackestone-packstone with fractures filled with sparitic calcite, bioclastic wackestone-floatstone with whole fossils and well preserved epifauna, grainstone-packstone with abundant red algae.

The high density of the identified algae indicates environmental conditions favourable for their development in a marine environment with low light levels. The prevalence of Corallinaceae and Sporolithaceae algae in particular indicates warm waters and depths of several tens of meters. Overall, microfacies analysis along with the fossil content of the studied succession indicate marine depositional environments with normal salinity, temporarily high basin energy, and predominantly carbonate sedimentation, but which were temporarily affected by siliciclastic inflows from the continent.

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A river ran through it – A remarkable new Upper Cretaceous vertebrate locality from Vălioara (Hațeg Basin, Romania)

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Uppermost Cretaceous continental deposits from Transylvania (western Romania) preserve one of the richest and most diverse European fossil vertebrate assemblages, including ‘dwarf’ insular dinosaurs together with other remarkable (endemic, relictual, and/or morphologically aberrant) taxa. Foremost among these uppermost Cretaceous outcropping areas is the Hațeg Basin, from where the ‘dwarf’ dinosaurs were first discovered over a century ago, and where fossiliferous deposits are discontinuously but widely distributed. In the northwestern part of Hațeg Basin, continental uppermost Cretaceous beds are grouped into the Densuș-Ciula Formation, characterized by its rather abundant fossil content and the widespread presence of volcanic/volcaniclastic components within the otherwise siliciclastic, alluvial deposits (Grigorescu, 1992). Despite the common presence of coarser, sandstone-conglomerate and even breccia deposits especially in its lower part (the Lower as well as the lower part of the Middle members), most of the important vertebrate bonebeds known previously from this unit were identified in relatively fine-grained floodplain and lake-related facies (e.g. Botfalvai *et al.*, 2017, 2025).

In 2019, while re-locating the century-old Kadić excavation sites, our team also identified one new, potentially fossil-rich accumulation (NVS) near Vălioara. Since then, the site was excavated continuously, yielding several hundred macrovertebrate fossils, as well as microvertebrates recovered through screen-washing. As one of the most notable features of site NVS, the bonebed is hosted by a succession of interbedded grey sandy conglomerates and coarse sandstones, suggesting deposition in a stacked succession of high-energy fluvial channels, unlike the low-energy sedimentary settings that characterize other sites from the area, and a somewhat uncommon occurrence in the uppermost Cretaceous of Hațeg Basin overall. Nonetheless, despite the high-energy depositional context indicated by the hosting rocks, the local vertebrate assemblage is characterized by the presence of several associated skeletons representing different taxa (cerapodans, titanosaurs, pterosaurs, crocodyliforms), as well as the often remarkable preservation of delicate, thin-walled bones.

The local assemblage is strikingly diverse, with amphibans (Albanerpetontidae), testudines (*Kallokibotion*), lizards, crocodyliforms (*Doratodon*, cf. *Theriosuchus*, *Acynodon*, *Allodaposuchus*), pterosaurs, diverse dinosaurs (Titanosauria, Hadrosauroidea, „Rhabdodontidae”, Theropoda) and multituberculate mammals represented. The available fossil material is currently under study, but its preliminary assessment indicates that it could contribute to a great extent to a better understanding of the local taxonomic identity and diversity of several groups such as crocodyliforms, ‘rhabdodontids’ or multituberculates. Furthermore, detailed sedimentological and taphonomic investigations are aimed to reconstruct the atypical depositional and fossil-accumulation history of this unique vertebrate bonebed site.

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Calcareous nannofossils across the Neoeuxinian–Holocene transition of the NW Black Sea

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The NW Black Sea preserves one of the most striking Late Quaternary paleoenvironmental records of the Pontocaspian domain, marked by the transition from the brackish-to-fresh Neoeuxinian lacustrine phase to the re-establishment of marine conditions during the Holocene, when reconnection with the Mediterranean reintroduced normal-marine salinity at around 9 ka BP. Calcareous nannofossils, owing to their high abundance, rapid speciation and sensitivity to salinity, temperature and nutrient regimes, are a key proxy for tracing this transition and for the biostratigraphic and paleoceanographic characterization of the interval.

This study is based on a sediment core recovered from the Romanian Exclusive Economic Zone of the NW Black Sea (44°04'26"N, 30°45'47"E; 219.8 m water depth), on the outer shelf to shelf-break. The succession spans the Late Neoeuxinian lacustrine phase through the Holocene marine reconnection, capturing the interval over which calcareous nannoplankton becomes established in the basin. The material was imaged by scanning electron microscopy (Phenom ProX G6, backscattered-electron detector, 15 kV), yielding a reference set of about 2,000 high-resolution micrographs documenting the assemblages and their state of preservation.

Conventional nannofossil identification under the microscope is time-consuming, expert-dependent and difficult to reproduce across large image datasets, which limits high-resolution quantitative work. To address this, we are developing an automated taxonomic identification workflow based on convolutional neural networks (CNNs), implemented in Keras/TensorFlow. The present stage focuses on the construction and expert annotation of the SEM image catalogue and on the design and comparative evaluation of candidate architectures — a custom CNN baseline alongside transfer-learning models (VGG16 and ResNet50) — together with image pre-processing and augmentation strategies appropriate to SEM micrographs. No classifier performance is reported here, as model training follows the completion of the annotated dataset.

Once trained and validated, the workflow is intended to provide objective, reproducible and scalable per-taxon classification, enabling consistent quantitative counting across the lacustrine-to-marine transition. This would support a higher-resolution reconstruction of the salinity and trophic changes that accompanied the Holocene flooding of the Black Sea, and offers a transferable approach for nannofossil-based studies elsewhere in the Paratethys–Euxine realm.

Acknowledgements. This work was carried out within the PNRR-funded project on the connectivity of the Neogene–Quaternary Eurasian Megalakes (GeoEcoMar; contract CF 97/15.11.2022, no. 760115/23.05.2023).

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From collection drawer to digital skeleton: CT reconstruction of a Devonian bony fish from Siberia

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The palaeontological collection of the State Scientific Research Institute Nature Research Centre (NRC) in Vilnius (Lithuania) represents one of the oldest and most extensive fossil archives in the Baltic region. Built primarily through the efforts of Lithuanian geologists and palaeontologists during the mid-20th century, the collection currently comprises more than 350,000 specimens, including nanofossils, microfossils, and macrofossils. The material originates from a broad geographical area encompassing Lithuania, Latvia, Estonia, Poland, Belarus, Ukraine, England, Germany, France, Svalbard, Iran, Australia, Uzbekistan, the Russian Arctic and Siberia among other places. Stratigraphically, the collection documents predominantly marine life spanning from the Cambrian to the Cretaceous.

Beyond its scientific significance, the collection constitutes an irreplaceable *ex situ* archive of palaeontological heritage. The biggest part of the specimens were collected from localities that have since become inaccessible, destroyed, or legally protected, preserving unique information that can no longer be obtained through fieldwork. Consequently, the collection serves as a valuable resource for both scientific research and heritage conservation.

During the ongoing revision of the collections, a remarkable specimen from the renowned ichthyological collection of Habil. Dr. Valentina Karatajūtė-Talimaa was re-examined. The specimen represents a Devonian bony fish collected from the Eriyechka River, a right tributary of the Kotuy River within the Khatanga River basin of Krasnoyarsk Krai, Siberia, Russia. The fossil remained partially embedded within the host rock and exhibited traces of earlier manual preparation attempts using a needle, which had apparently been abandoned before completion.

To investigate the concealed anatomy while avoiding potentially damaging mechanical preparation, Darja Dankina employed non-destructive X-ray computed tomography (CT) at the Royal Belgian Institute of Natural Sciences (RBINS), Brussels, Belgium. The resulting tomographic dataset was processed using the open-source software 3D Slicer to produce three-dimensional reconstructions of the specimen. The scans revealed exceptionally well-preserved anatomical details, including most of the vertebral column, parts of the ribs, fin elements, scales, and several cranial bones. However, some skeletal structures remained obscured due to preservation constraints, including compression of the specimen during fossilization, overlapping anatomical elements, and insufficient density contrast between certain bones and the surrounding matrix, which limited their clear visualization in the CT data. The study demonstrates how modern imaging techniques can unlock previously inaccessible palaeontological information from historical museum specimens while ensuring their long-term preservation and accessibility for future research.

Acknowledgements. We thank Camille Locatelli (RBINS) for operating the micro-CT of the RBINS.

Micropaleontological Study of Eocene Formations from the Buzău Valley Profile (Siriu Dam Area): Paleoenvironmental and Paleogeographic Implications

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This study presents a preliminary micropaleontological analysis of the Eocene flysch deposits outcropping on the left slope of the Siriu Dam, along the Buzău Valley, Romania. The research focuses on the microfaunal characterization of the Giurgiu–Ghelința Beds, which are developed within the Tarcău Facies of the Outer Carpathian Flysch zone. A total of six high-resolution micropaleontological samples were collected and processed from a continuous exposure to evaluate biostratigraphy, depositional mechanisms, and paleoecological conditions.

The micropaleontological analysis yielded a moderately diverse microfauna consisting of 28 species of deep-water agglutinated foraminifera (DWAf), five of which were classified under open nomenclature. The identified assemblage includes characteristic taxa belonging to the genera *Bathysiphon*, *Ammodiscus*, *Glomospira*, *Subreophax*, *Paratrochamminoides*, *Trochamminoides*, *Haplophragmoides*, *Reticulophragmium*, and *Karrerulina*. Notably, calcareous foraminifera are entirely absent throughout the sampled interval. Based on the taxonomic composition and the biostratigraphy distribution of the index species, a Middle Eocene age has been assigned to the investigated sedimentary sequence.

The total absence of calcareous tests and the exclusive occurrence of small-sized, siliceous agglutinated specimens strongly indicate that sedimentation occurred in a high-energy turbidite system at significant paleodepths, specifically exceeding 3,200 meters. This depositional setting was situated well below the Calcite Compensation Depth (CCD), associated with a distal basin plain environment according to established deep-water fan models.

From a paleoclimatic perspective, the deposition of these Middle Eocene sediments closely correlates with the global warming event known as the “Eocene Climate Maximum”. Regionally, the composition of the foraminiferal assemblage reflects the complex paleogeographic evolution of the northern margin of the Tethys Ocean. During this epoch, the basin was undergoing profound structural reorganizations, marking the initial fragmentation stages that eventually separated the Mediterranean realm from the Paratethys domain. Ultimately, this research underscores the high utility of small agglutinated foraminifera as sensitive proxies for reconstructing deep-sea eco-systems, bathymetry, and paleogeographic configurations within complex compressional basin margins.

Microfacies Characteristics of Late Jurassic Carbonate Clasts in the Krčedin Section (Fruška Gora Mts., Northern Serbia)

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The Krčedin section is exposed on the eastern foothills of the metamorphic Fruška Gora Mountain (northwestern Serbia). The section comprises mixed carbonate–siliciclastic deposits, including hemipelagic marlstones, radiolarian-spicule-bearing deposits, carbonate turbidites, and breccias. The lower part of the succession is characterized by alternating marly carbonates and redeposited shallow-water carbonate material, including partially silicified crinoidal limestones, peloidal limestones and carbonate breccias containing shallow-water biota. Upsection, marlstone sedimentation becomes dominant and is characterized by pyrite-rich and organic-rich intervals, black shale horizons, and the presence of trace fossils (*Chondrites*, *Planolites*). The upper part of the section is represented by quartz-rich siliciclastic turbidites showing a pronounced coarsening-upward trend. These deposits are truncated by an unconformity that is transgressively overlain by rudist-bearing marly limestones. Thin sections prepared from carbonate turbidites, and associated matrix sediments were analyzed for micropaleontological and microfacies data. Based on microfacies characteristics, the deposits can be divided into two major groups: (1) autochthonous pelagic to hemipelagic facies and (2) resedimented parautochthonous to allochthonous gravity-flow deposits. The background sedimentation is represented by radiolarian-spicule-bearing deposits and marlstones which were deposited under low-energy deep-marine conditions. These facies correspond to Standard Microfacies 1 (SMF 1) and Facies Zone 1 (FZ 1) of Flügel (2010). The resedimented deposits occur as carbonate turbidites and breccias interrupting the background pelagic sedimentation. Within the parautochthonous to allochthonous gravity-flow deposits, three facies types were recognized: (i) platform-derived grainstones containing benthic foraminifera, dasycladalean algae, cyanobacteria and microbial encrusters; (ii) crinoidal calciturbidites characterized by graded textures and mixing with basinal radiolarian-rich sediments; and (iii) carbonate breccias composed of shallow-water bioclasts, lithoclasts and basinal material. The redeposited assemblages are dominated by dasycladalean algae, including *Salpingoporella pygmaea*, *Aloisalthella sulcata*, and *Thaumatoporella parvovesiculifera*. The foraminiferal assemblages include *Mohlerina basiliensis*, *Pseudocyclammina lituus*, *Redmondoides lugeoni* and *Nauticulina* sp. The presence of *Aloisalthella sulcata*, *Pseudocyclammina lituus*, and *Mohlerina basiliensis* indicates a (Kimmeridgian–)Tithonian age for the source area of these shallow-water bioclasts. The studied carbonate turbidites document the existence of a nearby carbonate platform. Late Jurassic carbonate platforms are known from the Dinarides, where carbonate platforms developed on top of the obducted ophiolites, as well as from the Southern Carpathians and related Getic units. However, the entire sedimentary succession of Krčedin is markedly different from successions known from the Getic units or the Balkanides. Therefore, carbonate breccias containing both shallow-marine redeposited bioclasts and ophiolitic clasts provide strong evidence for Dinaridic provenance.

The early Eocene nummulitic limestones of Southern Dobrogea: a biostratigraphic, micropaleontological and paleoenvironmental approach

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The present study investigates the biostratigraphy and depositional environment of the nummulitic limestones of Southern Dobrogea. Although these carbonate deposits have been studied since the discovery of the first outcrops at Cetatea (Azarlâc), the age of these deposits remains debated and there were no attempts made to reconstruct the depositional setting.

The studied material consists of samples from a drill core recovered near Mangalia. The paleoenvironmental reconstruction was based on microfacies analysis carried out on thin sections. To constrain the age of the succession with biostratigraphic methods, we performed micropaleontological investigations on randomly selected larger benthic foraminifera (LBF) picked out from limestone residue left after acetic acid (98%) treatment of the samples, as well as on the calcareous nannoplankton.

The microfacies analysis reveals that the succession is dominated by packstones and floatstones with medium to well sorted skeletal grains. The main bioclasts are *Nummulites*, *Assilina* and orthophragminid tests, but small benthic foraminifera, echinoderms, bivalves are also present. The sedimentary structures indicate a moderate to high hydrodynamics, while the presence of authigenic glauconite points to a slow sedimentation rate. Overall, the depositional model is an oligotrophic, warm, normal marine environment on the middle part of a carbonate ramp. The point-counting quantitative microfacies analysis reveals the relationship between the fragmentation rate of the LBF bioclasts, the composition of the LBF assemblage and the D/T (diameter/thickness) ratio of the *Nummulites* tests.

The micropaleontological investigations identified seven *Nummulites* (*N. rotularius*, *N. distans*, *N. archiaci*, *N. praelucasi*, *N. alexisi*, *N. partschi*, *N. nitidus*), three *Assilina* (*A. laxispira*, *A. placentula*, *A. praespira*) and two *Operculina* (*O. escheri*, *O. karreri*) species. The recovered LBF assemblage of the SBZ11 shallow benthic zone, indicating a middle Cuisian (late Ypresian) age. The validity of the relative dating was verified by correlation with calcareous nannoplankton (NP) and orthophragminid zones (OZ). Furthermore, the studied limestone samples could be assigned to the Cetatea Formation based on the lithological characteristics and the faunal assemblage. The *Nummulites* fauna shows similarities with other coeval assemblages from the Peri-Tethys, showing that in the Eocene Southern Dobrogea belonged to the Northern Nummulitic Province.

The Paleogene-Neogene biostratigraphy and paleoecology of the Botiza area (Maramureş, Romania)

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The study area is located in the Botiza village, near Ancuța Guesthouse, Maramureş County. One of the main objectives of this study was to assign the investigated outcrop to a specific geological formation or geological unit. Although the outcrop had been examined previously, the investigation was qualitatively and based solely on calcareous nannoplankton assemblages (Chira et al. 2025). The results of the present study indicate that the succession is of Early Miocene age and therefore belongs to the Miocene Baia Mare Basin.

New data concerning the calcareous nannoplankton and foraminifera assemblages provide an improved understanding of the biostratigraphy and paleoenvironmental evolution of the studied succession.

The calcareous nannoplankton assemblages indicate a late Oligocene–Early Miocene age (NP19–NN2), based on the occurrence of *Helicosphaera ethologa*, *Isthmolithus recurvus*, *Reticulofenestra bisecta*, and *Cyclicargolithus floridanus*, while the foraminiferal assemblages indicate an Miocene age.

The Paleogene calcareous nannoplankton taxa could be reworked. Under this interpretation, the depositional age of the succession can be constrained to the Early Miocene (Aquitanian–Burdigalian).

The calcareous nannoplankton assemblages indicate a transition from a relatively cool marine environment to a warmer and more eutrophic setting, as inferred from changes in the relative abundances of *Coccolithus pelagicus* and *Reticulofenestra minuta*. Furthermore, the benthic foraminiferal assemblages indicate a change in bottom-water conditions throughout the succession, from oligotrophic conditions at the base, characterized by high percentages of epifaunal taxa, to higher organic matter availability towards the top, as reflected by an increase in the relative abundance of infaunal taxa.

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Lower Triassic deposits in Southern Croatia: gaining a better insight into the paleoenvironmental conditions by combining petrographic and paleontological methods

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Triassic deposits that originate from the western Tethys epicontinental shelf are common and well exposed in Central Dalmatia (Southern Croatia). The area between the Muć and Ogorje villages comprises Lower Triassic clastic and carbonate deposits that contain well-preserved macro and microfossils (Fio Firi et al., 2022). These deposits were studied macroscopically, from thin sections and from a residue obtained by dissolution in glacial acetic acid. Additionally, SEM with EDS and X-ray powder diffraction were used to obtain detailed information on the fossil remains and petrographic features of the rocks.

Various analytical methods revealed different fossil remains and their modes of preservation. Field work enabled the identification of rock types, sedimentary structures and textures, and recognition of seven facies associations. In addition, numerous macrofossils were documented, including bivalves (*Claraia*, *Eumorphotis*, *Unionites*, *Bakevella*, *Costatoria*, and *Avichlamys*), gastropods (*Werfenella*, *Natiria*), ammonites (*Tirolites*), and trace fossils (*Planolites*, *Paleophycus*, *Thalassinoides*, *Teichichnus*; Fio Firi et al., 2022). Thin sections provided details on the sedimentology of the samples and enabled differentiation between fossiliferous and barren limestones. Fossiliferous limestones commonly have packstone textures and are rich in fossil remains, mostly mollusk fragments and rare foraminifera, indicating deposition in a fairly shallow marine environment. Barren limestones have a mudstone texture with common organic-rich laminae, indicating deposition in a slightly deeper and inhospitable setting (Fio Firi et al., 2022).

Dissolution of selected limestone samples in acetic acid revealed the presence of fossils that were rare or not noted in thin sections. The extracted assemblage included well-preserved pyritized foraminifera (*Ammodiscus* and *Glomospira*), ostracod carapaces, and vertebrate teeth. Surprisingly, the foraminifera were most abundant within the “barren” limestones. The three-dimensional fossil remains enabled better assessment of their morphology, mineralogical composition, and fine-scale characteristics, as well as their modes of preservation.

The combined application of various methods and the resulting data enabled more detailed paleontological and paleoenvironmental interpretation, especially regarding the differences between fossiliferous and barren beds. The pyritized fossils point to diagenetic alteration and suggest hypoxic conditions. Altogether, the results of this study point to multiple relative sea-level oscillations and ongoing stressful environmental conditions during the recovery of marine ecosystems after the Permian–Triassic extinction, with water-column stratification and poor circulation.

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The Middle Triassic volcanic events, example from the Žumberak Mt. (Croatia)

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Middle Triassic represents an important time in the evolution of the External and Internal Dinarides (Schmid et al., 2020). In the area of the Žumberak Mt. in north-western Croatia Middle Triassic carbonate and (pyro)clastic deposits are common, but not always well exposed. Even though they were previously noted, pyroclastic rocks have not been dated before to determine the absolute age of the deposits, and to confirm the relative age determined by the fossils (e.g. Gorjanović-Kramberger, 1894; Šikić et al., 1979; Vidaković et al., 2023).

A small succession, only 50 cm thick, was excavated at the private terrain in the Vlačić Brdo village. It consists of tuff and clay layers, sandstones, and limestones rich in micro- and macrofossils. Zircon grains from volcanoclastic beds below and above the ammonoids rich layer yielded ages of $247,6 \pm 1,3$ Ma; $247,44 \pm 0,92$ Ma and $246,48 \pm 0,77$ Ma. Considering the analytical uncertainties, all three dates overlap and constrain an early Anisian volcanic events at ca. 247 Ma.

Limestones include sporadic occurrence of microfossils, like foraminifera, holothuroids and calcisphere, and various macrofossils, especially cephalopods. Ammonoids are the most common, but mostly preserved as molds and steinkerns.

Collected data on volcanism, as well as abundant fossil remains, provide information on various biotic and abiotic factors and environmental changes that influenced deep marine environment, and confirm the rifting event that affected the Northern Gondwana margin during the Anisian epoch.

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Biostratigraphic and Micropaleontological Investigation of the Sarmatian s.l. deposits in the Sâmnicele Valley (Middle Miocene, Romania)

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The Sâmnicele Valley section (Southern Romania, Getic Foredeep), part of the Dacian Basin, Eastern Paratethys, is notable for its Sarmatian microfossil assemblages and pyritized insects. Sarmatian s.l. deposits formed during the progressive restriction of the Paratethys, which promoted brackish conditions and endemic microfaunas (Popescu, 1995). This environmental change is linked to the Badenian–Sarmatian Extinction Event, dated at 12.65 Ma (Palcu et al., 2023), when most marine faunas disappeared (Filipescu and Silve, 2008), with comparable turnover recorded at the Konkian–Volhynian boundary (Lazarev et al., 2025).

The studied section contains foraminiferal assemblages dominated by *Dogielina*, *Elphidium*, *Articulina*, indicating shallow, restricted brackish environments with reduced oxygen near the sediment–water interface (Dumitriu et al., 2017). Ostracods such as *Aurila*, *Euxinocythere*, *Amnicythere* further support marginal shallow-water conditions.

Within this dysoxic, sulfate- and iron-rich setting, early diagenetic mineralization enabled the exceptional three-dimensional preservation of terrestrial insects. Bacterially produced hydrogen sulfide reacted with iron ions, forming sulfide coatings around insect carcasses.

The insect-bearing horizon, also containing fish debris, is correlated with the *Dogielina sarmatica* Zone (Popescu, 1995), indicating an Early Bessarabian age.

Due to the rarity of comparable Sarmatian occurrences in Europe, Sâmnicele Valley is of regional and continental importance. Its micropaleontological and taphonomic features show how brackish-water basins, under specific microbial and geochemical conditions, can generate true Konservat-Lagerstätten.

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Paleogene bauxites of the Mediterranean region: a case study from Albania

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Karst bauxites of the circum-Mediterranean region formed primarily during the Cretaceous–Eocene interval as a result of prolonged subaerial exposure and intense weathering of carbonate platforms. The Paleocene bauxite occurrences investigated in this study are located in Dajti Mountain, east of Tirana, Albania. The present study provides preliminary petrographic, mineralogical and geochemical data obtained through optical petrography and SEM-EDS. Petrographic analysis reveals a predominantly pisolitic to nodular fabric composed of abundant rounded to sub-rounded pisoids, ooids, and intraclasts embedded in a fine-grained ferruginous matrix. Many pisoids exhibit concentric coatings around heterogeneous nuclei, indicating multiple episodes of accretion and reworking during bauxite formation. Iron-rich rims surrounding several pisoids suggest fluctuating redox conditions during weathering and diagenesis. Relict carbonate fragments and partially bauxitized clasts preserved within the matrix indicate inheritance from the underlying carbonate substrate. Mineralogical observations reveal a heterogeneous mineral assemblage dominated by Al- and Fe-rich phases, characteristic of typical bauxitic constituents. SEM-EDS analyses identified aluminum-bearing minerals associated with iron oxides and titanium-bearing phases, together with accessory chromium-bearing minerals. Particular attention is paid to the occurrence of rare-earth-element (REE)-bearing phases enriched in La, Ce, Nd, Sm, Gd, Dy, Ho, Er, and Yb. Several grains also contain significant concentrations of Y, Zr, Hf, and Th, suggesting the presence of REE-phosphate minerals and zircon-related accessory phases. The identified mineral assemblage indicates a complex provenance and enrichment history involving both residual bauxitization processes and concentration of resistant heavy minerals.

Karst bauxites are valuable terrestrial archives of paleoclimatic and tectonic evolution. Bauxites are primarily recognized as the principal ore for aluminium production, in Europe particularly in the Mediterranean region. Recent studies (e.g., Greece, Turkey: Dedy *et al.*, 2016; Croatia: Kovačević Galović *et al.*, 2025) can be enriched in REE and associated trace elements. This indicates that these deposits have significant potential for economic exploitation to support modern technological needs. Our preliminary results contribute to the understanding of Mediterranean karst bauxite formation and provide a basis for further investigation into the economic and genetic significance of the Dajti bauxite deposits.

Acknowledgements. Field studies of B. Kołodziej in Albania were supported by the Central European Exchange Program for University Studies (CEEPUS RS-0038-21-2526).

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Another Piece in the Puzzle of Late Miocene Small Mammal Biochronological Mosaic of Anatolia: The Sütölçe Locality

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Situated at the crossroads of Europe, Asia, and Africa, Türkiye has historically served as a critical migratory corridor and a mosaic of favorable paleoenvironments for diverse faunal communities since the Neogene, further enriched by its proximity to the ancient Paratethys Sea. Moreover, the presence of numerous Neogene lakes, which once covered a substantial portion of the country, provided highly favorable conditions for fossilization. The approximately 450 documented Neogene fossil localities underscore this rich paleontological heritage, with 176 of these sites dated to the Late Miocene. During this time, Anatolia was part of the Greco-Iranian Bioprovince, with a fauna that is distinct from that of western Europe. However, the Late Miocene is mostly known by localities yielding large mammals, whereas the small mammal record is rather scanty.

Recognizing the limitations of directly applying the European Mammal Zone (MN) system to Turkish faunas, pioneering work by Ünay & De Bruijn (1984) initiated the development of a distinct Turkish zonation. Subsequently, Ünay et al. (2003) established an alphabetic biozonation for Turkey extending into the Early Pleistocene, primarily based on micromammal fossils. Although this biozonation is independent from the MN system, the Turkish zones were correlated one on one to MN units. The Early Miocene zonation was later revised by Bilgin (2022). She demonstrated that there are major diachronies between the MN units and the regional zonation. Thus, the correlation of Turkish mammal fossil localities with the MN zonation remains a subject of ongoing discussion, highlighting the need for refined regional chronologies.

In this context, recent fieldwork conducted near Sütölçe village on the Gelibolu Peninsula has uncovered a new fossil locality provisionally dated to the early Late Miocene. Excavations carried out in 2024 yielded approximately 400 specimens. Preliminary taxonomic analyses of this material reveal a diverse small mammal assemblage comprising both Rodentia and Eulipotyphla. The faunal composition is dominated by a new species of *Byzantinia* (43%), followed by *Myomimus* (26%), *Progonomys* (15%), Erinaceidae (*Parasorex voesendorfensis* and *Schizogalerix sinapensis*; 6%), and *Cricetulodon* (6%). Additionally, *Crusafontina endemica* (Soricidae; 1%), *Tamias* (1%), and minor components (each under 1%) including *Keramidomys*, *Muscardinus*, *Castor*, and Chiroptera (Vespertilionidae gen. et sp. indet.) are present. Ongoing, detailed systematic identifications are expected to further increase the documented species richness of the locality.

By utilizing fossil micromammals from this newly discovered locality, this study aims to revise the Late Miocene regional biozonation system originally established by Ünay et al. (2003). Integrating this new faunal data into the broader Paratethyan and European biostratigraphic frameworks allows for crucial correlations across the western Black Sea region. Given Sütölçe's strategic geographic position, these findings establish a direct paleontological bridge between Anatolia and neighboring regions, thereby enhancing our understanding of faunal migrations and shared climate events during the Miocene.

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Aegean ammonoids from Deșli Caira Section (GSSP candidate for the base of the Anisian Stage), North Dobrogea, Romania

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The Deșli Caira section (North Dobrogea Orogen, Romania) is known in the classic geological literature for the richness in various groups of fossils, but especially for the Triassic ammonoid faunas, since the early 20th century. This section was studied for more than 20 years by Eugen Grădinaru, former professor at the University of Bucharest, who proposed together with other several specialists the Deșli Caira section as a GSSP candidate for the base of the Anisian (Grădinaru et al., 2007). Even a lot of work was done during the 1990s and 2000s (Balini et al., 2024 and references therein), all this work did not lead to a formal GSSP proposal especially due to the lack of the publications of the taxonomic description of the ammonoid faunas. Our investigations started in 2023 with the aim to verify the potential of the previous ammonoid collections and continued during the last three years with the resampling of the section with bed-by-bed approach. Balini et al. (2024) published from Deșli Caira the next ammonoid taxa of Aegean age: *Stenopopanoceras transiens* Tozer, 1972; *Aegeiceras ugra* Diener, 1895; *Paracrochordiceras denseplicatum* Fantini Sestini, 1981; *Acrochordiceras* sp. ind.; *Leiophyllites pradyumna* Diener, 1895 and *L. pseudopradymna* Welter, 1915 and the two new taxa: *Gradinaruites aegeicus* Balini and Lăcătuș, 2024 and *Robinsonites simionescui* Balini and Lăcătuș, 2024.

The present contribution brings additional ammonoid data for the lowermost part of the Aegean. We improved the ammonoid fauna collection with new specimens belonging to subfamilies Noetlingitinae and Longobarditinae and some new additions to *Stenopopanoceras transiens* Tozer, 1972, from 11 to 18 specimens. The Noetlingitinae are represented by a new genus and two new species with stratigraphical position of specimens at the base of the Aegean part of the section. The features of the new genus are involute type of coiling, fastigate venter, ornamentation consisting in ribs and ceratitic suture line. The *Longobarditoides* cf. *caucasicus* Shevyrev, 1995 is positioned in the lowermost Aegean beds. The specimens exhibit involute coiling and acute venter since the smallest stages, and suture line visible in only one specimen but typical for the species.

The Aegean ammonoid fauna from Deșli Caira section is integrated in the understanding of Olenekian-Anisian Ammonoid Faunal Turnover and improve the potential of correlation of the section at global level.

Acknowledgements. The work was supported by the project FDI 835/2023-2025 to Iuliana Lazăr funded by ICUB (the Research Institute of the University of Bucharest) and project PNRR i8 64/2003 PACE. We acknowledge Marius Stoica and Valentin Răuță for their consistent help during the field work campaigns.

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Demise of the Ravni Carbonate Ramp and Wetterstein Carbonate Platform preserved in a far-travelled nappe in northern Montenegro (Ćehotina River section)

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Near Gradac in northern Montenegro, along the Ćehotina River, a unique allochthonous section preserves the evolution of the demise of Ravni Carbonate Ramp in the Middle Triassic, followed by the re-establishment of the Wetterstein Carbonate Platform in the early Late Triassic, subsequently overlain by Late Triassic deep-water limestones after a gap. This section differs significantly from sections of the East Bosnian-Durmitor megaunit.

The succession starts with shallow-water recrystallized limestones of the Ravni Formation (Pelsonian). Following a gap caused by uplift, grey fore-reefal siliceous limestones deposited, 16 m-thick. This part of the succession belongs to the middle-late Illyrian Rid Formation, dated by conodonts: *Gladigondolella tethydis*, *Paragondolella eotrammeri*, *Paragondolella excelsa*. Above this, a 12 m-thick series of grey limestones with chert nodules deposited, in the upper part with carbonate turbidites (Trnava Formation). The Fasnian-Longobardian age of the lower part of the siliceous limestone package is confirmed by conodonts: *Gladigondolella*-ME, *Gladigondolella tethydis*, *Neogondolella* sp., *Paragondolella excelsa*, *Paragondolella fueloepi*, *Paragondolella inclinata*, *Paragondolella* cf. *tadpole*, *Paragondolella trammeri*. An interbed of breccias with reef building organisms is present in the early Longobardian. In the upper part of this turbiditic package, a conodont sample yielded *Gladigondolella*-ME, *Gladigondolella tethydis*, and *Paragondolella polygnathiformis*, indicating an Early Carnian age and the onset of the Wetterstein Carbonate Platform. Overlying this, 20 m of early Carnian fore-reef limestones deposited, followed by reefal limestones of the Wetterstein Formation with a sedimentary gap at the top, expressed by intense karstification. This level was formed after the demise and uplift of the Wetterstein Carbonate Platform around the Julian 1/2 boundary. The drowning sequence overlying the Wetterstein Formation comprises grey siliceous limestones with turbidites and bivalves, 6 m-thick, after a long-lasting gap (Julian 2 to Tuvanian 1). The deep-water limestones contain following conodonts: *Carnepigondolella* sp., *Paragondolella carpathica*, *Paragondolella nodosa*, *Paragondolella polygnathiformis* - corresponding to the late Carnian (Tuvanian 2-3) age of the Stopića Formation. Upsection formed a 32 m-thick succession of early Norian dark-grey siliceous limestones with turbidites and bivalve interbeds of the Gučevo facies, with following conodonts: *Epigondolella quadrata*, *Epigondolella rigoi*, *Epigondolella spatulata*, *Epigondolella triangularis*, *Epigondolella triangularis* fauna sensu Karádi, *Metapolygnathus* sp., and a transitional form from *Norigondolella navicula* to *Norigondolella hallstattensis*. This part of the section represents the Early Norian and the carbonate turbidites derive from the Dachstein Carbonate Platform. The upper part of the Gučevo facies of middle Norian age comprises a 10 m-thick series of dark-grey siliceous limestones and breccias with bivalves, with following conodonts: *Epigondolella postera*, *Epigondolella slovakensis*.

The evolution of the Late Triassic part of the section is characterized by a deepening-upward trend. This contrasts with all other successions of the East Bosnian-Durmitor megaunit, where the flooding of the karstified and deeply eroded Wetterstein Carbonate Platform is dated as latest Carnian respectively earliest Norian. This indicates a provenance of the section from the transitional area between the Dachstein Carbonate Platform and the open (Hallstatt) shelf (Gučevo facies).

What radiolarians reveal about a changing Paratethys Sea: Insights from the Getic Depression (Romania)

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The evolution of the Paratethys was influenced by intermittent connections with the Mediterranean and Indo-Pacific regions during the Middle Miocene (Rögl and Steininger, 1984; Kováč *et al.*, 2007). Radiolarians are particularly important in this context, preserving a valuable record of these changes and providing evidence for reconstructing past marine connections and environmental conditions.

In the Romanian sector of the former Paratethys, the Badenian is generally considered the last marine stage. One of the most characteristic records of this interval is the “Radiolarian Shale Formation”, for which Paulian Dumitrică provided the first detailed descriptions of radiolarian and silicoflagellate assemblages (Dumitrică, 1964, 2016).

The studied material comes from the Pietreni area (Getic Depression, southern Romania), where this formation is well exposed. The succession consists of finely stratified dark clays interbedded with volcanic tuff layers and contains rich siliceous microfossil assemblages. The assemblage is dominated by radiolarians and accompanied by diatoms. Spumellarians are the most abundant and diverse group, whereas nassellarians are represented by fewer taxa, many specimens displaying excellent preservation.

The presence of *Didymocyrtis laticonus* and *Lithopera* sp. supports a Late Badenian age, corresponding to Zone RN5 (Riedel and Sanfilippo, 1970) emended by Riedel and Sanfilippo (1971, 1978) and Subzone RN5b (Kamikuri, 2022). Furthermore, the radiolarian association identified in the studied section shows strong similarities with radiolarian faunas previously reported from other localities in Romania and Poland (Barwicz-Piskorz, 1999). The abundance of radiolarians and the presence of volcanic tuff layers indicate increased silica input, likely favouring siliceous plankton productivity, while their stenohaline character indicates the persistence of normal marine conditions (Dumitrică, 1968).

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Redeposited corals from the Paleocene flysch of the Outer Carpathians (Czech Republic and Poland)

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Colonial corals occur in the Czech and Polish parts of the Outer Carpathians exclusively as redeposited clasts within flysch sequences. 18 colonial scleractinian coral species of 10 genera were previously described from Příbor area (northern Moravia, Czech Republic). According to Eliášová (1989) coral species indicate on upper Cenomanian–lower Santonian. These corals were redeposited, as they occur within deep-water flysch sediments of Senonian–Paleogene age (Ždánice-Subsilesian Unit, Western Outer Carpathians). Coral-bearing sediments are possibly of Paleocene age (Eliáš, 1998). Over 90% of the specimens belong to *Actinacis remesi* Felix, 1903. Recent studies have revealed a new coral locality in this area, in Paleocene Klokočov Member of the Frydek Formation. Almost all coral specimens (up to 20 cm in diameter) are strongly silicified. Three specimens of silicified *Actinacis* sp. were recognized also in the Skole Unit of the Polish Carpathians in Paleocene Babica Clays (debris-flow deposits) near the Rzeszów. Similar silicified corals occur in Quaternary alluvial gravels in Moravia and Poland.

Recent findings in alluvia of the Odra River in the Opole region (Silesia, southern Poland) revealed corals representing at least 6 genera. Most of them represent *Actinacis* sp., which like the specimens from the Outer Carpathians, are associated with polychaete worms (intergrowth symbiosis). Coral-bearing sediments of the submarine elevations of the Ždánice/Subsilesian/Skole basin were eroded after their emergence during the Laramide tectonic phase at the Cretaceous/Paleogene transition, resulting in the silicification and redeposition of the corals. Corals from Quaternary gravel alluvia are a result of the fluvial and glacial erosion of the Carpathian flysch and exhibit a complex, multi-stage history of redeposition.

Actinacis is an extinct genus of opportunistic poritid corals regarded as a pioneer taxon. Similar to modern *Porites*, it is considered one of the most environmentally stress-tolerant coral. The corals in question require description and revision. The age determination of the coral assemblages will be significant for understanding the global factors governing the development of reef corals in the northern part of the Carpathian Basin. Adopting the coral age determined by Eliášová (1989), this development can be linked to the Cenomanian–Turonian Thermal Maximum. However, Löser (2005) expressed the opinion that corals studied by Eliášová (1989) are probably younger than Cretaceous. If his view is confirmed by new taxonomic studies and revision of old collections, the development of discussed corals could be linked to the Paleocene–Eocene Thermal Maximum, especially early Paleogene hothouse. During thermal maxima, hermatypic corals expanded or escaped (including an *Actinacis* bloom) from the too hot subtropical Tethyan realm (Bosellini et al., 2025) into the cooler subboreal realm of the northern Carpathian Basin.

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Taxonomy of Lower Cenomanian corals of Grădiştea Muncelului – Cioclovina

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The Upper Cretaceous Scleractinia occurrences in Romania have been scarcely described in the geological literature until the 20th century. Stilla (1985) and Melinte-Dobrinescu (2010 and references therein) merely addressed the appearance of Scleractinia in the southeastern part of the Haţeg basin, Grădiştea Muncelului – Cioclovina area (Getic Domains, Southern Carpathians). Although in Romania the occurrences of Cenomanian mixed carbonate-siliciclastic deposits containing abundant benthic faunas are well studied, taxonomical papers with description involving corals were rarely published. Thus, this contribution aims to present the first taxonomical descriptions of the Cenomanian coral fauna association of this area.

Detailed lithostratigraphic log was produced for the studied section. 120 coral specimens were collected from a single carbonate bed, 0.9 to 1.2 meter thick. The fossils were prepared accordingly, cleaned with brush and ultrasonic cleaning bath. Approximately 50 thin sections were prepared for taxonomical and microfacies analyses.

The studied section is located in the Grădiştea Muncelului – Cioclovina area, at 4 km north-east from the Fizeşti Village. The Upper Cretaceous deposits of this area consist of marine sequences characterized by a variety of depositional settings developed from the Cenomanian up to the lower Maastrichtian, succeeded by upper Maastrichtian continental deposits. In terms of lithological units, the studied section is represented by Slatina Member (Valea Dreptului Formation) approximately 30 meters thick. Toward the upper part of this unit, three beds of bioclastic calcarenite are interbedded with silty mudstones. The upper bed is represented by a mixed carbonate-siliciclastic rock containing a rich fossil assemblage composed of irregularly dispersed colonial and solitary corals, sponges, gastropods, rudist and ostreoid bivalves, rare echinoids.

The next Scleractinia taxa from several families were identified in the studied section: Merulinidae (*Hydnophora*), Placocoeniidae (*Placocoenia*), Acrosmiliidae (*Brachyphyllia*), Synastreidae (*Brachycoenia*), Thamnasteriidae (*Thalamocaeniopsis*), Siderastraeidae (*Eosiderastrea*, *Astraeofungia*), Microsolenidae (*Eocomoseris*) and Meandrinidae (*Aulosmilia*); alongside with octocorals of order Helioporacea with *Heliopora*.

The microfacies is represented by silty floatstone with packstone matrix, with abundant bioclasts and non-skeletal grains of poorly sorted quartz.

The coral colonies infer harsh environmental conditions by exhibiting shrunk corallum, small polypierite diameters, and the strong integration levels. The planar geometry of the fossiliferous bed, the microfacies, the composition and taphonomy features of the fossil assemblage reflect very shallow inner platform conditions (5 to 10 m water depth), areas affected by tidal currents or subtidal areas of changing hydrodynamic conditions.

The Romanian taxonomical portfolio of the Cenomanian corals is rather scarce. However, the faunal assemblage found in Grădiştea Muncelului–Cioclovina area sheds new light over these rare North Peri-Tethyan occurrences.

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“Curiouser and curiouser!” — bivalves within a large Cretaceous ammonite (Santonian) from the Shumen Formation, Bulgaria

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A large specimen of the ammonite *Parapuzosia daubreei* (de Groussouvre, 1894) (1.44 m diameter) on display in the National Museum of Natural History, Sofia (NMNHS specimen number F-31420) reveals an interesting taphonomic story. The specimen was collected from Upper Cretaceous (Upper Santonian) sediments from the roof of a cave near Shumen, Bulgaria nearly a century ago in 1932 (Boev, 2022).

The ammonite displays “pits” and “rings” on its smooth “outer” surface (in actuality the outermost surface of the sediment infilling the body chamber). The “rings” and “pits” (the latter lacking sediment infill) are typically between approximately 1-2 cm in diameter. There are estimated to be at least 120 of these structures within the area of the body chamber. I believe these represent a new record - different from perforations and depressions that have previously been reported from ammonite shells - hence the idiom for emphasis in the abstract title.

Silicone rubber (silicone putty) casts were taken from 13 of the pits to aid in identifying the “pit-maker(s)”. The casts were identified as external moulds of the valves of a bivalve mollusc (both left and right valves being present) identified as “*Astarte*” *gigantea* (Leymerie). The ring structures are considered to be sediment-filled bivalves; the pits lack sediment infill today. Both valves of the bivalves may have been articulated at the time of burial although this has not been observed (there has been taphonomic shell loss of the ammonite conch and bivalve shells). A bivalved condition could explain why all of the pits reveal the same “convex-up” valve orientation (with respect to the wall of the conch). For the bivalves to have been deposited on, or attached epifaunally to an ammonite steinkern is not credible given that the bivalves appear embedded in the sediment infilling the body chamber.

Clearly, for the bivalves to be preserved in the sediment infilling the ammonite’s body chamber the cephalopod must have already been dead. The valves of the bivalves observed in the pits (and the silicone rubber casts) have their commissures parallel to the body chamber wall. Assuming that the bivalve is a shallow burrower (cf. *Astarte* in Stanley, 1970), the bivalves would be very unlikely to show a consistently parallel orientation of their commissures if actively burrowing in sediment in the body chamber of the dead ammonite. The bivalves were likely already dead or scoured and exhumed possibly while still alive by bottom water currents from a nearby benthic habitat. The shells were then washed into the ammonite’s body chamber, during sediment infill of the prone, dead ammonite on the seafloor. Such a depositional scenario is consistent with the sedimentology of the Shumen Formation.

Acknowledgements. Many thanks to: Barbara Radulovic for identification of the bivalve species; Latinka Hristova and Vladimir Nikolov for access to the ammonite; Lubomir Metodiev, Barbara Radulović; and Vladan Radulović for feedback on the abstract; Vyara Idakiev; Lubomir Metodiev; Neda Motchurova-Dekova; Barbara Radulović; Vladan Radulović; Ivaylo Raykov; and Rostislav Trajanov for valuable discussion and information.

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Late Jurassic climate-change-induced reorganization of marine microplankton assemblages in the Transdanubian Range (Hungary)

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The Late Jurassic–earliest Cretaceous interval was marked by major biotic and environmental changes. These were investigated in an Upper Jurassic–lowermost Cretaceous succession represented by radiolarite, calcareous marl, nodular limestone (Ammonitico Rosso), and Maiolica/Biancone facies within a 164 meters thick, continuous pelagic section at Sümeg (Transdanubian Range, Hungary). A new dataset comprising microfossils, calpionellid, calcareous nannofossil and radiolarian assemblages is presented to establish an integrated stratigraphic framework. Magnetic susceptibility (MS) and cyclostratigraphic analyses were additionally applied to reconstruct climatic and paleoceanographic changes in the study area.

The heavy-mineral content of the calcareous marl was investigated preliminarily. Although its precise age and provenance remains uncertain, its accumulation suggests humid and warm climatic conditions. The material likely originated from the weathering of garnet amphibolite affected by epimetamorphic retrograde overprinting. However, geodynamic setting responsible for the accumulation of this unit remains unresolved.

Four climatic–paleoceanographic phases were identified, during which alternating humid and arid conditions, influenced sedimentation, water-column stratification, and trophic conditions, ultimately driving the reorganization of pelagic microplankton assemblages. We infer rapid weakening or collapse of the monsoon system at the onset of the early Tithonian, accompanied by a shift in sedimentation toward nodular limestone facies (Ammonitico Rosso). During the middle part of the early Tithonian, a pronounced decline in MS values likely reflects increasing aridity. This interval coincides with a decline in radiolarian abundance, the proliferation of pelagic *Saccocoma* crinoids, and the first bloom of calcareous nannofossils, referred to as Nannofossil Calcification Event I (NCE I). The transition from microgranular to hyaline calpionellids occurred during the establishment of persistently arid climatic conditions. MS values remained generally low but highly variable until the earliest Berriasian. This interval encompasses the dominance and subsequent decline of *Saccocoma* as well as the onset of Nannofossil Calcification Event IIA (NCE IIA). Cyclostratigraphy analysis demonstrates that, during the aridification trend of the early Berriasian, periodic antiphased fluctuations in siliceous and calcareous zooplankton abundances were likely controlled by orbitally forced climatic variability. Intervals dominated by radiolarians may be linked to episodes of enhanced upwelling activity. Previously proposed climate models for NW Europe are broadly consistent with our interpretation, although the two regions likely belonged to different climatic belts.

Acknowledgements. This work is dedicated to the memory of Emő Márton (1940–2025), who was a pioneer of Central European paleomagnetism and magnetostratigraphy, and carried out the first paleomagnetic studies of the Sümeg section. The authors are grateful to Damian Lodowski and Gábor Imre, the Nature Conservation Department of the Veszprém County Government Office, and Geopark Group Leader Barnabás Korbély on the behalf of Balaton Highland National Park and the Bakony–Balaton Geopark Directorate. The authors acknowledge the GINOP-2.3.3-15-2017-00043 project. The work of BCS and RL was supported by the MTA-HUN-REN CSFK Lendület PannonVulkán Research Group.

Integrated micropaleontological study of a continuous Badenian succession in the Făget Basin (Transylvania, Romania)

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Middle Badenian marine sedimentary deposits exposed in the Făget Basin are currently limited in both number and stratigraphic thickness, restricting detailed paleoenvironmental investigations based solely on outcrop data. The availability of continuous core material drilled through Badenian successions provided an exceptional opportunity for high-resolution micropaleontological analyses. A total of 22 systematically collected samples, selected following detailed sedimentological logging, were analyzed for their microfossil content. Benthic foraminiferal assemblages are abundant (with maximum absolute abundances reaching 250 specimens per 100 g of dry sediment), highly diverse (maximum Fisher's alpha index of 36), and exceptionally well preserved. The assemblages are dominated by representatives of the genera *Bulimina*, *Bolivina*, *Cassidulina*, *Nonion*, and *Melonis*. Variations in benthic foraminiferal distribution were used to reconstruct key paleoecological parameters, including bottom-water oxygenation, nutrient availability, and substrate characteristics. A novel aspect of this study is the assessment of human-induced variability in taxonomic identifications. A subset of samples was independently analyzed by two researchers, allowing the evaluation and comparison of discrepancies in taxonomic determinations and their potential implications for paleoenvironmental interpretations. The calcareous nannofossil assemblage is dominated by *Reticulofenestra minuta*, indicating nutrient-rich, eutrophic water column conditions. The integrated micropaleontological dataset enabled the assignment of the studied deposits to the M6 planktonic foraminiferal biozone and the NN5 calcareous nannoplankton biozone, confirming a middle Badenian age. These results provide new insights into the paleoenvironmental evolution of the Făget Basin and demonstrate the value of combining foraminiferal and calcareous nannofossil evidence with quantitative assessments of taxonomic uncertainty.

Acknowledgements. The authors thank S.C. GeoLogic Site S.R.L. for providing the borehole samples.

Foraminiferal response to the oceanic anoxic events OAE1b and OAE1d in Aptian–Albian successions of the Budva Zone (Montenegro)

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This study presents a new micropaleontological data on benthic and planktonic foraminiferal assemblages from the Aptian–Cenomanian ammonite-bearing successions of Kotražica focusing on palaeoecological dynamics and biostratigraphy in relation to OAEs. The Upper Aptian to lowermost Cenomanian successions comprises four sedimentary cycles dated by ammonoids and foraminifera: Section 1 is subdivided in three sedimentary cycles with a fining-upward and deepening-trend, Section 2 has one cycle with fine-grained sedimentary rocks and corresponds to more basin-ward depositional realm.

The first sedimentary cycle of Section 1 comprises orbitolinid-bearing limestones overlain by sandy limestones, sandy marlstones, and turbiditic sandstone beds, defining an overall fining-upward succession. The lowermost part of the Cycle 1 records the drowning of an orbitolinid-bearing carbonate ramp and is characterized by agglutinated benthic foraminiferal assemblages, planktonic forms are rare. The distribution of agglutinated benthic foraminiferal assemblage (*Debarina hanounerensis*, *Ammobaculites carpathicus*, *Tritaxia gaultina*, *Eobigenerina variabilis*, *Gaudryinella sherlocki*, *Gaudryina oblonga*, *Glomospira urgoniana*, *Falsogaudryinella tealbyensis*, *Novallesia producta*, *Nezzata simplex*) and rare occurrence of planktonic forms (*Hedbergella aptiana* and *H. infracretacea*) in basal part indicating a low-oxygen deeper-water environment during the latest Aptian.

The Cycle 2 records intense volcanic activity and is dominated by turbidites and mass-transport deposits. These sediments contain abundant reworked shallow-water bioclast, including orbitolinid foraminifera, corals and algae. The Fe-rich and glauconitic sandstones overlie the slump deposits, bearing mixed fossil fauna (ammonites, bivalves) reflecting deep-water sedimentation. The lower part records a major shift in foraminifera assemblages, marked by the replacement of benthic-dominated forms by low-diversity planktonic assemblages dominated by small hedbergellids, as a response to environmental stress associated with the ocean anoxic event OAE1b (Aptian–Albian transition). The occurrence of *Hoplites* (*Isohoplites*) *steinmanni* and *Phylloceras* (*Hypophylloceras*) *velledae* allows assignment to the *Douvilleiceras mamillatum* Zone (latest Early Albian).

The Cycle 3 comprises slump deposits, glauconitic sandstones, marlstones, siltstones and volcanic ash layers rich in ammonoid fauna and planktonic foraminifera assemblages. The uppermost part of the Section 1 contains a diverse ammonite fauna indicative of the *Mortoniceras perinflatum* Zone (late Albian), and records a major increase in planktonic foraminifera of the latest Albian: *Parathalmanninella appenninica*, *Pseudothalmanninella* sp., *Ticcinella* sp., *Muricohedbergella delrioensis*, *M. planispira*, *Microhedbergella rischi*, *Planoheterohelix moremani*, *Laevilla bentonensis*.

Section 2 consist of siltstones, marly claystones, volcanic ash layers, and organic-rich fine-grained deposits. Based on ammonite fauna, the fine-grained upper part of the cycle corresponds to the *Mortoniceras perinflatum* zone. The overlying organic-rich siltstone and marly claystones containing abundant planktonic foraminifera (*Parathalmanninella appenninica*, *Planomalina buxtorfi*, *Praeglobotruncana delrioensis*, *Muricohedbergella delrioensis*). The rare benthic foraminifera are represented only with calcareous forms. The interval correspond to the *Parathalmanninella appenninica* Zone to latest Albian age. Above this level, marly claystones of the uppermost part contain inoceramid bivalves (*Gnesioceramus crippsi*) of the earliest Cenomanian. The uppermost organic-rich interval records reduced oxygenation and a major shift in ecosystem consistent with OAE1d conditions, with the presence of earliest Cenomanian inoceramids documenting continuation of stressed conditions across the Albian–Cenomanian boundary.

Cyclostratigraphical, stable isotopic and elemental analysis of the global Devonian–Carboniferous boundary in the Hakkâri–Şırnak area, Arabian Platform (Southeast Türkiye)

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Late Devonian–Early Carboniferous successions in Hakkâri province, Southeastern Türkiye are studied by sedimentological, cyclostratigraphical, biostratigraphical, stable isotopic and elemental analysis.

The Güzeldere section covers a 302 m thick interval where 81 samples were collected. It starts with light greybeige, thick and cross-bedded quartz arenites and alternates with iron bearing quartz arenites and some laminated mudstones. This basal part presents a 70m thick clastic interval within Late Devonian.

Towards middle part of the section, cyclic alternation of poorly sorted polygenetic conglomerates and fine-grained reddish coloured siltstones and thick bedded, reddish-bordeaux colored cross bedded quartz arenitic and arkosic sandstone and thin bedded reddish bordeaux colored laminated mudstones in meter scale and as a fining upward sequence are observed. Above this level, thickness of sandstones decreases and thinner sandstone and mudstone alternation appears as cyclic nature of the section.

At the top part of the middle part of the section, thick quartz arenites with cross bedding are observed and are overlain by limestones with stromatolites and laminated limestones. A thick black shale interval starts just above sandy limestone with brachiopods.

Black shales are laminated and silty and display cyclic alternation of laminated and brachiopod-rich mudstones, paper shales and limestones.

The Devonian–Carboniferous boundary lies within this thick black shale interval. After black shale interval, thin bedded limestone and shale alternation takes place and overlain by thick dark gray limestone with abundant brachiopods. This interval lies within early-middle Tournasian. After that level, presence of shale and mudstones decreased and limestones shows thicker succession and display alternation of micritic limestones and packstones with abundant fossils including brachiopods, bryozoa, corals, plecyopoda, gastrapoda.

The studied section shows a transgressive succession with a record of relatively sudden sea-level rise. Biostratigraphic zonations are made by conodont, ostracod, and palynological studies and helped to determine the Late Devonian to the Early Carboniferous boundary. Study indicates the presence of a rich miyospor paleoflora extending from Zone LL to Zone VI. The biological contents identified can be associated with the Devonian end biotic crisis, the Hangenberg Event, and the ecological recovery processes at the beginning of the Carboniferous. Furthermore, the occurrence of *Gnathodus pseudosemiglaber*, *Bispathodus stabilis stabilis* and *Bispathodus stabilis vulgaris* within conodont assemblage recovered from the upper part of the studied succession provides evidence for an Early Carboniferous age of the Güzeldere section.

Stable isotope analysis ($\delta^{13}\text{C}_{\text{carb}}$) present a curve with a strong negative $\delta^{13}\text{C}$ excursion with 6 permil shift and the peak of this negative shift is just above the D/C boundary and can be easily correlated with global Famennian–Tournasian isotope curves (Korn et al, 2024, Al Huseyni and Ruebsam, 2020). Just below this negative shift, there is a strong positive shift with 3 permil and can be interpreted as Hangenberg event of the Late Devonian.

Element analysis display a parallel shifts with stable isotope curve around the D/C boundary. Enrichment of Ba, V, Co, U, Cr, Ce, Fe, Zn, Ti, Zr, P and Al are easily visible and even they show two

levels of enrichments including just above the boundary. However, Sr, Ca, Mg, Mn display strong decreases in values around the boundary. Values of Hg do not present any considerable shift around the boundary.

Acknowledgements. This study was supported by the TÜBİTAK project numbered 123Y474.

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Session GS14

Stratigraphy, Sedimentology, and Facies Analysis

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Triassic intraplateform basins? What is written in the Triassic-Jurassic sedimentary successions of the Western Tethys Realm?

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To reconstruct the Triassic–Jurassic geodynamic evolution through time and space and to distinguish the various lithologies, a high-resolution litho- and biostratigraphy is the necessary base. In cases various lithologies are defined as basin-wide useable formations, in other cases several formations are united into a group, because the included formations are characterized by facies transitions, mixed lithologies, or are not mappable lithostratigraphic units. To invent for identical lithostratigraphic units in different countries/areas independent formations with definition of a separate type-section confuse only readers, hamper the scientific progress, and result often in regional insufficient interpretations which cannot be easily compared with the over-regional tectonostratigraphic evolution, i.e. the geodynamic evolution of the birth and death of an oceanic realm (Wilson cycle). In the Neo-Tethys Wilson cycle the carbonate dominated passive continental margin evolution started in the Middle Triassic (Pelsonian) and ended in the Middle Jurassic with obduction of Neo-Tethys derived ophiolites. During this evolution carbonate platforms were formed predominantly in the Late Triassic (Wetterstein and Dachstein Carbonate platforms). For passive continental margin settings, an intraplateform basin is defined as a deep-water depositional realm situated between two carbonate platforms with lively carbonate production. A basin between the continental realm, i.e. the shore line and a platform (or rising reef-rims) is defined as deep lagoon or empty bucket. After the demise of the Middle Anisian shallow-water carbonate ramp and the formation of a horst-and-graben morphology no significant long-lasting shallow-water carbonate production can be recognized. This change was termed Reifling turnover, and can be traced throughout the whole Western Tethys Realm. The late Middle Anisian to Early Carnian deep-water sedimentary rocks cannot be attributed as “intraplateform basin”, because during this time span no huge carbonate platforms existed. In the latest Ladinian respectively in the Early Carnian the first important carbonate platform cycle started with the evolution of the Wetterstein Carbonate platforms established predominantly on top of preexisting morphological highs and started from there to prograde rapidly towards the basins (grabens/halfgrabens) formed during the Late Anisian extension. Carbonate production of the Wetterstein Carbonate Platform evolution stopped abruptly around the Julian 1/2 boundary and not all preexisting deep-water areas could be filled by the carbonates of this platform. During the short time span of several independent Wetterstein Carbonate platforms also short-living intraplateform basins could be recognized. Carbonate production recovered during the Late Carnian and gave rise for the evolution of the huge Norian-Rhaetian Hauptdolomite/Dachstein Carbonate Platform. The enormous carbonate production of this platform was able to fill all remaining older depressions in the shelf area already in the Early Norian. After the demise of the Dachstein Carbonate Platform during the Triassic/Jurassic mass extinction a hemipelagic shelf evolved (Early-Middle Jurassic). The Middle-Late Jurassic is characterized by ophiolite obduction and the formation of various mélanges and nappe thrusting. Trench-like basins were formed in front of the newly formed nappe stack, and by the erosional products predominantly of the imbricated outer shelf (Triassic deep-water limestones). In cases deep-water Hallstatt nappes were bulldozed by the obducting ophiolites to the foreland.

Mineralogical and petrographic analysis of thermal travertines in Banpotoc–Cărpiniș quarries (Hunedoara country, Romania)

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Travertines represent continental carbonates that form around thermal springs, rivers and occasionally lakes, through the precipitation of calcite or aragonite from saturated waters (Pedley, 1990; Ford, 1996; Pentecost, 2005). This study focuses on the mineralogy and petrography of the travertines in Banpotoc–Cărpiniș areas, where these deposits are exploited for use in construction since the nineteenth century. Due to their importance, previous studies mainly focused on their geotechnical and mechanical properties (Marinescu et al., 2017; Madear et al., 2023).

The mineralogy of these deposits revealed a predominance of calcite, along with few amounts of quartz and clay minerals. The clay fraction (< 2mm) on oriented, glycolated, 400°C and 550°C heated specimen showed the occurrence of smectites, along with sepiolite, illite and kaolinite. The occurrence of smectites and sepiolite is consistent with alkaline hydrochemical conditions commonly associated with karstic and hydrothermal environments (Grim, 1968; Millot, 1970; Galán & Pozo, 2011).

The petrographic analysis of these rocks reveals the occurrence of both crystalline travertines and mudstone to wackestone calcareous tufas (Dunham, 1962). The first ones contain well-developed calcite, whereas the second ones are characterized by microsparitic to sparry calcite. Both deposits contain abundant vuggy and tubular pores, few plant-root traces, laminar crusts, and localized iron oxide/hydroxide infillings. Diagenetic features include dissolution that increased pores connectivity with meteoric recrystallization of drusy and dogtooth-like calcite cements lining their edges. These findings reveal the predominance of karstic and alkaline chemical environments represented with fluctuations between thermal and meteoric (freshwater) conditions.

Acknowledgements. Special thanks to the department of Geology of Babes-Bolyai University. Expressions of gratitude the “Agence Universitaire de la Francophonie” for funding this research project through Eugen Ionescu post-doctoral program.

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Lower Devonian cherts of the Vrabcha Formation (Morava Unit, SW Bulgaria): petrography, geochemistry and depositional settings

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The Morava tectonic unit (after scheme of Dabovski and Zagorchev, 2009) in southwestern Bulgaria represents a system of nappes composed of Precambrian gneisses and migmatites, as well as Lower Paleozoic sedimentary successions. The Upper Silurian–Lower Devonian siliceous-shale-carbonate sequence in this unit was assigned by Spassov (1973) to the Vrabcha Formation. The latter comprises graptolitic shales (in its lower part), limestones with shale intercalations and dark grey to black cherts. The biostratigraphy of these deposits, exposed near the Gorna Vrabcha village, has been studied by Spassov (1973), Sachanski *et al.* (2005) and Boncheva *et al.* (2007).

The present work is focused on the Lower Devonian cherts of the Vrabcha Formation and aims to investigate the source of silica and the depositional environment (continental margin, pelagic, or ridge-proximal) of these rocks, based on the obtained petrographic and geochemical data.

The studied cherts are poorly exposed and occur within Lochkovian strata in the Gorna Vrabcha section 2 and Pragian strata in the Gorna Vrabcha section 3 (Boncheva *et al.* 2007) and the Mureno locality. They often alternate with light grey variably clayey tentaculitic limestones.

Under the microscope, these silicites are referred to as radiolarian cherts. They consist of microcrystalline quartz groundmass with dark brown or black color and various amounts of chalcedonic radiolarian tests. Opaque minerals are also commonly observed. The rocks are crosscutted by numerous quartz veins of varying thickness and orientation.

The presence of radiolarian tests, the Si/Si+Al+Fe+Ca ratios (ranges from 0.83 to 0.98), and Al–Fe–Mn diagram (after Adachi *et al.* 1986) in which the samples plot within the non-hydrothermal field, indicate that the silica in these cherts is predominantly of biogenic origin. The observed Al₂O₃, Fe₂O₃, TiO₂, La_n, and Ce_n contents suggest that the siliceous rocks of Vrabcha Formation were deposited in a pelagic environment, most likely within the Paleo-Tethys Ocean.

Acknowledgements. The Bulgarian National Science Fund of the Ministry of Education and Science, Grant KP-06-N84/1, supported this study.

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Mid-Cretaceous successions in the Eastern Carpathians: Micropalaeontological, geochemical, and sedimentological studies

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Most Oceanic Anoxic Events (OAEs) during the mid-Cretaceous were driven by severe climate changes, carbon cycle perturbations, and tectonic activity. A key signature of these events is the deposition of organic-rich black shales featuring distinct $\delta^{13}\text{C}$ isotope excursions. Focusing on the late Albian – early Cenomanian interval from the outer Eastern Carpathians, this study evaluates the sedimentological processes to identify potential OAEs by integrating calcareous nannoplankton biostratigraphy with $\delta^{13}\text{C}$ chemostratigraphy in order to delineate these anoxic intervals. Discerning OAEs and their lithological expressions has long been challenging in this region. This difficulty stems from widespread, deep-sea anoxic sedimentation within small, isolated basins that suffered from restricted circulation throughout the Early Cretaceous. Consequently, discovering new stratigraphic units is essential to better understand these complex processes.

Through these analyses, three distinct mid-Cretaceous events have been identified: the Albian-Cenomanian Boundary Event (ACBE), the Middle Cenomanian Event (MCE), and the Cenomanian-Turonian Boundary Event (OAE2). Calcareous nannofossil biostratigraphy places the ACBE within the UC0 zone and the MCE within the UC3a subzone. OAE2 represents the most prolonged event in the studied area, spanning the late Cenomanian to early Turonian. It exhibits three distinct peaks in the late Cenomanian (UC3e–UC5c biozones) and a final peak in the early Turonian (UC6 biozone). Lithologically, the successions consist of black and dark-grey shales, grey marls, and minor centimeter-scale radiolarites, all showing pronounced spikes in Total Organic Carbon (TOC) and Organic Matter (OM) that align with the OAEs. Moving forward, integrating additional proxy analyses will provide deeper insights into the underlying sedimentary processes, ultimately improving the resolution of these Cretaceous anoxic events on both local and global scale.

Acknowledgements. The research leading to these results was supported by the Ministry of Education and Research – NUCLEU Programme: PN 23 30 01 01 and PN 23 30 02 01.

Mercury anomalies and mercury isotopes in Silurian sediments from Asaritsa, western Balkan, Bulgaria

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We report mercury contents and new mercury isotope data for Silurian marine sediments from the Asaritsa section, western Balkan, Bulgaria. This is the only documented Llandovery sequence in Bulgaria that spans the upper Aeronian *Stimulograptus sedgwickii* and the lowermost Telychian *Spirograptus guerichi* graptolite biozones. The sedimentary succession comprises Aeronian graptolitic black and siliceous shales grading upwards into a graptolite-barren interval composed of pale-colored shales, siliceous shales, and bedded cherts (lydites), and is capped by black shales of the Telychian Stage (Sachanski, 2017). The Aeronian–Telychian boundary is assumed to lie within the pale-colored shale interval.

Baseline Hg concentrations throughout the profile are below 200 ppb and rarely exceed 100 ppb. Two distinct positive anomalies are identified, one reaching ca. 400 ppb, and a more significant one that peaks at nearly 1900 ppb. The latter occurs in the black and siliceous shales of the *sedgwickii* Biozone, and the former in the black shales of the *guerichi* Biozone.

Total organic carbon contents generally follow the Hg enrichment pattern with values typically <1 wt% and peaking at ~3 wt% in the Hg-rich sediments. Throughout the section, Hg/TOC ratios are mostly <300 ppb/%. Elevated Hg/TOC ratios of ~600 ppb/% occur in the lower part of the *sedgwickii* Biozone – the interval with marked Hg and TOC enrichment. Significantly higher Hg/TOC values exceeding 1400 ppb/% occur in the lower portion of the pale-colored shale interval.

The mercury isotopic composition of the samples shows different magnitudes for both mass-dependent ($\delta^{202}\text{Hg}$) and mass-independent ($\Delta^{199}\text{Hg}$) isotopic fractionation. The typical $\delta^{202}\text{Hg}$ range is between –0.19‰ and –1.17‰, with one sample having lower reading of –2.47‰. These values are within the range of both terrigenous organic matter and volcanic sources (e.g., Them et al., 2019). The magnitude of mass-independent fractionation is relatively smaller, with $\Delta^{199}\text{Hg}$ mostly within –0.01‰ and –0.11‰ and two samples having slightly positive $\Delta^{199}\text{Hg}$ values of +0.07 ‰ (lydite) and +0.09‰ (pale-colored shale). Nevertheless, all $\Delta^{199}\text{Hg}$ measurements in this study, including those for the Hg-rich intervals, are consistent with a volcanic Hg source (–0.1 to +0.1‰; Moynier et al., 2021).

Acknowledgements. This work is supported by the Bulgarian National Science Fund, contracts КП-06-ДВ/6 and КП-06-ПН 64/2.

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Tithonian “Paraflysch” above obducted ophiolites (East/Main Vardar) in Gjilan Area, SE Kosovo with reworked material from a carbonate platform to the west: are the ophiolites all the same and derive from the Neo-Tethys?

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The East Vardar Ophiolites and their provenance are still a matter of controversial discussion. Most authors place these ophiolites east of a proposed Sava suture zone. To provide new data for the discussion, we studied a series of units north of Parallova village, Gjilan area (SE Kosovo), where two different tectonic units could be distinguished.

The lower unit consists of metamorphosed Late Triassic–Jurassic carbonates. The succession starts with shallow-water open-lagoonal Dachstein carbonates overlain by reefal to fore-reefal limestones, followed by non-recrystallized shallow-water limestones with well-preserved microfacies, and Early Jurassic limestones. The identified microfacies correspond to transitional facies between the Lithiotis Carbonate Ramp and the drowned Dachstein Carbonate Platform. This metamorphosed succession shows similarities to the Pelagonia domain of the Hellenides.

The upper unit consists of non-metamorphosed ophiolites with ophiolitic mélanges at the base, comprising an OM3-type mélange overlain by an OM2-type mélange, and an overlying Tithonian overstep sequence. The ophiolitic unit is relatively thin compared to other ophiolite units in the Dinarides–Albanides–Hellenides, indicating deep erosion. This sequence begins with a basal conglomerate that locally contains metre-sized blocks of recrystallized shallow-water carbonates and fills depressions of the erosional unconformity. Upsection, carbonate beds contain shallow-water bioclastic material derived from a carbonate platform margin and platform interior comparable to the Kurbnesh Carbonate Platform. The carbonate clasts yield a rich microfossil assemblage including *Mohlerina basiliensis*, *Neokilianina rahonensis* and *Labyrinthina mirabilis*, indicating a Kimmeridgian–Tithonian age. The succession continues upward into turbiditic deposits showing a fining-upward trend and ultimately passes into organic-rich marls of probable Berriasian–Valanginian age.

The overlying succession resembles the Tithonian/Berriasian–Valanginian Firza Formation in Albania, sealing the obducted ophiolites and contains reworked reefal material derived from the Kurbnesh Carbonate Platform. In the so-called East Vardar zone, this succession corresponds to the “Paraflysch sequence” and shows close similarities to successions known from the Axios Zone and the Vardar Gorge in Macedonia, deposited above the eastward downgliding ophiolites during Tithonian and younger uplift and unroofing. The succession records post-obduction uplift, erosion, and progressive basin deepening. Continued unroofing is reflected by the fining-upward trend of the turbiditic succession.

Integrated biostratigraphy and sedimentology of the Paleogene–Neogene deposits from Bârsana (Maramureş, northern Romania)

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The Bârsana section, located near the Bârsana Monastery (Maramureş, northern Romania), represents one of the best-exposed successions of the uppermost Paleogene Strâmtura Formation of the Petrova Nappe, overlain by Badenian deposits, similar to those of the Transylvanian Basin. The focus of this study is a high-resolution biostratigraphic investigation of calcareous nannofossils and foraminifera, integrated with detailed sedimentological observations. Previous studies of the area were recently published by Aroldi et al. (2025) and Chira et al. (2025). Building on these investigations, we refine the calcareous nannoplankton biostratigraphy and integrate calcareous nannofossil and foraminiferal assemblages with sedimentological data in order to improve the biostratigraphic and sedimentological framework.

The lower part of the investigated section is composed of the Strâmtura Formation, which conformably overlies the Petrova Formation and represents the uppermost unit of the Petrova Nappe, an east-verging tectonic unit bounded to the south by the Bogdan Vodă Fault System. The formation consists of thick, amalgamated turbiditic sandstone beds interbedded with thinner pelitic intervals. Sandstone beds display sharp basal contacts and are either massive or normally graded, while thinner beds locally preserve Bouma-type sedimentary structures. Facies analysis indicates deposition from high-density turbidity currents in a relatively proximal setting, most likely corresponding to a mid-fan lobe environment. The succession is tectonically deformed, with chevron folds and fault slickensides affecting the Paleogene deposits. In the lower part of the outcrop, the analysed samples from Strâmtura Formation yield a low-diversity calcareous nannoplankton assemblage dominated by *Reticulofenestra minuta*, *R. reticulata*, *R. dictyoda*, *Coccolithus eopelagicus* and *C. pelagicus*, suggesting a late Priabonian–?Oligocene age.

The Petrova Nappe is unconformably overlain in the upper part of the succession by Badenian (Middle Miocene) deposits, similar to the Dej Tuff Formation of the Transylvanian Basin. These deposits yield calcareous nannoplankton assemblages assigned to the NN5 (*Sphenolithus heteromorphus*) and NN6 (*Discoaster exilis*) biozones.

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The Lower Permian red beds of Sirinia Basin, South Carpathians

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The Sirinia Basin, also known as the Svinița-Svinecea Mare sedimentary zone, belongs to the Upper (Internal) Danubian Units of the South Carpathians, including Palaeozoic, Mesozoic and Cenozoic sedimentary formations. The Palaeozoic formations represent a Variscan molasse, developed in intra-mountainous settings, unconformably overlying the metamorphic basement (Răileanu, 1953; Stănoiu and Stan, 1986; Seghedi, A. et al., 2001; Seghedi, I., 2010). The Variscan molasse of the Sirinia Basin include the terrestrial, coal bearing Cucuiova Formation (Upper Carboniferous, Westphalian A -Stephanian), the Povalina Formation (Lower Permian, Autunian) and the Trescovăț Formation (Lower Permian, post-Autunian). The Povalina Formation is represented by: a. the Staricica Member with mudstones, red beds, lacustrine limestones, sandstones and conglomerates, unconformably overlying the Carboniferous Cucuiova Formation, and b. the Ielișova Member siliciclastics.

The study focuses on the Permian red beds rich in terrestrial plant roots from the Staricica Member of the Povalina Formation, outcropped close to Starișteea (also known as Staricica, Staricea) Valley, in an area preliminary studied by Nuțu-Dragomir (2017).

The studied red beds contain centimetric-to-decimetric layers of conglomerates and sandstones interbedded with fine-grained reddish deposits, with lenses of lacustrine limestones. The coarser-grained layers display lenticular and tabular geometries in the channel infillings.

The palaeosols are rich in rhizoliths, carbonate nodules, and small ferricrete crusts and nodules. The most significant structures are fossilized roots. The root traces (rhizoliths and molds of root pathways) are centimetric to decimetric in size and they are arranged obliquely and vertically within the red beds (palaeosols). These palaeosols are interbedded with alluvial-fluvial channels (Săsăran et al., 2023). The lower boundary of the channels is erosional, while the upper boundary is gradational or sharp. Within the channel fills, erosionally stacked coarse-grained deposits (conglomerates) produced by debris flows (torrential flows) characterized by subangular to rounded clast shapes (Săsăran et al., 2023). The pebbles consist of fragments of metamorphic rocks (mica schists and quartzites) as well as magmatic rocks (rhyolites and basalts). Horizontal parallel laminations and trough cross-beddings are also recognized within the sandy deposits of the channels. Crevasse splay channels also occur interbedded with the palaeosols, with a weakly developed erosional lower boundary and a silty-sandy fill. The lacustrine/palustrine limestones are micritic and contain peloids, bioclasts (small sized gastropods, ostracods, charophytes), and fragments of organic matter. Based on the morphologies of the sedimentary bodies and the sedimentary structures found in these Permian deposits, it can be stated that these deposits accumulated in an alluvial-fluvial environment. In the interchannel zones, soils colonized by terrestrial plants developed, while the depressed zones could have provide favorable conditions for lacustrine/palustrine limestone deposition.

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New biostratigraphic and microfacies data on the Lower Devonian siliceous-carbonate sequence of Vrabcha Formation near the village of Mureno (Morava Unit, SW Bulgaria)

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The upper Silurian–Lower Devonian carbonate sequence from the Morava tectonic unit in southwestern Bulgaria has been referred by Spassov (1973) to the Vrabcha Formation. The latter consists of graptolitic shales, variably clayey limestones, and cherts. These deposits occur in allochthonous position and have been affected by both Varisian and Alpine tectonic events.

The biostratigraphy of the unit has been studied by Spassov (1973), Boncheva (1987; 1991), Sachanski (1996), and Boncheva *et al.* (2007) in several sections near the villages of Gorna Vrabcha and Mureno. The only facial data concerning the Vrabcha Fm. deposits have been also published by Boncheva *et al.* (2007).

This study presents new biostratigraphic and microfacies data on the Lower Devonian deposits of Vrabcha Fm. outcropped western of the Mureno village. A review of the Bulgarian geological literature shows that this locality has not been investigated so far. The succession is represented by deformed in centimetre-scale folds dark gray to black cherts and clayey limestones, passing into light grey clayey tentaculitic limestones.

Under the microscope, four microfacies types are distinguished and described: MFT 1: *Styliolina* packstone/grainstone, MFT 2: recrystallized bioclastic-peloidal packstone/grainstone, MFT 3: *Nowakia* floatstone and MFT 4: radiolarian chert. They are interpreted as formed in open-marine deep water and basin depositional environments.

Despite the poor preservation of the paleontological material, the biostratigraphic analysis clearly proved the presence of the index species *Nowakia acuaria* (Richter, 1845). The latter is found together with specimens from the genus *Styliolina* Karpinskij, 1884. This specific tentaculitic association was described by Bouček (1964), who reported that the first representatives of the genus *Styliolina* appeared exactly during the Pragian stage. The co-occurrence of the two taxa, especially the index species *N. acuaria* (Richter, 1845), gives us a reason to determine the age of the studied sediments as Pragian (Early Devonian). The registered fossil association and microfacies allow a direct correlation of the new outcrop near the village of Mureno with the studied by Boncheva *et al.* (2007) Gorna Vrabcha 3 section.

Acknowledgements. The Bulgarian National Science Fund of the Ministry of Education and Science, Grant KP-06-N84/1, supported this study.

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Jurassic–Early Cretaceous evolution of the easternmost Alpine–Atlantic realm: facies and biostratigraphic record from the Serbian Carpathians

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The Jurassic–Early Cretaceous successions of the Danubian Unit in the Carpatho-Balkanides, studied in three structurally superposed sections in the Danube River valley (Djerić et al. 2026), record the evolution of the southern passive margin of the Alpine Atlantic domain. Integrated sedimentological, biostratigraphic and chemostratigraphic constraints document an evolutionary progression from Early-to-early Middle Jurassic syn-rift extension and subsidence, through Bajocian–Oxfordian tectonic quiescence, to the late Oxfordian–Kimmeridgian onset of a Štramberk-type carbonate platform. The Lower Jurassic–Bajocian interval records a continental to shallow-marine transgression linked to early rifting of the easternmost Alpine Atlantic domain. Continental break-up and syn-rift differential subsidence led to the establishment of a horst-and-graben system marked by condensed Rosso Ammonitico deposition on structural highs and accumulation of thick radiolaritic basinal successions. Bajocian–Oxfordian tectonic quiescence was followed by the late Oxfordian–Kimmeridgian development of Štramberk-type carbonate platforms that prograded basinward until the early Late Tithonian. Calcareous turbidites reached proximal basinal settings during the late Oxfordian, whereas distal areas remained carbonate-starved until the Tithonian, when episodic platform-derived mass-transport deposits were transported into the basin. During the Berriasian–Valanginian, Biancone-type hemipelagic limestones blanketed the entire region, reflecting the stabilization of outer-shelf to basinal conditions across the former horst-and-graben topography.

Regional correlation with coeval successions in Romania (Southern Carpathians), Tisza, the Western Carpathians, the Southern and Eastern Alps, and the Apennines demonstrates the coherence of the Danubian Unit as part of the southern Alpine Atlantic passive margin, refining existing Mesozoic palaeogeographic interpretations of the Alpine–Carpathian realm.

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New occurrence of Upper Jurassic limestones in the Padiş Karst Plateau (Bihor Mountains). Microfacies and Biostratigraphy.

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The Upper Jurassic carbonate deposits in the central part of the Bihor Unit (Bihor Mountains), unlike those in the Pădurea Craiului Mountains which have been extensively studied in recent years (e.g., Bucur & Cociuba, 1996; Cociuba, 2000; Bucur et al., 2010, among others), remain poorly understood from both sedimentological and microfacies perspectives. This limited knowledge is largely due to the scarcity of suitable outcrops, particularly on the Padiş Karst Plateau, as well as to the fact that the few existing exposures are strongly affected by contact metamorphism induced by nearby Cenozoic igneous bodies (Bleahu, 1975). In addition, the morphology of the area, characterized by steep slopes and vertical walls, makes the accessible outcrops difficult to sample.

Taking these considerations into account, the main objective of this study is to describe and interpret a previously undocumented carbonate succession in the western part of the Padiş Karst Plateau. Our work focuses on analyzing the dominant microfacies types and observe their sedimentological characteristics, as well as identifying the associated micropaleontological assemblages. These data will allow us to determine the age of the deposits and interpret their depositional settings, ultimately enabling us to place our results within a broader regional geological context.

Following the preliminary analysis of our data, we separated three dominant microfacies types: MFT1 - fractured mudstone (partly exhibiting fenestral fabric), containing rare peloids and mollusk shell fragments; MFT2 – fine peloidal-bioclastic grainstone with rare algal fragments and small benthic foraminifers; MFT3 – bioclastic-peloidal wackestone/packstone with benthic foraminifers and well preserved green algae and gastropods. These microfacies types indicate subtidal (MFT2-3) and intertidal (MFT1) depositional environments, corresponding to the internal areas (lagoon) of a carbonate platform (cf. Flügel, 2010). Concerning the micropaleontological assemblage, diversity is limited, but several levels (MFT2–3) are remarkable for their abundance of well-preserved green algae (*Aloisalthella sulcata*) and larger benthic foraminifers (*Parurgonina caelinensis*, *Neokilianina rahonensis*, *Redmondoides lugeoni*, etc.). These taxa indicate that the studied deposits are Late Jurassic in age, developed between the Kimmeridgian and early Tithonian.

The studied area can be correlated, based on all its sedimentological features, with what is known as the Secătura Member from the Albioara Formation (cf. Cociuba, 2000) of the Bihor Unit, a typical inner-platform formation that crops out extensively within the Pădurea Craiului Mountains.

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Preserved against the odds: shallow-marine mass-transport deposits (MTDs) from the Eocene of Croatia

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Mass-transport deposits (MTDs) result from gravity-driven resedimentation processes and are typically best preserved in deep-marine environments, where erosion and sediment reworking are limited or negligible. In contrast, shallow-marine settings are typically considered unfavourable for the preservation of such features due to intense wave activity, bioturbation, and erosion. Here we present several types of MTDs that are interbedded within shallow-marine Eocene deposits exposed near the town of Novigrad in northern Dalmatia (Croatia), representing an unusual and noteworthy geological phenomenon.

The studied succession is approximately 600 m thick and comprises calciclastic sediments deposited in the Novigrad piggyback basin that developed within the wedge-top depozone of the North Dalmatian foreland basin during uplift of the Dinarides (Gobo *et al.*, 2024). Sedimentation occurred across a range of coastal to shallow-marine environments. The identified MTDs range from 13 cm to 6 m in thickness and include slumps, slump-debrites, rockfall deposits, and debrites deposited from debris flows of variable competence. Most of them occur in association with well-bedded offshore and offshore-transition facies, indicating sediment failures above the storm wave base and relatively short transport distance.

Sediment destabilization was likely triggered by several interacting factors, including: (i) synsedimentary earthquakes related to basin tectonics, (ii) elevated pore-water pressure within unconsolidated sediment, and (iii) wave loading during storm events. The sedimentary succession is further characterized by numerous transgressive–regressive cycles reflecting relative sea-level fluctuations. The MTDs occur predominantly within regressive intervals, suggesting deposition under relatively shallow-water conditions, where wave-induced stress on the seabed and reduced hydrostatic pressure enhanced slope instability. The gravel fraction of these MTDs contains extra-formational clasts ranging in age from the Cretaceous to the late Eocene, suggesting multiple phases of erosion and redeposition.

Although relatively small in size, the studied MTDs display distinctive and peculiar sedimentological characteristics rarely documented in shallow-marine settings. Their preservation challenges conventional models that restrict MTDs primarily to deep-water environments and highlights the complex interplay of tectonics, storms and sea-level fluctuations in controlling sediment remobilization within evolving foreland basins.

Acknowledgements.

We thank our late colleague Ervin Mrinjek for his work, knowledge of the area, and invaluable contribution to this research.

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Mineralogical considerations on the Upper Cretaceous matrix of a unique assemblage of ammonites from the Babadag Basin (Romania)

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This preliminary study presents paleontological and mineralogical analyses of the Upper Cretaceous ammonite deposits in the Babadag Basin (Dobrogea, Romania). The thickness of the Cretaceous deposits varies between 1600 and 200 m and they overlay older Proterozoic, Paleozoic, Triassic and Jurassic sedimentary formations, with the existence of some stratigraphic condensation zones in the eastern part of the basin assumed by some authors.

In the Cretaceous evolution of the Babadag Basin, two transgressive episodes are marked, one in the late Albian – Cenomanian period represented lithologically by the predominantly detrital-carbonate Iancila Formation and another in the Turonian – Coniacian, lithological represented by the marly-calcareous Dolojman Formation. In the composition of the two formations, several members of different ages or facies were separated. Ammonites occur in the upper part of the Dolojman Formation.

Several ammonite specimens with a diameter greater than 40 cm were collected from the Coniacian strata that appear today in the Jurilovca quarry. Ammonites belong to the Family Puzosiidae and some are large and well preserved (the whole living chamber); on the living chamber they preserves strong ribbing which became more and more projected on the ventral side, as special features. From the observations so far, the level of ammonite marls lies above a level rich in Zoophycos. The ammonite layer appears to contain a high concentration of large specimens, a situation similar to that described in Westphalia at the Cenomanian level, marked as an anoxic event. Brownish - brown nodules with a botryoidal appearance can be observed here and there on the ammonite specimens.

X-ray powder diffraction highlighted the presence of very poorly crystallized mineral phases in which iron oxides predominate. The peaks of goethite can be determined with difficulty. The oxide-ferric content was also attested by SEM analysis. The presence of small barite crystals, in small proportions, is noteworthy. The mineralogical composition of the nodules may suggest the existence, at some point in the evolution of the ammonites, of an oxygen-rich environment, with a relatively shallow depth in which the ammonites were a “support” for the precipitation of secondary minerals such as goethite. XRD analysis of the calcareous formations from which the ammonites were collected indicates the presence of calcite in a proportion of over 90% and quartz (approximately 7%), to which are added clay minerals.

Acknowledgements. This work contributes to projects PN 23-39-03-01, 23-39-01-01, PN23-39-02-01 and PN23-39-02-06 — Contract no. 34N/2023, funded by the Romanian Ministry of Education and Research.

The Late Triassic sedimentary evolution of the carbonate sequence from Merișor Hill (Codru-Moma Mountains, Romania)

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The southwestern flank of Merișor Hill (Vașcău Plateau, Codru-Moma Mountains) offers a unique opportunity to examine the depositional patterns, sedimentary features, and compositional characteristics of an Upper Triassic carbonate succession formed during the late Carnian to early Norian. These carbonates have traditionally been assigned to an undifferentiated Carnian–Rhaetian thick reefal limestone sequence (Bleahu et al., 1979), which should belong to the Colești Nappe (Panin et al., 1980), the believed uppermost unit of the Codru Nappe System. It is noteworthy that the last study that included the carbonate deposits of Merișor Hill was carried out nearly one hundred years ago by Kutassy (1928). Consequently, the microfacies, microfossil assemblages, and the integration of this section into the broader evolution of the Late Triassic Neo-Tethyan carbonate factories remain essentially unknown.

Based on our new outcrop observations, biostratigraphic age dating, and microfacies analyses, we reconstruct the sedimentary evolution of the carbonate sequence at Merișor Hill, with particular emphasis on the key events (such as cyclicity, exposure phases, and drowning episodes) that influenced its overall development throughout the Late Triassic. The conodont assemblages, supported by other paleontological groups such as halobiid bivalves and encrusting microorganisms, indicate a sedimentary evolution ranging from the late Carnian (Tuvalian) to the early Norian (Lacian 2).

Starting in the Tuvalian, the studied succession displays a roughly 140-meter-thick cyclic depositional pattern that allow us to distinguish four thick-bedded, fore-reefal, small-order carbonate cycles, three of the them in the late Carnian, and one in the early Norian. In the late Carnian, as indicated by the depositional textures of their main components, each of these reef-influenced cycles is characterized by a shallowing-up trend, followed by karstification features and breccia formation toward their uppermost part, and subsequently by a drowning phase marked by the deposition of dm-thick pelagic carbonate levels containing fine-grained turbiditic material. The demise of the last Tuvalian cycle records the Carnian/Norian boundary and is marked by the appearance of *Halobia austriaca* lumachelles, the FAD of *Norigondolella navicula* as well as by the deposition of deeper-marine carbonate levels containing ammonoids. These bivalve agglomerations formed after the subsequent drowning of this final reef-influenced cycle, accumulating within small depressions that most likely developed on the inherited erosional topography associated with the demise of the third cycle. Above the *Halobia* lumachels, a twenty-meter-thick sequence of coarse-grained carbonates with reef debris that contain Lacian conodonts are developed next in succession, followed by the appearance of another *Halobia* lumachelle (*Halobia styriaca*). Above this level, massive Dachstein reef limestones are developing containing various reef dwellers (mainly encrusting microorganisms) and coral fragments, indicating the first cycle of the Dachstein Carbonate Platform.

Overall, based on our new data, the Tuvalian part of the carbonate succession at Merișor Hill represents a previously undocumented, cyclically developed transitional Late Triassic facies that resembles a carbonate ramp affinity, formed after the demise of the Wetterstein Carbonate Platform and before the onset of the Dachstein Carbonate Platform. It represents most likely a forerunner of the emergence of the early Norian Dachstein reef cycle (Zöhrer et al., 2026).

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Application of XRF geochemical logging of geological samples for correlation between field sections and oil&gas exploration wells drilled in Outer Carpathians (Poland)

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Geological research in the Carpathians has been ongoing for centuries. This gained momentum in the mid-19th century when oil and natural gas fields were discovered in three regions of the Outer Carpathians (Poland, Ukraine and Romania). The first oil well in Poland was drilled in the Gorlice area in 1852. Until the 1950s, hydrocarbon exploration relied primarily on basic surface geological methods such as geological mapping, tectonic studies, and analyzing the distribution of hydrocarbon seeps on the surface. The main sources of geological information from boreholes were core samples and drill cuttings collected while drilling. From the 1950s onwards, the development of downhole and seismic geophysical methods, as well as gas chromatography, gradually began to replace basic geological surveys. Over the last 40 years, well logging, petrophysics and seismic surveys have become the dominant methods in hydrocarbon exploration, largely marginalizing field geological surveys and the description of geological samples collected while drilling. This is mainly due to the subjective nature of geological descriptions and stratigraphic classifications, and the intangible nature of geological data, which makes it incompatible with geophysical data.

Technological advances and the miniaturization of X-ray fluorescence spectrometers over the past 15 years, coupled with their increased availability, have paved the way for the large-scale digitization of geological samples collected from boreholes. The widespread occurrence of rock outcrops in thrust belt areas has also enabled sedimentary successions logging, allowing these sequences to be digitized. This has led to the creation of detailed field reference sections for exploration wells.

In order to bring back the value of geological samples in oil&gas exploration projects, large-scale fieldwork focusing on the sedimentary sequence of the Silesian Unit has been conducted in the Outer Carpathians between 2018 and 2023. Over 3500 field samples representing the Early Cretaceous to Late Oligocene sedimentary sequence with a cumulative true stratigraphic thickness (TST) of over 6000 meters have been collected. Field works targeted field sections with the least tectonic engagement. To provide additional tectonic and TST control, LIDAR images, dip measurements, and GPS/GPRS measurements were applied. As a result of the fieldwork, a generalized synthetic sedimentological section of the Silesian Unit has been established. The stratigraphic control of the field section was based on lithostratigraphic, biostratigraphic, and chemostratigraphic methods. To enable field-to-well correlation, drill cuttings were obtained from two archival oil wells (Pola-2, Pola-3), drilled in the Gorlice area between 2009 and 2010.

Digitization of geological samples was conducted using geochemical analysis, which included XRF analysis supported by XRD and TOC analyses. The geochemical datasets were used to perform mineralogical and lithological modelling, delivering synthetic gamma ray, grain density and synthetic interval velocity logs.

The obtained large-scale digital datasets enabled the identification of the geochemical fingerprints of the lithostratigraphic units of the Silesian Unit and the running of field-to-well correlations. The collected data can be used as a reference for seismic interpretation and petrophysical formation evaluation, and can establish high-quality stratigraphic control over oil and gas and geothermal wells drilled in the Outer Carpathians thrust belt.

Statistical distribution of holes in holy stones (Hühnergötter)

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Holy stones (hag stones, adderstones, Hühnergötter) are stones with naturally occurring holes, believed to have magical powers that occupy an important place in the folklore of Baltic peoples, but their genetic classification and topological form is almost ignored in petrology.

Our study of holy stones involved two populations, the one consisting of prominent examples featuring in illustrated literature, or typical specimens exhibited in museums and public places. The other group consisted of accessible specimens found in a number of collections, allowing precise measurements and systematic comparisons.

The material composition of 647 holy stones is as follows: flint 603 (93%), quartzite 22 (3%), limestone 7 (1%), volcanics 5 (1%), sandstone 5 (1%), other 5 (1%).

It is generally assumed that pure mechanical erosion will never produce holy stones, so their form is due to a combination of a pre-existing inhomogeneity, chemical weathering and mechanical erosion.

The holes in flint and limestone holy stones are biogenic, originating either as concretions, or surviving hollows in fossil structures. In (meta) quartzite the hole is the void left by chemical erosion of a needle like mineral shaped during metamorphosis. In volcanics the hole probably originated as a fluid filled void (bubble). In the „other” category we find examples of rare rock types, including a meteorite.

Size distribution of holy stones was studied for finding the contribution of genetic classes to differences of shape and to such parameters as the mean weight, axis lengths and ratios. Two ratio parameters are particularly important for characterisation: the c/a projection sphericity and the h/b hole diameter ratio. Size related parameters follow lognormal distribution, ratio parameters are normally distributed, as expected.

Topology of holy stones is studied by counting the holes i.e. classifying by topological genus. Distribution by genus is as follows: G1 (1 hole) 75%, G2 (2 holes) 17%, G3 (3 holes) 6 %, G4-G7 (4 or more holes) 2%. Statistical tests were carried out to decide if these topological classes are independent.

As a null hypothesis it was assumed that the number of holes in holy stones follows the zero-truncated-Poisson (ZTP) distribution law. On the basis of statistical tests this hypothesis was rejected.

A separate study found the overall frequency of holy stones to be about 0.2 % in flint gravel, which is the most prolific source of holy stones. This also indicates that the distribution is *zero-inflated negative binomial* (Pascal) distribution.

Acknowledgements. I would like to thank to Andrea and Gerhard Rosche and their family in Rostock/Stralsund, to Dr. David Lawrence and to Dr. Istvan Viczian for allowing access to their collections.

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Revision of the Triassic evolution of the Bükk Mts. (northeast Hungary)

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South Alpine – Dinaric affinities of the Bükk Mts. (northeast Hungary) were noted already in the 1930s. Although large part of the area is built up by Triassic successions, it is difficult to get a detailed picture of the Triassic tectonostratigraphy and paleogeographic relations of the area as biostratigraphic data remain scarce due to the metamorphic overprint of the rocks. Triassic lithostratigraphic tables of the Bükk Mts. follow the historical intraplateau basin model with continuous platforms and long-lived basins between them. Placing the area in the broader region is still a challenge as the Bükk seemingly shows a geodynamic evolution markedly different from the rest of the Western Tethys Realm.

The aim of our research was to refine the age of Triassic formations and clarify the Middle and Late Triassic tectonostratigraphic development of the area based on conodont biostratigraphy. Positive conodont samples are predominantly located in the Southern Bükk. The color of the conodont elements is black to grey (CAI values 5.5 to 6).

Conodont data enabled the establishment of four facies belts in the Southern Bükk. The southern part of Hór Valley is represented by lower Carnian (Julian 1) shallow-water limestone, which correspond to the Wetterstein platform evolution. Directly overlying open-marine rocks yielded an upper Carnian (Tuvalian 2) conodont assemblage, revealing a long gap between the platform carbonate and the flooding surface. Lower and Middle Norian conodonts prove continuous basin development over the Wetterstein platform. The northern part of Hór Valley shows deep-water evolution from the Ladinian to the late Norian (Sevatian) with volcanic activity in the late Carnian (Tuvalian 2/3). The “Mid-Carnian” gap is realized also in this basinal succession. The area east of Felsőtárkány is characterized by a carbonate ramp in the Anisian, which is overlain by volcanoclastic sediments of Late Anisian (Illyrian) age. These are followed by the development of a basinal sequence from the Anisian–Ladinian boundary interval up to the Rhaetian. The Carnian gap and the upper Carnian vulcanite is present also in this facies belt. A breccia level is observed in the Sevatian. In the westernmost facies zone (north of Eger) the Wetterstein platform is overlain, after the gap, by Tuvalian open-marine sediments. This is followed by upper Tuvalian shallow-water limestones, which were flooded in the latest Tuvalian. The Dachstein platform evolution started in the earliest Norian and the drowning of the platform is recorded in the latest Sevatian, around the Norian–Rhaetian boundary.

Our new biostratigraphic data do not confirm continuous platform evolution and the existence of coeval intraplateau basins during the Triassic in the Bükk Mts. Rather, the separate evolution of the Wetterstein and Dachstein Carbonate Platforms could be proven. The recognition of the “Mid-Carnian” gap, as well as the documentation of four facies zones enables a better correlation of the Bükk with the Triassic of the Dinarides.

Acknowledgements. The research was funded by the Bolyai János Research Grant of the Hungarian Academy of Sciences, the National Research, Development and Innovation Office of Hungary (NKFIH STARTING 149443 grant).

Triassic Hallstatt exotic blocks in the Avdella and Koziakas mélanges (Hellenides): Provenance and geodynamic implications for Neo-Tethyan ophiolite emplacement

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Jurassic sedimentary mélanges beneath Neo-Tethys ophiolites, traceable across the Alpine-Dinaridic-Hellenide orogenic belt, constitute chaotic tectono-sedimentary archives preserving exotic blocks that record the evolution of the former passive continental margin and the opening and closure of Neo-Tethys Ocean. We provide conodont biostratigraphic data from carbonate exotic blocks of the Avdella and Koziakas mélanges in Greece, integrated with regional structural observations, to address the ongoing debate regarding the Pindos ophiolite provenance and Pindos Unit. These mélanges are characterized by a Middle to early Late Jurassic argillaceous-radiolaritic matrix containing, in addition to open-marine carbonate blocks, ophiolitic detritus, Triassic radiolarites, and younger shallow-water carbonate material. Conodonts extracted from open-marine carbonate exotic blocks yield ages spanning the latest Ladinian–earliest Carnian, late Carnian, and Norian, while lithological and microfacies characteristics allow a precise correlation with coeval Hallstatt Limestone facies originally deposited along the western outer shelf domain of Neo-Tethys Ocean from the middle Anisian to Rhaetian. Structural observations, including NW-SE trending asymmetric tight to sub-isoclinal folds and ductile to semi-ductile shear zones, consistently indicate a west- to southwest-directed sense of shear related to Middle to early Late Jurassic obduction of the Pindos and related ophiolites, locally overprinted by younger post-obduction deformation. The Avdella and Koziakas mélanges are thus interpreted to have formed ahead of the westward-advancing ophiolite nappe stack during Middle to early Late Jurassic obduction of the Neo-Tethys oceanic floor, a process that progressively disrupted the architecture of its passive continental margin. Initially, trench-like deep-water basins developed in front of the advancing nappe stack, receiving material from the obducting ophiolites and their associated radiolaritic cover, and from the former passive margin, including Hallstatt Limestone facies. Subsequently, progressive shortening and shearing led to the incorporation of these basin fills into the nappe stack, producing the characteristic block-in-matrix fabric of the mélanges. Correlation of the Hallstatt exotic blocks within the Avdella and Koziakas mélanges with the complete Middle to Late Triassic open-marine succession of the Pindos Unit identifies the latter as their paleogeographic source (Kostaki *et al.*, 2024). West- to southwest-directed sense of movement recorded within the mélanges suggests that the Middle to Late Triassic open-marine Pindos succession, reflecting Hallstatt Limestone facies, was originally part of the Middle Jurassic advancing nappe stack. Forming an integral part of the passive continental margin developed east of Pelagonia and facing Neo-Tethys Ocean, this succession was subsequently bulldozed and transported westward onto the foreland by the obducted Neo-Tethys ophiolites shedding material into the mélanges. Our results are consistent with a well-arranged western passive continental margin of the Neo-Tethys Ocean, with comparable evidence across the Alpine-Dinaridic-Hellenide orogenic belt, supporting a coherent geodynamic model characterized by a single Neo-Tethys Ocean and predominantly west- to southwest-directed ophiolite obduction, without the existence of an autonomous Pindos Ocean or a Triassic–Jurassic basin.

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Diversity of turbidite architecture of Lhoty Formation (Albian–middle Cenomanian) recorded in Kozy quarry (Carpathians, Silesian Nappe, Poland)

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The Lhoty Formation (300–450 m thick) represents an extensive turbidite system infilling the proto–Silesian Basin (Severin-Moldavidic Basin *sensu* Ślącza et al., 2006), a component of the Outer Carpathians. It records sedimentation during the extensional stage of basin development in the Albian–middle Cenomanian. In Poland, the formation is exposed within the Silesian and Subsilesian nappes and is subdivided into three units (Ślącza et al., 2006): (1) Lower Lhoty Beds (up to 80 m), locally developed, composed mainly of thick-bedded conglomerates and coarse-grained sandstones; (2) Middle Lhoty Beds, the most widespread unit, dominated by thin- to medium-bedded sandstones interbedded with non-calcareous dark grey to black and greenish-grey mudstones; and (3) Upper Lhoty Beds (up to 50 m), consisting of thin- to medium-bedded cherts and sandstones with spongiolite intercalations (Mikuszowice Chert Member). In the northern Silesian Nappe and in the Subsilesian Nappe, the Upper Lhoty Beds are partly or entirely replaced by the Gaize Beds, composed of thick-bedded siliceous sandstones with spongiolites.

The studied section is located in the Kozy Quarry (~7 km east of Bielsko-Biała), within the western Silesian Nappe, where an almost complete, gently dipping succession of the Lhoty Formation is exposed, overlying the Veřovice Formation (Aptian–Albian). The Lower Lhoty Beds are absent, and the analyzed interval corresponds to the Middle Lhoty Beds. Quarry walls reach ~20–60 m in height and extend laterally for over 150 m, offering exceptional three-dimensional exposure.

The succession is dominated by thin- and medium-bedded sandstones interbedded with dark grey, black, and greenish mudstones. Locally, thicker sandstone beds, occasionally conglomeratic, occur. Some beds display irregular basal and/or upper surfaces. Drone-based photogrammetry enabled analysis of bed morphology and lateral facies variability, complemented by detailed sedimentological logging. Facies variability is comparable to the nine facies identified in the Zagórník-Rzyki section (~15 km east; Łapcik, 2023), although the larger exposure scale provides enhanced insight into spatial heterogeneity. In addition to classical turbidites and hemipelagic deposits, banded sandstones and structured sandstone-mudstone (heterolithic deposits) are common, representing transitional flow deposits (Stevenson et al., 2020; Łapcik, 2023). The succession also exhibits frequent erosion and amalgamation surfaces, loading-related deformation, lag deposits, and abrupt bed-thickness changes. These features indicate relatively proximal depositional conditions with unsteady and supercritical flows, despite the high mud-to-sand ratio and predominance of thin-bedded strata.

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Microfacies and mineralogy of the Deșli Caira carbonate succession across the Olenekian-Anisian Boundary (North Dobrogea Orogen, Romania)

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The Deșli Caira (North Dobrogea Orogen, south-eastern Romania) is one of the few continuous sections in the world which corresponds to the late Spathian – early Aegean stratigraphic interval and is a candidate for the GSSP of the Anisian base.

The present study documents the main facies and microfacies types, the mineralogical data and infer the depositional paleoenvironment of these carbonate deposits across the Olenekian-Anisian Boundary.

Three detailed lithostratigraphic logs (B1-B3) and field observations focused on lithology, sedimentary structures, fossil content and taphonomic features were performed. Samples were collected at meter to centimetre scale resolution and 80 polished surfaces and 430 thin sections were prepared for microfacies and mineralogical analyses.

The carbonate sequence from Deșli Caira section B1 is 39 meters thick and consists of Hallstatt-type carbonates, represented by alternance of centimetre to decimetre-thick beds of light grey, pink to reddish limestones interbedded at few intervals with brick-red nodular marly limestones. These are composed of mudstone to wackestone and floatstone with several packstone intercalations. The wackestone to floatstone microfacies contain planktonic bivalves, ostracods, gastropods, crinoid ossicles, ammonoids, calcified radiolarians and rare benthic foraminifera. The matrix is micropeloidal and recrystallized. Bioclasts and complete shells are not bioeroded, do not show signs of peripheric micritisation and are not encrusted, suggesting rapid burial. The packstone intercalations consist of small planktonic bivalves microcoquina interpreted as current induced biogenes. The presence of ammonoids, rare brachiopods and peloids, suggests a deeper hemipelagic environment. Locally the sediment is weakly bioturbated. Some beds contain numerous ammonoids that are generally well preserved, and all exhibit consistent geopetal filling with the polarity of the bed. The pelagic micrite filling the phragmocones, is the same as the enclosing matrix (in all the beds), indicating that the infilling of the shells was produced rapidly on the substrate surface before burial.

Tentative X-ray diffraction screening was conducted on 14 samples selected from the lower, middle, and upper parts of section B1. Calcite was dominant in all samples, while quartz was present as low-intensity peaks. The XRD screening also revealed the presence of hematite in several samples from the lower part of the section. Chlorite and clay minerals (kaolinite and palygorskite) were the most common minerals found at all levels. Dolomite was also notable, occurring together with hematite and palygorskite in samples around the possible boundary. The presence of quartz together with clay minerals and chlorite is puzzling and may indicate either limited terrigenous input or aeolian input.

The Triassic Hallstatt-type limestones are generally known for their complex paleoenvironmental and diagenetic histories which document a slow burial and low sedimentation rates. However, there are particularly sections, as Deșli Caira, which do not reveal these features and no taphonomic or stratigraphic condensation across the Spathian-Aegean succession. The carbonate succession from Deșli Caira section was accumulated on open-marine pelagic environments, on pelagic to hemipelagic environments with unusual high rates of carbonate sedimentation.

Acknowledgements. This work was funded by the Research Institute of the University of Bucharest, project FDI 835/2023-2025 and by project PNRR i8 64/2003 PACE.

Foreland lower plate evolution under the influence of two compressional systems. Case study: Eastern Moesian Platform during Badenian – Early Sarmatian

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The foreland basins evolve under the orogen loading. Additional compressional stress with a different orientation has been observed in several areas, including in the Eastern Moesian Platform, Romania, where the two compressional systems are nearly perpendicular. The Moesian Platform is a tectonic mosaic composed of crustal blocks (e.g. Central and South Dobrogea) with contrasting rheological properties, separated by regional crustal Capidava – Ovidiu and Intra – Moesian Faults. The platform interacts with the North Dobrogea Orogen along the Peceneaga – Camena Fault. Its last stage of evolution, Miocene to present, overlies with the Carpathian foreland development and implies the presence of an intrabasinal sedimentary source associated with the forebulge migration, uplift and erosion. Adding a secondary NNE-SSW compressional stress impacted the forebulge position and evolution. These observations are derived from the interpretation of a large 3D seismic dataset, well data and outcrop observations. We propose a model describing the formation and infill of the deep canyons observed in the Eastern part of the Moesian Platform. The canyons are SSE-NNW oriented with up to 1000 m shelf- and slope- incisions. Badenian to Lower Sarmatian deposits represent the fill from Arcanu to Zavoia canyons, W to E, the latter being the deepest incised, in the vicinity of the Capidava – Ovidiu Fault. These canyons are diachronous relative to the Movila Miresii Canyon, east of the Bordei Verde High, with a Sarmatian – Meotian sedimentary fill. Although initiated in fluvial dominated environment probably during the Early Oligocene, we propose that the subsequent deepening to hundreds of meters, occurred in marine conditions triggered by marine density currents before Late Badenian. Integrating interpretation of seismic attributes with core descriptions, we derived gross depositional environment maps for seven depositional cycles within Badenian to Early Sarmatian sequence. During Badenian, the deep marine conditions are predominant with amalgamated channel belts and sedimentation confined to Zavoia Canyon for the oldest three depositional cycles identified, while the fourth cycle infills the smaller adjacent canyons as well. During Early Sarmatian, three depositional cycles have been documented: the first cycle had significant fault-controlled local deposition in Zavoia Canyon, the second cycle, is dominated by mixed clastic sequence, with oolitic shoals and tidal channels on the shelf and slope mudstones with local low-energy tidally reworked dunes. The third cycle, uppermost Lower Sarmatian is deposited in shallow marine conditions with oolitic shoals deposited in lagoons, in the south, to barrier reef at the shelf break and wackestone-mudstone on the slope, to the north.

Acknowledgements. This work was performed in 2021 – 2023 in a RioMar Consortium collaboration between HOCOR, University of Austin and OMV Petrom. We acknowledge the useful discussions with OMV Petrom colleagues: Roxana Duduș, Livia Popa, Isabela Mariș, Oana Dăscălescu, Mihai Rădoiaș. We thank Csaba Krézsek for agreeing to present this work. The study integrates the 2022 laboratory results from CGG Robertson.

Litological and biostratigraphic characteristic of the Cenomanian-Turonian deposits at the Ananuri section (eastern Georgia)

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The Late Cretaceous was characterized by high global sea levels and widespread carbonate sedimentation throughout the Tethyan realm. Calcareous nannoplankton and planktonic foraminifera played a major role in the formation of carbonate deposits, and their skeletal remains constitute the principal components of Upper Cretaceous limestones and marls (Kopaevich, 2024).

The Upper Cretaceous deposits of eastern Georgia are important for reconstructing the evolution of marine basins, changes in sedimentary environments, and associated biotic events (Gambashidze, 1981). The Ananuri section, located within the Mestia–Tianeti Zone of the southern slope of the Greater Caucasus (Gamkrelidze, 2015), is one of the most informative Upper Cretaceous sections in eastern Georgia. The section lies within the Aragvi River basin (Gambashidze, 1991), where natural exposures provide an almost continuous record of the Upper Cretaceous succession.

The aim of this study is to reconstruct lithological and biostratigraphic changes in the Cenomanian–Turonian succession of the Ananuri section and to interpret them in the context of the evolution of the northern Tethyan margin. The study is based on field investigations since 2010. Biostratigraphic interpretation is based on assemblages of planktonic foraminifera and calcareous nannoplankton, which were used to establish the biostratigraphy and reconstruct depositional environments.

The section begins with the terrigenous deposits of the Ukugmarti Formation (Gambashidze, 1979), represented by conglomerates, polymictic sandstones, marly shales, and marls. These deposits yield assemblages of planktonic foraminifera represented by *Muricohedbergella planispira*, *Microhedbergella rischi*, *Rotalipora cushmani*, *Thalmaninella appenninica*, *T. brotzeni*, *Planomalina buxtorfi*, and *Planomalina caseyi*. Among the calcareous nannoplankton, *Eiffellithus turriseiffelli* indicating, indicating an Early Cenomanian age for these deposits.

The overlying Ananuri Formation (Gambashidze, 1979) is characterized by the siliceous deposits, including an interval of black silicites. The lower part of the formation contains *Rotalipora cushmani*, *Thalmaninella greenhornensis*, and *Praeglobotruncana gibba*. Higher in the section, *Whiteinella brittonensis* and *Whiteinella archaeocretacea* appear, whereas the upper part is characterized by *Whiteinella baltica*, *Dicarinella imbricata*, *D. hagni*, and *Helvetoglobotruncana helvetica*. Benthic foraminifera are represented by few specimens.

The Ananuri Formation gradually passes upward into the red carbonate-siliceous deposits of the Margalitisklde Formation (Gambashidze, 1979). Its lower part contains *Marginotruncana lapparenti*, *Marginotruncana pseudolinneiana*, *Planoheterohelix moremani*, and *P. reussi*.

The middle part of the Margalitisklde Formation is characterized by the first appearance of *Dicarinella canaliculata*, *Marginotruncana renzi*, and *M. marginata*, whereas the upper part contains *Marginotruncana angusticarinata*, *M. sigali* and *Archaeoglobigerina cretacea*.

The observed lithological and micropalaeontological changes are consistent with current concepts of the Late Cenomanian–Turonian reorganization of marine ecosystems associated with Oceanic Anoxic Event 2 (OAE2) and the subsequent restoration of open-marine carbonate sedimentation. The distribution of planktonic foraminifera and calcareous nannoplankton reflects the evolution of the basin from Early Cenomanian terrigenous sedimentation to the development of siliceous deposits and the establishment of a Turonian pelagic carbonate basin.

The integrated lithological and micropalaeontological data demonstrate that the Ananuri section represents one of the most informative Upper Cretaceous sections in eastern Georgia for investigating the transition from the Cenomanian–Turonian Oceanic Anoxic Event (OAE2) to the post-anoxic stage of marine basin evolution.

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Microfacies and microfossils identified in the Upper Jurassic–Lower Cretaceous limestones of the Vălani Nappe (Bihor and Pădurea Craiului Mountains)

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The Vălani Nappe is located in the Northern Apuseni Mountains and it forms the basal unit of the Codru Nappe System. It is a cover nappe that shares similar characteristics with the Bihor Unit and the Finiș Nappe (Patrulius, 1971). The Upper Jurassic–Lower Cretaceous succession of the Bihor Unit and the Vălani Nappe share similar facies and depositional characteristics. On the other hand, the Upper Triassic of the Vălani Nappe contains Carpathian Keuper-type facies which are similar with equivalent deposits from the Finiș Nappe (Patrulius, 1971).

The Vălani Nappe forms extensive outcrops in the southern and south-western part of the Pădurea Craiului Mountains (Vălani, Căbești, Meziad) and the south-western part of the Bihor Mountains (Sighiștel Valley).

The studied areas are located in the south-western part of the Bihor Mountains, in the Sighiștel Valley basin, in the Bulzu Valley area, near Fânațe, and in the south-western part of the Pădurea Craiului Mountains (Meziad – Valea Șeasa, Valea Peșterii; Sitani – Valea Pietrii). Approximately 800 samples were collected from the following sections: Sodolu Prelucii, Sodolu Pietrii, Sighiștel Vale, Valea Frăsinesei, Sodolu Chifului A, Sodolu Chifului B, Sodolu Mare, Valea Laurului-Dealul Grohoților, Sodolu Măguri, Valea Șeasa, Valea Peșterii, Valea Pietrii. In terms of outcrop features, the studied limestones are either massive or stratified in centimeter-decimeter to meter thick carbonate beds and banks. Corals, sponges and other bioclasts (gastropods, bivalves) are visible.

The following facies types are present in the Bihor Mountains: wackestone-packstone with encrusting organisms, peloidal bioclastic packstone-grainstone, bioclastic grainstone-rudstone with encrusting organisms, coral-microbial boundstone with cement crusts, boundstone with wackestone type internal sediment, coarse bioclastic intraclastic grainstone, fenestral oncoidal wackestone-packstone to grainstone, oncoidal wackestone, wackestone with laminoid-fenestral structures.

In the Pădurea Craiului Mountains, the following facies types were identified: bioclastic wackestone, wackestone with *Bacinella*-type structures, bioclastic packstone-grainstone, peloidal fenestral intraclastic grainstone.

The micropaleontological assemblage consists of encrusting organisms [*Crescentiella morronensis* (Crescenti), *Perturbatacrusta leini* Schlagintweit & Gawlick], dasycladalean algae [*Aloisalthella sulcata* (Alth), *Neoteutloporella socialis* (Praturlon), *Petrascula bursiformis* Etallon, *Salpingoporella pygmaea* (Gümbel), *Salpingoporella annulata* Carozzi], foraminifera [*Coscinophragma* sp., *Everticyclammina* sp., *Frentzenella involuta* (Mantsurova), *Labyrinthina mirabilis* Weynschenk, *Meandrospira favrei* Charollais et al., *Moulladella jourdanensis* (Foury and Moullade), *Rectodictyoconus giganteus* Schroeder, *Sabaudia minuta* (Hofker)], and pelagic microfossils (*Calpionella alpina* Lorenz).

Microfacies analysis indicates that these limestones were accumulating in different depositional settings ranging from slope to platform margin and inner platform areas. The micropaleontological assemblage characterizes the Kimmeridgian–Berriasian–Valanginian and Barremian–Aptian age intervals.

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Sedimentary characteristics of calciclastic offshore-transition deposits in the Ostrovica piggyback basin (North Dalmatian foreland basin, Croatia)

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The Promina Beds represent a calciclastic sedimentary succession, approximately 2000 metres thick, that was deposited in the wedge-top depozone of the North Dalmatian foreland basin. Sedimentation took place from the middle Eocene to the Oligocene in several piggyback basins comprising deep-marine to shallow-marine and alluvial environments.

The sedimentary succession hereby described for the first time belongs to the Promina Beds and is located near Ičevo village in the Ostrovica piggyback basin. The investigated sedimentary succession is at least 200 metres thick and comprises four facies: (i) bioturbated calcilutite, ranging in thickness from 0.5 cm to 13 m; (ii) calcisiltite, ranging in thickness from 2 cm to 78 cm; (iii) calcarenite, ranging in thickness from 1 cm to 90 cm; (iv) heterolithic beds, ranging in thickness from 2 cm to 429 cm. Calcarenite beds have sharp bedding planes, locally showing plane parallel lamination, and combined/wave ripples on top. They are intercalated with finer-grained deposits and are interpreted as tempestites. The distribution of facies suggests deposition in the distal part of the offshore-transition zone. Plant debris in both fine-grained and coarse-grained beds indicates intermittent terrigenous input.

Micropalaeontological analysis revealed scarce and sporadic fossil remains, which mostly consist of recrystallized planktonic foraminiferal tests. Preliminary identification is viable at the genus level and indicates a microfossil assemblage corresponding to the middle to late Eocene interval. Analysis of calcareous nannofossils revealed an assemblage of 24 taxa. The age was determined based on the presence of *Discoaster nodifer* (Bramlette & Riedel, 1954) Bukry, 1973, *Discoaster tanii* Bramlette & Riedel, 1954 and *Reticulofenestra bisecta* (Hay, Mohler & Wade, 1966) Roth, 1970, corresponding to the late Bartonian (NP17 nannozone). The succession is intensely bioturbated with *Thalassinoides* and *Bichordites* burrows. The resedimentation of coarser-grained, nutrient-rich sediments during storm events likely caused increased activity of benthic organisms, which is reflected in the abundance of the aforementioned ichnogenera.

In the Ostrovica piggyback basin, occurrences of hyperpycnites, carbonate mud mounds, and macrofossil-rich marls have previously been documented and attributed to reduced terrigenous input. The sedimentary succession at Ičevo differs from other deposits of the Ostrovica piggyback basin, but shares certain similarities with the Benkovac Stone unit to the northwest of the study area. The Benkovac Stone unit is known for its numerous ichnotaxa and represents deposition in the proximal offshore-transition zone towards the shoreface. Unlike the Benkovac Stone unit, the studied succession at Ičevo is poor in the number of ichnotaxa. Its characteristics resemble the distal part of the informal Debelo Brdo unit, which precedes the deposition of Benkovac Stone unit.

Based on all available data, the studied sedimentary succession at Ičevo is interpreted as a distal part of the offshore-transition zone that was subject to intermittent terrigenous input.

Mineralogical and geochemical approach of argillaceous sediments from Manolea (Moldavian Platform)

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The Moldavian Platform evolved during the middle to late middle Miocene as a foreland basin system developed in the front of the emerging Eastern Carpathians orogenic belt. The sedimentary successions from this basin were accumulated into four depozones e.g. wedge-top, foredeep, forebulge, backbulge. The outcrops from Manolea area (Suceava county) were accumulated in a distal foredeep depozone consisting mainly recurrent sandy and argillaceous deposits. The analyzed samples from the present study were collected from the argillaceous deposits within the Manolea outcrop. The mineralogical investigation (XRD) and geochemical analysis (XRF), both of them upon bulk samples, were used for a better interpretation of the paleo-environmental conditions and classification of sedimentary material.

The XRD patterns show that there are some variations of the minerals abundance from the lower to upper level, with quartz remaining the main rock forming mineral (47%, 54%, 62%, 39%), followed by an decrease for illite/muscovite (ill/Ms) (28 %, 14%, 9%, 14%) and an increase of montmorillonite upward (5%, 7%, 12%, 12%). Feldspars contribution is slightly higher for albite comparing with orthoclase, with neither exceeding 10 %. Calcite and dolomite were also found (16%, 14%, 11%, 28%). The calcite enrichment in the upper horizon is partly related to the higher abundance of the fossil tests, while in other horizons the tests are almost absents. Base on mineralogical composition, the samples can be attributed to argillaceous/siliceous mixed group.

Also the mineral association (Qtz+Ill/Ms+Mont+Chl+Kln) denotes the terrigenous origin of clastic material. This feature is inferred by the geochemical composition as well. The weight ratios Al₂O₃/SiO₂ and Al₂O₃/TiO₂ reflect the felsic-dominant composition of source material. The ration such as Zr/Ti (0.035 in average) denotes a homogenous sorting trend from lower to upper level. However, the third level with slightly higher content of Zr (Zr/Ti = 0.051) suggests a lower sorting degree of clastic material which can be connected to the water level change. This presumes a climatic change, which is supported by Sr/Ba ratio increases possibly due to the more intense evaporation and/or a decline in water supply. Also this last ratio infers the salinity modification toward more saline water during III level deposition. Rb/Sr ratio, which decreases upward, infers a dryer period during III and IV deposition as well.

Consequently, in the Manolea profile, a limited mineralogical and compositional variation was noted. The dominant felsic material from the western source area was modified primarily by weathering and sorting within the depositional basin, where salinity moderately varied, likely due to reducing precipitation and evaporation. The effects of eodiagenesis associated to fluid circulation can be attributed according to the presence of gypsum near kaolinite and montmorillonite or illite. Moreover, the occurrence of smectite together with disordered illite-smectite, along with the relatively broad basal (d001) reflections of the clay minerals, points to poor structural ordering and a low degree of diagenetic maturity, consistent with shallow burial and limited thermal overprint.

The Carnian sedimentary evolution of the Strâmtura Valley section (Apuseni Mountains, Romania)

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The analysis of four carbonate subsections from the larger Strâmtura Valley succession provides new insights into the early Carnian evolution and subsequent demise of a Wetterstein Carbonate Platform transitional to a basin sequence, which developed along the western passive margin of the NeoTethys Ocean. Through an integrated sedimentological, microfacies, paleontological, and conodont based biostratigraphic study, we document the onset of platform development in the early Carnian and refine previous interpretations that were based on limited datasets.

The succession records cyclical deposition of shallowwater, fine to coarsegrained carbonate debris and reefal blocks into a siliciclasticinfluenced openmarine setting, corresponding to three progradational reef cycles: two “Cordevolian” phases and a more pronounced Iulian 1 phase. This final reef cycle is identified by the presence of a large carbonate block (the Strâmtura Limestone), which preserves a hybrid reefal framework dominated by calcified sponges (*Ceotinella*, *Solenolmia*), microproblematic organisms (*Isnella*, *Tubiphytes* spp., *Baccanella*, *Ladinella*, etc.), diverse microbialites, and multiple generations of early marine cements.

The Strâmtura Valley section records the combined influence of shortterm sealevel fluctuations and synchronous tectonic activity. Karstified surfaces and large displaced reefal blocks reflect repeated brief exposures of the reef crest, whereas the stacked siliciclasticrich openmarine deposits indicate a steep platform margin adjacent to a basin characterized by relatively high subsidence rates. These conditions, together with increased siliciclastic influx and Carnian tectonic movements, favoured slope instability and the downslope transport of both fine carbonate debris and large Wetterstein reef blocks.

Overall, these findings highlight the significance of early Carnian Wetterstein reefs and their adjacent basins for reconstructing Late Triassic carbonateplatform dynamics in the western Tethyan realm. The Strâmtura valley section preserves the time span from the onset of the Wetterstein Carbonate Platform to their final stage shortly before their demise around the Julian 1/2 boundary before the onset of the so-called Carnian Pluvial Event, Mid-Carnian Wet Intermezzo, or the more neutral term Reingraben turnover.

Sedimentological implications of mineralogy and origin of clay minerals assemblages in the Miocene salt deposits of Romania

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The most important salt deposits of Romania have been formed during two main periods: Lower Miocene, with important evaporite formations developed exclusively within Pre-Carpathian depression, and Middle Miocene, with salt formations located in Pre-Carpathian, Transylvania and Maramureş depressions. The salt bodies may include, in places, various amounts of pelitic fractions of allochthonous origin, represented by thin interbeds, breccia fragments or finely disseminated clay particles.

X-ray diffraction study showed distinct lateral and vertical variations in clay mineral composition of the Miocene deposits. Thus, in the East Carpathian foredeep (Moldavia region), the lower part of the Early Miocene is characterized by a clay mineral assemblage practically devoid of smectite, this one occurring and becoming a permanent component only at the end of the Early Miocene. Instead, within East Carpathian Bend and South Carpathian foredeep (Muntenia region), the whole Miocene pile of deposits shows various, but always present, contents of smectite.

Some earlier sedimentological investigations concerning paleocurrent directions pointed out two main source areas for the Miocene arenitic and ruditic deposits: a western one, consisting of the emerging areas of the East Carpathians and an eastern one, represented by the Foreland. Our investigations showed that the clayey material supplied by the Carpathian source area is characterized by a rather complex mineral assemblage: degraded illite (dominant), smectite, chlorite, kaolinite and random mixed-layer clay minerals of the illite-smectite type. On the other hand, clay mineral association which are derived from the Foreland are devoid of smectite and consist mostly of a binary assemblage: well crystallized illite (dominant) and chlorite ($\pm$ kaolinite).

The mineralogy of clays, associated or contained within Miocene evaporitic deposits, generally follows the distribution pattern of the detrital sequences encompassing them. During Lower Miocene salt deposition, the Foreland was the main source area for the Moldavian segment of the Foredeep and, consequently, the clays associated with, or included within salt and potassium salt deposits are characterised by a binary assemblage (illite + chlorite), or even a monomineral one (illite). Middle Miocene sedimentation was controlled mainly by sedimentary supplies from the Carpathian area, which determined a specific clay mineral association, consisting besides illite (dominant) and chlorite (important), of smectite as well. As regards Middle Miocene salt deposits of Transylvania depression, clay mineralogy shows an illite-chlorite assemblage with accidentally significant amounts of kaolinite in some western occurrences (Ocna Dej, Ocna Sibiului), suggesting the contribution of the emerged Palaeogene kaolinite-rich formations from the north-western edge of the basin and only a weak influence of the volcanic material supplies.

The peculiar evolution of the clay mineral assemblages within Lower and Middle Miocene salt formations emphasizes that clay fractions are mainly inherited from the land, even some transformation and/or neoformation processes are to be admitted, in order to explain the presence of some rectorite-like and corrensite-like minerals, or some smectite-rich samples. Clay mineralogy may become a valuable tool for stratigraphic correlations of evaporite sequences, and suggests, also, the possibility to determine the age of the salt deposits involved in the complex nappe and/or diapir fold tectonics of the Carpathians.

Depositional Environment of the Paleogene Ruslar Formation, NE Moesian Platform (NE Bulgaria): Evidence from Bulk-Rock Elemental Data

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The Oligocene Ruslar Formation (SE Moesian Platform) is composed predominantly of organic-rich, finely laminated pelitic rocks (shale and claystone) with rare sandstones, siltstones and limestone beds deposited under initially oxic, followed by dysoxic to anoxic conditions (Sachsenhofer et al. 2009), and it is considered a potential source for gas and oil production in Bulgaria (Dimitrov 2015). The rocks of the Ruslar Formation from the Kamchia Depression have been previously characterized for TOC, Rock-Eval, organic geochemistry, and carbon isotopes to reconstruct the depositional environment and hydrocarbon generation potential of this formation (Sachsenhofer et al. 2009). In contrast, the inorganic geochemistry of the Ruslar Formation rocks has not been studied, despite its potential value for reconstructing the sediment source and the water dynamics of the depositional basin, including water circulation, sorting processes, and prevailing redox states. Here, we present preliminary major (XRF data) and trace element results (LA-ICP-MS data) for 23 drill core siliciclastic rocks from the Ruslar Formation in the north-eastern part of the Moesian Platform (Durankulak and Krapets areas) and discuss their significance for the paleoenvironmental reconstruction.

The studied siliciclastic sediments have a narrow range of major elements (e.g. Al 7.6-10.3 wt %, Ca 0.28-0.38 wt %, Si 24.5-27.9 wt %), as well as LOI (10-15 wt%) reflecting similar proportion of major rock-forming minerals in most samples. The low Ca contents and the high Al and Si contents show the predominance of detrital clay minerals and sand over carbonates in the samples. Relatively low Zr/Al₂O₃ ratios (8.3-13.3) suggest deposition in a low-energy (deep water) environment with more clay minerals than sand. Relatively low Al₂O₃/TiO₂ ratios (19-23) reflect source rocks with intermediate lithology.

Intermediate values of the Chemical Index of Alteration (CIA=78-83) correspond to a warm and humid climate with moderate chemical weathering. Higher Co/Mn contents (>0.4) controlled by the weathering processes point towards sediment accumulation in a restricted basin for the Ruslar Formation. The low-intermediate Mo content (5.3-6.4 ppm), relatively low U/Th (0.2-0.4), low-intermediate Mo/Al ratios (0.5-0.7) reveal overall suboxic condition near the boundary with oxic settings of sediment deposition.

The elemental content of the studied shales from the Ruslar Formation suggest source lithology and degree of weathering comparable to those of the Jurassic formations from the Western Moesian Platform (Georgiev et al., 2022), but differ from them in terms of paleoredox parameters, hydrodynamic sorting, and degree of water circulation.

Acknowledgements. This work is supported by the Bulgarian National Science Fund, Contract KPI-06-ДБ/6.

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Microfacies and stratigraphic data from the Bulz Dolomite Formation (Anisian; Apuseni Mountains, Romania): implications for paleoenvironment, diagenesis, and correlation

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Due to the scarcity of international literature on the Middle Triassic Bulz Dolomite Formation (Apuseni Mountains, Romania), its paleoenvironmental reconstruction and regional correlation have largely relied on analogies rather than detailed microfacies characterization. Macroscopically, the Bulz Dolomite is typically thin-bedded, fine-crystalline, and dark grey to black in color. Based on previous descriptions, it contains small gastropods and *Costatoria costata* remains (Highiş Mountains), as well as *Lyriomyophoria elegans* (Codru-Moma Mountains) and *Dadocrinus*.

This study aims to characterize the microfacies and microfossil assemblages of the Bulz Dolomite to interpret its depositional environment, outline its diagenetic history, and refine regional stratigraphic correlations. To achieve this, we investigated over twenty outcrop samples from the Highiş (Galşa and Măderat) and Codru-Moma Mountains (Tărcăița, Valea cea Mică) utilizing conventional microfacies analysis, supplemented by UV/VIS fluorescence and cathodoluminescence microscopy.

Micropetrographic analyses reveal both fabric-retentive and fabric-destructive dolomitization. Where primary fabrics are preserved, the precursor carbonate sediments exhibit microbial boundstone, as well as peloidal ± bioclastic ± lithoclastic wackestone, packstone, or grainstone textures. In addition to the mentioned textural types, dolomite crackle breccia was also identified. Furthermore, fabric-retentive dolomitization preserved stratigraphically and paleoenvironmentally significant fossils, including dasycladalean algae (*Teutloporella peniculiformis*, *Physoporella pauciforata*) and benthic foraminifera (*Hoyenella sinensis*, *Glomospira* species). This diagnostic fossil assemblage confidently assigns the formation to the Anisian, corroborating previous hypotheses.

The multiphase diagenetic history includes early reflux dolomitization driven by hypersaline fluids, as evidenced by relict anhydrite. The ubiquitous pyrite cement is also a product of early diagenesis. Subsequent deep burial resulted in fabric-destructive dolomitization, chemical compaction, and saddle dolomite crystallization. During telogenesis, oxidizing meteoric waters altered the early pyrite cement to goethite; furthermore, late blocky calcite cementation and dedolomitization occurred, while anhydrite was replaced by calcite. In the Valea cea Mică section, Fe-calcite precipitated within fractures and vuggy pores under reducing conditions during the initial stages of exhumation. The formation underwent multiphase brittle deformation; however, the details of the processes driving this still require further investigation.

Detailed micropetrographic and paleontological comparisons reveal compelling lithological, diagenetic, and biostratigraphic affinities between the Bulz Dolomite and the Szeged Dolomite Formation (located in the basement of the southeastern Pannonian Basin). This correlation demonstrates the existence of an extensive Anisian evaporitic-carbonate shelf across the Tisza Mega-unit.

This study represents a collaborative effort by members of the “Terra Tempus” Paleoclimate and Paleoenvironment Research Group, University of Szeged. The research was supported by the National Research, Development and Innovation Fund of Hungary (project nos. K 108375 and K 131690).

Oxfordian sponge-microbial carbonates from Cehirgea -Veriga area (Central Dobrogea, Romania)

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The Upper Jurassic carbonate successions from the Central Dobrogea (Romania) represent important records of the sponge-microbial buildups developed on the Moesian Platform. They exemplify similar reef buildups developed along the northern Tethyan shelf. Previous studies on the lithofacies, microfacies, paleontology and sedimentology of these carbonate buildups were performed by Bărbulescu (1974), Drăgănescu (1976), Herrmann (1996 and references therein). However detailed microfacies analyses of these carbonates still need to be performed. The aim of the present study is to document the main facies and microfacies and to describe the complex microbial fabrics (stromatolites, thrombolites and to interpret the depositional conditions of these carbonate deposits.

The studied succession crops out in the Cechirgea–Veriga area, between Tichilești and Topalu. Six detailed lithostratigraphic logs and field observations focused on lithology, sedimentary structures, fossil content and taphonomic features were performed in the former abandoned limestone quarries and natural outcrops. Samples were collected at meter to centimeter scale resolution and 40 polished surfaces and 350 thin sections were prepared for microfacies analyses.

The studied carbonate succession is about 160–170 m thick and includes two units: the upper part of the Visterna Member represented by medium-bedded sponge biostromes, dominated by hexactinellid and lithistid sponges developed around small microbialite mounds and the Cechirgea Member mainly formed by thin to medium bedded carbonates with laminated fabric, previously described as an alternance of microstromatolites and megastromatolites by Drăgănescu (1976). The sponge-microbial buildups include bioclastic-intraclastic-peloidal floatstone to wackestone, peloidal stromatolites, thrombotic microbial carbonates and mudstones. Small domal stromatolites (3-7 cm diameter), composed of crinkle, micropeloidal laminae alternating microsparitic laminae were observed. The laminated carbonates contain sponges, bivalves, brachiopods, serpulid tubes, rare bryozoans, belemnites, nautiloids and ammonoids. The microencrusters *Crescentiella morronensis* (Crescenti) are important component of the sponge-microbial framework. Other encrusting organisms are represented by *Terebella lapilloides* Münster, serpulids, bryozoans and sessile foraminifera (*Bullopore* sp.). The Oxfordian carbonates from the Cechirgea–Veriga area record the development of sponge-microbial buildups in a shallow to moderately deep open-marine setting. Well-developed microbialites suggest low sediment input, moderate water energy and good conditions for benthic microbial communities. Levels with rare or absent macrofossils suggest low-oxygen environment. These features indicate deposition on a carbonate mid to outer-ramp settings, where microbial growth, sponge communities and early stabilization of the sea floor played an important role.

Acknowledgements. This work was supported by project 7422/2023-2024 funded by the Research Institute of the University of Bucharest.

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Interfingering of different Eocene basin floor fans in the remnant subducted ocean

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The interfingering between distinct basin-floor fan systems is less documented due to the similarity of facies and the difficulty in distinguishing sediment provenance. The Eocene deposits of the Eastern and Southern Carpathians provide such an environment owing to their distinct facies and relatively well-constrained geochronological source areas. Opened in the Middle Jurassic, the Ceahlău–Severin Ocean separated the Dacia mega-unit (current Getic and Bucovinian nappes) from a collage consisting of the East-European, Scythian, Moesian/Danubian platforms, and North Dobrogea Orogen. While Dacia is mainly characterized by Ordovician U–Pb zircon ages (ca. 460 Ma), with subordinate populations at ~320 Ma and ~600 Ma, the platform units exhibit Cambrian, Neoproterozoic, and older (>1 Ga) ages, as well as ages around 245 Ma and 290–320 Ma. Subduction initiated during the Early Cretaceous led to the consumption of the oceanic crust until the Eocene, although this issue remains debated. The first major post-Cretaceous thrusting events occurred in the Miocene, shaping the external nappes of the Eastern Carpathians, which preserve the Eocene deposits discussed here. Western internal deposits, in their current position, display turbiditic channel–levee and frontal splay associations. Lithic sandstones containing metamorphic clasts, paleocurrent data, and especially the U–Pb detrital zircon (DZ) age spectra point to similarities with the metamorphic basement of the Dacia unit. More external deposits are deep-sea carbonate-dominated, with intercalations of sandstones containing distinctive green low-grade metamorphic clasts, regionally recognizable. Their U–Pb (DZ), ages show affinities with the eastern external platform domains. The central basin sector is characterized by facies interfingering sourced from both internal and external domains, alternating calcareous, quartzous and lithic sandstones. The mixing area is extensive, with platform-related ages (>1 Ga) occurring even in the most internal basin facies, and conversely, Dacia-derived ages present in the outermost nappes. Eocene exhumation -constrained by AFT data - of the South Carpathian basement, together with dominantly north-directed longitudinal paleocurrent patterns, suggest this region as the main source of lithic sand for the Eastern Carpathian basin, sediment transfers likely occurred through intra-montane depressions and the Getic foredeep.

Acknowledgements. This work was supported by a grant of the Ministry of Education and Research, CCCDI - UEFISCDI, project number PN-IV-P6-6.1-CoEx-2024-0042, within PNCDI IV and OMV-Petrom Project 2024.

Recognition of the Proposed Jarovian and Radotinian Stages within the Přídolí Series in Bulgaria

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The base of the Přídolí Series is defined by the first appearance datum (FAD) of the graptolite *Neocolonograptus parultimus*, whereas its upper boundary is established by the FAD of *Uncinograptus uniformis*. At present, no formal subdivision of the series has been established.

Manda *et al.* (2023) proposed a subdivision of the Přídolí Series into a lower Jarovian Stage and an upper Radotinian Stage. The base of the Jarovian Stage coincides with that of the Přídolí Series. The graptolite *Wolynograptus bouceki* has been proposed as the most suitable biostratigraphic marker for the base of the Radotinian Stage. Its appearance closely coincides with the first occurrences of the conodont *Oulodus detortus* and the cephalopod *Kopaninoceras fluminense*. The *bouceki* Biozone is characterized by the successive appearance of faunal elements that were previously recorded in the upper *transgrediens* Biozone. The upper stage is characterized by a proliferation of scyphocrinid crinoids. The higher part of the Radotinian Stage comprises the *Wolynograptus perneri* Biozone and the conodont *eosteinhornensis s.s.* and *klonkensis* biozones, all of which precede the Transgrediens Event in the uppermost Přídolí.

Occurrences of the Přídolí Series in Bulgaria have been reported from the Svoge, Lyubash–Golo Bardo, and Morava tectonic units (Dabovski and Zagorchev, 2009).

In the Svoge and Lyubash–Golo Bardo tectonic units, the lower and upper boundaries of the Přídolí Series are defined by the first occurrences of *Neocolonograptus parultimus* and *Uncinograptus uniformis*, respectively. Although *Wolynograptus bouceki* has not yet been recorded in Bulgaria, the presence of the Radotinian Stage in the Svoge Unit is inferred from the occurrence of scyphocrinid crinoids, *Wolynograptus perneri*, and *Istrograptus transgrediens* (Sachanski, 2015). In the Lyubash–Golo Bardo Unit, detailed conodont investigations of the carbonate interval may provide evidence for the presence of the Radotinian Stage, whereas the available data from the shale succession indicate the occurrence of the Jarovian Stage (Spasov, 1963).

In the Morava Unit, the Přídolí Series has been identified primarily on the basis of conodont biostratigraphy (Boncheva *et al.*, 2007).

Acknowledgements. The Bulgarian National Science Fund of the Ministry of Education and Science, Grant KP-06-N84/1, supported this study.

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Preliminary Insights into Jurassic Phosphorites of Albania: An Integrated Multi-Analytical Study

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Albania hosts several phosphatic deposits developed within the Ionian Zone that preserve a record of phosphogenesis and sedimentary evolution along the western Tethyan margin. This study presents preliminary results from an integrated petrographic and mineralogical investigation of the Bogaz phosphatic deposits in southern Albania. The applied methodology combines thin section petrography, X-Ray Diffraction (XRD), FTIR spectroscopy and Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS) analyses to investigate phosphatization processes and diagenetic evolution. Phosphatic mineralization occurs mainly as dark bituminous infiltrations and cement filling fractures in brecciated carbonate rocks composed of angular limestone and locally dolomitized carbonate clasts. The carbonate clasts predominantly consist of peloidal packstone to wackestone facies containing abundant calpionellids (*Calpionella alpina*), whereas shallow-water involutinids including *Aulotortus* sp., were identified in other carbonate clasts. While previous studies described Bogaz breccias as being composed predominantly of Lower Jurassic (Pliensbachian) carbonate clasts, the present petrographic observations suggest that at least part of the carbonate clasts are of Late Jurassic (Tithonian) age, possibly reflecting phosphatic horizons of different stratigraphic levels.

XRD analyses indicate calcite and carbonate fluorapatite as the dominant mineral phases, while FTIR spectra reveal characteristic phosphate and carbonate absorption bands, confirming carbonate substitution within the apatite structure. SEM-EDS analyses identified Ca-P-F rich apatite phases associated with Fe-rich aggregates. The framboidal morphology of these Fe-rich aggregates, together with the occurrence of partly altered pyrite crystals, indicates the former presence of sulfide phases subsequently affected by oxidation. Pyrite oxidation may have generated acidic fluids, promoting oxidation of U⁴⁺ to U⁶⁺ and subsequent uranium remobilization. SEM-EDS analysis also reveals the presence of Bi-rich (up to 60 wt%) micrometric almost rectangular phase interpreted as bismoclite within phosphatic cement. Considering the strong affinity of Bi³⁺ with Ca²⁺ in apatite structure and the secondary origin of bismoclite these phases may reflect alteration of primary Bi-rich carbonate fluorapatite under oxidizing conditions and followed by post-mineralization brecciation.

These preliminary results highlight a complex evolution involving brecciation, phosphatization and post-depositional alteration. The association of shallow-water and pelagic carbonate clasts may suggest reworking and redeposition of carbonate material prior to late diagenetic phosphatization. Ongoing studies will further refine the age and diagenetic evolution of the Bogaz deposit within the western Tethyan context.

Acknowledgements. This work was carried out within CEEPUS Mobility Programme. We gratefully acknowledge Prof. Hans-Jürgen Gawlick (Montanuniversität Leoben) for his valuable scientific guidance in the interpretation of carbonate microfacies and the professors of the Institute of Geological Sciences, Jagiellonian University Kraków, for their support during the XRD, FTIR and SEM-EDS analyses.

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Polar constituents in mudstones of Maritsa Iztok Basin, Bulgaria: a geochemical study on OM floral progenitors and diagenetic changes

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Three palaeo-communities were depicted for the Upper Miocene- Lower Pliocene lignite-mudstone sequences of Maritsa Iztok Basin (Bulgaria). The pre-swamp environment is the first one characterized by standing or slow moving fresh waters with detrital organic matter (OM) deposition. The second one is the swamp environment of detrital forest trunks. The main communities were composed of trees of Cupressaceae, Taxodiaceae, and Podocarpaceae Families accompanied by trees of Betulaceae Family and herbaceous plants. Different *Sphagnum* species were also abundant. Polar terpenoids ratio differentiated slight climatic oscillations for the samples with a strong Gymnospermae dominance. The moss swamp environment with very fluctuating elements is third one. A *Sphagnum*-dominated peat developed pointing to shallow (maximal 5 m depth) waters.

The study provides further insight into the OM composition in a lignite-mudstone sequence from Maritsa Iztok Basin. The polar constituents, *n*-alkanoic acids, *n*-alcohols, polar di-, polar tri- terpenoids, steroids, benzoic acids, lignin-derived aromatic acids, saccharides, etc. of samples from the mudstone layers interbedding the lignite seams were analyzed with the aim to obtain information on OM input and diagenesis mainly through fatty acid (FA) analysis. We applied a strategy based on sequential FA identification and comparison of individual component relative concentrations and ratios vs. depth.

Fatty acids and polar diterpenoids predominate in the soluble organic matter. There is a great variety of FAs: (i) linear FAs, *n*C5-*n*C24, with *n*C16 strong dominance, ca. 50 rel.%, with a total prevalence of the “even” numbered homologues; (ii) short chain FAs, *n*C16-*n*C20, approximately 40 rel. %; (iii) long chain FAs, *n*C21-*n*C24, <10 rel. %. Regardless of the similarities in FAs pattern of the distributions for the sequence, there are some tendencies triggered by depth increase: namely, (i) the portion of the short chain FAs, *n*C16-*n*C20, augments by 12 rel. % mainly due to *n*C16 increase at the expense of the decrease in the long chain ones; (ii) the relative amount of the shortest members, *n*C7-*n*C15, remains relatively constant, ca. 50%.

A peculiarity of the samples studied is also the extreme assortment of the polyfunctional short chain FAs, i.e. dicarboxylic, *n*C2 - *n*C9, linear and branched homologues, hydroxy FAs, saturated and unsaturated ones, isoprenoid, etc. The variability of the shortest chain FAs and their polyfunctionality points to the intensive diagenetic transformation of the detritic OM composed by the lignin, altered carbohydrates and lipid remains.

The abundance of polar diterpenoids, i.e. ferruginol, sugiol, dehydroabietic acid, etc. is a signature of a preferential Cupressaceae/Taxodiaceae contribution in the palaeoflora. The presence of the polar triterpenoid lupanol attests that Betulaceae has an important input to the palaeomire and β-amyrin presence additionally strengthens the proof for detectible Angiospermae contribution.

In short, the investigation expands the knowledge on OM floral progenitors, provides proofs on the input of the OM forming compounds and attempts highlighting their diagenetic transformations with time.

Acknowledgements. The study was funded by the National Science Fund, Ministry of Education and Science, Bulgaria, Project KP-06-H64/2022.

The Farony Member – new Upper Cretaceous lithostratigraphic unit of the Ropianka Formation in the Magura Nappe (Outer Western Carpathians)

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The study area is located within the Western Outer Carpathians, specifically within the southernmost nappe, the Magura Nappe. Its sediments were deposited in the northern part of the Tethys Ocean, spanning a time interval from the Upper Cretaceous to the Middle Miocene. Due to lithofacies variations, several subunits have been distinguished within the nappe. The study area is situated within the Bystrzyca Subunit.

The newly distinguished Upper Cretaceous member occurs within the Ropianka Formation of the Bystrzyca Subunit. The Ropianka Formation is represented by thin- to medium-bedded flysch, with thick-bedded sandstone intercalations, which form a 100–250 m thick complex in the lower part of the formation, known as the Szczawina Sandstone Member (Teták et al., 2017).

The Farony Member is represented by red shales with intercalations of strongly bioturbated green shales, reaching a total thickness of several meters. The red shales are dominant and thicker compared to the green ones. Individual red shale beds range from a few centimeters to >10 cm in thickness. The green ones are thinner, ranging from a few millimeters to a few centimeters. These shales are hard, silicified, and fracture into sharp-edged, angular blocks and fragments. Single beds of grayish-green, fine-grained, thin-bedded sandstones with glauconite are sporadically encountered within the shales.

The sediments of the Farony Member were described in Poland as local packages of variegated shales occurring within the Ropianka Formation of the Bystrzyca Subunit on the northern slopes of the Gorce Mountains. However, detailed studies have shown that these deposits occur in a narrow belt extending from the Gorce Mountains in Poland in the east to the southern slopes of Pilsko Mt. in Slovakia. Their age has been determined as Maastrichtian based on agglutinated foraminifera (the interval of the co-occurrence of *Caudammina gigantea* (Geroch), *Caudammina ovulum* (Grzybowski), *Caudammina excelsa* (Dyląganka), *Saccammina–Placentammina acme*, and *Rzehakina inclusa* (Grzybowski); Szczęch et al., 2026).

The name "Farony" originates from the Farony hamlet located in the village of Szczawa, Poland. An outcrop in the Kamienicki Creek, within the Rzeki hamlet of Lubomierz village, Poland (49.592889° N, 20.235167° E), has been designated as the stratotype section. Two reference sections have also been established: an outcrop on the left bank of the Bystrý potok stream, north of Mútne village in Slovakia (49.487994° N, 19.275165° E), and another in the Ratułowiec Creek, Božki hamlet of Lubomierz village, Poland (49.614629° N, 20.170706° E). The deposits of this member constitute an important regional correlation horizon within the Ropianka Formation.

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The real age, Lower Badenian, of the Slănic Tuff (Prahova, Romania)

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It is quite natural that the Slănic Tuff was considered, on lithostratigraphic criteria, an equivalent of the important Badenian (ex-Tortonian) tuff levels from Ocnele Mari (Govora Tuff), from the extra-Carpathian area, but also an equivalent of the Dej Tuff, respectively of the Perșani Tuff, from the Transylvanian Basin (Szakács et al., 2012). Therefore, these tuffs were placed stratigraphically towards the lower part of the Badenian deposit stack, thus being related to the upper part of the Lower Badenian. The Badenian evaporitic deposits (gypsum, salt), synchronous in the extra-Carpathian area and in the Transylvanian Basin, arranged over the tuff packages mentioned above, were thus related to the Middle Badenian. Attempts were made to determine the absolute age of the Dej Tuff by different methods, which led to temporal values of around 15 Ma. More precisely between 15.1 and 14.8 Ma (see the reference work in this regard from 2012 prepared by a team of authors led by Szakács). Nicolescu and Mârza (2010) determined an age of 15.1 ± 0.5 Ma for this tuff using the (U–Th)/He method. Subsequently (2017, 2018), a research team led by Bojar proposed an absolute age of only $13.6\text{--}13.7 \pm 0.2$ Ma for the Slănic Tuff (at Piatra Verde), obtained via the $40\text{Ar}/39\text{Ar}$ method. The analyzed sample (a white tuff layer) was collected from the median part of the package of deposits corresponding to the Slănic Tuff. Consequently, according to these authors, the Slănic Tuff would be placed at the transition between the Middle and Upper Badenian. This would imply that the Slănic Tuff is not synchronous with the Dej Tuff but is somewhat younger - a conclusion that is stratigraphically inconsistent with reality. Thus, the lower age value obtained by the Bojar team for the Slănic Tuff most likely reflects a "rejuvenation" resulting from post-depositional geodynamic processes. This theoretical possibility had already been considered in a 2012 study (Szakács et al.) regarding lower age values obtained for the Dej Tuff using some analytical methods.

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High-resolution sequence stratigraphy of Negotin area, Dacian Basin (Eastern Serbia)

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Small remnants of the Dacian Basin, a marginal basin of the Eastern Paratethys, are preserved in eastern Serbia near Negotin. During its existence, this brackish marginal sea underwent major climatic and water-level changes. A significant water-level drop of approximately 300 m occurred during the Khersonian, under arid climatic conditions, and was followed by the Meotian transgression and a more humid climate (Palcu et al., 2019).

Using high-resolution sequence stratigraphy combined with sedimentological and biostratigraphic methods, three outcrops were studied and correlated with existing literature data. For each outcrop, a sedimentological log was constructed, in which different facies were distinguished based on grain size, sedimentary structures, and fossil content. The identified facies were subsequently grouped into facies associations corresponding to specific depositional environments. Based on facies associations and stacking patterns, parasequence boundaries were identified following sequence stratigraphic principles.

Based on biostratigraphic evidence, the investigated sections span the interval from the Khersonian (8.9–7.6 Ma) to the Meotian (7.6–6.1 Ma) (Raffi et al., 2020). Khersonian coarse sands and gravels are characterized by abundant shell beds mainly composed of different *Macra* species, as well as the foraminifera *Ammonia beccarii* and *Elphidium crispum*. The Meotian age was determined by the presence of gastropods such as *Theodoxus* and bivalves *Congeria* and *Psilunio*.

The Khersonian coarse clastic sediments were deposited in generally proximal high-energy shallow water environments, as indicated by the presence of gravel and coal clasts. Measured structures in gravelly sands shows paleo transport generally from the east. The presence of two cemented carbonate beds composed of shell debris, one in the middle and one at the top of the section, probably reflects periods of increased evaporation and drier climatic conditions, consistent with Khersonian climate models (Lazarev et al., 2020). No distinct lithological boundary between the Khersonian and Meotian successions was observed. During the Meotian, sedimentation occurred under fluctuating water energy regimes. Sands were deposited during periods of higher-energy flow, whereas clays and silts accumulated in relatively stagnant water conditions with minor influence of high energy flow marked by sandy intercalations.

Khersonian deposits are interpreted as representing the regressive part of the depositional sequence, whereas the Meotian deposits record a transgressive phase characterized by retrogradational stacking patterns. The studied interval is interpreted as a single third-order depositional sequence characterized by a transition from regressive/progradational to transgressive/retrogradational conditions, without a clearly exposed sequence boundary between the Khersonian and Meotian successions.

Acknowledgements.

Special thanks to the IAS for financial supporting this research via Judith McKenzie Fieldwork Award.

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Session GS15

Tectonics and Structural Geology

Conveners:

Liviu Matenco, Alexandra Tămaş

The Role of Structural Geology in the Energy Transition

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Structural geology is critical to the development of a number of subsurface applications required for the energy transition (such as CO₂ storage, geothermal, hydrogen and compressed air storage, geological disposal of radioactive waste). The skills, methods, and experience typically found in a traditional structural geologist's toolbox can be readily applied to these developing and emerging industries. In this presentation we will evaluate some of the key geological challenges in these applications, and highlight where there is a clear role for structural geology and subsurface geoscientists.

It will become clear that effective usage of the subsurface for decarbonisation will require an understanding of systems and lithologies not always fully appreciated by oil and gas exploration and development, but also require an understanding of conflicting uses of the subsurface. For example, recent research at the British Geological Survey has highlighted large parts of the UK that have potential for multiple energy transition applications, these have been termed super regions or 'Goldilock Zones'. To fully appreciate any interdependencies or conflicting usage of these areas we need a deeper understanding of geological structures in these areas and how they control and influence fluid flow.

Evolution of the Carpathian Foreland Basin and its link with collision and slab detachment

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The Carpathians are a typical Mediterranean-type orogen that resulted from slab roll-back, nappe accretion, collision and slab detachment. We will use basin-scale sedimentological and provenance analysis to reconstruct the Miocene to recent evolution of the Carpathian Foreland Basin. Paleontological observations will highlight the basin's biogeographic relations with the surrounding regions, demonstrating the creation and destruction of topographic barriers with the Pannonian Basin and the Black Sea. Results from inverse modelling of thermochronological data from the Carpathians with PECUBE will be used to understand the timing and volume of sediment supply from different parts of the mountain belt, which will then be compared to deposition over time in the foreland basin. Finally we will establish a link between the geodynamic events in the subduction system, particularly collision and slab-detachment, and the evolution of the foreland basin. Since there are many similarities between the Carpathians and other roll-back orogens, our results might be interesting for researchers studying other Mediterranean-type orogens.

Correlation of the Alpine polyphase/polystage tectonic units from the East and South Carpathians involving the pre-Mesozoic basement and related sedimentary covers

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The Alpine structural units of the Carpathian belt, classified as “Dacides” and “Moldavides”, show internal basement-cover units; the Median Dacides (derived from the Dacia microcontinent) and Marginal Dacides (an external crustal fragment) are separated from each other by a rift domain evolving by the Upper Jurassic to an oceanic basin (Outer Dacides).

The syn-orogenic nappes and nappe stacks are updated and cartographically separated on a new Geological Map of Romania 1:200 000 scale (editors: Gheuca and Ilinca, 2026, in press). Cross sections at scale 1:200 000 published by the Geological Institute of Romania are figured for the entire orogenic belt. A complete classification of these nappe complexes include:

Transilvanides: Rarău, Hăghimaş, Olt, Perşani nappes

Pienides: Pinenine klippen, Botiza, Petrova and wildflysch nappes

Median Dacides: Bucovinian-Subbucovinian-Supragetic; Infrabucovinian-Getic nappe complexes

Outer Dacides: Black Flysch, Baraolt, Ceahlău, Bobu and Severin-Obârşia nappe complex

Marginal Dacides: Upper Danubian, Lower Danubian, Coşuştea Nappes

Moldavides: “Curbicortical” Flysch, Macla, Audia, Tarcău, Marginal Folds and Subcarpathian nappes.

The Carpathians represent an Alpine polystage fold and thrust belt, including basement-cover units of the East and South Carpathians with some similar features, as well as different/contrasting lithological and structural characters connected by a bend zone of direct correlation of the basement and cover units. Our proposed correlation of the Alpine polyphase tectonic units of the East and South Carpathians in 2008 is based on Geological maps of Romania 1:200 000 scale (editors: Gheuca and Ilinca 2026, in press), and various published maps and articles.

The following guidelines and features are used: a) the timing of the main nappe stacking events: Middle Cretaceous (Austrian phase), Upper Cretaceous (“Laramide” or “Getic” phase), as well as Miocene events; b) the cartographic differentiation of the post-nappe covers, as major sedimentary-structural markers defining the Cretaceous contraction-collision related events (Austrian and Laramide/Getic in the South Carpathians cf. Balintoni et al., 1989; Iancu et al., 2005a); the coeval events and structures were previously figured in the East Carpathians by Gheuca (in Iancu et al., 2002, unpublished report); the involved pre-Mesozoic basement/cover formations as well as Mesozoic covers (Triassic-Jurassic-Lower Cretaceous in Getic-Supragetic and Jurassic-Cretaceous in Danubian); c) the polyphase folds and nappe complexes resulted from contraction-collision-extension Cretaceous events, followed by Miocene deformation; d) different ages, structural level and geotectonic setting of the successive thrust faults which defined the nappe bodies in the Cretaceous and Miocene times; different symbols are used on maps; e) the folds and nappe complexes are the effects of the “Austrian” (intra-Aptian) contraction phase and simple shear processes leading to the generation of the “internal” nappe piles (Getic/Supragetic/Severin in the South Carpathians and the “Crystalline-Mesozoic zone” in the East Carpathians) and the folding of the pre-Albian Mesozoic formations; basement and rift-related units were in tectonic contact in the Aptian time, as Albian coarse grained successions (e.g. Bucegi conglomerates in the bend zone of the Carpathians) seal the thrust lines in between; the Upper Cretaceous Banatitic intrusions are post-Austrian markers, while Upper Senonian-Paleocene volcanics are post-Laramide, extension related in the South Carpathians; f) distinct effects of the Laramide (Getic) phase (intra-Senonian or intra-Maastrichtian) in the South and East Carpathians. The Miocene-Paleogene and Neogene sedimentary successions show distinct orogenic evolution.

Vein mineralogy and fracture reactivation potential in the Boda Claystone Formation (SW Hungary): integrating vein evolution with the present-day stress field

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The long-term safety of deep geological repositories depends on the ability to identify fracture populations that may act as potential fluid pathways under present-day and future stress conditions. Although fluid migration in low-permeability host rocks is commonly controlled by fractures, many of these structures are at least partially mineralised, and their hydraulic and mechanical behaviour cannot be inferred from geometry alone.

The Boda Claystone Formation of southwestern Hungary is being investigated as a potential host rock for a high-level radioactive waste repository. This study combines petrographic and geochemical characterisation of mineralised fractures (tectonic veins) with structural and geomechanical datasets from the BAF–3, BAF–3A and BAF–4 boreholes to evaluate the potential mechanical significance of different vein populations.

Petrographic, cathodoluminescence, Raman spectroscopic, fluid inclusion and isotope-geochemical investigations identified six vein generations recording multiple stages of fluid migration and fracture sealing. The vein generations display distinct mineralogical compositions, textures and cementation mechanisms, including crack-seal calcite veins and anhydrite-dolomite veins. Structural information is provided by oriented core scanning and borehole image log interpretations, which allow the orientation and spatial distribution of both open and mineralised fractures to be assessed.

The present-day stress field is constrained by in situ stress measurements obtained through overcoring (IST) tests and subsequent geomechanical evaluations. Additional constraints are provided by laboratory-derived mechanical parameters, including elastic properties and strength measurements. These datasets offer an opportunity to assess how vein mineralogy and growth morphology may influence the mechanical response of fractures under the current stress regime.

Preliminary observations indicate that different vein generations are likely to exhibit contrasting mechanical behaviour owing to variations in mineralogy, texture and inferred cohesion. Consequently, fracture populations with similar orientations may not share the same reactivation potential. These observations highlight the importance of integrating vein characterisation with geomechanical analyses when evaluating the hydraulic significance of fracture systems.

The study demonstrates how petrographic and geochemical information can improve the interpretation of fracture networks beyond purely geometric approaches. The proposed workflow may contribute to more realistic assessments of fracture-controlled fluid migration in repository host rocks and other low-permeability subsurface systems.

Acknowledgements. The research was supported by the National Research, Development and Innovation Fund, Hungary (OTKA PD-147180 project).

Tectonostratigraphic evolution of Paleogene supradetachment basins and its control on epithermal gold mineralization: case study from the Krumovgrad region, Bulgaria

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The Krumovgrad region, located in the Eastern Rhodopes of Bulgaria has been the subject of both academic and industry interest due to its complex geological history and its significance for the mining sector. The region is characterized by late Eocene exhumation of the Kesebir-Kardamos metamorphic core complex, formation of Eocene-Oligocene basins and Early Oligocene bimodal volcanism. The district is home to Ada Tepe mine, that exploited a low-sulphidation type sedimentary rock-hosted epithermal gold-silver deposit. However, the interplay between tectonics, sediment deposition and the gold-bearing hydrothermal system is still not thoroughly understood.

We apply an integrated approach incorporating surface mapping, borehole data, 3D modelling and facies distribution of gold-bearing hydrothermal system to define three primary tectonostratigraphic episodes in the evolution of the sedimentary basins and highlight their implication for understanding the structural controls on epithermal mineralization in the region:

1) Formation of tectono-sedimentary breccia and conglomerate in the immediate hanging wall of the detachment fault reflects the earliest episode of basin evolution. Several local depocenters are shaped by corrugations in the detachment fault and development of listric faults. These syn-detachment sedimentary products act as the main host rock for the gold-bearing quartz vein developed above the fault zone in Ada Tepe deposit and other satellite prospects along the hinge line of the Kesebir-Kardamos dome.

2) Development of horst-and-graben fault structures controlling deposition of alluvial conglomerates and sandstones. Differential uplift and subsidence of fault blocks, as evidenced by the formation of syn-depositional extension-parallel fault structures aided the delineation of local sub-basins. Syn-sedimentary hydrothermal activity is marked by interlayered sinter deposits and authigenic enrichment of mineralization related chalcophile elements in reduced sediments. The extension-parallel structures serve as hydrothermal fluid conduits proximal to graben and half-graben boundaries.

3) Onlap of shallow marine sediments, which unconformably overlay the earlier syn-detachment strata. Reactivation of existing extension-parallel and other favourably oriented structures is common and linked either to the Oligocene volcanism or to latest Oligocene-Early Miocene shortening. This stage played an important role in the preservation and exhumation of previously formed gold mineralization.

This study demonstrates that the spatial distribution, structural localization and preservation of epithermal gold mineralization in the Krumovgrad region were controlled by the progressive development of Eocene-Oligocene supradetachment basins. It highlights the advantages of utilizing tectonostratigraphic approaches for understanding supradetachment basin evolution and structural controls on epithermal gold mineralization.

Acknowledgements. Support from DPM Metals Krumovgrad team is greatly appreciated.

Application of UAV photogrammetry in structural analysis of the Klikuszowa Quarry (Outer Western Carpathians, Poland)

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Structural features of the Klikuszowa quarry, located in the Polish part of the Outer Western Carpathians (Magura Nappe, Krynica Subunit), were studied using Structure from Motion (SfM) photogrammetry. Our goal was to evaluate the efficiency of data derived from this method for high-accuracy structural measurements. Although the quarry was previously analyzed using traditional methods (Cieszkowski et al., 1998), it has since been significantly expanded, exposing new sections for investigation. The quarry is excavated in the Magura Sandstone of the Poprad Member (Magura Formation, Upper Eocene – Oligocene), which is characterized by a prevalence of thick-bedded sandstones with minor intercalations of thin- to medium-bedded flysch in the upper part of the profile. A system of transverse and oblique faults trending NNW–SSE and NNE–SSW, alongside another set of NE–SW trending faults, is developed in the area. The bedding in the quarry is in a normal position, dipping toward the SW at an angle of approximately 20–35°. The Lepietnica fault zone, or rather its core, is located approximately 100 m north of the quarry, striking NE–SW along the river valley.

The data were obtained via unmanned aerial vehicle (UAV) mapping. A Mavic 3E drone, flying an automated mission, acquired 2,766 images in nadir and oblique orientations with RTK-augmented position metadata. The image set was processed in Agisoft Metashape Professional using a standard workflow, resulting in a dense point cloud and a DEM. For structural measurements, we used CloudCompare software equipped with the “Compass 2.0” plugin. Manual surface measurements yielded 623 joints and 72 bedding planes. Additionally, the “Facet/fracture detection” tool was applied for the automatic extraction of planes. After quality filtering and refinement, 1,605 planes were obtained.

The results demonstrate the high applicability of this approach in efficiently collecting large, high-quality data samples, even from quarry walls with limited accessibility due to their height and ongoing mining activity. Manual plane fitting allowed us to maintain strict control over the measured surfaces, whereas automated facet detection introduced some uncertainties related to the capturing of artificial surfaces. Integrating SfM measurements with regional-scale data (maps, airborne LiDAR) and outcrop-scale field observations establishes a robust multiscale framework for structural interpretations. In the case of the presented study, we demonstrated that the Lepietnica Fault is a complex zone, while the fracture network in the quarry remains consistent with the regional tectonic evolution of the Outer Carpathians.

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Conjugate fracture systems as indicators of regional stress, Valja Saka prospect, Eastern Serbia

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The Carpatho-Balkanides represent a major tectonic belt in southeastern Europe, composed of extensive fault systems and multiple deformation phases (Schmid et al., 2008; Krstekanić et al., 2022). Major sets include NNW-SSE to N-S basement structures, Late Cretaceous N-S to NW-SE corridors, Miocene E-W extensional systems and subsequent strike-slip corridors such as the Timok-Cerna dextral and NW-SE sinistral sets (Knaak et al., 2016). These structures reflect progressive strain partitioning during indentation of the Moesian Platform (Krstekanić et al., 2022).

This study presents subsurface structural data from the Valja Saka prospect, located few km north of Čoka Rakita and Dumitru Potok, on the north western margin of the Timok Magmatic Complex. Drill core analysis focused on fracture planes and slickenside lineations, with only fractures showing clear kinematic indicators systematically measured. Over one hundred observations across different lithologies were compiled, providing a statistically significant dataset for reconstructing stress orientations at the micro scale. Fracture networks in drill core often develop as conjugate fracture systems, formed under differential stress conditions. These systems occur in predictable pairs oriented at characteristic angles to maximum compressive stress, thereby recording paleo stress orientations. One set reflects compression, while the complementary set indicates extension. Because of this relationship, conjugate fracture analysis is widely applied in structural geology to reconstruct brittle stress fields (Hancock, 1985; Twiss & Moores, 2007).

The orientations identified in Valja Saka demonstrate a clear correspondence with the regional tectonic framework. Drill core measurements reveal N-S fabrics interpreted as basement structures, NW-SE corridors reflecting Late Cretaceous deformation, E-W normal faults characteristic of Miocene extension and younger strike slip systems indicating later reactivation. These orientations reproduce structural trends observed regionally, providing a micro scale confirmation of large scale tectonic phases. The Valja Saka dataset establishes a chronological evolution from reactivated basement fabrics, through extensional faulting, to strike slip corridors associated with progressive bending and strain partitioning.

By integrating these fracture measurements with regional tectonic models, this study demonstrates that local subsurface data not only validate but also refine the Carpatho-Balkanide deformation sequence. The results underscore the importance of systematic core analysis in bridging micro scale fracture evidence with regional geodynamic evolution, offering a rare subsurface perspective on the north western margin of the Timok Magmatic Complex.

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Challenging issues to reveal the geological structure, tectonic evolution of the Odessa Shelf, Ukraine

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The northwestern shelf of the Black Sea mega-basin is the main gas production area within the Southern oil and gas region of Ukraine. This region offers Ukraine great opportunities for hydrocarbon prospecting and exploration in the yet unexplored area. In 2021, PGS Exploration ASA, under a contract with NJSC Naftogaz of Ukraine, conducted high-resolution 3D seismic acquisition coupled with detail bathymetric mapping in a shallow water area of 5000 square kilometers in the Inner Far Northwestern shelf of the Black Sea of Ukraine. Seismic data processing included state-of-the-art depth processing, namely FWI, KPSDM and SWIM, which was a milestone in the exploration of the region (Kitchka et al., 2025).

The area of study, the conjugation zone between the slope of Precambrian EEP, Paleozoic-Cimmerian Scythian platform and younger Meso-Cenozoic Black Sea basin, is, in fact, surprisingly complex in terms of tectonic structure of the whole region that is making it as the most interesting area from the geological point of view.

Successful multi-level signal processing, velocity modeling/matching selection and event correlation within the cube made it possible to build a coherent and kinematically balanced three-dimensional fault model of the area studied. The analysis of the structure-forming basement in sedimentary basins aims to substantiate the origin of oil and gas traps in the sedimentary cover and in the basement itself, especially if it belongs to the so-called transitional type like in this case. This analysis proved the validity of the predictions made by previous generations of Ukrainian petroleum geologists, who foresaw the extension of the petroleum geological conditions of the Dobrogea foredeep under the waters of the Black Sea (Krylov sub-basin), but with better initial reservoir pressure and sealing, and therefore bigger hydrocarbon potential. Like in the Moesian Platform the Eo-Cimmerian unconformity plays an important role in deciphering tectonic structure and evolution of the region.

The acoustic basement of the area is heterogeneous and heterochronous, with Cadomian metamorphic unit subjected later by Variscan and Cimmerian rejuvenations within the Kiliya-Zmiinyi uplifted zone. The recognized and mapped Eo-Cimmerian unconformity is an important geological feature for understanding the structural model of the acoustic pre-Jurassic basement, as well as the tectonic evolution of the region as the whole. Mid-Jurassic rifting has been identified in the study area like in the Dobrogea Foredeep, Mountain Crimea and Greater Caucasus, while the well-documented early Cretaceous one took place further south, within the Karkinit sub-basin and West Black Sea basin itself. The extension of the North Dobrogea Foredeep into the Black Sea was confirmed, and elements of its petroleum systems were transferred to the adjacent offshore domain, where potential hydrocarbon traps were found in the eroded Paleozoic carbonate platform.

More than forty promising structural and non-structural leads (including 15 ones recognized for the first time) were identified and characterized in the Dolphin 01-10 E&P special permits of NJSC Naftogaz of Ukraine within the Inner zone of the northwestern Black Sea shelf based on the latest 3D seismic data processing and analysis of geological and geophysical information.

Acknowledgements. The study was done under the UGV R&D Contract #57.0001255.

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Core-complex in the wrong tectonic position? Towards solving the puzzle of Altân Tepe unit

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European Hercynian orogens with documented extensional core-complexes are lower crustal domes associated with high temperature conditions, migmatization and late stage hydrothermalism. One example was recognized in North Dobrogea of Eastern Europe (the Megina dome of Mârza-Ene et al., 2026). One other extensional dome (Altân Tepe) is apparently located in the neighbouring Central Dobrogea part of the tectonically stable Moesian Platform, which is a wrong location for an orogenic core-complex. With no previous structural quantification, we used field and microstructural kinematic observations to verify if this dome is indeed a typical core-complex. The results indicate a similar evolution with Megina, an initial top-NE nappe stacking during Late Carboniferous – Permian burial metamorphism, followed by Triassic extensional exhumation, retrograde metamorphism and top-SE ductile shearing that formed an orogen-parallel extensional dome. Electron microprobe analyses on thin sections and geochemistry from both core-complexes estimate prograde metamorphic conditions of 550 ± 30 °C and ~6 kbar with a common subduction setting of the original protolith. The Altân Tepe metamorphics were originally part of a sedimentary sequence with basal basaltic lava flows, which is geochemically characteristic for an island-arc, whereas the geochemistry of metamorphics of the Măcin unit indicates an ophiolite complex containing deep water sediments. Both were subsequently subducted and metamorphosed during the Hercynian collision. These results demonstrate that the Altân Tepe unit is part of the North Dobrogea orogen and the contact with the Moesian platform formed subsequently by the activity of a large offset strike-slip fault. In conclusion, our research in North Dobrogea demonstrates subduction of an island-arc during the Paleotethys' closure, burial and metamorphism, which formed a typical Hercynian orogen containing Middle Triassic high-temperature core complexes, subsequently affected by Late Jurassic – Early Cretaceous Cimmerian oblique thrusting associated with large offset strike-slip in the orogenic core.

Acknowledgements. We acknowledge the ongoing Utrecht collaboration with Alissa Kotowski and her GeoLab colleagues and Peter Luffi for insightful discussions.

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Thermochronological constraints on the thickening-to-extension transition in the eastern Albanides: an Oligocene volcanic marker in the Albanian-Thessalian Basin

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The Albanian-Thessalian Basin is one of the largest intramontane basins of the Internal Albanides, yet its post-depositional thermal evolution remains poorly constrained. We present two previously unpublished low-temperature thermochronological datasets from the Korça sector (SE Albania) of the basin, and use them to reconstruct the tectono-thermal history of the basin from Oligocene deposition through burial, heating and exhumation.

Detrital apatite fission-track (AFT) analysis of a Middle–Upper Oligocene (~28–24 Ma) sandstone from the western part of the basin reveals three grain-age populations centred at 50.1 ± 10.6 Ma, 26.1 ± 4.2 Ma and 14.3 ± 3.3 Ma. The oldest population (50.1 ± 10.6 Ma) records source terranes affected by Eocene cooling. The intermediate population (26.1 ± 4.2 Ma) overlaps, within uncertainty, the depositional age of the host sandstone and is interpreted as a near-syn-depositional detrital signal derived from Oligocene-cooled source terranes possibly including contemporaneous volcanic input, rather than full post-depositional resetting. The youngest population (14.3 ± 3.3 Ma) is younger than the depositional age of the host sandstone and is interpreted as evidence for partial post-depositional resetting within the basin fill.

In the central part of the basin, where the Oligocene succession is structurally elevated within an uplifted block southeast of the city of Korça, a multi-system study of the Boboshtica volcanic tuff yields zircon fission-track (ZFT) and zircon (U-Th)/He (ZHe) ages of 27.8 ± 1.5 Ma and 27.5 ± 0.4 Ma, respectively, together with an apatite (U-Th)/He (AHe) age of 4.2 ± 0.3 Ma. The concordant zircon ages confirm the Oligocene age of the volcanic event and demonstrate preservation of the original volcanic signal, providing an absolute chronostratigraphic tie point within the basin, while the much younger AHe age records final cooling through the apatite helium partial retention zone during the latest stages of basin evolution.

Together, the two datasets reveal a multi-stage evolution: Oligocene basin development and deposition of the volcanic marker, post-depositional burial and heating sufficient to partially reset detrital apatites while preserving the zircon systems of the volcanic tuff, and final latest Miocene-Pliocene exhumation. This late cooling stage is broadly contemporaneous with the rapid exhumation previously documented in the Korabi domain (Muceku et al., 2006, 2008), suggesting a regional tectonic event affecting the eastern Internal Albanides. The Boboshtica volcanic marker thus provides a direct thermochronological archive linking Oligocene basin development to Pliocene exhumation, and offers new insights into the transition from crustal thickening to extensional exhumation in the eastern Albanides.

Cimmerian medium grade metamorphic reworking in the Central Dobrogean basement: structural implications

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The basement of the Central Dobrogea, part of East Moesia, consists of two terms, the very low grade Histria Formation and the underlying medium grade Altın Tepe metamorphic complex, appearing in the hinge of an antiform along the northern tectonic boundary of Central Dobrogea (the Peceneaga-Camena Fault).

Although the Ediacaran age and turbiditic nature of the Histria Formation are well established (Seghedi, 2012 and refs. therein), the geochronology data pertaining to Altın Tepe are scarce, relying only on Neoproterozoic to Early Cambrian K-Ar ages (Giușcă et al., 1967).

Therefore we investigated its U-Th-Pb^I metamorphic age on monazite in a staurolite micaschist from the median terrigenous formation of the complex, by performing *in situ* measurements on a 5-spectrometer Cameca SX100 microprobe operated at high (150 nA) beam current and 20 kV at the former Institut für Mineralogie und Kristallchemie (IMK) in Stuttgart. Major and trace elements were measured during the same session using a set of natural and synthetic standards. The individual analyses were processed according to Săbău (2012) for error propagation from concentration to age data, and pooled in coherent Gaussian domains used for the deconvolution of the age probability distribution function.

The results obtained from 53 individual analyses showed a bimodal distribution with a well-defined Ediacaran peak at 569.8 ± 13.11 Ma (19%) followed by an extended gap and the main cluster ranging from 187.3 ± 10.69 to 170.4 ± 10.08 Ma (60%). The latter marks a hitherto unknown pervasive medium grade Neo-Cimmerian metamorphic overprint, besides underscoring the tectonic relationships between the two building blocks of the Central Dobrogean basement (see also Mureșan, 1971 and Seghedi, 2012).

Although the structural connection between North Dobrogea and the Crimean Mountains during the Mesozoic is a well established fact, as first noted by Munteanu-Murgoci (1911), the presence of a medium-grade Neo-Cimmerian metamorphic sliver with pan-African inheritance exhumed at the boundary between North and Central Dobrogea is surprising.

Acknowledgements. Research supported by grants PN-II-ID-PCE-2011-3-0030 (UEFISCDI) and PN23-39-02-04 (ANC). Hans-Joachim Massonne kindly granted access to the analytical facilities of IMK and Thomas Theye provided invaluable assistance with the microprobe work.

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Continuous palinspastic reconstruction of the Pannonian Basin from nowadays to Oligocene

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The Pannonian Basin system represents a complex Neogene continental back-arc basin system in Central Europe, formed through the interplay of subduction rollback, microplate extrusion, and localized indentation. The present-day configuration of its principal terranes—ALCAPA, Tisza–Dacia, and the Dinarides—reflects large-scale displacements, vertical-axis rotations, and significant intra-terran extension documented by tectonic, paleomagnetic, and stratigraphic studies.

This study presents an initial iteration for continuous, map-view palinspastic reconstruction of the Pannonian Basin from the present back to the Oligocene. The model integrates published paleomagnetic datasets, structural and geometric constraints, and interpretations derived from seismic data. Terranes are subdivided into kinematically coherent blocks, which are restored through time using rotation and translation parameters constrained by paleomagnetic directions and the spatial-temporal evolution of metamorphic core complexes (MCCs). The European Platform is treated as a passive backstop, ensuring geometrically closed restorations throughout the reconstruction process.

Special attention is given to the northeastern sector of the basin system, where the evolution of the North Hungarian and Eastern Slovakian Basin blocks, together with associated Neogene volcanic activity, provides key constraints on regional kinematics. The development of the NE Hungarian volcanic fields and their continuation into the Eastern Slovak Basin is interpreted in the context of extensional deformation linked to back-arc dynamics and slab retreat. These volcanic and sedimentary systems record the timing and geometry of block rotations, extension, and basin opening, and thus represent critical markers for validating the reconstruction.

Acknowledgements. This work was supported by the Hungarian National Research, Development and Innovation Office (No. 145905) and by the MTA–HUN-REN CSFK Lendület “Momentum” Pannonian Volcano Research Group. The research was also supported by MOL Nyrt.

Microstructural records of fluid migration and deformation in the Juhhodályvölgy Marble (Ófalu, Hungary)

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The Goldgrund Valley near the village of Ófalu (SW Hungary) exposes a variety of metamorphosed and mylonitised lithologies, collectively referred to as the Ófalu Metamorphic Complex (M. Tóth et al., 2005; Balla & Gyalog, 2009). These Paleozoic rocks were juxtaposed within a regional shear zone, the Mecsekalja Zone, most likely during the Variscan orogeny. To understand the multi-stage tectonic and hydrogeological history of this region, the present study focuses on the Juhhodályvölgy Marble, which may provide broader insights into the entire metamorphic complex (Dabi et al., 2009, 2011).

Field observations of the marble alongside the adjacent Studervölgy Gneiss and Kövespatak Quartz Phyllite reveal a consistent NE–SW striking metamorphic foliation. This structural coherence suggests that these units were already spatially associated prior to the late Carboniferous–early Permian regional metamorphism (270–303 Ma), as constrained by ⁴⁰Ar/³⁹Ar ages (Lelkes-Felvári et al., 2000). This pre-existing ductile framework was likely reactivated and modified during subsequent brittle deformation phases.

To reconstruct these later events, rock samples from the Juhhodályvölgy Marble were analysed using polarizing and cathodoluminescence (CL) microscopy, Raman microspectroscopy, X-ray fluorescence (XRF) spectrometry, and fluid inclusion microthermometry. While multiple models exist regarding the exact origin of the host rock, petrographic analysis reveals a highly heterogeneous microstructure shaped by repeated episodes of brittle fracturing and subsequent recrystallisation. This brittle deformation generated the secondary permeability necessary for subsequent fluid migration. Micro-scale analyses combined with orientation data distinguish two main generations of mineral veins. One set aligns with the NE–SW striking foliation, while the other is oriented nearly perpendicular to it. Most veins display syntaxial textures composed of elongate blocky and blocky calcite crystals. CL imaging indicates that the NE–SW striking veins formed through a single-stage precipitation event. In contrast, the NW–SE striking veins record a dual-stage cementation history: an early phase of orange-luminescent calcite along the vein walls, followed by dark blue-luminescent overgrowths.

Integrated microstructural and microthermometric data indicate a multi-stage post-metamorphic history. The individual vein systems opened in multiple discrete stages, frequently incorporating oxidised wall-rock inclusions. Fluid inclusion microthermometry shows that the initial vein precipitation involved low-salinity (~0.71 wt.% NaCl eq.) fluids, presumably forming at shallow crustal depths. However, calcite crystals within the veins — which are strictly absent in the host rock matrix — display Type I–IV deformation twins. This feature indicates a late-stage deformation exceeding 250 °C. This subsequent deformation potentially caused the natural stretching of primary fluid inclusions; consequently, the measured values do not reflect “true” homogenisation temperatures. In conclusion, the results show that the Juhhodályvölgy Marble records a complex structural evolution: ductile regional metamorphism, followed by shallow brittle exhumation with low-salinity fluid influx, and a later >250 °C tectonic reactivation.

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Insights into the role of mobile shales in the Romanian Eastern Carpathians fold-and-thrust belt

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Fold-and-thrust belts comprising mobile shales and salt within their stratigraphy cause significant challenges for structural analysis, especially for subsurface interpretation (e.g. Soto et al. 2021). Salt and shale commonly act as décollement levels, controlling the structural style and shaping the geometry of the fold-and-thrust belt (e.g. Couzens-Schultz et al. 2003; Koyi and Mansurbeg 2021). The coexistence of both mechanically weak layers further complicates deformation patterns, leading to a diverse range of structures and uncertainties in subsurface interpretation (e.g. Butler et al., 2025). While the role of salt has received considerably more attention in the Romanian Eastern Carpathians (e.g. Schleder et al. 2019; Tămaş et al. 2020), the role of shales is generally overlooked. Most available cross-sections suggest a forward-propagating sequence of thrust faults involving the entire stratigraphy, yet many present geometric and kinematic challenges.

This study combines field observations and scaled analogue modelling to assess the role of shales in the structural style of the Eastern Carpathian fold-and-thrust belt and to investigate the key parameters controlling deformation. Particular attention is given to thin brittle sandstone units occurring between mechanically weak shale or salt detachments. Field observations identify three major shale intervals within the Lower Cretaceous, Upper Eocene-Oligocene, and Lower Miocene successions, commonly characterized by chaotic fabrics, foliated anastomosing shear zones, hydraulic fracturing, and intense folding.

The analogue experiments show that the structural style varies depending on the mechanical properties and geometry of the detachments. The supra-detachment sequence is characterized by lift-off box folds, triangle zones, and imbricate stacks, whereas the strata between detachments develop decoupled disharmonic buckle folds, recumbent anticlines, and faulted folds. These shorter-wavelength structures are decoupled from the longer-wavelength underlying sequence. The combined field observations and analogue modelling demonstrate that shales play a key role in vertical decoupling, localized folding, and structural compartmentalization, providing a better-constrained framework for subsurface interpretation and the prediction of subsurface structures relevant for energy resources.

Acknowledgements. The work of D.M.T. and A.T. was supported by a grant from the Ministry of Research, Innovation, and Digitization, CNCS - UEFISCDI, project number PN-IV-P2-2.1-TE-2023-0402, within PNCDI IV.

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Late Pliocene – Quaternary structures of the Western Black Sea shelf

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The development of a siliciclastic shelf is controlled by the interplay between accommodation space generation, sediment supply, and climatic conditions, particularly in the source area. The processes and mechanisms responsible for the formation of continental slopes are recorded in their geometry and lithological architecture; therefore, their analysis is essential for understanding their evolution.

For the Romanian sector of the Black Sea, relatively few studies have addressed this topic in detail, and most of them were published more than a decade ago. In this study, we use a dense network of 2D seismic lines from previously published datasets to map and characterize seismic features and facies, and to define their sedimentary and stratigraphic significance.

Our interpretation focuses on the Late Pliocene–Quaternary architecture of the shelf–slope–deep-water system in the Romanian Black Sea. This interval is crucial for understanding the geological evolution of the basin, as the northwestern continental shelf prograded tens of kilometers into the basin over a relatively short period of time. This rapid progradation suggests accelerated basin subsidence, coeval with an increased sediment supply previously trapped within the Dacian Basin and subsequently released following a sea-level fall, before being transported into the Black Sea through the Scythian Gateway.

Our seismic interpretation reveals several higher-order depositional sequences within the Pliocene–Quaternary succession, bounded by sequence boundaries and their correlative surfaces, which have been mapped across the Romanian shelf. In addition, we performed a seismic facies analysis of the internal architecture of the deep-water deposits, distinguishing four main facies: mass-transport complexes, channel–levee systems, frontal splays (lobes), and pelagic sediments.

The analysis of the sedimentary architecture provides essential information on sediment sources, transport pathways, and depositional processes. The results contribute to clarifying aspects of the evolution of the Romanian continental slope that have not previously been investigated in detail and provide the basis for the development of a comprehensive genetic and evolutionary model of the Romanian continental slope in the Black Sea over the last 6 Ma.

New structural data in the area of the Badenian salt deposit from Slănic Prahova (Romania)

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The instability phenomena (which occurred in the years 2023 and 2024) within the city of Slănic Prahova (collapse cones) led us to more detailed research (scale of 1:5,000) of the area related to the Badenian salt deposit developed here, research conducted during 2024 (preliminary map) and 2025 (Geomonitor project). The new map obtained through field mapping reflects, as accurately as possible, the area of extension of the Lower Badenian deposits (tuffs, marls, gypsums), of the Middle Badenian deposits (Salt Formation with salt and marls), of the Upper Badenian deposits (Shales with Radiolarians and Marls with Spiratella), but also of the pre-Badenian deposits ones (Oligocene and Burdigalian). But this map includes a significant number of faults, with very different orientations, highlighted for the first time in this area. Faults with NW-SE, NE-SW, NNW-SSE, WNW-ESE and ENE-WSW orientations are especially distinguished. But segments of faults with other orientations were also highlighted (E-W, NNE-SSW). The faults located in the mining area on the left slope of the Slănic Valley, taken from the documentation of the salt mine Slănic (signed Maria Milea) have been integrated into the dislocation systems highlighted by us. To the northwest part of the researched area the reverse Tâncava fault is noticeable and along this fault the Lower Badenian deposits, located below the plane of this fault, are tightly folded as an effect of the New Styrian tectonic phase, manifests prior to the accumulation of the Badenian salt lens. Along a WNW-ESE trending fault is located the Baia Roșie on the site of a former natural karstic lake which appeared here as a result of an earthquake in 1893. Other sinkholes that reflect the natural karst of the salt deposit Slănic are inscribed on faults with different orientations (NNW-SSE, NW-SE – the collapse cone from 2023, or with other directions). The collapse cone of April 2024 is also placed along a NNW-SSE trending fault which affects the reverse Tâncava fault to the northwest. This fault (NNW-SSE) was highlighted on a certain segment through a microgravimetry study. All these observations support the idea of an obvious structural (tectonic) control over the natural salt karst of this area. At the same time, it can be stated that all natural exokarst forms observed by us have no connection with salt exploitation works at Slănic (old or modern). Instead in this area they are well known the exokarstic forms (sinkholes) of anthropic nature due to the old mining operations (such as Ocna Veche, Băile Verzi, Ocna Dorobănești or those from Sistemica zone). The major plicative structure in this area, the Slănic syncline, with general direction east–west, are axial ups and downs, but also an axial plane with a sinuous path. The Badenian salt deposit of Slănic has a pillow shape which corresponds to an incipient diapirism. A variant of a cartographic interpretation of the area with lower Pleistocene deposits (gravels) located on the ridge east of Slănic could illustrate clear effects (faults) of the Pasadenian tectonic phase.

Petrography and evolution of tectonic veins from the Bkf–5 borehole of the Mórág Metagranite Complex, Hungary

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The brittle structural evolution and fracture-filling mineralisation of crystalline rocks provide important constraints on long-term fluid migration and tectonic reactivation in the upper crust. This is particularly relevant in the context of geological repositories, where fracture networks may control the fluid migration pathways.

This study investigates tectonic veins and associated brittle structures in the Bkf–5 borehole near the Bataapáti radioactive waste repository, within the Mórág Metagranite Complex of southern Hungary. The host rock represents a Variscan granitoid basement unit affected by multiple phases of magmatic, metamorphic, and brittle deformation. The primary objective of the study is to reconstruct the paragenetic sequence of vein mineralisation, as well as to interpret the relative timing and conditions of fluid migration and deformation events recorded in the rock body.

The rock samples were examined using polarised light microscopy, carbonate staining, cathodoluminescence (CL) microscopy, and Raman microspectroscopy. These methods enabled the detailed petrography of the monzogranite host rock, vein textures, cement minerals and deformation microstructures.

As a result, a minimum of eleven distinct cementation phases were identified, revealing a complex history of repeated fracture opening and mineral precipitation. The earliest vein-forming event is represented by syntaxial, inclusion-rich elongate blocky calcite crystals that nucleated on fracture walls and grew toward vein centres. These early calcite crystals were commonly overgrown by fine-grained calcite and later by dolomite. Subsequent stages include space-filling calcite, fluorite, and quartz precipitation. The youngest phases include iron-rich fine-grained calcite and late microvein networks. CL imaging revealed systematic variations in luminescence colour and intensity, allowing the discrimination of multiple cement generations and fluid migration events.

Structural observations indicate that fracture evolution was controlled by shear and extensional deformation, as evidenced by slickenfibres, microbreccias, and syntaxial vein textures. These features record repeated episodes of fluid migration through an evolving fracture network.

Overall, the results demonstrate that the Mórág Metagranite Complex experienced multiple episodes of fluid migration and fracture reactivation, producing a complex multi-stage vein system. The reconstructed paragenetic sequence provides new insights into the long-term hydrogeological evolution of fractured crystalline basement rocks relevant to potential geological repository settings.

Acknowledgements. The authors thank Public Limited Company for Radioactive Waste Management (RHK Kft.) for providing the investigated samples and for permission to publish the results of this study.

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Session GS16

Geochronology and isotope geochemistry

Conveners:

Réka Lukács, Alida Gabor, Constantin Balica

Radiocarbon dating of climatic and environmental records — applications and prospects for the development of preparation methods

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From the early days, radiocarbon dating was the most valued method for dating archives of past climatic and environmental changes (Hajdas *et al.*, 2021). Analytical developments, as well as the advent of accelerator mass spectrometry (AMS) after the first three decades, led to even wider use of this method in geochronology. For example, in the late 1980s, ¹⁴C ages of selected individual foraminiferal species were measured, allowing for improved chronologies of marine sediments. Radiocarbon dating of terrestrial macrofossil fragments extracted from lake sediments eliminated the problem of hard water effects in lakes. These and other examples accelerated progress in climate research and paved the way for even more sophisticated developments in AMS techniques, enabling the analysis of samples as small as tens of micrograms of C. The presentation will explore the applications of ¹⁴C dating to the chronologies of various archives (marine and terrestrial) that have been crucial for climate research, such as dating late glacial boundaries or dating anthropogenic sediments. The practical application of radiocarbon dating is found in many research disciplines (Hajdas *et al.*, 2021).

The accuracy and precision of radiocarbon dating results depend largely on sample selection and proper sample preparation (Hajdas *et al.*, 2024). The importance of this first step in the ¹⁴C analysis will be highlighted. The presentation will discuss the application of ¹⁴C dating to the chronologies of various archives (marine and terrestrial), which have been crucial for climate research, such as dating late glacial boundaries or dating anthropogenic sediments. The potential of modern carbon isotope analysis will also be explored, as well as the challenges encountered in studying past climate and the environment.

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Geochronology and geochemistry of alkaline intrusive rocks from Poiana Mărului – Șinca Nouă

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This study presents zircon U–Pb geochronology and whole-rock geochemistry for a suite of evolved alkaline magmatic rocks from the Poiana Mărului–Șinca Nouă area, exposed along the Vulcănița and Tifa valleys. The intrusions occur mainly as dykes and veins emplaced within the metamorphic rocks of the Supragetic Formation and are generally parallel to the valley orientations (Săndulescu, 1984; Savu *et al.*, 1981). Both mafic and felsic lithologies are present; however, this study focuses on the felsic varieties due to their higher zircon abundance.

Whole-rock major, trace and rare earth elements were determined using X-ray fluorescence (XRF) and LA-ICP-MS on homogenized glass beads. The analysed samples range in composition from trachytes to rhyolites. The rocks are characterized by negative Ti anomalies, positive Pb anomalies, and only weak Nb–Ta depletion. Chondrite-normalized REE patterns display strong LREE enrichment relative to HREEs, resulting in steeply fractionated profiles typical of evolved alkaline magmas.

Zircon crystals were separated using standard methods, including crushing, milling, sieving, magnetic separation and heavy liquids (sodium polytungstate). U–Pb analyses were performed by LA-ICP-MS using an Iridia Excimer Laser coupled to a Thermo iCAP RQ single quadrupole ICP-MS. Analytic conditions consisted of 20 s ablation and 20 s washout intervals.

The primary reference material used was SLF (Sri Lanka Zircon), whereas Plešovice and FC-1 zircons were used as secondary standards. Concordia and weighted mean ages range from 177 to 162 Ma, indicating a Middle to Late Jurassic magmatic event. Zircon Th/U ratios are consistently greater than 0.3, with an average value of approximately 0.6, supporting a magmatic, possibly extensional origin. These results provide new constraints on Jurassic alkaline magmatism in the South Carpathians and suggest emplacement in an extensional tectonic setting, potentially linked to the opening of the Ceahlău–Severin Ocean.

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Low-temperature thermochronology on magmatic rocks associated with Chelopech Cu-Au deposit, Bulgaria

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The Chelopech high-sulphidation epithermal Au-Cu deposit is part of the Panagyurishte Ore District in Bulgaria. It is situated within the Late Cretaceous Apuseni-Banat-Timok-Sredna Gora metallogenic belt. The time of the magmatic and ore-forming events in the Chelopech area were previously well constrained by zircon U-Pb geochronology at 92.5–91 Ma. Hydrothermal alteration and ore formation as well as deposit preservation were structurally controlled and related to the activity of the Petrovden fault that displaced the deposit. After this Late Cretaceous magmatic and metallogenic event, the region was subjected to compression during Late Alpine time resulted in the emplacement of the Chelopech thrust. The thrusting was followed by a regional extension starting from the Eocene.

Here we provide the results of the first apatite fission-track (FT) together with biotite, K-feldspar and amphibole ⁴⁰Ar/³⁹Ar multiple single grain fusion analysis on the Late Cretaceous magmatic rocks associated with the Chelopech deposit. These rocks were sampled in aim to reveal the post-magmatic/metallogenic evolution of the area and to give constraints for the Late Alpine fault activity that is of crucial importance for the accommodation, preservation and/or erosion of the deposit.

The obtained results reveal at least three major cooling episodes since the Late Cretaceous. The ⁴⁰Ar/³⁹Ar weighted mean ages of 92.12 ± 0.60 Ma (amphibole) and 89.17 ± 0.34 Ma (biotite) are interpreted as representing the time of cooling below 500 °C and 300 °C after the emplacement of the sampled magmatic bodies. The ⁴⁰Ar/³⁹Ar weighted mean age of 78.28 ± 0.45 Ma (K-feldspar) could be related to cooling after a tectonic (e.g. initial activity along Petrovden fault) or magmatic event at this time.

Four rock samples yield apatite FT ages between 48.6 ± 4.1 Ma and 37.7 ± 3.7 Ma. The confined mean track lengths are between 13.83 ± 1.53 µm and 14.46 ± 1.09 µm. The Dpar values vary from 2.27 µm to 2.61 µm (with standard deviation of approx. 0.30 µm). Modelling of the apatite fission track data using HeFTy software revealed two stages of rapid cooling below 120 °C — the first one between 52 and 45 Ma probably related to the syn- to post-Late Alpine thrusting denudation and the second one between 38 and 35 Ma triggered by the post-orogenic middle to late Eocene extension and exhumation. The modelling of one sample revealed another later stage of rapid cooling between 22 and 20 Ma related to the post-orogenic Miocene exhumation and extension.

Acknowledgements. This work has been carried out in the framework of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers № 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria. We are grateful to DPM Metals Chelopech for their technical support and co-operation during the field work, sampling and discussion of the results.

Detrital zircon evidence for improved age constraints and sediment provenance changes during the marine-to-continental transition in the Upper Cretaceous Bozeş and Sebeş formations, southwestern Transylvanian Basin (Romania)

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The southwestern Transylvanian Basin preserves one of the most complete Upper Cretaceous marine-to-continental successions in southeastern Europe. Exposed in the Petreşti-Arini area, the transition from the marine Bozeş Formation to the continental Sebeş Formation records sea withdrawal and emergence of the Haţeg Island landmass (Vremir *et al.*, 2014). Recent biostratigraphic studies constrained the age of the marine part of the succession to the late Campanian, and demonstrated that continental environments became established earlier than previously assumed, in the later part of the late Campanian (Bălc *et al.*, 2024). Meanwhile, the age of the overlying Sebeş Formation is established less rigorously, assumed to cover either part of, or else the entire Maastrichtian (Vremir *et al.*, 2015).

To investigate depositional timing as well as sediment provenance and source-area evolution during this transition, we acquired detrital zircon U–Pb ages from samples collected at Petreşti from the uppermost Bozeş Formation, including the transitional interval, and the lowermost Sebeş Formation, as well as from successively younger continental beds exposed at Sebeş-Glod, Lancrăm and Oarda de Jos.

The detrital zircon spectra reveal a persistent provenance signal dominated by sources located within the Getic and Supragetic units of the Southern Carpathians. However, the abundance of Banatitic (i.e. Late Cretaceous) magmatic zircons varies significantly throughout the succession. The marine Bozeş samples contain only a minor proportion of relatively old Banatitic zircons, whereas the transitional interval records a pronounced influx of late Campanian Banatitic material. In contrast, Banatitic zircons become absent from the overlying lowermost Sebeş Formation samples at Petreşti-Arini. Surprisingly, Banatitic zircons reappear in the younger continental deposits from Sebeş-Glod, Lancrăm and Oarda, indicating renewed sediment supply from Banatitic sources after a period of apparent exclusion.

The youngest detrital zircon populations yield maximum depositional ages ranging from approximately 79 Ma in the upper Bozeş Formation to 74.5 Ma in the Sebeş-Glod–Lancrăm outcrops, further reinforcing, even improving, recently proposed late Campanian chronologies for the emergence of the Transylvanian Landmass. The observed fluctuations in Banatitic zircon abundance suggest short-lived but significant reorganizations of sediment-routing systems during the final stages of marine regression and subsequent early-stage continentalization. These results provide new constraints on the paleogeographic evolution of the southwestern Transylvanian Basin and highlight the dynamic relationships between tectonic uplift, volcanic activity, drainage reorganization, and sediment dispersal during the advent of Haţeg Island ecosystems.

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Optical bleaching of ESR centres in natural quartz: implications for ESR dating

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Electron Spin Resonance (ESR) signals in quartz are important proxies for assessing optical resetting and equivalent dose in geochronology and sediment provenance studies, as different paramagnetic centres exhibit distinct responses to radiation and light exposure. Among these, E' and peroxy centres are widely used for provenance analysis, whereas Ti-related centres and the aluminium-hole centre ($[\text{AlO}_4/\text{h}]^0$) are used in ESR dating. Although the multiple-centre approach, using both $[\text{TiO}_4\text{-Li}^+]^0$ and $[\text{AlO}_4/\text{h}]^0$ signals, is routinely applied to evaluate signal resetting prior to age determination, the extent to which each ESR centre can be optically bleached remains a central unresolved question. Previous studies have reported substantial residual signals for $[\text{AlO}_4/\text{h}]^0$ even after prolonged optical exposure, creating challenges for dating (Timar-Gabor et al., 2020).

In this study, we investigate the bleaching behaviour of four ESR centres (E', peroxy, $[\text{TiO}_4\text{-Li}^+]^0$, and $[\text{AlO}_4/\text{h}]^0$) in natural quartz extracted from rock and sediment samples representing diverse geological provenances worldwide. Samples were measured with their natural dose and after the addition of a 40,000 Gy laboratory dose to evaluate the role of prior dose history on bleaching efficiency. One representative sample was also used to examine the effect of optical exposure on the ESR dose response curve.

The results reveal clear centre-specific bleaching behaviour. The most significant finding is that $[\text{TiO}_4\text{-Li}^+]^0$ centres bleach completely, whereas $[\text{AlO}_4/\text{h}]^0$ signals remain largely unbleachable, retaining substantial residual intensities that increase with the previously absorbed dose.

These findings provide new insights into the optical stability of quartz ESR centres, highlighting the challenges of the $[\text{AlO}_4/\text{h}]^0$ centre for ESR dating and emphasizing the importance of dose history when interpreting ESR signals in quartz. At the conference, the fundamentals and current challenges of ESR dating will be discussed, along with future perspectives for improving the application of quartz ESR systems.

Acknowledgements. This research is funded by the European Research Council (ERC) Consolidator Grant PROGRESS-CoG, “Reading provenance from ubiquitous quartz: understanding the changes occurring in its lattice defects in its journey in time and space by physical methods”.

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Re-Os geochronology and provenance of graphitized carbonaceous clasts from Middle Permian conglomerates, Ochindol Formation, West Balkan Zone, Bulgaria

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Siliciclastic sedimentary sequences deposited mainly in continental environments unconformably overlie the Late Paleozoic metamorphic greenschist basement of the West Balkan Zone. Within the Berkovitsa Unit, these sedimentary sequences host variably sized clastic sediments of presumed Late Carboniferous – Early Permian age as inferred from fossilized plant findings (Yanev and Tenchov, 1978). In contrast to other coal-bearing formations, the argillaceous-terrigenous Ochindol Formation contains deformed coal lenses. The biostratigraphic age of the Ochindol Formation has been assigned to the Late Stephanian (~304–299 Ma), but recent U-Pb detrital zircon geochronology of these conglomerates yields a maximum age of deposition at 268 Ma (see Vladinova et al., this volume). This study reports preliminary Re-Os ages of partially graphitized clasts of carbonaceous material (CM) from the Ochindol conglomerate and their significance for reconstructing Late Paleozoic metamorphic events.

The CM clasts were sampled near the lower unconformable boundary of the Ochindol conglomerate with the underlying Late Paleozoic volcanic rocks, near the Ignatitsa village. Raman spectroscopy carried out at the Faculty of Physics, Sofia University reveals varying degree of thermal maturity, between 238–380 °C (Kouketsu et al., 2014). Carbon isotopic composition of the CM-bearing clasts was determined by EA-IRMS at the University of Calgary. The $\delta^{13}\text{C}$ varies slightly, from –26.9 to –25.5 ‰, within the expected range of biogenic sources.

Representative, albeit heterogeneous, conglomerate powders were spiked and digested in chromic acid. The Re and Os were extracted and measured by N-TIMS at AIRIE following established procedures. Re-Os data define a diffuse array with positive slope in Re-Os isochron space with scatter likely caused by mixed organic reservoirs, degree of graphitization, and/or heterogeneity among outcrop samples. Nonetheless, a preliminary three-point regression yields 287 ± 17 Ma providing a tenable age for the CM formation and basis for further Re-Os investigation.

Although the uncertainty overlaps the biostratigraphic age of the Ochindol Formation, the obtained Re-Os age is also consistent with a (neo-)Variscan greenschist facies metamorphic event reported for the study area. The lower limit of this event is constrained by a 294 Ma U-Pb zircon age for the Rzhana granite (Bonev et al., 2026) and the upper limit is defined by the maximum age of deposition of the CM-bearing Ochindol Formation at 268 Ma.

Acknowledgements. This study was funded by the Bulgarian National Science Fund, contract KP-06-N74/4.

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Electron-beam dose dependence of the non-bridging oxygen hole centre in quartz across diverse rocks and sediments revealed by scanning electron microscopy: potential implications for provenance and thermochronology

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Despite being one of the stoichiometrically purest minerals (ideal formula SiO_2), quartz exhibits various intrinsic and impurity-related defects that contain important genetic information. We report scanning electron microscopy (SEM) coupled with cathodoluminescence (CL) wavelength-resolved spectroscopy on quartz from different rock types spanning a wide range of geological settings and ages to investigate defect phenomena. All samples show two main emissions: a red band at ~ 1.93 eV (~ 643 nm), attributable to non-bridging oxygen hole centres (NBOHC) defects, and a blue band at ~ 2.7 eV (~ 450 nm), explained by Ti-related defects. The origin of NBOHCs is relatively well understood and may result from intrinsic mechanisms or extrinsic pathways involving radiolysis of passivated precursor sites such as hydroxyl-related defects. Radiation-damage experiments under controlled electron irradiation in SEM provide a tool to study defect formation dynamics. We investigate the evolution of the NBOHC defect at different irradiation times (electron doses). CL acquired during SEM irradiation shows monotonic growth of the ~ 1.9 eV emission described by the sum of two saturating exponentials, interpreted as coexistence of hydroxyl-mediated defect generation and intrinsic rupture of Si-O-Si bridges or peroxy Si-O-O-Si linkages. SEM-induced NBOHC luminescence is therefore controlled by the balance between hydrogen chemistry and intrinsic bond rupture, reflecting quartz geological type. The initial CL intensity records the natural balance among α -radiation damage, thermal resetting, and hydrogen passivation. These relations suggest CL from the NBOHC as a potential quartz-intrinsic provenance indicator or thermochronometer.

Acknowledgements. This research is funded by European Research Council ERC grant PROGRESS-CoG “Reading provenance from ubiquitous quartz: understanding the changes occurring in its lattice defects in its journey in time and space by physical methods”.

Geochemistry of CO₂-rich gas emissions in the Carpathians: multiscale geological sources and implications for orogenic degassing

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Degassing of deep-seated fluids is a key process in orogenic systems, yet its sources and controlling mechanisms remain poorly constrained. The Carpathians form one of Europe's largest continuous orogenic belts (~1300 km) and a major degassing province, yet have been largely absent from global degassing surveys. We present the first orogen-scale geochemical dataset and map of CO₂ and CH₄ emissions across the Western and Eastern Carpathians, integrating chemical and isotopic analyses with lithological and structural constraints. CO₂ emissions concentrate in the Neogene–Quaternary volcanic arc and in carbonate-rich flysch nappes along tectonized suture zones (e.g. Magura, Pieniny, Ceahlău-Severin), whereas mostly thermogenic CH₄ dominates the Outer Flysch belt.

Helium isotopes reveal variable mantle-crustal mixing: elevated R/R_a values (>3) near long-dormant volcanic centres, especially Ciomadul, reflect persistent deep magmatic reservoirs supplying 60–70% mantle/magmatic ³He, whereas radiogenic ⁴He dominates non-volcanic flysch and metamorphic regions (R/R_a ~0.02). CO₂ is the primary carrier of mantle He, but metamorphic devolatilization of marls and carbonates at 5–20 km depth, supported by thermodynamic modelling, provides the principal crustal CO₂ source, consistent with “orogenic CO₂ degassing” in other collisional belts. Carbon isotopes and CO₂/³He ratios indicate heterogeneous, largely non-biogenic carbon sources along a mantle–limestone mixing line, with crustal-derived CO₂ of 80–95% in non-volcanic areas and 40–70% in volcanic areas. Degassing sites cluster along nappe boundaries and fault zones, where enhanced permeability enables rapid volatile ascent.

Calculated mantle-derived He fluxes reach 1.59×10^{-13} g m⁻² s⁻¹ at Ciomadul, up to three orders of magnitude above stable continental crust. Combining He fluxes with CO₂/³He yields a total mantle-derived CO₂ flux of 4.66 Mt yr⁻¹ for the Carpathians (~100,000 km²), comparable to other active orogens. The Carpathians share the volatile-geochemical signature of other Tethyan orogens (Pyrenees, Alps, Caucasus, Himalayas), establishing them as a globally significant degassing province and a key natural laboratory for quantifying deep-Earth contributions to the global carbon cycle.

Acknowledgements. B.M.K. acknowledges funding from the János Bolyai Research Scholarship of the Hungarian Academy of Sciences and from the research project of the MTA–HUN–REN CSFK Lendület “Momentum” Pannonian–Volcano Research Group, supported by the Hungarian Academy of Sciences (grant nr. LP2024-9/2024).

Evaluation of conventional quartz extraction protocols for optically stimulated luminescence (OSL) dating by scanning electron microscopy (SEM) coupled with energy dispersive X-ray (EDX) spectroscopy

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Quartz purity is essential for reliable optically stimulated luminescence (OSL) dating, yet the mineralogical evolution of sediment samples during extraction is rarely documented at each preparation stage. This study uses scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM–EDS) to characterise two loess samples from the Urluia section, Dobrogea, Romania, across sixteen successive stages of a standard OSL quartz extraction protocol. Four compositional indices — the Quartz Purity Index (QPI), Feldspar Contamination Index (FCI), Heavy Mineral Index (HMI), and Carbonate Index (CI) — are introduced to quantify purification efficiency. Each preparation stage contributed differently: HCl treatment primarily removed carbonates, grain-size separation and density fractionation reduced heavy minerals by ~99%, and feldspar removal resulted from the combined effects of density separation and HF etching. Despite identical protocols, two samples collected from stratigraphically adjacent positions showed markedly different HF etching efficiencies, reaching ~94% and ~66% quartz purity, respectively. However, luminescence measurements showed similarly weak feldspar signals in both samples, with intensities substantially lower than the quartz OSL signal. These results demonstrate that purification efficiency cannot be assumed to be uniform across samples and highlight SEM-EDS as a practical quality-control tool for OSL sample preparation.

Acknowledgements. This research is funded by European Research Council ERC grant PROGRESS-CoG “Reading provenance from ubiquitous quartz: understanding the changes occurring in its lattice defects in its journey in time and space by physical methods”.

The age of the Akçaabat gold deposit in the Menderes Massif, western Anatolia, Türkiye: evidence from in situ Rb-Sr dating of K-bearing minerals

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The Akçaabat gold deposit is mainly composed of massive arsenopyrite veins in strongly foliated augen gneisses of the Çine Sub-massif in western Turkey. K-bearing minerals from orogenic gold veins were dated by the in situ Rb-Sr method in order to determine the formation age of the Akçaabat gold deposit. Textural relationships between the vein minerals suggest that arsenopyrite, K-feldspar, quartz, and muscovite formed in one paragenetic stage. Native gold, native bismuth, scorodite, and galena were introduced in a later paragenetic stage. The isochron derived from K-feldspar and muscovite occurring in the veins yielded 31.3 ± 4.7 Ma. In situ Rb-Sr dating of the same assemblage (K-feldspar and muscovite) in the host rock gave an isochron age of 40.8 ± 3.8 Ma, 10 Ma older than the vein ages, and corresponding to peak metamorphism of the regional main Menderes metamorphism during the Alpine-Himalayan orogenic event. Biotite from the host rock gave an isochron age of 28.1 ± 2.2 Ma and probably reflects the cooling age. Homogenization temperatures from fluid inclusions in quartz show that quartz formed at 280–390 °C but has a dominant mode in the 350–360 °C temperature interval. The age of vein formation was successfully distinguished from the age of the Alpine-Himalayan orogenic event associated with main Menderes metamorphism. This study demonstrates that in situ Rb-Sr isotopic method can be applied to resolve absolute dating of orogenic deposits in metamorphic complexes.

Acknowledgements. VBE wishes to acknowledge SIDA (the Swedish International Development Cooperation Agency) for the Minor Field Studies (MFS) scholarship, which made eight-week field work in Türkiye possible. The authors gratefully acknowledge Tolga Oyman for his help with sample preparation and fluid inclusion analyses.

Provenance of the Jurassic Bayırköy Formation in the western Sakarya Zone, NW Türkiye: trace element composition and U-Pb ages of detrital rutiles

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This provenance study focuses on detrital rutile grains from Jurassic sandstones of the Bayırköy Formation in the western Sakarya Zone. The Jurassic Bayırköy Formation is exposed in the western part of the Sakarya Zone, which is chiefly composed of sandstone with alternations of conglomerate, mudstone and marl. Herein, we present trace element geochemical and LA-ICP-MS U-Pb data of detrital rutile grains from Jurassic sandstones of the Bayırköy Formation to characterize and differentiate potential source lithologies. The Jurassic sandstones are yellowish brown-colored, medium- to coarse-grained and well-bedded. Cr and Nb concentrations of detrital rutile grains in the Jurassic sandstones vary from 6 to 6855 µg/g and 37 to 13440 µg/g, respectively. According to the Cr-Nb discrimination, the great majority of detrital rutile grains (77%) are sourced from metapelitic rocks such as mica schist and paragneiss, the rest of detrital rutile grains (23%) are derived from metamafic rocks such as amphibolite, eclogite and metagabbro. Trace element composition of detrital rutile grains demonstrates that the source rock lithology is predominantly metapelitic in origin. The Zr-in-rutile temperatures range from 471 °C to 798 °C with an average temperature of 635 °C at P = 10 kbar, which indicates amphibolite-facies metamorphic conditions. The U-Pb age data of detrital rutile grains range from 346 Ma to 313 Ma, which yield the age of metamorphism for the potential source rocks of detrital rutile grains in the Sakarya Zone. Trace element compositions, Zr-in-rutile thermometer and U-Pb rutile geochronology show that detrital rutile grains were predominantly derived from early Carboniferous rocks that underwent metamorphism under amphibolite-facies conditions. Exposures with Variscan amphibolite-facies metamorphic basement rocks can be assumed as likely sources for these sandstones in the Jurassic Bayırköy Formation. Amphibolite-facies metamorphic rocks in the Sakarya Zone seem to be the primary source lithologies for the detrital rutile grains in the Jurassic sandstones. Another conceivable source for detrital rutile grains could be syn- to post-tectonic Carboniferous granites, mesothermal gold deposits and granite-pegmatite-hosted W-Sn mineralization, owing to elevated Sn and W concentrations in detrital rutile grains.

Acknowledgements. This study was supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK) grant 124Y293 and the Scientific Research Coordination Unit of Çanakkale Onsekiz Mart University under the project number FBA-2023-4284.

High-resolution laser ablation mapping and stable isotope analysis of cryogenic cave carbonates from Scărișoara Ice Cave, Romania

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Cryogenic cave calcite (CCC) is a relatively rare secondary cave deposit that forms in periglacial environments when drip water freezes and expels dissolved constituents, predominantly as calcium carbonate. Although the formation mechanism of CCC has been recognized for several decades, previous work has largely focused on deposit morphology and bulk stable isotope composition.

In this study, we investigate the elemental and stable isotopic characteristics of cryogenic cave carbonate “pearls” from Scărișoara Ice Cave, Romania. Samples were collected from locations within the cave where active drip water occurs. Individual pearls (millimeter- to centimeter-scale) were embedded in epoxy resin, sectioned, and analyzed along polished surfaces. The spatial distribution of trace elements, particularly those likely derived from atmospheric deposition rather than bedrock sources, was characterized using laser ablation inductively coupled plasma time-of-flight mass spectrometry (LA-ICP-TOF-MS). Elemental mapping was performed with a Teledyne Photon Machines Iridia 193 nm excimer laser coupled to a Nu Instruments Vitesse TOF-ICP-MS. Stable isotope compositions ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) were measured using laser ablation isotope ratio mass spectrometry (LA-IRMS), employing a Photon Machines Fusions CO₂ laser coupled to a Sercon HS2022 IRMS.

The elemental data reveal pronounced internal zoning within the CCC deposits. Layers indicative of detrital input — defined by elevated ^{89}Y and low $^{48}\text{Ca}^{+}/^{28}\text{Si}^{+}$ ratios — alternate with chemically homogeneous layers. Notably, detrital-rich layers frequently contain 3–5 μm particles enriched in gold (Au). These particles are interpreted as anthropogenic in origin, likely transported by wind from nearby regions with a history of intensive gold mining.

New U-Pb detrital zircon geochronology of the Late Paleozoic Ochindol and Vranska Formations in the vicinity of Zverino Village, West Balkan Zone, NW Bulgaria

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The West Balkan Zone exposes a Neoproterozoic–Cambrian low-grade crystalline basement unconformably overlain by Late Paleozoic–Mesozoic siliciclastic cover sequences. The Late Carboniferous Ochindol Formation comprises conglomerate, sandstone, siltstone, and coal argillite deposited in alluvial–fluvial settings (Yanev et al., 1978 and references therein), while the stratigraphically younger Vranska Formation consists predominantly of breccia-conglomerate of proluvial fan origin, and of Early Permian age inferred from regional stratigraphy. We present new U-Pb detrital zircon data for both formations, providing the first age constraints on their maximum depositional ages (MDA).

Detrital zircons from the Ochindol Formation are predominantly euhedral to subhedral, with subordinate rounded grains. The ²⁰⁶Pb/²³⁸U ages of detrital zircons from the Ochindol Formation range between 2512 Ma and 268 Ma, but are mostly grouped into one clearly defined peak by the dominant Carboniferous–Permian populations with concordant clusters at 340.2 ± 8.5 Ma, 303 ± 1.8 Ma, 297 ± 1.6 Ma, 279.1 ± 1.6 Ma, 268.2 ± 2.6 Ma. Another less prominent peak is defined by Neoproterozoic zircons ranging within 625–599 Ma. The youngest population of concordant zircons delivers a MDA of 268.2 ± 2.6 Ma for the Ochindol Formation.

Detrital zircons from the Vranska Formation range from euhedral to well-rounded. The ²⁰⁶Pb/²³⁸U ages of zircon populations from breccia-conglomerate of the Vranska Formation vary widely within age interval 2987–247 Ma pointing to three prominent peaks: 1) a peak of Carboniferous–Early Permian ages with concordant clusters at 334.3 ± 3.3 Ma, 325.4 ± 1.8 Ma, 317.6 ± 2.1 Ma, 306.5 ± 1.4 Ma, 295.3 ± 2 Ma, 290.3 ± 3.2 Ma; 2) a peak of Neoproterozoic ages with concordant clusters at 649.4 ± 3.8 Ma, 616.7 ± 4.7 Ma, 602.7 ± 3.2 Ma, 583 ± 3.9 Ma, 564.9 ± 3.6 Ma; and 3) an Archaean–Paleoproterozoic peak defined by reworked grains clustering at 2058 ± 19 Ma. The youngest detrital population is represented by a single zircon with a Permo–Triassic age of 247 ± 11 Ma.

The MDA of 268.2 ± 2.6 Ma from the Ochindol Formation indicates sedimentary deposition extending into the Middle Permian, postdating its previously assigned Late Carboniferous age. Permo–Triassic MDA of the Vranska Formation correlates very well with a conglomerate of the westward extension of the same formation in the Belogradchik Unit (Filipov et al., 2024). These results revise the Late Paleozoic–Early Mesozoic tectono-stratigraphic framework of the West Balkan Zone and imply a Late Permian–Early Triassic magmatic sources contribution of detritus to the sedimentary basin.

Acknowledgements. This study was funded by the National Science Fund (Bulgaria) via contract KP-06-N74/4.

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Modification of crude oil Re-Os isotope system by basin-scale fluids from Miocene volcanic successions in the Niigata Basin, Central Japan

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Rhenium-osmium (Re-Os) geochronology is the only method capable of directly constraining the timing of oil generation. However, its application to crude oil can be compromised by secondary processes, such as oil-water interactions (Georgiev et al., 2021; Hurtig et al., 2019) and thermochemical sulfate reduction (Lillis and Selby, 2013), which disrupt the closed-system behavior of Re and Os in oil and may lead to inaccurate age determinations. Therefore, to provide robust interpretations of Re-Os data for crude oil, it is essential to identify the types of secondary processes involved, clarify their mechanisms, and evaluate the extent to which they affect Re-Os ages.

Our preliminary results show that the Os isotope composition (¹⁸⁷Os/¹⁸⁸Os) of crude oils from the Niigata basin in central Japan is significantly lower, with an average value of 0.26, than that of their source rocks, which average 0.71. This finding differs from previous studies that show similar ¹⁸⁷Os/¹⁸⁸Os ratios between oils and their source rocks at the time of oil generation (e.g., Finlay et al., 2011). It suggests that the Niigata oils were affected by the input of materials containing unradiogenic Os. We hypothesize that volcanic/volcaniclastic rocks deposited during Miocene back-arc basin formation in Japan contributed to this secondary process. This hypothesis is based on the low ¹⁸⁷Os/¹⁸⁸Os ratios of mantle-derived materials. To test this hypothesis and reveal the mechanism of this secondary process, we conducted Re-Os analyses of volcanic rocks and reservoir sandstones. We also used biomarker data and thin-section observations to support the interpretation of the Re-Os results.

The volcanic/volcaniclastic rocks yielded ¹⁸⁷Os/¹⁸⁸Os ratios of 0.19–0.35, overlapping those of the Niigata oils, suggesting they could have supplied unradiogenic Os to the petroleum system. However, direct contact between the oils and volcanic rocks is unlikely because the Early Miocene volcanic rocks occur stratigraphically below the Upper Miocene source rocks and Lower Pliocene reservoir rocks. We therefore propose that basin-scale fluids transported unradiogenic Os from the volcanic rocks into the reservoirs via regional faults. These results indicate that underlying volcanic/volcaniclastic successions and associated fluid flow can modify the Re-Os geochronology of crude oil in back-arc basins such as the Niigata Basin.

Acknowledgements. This work was supported by The International Joint Graduate Program in Earth and Environmental Sciences (GP-EES), Tohoku University.

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Session GS17

Open Session

Pan-European Database of Geological Sites

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Europe's geological heritage is vast, fragmented, and unevenly documented. National surveys, universities, and local authorities each maintain their own datasets, often in incompatible formats and without common access standards. There are many publications in journals (e.g., Gál et al., 2024; Pál & Veres, 2026; Petrosino et al., 2019), dedicated magazines (e.g. free EGN Magazines), and books (Reynard & Brilha, 2025; UNESCO, 2024). A Pan-European Database of Geological Sites would unify this knowledge into a single, authoritative reference—supporting research, education, conservation, and safe public engagement with the natural world.

Without such a system, field trip organisers rely on scattered web pages, outdated information, and informal local knowledge. Researchers struggle to find sites across borders. Protected areas lack consistent baseline data for monitoring and management. A Pan-European database closes these gaps and makes geological heritage a visible, usable public asset rather than an unseen layer of data repositories.

International efforts exist, such as the International Commission on Geoheritage (ICG), the International Union of Geological Sciences (Ehling et al., 2024; IUGS, 2022, 2024), the European Geoparks Network, and UNESCO International Geosciences and Geoparks (UNESCO-IGGP)(UNESCO, 2024), but these are limited and serve other purposes.

The goal of this database is to provide safe grounds for geological training for students. The sites are not like protected geoparks; you can use a hammer on rocks (in certain sites, some restrictions may apply) or take samples. These sites are for learning. Each site comes with very detailed information, not only on the geological background but also on location, access, safety, emergency information, and so on.

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GEOLAB project – Infrastructure reconstruction and procurement of instruments at the Croatian Geological Survey

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The “*Infrastructure Renovation and Procurement of Instruments at Croatian Geological Survey – Geoscientific Laboratories*” GEOLAB project (NRRP.C3.2-I2.04.0001) involves the renovation of the existing CGS's premises and the procurement of new equipment. The Ministry of Science, Education and Youth of the Republic of Croatia was the authority for the component C3.2 Raising Research and Innovation Capacity. The grant agreement was assigned in 2025 worth 7,408,540.66 euros and was financed by the European Union, under the call for grant applications (reference number: C3.2.R2-I2.04) within the NextGenerationEU 2021–2026 framework.

Project Team members are: Director Staša Borović, Assistant Director Duje Kukoč and Project Manager Marija Horvat. Project Advisory Board members are: Petra Bajo, Maja Briški, Ana Čaić Janković, Tihomir Frangen, Nikola Gizdavec, Vlatko Gulam, Nikolina Ilijanić, Ozren Hasan, Ana-Maria Heski, Branko Kordić, Ivan Kosović, Tamara Marković, Slobodan Miko, Ivan Mišur, Ivan Sokač, Martina Miko Šparica, Marko Špelić, Lara Wach and Tanja Zebić.

Instruments, scientific equipment and laboratory furniture, and software procured as part of the project include: multi-collector inductively coupled plasma mass spectrometer with nebuliser and autosampler; laser ablation system coupled with inductively coupled plasma mass spectrometer and autosampler; isotope ratio mass spectrometers with three distinct peripheral units, providing a comprehensive platform for analysing carbon, oxygen and nitrogen isotopes in solid samples and water; scanning electron microscope equipped with secondary electron and backscattered electron detectors, energy-dispersive X-ray spectroscopy for elemental analysis and cathodoluminescence, together with a carbon/gold (C + Au) evaporator; luminescence dating instruments (TL/OSL and IRSL/OSL) with associated equipment; gamma spectrometer; optical microscopes for polarised and reflected light, equipped with a digital camera; an X-ray tube, along with software packages and database updates for X-ray diffractometer; fusion sample preparation device for inductively coupled plasma mass spectrometer; magnetotelluric and audiomagnetotellurics equipment upgrade; electrical tomography equipment; shallow seismic refraction equipment; ground-penetrating radar GPR; GNSS/total station system for terrestrial surface deformation monitoring; sub-bottom profiler (sparker); VNIR hyperspectral camera; field fluorimeters; TOC and TN analysers for water; an analytical balance with an ioniser module and a micro-analytical balance with sixth-decimal readability; and software for the interpretation of geological and geophysical data (RadEX PRO software, software for analysing deep well logging data, ENVI PRO software for integrated processing, classification and interpretation of satellite, aerial and terrestrial images collected by passive and active sensors (multispectral, hyperspectral and radar images), software for displaying and analysing large amounts of data obtained from remote sensing, SOCET GXP extreme software) and upgrading of CGS's IT equipment of servers, storage, network components, and firewall.

Filtered ventilation systems for heating, cooling and air handling have been installed in the laboratory areas designated as clean rooms in accordance with ISO 14644-1:2015 standards minimum class 7, and minimum class 6 for sample preparation in the three metal-free ultraclean workstations.

The mentioned equipment contributes to the realization of the goal of the GEOLAB project, i.e. the development of modern scientific and technological infrastructure for targeted and applied research, the strengthening of Croatian Geological Survey's research capacities and the improvement of cooperation with domestic and international institutions.

Some outstanding geochemical characteristics of coals in Slovenia (SW Pannonian Basin, NW Dinarides, Istria)

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Coals in Slovenia situated at the junction of the Southern Alps, Pannonian Basin, Dinarides, and Istria (part of the Adria-Apulia microplate) have been exploited from the end of the 18th century onwards in different time periods and areas in 35 well documented coal mines. They were used in households, blacksmithing and ironwork, glassmaking, shipping transports, and to the largest degree for railway transports (1850–1978) and for electricity production from 1905 until now. The largest production was in the early 1980s, with 6.75 Mt/y of ortho- and meta-lignite, i.e. around 3.4 t/cap. At the present, only one underground lignite mine is still in operation with ca 2.18 Mt/y production.

The great majority of coals in Slovenia are Tertiary in age (Hamrla, 1985/86; Markič et al., 2007). They are paralic coal deposits (SW Pannonian Basin), intramountain coal deposits (Alps and Dinarides), and lagoonal coals (Istria). Paralic and intramountain coal beds are interbedded in clastic sediments: clays, marls, fine sands, whereas the lagoonal in the limestones. In most cases, these were influenced by the predominantly carbonate hinterlands. Therefore, coals in Slovenia are generally characterized as Ca-rich coals. Primarily these were deposited in topogeneous mires with a considerable mineral matter influx, alkaline environment and considerable bacterial activity. Hence, coals are of a medium to low grade (ash contents above 15 %). Petrographically, coals of Slovenia are predominantly humic coals, with some sapropelic varieties (e.g. the Istria coals) (Paleogene) and in the top of the Zasavje (Oligocene) coal seam.

Coals in Slovenia, generally, are not enriched in a suite of trace elements, as detailed studies revealed in the last decades (1990 onwards). However, some very outstanding geochemical characteristics do exist for the coals in Slovenia. Among them are moderate to high sulphur (S) contents (1–3 %, extremely up to 10 %, respectively), uranium (U) contents (up to 250 ppm), arsenic (As) contents (up to 300 ppm) and significant Mo contents. Vanadium (V) is known to be enriched in some coal ashes as well.

Geochemical features of coals in Slovenia are undoubtedly to a great measure a consequence of their primarily peat forming environments, hinterland, biosphere and geochemical processes during very early diagenesis (early coalification). But their petrology (petrography, coalification rank) altered during geological time and geophysical circumstances. So did their isotopic composition (Kanduč and Markič, 2024), both in respect to basic plant communities and coalification processes.

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From bedrock, through soil, to the grapevine: geochemistry and nutrient transfer in the Miniş–Măderat area (Carpathian–Pannonian Region, Romania)

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Terroir reflects multiple interacting factors, but bedrock geochemistry provides the initial template for geomorphology and soil development, which signal may be weakened by hillslope processes, pedogenesis and climate. Geoterroir describes vineyard sites where bedrock becomes an active determinant of site character. The historic Miniş–Măderat Vineyard in the southwestern Apuseni Mountains provides a vineyard-scale natural laboratory for studying lithology-controlled vineyard heterogeneity. Three sites were selected to represent the dominant bedrock types — metagabbro, syenogranite, and phyllonite — which define distinct Vineyard Geological Identities (VGI). Rock, soil, and grapevine samples were collected to assess potential bedrock–soil–vine relationships through integrated geochemical analysis, focusing on elements relevant to grapevine health. The description of rocks can be found in the abstract “Lithology-controlled Vineyard Geological Identities in the Miniş–Măderat area (Carpathian–Pannonian Region, Romania)”.

Soils developed on metagabbro show, relative to the other soils, high concentrations of P (620–940 ppm), Ca (0.56–1.04%), Mg (0.76–1.20%), Fe (3.11–3.76%), Mn (553–756 ppm), Cu (66–71 ppm), and Zn (60–69 ppm), with K ranging between 0.28–0.32%, Na between 300–400 ppm, and Ti between 0.1–0.2%. Grapevines growing on these soils contain P at 2800–3300 ppm, K at 1.42–1.64%, Mg at 1550–1650 ppm, Fe at 70–80 ppm, Mn at 18–25 ppm, Cu at 9–10 ppm, B at 28–29 ppm, and Zn at 15–16 ppm.

Phyllonite-derived soils are characterized by lower Ca (0.21–0.28%), Mg (0.44–0.49%) and Na (100–200 ppm), P (320–570 ppm), K (0.26–0.29%), Fe (2.72–3.06%), Ti (0.02%), Cu (47–51 ppm) and higher Mn (814–816 ppm) and Zn (61–78 ppm). Grapevines on phyllonite contain P at 2560–2790 ppm, K at 1.36–1.73%, Mg at 1270–1430 ppm, Fe at 50 ppm, Mn at 52–63 ppm, Cu at 7–8 ppm, B at 22–27 ppm, and Zn at 16–17 ppm.

Syenogranite-derived soils show concentrations of P at 560–800 ppm, K at 0.27–0.49%, Ca at 0.61–0.77%, Mg at 1.68–1.92%, Na at 300–500 ppm, Fe at 3.26–3.72%, Al at 2.69–2.74%, Ti at 0.20–0.22%, Mn at 574–611 ppm, Cu at 54–59 ppm, and Zn at 57–74 ppm. Grapevines from this substrate contain P at 2730–2800 ppm, K at 1.58–1.81%, Mg around 1410 ppm, Fe at 50 ppm, Mn at 36–42 ppm, Cu at 8 ppm, B at 20–21 ppm, and Zn at 18–19 ppm.

Boron (<20 ppm) and Mo (<1 ppm) in soils and Ca (<2%), Na (<100 ppm), Al (<100 ppm) and Ti (<10 ppm) concentrations in grapevine were below the measurement threshold. Lower-elevation vineyard soils are generally enriched in Ca, Al, Fe, and Ti, whereas Mn is higher at higher elevation.

The geochemical results allow the identification of element-specific relationships within the rock–soil–plant systems and provide insight into their transfer behavior. This approach contributes to a detailed interpretation of VGI.

Lithology-controlled Vineyard Geological Identities in the Miniş–Măderat area (Carpathian–Pannonian Region, Romania)

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Terroir characterization remains a multidisciplinary challenge, as bedrock geochemistry provides a fundamental basis for geomorphology and soil composition. However, lithological signals are commonly attenuated by hillslope processes, pedogenesis, and climatic control within the so-called Critical Zone, at the bedrock–soil interface. Geoterroirs — areas where bedrock directly controls vineyard identity — emerge under specific conditions, including minimal relief, thin soils, high lithological diversity, and limited lateral material transport.

The historic Miniş–Măderat Vineyard (southwestern Apuseni Mountains, Romania) provides a vineyard-scale natural laboratory for investigating lithology-controlled Critical Zone heterogeneity. This study presents a vineyard-scale assessment of how bedrock composition controls distinct Vineyard Geological Identities (VGI). Based on vineyard geological mapping and integrated petrological and bulk-rock geochemical data, three geoterroirs were identified as lithology-governed Critical Zone domains.

The Napos geoterroir, developed on metagabbro, is characterized by elevated TiO₂, Al₂O₃, Fe₂O₃, MgO, and CaO concentrations relative to the average upper continental crust (UCC), and systematically lower SiO₂ and K₂O contents. In contrast, the Hársfa geoterroir, hosted by syenogranite, is enriched in SiO₂, Na₂O, and K₂O and depleted in TiO₂, Al₂O₃, Fe₂O₃, MnO, and MgO relative to the average UCC. The Sida Lazar geoterroir represents a distinct lithological and geochemical domain developed on phyllonitic bedrock, marked by higher Al₂O₃, K₂O, and Fe₂O₃ concentrations, near-average SiO₂ and TiO₂ levels, and lower MgO, CaO, Na₂O, and MnO relative to the average UCC.

These lithology-specific VGIs constrain weathering pathways of rock-forming minerals, elemental mobility, and the mineralogical framework of the weathering crust, thereby exerting a first-order control on soil composition, physical properties, and nutrient availability. Our results demonstrate that bulk-rock geochemistry is a key driver of vineyard-scale Critical Zone differentiation and provides a scalable framework linking bedrock geochemistry, soil formation, and Earth surface processes in heterogeneous terrestrial environments. These findings highlight lithological controls on near-surface elemental cycling at the vineyard scale.

Special session SS1

**Come together: Tracing explosive silicic volcanism
and its impact across the Alpine-Mediterranean
region during the Paleogene and Neogene**

Conveners:

Réka Lukács, Mihovil Brlek

Explosive volcanism coming to the rescue in stratigraphy: $^{40}\text{Ar}/^{39}\text{Ar}$ dating of Early-Middle Miocene volcanic ashes in the Carpathian-Balkan area

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Explosive silicic volcanism of the Carpathian-Pannonian Region generated many tephras that were deposited in a variety of sedimentary basins across the Alpine-Mediterranean region during the Early and Middle Miocene. During my PhD we focused on these widespread tephras as a chronostratigraphic tool. Igneous minerals such as feldspar, hornblende and biotite, formed during the eruptions, are often preserved in these volcanic ashes and can be dated using the $^{40}\text{Ar}/^{39}\text{Ar}$ method. This approach permits to obtain numerical ages for strata that are difficult to date precisely based on biostratigraphy. In this talk, I will show how $^{40}\text{Ar}/^{39}\text{Ar}$ dating of volcanic deposits allowed to date the infill of the Transylvanian Basin and calculate depositional rates by extrapolation of the ages to seismic sections in the basin center. I will also show how we used this approach to date the evaporites of the Badenian Salinity Crisis, which revealed that this event was triggered by the Mid Miocene Climate Transition. Finally, we will turn to the Dinarides where $^{40}\text{Ar}/^{39}\text{Ar}$ dating of volcanic ashes allowed to date a variety of lakes from the Dinaride Lake System, thereby shedding new light on the evolution of its rich freshwater fauna and the arrival of *Gomphotherium* in Europe. Finally, I will spend a few words on a new radio-isotopic dating method that we are currently developing, which allows to obtain U-Pb ages on the shells of fossil oysters, which allows to obtain numerical ages in fossiliferous shallow marine settings in the absence of volcanic ashes.

External Dinaridic residual record of regional silicic volcanism, intense chemical weathering and tectono-stratigraphic evolution intertwined during Oligo-Miocene (Alpine-Mediterranean region)

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The Alpine-Mediterranean region (AMr) offers a natural laboratory for studying processes across various environments from asthenosphere to atmosphere and their interactions over a wide temporal and spatial range. The Earth's surface is an interface for many of these processes, such as volcanism, weathering, sedimentation, and topographic, landscape, and climate evolution. To better understand volcanism, sedimentary basin formation, and weathering during the Paleogene and Neogene in the AMr, a multi-proxy approach applied on the most appropriate geological records has proven as indispensable. Accordingly, residual deposits, such as karst bauxites, *terra rossas*, red clays and kaolin deposits, if subjected to an integrated approach based on diverse analytical methods, may offer invaluable insights on the intertwined factors responsible for their formation. These deposits develop from pervasive physical, chemical, and/or biological alteration of precursor material during subaerial continental weathering. As such, they are

important terrestrial archives of paleoenvironmental and paleoclimatic conditions at the time of their formation, with even more utility when interpreted with their temporal record of formation. In addition, applying a multi-proxy approach on residual deposits can reveal their provenance, timing of regional volcanism, local paleorelief during deposition, sedimentation processes and the tectonic implications of these factors. Recently, U-Pb geochronology of detrital zircon from karst bauxites, red clays and kaolin deposits of the Eastern Alps-Western Carpathians and the External Dinarides was used to constrain their maximum age of deposition and the timing of the intense chemical weathering at mid-latitudes during Paleogene and Neogene, which also helped to improve existing stratigraphic records by providing critical geochronology data on previously unconstrained deposits. Based on detrital zircon U-Pb age populations, the provenance of the precursor material of these residual deposits was also tentatively suggested. However, more comprehensive detrital U-Pb geochronology and additional geochemical proxies, such as hafnium (Hf) isotope compositions of dated zircons, are required to robustly constrain the volcanic sources and provenance of Neogene and Paleogene, as well as pre-Cenozoic zircons from the External Dinaridic residual deposits.

We present detrital zircon *in situ* U-Pb geochronology and Hf isotopic compositions of dated zircon crystals, alongside integrated mineralogical and geochemical analysis, from karst residual deposits underlying Dinaride Lake System deposits from six localities in the Sinj and Livno-Tomislavgrad Basins, and from one locality in the northern External Dinarides. The aim of the study is to identify potential provenance of the precursor material of residual deposits by placing new constraints on the source of detrital zircons in the External Dinarides, especially of the predominant Neogene and Paleogene volcanic zircons supplied by the Cenozoic volcanic edifices across the AMr (e.g., Carpathian-Pannonian Region during Neogene, and Internal Dinaridic, Rhodopean and/or Alpine/central-western peri-Mediterranean sources during Paleogene). Moreover, these data also allow for new constraints on the maximum depositional ages of individual occurrences of residual deposits, and interpretations regarding their complex formation history and stratigraphic relations. More broadly, integrating these new interpretations into a regional context reveals diachroneity of lacustrine flooding throughout the Sinj Basin. Furthermore, we use these ages to evaluate the timing of intense chemical weathering at paleo mid-latitudes, building a continental paleoclimatic record. Together, these data provide new insights into the tectono-stratigraphic and paleogeographic evolution of the Dinarides.

Detailed mapping of the 14.9 Ma Demjén Ignimbrite (northeastern Hungary): thickness and lithofacial variations in the eruptive sequence

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The largest Miocene silica-rich, caldera-forming eruptions in Europe occurred in the Carpathian-Pannonian Region between 18.1 and 11.6 Ma. Their near-proximal to proximal deposits are widely exposed in northeastern Hungary, but the related calderas are inferred to be buried beneath thick sediments of the northern Great Hungarian Plain. Among the most widespread eruption units, the Middle Miocene (Badenian) dacitic Demjén Ignimbrite (DI; 14.88 ± 0.014 Ma zircon U-Pb ID-TIMS age) has a characteristic mineralogical (plagioclase, biotite, amphibole, $\pm$ quartz) and geochemical composition, which makes it easy to recognize in the field. We carried out detailed geological and structural mapping from the Bükkalja Volcanic Field to the Cserhát Hills (>200 km²) to constrain the areal distribution and thickness variations of the DI. The mapping revealed numerous faults, some of which show km-scale sinistral displacement during the Middle Miocene. We identified the DI as a continuous eruptive sequence composed of four pyroclastic units and documented 45 vertical volcanological successions.

Based on well-constrained formation boundaries and the presence of an ubiquitous alluvial volcanoclastic bedrock units, the DI was deposited mainly in nearly flat areas, spreading and thinning radially from the source. The thinner, well-bedded/laminated basal (A-B) and uppermost D units were emplaced by small, highly unsteady, partly dilute pyroclastic density current pulses. Unit C comprises several unwelded and variably welded and/or silicified ignimbrite flow units, mainly separated by thin surge deposits. Glass chemistry is largely homogeneous throughout the sequence, suggesting evacuation of the same magma batch during the eruptions. The widespread occurrence of the terminal Unit D allowed us to estimate depositional thicknesses of DI ranging 5–470 m. Based on these thickness data, we estimated a total erupted volume of ~ 220 km³ for the mapped area alone.

Contrary to earlier studies, we recognized >400 m thick intracaldera or caldera rim DI deposits in the eastern Mátra Mts. Here, the bulk of Unit C is strongly altered and contains multiple lithic breccia horizons. A characteristic lower breccia horizon, also observed in neighboring areas, likely records the main caldera collapse event.

We recognized a clear stratigraphic superposition of the DI from the caldera to distal areas: series of Unit A-D between well-defined volcanoclastic bedrock/covering formations. No evidence was found for significant volcanoclastic intercalations or erosional hiatuses in any of the vertical sections of the DI; instead several tectonic repetitions of certain units were identified. Based on these and other observations (e.g. abundance of composite cooling units), we propose that the DI was emplaced during a single, short-lived (days-months) eruptive phase.

Acknowledgements. Funding: Hungarian National Research, Development and Innovation Office (No. 145905, 134873); MTA–HUN-REN CSFK Lendület “Momentum” Pannonian Volcano Research Group; MOL Nyrt.

Large-volume Miocene silicic volcanism in the Pannonian Basin: geochronological and geochemical correlation across central and southern Europe

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Neogene silicic volcanism in the Pannonian Basin (Eastern Central Europe) represents the most voluminous explosive activity in Europe over the past 20 million years, producing more than 4,000 km³ of tephra during a period of significant lithospheric extension. Integrated field and borehole data from northern to northeastern Hungary, combined with zircon U–Pb geochronology and zircon–glass geochemistry, reveal multiple >100 km³ explosive eruptions between 18.1 and 11.5 Ma. Major eruptive phases occurred between 18.1 and 14.4 Ma in the Bükkalja Volcanic Field (BVF), followed by younger activity (13.1–11.6 Ma) in the Tokaj Mountains, marking an ignimbrite flare-up period and subsequent eastward migration of volcanism.

Distinct geochemical fingerprints, including wide variability in zircon ε_{Hf} values (>10) and volcanic glass trace element ratios (~5 in La/Nb), allow robust correlation of eruptive units across Central and Southern Europe, even where primary volcanic textures are obscured by alteration. These correlations link proximal units in Hungary to distal ash deposits preserved across a broad region, including Italy (e.g., the orbitally tuned La Vedova section near Ancona), as well as the Czech Republic, Slovakia, Austria, Germany, Croatia, and Romania. Several key eruptions (at ~18.1, 17.3, 14.9, 14.4, and 13.1 Ma) can be traced regionally. The widespread occurrence of coeval, thick volcanoclastic successions in proximal settings, together with their enormous volume, suggests that many of these eruptions were caldera-forming and may have reached VEI 7–8 magnitudes. Distal ash deposits, frequently transported over distances exceeding 1,000 km and locally reworked in subaqueous environments, further emphasize the exceptional size of these eruptions. The identification of multiple correlated ash layers, both proximal and distal, also indicates a higher eruptive frequency and faster volcanic tempo than previously recognized.

These results significantly refine the Miocene tephrochronological framework of Central and Southern Europe and highlight the broader implications of Pannonian Basin volcanism for regional paleogeographic reconstructions, basin evolution, and long-distance tephra dispersal.

Acknowledgements. This work was supported by the Hungarian National Research, Development and Innovation Office (No. 145905) and by the MTA–HUN–REN CSFK Lendület “Momentum” Pannonian Volcano Research Group.

Miocene silicic volcanism of the Nyírség Sub-basin (Pannonian Basin): insights from deep drill cores

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The Pannonian Basin represents a complex back-arc basin system in which volcanic complexes play a key role in reconstructing basin evolution. Products of the Miocene silicic volcanism, responsible for the largest volcanic eruptions in the basin, are exposed in the Bükkalja Volcanic Field and Tokaj Mountains, but also occur buried beneath Late Miocene (Pannonian) sediments of the Great Hungarian Plain within the Nyírség Sub-basin, where they were revealed by hydrocarbon exploration drilling. Integrated geophysical and seismic data indicate that the sub-basin is characterized by deep (>3000 m) grabens and depressions separated by structural highs. These structures are infilled by 1000–3000 m thick volcanic and volcano-sedimentary successions of the Nyírség Volcanic Complex, comprising intermediate volcanic rocks (andesite lavas and pyroclastic rocks) and silicic volcanic units (rhyolitic-dacitic lavas and pyroclastic rocks), overlain by Pannonian sediments. The volcanic successions are interrupted by Badenian–Sarmatian (Middle Miocene) sedimentary intercalations (claystone, marl and calcareous sandstone), as confirmed by micropaleontological observations. Despite their significance, these buried volcanic complexes have not yet been investigated using modern integrated approaches combining U–Pb zircon geochronology, petrology, geochemistry and volcanology.

This study focuses on the re-evaluation of volcanic successions penetrated by the Komoró-I, Gelénes-1 (Ge-1) and Beregdaróc-3 (Bd-3) boreholes in the northeastern part of the Nyírség Sub-basin. The Ge-1 and Bd-3 boreholes are located in close proximity and intersect comparable silicic volcanic sequences composed predominantly of rhyolitic tuffs and lapilli tuffs. In both successions, two major eruptive units can be distinguished and are separated by a sedimentary intercalation indicating a volcanic hiatus. Their correlation is supported by similar Sarmatian eruption ages ($12.0\text{--}12.3 \pm 0.2$ Ma) and comparable zircon trace-element compositions. The Ge-1 borehole terminated within a perlitic rhyolite lava unit. This interval is interpreted as a lava dome, as no evidence of welded, fragmented juvenile clasts or lithic clasts was observed. A complete volcanic edifice was penetrated by the Komoró-I borehole, in a separate graben located farther to the west. In contrast to Ge-1 and Bd-3, the approximately 1400 m thick volcanic succession overlying Triassic carbonates is less felsic in composition. The thick intermediate lava-dome complex, composed of porphyritic pyroxene andesite and dacite, is associated with intercalated dacitic tuff layers. U–Pb zircon geochronology indicates an age of $12.5\text{--}12.6 \pm 0.2$ Ma for the entire complex. This succession is overlain by pumice-bearing rhyolite-rhyodacite tuff and lapilli-tuff units. The youngest dated eruptive unit yields 11.6 ± 0.2 Ma age and exhibits slight differences in zircon geochemistry compared to the lava dome units, suggesting the eruption of a compositionally distinct magma.

Geochronological data indicate that basin opening, subsidence and infilling by predominantly volcanic and volcano-sedimentary deposits occurred rapidly during the Sarmatian and continued into the Pannonian.

Acknowledgements. This work was supported by the Hungarian National Research, Development and Innovation Office (No. 145905) and by the MTA–HUN-REN CSFK Lendület “Momentum” Pannonian Volcano Research Group. The research was also supported by MOL Upstream Plc.

Special session SS2

**Critical and strategic raw materials
in the Alpine-Balkan-Carpathian-Dinaridic region:
exploration, EU policy implementation, circular
economy, and societal challenges**

Conveners:

*Sibila Borojević Šoštarić, Vasilios Melfos, Irena Peytcheva,
Marian Munteanu*

Critical Raw Materials for Europe's Green and Digital Transition: The RAMP Partnership and the Policy Landscape for the Balkan-Carpathian Region

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Europe's green and digital transition depends on a secure supply of critical raw materials (CRMs), yet the EU consumes about a quarter of global raw materials while producing only a small fraction domestically (Kampmann et al., 2024). Demand for CRMs such as lithium, cobalt, copper, and rare earths is projected to rise sharply by 2050, while supply chains remain concentrated among few third countries (Kampmann et al., 2024). The Critical Raw Materials Act (CRMA), in force since 2024, sets binding 2030 benchmarks: 10 percent of EU consumption from domestic extraction, 40 percent from EU-based processing, 25 percent from recycling, and no more than 65 percent dependence on any single third country per material (European Commission, 2024). Meeting these targets requires coordinated European research and innovation (R&I), building geological knowledge, technology, and societal acceptance for domestic supply, alongside better geological data access and cross-border integration of national geological information systems.

RAMP, the Raw Materials Partnership for the Green and Digital Transition, is a Horizon Europe co-funded partnership operating since 2026, succeeding ERA-MIN, a series of European research area networks coordinating national raw materials R&I funding since 2011 (Kampmann et al., 2024). RAMP brings together over 50 partners, mostly national and regional funding organisations, with a total partnership volume of roughly 350 million euro over eleven years (Kampmann et al., 2024). It covers three core themes, resilient primary and secondary supply, efficient use of raw materials in design and production, and sustainable use and reuse of products, plus three crosscutting themes on policy, societal sustainability, and innovation capacity (Kampmann et al., 2024). Its first Joint Transnational Call, opened in 2026 with nearly 40 million euro, spans exploration, extraction, processing, circularity, and social acceptance. RAMP also clusters R&I results, builds workforce capacity, and feeds evidence into CRMA implementation and policy processes.

The Balkan-Carpathian region combines a long mining history, promising discoveries, and strong geological expertise, with growing representation of its funders and institutions within RAMP. Meeting the CRMA benchmarks here depends on aligning national exploration strategies with coordinated transnational research, integrating national geological infrastructure and data across borders, and engaging industry and civil society, while addressing the tension between rising material demand and limited societal acceptance of extraction and processing in parts of Europe. As a geological congress focused on the Carpathian-Balkan-Dinaric domain, this venue is directly relevant, given the region's role as a source of geological data, mineral deposits, and expertise underpinning both RAMP and CRMA implementation.

Acknowledgements. RAMP is co-funded by the European Union's Horizon Europe programme.

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Celestine mineralizations in Bulgaria – a review

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Strontium is a soft silver-yellow alkaline earth metal occurring as two main strontium-bearing minerals: celestine (SrSO₄) and strontianite (SrCO₃). Strontium products are used in the glass industry, the electrical and electronics industry (as batteries and optical devices), in pyrotechnics, drilling fluids, ceramic magnets, and medicine. It has been recognized as a Critical Raw Material (CRM) in the European Union since 2020 (European Commission, 2020).

At present, no industrial deposit of celestine has been proven in Bulgaria. However, hydrothermal, sedimentary and infiltration genetic types of celestine mineralization have been identified (Trashliev, 1988). Hydrothermal celestine often associates with fluorite, calcite and barite and was found in the Yugovo deposit in the Central Rhodopes (Todorov and Angelov, 1992), the Sedmochislenitsi deposit in the Vratsa district, Balkan Mts (Atanassov and Lilov, 1968) and the Rosen deposit in the Burgas district (Atanassov, 1969).

Sedimentary celestine associates mostly with evaporites. This type of celestine mineralization has been described within the Miocene evaporites near Koshava, Gomotartsi and Negovantsi villages (Vidin district) and Oryahovo town (Vratsa district) in northwestern Bulgaria (Trashliev, 1988), as well as in the Triassic sediments from deep oil and gas wells in the Central Fore-Balkan (Vaptsarova *et al.*, 1979).

Infiltration celestine has been studied in the Lower Cretaceous marls from northeastern Bulgaria. This celestine occurs in carbonate-clayey sediments of the Gorna Oryahovitsa Formation in the Veliko Tarnovo, Targovishte, Shumen and Varna districts (Donchev *et al.*, 2004). Breskovska (1959) also described infiltration celestine from the Aptian sandy limestones, to the north of Goritsa village (Targovishte district).

Acknowledgements. This work has been carried out in the framework of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers No. 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria.

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ADRIA region – beyond conventional mining

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The ADRIA region (Albania, Bosnia and Herzegovina, Croatia, Montenegro, North Macedonia, Serbia and Slovenia) represents one of Europe's most diverse critical and strategic raw material (CRM/SRM) provinces. Current production is dominated by copper, chromium and nickel, whereas future development is expected to rely increasingly on titanium, vanadium, lithium and boron. Serbia is the largest regional copper producer, yielding 292.9 kt of mine copper in 2024 from the Bor mining district (Veliki Krivelj, Majdanpek, Jama, Cerovo and Čukaru Peki), equivalent to approximately 37% of current EU mine copper production (Zijin Mining, 2025; Grohol and Veeh, 2023). Together with North Macedonia (Bučim–Borov Dol), the ADRIA region contributes more than 40% of EU primary copper production, supporting the European copper value chain through domestic smelting and refining in Serbia and processing of North Macedonian concentrates in Bulgaria. Chromium and nickel production is concentrated in Albania, one of only two significant European chromite producers alongside Finland, with active nickel laterite mining (U.S. Geological Survey, 2025). Although Albania has no current titanium or vanadium production, the Butmi and Sukaxhi titanomagnetite deposits and the Liqeni i Kuq iron-nickel project have reached advanced exploration and feasibility stages. North Macedonia hosts additional feasibility-stage iron-nickel (Rakle, Studena Voda), titanium-iron (Mitrašinci), molybdenum (Strelci) and copper (Petrošnica) projects, confirming the region's long-term development potential (Borojević Šoštarić *et al.*, 2022 and references therein).

The Miocene volcano-sedimentary basins of the Sava Suture Zone constitute Europe's most advanced lithium-boron province. The Jadar deposit, the type locality of the unique Li-borosilicate mineral jadarite ($\text{LiNaSiB}_3\text{O}_7(\text{OH})$), contains 16.6 Mt of measured ore (1.81% Li_2O ; 13.4% B_2O_3), 55.2 Mt of indicated ore and 84.1 Mt of inferred ore. Although currently under care and maintenance following prolonged permitting delays and social opposition, the project retains EU Strategic Project status under the Critical Raw Materials Act. Together with the Valjevo, Rekovac, Jarandol–Piskanja, Jarandol–Pobrdje, Dobrinja–Pranjani, Viti, Vranje and Lopare projects, the Miocene Western Balkan lithium-boron metallogenic zone contains approximately 17 Mt of proven ore reserves, 126 Mt of indicated resources and 274 Mt of inferred resources (Borojević Šoštarić and Brenko, 2023).

Historical mining has also generated significant secondary CRM resources. More than 1,800 mine waste deposits contain approximately 3.2 Bt of flotation tailings, red mud, coal fly ash and phosphogypsum enriched in REE, Sc, Ga, Ti, V and other critical elements (Radusinović and Papadopoulos, 2021; Šajn *et al.*, 2022).

Beyond conventional mining, the ADRIA region offers an overlooked opportunity through renewable geological resources. Solar saltworks along the eastern Adriatic (Croatia, Slovenia and Albania) annually produce approximately 170–230 kt of sea salt, generating magnesium-rich bittern and reject brines with a theoretical recovery potential approaching 100 kt Mg per year, representing one of Southeast Europe's largest renewable magnesium resources. Geothermal fluids from the Velika Ciglena field (Croatia) contain approximately 45 mg/L Li, corresponding to a theoretical annual production of about 240 t Li. Considering Croatia's 28 active geothermal exploration licences, identifying only 3–4 lithium-bearing systems comparable to Velika Ciglena could theoretically supply the lithium required for Rimac Technology's announced production of up to 100,000 battery systems annually, highlighting the strategic potential of integrating lithium recovery into future geothermal developments.

Acknowledgements. This work was supported by the NPOO GeoCritical project, UNIZG-RGNF.

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Mineralogy, geochemistry and origin of manganese mineralization in the Srednogorie Zone, Bulgaria

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The complex Alpine evolution of the Srednogorie Zone was characterized by intensive subduction-related Late Cretaceous magmatism and Upper Cretaceous sedimentary and volcano-sedimentary successions over Caledonian–Hercynian basement fragments and deformed Early Mesozoic sediments. The Srednogorie tectono-magmatic and metallogenic zone forms part of the Apuseni–Banat–Timok–Srednogorie magmatic arc within the Carpathian–Balkan orogen and hosts porphyry Cu ± Au ± Mo and epithermal Au–Cu deposits. Late Alpine compressional events related to closure of intra-arc and back-arc basins generated predominantly NW–SE-trending fault structures that were subsequently affected by Mn–Fe–Si hydrothermal exhalative activity.

Manganese mineralization occurs as layers, lenses and massive to irregular bodies, commonly along brittle contacts between volcanic rocks and clayey reddish limestones. Ore bodies occur in both sedimentary and volcanic rocks. The largest occurrence is the Pozharevo deposit in Western Srednogorie, whereas numerous smaller manganese-bearing ore occurrences are distributed throughout the Central and Eastern Srednogorie zones.

Mineral relationships and associations were investigated by optical microscopy, SEM-WDS, XRF, XRD, LA-ICP-MS, element mapping and Sr–Nd–Pb isotope geochemistry. Pyrolusite is the dominant Mn ore mineral, accompanied by subordinate Mn oxides and hydroxides. Quartz, chalcedony and calcite constitute the main gangue assemblage. Trace-element distributions vary across the Srednogorie Zone. The Pozharevo deposit (Western Srednogorie) is characterized by enrichment in Cu, V, Ni, Zn, As, Ba, Mo, W and REE. Manganese mineralizations in Central Srednogorie display elevated concentrations of V, Zn, Ba, W, Mo, Co, Ni, Cu, As, Tl and Sr, whereas Eastern Srednogorie occurrences are predominantly enriched in Cu, As, Zn, V, P, Ba and Sr.

Combined Sr–Nd–Pb isotope data constrain the origin of the mineralizing fluids. Most Mn ores display ⁸⁷Sr/⁸⁶Sr ratios between those of Late Cretaceous seawater and local volcanic rocks, indicating mixing between seawater-derived fluids and volcanogenic Sr and suggesting that much of the Mn was derived from the volcanic rocks. Sample BG24-1 exhibits a more radiogenic Sr composition (⁸⁷Sr/⁸⁶Sr = 0.70835), suggesting an additional crustal contribution.

Neodymium isotope compositions further support a volcanic component. Reddish limestones yield the lowest εNd values (–8.9 to –4.9), whereas volcanic rocks show the highest values (–2.1 to –1.1). Mn ores display intermediate compositions (–8.4 to –1.7), reflecting mixing between sedimentary or seawater-derived and volcanogenic sources. Lead isotope signatures are consistent with the Sr and Nd data and indicate mixed sedimentary and volcanogenic contributions to both the mineralizing fluids and host rocks.

These isotopic constraints suggest that Mn was leached from volcanic rocks by circulating seawater-derived hydrothermal fluids during the Late Cretaceous. Subsequent mixing of ascending Mn-rich fluids with seawater or oxidized pore waters facilitated Mn oxidation and precipitation of Mn oxyhydroxides and carbonates. The mineralization records remobilization of volcanogenic Mn within a hydrothermal-sedimentary system.

Acknowledgements. This study was supported by a 2024 student research grant from the Society of Economic Geologists Foundation, McKinstry Fund, and by the National Science Program “Critical and Strategic Raw Materials for a Green Transition and Sustainable Development” funded by the Ministry of Education and Science of Bulgaria.

Bismuth-bearing mineralization in Bulgaria: new mineralogical and geochemical data from the Western Rhodopes

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Bismuth (Bi) is a critical raw material commonly occurring as a by-product in hydrothermal ore systems. Owing to its low toxicity, bismuth is increasingly employed as a lead substitute in alloys, lead-free solders, pharmaceuticals and other technological applications. In Bulgaria, although no primary bismuth deposits are currently known, Bi-bearing minerals are widely distributed within the country's major metallogenic provinces, including the Srednogorie Zone, the Rhodope Massif and the Strandzha region. The most common Bi mineral is bismuthinite (Bi_2S_3), commonly associated with native bismuth, Pb–Bi–Ag sulfosalts and Bi-bearing sulfides in porphyry, epithermal, polymetallic and tungsten-bearing ore systems.

This contribution reviews the available information on bismuth mineralization in Bulgaria and presents new mineralogical and geochemical data from two Bi-bearing hydrothermal deposits in the Western Rhodopes – the Babyak Mo–Ag–Au–W–Bi–polymetallic deposit and the Grancharitsa W deposit.

At the Babyak deposit, bismuth occurs as bismuthinite, Pb–Bi–Ag sulfosalts and microscopic inclusions associated with molybdenite. LA-ICP-MS analyses reveal Bi concentrations in molybdenite ranging from 1 to 8600 ppm (average 830 ppm), together with elevated Pb and Ag concentrations. Strong positive correlations between Bi and Ag ($r = 0.98$), Bi and Pb ($r = 0.82$), and Pb and Ag ($r = 0.85$) indicate the presence of fine-grained Ag-bearing Pb–Bi sulfosalts associated with molybdenite and suggest a close genetic relationship between these elements during ore formation.

At the Grancharitsa deposit, previous mineralogical studies reported bismuthinite in association with scheelite, pyrite, molybdenite, arsenopyrite, ferberite and cassiterite within a scheelite-bearing hydrothermal system. New SEM-WDS analyses confirm the presence of nearly stoichiometric bismuthinite with Bi contents reaching 80.4 wt.% and minor Pb, Se and Sb enrichment. LA-ICP-MS analyses indicate low Bi concentrations in pyrite (up to 50 ppm) and significantly higher contents in molybdenite (up to 7600 ppm), demonstrating preferential partitioning of bismuth into molybdenite and Bi-bearing mineral phases. Comparable Bi concentrations in molybdenite from the Babyak and Grancharitsa deposits indicate that this mineral may represent an important host of bismuth in magmatic-hydrothermal systems of the Western Rhodopes.

The available mineralogical and geochemical data indicate that bismuth is more widely distributed in Bulgarian hydrothermal systems than previously recognized and occurs both as independent Bi minerals and as a trace component in major ore minerals. The examples from Babyak and Grancharitsa illustrate the metallogenic significance of bismuth in polymetallic and tungsten-bearing hydrothermal systems and indicate the potential for future evaluation of Bi as a by-product critical raw material in Bulgaria.

Acknowledgements. This study was supported by the National Science Program “Critical and Strategic Raw Materials for a Green Transition and Sustainable Development” funded by the Ministry of Education and Science of Bulgaria and by the Bulgarian National Science Fund under project KP-06-M84/1.

Bulgaria's National Scientific Program for Critical Raw Materials

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The National Scientific Program “Critical and Strategic Raw Materials for Green Transition and Sustainable Development” (2024–2029) is a nation-wide research initiative uniting more than 220 researchers from 14 universities and research institutes. The team jointly explores various aspects of critical raw materials (CRM) in Bulgaria: applications, geologic controls, prospective areas for primary raw materials deposits, raw materials from secondary sources, innovative methods for CRM extraction, energy resources of the country, environmental and societal impacts.

The main work activities are organized in 10 work packages as follows: 1) deposits and occurrences of CRM; CRM summaries by commodity and by deposit type; prospective areas; 2) tectonic and structural controls on CRM deposit formation; novel exploration methods; 3) Bulgaria's potential for energy resources (conventional and unconventional hydrocarbon reserves, coals, biofuels and low-temperature geothermal energy); 4) methods for efficient processing of CRM ores and CRM extraction (e.g., through pressure, bio-electrochemical, and microbial leaching); 5) industrial and residential waste (coal and ore mine wastes; coal ash) as a source of CRM; 6) environmental impacts in areas of CRM mining (air, water, soil, biodiversity); 7) social and economic impacts of CRM mining; legislation; 8) GIS database of published and newly acquired CRM data; 9) international practices; 10) public outreach.

Here, I provide the rationale for establishing the Program and a brief historical timeline of the project, present an overview of the structure of the Program, outline the main work activities and summarize selected outcomes from the first stage and current results. As of June 2026, these include 42 scientific publications in journals with impact factor, 16 critical mineral summaries (Bi, PGE, V, W, Ti, B, He, Ge, Mg, Ni, Sr, fluorite, barite, phosphorite), 41 presentations at national or international conferences, 8 organized seminars or specialized sessions at national or international conferences, 6 organized media events or exhibitions, a representative public opinion poll on a national level regarding perception of mining and processing activities, summaries of CRM extraction methods, summaries of expert opinions (scientists, business, local, regional and national administration) on economic and demographic issues related to CRM, and 42 media interviews in national and international newspapers, TV and radio programs.

This summary will also include a tour of the recently launched website of the Program, available at <https://kss.geology.bas.bg/bg>, which hosts detailed, publicly available information on the goals, participants, and results of the Program.

Acknowledgements. This work has been carried out in the framework of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers No. 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria.

Gallium distribution in silicate minerals from pegmatites of the Madan and Arda lithotectonic units, Rhodope metamorphic complex, Bulgaria

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Gallium is a critical trace element with both lithophile and chalcophile behaviour, essential for modern high-tech industries. Its average concentration in the Earth's crust is ~17–19 ppm. Due to its geochemical affinity for aluminium, gallium is commonly incorporated into aluminosilicate minerals through Al-substitution in crystal structures. Elevated Ga concentrations may occur in specific geological environments, including rare-metal granitic pegmatites, alkaline igneous complexes, and hydrothermal systems. However, the element is mainly recovered as a by-product from bauxite and zinc-bearing sulphide ores. In pegmatites, gallium enrichment is controlled by Al-rich silicate minerals and accessory phases capable of incorporating this element into their crystal structure.

The study summarizes the distribution of gallium in silicate minerals from pegmatites hosted in the Madan and Arda lithotectonic units of the Rhodope Metamorphic Complex, Bulgaria. The investigated NYF-pegmatites commonly occur as massive dykes and lenses up to 2 m thick. They are emplaced either concordantly with or cross-cutting the main foliation of gneisses, amphibolites, and marbles. The pegmatites are exposed in the underground workings of the Petrovitsa, Govedarnika, and Djurkovo Pb-Zn deposits, as well as near the Strashimir Pb-Zn vein deposit. The mineral assemblage of the studied pegmatites consists of K-feldspar, plagioclase, quartz, micas ± garnet, with accessory titanite, apatite, zircon, allanite-(Ce), monazite-(Ce), and rarely Nb-Ta oxides (ishikawaite). The pegmatites are affected by subsequent hydrothermal alteration, represented by epidote-group minerals (clinozoisite-epidote_{ss}), chlorite, carbonates, and sericite.

LA-ICP-MS data reveal heterogeneous distribution of gallium among the investigated mineral phases. In pegmatites from the Strashimir area, clinozoisite-epidote_{ss} contains 30–117 ppm Ga, whereas allanite-(Ce) represents the most enriched phase, with concentrations reaching up to 2181 ppm. Titanite contains 28–52 ppm Ga.

In the Petrovitsa pegmatites, clinozoisite-epidote_{ss} incorporates 21–169 ppm Ga, allanite-(Ce) contains 601–1190 ppm, and titanite shows concentrations of 12–110 ppm. Chlorite formed as an alteration product of micas contains ~25 ppm of the element.

Pegmatites from the Govedarnika deposit demonstrate similar characteristics, with Ga contents of 43–259 ppm in clinozoisite-epidote_{ss}, up to 881 ppm in allanite-(Ce), up to 12 ppm in titanite, and up to 169 ppm in chlorites.

In the Djurkovo pegmatites, clinozoisite-epidote_{ss} incorporates 59–191 ppm, allanite-(Ce) 340–452 ppm, garnet 44–79 ppm, ishikawaite 56–87 ppm, and titanite up to 36 ppm. Potassium-feldspar contains up to 35 ppm Ga, whereas albite up to 71 ppm.

Generally, gallium is characterized by a highly dispersed distribution in the studied pegmatites, mainly controlled by mineralogical factors. Allanite-(Ce) is the principal Ga-bearing mineral, followed by clinozoisite-epidote_{ss}. Feldspars, garnet, titanite, chlorite, and ishikawaite represent additional Ga-hosts. The presence of Ga in both primary pegmatitic and secondary hydrothermal minerals indicates redistribution of this critical element during late magmatic and hydrothermal processes.

Acknowledgements. The study is supported by the Bulgarian National Science Fund project LiBeRE KP-06-N94/3 and contributes to the aims of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers No. 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria.

Rovina Project, Hunedoara County, Romania – from exploration to operation: challenges for the implementation of an EU strategic project

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This abstract focuses on the challenges encountered during the process of implementation of the Rovina Mining project. The Project is located in west-central Romania, lying within the historic gold-mining district known as the ‘Golden Quadrilateral’, with estimated +55 Moz of gold produced well before the Roman period (more than 2000 years ago). The bulk of this historic production has come from Neogene volcanic-hosted low- to intermediate-sulfidation epithermal veins. The Golden Quadrilateral is also host to porphyry copper deposits of similar age, which can occur in proximity to the epithermal gold mineralization (Halga *et al.*, 2010).

SAMAX Romania holds the Rovina Mining Licence and, between 2004 and 2012, after over 135,000 m of diamond drilling and spending over 135 M US\$ in exploration, has identified three porphyry Cu-Au deposits. The resources identified in the three deposits total 406 Mt of ore with a metal content of over 635,000 t of Cu and approximately 300 t of Au, intended to be mined through an investment of approximately 700 million USD from the private investor, Euro Sun Mining Inc., listed on TSX (Euro Sun Mining Inc., 2022).

The Rovina Mining Project aims to exploit the three deposits over 35 years in two phases. In phase 1 (17 years), the Rovina-Remetea and Colnic deposits will be mined in open pit operations. In phase 2 (18 years), Valea Gârzii-Cireșata will be mined as an underground operation. Once mining commences, operations are expected to create 1500 permanent jobs and to benefit around 3500 family members directly through increased household income and economic opportunity.

The ore will be processed by a simple flotation process, without the use of cyanide. The tailings from the flotation plant will be filtered and co-deposited with the waste rock from the open pits, thus eliminating the need for the construction of a classic tailings management facility. This will allow a progressive ecological restoration of the landfills compared to the classical option of environmental restoration at the end of exploitation.

In March 2025, Rovina was declared a strategic project at EU level following the CRMA Regulation, due to its copper resource. However, there are several challenges to be faced on three levels. Concerning the local authorities, there is a lack of land registries over the footprint of the Project. This responsibility has been taken over by the Company to start the identification of landowners and register the plots at its own expense (started in 2012 and ongoing). Additionally, the administrative cost for land rezoning, which is the responsibility of local authorities, as stipulated by the Mining Law and CRMA, is also now at the Company’s expense. In addition, there are serious discrepancies at the Forestry Department between their forest maps and the reality in the field, making the reconciliation for land registering difficult.

Secondly, at the national authorities’ level, there were delays in awarding the mining licence, e.g., instead of 90 days stipulated by the Mining Law, this took over 4 years to be received. The Project now also faces legislative delays in implementing the CRMA regulation, for example, the Single Point of Contact and the merger of environmental procedures from two to one. The Project’s progress has been hindered by inconsistencies between the legislative frameworks governing different public institutions. Each authority has applied its own legislation independently, without alignment or coordination with other relevant authorities, creating significant challenges and delays throughout the permitting and authorization process. As a general observation, there is very weak or no harmonization of national legislation regarding the CRMA Regulation.

Finally, the NGOs are carrying out extensive media and social media disinformation campaigns regarding mining projects and have initiated numerous court cases against development projects. The NGOs have also acquired small plots of land (up to 500 sqm) in the footprint of the mining projects to use their property to stop the authorization process.

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Potential for rare earth element (REE) deposits in Bulgaria and license areas

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The growing demand of the modern economy for REE necessitates a reassessment of Bulgaria's potential for their exploration and extraction.

The alkaline magmatism near the village of Svidnya, Western Stara Planina, has the greatest potential for REE. The potassium-alkaline rocks are small hypoabyssal bodies and dikes of shonkinites, K-alkaline syenite porphyries and quartz syenites. REE vary from 400–500 ppm in the rocks to 3000 ppm in metasomatites. Apatite reaches 3–4%, with REE content up to 5000 ppm. The average REE content is 778 ppm. Technological studies show easy enrichment of apatite and the possibility of extracting a high percentage of REE.

There are several types of pegmatites in Bulgaria. REE pegmatites are embedded in metamorphic rocks. They are widespread in Sakar, the Rhodopes, Rila and Sredna Gora. The most promising are migmatitic pegmatites, which contain an average of 557 ppm REE. They are enriched in LREE, with the main carrier being orthite. The richest pegmatites are in the valley of the Vacha River, with thousands of pegmatite veins. Microcline-oligoclase pegmatites near Pastra, NW Rila, contain 313 ppm REE, with increased contents of HREE. Rare metal pegmatites show a connection with granite massifs and high contents of Li, Cs, Be, Nb, Ta, Sn and W. They are found in Sredna Gora (Smilovene), the Western Rhodopes (Vishteritsa) and Rila.

Bauxite occurrences. In Bulgaria, several small karst bauxite deposits are known around the town of Tran. The REE content in the deposit near the village of Paramun is 632 ppm, accompanied by increased concentrations of Ti, Sr, P, Zr, Ni, V and Li. This suggests opportunities for these elements to be by-products in future exploitation of bauxites.

Modern deep-sea polymetallic nodules. Bulgaria participates as a partner in the Interoceanmetal Joint Organization (IOM), which has a licence to explore the ocean floor in the Clarion-Clipperton Zone, NE Pacific. The IOM estimated resources of polymetallic nodules are 272.5 Mt, with the main metals being Mn, Ni, Cu and Co. The nodules also contain Mo, Zn, V, Pb, Sr, Ba, As, Ti and Fe. Σ REE is on average 498.64 ppm, and Σ HREE 73.91 ppm. REE and other trace elements are potential by-products of the main extraction, which increases the importance of polymetallic nodules.

Secondary raw materials. Phosphogypsum is a technogenic waste raw material in the production of phosphorus fertilizers from apatite. Apatite from the Kola Peninsula, used years ago, contains impurities of REE, Sr, Ti and F. LREE predominate, being enriched in Eu and Y. The average REE₂O₃ in phosphogypsum is 0.5% as phosphates, and SrO 1.75%, as celestine. The accumulated phosphogypsum near Dimitrovgrad is about 8 Mt and can be considered as a potential raw material for REE and Sr. Thirty years ago, the Geological Institute of BAS began the study of phosphogypsum as a potential raw material. A hydrochemical method for the enrichment of REE and Sr in phosphogypsum was developed and successful semi-industrial trials were achieved. Today, the question of renewing these studies and assessing economic feasibility is being raised again.

Acknowledgements. The study is supported by the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”.

Building a machine-friendly, geologically-contextualized dataset for the Carpathian–Balkan region: integrating lithostratigraphic lexicons, survey data, and mineral project records

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Assessment of critical raw material (CRM) potential in the Carpathian–Balkan region is constrained not by absence of data, but by its fragmentation across formats, languages, and institutional silos: national geological surveys, scientific literature, and corporate technical disclosures each describe overlapping geographic space using incompatible vocabularies and structures. This paper presents the construction of an integrated, machine-friendly dataset for the countries across the Carpathian–Balkan region, designed to bridge these sources through a shared geological reference framework.

The core of the framework is a lithostratigraphic lexicon currently under construction, which standardizes formation and unit names across national geological survey nomenclatures and links them to formal stratigraphic units, resolving the synonymy and translation barriers that currently prevent cross-border correlation of geological information. Baseline geological data, primarily BGR pan-European coverages (IGME 5000, Precambrian, GEMAS), are being reorganized and indexed against this lexicon, with enrichment from regional literature, mostly from *Geologica Balcanica*, the official CBGA journal, which provides both stratigraphic detail and a structured author/contributor network relevant to regional expertise mapping.

In parallel, technical disclosures from mining companies (e.g., JORC and NI 43-101 reports) are being extracted and structured at the project level, capturing location, commodity, deposit type, ownership, and development stage. Metallogenic models for the principal ore-forming systems of the region (e.g., Tethyan porphyry-epithermal, VMS, sediment-hosted, skarn) are being compiled from reference monographs and specialized journal sources (e.g., Laznicka, 1985, and *Economic Geology*) and organized for spatial association with both the geological and project layers.

All three layers (geological/lithostratigraphic, literature-derived metallogenic, and project/corporate) are being consolidated into a hybrid database architecture: a MongoDB document store for heterogeneous source records, linked through a graph database (Neo4j) that encodes relationships between stratigraphic units, metallogenic models, and mineral projects. The resulting dataset is designed as a geologically-contextualized, machine-friendly resource enabling downstream analyses, including project development-history review and regional prospectivity assessment, that current fragmented sources do not support. A public-facing geoportal exposing this dataset is available at www.infomineral.com/rnd/carpathian_balkan, providing open access to the integrated geological and project framework for the research and exploration community.

By lowering the barrier to cross-jurisdictional data correlation, this work aims to support the geological data access and exploration prioritization goals central to CRMA implementation in Member States. This paper reports on the design and current build status of this infrastructure, intended as an open methodological contribution for data integration in underexplored European regions.

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Manganese – a critical element of great potential in Bulgarian deposits and geological exploration areas

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Manganese, an element included on the European Union's list of Critical Raw Materials, is a paramagnetic, relatively hard, yet brittle metal. It is highly effective in sulphur fixation, acts as a powerful deoxidizer, and plays an essential role in steel production. Manganese is also widely used in the manufacture of aluminium alloys, dry-cell and lithium-ion batteries, and pigments.

Bulgaria's most significant manganese resource is the Obrochishte manganite–hydrosilicate–carbonate deposit, located within the Lower Oligocene marine sediments. With reported resources of approximately 16 Mt of ore, it is the largest known manganese deposit in Europe.

The deposit formed in a very shallow environment, where the manganese mineralization occurs in one to four beds with a cumulative thickness of up to 11.3 m. The pisolitic manganese ore is enriched in phosphorus, yttrium, heavy REE, and uranium. The origin of the Obrochishte deposit has long been debated, with proposed models including sedimentary, volcano-sedimentary, and exhalative processes.

A recently proposed volcanological model suggests that the primary manganese carbonates formed through the dissolution of volcanic material in a volcanically induced anoxic–euxinic marine basin, followed by the partial oxidation of the carbonates to manganese oxides. An alternative model proposes the development of a thick lateritic weathering crust during the Eocene, which was subsequently eroded and transported as iron and manganese oxides into the redox-stratified western Black Sea. Manganese accumulated within the suboxic water, and the Early Oligocene transgression transported it onto the shallow continental shelf, where manganese oxides precipitated and were subsequently transformed into manganese carbonates during early diagenesis. Additional manganese was supplied by submarine groundwater discharge, while part of the manganese carbonate precipitated directly from the water column.

In addition to terrestrial manganese deposits, modern polymetallic ferromanganese nodules from the deep Pacific Ocean are gaining strategic importance as a potential future source of critical raw materials. Collectively, these nodules contain greater quantities of Mn, Ni, Co, Tl, Y, and As than the entire global terrestrial reserve base. As a member of the Interoceanmetal intergovernmental organization, the Republic of Bulgaria participates in the exploration of a licensed area within the Clarion–Clipperton Zone. The ferromanganese nodules, predominantly of mixed hydrogenetic–diagenetic origin, contain economically significant concentrations of manganese (31.4%), nickel (1.3%), copper (1.3%), cobalt (0.16%), and zinc (0.16%). Elevated concentrations of lithium, REE, vanadium, and tungsten further enhance their potential as valuable by-products, thereby increasing the overall economic attractiveness of future mining operations.

Smaller manganese deposits occur within the intra-arc Sredna Gora trough. The manganese oxide ores occur as veins within Santonian–Campanian volcanic tuffs and as nodules, lenses, and irregular bodies hosted by limestones. Isotopic evidence indicates mixed sedimentary and volcanogenic contributions to both the mineralizing fluids and the host rocks. These deposits contain manganese ores enriched in Cu, Ni, Zn, and Ba, with manganese concentrations ranging from 10 to 65 wt.%.

Acknowledgements. This work was carried out within the framework of the National Science Programme *Critical and Strategic Raw Materials for a Green Transition and Sustainable Development*, approved by Resolution No. 508 of the Council of Ministers of the Republic of Bulgaria (18 July 2024) and funded by the Ministry of Education and Science of Bulgaria.

The Romanian Programme for General Exploration: the burden of an early start

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In Romania, after 1990, the mining industry had a declining trend. In the interval 1998–2010, the Romanian Government decided the closure, conservation and monitoring of post-closure environmental factors for 556 mines. In many of the sulfide deposits with closed mines, ore resources are not exhausted. In most of these deposits, the contents of critical raw materials other than copper were only sporadically investigated. Therefore, the investigation of waste rock dumps and tailings ponds could provide information not only about the possibilities of being themselves exploited with profit, but also to get insights into the CRM contents of the primary ores. This is a good reason to use the National Programme for General Exploration (NEP; Art. 19 of the CRMA) for the investigation not only of primary resources but also of secondary ones (Art. 27 of the CRMA).

In its first 5 years, the NEP in Romania aims at the investigation of: (1) selected waste rock dumps and tailings dams in the Eastern Carpathians and Apuseni Mountains; (2) graphite-rich rocks in the metamorphic formations from the Eastern Carpathians; (3) borate mineralization at Pietroasa, Apuseni Mountains; (4) the Tisovița-Iuți serpentinite complex, Southern Carpathians (Mg, Ni, Co ± PGE); (5) Co, Ni, Cu, Sb, Bi, As epithermal veins in the Leaota Mountains, Southern Carpathians. The proposed investigation will use legacy data, remote sensing data, ground and airborne geophysics, drilling (for secondary mineral resources), geochemical and mineralogical investigation, and geological modelling.

The NEP in Romania is not funded yet. The measures indicated for NEPs in the CRMA, Art. 19 (2), are prospecting works, according to the Romanian Mining Law 85/2003. Romania also has additional provisions for prospecting works, regulated by Law 27/2018 (Law of the Geological Programme at National Scale – GPNS). GPNS was designed to facilitate prospecting for purposes similar to the ones in NEP but is not targeted only at CRM, containing general provisions on the type of works and on the procedures of project proposal assessment, approval and monitoring. GPNS received funding every year after its publication and should have been ahead of NEP in its achievements, but the allocated funds were never used because of bureaucratic issues. Therefore, after the CRMA issuance, Romania is in the situation of having two national prospecting programmes and is now trying to make GPNS work, in order to access the allocated funds and use them for NEP as part of GPNS.

Geological framework of high helium concentration in the Eastern Transylvanian Basin (Romania)

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Helium (He) is a noble gas used in a wide range of industrial, analytical and medical applications, including the manufacturing of semiconductors and optical fibre, cryogenic applications and magnetic resonance. It is a non-renewable resource, being derived only through extraction from natural gas fields with concentrations exceeding 0.3 vol%, which is the threshold for economic exploitation. Accordingly, He is included in the list of critical raw materials considered by the European Parliament and Council (European Commission, 2023). Currently, He is substantially extracted only from sedimentary reservoirs in the United States, Qatar and Algeria. The recent geopolitical situation in the Hormuz strait has induced further constraints on the He supply chain from Qatar. In Europe, only Poland produces low amounts of helium.

Consequently, efforts are necessary to identify new He deposits capable of providing reserves to meet current demand.

Geochemical studies demonstrated the existence of He concentrations up to 1.5 vol% (5 times the economic threshold) in Romania, at Homorod, Eastern Transylvanian Basin (Etiope *et al.*, 2011). The gas naturally reaches the surface through a cluster of seeps. This occurrence is further investigated by the ENGAGE-LAB (Babeș-Bolyai University), through multiple geochemical surveys in the region.

Here, the geological context of the Homorod He-bearing area is described, addressing the factors leading to He production and accumulation. In the region, we identified the two main geological factors which typically characterize He-prone areas: (a) radioactive granitic basement (part of the Dacia mega-terrane), as potential source rock of helium (Bowman *et al.*, 2020); (b) uplifted basin (Krężsek *et al.*, 2010), which induced pressure decrease (depressurization) in the deep aquifers, with consequent exsolution of the gases with lower solubility, He and N₂.

The He-bearing seep is the result of gas migration along a N-S fault, as suggested by Electrical Resistivity Tomography (Chitea *et al.*, 2020). The present geological assessment serves as a reference for geochemical studies that will characterize the areal He distribution and its correlations with stratigraphic and structural elements of the region.

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Critical raw material potential of porphyry copper systems from the ore to the tailing: a case study of the Chelopech high-sulfidation Cu–Au epithermal deposit, Bulgaria

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Mineral raw materials (RMs) have a crucial role in the economic and cultural development of human societies. In the last decade, 34 elements or groups of elements have been defined as critical and strategic (CS) for the European Union (<http://data.europa.eu/eli/reg/2024/1252/oj>) due to their high importance in the green and digital transitions and their use in high-technology and energy products, defence and aerospace, but also in every-day life applications. At the same time, there is a risk in the supply of these commodities, whose production is concentrated in a few, mainly non-European countries (e.g. China), making their use dependent on geopolitical tensions and negative environmental management.

Porphyry and related epithermal Au–Ag ores are the world's most important deposits of Cu, with significant Mo, Au and Re reserves and minor amounts of some other metals such as Ag, Pb, Zn, Pd, Bi, Te and Se. The Chelopech deposit is one of the largest Cu–Au epithermal deposits of Europe and belongs to the Late Cretaceous Apuseni–Banat–Timok–Srednogorie magmatic and metallogenic belt. It is a major producer of Cu and Au, but the information on its CSRM potential is scarce. In the present study, we provide data on the major and minor elements in ores that feed the flotation plant at the Chelopech mine and their behaviour during the different steps of Cu- and Py-concentrate production, as well as in the intermediate and final wastes. Some preliminary data on the final distribution of the elements in the tailings are shortly discussed.

During two randomly chosen days, the Cu–Au bearing ores were combined from three to seven exploitation blocks. Optical, cathodoluminescence and scanning electron microscopy were combined with elemental (XRF, LA-ICP-MS) and quantitative mineralogical (QEMSCAN) analyses to define the mineral and geochemical characteristics of the studied samples. The main ore minerals were chalcopyrite, bornite, enargite/luzonite and tetrahedrite-tennantite, with minor sphalerite, galena, aikinite, hessite and rare Au–Ag phases. They were observed in a groundmass of characteristic mineral associations of the advanced argillic alteration zones. In the flotation feed the typical Ge, Ga, Co and Sn contents were >20 ppm, slightly higher for Te (40–45 ppm), Se (60–75 ppm), Sb (60–75 ppm), Bi (20–40 ppm), Zn (250–260 ppm) and Pb (300–750 ppm), and negligible for W, Mo, Re, In and Sc. The only elements in high content (except the major Cu) were As (1500–1600 ppm) and Ti (3000–3500 ppm). The majority of the above elements increase in the final Cu-concentrate in the range of single, tens or hundreds of ppm (e.g. Ge 30–60 ppm, Se 300–320 ppm), whereas As is in a valuably high content of >2.5 wt%. Almost all CSRMs were in low content in the tailings, where mainly aluminosilicate and oxide-sulfate minerals accumulate. One important conclusion is that the development of a suitable As-extraction technology may have a positive impact on the effective usage of the ores, diminishing the possible negative impact on the environment.

Acknowledgements. The study is partly supported by the “NextGeneration EU” REXPro project, contract BG-RRP-2.011-0040, and is a contribution to the Bulgarian National Scientific Program “Critical and strategic raw materials for a green transition and sustainable development”.

(Fe,Mn)-(Nb,Ta,Ti) and (Y,REE,U,Th)-(Nb,Ta,Ti) oxide minerals in heavy fractions of soils and river sediments in the area of the Grantcharitsa tungsten deposit, Western Rhodopes, Bulgaria

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A large group of minerals – carriers of the critical elements REE+Y, Nb, Ta and Ti – has been discovered in the heavy fractions of alluvial soils and river sediments within the Grantcharitsa tungsten deposit (Western Rhodopes), indicating possible additional ore potential of the deposit. (Fe,Mn)-(Nb,Ta,Ti) oxide minerals (columbite-(Fe), Nb-Ta rutile and Nb-Ta pyrophanite/ilmenite), (Y,REE,U,Th)-(Nb,Ta,Ti) oxide minerals (ishikawaite, euxenite-(Y), uranopolycrase) and minerals from the pyrochlore group (betafite subgroup) have been identified. Columbite-(Fe) is the most important and widespread mineral of the group under consideration and has atomic ratios Ta/(Ta+Nb) of 0.02–0.22 and Mn/(Mn+Fe) of 0.34–0.5. It occurs in association with all the above minerals and is represented by at least two types: (i) complex intergrowths with Nb-Ta rutile ($\pm$ Nb-Ta pyrophanite/ilmenite) as a result of subsolidus processes (Okrusch *et al.*, 2003), and (ii) prismatic, commonly zoned individual crystals or intergrowths, most often with euxenite. Niobium-tantalum rutile shows a strong predominance of Nb over Ta – Nb₂O₅ (up to 21 wt.%) and Ta₂O₅ (up to 4.5 wt.%) – which is also characteristic of pyrophanite/ilmenite, but at significantly lower contents of both elements (Nb₂O₅ up to 0.6 wt.% and Ta₂O₅ up to 0.3 wt.%). The studied (Y,REE,U,Th)-(Nb,Ta,Ti) oxide minerals are metamict due to the high content of UO₂ (up to 32 wt.%). To identify these minerals, the CV1-CV2 identification diagram of the three-group model of Ercit (2005) was used. Two subgroups are clearly distinguished within this group of minerals: (i) minerals enriched in Y, Nb, Ti and U – ishikawaite (samaraskite group), euxenite-(Y) and uranopolycrase (euxenite group), and (ii) minerals characterized by a high content of Ca, U, Nb and Ti and the absence of Y – betafite (pyrochlore group). Minerals of the first subgroup occur as individual, usually zoned crystals or intergrowths with columbite, while minerals of the second subgroup metasomatically replace columbite. The textural relationships between columbite-(Fe) and (Y,REE,U,Th)-(Nb,Ta,Ti) oxide minerals and their chemical similarity (Nb $\gg$ Ta, high content of Y, Ti, U) suggest their common origin from NYF granitic pegmatites associated with I- (or A-) type granites. It is assumed that the source of these minerals are granitic pegmatites, which form thin dikes with a thickness of 10 to 70–80 cm in the Grantcharitsa body of Late Cretaceous granodiorites. So far, in these pegmatites we have only identified needle-shaped crystals of Nb-rutile and columbite-(Fe) with composition identical to that of these minerals in soils and sediments.

Acknowledgements. This work has been carried out in the framework of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers No. 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria.

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Staurolite as the principal Li-concentrator in amphibolite-facies metapelites: evidence from the Sakar Mountain, Bulgaria

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Lithium is a strategic critical raw material that plays a fundamental role in the global transition toward renewable energy technologies. Although Li-resources are traditionally associated with granitic pegmatites and continental brines, metamorphic rocks may represent significant secondary Li-hosts where lithium is redistributed and concentrated through mineral-specific partitioning during regional metamorphism. Understanding the mineralogical controls on Li-incorporation is therefore essential for evaluating its mobility, retention, and potential enrichment in metamorphic terranes. This study investigates the mineral composition and major- and trace-element geochemistry of staurolite-garnet mica schists from the Sakar Mountain, southeastern Bulgaria, with particular emphasis on identifying the principal mineral Li-concentrators and assessing their significance within amphibolite-facies metamorphic systems.

The studied metapelites consist of a characteristic mineral assemblage involving staurolite, garnet, biotite, chlorite, sericite, quartz and accessory fluorapatite and monazite-(Ce). Major-element compositions indicate chemically homogeneous Fe-rich staurolite containing 47–55 wt.% Al₂O₃, 10.5–12.5 wt.% FeO, 1.8–2.2 wt.% MgO, 28–29 wt.% SiO₂ and 0.40–0.53 wt.% TiO₂. Garnet is predominantly almandine-rich and exhibits only limited compositional zoning based on variable Mn-incorporation (0.6–4.2 wt.% MnO). Trace-element content reveals that garnet preferentially incorporates Y, Sc and HREE. Staurolite is significantly enriched in transition and HFS elements, including Zn (2400–3500 ppm), Ga (137–203 ppm), Cr (74–208 ppm) and V (93–132 ppm). Notable Be incorporation (28–51 ppm) is detected exclusively in staurolite. Biotite is characterized by elevated Rb (620–686 ppm), Ba (370–450 ppm), and V, Cr, Ni, Zn, Nb. Chlorite preferentially hosts Cr (100–190 ppm), Ni (~110 ppm) and Co (~40 ppm). These signatures illustrate distinct trace-element partitioning among coexisting ferromagnesian silicates. Lithium shows the strongest mineralogical fractionation observed within the studied assemblage. Staurolite contains the highest incorporation (492–905 ppm, typically 600–720 ppm), substantially exceeding those of biotite (154–185 ppm), chlorite (108–165 ppm), garnet (24–52 ppm) and sericite (4–9 ppm).

The combined EPMA and LA-ICP-MS dataset demonstrates that the geochemical evolution of the Sakar Mountain staurolite-garnet schists is governed by specific trace-element partitioning established during regional metamorphism. Lithium is preferentially incorporated into Fe-Mg aluminosilicates, with staurolite representing the dominant Li-concentrator under amphibolite-facies conditions. The obtained mineral and chemical data provide insights into Li-mobility during progressive metamorphism and the role of metamorphic fluids in trace-element redistribution. The compositional data suggest that staurolite-bearing metapelites might constitute a potential Li-reservoir in metamorphic terrains.

Although Li-contents are below the economic threshold, the identified Li-bearing assemblage provides valuable information on the partitioning, fluid-rock interaction, and the evolution of lithium within the Earth's crust. The results contribute to a better understanding of Li-behaviour in metamorphic environments and complement the data on lithium geochemistry in the Balkan Peninsula, thus providing a framework for future exploration strategies targeting critical raw materials in metamorphic provinces in Bulgaria.

Acknowledgements. The study is financially supported by the Bulgarian National Science Fund, project LiBeRE KP-06-N94/3, and contributes to the aims of WP I.1 of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers No. 508/18.07.2024 and funded by the Ministry of Education and Science of Bulgaria.

Petrography, geochemistry and maturity of glauconite across Upper Cretaceous formations from the SE Moesian Platform and Eastern Balkanide Zone (Eastern Bulgaria)

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Glauconite is widely recognized as an indicator of low sedimentation rate, a reliable stratigraphic marker and a redox proxy in marine sedimentary environments. In response to growing global demand for critical and strategic raw materials, glauconite has also gained attention as a potential slow-release K fertilizer, source of trace elements, and versatile natural resource. This study summarizes petrographic and geochemical data for glauconites from four Upper Cretaceous sedimentary formations (Fm) outcropping in Eastern Bulgaria. Samples from the Madara Fm (Md) and Dobrindol Fm (Dd) in the SE part of the Moesian Platform, and two informal units from the Eastern Balkanide Zone – the “Sandstone Fm” (Ss) and the “Flysch Fm” (Fl) – were compared to evaluate the composition, maturity, and crystal chemistry of glauconite. These units represent distinct depositional environments, ranging from a carbonate ramp and a carbonate-siliciclastic shelf to a transitional-to-marine setting with high terrigenous input.

Optical and scanning electron microscopy show variable size (up to >500 µm), different substrate types (biogenic and abiogenic), morphology and internal texture, and common apatite inclusions in glauconite grains (Md and Dd Fms). Electron probe microanalysis of 70 pellets revealed generally consistent compositional ranges within each sample, with the widest variations occurring in the samples from the Ss and Fl Fms. The K₂O content ranges from 5.87 to 9.15 wt%, with sample averages of 6.99 wt% (Fl), 8.41 wt% (Ss), 8.34 wt% (Dd), and 8.63 wt% (Md), indicating predominantly evolved to highly evolved stages of glauconite maturity. The average Fe₂O₃ content is 18.06 wt% (Fl), 23.82 wt% (Ss), 24.51 wt% (Dd) and 23.88 wt% (Md), exhibiting a strong positive correlation with K₂O ($R^2 = 0.79$). Al₂O₃ varies significantly from 3.83 to 13.08 wt%, with the highest contents measured in the pellets from the Flysch Fm. TiO₂, MnO, CaO, Na₂O, and P₂O₅ are present in minor or negligible amounts, with CaO and P₂O₅ exhibiting a very strong positive correlation ($R^2 = 0.94$), matching the observed apatite inclusions. TiO₂ values are slightly elevated in the glauconites from the siliciclastic-dominated units (i.e. Ss and Fl). Crystal chemistry calculations show that, while tetrahedral Si⁴⁺-Al³⁺ substitutions remain relatively uniform across the studied samples, variations in interlayer and octahedral features mark distinct maturity stages. While the Md, Dd and Ss samples feature elevated K⁺ (av. 0.7–0.8 apfu), the Fl Fm sample represents a less evolved glauconite phase (K⁺ = 0.51–0.72 apfu), with lower, but nonetheless prevalent, octahedral iron occupancy.

The observed chemical variations reflect the control of depositional environments and terrigenous influx on the glauconitization process in the studied formations. The chemical characteristics of the investigated glauconites are comparable to those reported for glauconite materials studied as alternative K-bearing resources, while follow-up trace element studies would further evaluate their potential as a source of critical or strategic raw materials.

Acknowledgements. This work has been carried out in the framework of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers No. 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria.

Assessment of critical element concentrations in waste products from Thermal Power Plant Maritsa East 2, Bulgaria

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Maritsa East 2 Thermal Power Plant (TPP) is the largest coal-fired power plant on the Balkan Peninsula, with a total installed capacity of 1,600 MW. It is located in southeastern Bulgaria and operates with East-Maritsa lignite. A total of 31 samples were investigated: 11 bottom ashes (BA), 11 fly ashes collected downstream of the regenerative air preheater (OFAP), 7 electrostatic precipitator fly ashes (FA), one ash–slag mixture (ASM), and one flue gas desulfurization gypsum (FGD gypsum) sample. Concentrations of 63 elements were determined by ICP-MS after four-acid digestion. The results were compared with world average concentrations (Clarke values) for ashes derived from low-rank coals. Based on the calculated concentration coefficients (CC), the analyzed elements were classified as: depleted ($CC < 0.5$), normal ($0.5 < CC < 2$), slightly enriched ($2 < CC < 5$), enriched ($5 < CC < 10$), significantly enriched ($10 < CC < 100$), and unusually enriched ($CC > 100$). Among the BA and OFAP samples, Pd was the only element exhibiting significant enrichment, with CC ranging from 9.5 to 16.4 and from 9.3 to 15.7, respectively. Compared with BA and OFAP, the FA samples contain a larger number of elements with concentrations exceeding their respective Clarke values (18 elements) and generally display higher enrichment factors. The normally enriched group comprises 24 elements, including Ti, Mn, Li, Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Se, Rb, Sr, Nb, Ag, Cd, In, Cs, Ba, W, Au, Pb, and Th. FA represents the most efficient natural concentrator of Pd among all tested samples, with concentrations ranging from 15.7 to 25.7 times the corresponding Clarke value. The ASM shows moderate enrichment (from 2 to 7 times) in Bi, Te, Cd, As, Ge, Pb, and Rh relative to BA, and in As, Bi, Te, Cd, Se, and Sb relative to FA. The FGD gypsum is only slightly enriched in Se, exhibiting concentrations approximately 1.2 times higher than those measured in the BA samples. The samples have low contents of REY+Sc and are ordered as follows: ASM (153.8 ppm) > OFAP (144.5 ppm) $\approx$ FA (144.4 ppm) > BA (132.1 ppm). The calculated outlook coefficient (OC) indicates that these combustion by-products have limited economic potential as a source of rare earth elements. The investigated samples are characterized by low concentrations of most analyzed elements, which are predominantly depleted or normally enriched relative to world average abundances. Palladium is of interest, showing above-Clarke concentrations in most of the samples. In view of continuing advances in extraction technologies and the development of environmentally “green” leaching reagents, the utilization of wastes generated by Maritsa East 2 TPP as secondary raw materials for the recovery of critical raw materials appears increasingly promising.

Acknowledgements. The study is supported by TPP “Maritsa East 2” EAD and by the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers No. 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria.

Preliminary data on critical element concentrations in lignite from the Stanyantsi coal basin, Bulgaria

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The Stanyantsi lignite basin is located approximately 60 km northwest of Sofia. It is represented by a single Late Miocene coal seam, 15–30 m thick. The seam is composed of dull detrital coal with mineral inclusions of quartz, illite, kaolinite, calcite, and pyrite. The contents of Li and 65 additional elements were studied in four composite samples: vitrain, run-of-mine coal from the working face (RC), feed coal for thermal power plant (FC), and coaly clay (CCL). Their ash yields are 14.3%, 27.2%, 40.2%, and 65.2%, respectively.

The analytical methods applied were ICP-OES (BDS EN ISO 11885:2009) and LA-ICP-MS on pressed pellets. The concentration coefficients (CC) of the elements were calculated by comparing the measured contents with global values (Clarke) for low-rank coals.

Vitrain is characterized by 10 elements whose concentrations are equal to or exceed the Clarke values: S, Ca, Fe, Ni, As, Se, Sr, Cd, Te, and Au. Most elements in this sample are depleted ($CC < 0.5$) or normally enriched ($0.5 < CC < 2$). Exceptions are Ca, As, and Cd, which are slightly enriched ($2 \leq CC < 5$); Fe, which is enriched ($5 \leq CC < 10$); and Te and Au, which are significantly enriched ($10 \leq CC < 100$).

The RC and FC contain 35 and 38 elements, respectively, whose concentrations are equal to or exceed their Clarke values. The RC is slightly enriched in S, K, Ca, Cr, Fe, Ni, As, Se, and Sr; enriched in Re; and significantly enriched in U and Au. The FC is slightly enriched in Al, S, K, V, Cr, Mn, Fe, Co, Ni, Zn, Ga, Rb, and Cs; enriched in As and U; significantly enriched in Rh and Pd; and anomalously enriched in Au.

The dominant mineral mode of occurrence of the elements is confirmed by the vitrain/CCL, RC/CCL, and FC/CCL ratios. In this case, even the organophilic element Ge appears to have a predominantly mineral mode of occurrence. A weak affinity to organic matter and to associated sulfides/sulfates (?) is indicated for Ca, Fe, As, Mo, and Sb.

High correlation coefficients ($r \geq 0.95$) with ash yield are observed for Li, Be, Na, Mg, Al, Si, P, K, Sc, V, Cr, Zn, Ga, Ge, In, Cs, La, Ce, Pr, Nd, Sm, Eu, Yb, Lu, Hf, Re, Tl, Pb, Bi, and Th. The preliminary results indicate that the Stanyantsi coals are poor in critical elements and that their concentrations are mainly associated with the mineral matter. The outlook coefficient indicates that these coals are not promising for REE recovery. However, the elevated contents of Rh, Pd, Au, and Te in some of the samples are of interest and require more detailed investigation.

Acknowledgements. The study is supported by the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers No. 508/18.07.2024 and funded by the Ministry of Education and Science (MES) of Bulgaria.

Special session SS3

**Exploring the Paratethys and Euxine Basins: Recent
Advances and Novel Research Directions**

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Modern sedimentary structures bearing shallow gas – organic matter in an anoxic basin – Black Sea

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Black Sea is the largest anoxic basin in the world and has one of the largest biogenic gas accumulation in Europe, the Domino structure that is located on the continental slope. Other structures with biogenic methane are Midia, Ovidiu, Cobălcescu, Doina, Doina Sister and Ana. All the above mentioned gas fields are of Lower Pontian and Dacian ages (Moroşanu, 2012). Additional to the biogenic methane accumulations there are organic matter accumulations, as is the sapropel layer on the continental slope. The sapropel layer is the product of organic matter accumulation after the invasion of the Mediterranean waters into the Black Sea, at the end of Last Glacial Maximum – LGM. The Neoeuxinian phase of the Black Sea, when this basin was a lake, can be seen as the last episode of the Eurasian megalakes evolution.

The nowadays anoxic part of the Black Sea is below 120–150 m water depth and it is due to the vertical layering of the water mass, as the result of the more saline waters that entered the basin after the deglaciation of the LGM ice cap. This layering impeded the vertical mixing of the water masses and as consequence the oxygen from the shallow waters cannot feed the deeper water masses, depleted in oxygen as the result of the biogenic consumption. It is well known the organic matter is better accumulating in anoxic waters, being protected against the biogeochemical oxidation processes. Below a few centimeters under the sea bottom, the pore water is already depleted in oxygen. The prerequisite to store large amounts of organic matter is to have a large turnover of the marine plankton and/or an important terrestrial input. The sedimentation rate is another important parameter that helps to the rapid burial of the organic matter and thus impeding the oxydation processes.

Former and more recent of our researches revealed gas seeps in the water column on the upper slope, shelf break area, and even on the shelf (Ion et al., 2002). These researches also evidenced biogenic methane accumulations in shallow sediments. We recently discovered shallow sedimentary structures on the shelf area, which have gas charged seismic facies. These sedimentary bodies are in relationship with the former Quaternary paleo-network of rivers that incised sub-aerial shelf during low stands during glacial times. Our researches using high and very high resolution reflection seismics revealed very specific fluvio-deltaic sedimentary bodies. Below this features there are some typical biogenic gas (methane) accumulations. These results can be seen as an useful proxy of biogenic methane production, migration, and accumulation in marine sediments.

Acknowledgements. Project PN23300201 funded by Romanian Government, Ministry of Education and Research. Project PNRR C9 – I8 “Multiproxy reconstruction of Eurasian Megalakes, connectivity and isolation patterns during Neogene-Quaternary times”, code 97/15.11.2022, Contract No. 760115/23.05.2023.

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The late Volhynian depositional environments of the inner foredeep (Eastern Carpathian Foreland Basin) revealed by Bogata and Seaca brooks

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The late middle Miocene (Sarmatian *s.l.*) sedimentary successions outcropping in two brooks from the northern part of the Moldavian Plateau were analysed from micropaleontological and sedimentological point of view. The Bogata and Seaca brooks are cropping out sedimentary deposits that were accumulated in the inner foredeep depozone of the Eastern Carpathians Foreland Basin (ECFB).

In the Bogata brook a series of composite outcrops were logged bed by bed through the sedimentary facies analysis in order to establish the depositional environments. The identified facies associations revealed the existence of a dynamic margin within the sedimentary basin, starting with upper shoreface deposits with sandy mudstones and sands with swaley cross stratification, continuing with silty deposits with continental gastropods (*Helix*) and finishing with trough cross stratified gravels that indicate a fluvial deposition.

The Seaca brook deposits are also complex by meanings of depositional environment. The sedimentary succession is starting with upper shoreface sandy deposits and evolves to clays associated with 30 cm thick coal horizons.

In order to establish the age and the paleoecological evolution from the inner foredeep deposits of the ECFB a micropaleontological analysis of the fine-grained deposits was conducted.

The micropaleontological assemblages identified in the samples from marine sedimentary successions of Bogata and Seaca brooks are rather interesting, revealing a mixed microfauna containing reworked Badenian taxa as *Uvigerina* and *Cibicides* and *in situ* Sarmatian (late Volhynian) *Pseudotriloculina consobrina* associated with ostracods as *Cyprideis* spp.

The stacking of the facies associations identified in the Bogata and Seaca brooks revealed a prograding shoreline starting to upper shoreface deposits that evolved further to the coastal plains and fluvial environments.

The micropaleontological assemblages indicate the late Volhynian age of the deposits and a brackish shallow water environment with a well oxygenated seafloor.

Acknowledgements. We acknowledge funding from the European Union (Recovery and Resilience Facility) through Romania's National Recovery and Resilience Plan (PNRR), C9 – I8, grant 97/15.11.2022.

Insights global and regional changes within the Late Eocene to Early Oligocene interval: The record of the Eastern Carpathians

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Within the Late Eocene to the Early Oligocene interval, major climatic and palaeoenvironmental changes took place, such as cooling of the deep-ocean and surface-oceans, growth of the ice-sheets, and a significant global sea-level drop. These modifications led to the shift from a Greenhouse climate mode of the Late Eocene to an Icehouse Climate during the Early Oligocene (i.e., Haq et al., 1987; O'Brien et al., 2020). Multiple causes have been claimed, including the decline in carbon dioxide, high tectonic activity that changes ocean gateways, and paleogeographic landscape, i.e., India collision to Asian block, separation of Antarctica from Australia, and realignment of Pacific mid-ocean ridge (Bowen, 2007). Hence, the Oligocene represents a pivotal shift from a tropical to a cooler world, marked in the sedimentary record and biotic turnover.

At the end of the Eocene an outstanding event took place in the Tethyan Realm, i.e., the demise of the above-mentioned domain, leading to the occurrence of Mediterranean and Paratethys. The later realm was the largest anoxic basin of Paleogene times, covering large areas of Europe and Asia (i.e., Steininger and Godfrid, 1999; Palcu et al., 2023).

This work documents the Eocene-Oligocene transition in the southern part of the Eastern Carpathians (Romania), based on various proxies, such as stable isotopes ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$), bulk geochemistry (TOC and CaCO_3), and biotical changes (mainly of the calcareous nannofossil distribution pattern), along with modification in the palaeosetting from an oxic regime to an anoxic one. By integrated these data, we correlated the events recognized at regional level, in the Central Paratethys with the global ones, contributing to a better understanding of how sedimentary basin isolation may modify or even hide the global climate signals, due to the regional geological setting.

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Architecture of folds and thrust belt of the Eastern Carpathians: Case study Moinești–Târgu-Ocna

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From a structural perspective, several tectonic units with specific structural styles can be distinguished within the Eastern Carpathians, illustrating the structural evolution of this belt during Cretaceous–Pliocene tectonic transport to their current configuration. The tectonic units are aligned along the mountain range in nappes or systems of nappes, generally younger eastward, with a few notable exceptions. The Eastern Carpathian outer structures, containing a sedimentary cover, comprise the thick-skinned nappes of the Outer Dacides (Baraolt, Ceahlău, and Bobu) and thin-skinned nappes of the Moldavides. The latter are divided (from W to E) into the Inner Moldavides (Teleajen, Macla, and Audia nappes) and the Outer Moldavides (Tarcău, Vrancea and Subcarpathian nappes).

The orogen can be broadly divided into a metamorphic core zone and the fold and thrust belt (FTB); the latter was classically separated into internal flysch, median flysch, and external flysch (Moldavides) including the Tarcău, Vrancea and Subcarpathian nappes, which encompass our study area.

The investigated Moinești–Târgu Ocna area is located within Bacău County and falls, from a geological perspective, within the Outer Moldavides, exposing the Tarcău and Subcarpathian nappes. The Vrancea Nappe occurs only in boreholes and crops out south of the above-mentioned area, in the Slănic–Oituz half-window. The Târgu-Ocna Rabotage Slice also occurs within the investigated area, in front of the Tarcău Nappe / on the Subcarpathian Nappe, and representing the most external part of the Eastern Carpathian FTB, made of stacked Paleogene–Miocene sediments which are locally covered by thrusting Cretaceous–Paleogene sediments of the inner (western) Tarcău Nappe, during out-of-sequence thrusting, due to Middle Sarmatian locking of the Pericarpethian thrust front.

Using modern geological and geophysical investigation methods, we have revealed the internal architecture of the studied area and constrained a new structural model using 3D seismic data calibrated with stratigraphic and structural data from boreholes.

In contrast to classical interpretations that identify fault zones as a characteristic feature of the Tarcău Nappe north of Moinești and in the Târgu-Ocna area, our interpretation reveals that the Moinești structure displays the typical characteristics of a complex duplex stack with refolded thrust faults and horses. This geometry accounts for the abrupt changes between normal and high-angle dipping strata in this sector of the Eastern Carpathian FTB, and we propose that the structure represents the Vrancea Nappe (Marginal Fold Nappes). Such duplexes are well documented in fold-and-thrust belts worldwide and can be identified even where seismic data quality is limited, provided sufficient borehole constraints are available.

Documenting the demise of an ocean by multi-proxy basin-state reconstructions in the northern Tethys–Paratethys records

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The Tethys–Paratethys region has undergone a profound transformation: from a fully oceanic realm (until the end of the Eocene), through an anoxic, ocean-disconnected sea (Oligocene), to fragmented evaporitic and brackish basins episodically invaded by marine waters (Early and Middle Miocene), and ultimately to a large lacustrine system (Late Miocene) that fragmented into the Euxine marine basin—the largest anoxic sea today—and the Caspian lacustrine basin—the world’s largest lake. This trajectory, heterogeneously distributed across sub-basins and operating at multiple timescales, demands a multi-basin, multi-dimensional analytical framework that simultaneously captures salinity, basin hydrological state (e.g., endorheic vs. exorheic connectivity), and water-mass provenance, integrated with biostratigraphic and paleoenvironmental data.

We present an integrated study employing elemental geochemistry across multiple paleoenvironmental dimensions—paleosalinity proxies (B/Ga, Sr/Ba, S/TOC) and paleoventilation indicators (Mo-EF, V-EF, Zn-EF, TOC/P)—alongside strontium isotope composition (⁸⁷Sr/⁸⁶Sr) for water-mass provenance. The isotopic signature directly distinguishes the contributions of seawater, continental runoff, and internal basinal evolution during isolation, uniquely separating genuine marine inflow from internally generated salinity.

This multi-proxy convergence reveals that Eastern Paratethys connectivity operated not as a simple on-off switch but as a gradual, episodic system, with repeated brief marine-inflow pulses superimposed on long-term isolation trends. Critically, this complexity is invisible to salinity proxies alone. We therefore propose a revised framework for quantifying marine connectivity in restricted basins that replaces binary thinking (connected/isolated) with a multi-dimensional space encompassing (1) salinity reconstructions, (2) basin hydrological state (from elemental geochemistry), and (3) water-mass identity (from ⁸⁷Sr/⁸⁶Sr).

The framework reveals the following trajectory: partial isolation initiated at the beginning of the Oligocene and intensified to full isolation through the Early Miocene and early Middle Miocene, followed by a brief Middle Miocene reconnection to the global ocean. From the late Middle Miocene onward, intra-Paratethys connectivity (between the Central and Eastern basins) became the dominant driver of environmental change, replacing direct ocean connectivity until the Plio-Pleistocene, for which the record remains sparse. This episodic, spatially variable connectivity, which characterized the broader Tethys–Paratethys realm throughout the Paleogene–Neogene, carries profound implications for understanding (a) the evolution of Mediterranean gateway systems, (b) the paleoceanographic forcing of global carbon-cycle and biotic events during basin transitions, and (c) the recognition and quantification of cryptic marine pulses in the geological record. The framework is portable to other restricted and endorheic systems—such as the Aptian–Albian Western Interior Seaway and Messinian Mediterranean.

Acknowledgements. We acknowledge funding from the European Union (Recovery and Resilience Facility) through Romania’s National Recovery and Resilience Plan (PNRR), C9 – I8, grant 97/15.11.2022, Dutch Research Council (NWO) – grant Veni.212.136, and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) grants 2018/20733-6 and 2024/21420-2.

Sedimentary record of Miocene forebulge migration in the East Carpathians: Insights from the Green-to-Grey Formation transition

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The Subcarpathian Nappe, the outermost tectonic unit of the Eastern Carpathians, comprises sediments ranging from the late Eocene to the late Miocene. The middle–late Burdigalian interval records a transition from predominantly green to grey deposits, most likely reflecting a change in sediment provenance. Middle Jurassic extension led to the formation of the narrow Ceahlău–Severin Ocean, a branch of the Alpine Tethys that separated the Dacia mega-unit (Getic and Bucovinian domains) from the European margin (Moesian, Scythian, East European platforms, and the North Dobrogea Orogen). Following westward subduction of newly formed oceanic lithosphere from the Barremian–Aptian to Eocene(?)–Miocene, the Carpathian domain evolved from a remnant oceanic basin into a peripheral foreland basin connected to the Paratethys. The Burdigalian Green Formation (Moisa) records alternating dry–wet conditions, expressed by transitions from thin gypsum layers and reddish carbonate crusts to greenish carbonate marls and shales, and further to decimetre- to metre-thick green lithic sandstones accumulated in marginal-marine settings. The green color reflects abundant chlorite derived from low-grade metamorphic clasts. These clasts indicate an eastern, platform-related provenance, supported by detrital zircon U–Pb ages showing dominant peaks at ~570 and ~330 Ma, along with significant populations older than 1 Ga (e.g., 1.6–1.7 Ga). The Grey Formation (Burdigalian–Badenian) shows cycles that start with offshore deposits of grey shales, thin sandstones, and gypsum, grading upward into sandy shoreface facies. Maximum depositional ages U–Pb (DZ) range between 15.6 and 16.3 Ma. The sandstones are lithic and lack chlorite-bearing clasts, although metamorphic fragments remain common. Detrital zircon spectra from two samples show a distinct shift, dominated by younger populations (~15 Ma and ~85 Ma), characteristic of Carpathian Neogene and Banatitic magmatism. Additional peaks at 270–340 Ma, 400–490 Ma, and 510–630 Ma are representative, whereas ages >1 Ga are rare. This pattern indicates significant input from late Cretaceous–Neogene magmatism and Bucovinian basement sources (420–490 Ma and 550–630 Ma), pointing to a predominantly Carpathian provenance. Minor age populations typical of platform units and the North Dobrogea Orogen (250–300 Ma and 550–620 Ma) were likely recycled from Cretaceous–Paleogene deposits of the thin-skinned Outer Carpathian nappes during their erosion. The late Burdigalian transition from the platform-fed Green Formation to the orogen-derived Grey Formation reflects a major reorganization of the foreland system. Initial orogenic wedge loading triggered activation and outward migration of the forebulge, supplying green schist detritus to the basin. This was followed by relaxation and uplift of the Carpathian orogenic wedge, which became the dominant sediment source, while the forebulge migrated inward and ceased contributing chlorite-rich material.

Acknowledgements. This work was supported by a grant of the Ministry of Education and Research, CCCDI – UEFISCDI, project number PN-IV-P6-6.1-CoEx-2024-0042, within PNCDI IV.

From the Drava to the Sava Basin: Lake Pannon regression and tectonic inversion in the SW part of the Pannonian Basin System, Croatia

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The Late Miocene to Pliocene sedimentary infill of Lake Pannon represents an archive for reconstructing lake regression, sediment routing and the onset of tectonic inversion in the southwestern Pannonian Basin System. However, despite numerous studies, geochronological constraints on the timing of shelf-slope progradation, vanishing of deep-lacustrine environments and transition toward deltaic and fluvial settings remained limited, particularly along its SW margin. This contribution presents an integrated case study from the eastern Drava Basin, where reflection-seismic data interpretation, well-core data, biostratigraphy, authigenic $^{10}\text{Be}/^9\text{Be}$ dating and Bayesian age-depth modelling were combined to constrain Late Miocene to Pliocene basin filling. Results indicate that turbiditic infill started at around 9.9 Ma, most likely sourced by the paleo-Drava and paleo-Mura sediment-routing systems. Subsequent shelf-slope progradation, partly influenced by the later-arriving paleo-Danube system, occurred between approximately 6.5 and 6.2 Ma, leading to disappearance of deep-water lacustrine environments about 1 Myr earlier than previously assumed. The same chronostratigraphic framework constrains the observed regional unconformity and the onset of basin inversion to approximately 6.4 Ma.

Beyond the Drava Basin, these results open a broader regional opportunity for applying integrated dating approaches to the poorly constrained Late Miocene–Pliocene evolution of the Sava Basin. This is relevant for Lake Pannon deposits and associated marginal environments, as well as Pliocene lacustrine to terrestrial successions. In the Sava Basin, correlations between outcrops, deep wells and seismic data are challenging, especially where inherited fault systems, differential subsidence and later basin inversion affected accommodation, sediment sources and routing systems leading to subaerial erosion and potential redeposition of older Upper Miocene or Pliocene deposits. The current dataset includes an interpreted, selected intra-turbidite seismic reflectors, observed clinoform geometries, an interpreted northeastern marginal inversion fault, and sampled Upper Miocene to Pliocene deposits from wells and outcrops for authigenic $^{10}\text{Be}/^9\text{Be}$ dating. Recent sediment samples were also collected to constrain the initial $^{10}\text{Be}/^9\text{Be}$ ratio, critical for applying the method in a new basin-margin setting.

The Drava Basin example provides both a methodological framework and a regional reference point for chronostratigraphic testing in the Sava Basin. In this context, geochronological constraints are not treated only as stratigraphic age control, but as a basis for testing the timing and consequences of tectonic inversion, including its influence on accommodation, sediment routing, erosion and preservation of marginal lacustrine to terrestrial successions. This is important because inherited basin-margin structures in the Sava Basin are close to other seismically active fault zones, including active structures along the southwestern basin margin. A time-calibrated reconstruction of the transition from Lake Pannon to post-lacustrine depositional systems can therefore provide a foundation for future studies of neotectonics, active faulting and sedimentary-system evolution along the southwestern margin of the Pannonian Basin System.

Acknowledgements. Presented research was conducted in the scope of the internal research project GeoSAVAGE at the Croatian Geological Survey, funded by the National Recovery and Resilience Plan 2021–2026 of the European Union – NextGenerationEU, and monitored by the Ministry of Science and Education of the Republic of Croatia.

Special session SS4

**From crystal archives through magmatic processes
to geodynamic evolution**

Conveners:

Vlad-Victor Ene, Szabolcs Harangi, Mihai Ducea

Reprocessing and re-equilibration in a crystal mush: Insights from the Ciomadul dacite

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Complex transcrustal magma plumbing systems are common beneath volcanoes in a wide range of tectonic settings. In many cases, an evolved, highly crystalline magma reservoir (‘crystal mush’) develops at upper- to mid-crustal levels, which is underlain by a less evolved, hotter magma reservoir (‘hot zone’) in the lower crust. Growing evidence indicates that such magma systems may evolve and persist for tens to hundreds of thousands of years. The magmatic “memory” preserved in crystals from the different crustal reservoirs may, however, progressively fade owing to extensive resorption or diffusive re-equilibration. In this study, we show that trace-element zoning in amphibole macrocrysts derived from a crystal mush reservoir may provide a unique record of long-term magma reservoir processes, which are not recorded in major-element compositions.

The studied amphibole crystals originate from the dacitic Ciomadul volcanic complex (East Carpathians, Romania). A long-lived mid-crustal crystal mush reservoir developed beneath the volcano and was sustained by multiple magma replenishment events over the past ~160 kyr. Crystals derived from the crystal mush and from recharge magmas are mixed in the eruptive products, but they can be distinguished based on their major (Mg, Al, Ti) and trace element (Sr, Ba, Cr, Zr) compositions.

The amphibole BSE images and major-element compositions of recharge crystals show complex normal-zonation with oscillatory-zoned interior, while the crystal-mush amphiboles are generally homogeneous. However, high-resolution LA-ICP-MS trace-element maps of crystal-mush amphiboles help to reveal cryptic zoning that is invisible in the BSE images or major-element chemistry. The most prominent zoning feature comprises 6–70 µm-thick alternating Cr-rich zones that resemble those in recharge-derived amphiboles, although their boundaries are less sharply defined. In addition, V, Zr, Sr, LREE, Sm and Ba preserve complex zoning patterns (oscillatory zoning, resorption surfaces, patchy textures), although they exhibit more diffuse compositional gradients than Cr. Crystal-mush amphiboles further reveal progressively more patchy and spongy textures from older to younger eruptive units, particularly in Cr–Nb–Ba–La element maps, suggesting enhanced recrystallization through crystal defects.

The preservation of zoning patterns in recharge-related elements within crystal mush amphiboles likely reflects the combined influence of strong compatibility (Cr); strong chemical bonding (Cr, V, Zr); relative insensitivity to the melt and amphibole structure (Cr, Sr, Ba) and pressure or temperature (Cr, V, Ba, Sr, Zr); and expected slow diffusivity (Cr, Zr). We propose that these mush-type amphibole crystals with cryptic trace-element zonations were originally transported into the mush during recharge events, and the observed zoning patterns are interpreted to reflect repeated magma replenishments, and to a lesser extent, variations in oxidation state. We presume that Cr-rich growth zones in amphibole, analogous to those documented in olivine and pyroxene, can record magma recharge events that remain detectable despite major-element homogenization. In contrast, major elements and non-ideal-sized ions are more susceptible to modification through diffusion, exchange reactions, and recrystallization during prolonged storage within the crystal mush.

Acknowledgements. This work was supported by the MTA–HUN-REN CSFK Lendület “Momentum” Pannonian Volcano Research Group), and measurements co-financed by LabEx VOLTAIRE (ANR-10-LABX-100-01) in the facility of ISTO-CNRS, Orléans.

Zircon Geochemistry of High Sr/Y and Calc-Alkaline Magmas from the South Apuseni Mountains

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Zircon geochemistry is used to constrain magma sources, melting depths, crystallization temperatures, redox conditions, and magmatic processes such as crustal assimilation, co-crystallization, and mineral fractionation. These processes may be obscured in whole-rock analyses, particularly in crystal-rich intermediate porphyritic rocks. In this study, we present zircon trace element and Hf isotope data for normal calc-alkaline and high Sr/Y magmatic suites from the South Apuseni Mountains (SAM).

The SAM Neogene igneous suites consist predominantly of rocks with intermediate compositions, with subordinate basaltic andesites and dacites, emplaced in extensional tectonic settings. Despite this, the rocks display typical arc-like whole-rock geochemical signatures, including enrichment in LILE, elevated LREE/HREE ratios, and pronounced negative Nb–Ta and Ti anomalies. Several models have been proposed to explain the occurrence of high Sr/Y magmas, including melting of metasomatized subcontinental lithospheric mantle, melting of delaminated eclogitized lower crust, and variable mixing between mantle- and crust-derived components (Seghedi et al., 2022).

Zircon populations from adakite-like and normal calc-alkaline suites show substantial overlap in Eu/Eu* or Th/U ratios, suggesting these parameters are more spatially controlled than process-dependent. However, zircons from high Sr/Y rocks exhibit higher median U/Yb and Th/Yb ratios, consistent with their whole-rock compositions. The presence of multiple (U, Th)/Yb ratios for the same Eu/Eu* values present in high Sr/Y rocks might indicate mixing of magmas with different histories/sources. Additionally, zircons from samples with the highest whole-rock Sr/Y ratios display a decoupling between Th and U that is not evident in the corresponding whole-rock data.

Median ϵ_{Hf} values range from approximately -2 to $+10$, although significant intra-sample variability exists. Post-10 Ma rocks from the northern SAM contain Neogene zircon populations with both positive and negative ϵ_{Hf} values ($+7$ to -20), indicating interaction between a crustal end-member and a more juvenile component. In the normal calc-alkaline suites, median (U,Th)/Yb ratios positively correlate with ϵ_{Hf} , suggesting crustal influence on these trace element ratios. In contrast, no systematic relationship is observed for zircon populations from high Sr/Y rocks.

These results indicate that zircon geochemistry preserves source and differentiation signatures that are only partly expressed in whole-rock compositions. The absence of a systematic relationship between ϵ_{Hf} and (U,Th)/Yb in the high Sr/Y suites, together with a higher spread in the same ratios for similar Eu/Eu* values, suggests that the processes responsible for generating high Sr/Y magmas differ from those controlling the normal calc-alkaline suites and may involve distinct source characteristics and/or crystallization histories.

Acknowledgements. This work was supported by a grant of the Ministry of Education and Research, CCCDI – UEFISCDI, project number PN-IV-P6-6.1-CoEx-2024-0042, within PNCDI IV. The authors acknowledge funding of project #64 by the program PNRR-III-C9-2023–18 of the Romanian MCID (64/30.07.2023) and project PN-IV-P1-PCE-2023-0204 funded by UEFISCDI.

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Mixing Matters: Insights into Magma Evolution from Apatite Geochemistry

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Constraining pre-eruption magmatic processes and the state of magma reservoirs beneath volcanoes are key to better understand volcanic hazards and improve eruption forecasting. Volcanic formations of past eruptions and their mineral constituents are important witnesses which can provide important information. Among them, apatite is a common accessory mineral with a wide stability field and containing various volatile components as well as trace elements, which are sensitive to the magmatic conditions and magma environments. Interaction of various magmas, i.e., mixing or mingling of different magmas often triggers eruption rapidly, even after a long repose time.

Ciomadul, the youngest volcano in east-central Europe, provides an excellent natural laboratory for investigating magmatic evolution and eruption dynamics. It is made up dominantly of K-rich dacitic volcanic rocks, formed by lava dome extrusions and explosive eruptions. The volcanic system is characterized by a long-lived, low-temperature (<750 °C) silicic crystal mush that repeatedly interacted with less evolved, hydrous, hotter (>900 °C) recharge magmas. The wide compositional range of apatite preserved in Ciomadul's eruption products reflects the evolution of these magmatic environments.

The investigated apatite samples were divided into two major compositional groups: a felsic, crystal mush-dominated group represented by older lava domes and two younger eruptive units, and the other group contains crystals exclusively from young pumices. They differ in volatile contents, such as Cl/OH and Cl/F ratios and they can be clearly distinguished by their Mg contents (100–200 ppm and 500–800 ppm, respectively). Among the trace elements, only Sr (800–1200 ppm and 1200–2500 ppm) and Ba (<5 ppm and 5–15 ppm) show distinct compositional characteristics, whereas rare earth element concentrations are rather similar. The Eu anomaly (expressed as Eu/Eu*) values show no systematic distinction between the two groups. Apatite from the felsic mush-dominated samples displays a broader range of Eu/Eu* values (0.55–0.80), whereas the recharge apatite samples are characterized by a narrower interval (0.65–0.73). In addition, a few apatite crystals have transitional composition between the two end-member groups. This is consistent with the existence of two major magmatic environments at Ciomadul, i.e. a long-standing evolved crystal mush reservoir at mid-crustal depths and a superhydrous intermediate recharge magma, which was characterized only by the youngest eruptive stage. Magma mixing occurred between the two magmas leading to hybrid magma composition and crystallization of transitional-type apatite briefly prior to eruptions. Such limited interaction resulted in eruptible magma transporting crystal cargo mostly from the recharge magma. These eruptions were dominantly explosive in contrast to the dominant lava dome extrusions during the previous eruptive period.

Acknowledgements. This work was supported by the MTA–HUN-REN CSFK Lendület “Momentum” Pannonian Volcano Research Group.

Message from the upper mantle: origin of the alkali basalt magmas in the Pannonian Basin

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The emplacement of basaltic magmas is one of the most prominent geological processes on Earth. Plate tectonic theory explains most volcanic activity as a manifestation of processes occurring at plate boundaries. However, intraplate volcanism appears to be controlled not directly by plate motion but by mantle processes. Most basaltic magmas are generated by varying degrees of partial melting in the upwelling asthenosphere, yet the mechanisms responsible for initiating this melting remain poorly understood. Petrogenetic modelling suggests that mantle melting may occur at depths of up to ~100 km beneath the lithosphere. Such melting cannot be explained by a purely peridotitic source but instead requires either the presence of water or recycled crustal components, such as eclogite or pyroxenite, to lower the solidus temperature and enhance melt productivity. Furthermore, growing evidence indicates that melting occurs over a broad depth interval and that erupted basaltic magmas represent aggregated melts derived from a compositionally heterogeneous mantle source.

Early-crystallized mineral phases, such as olivine and spinel in erupted basaltic magmas, provide valuable information about mantle melting processes. Trace elements in olivine, including Ni, Mn, Ca, and Zn, are sensitive to the lithological composition of the magma source, whereas Al can be used to estimate both the crystallization temperature and the mantle potential temperature. In addition, the composition of spinel inclusions hosted by olivine macrocrysts also reflects the nature of the mantle source. Here, we attempt to capture these messages from the mantle by investigating olivine–spinel pairs in alkaline basalts from several volcanic fields in the Pannonian Basin. In this region, alkaline basaltic volcanism began 12 Ma ago and culminated between 5 and 2 Ma. The youngest eruption formed the Putikóv volcano in the northern Pannonian Basin only 100–500 ka ago, whereas the latest eruptions in the Perşani volcanic field occurred at around 600 ka. This geologically recent volcanism implies that the asthenospheric mantle beneath the Pannonian Basin is still capable of generating basaltic magma.

Olivine compositions from the central and northern parts of the Pannonian Basin indicate that the mantle source region likely contained eclogite and/or pyroxenite, consistent with trace element modelling results. Ca diffusion modelling in olivine suggests that basaltic magmas ascend from the upper mantle to the surface within a few days, although in a few cases, magma accumulation occurred at the crust–mantle boundary zone. The calculated mantle potential temperatures (1350–1400 °C) do not support the presence of a thermal anomaly but refine our understanding of the lithospheric geotherm. In contrast, basaltic magmas from the Perşani volcanic field, in the southeastern part of the Carpathian–Pannonian Region, were generated by partial melting of pure peridotite, presumably metasomatized by fluids released from the descending slab beneath the Vrancea zone. The notable compositional range in the spinel compositional dataset even in single basalts further confirms the heterogeneous nature of the asthenospheric mantle and supports the aggregated melt model for the generation of basaltic magmas.

Acknowledgements. This study belongs to the BAVOLPA NKFIH–NKKP research project No. 152618.

Making arclogites: constraints from phase equilibria and trace element modeling

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Garnet + clinopyroxene ± amphibole dominated, iron-rich ultramafic rocks known as ‘arclogites’ are widely agreed to represent solid residua of magma differentiation at high pressures characterizing the bottom of thick continental arcs. The formation of arclogitic assemblages is commonly attributed to two contrasting magma evolution scenarios operating in the deep arc crust: (1) they are partial melting residua of mafic lithologies and (2) they represent cumulates of crystallizing primitive (basaltic) melts. Distinguishing the two scenarios based on petrographic criteria is challenging due to the absence of unambiguous distinctive textural features, and is further complicated by the often pervasive subsolidus re-equilibration of arclogites. On the other hand, to our knowledge, no reliable chemical fingerprints discriminating the two scenarios have been proposed this far.

In order to identify chemical markers with the potential of distinguishing these scenarios, here we focus on a series of trace element ratios considered helpful in identifying garnet fractionation, and evaluate their behavior during fractional melting and fractional crystallization of mafic systems at various pressures. Relying on thermodynamic phase equilibria modeling and appropriate mineral/melt trace element partition coefficients, we show that, when plotted against MgO or SiO₂ used as magmatic differentiation indicators, Dy/Yb and similar REE/REE ratios in melts not only successfully isolate the garnet fractionation sequences along various igneous processes, but also unambiguously discriminate fractional melting trends (Dy/Yb increasing with increasing MgO) from fractional crystallization trends (Dy/Yb increasing with decreasing MgO). Comparing the modeled trends to a global compilation of chemical data representing volcanic and plutonic rocks from modern and ancient arcs, we find that thick continental arcs, such as the modern Central Andes and the Late Cretaceous Central Sierra Nevada, display clear evidence of partial melting producing garnet-bearing (ultra)mafic residua along with felsic melts, whereas sample suites from thinner arcs lack such signs. In contrast, regardless of the scale of observation, be it local or regional, none of the evaluated old and modern arc suites appear to carry convincing evidence of garnet removal during melt crystallization. Furthermore, our modeling indicates that fractional crystallization of garnet is limited by the phase equilibria topology of mafic systems and the elevated geothermal gradients characterizing arc environments. Hence, our assessment strongly suggests that high-pressure fractional melting of mafic lithologies is the likely mechanism of arclogite formation worldwide.

Acknowledgements. This work was supported by project PN-IV-P1-PCE-2023-0204 funded by UEFISCDI Romania.

Major, trace element and noble gas isotope composition of olivine from the alkaline basalts of the Perşani Volcanic Field, Romania: constraints on the magma source region

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Olivine, as the first crystallization product from basaltic melt, provides important information about magma origin. Here we provide a detailed textural, major and trace element, and noble gas isotope compositional data for an alkaline basalt suite from the Perşani volcanic field (PVF) of the Carpathian-Pannonian Region. This is the youngest monogenetic volcanic field (1.3 Ma–0.6 Ma) formed in a geodynamically still active zone. A descending, vertical lithospheric slab results in frequent earthquakes, whereas nearby, another young volcanic system is found (Ciomadul). The alkali basalt magmas were formed due to decompression melting in the asthenosphere, at 70–80 km depth.

Olivine composition is used to characterise the nature of the asthenospheric mantle in a postcollisional tectonic setting. Noble gas isotope ratios, especially $^3\text{He}/^4\text{He}$, are sensitive indicators of mantle composition. There are relatively comprehensive data on mantle xenoliths, however, only sporadic data are from olivine crystals of basalts worldwide. This is partly due to the sample preparation challenges of such studies since relatively large amount of clean olivine separates is required for the detection of low gas concentrations from the melt and fluid inclusions.

In the Carpathian–Pannonian Region, noble gas isotopes from olivine autocrysts of basaltic rocks were firstly analyzed in this research work. Following a multi-step sample preparation process, we analyzed the olivine separates using a noble gas mass spectrometer. Petrographic characteristics and major and trace element composition of most olivine crystals suggest early crystallization from primary basaltic magma. Textural and compositional characteristics of olivine suggest fast magma ascent; thus, the olivine crystals preserved the original noble gas isotope ratios in their trapped melt and fluid inclusions in most samples. In other cases, stalling in the lower crustal depth and mixing of magmas with different evolution states were recognized which affected the noble gas isotope ratios.

We got relatively low, $\sim 3\text{--}6 R/R_a$ values ($(^3\text{He}/^4\text{He})_{\text{sample}}/(^3\text{He}/^4\text{He})_{\text{atmosphere}}$), similar to the values obtained from the olivine and pyroxene crystals of lithospheric mantle xenoliths in the PVF alkaline basalts, but significantly lower than the typical ratio of the MORB-type depleted mantle ($\sim 8 R_a$). The low values can be explained by metasomatism of the asthenospheric mantle by recycled crustal fluids during former subduction and/or ^4He addition to the asthenosphere from the radioactive decay of U and Th originated from the subducted lithospheric slab. Evidence for lithological heterogeneity of the magma source region was not found. The Ni, Mn and Ca and content of olivine autocrysts suggest peridotite mantle source for the basalts. Additionally, olivine-spinel thermometry calculations for the crystallization temperature as well as the calculated primary magma temperature suggest a normal thermal state of the asthenosphere ($\sim 1360^\circ\text{C}$) without temporal changes during volcanism. Our results suggest that in a postcollisional setting the asthenospheric mantle beneath the PVF is contaminated by subduction-related fluids.

Acknowledgements. This study is part of, and has been supported by, the MTA–HUN-REN CSFK Lendület "Momentum" Pannonian Volcano Research Group (LP2024-9/2024) and by the Hungarian National Research, Development and Innovation Office to project BAVOLPA (No. 152618).

Zircon Trace-Element Characterization of a Thin-Crust End-Member: Insights from the Aegean Arc

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Quantifying paleocrustal thickness in ancient orogens is an important objective in geoscience research. Recent efforts in geochemistry aimed at quantifying orogenic crustal thickness (the so called chemical paleomohometry) have shifted from whole-rock geochemical approaches toward mineral-scale proxies, particularly zircon, owing to its exceptional mechanical and chemical durability and its ability to preserve geochemical information over billions of years in addition to being datable. Beyond U–Pb geochronology, zircon trace-element compositions provide valuable insights into magmatic processes, including crystallization depth, mineral fractionation, and magma mixing. However, robust zircon-based models for crustal thickness reconstruction require calibration against modern settings representing both thin- and thick-crust end-members. This study focuses on the thin-crust end-member through the investigation of zircons from calc-alkaline stratovolcanoes on the Methana Peninsula and Poros Island in the Aegean Arc.

Zircons were extracted from a suite of calc-alkaline andesites and dacites ($\text{SiO}_2 = 58.0\text{--}64.5$ wt.%) exhibiting characteristic subduction-related geochemical signatures. Cathodoluminescence imaging reveals predominantly oscillatory and sector zoning, with no evidence of inherited cores, indicating crystallization from recent magmatic pulses rather than the recycling of older crustal material. Trace-element analyses show typical magmatic zircon REE signatures, including HREE enrichment, a positive Ce anomaly, and a weak negative Eu anomaly.

To assess crystallization depths, pressure-sensitive trace-element ratios linked to mineral co-crystallization were evaluated. The analyzed zircons display elevated HREE concentrations and consistently low Dy/Yb ratios. Because Dy is preferentially incorporated into amphibole relative to Yb, while garnet strongly sequesters HREEs, these signatures indicate crystallization in a low-pressure fractionation assemblage broadly consistent with relatively thin crust. Application of the zircon-based crustal thickness equations of Tang et al. (2021) yields estimates of approximately 60 km, substantially greater than those derived from the whole-rock methodology of Profeta et al. (2015) (~45 km), themselves suggesting crustal thicknesses that are too high. Independent geophysical constraints show that crustal thickness is ~35 km at the western end of the Aegean arc. These discrepancies highlight the need for further refinement and calibration of zircon trace-element mohometers. Nevertheless, zircon remains a promising proxy because it enables crustal thickness reconstruction.

By characterizing the trace-element signatures of zircons formed in a well-constrained thin-crust setting, this study provides a critical benchmark for the empirical calibration of zircon-based crustal thickness proxies. Such calibrations will improve the reliability of zircon as a high-resolution archive for reconstructing the evolution of ancient continental crust.

Acknowledgements. This work was supported by a grant of the Ministry of Education and Research, CCCDI – UEFISCDI, project number PN-IV-P6-6.1-CoEx-2024-0042, and project PN-IV-P1-PCE-2023-0204 funded by UEFISCDI.

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Crystal mushes as cryptic zircon factories: Evidence from magmatic enclaves in andesites from South Apuseni Mountains, Romania

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We report new U–Pb ages and trace-element compositions on zircons hosted by basaltic-andesitic magmatic microgranular enclaves (MMEs) and their porphyritic andesite host from the Neogene, Almaşul Mare intrusion, South Apuseni Mountains, Romania, in an attempt to place temporal constraints on magma reservoir processes. U–Pb ages demonstrate that zircons from enclaves and host rock overlap within uncertainty, indicating that all crystallized within the same magmatic system. Petrography, mineral chemistry, and amphibole thermobarometry show that the enclaves represent crystal-rich mush fragments formed at ~6 kbar and subsequently mobilized into a shallower andesitic magma reservoir. Despite their mafic bulk composition, the enclaves contain abundant zircons.

Based on their morphology, two distinct zircon populations were identified in the analyzed enclaves. The first zircon population consists of short prismatic crystals characterized by typical highly fractionated REE patterns (LREE-depleted and HREE-enriched), and pronounced negative Eu anomalies. These zircons closely resemble the dominant zircon population in the andesite host, suggesting crystallization within the main magmatic reservoir during coeval feldspar growth, followed by settling and accumulation along with the main cumulate-forming minerals (plagioclase, amphiboles and oxides). In contrast, the second population observed had zircons with elongated and thin morphologies that also contain abundant apatite and silicate melt inclusions. Some of these zircons featured central melt channels parallel to c-axis, indicative of rapid crystallization during undercooling. These melt inclusions are highly evolved (up to 78 wt.% SiO₂), while zircon compositions display overall more elevated REE and other trace element concentrations, and substantially weaker Eu anomalies compared to the first zircon population. These characteristics indicate crystallization from chemically evolved interstitial liquids that became isolated within the mush crystalline framework and continued to differentiate independently of the larger magma reservoir. Most of the zircons in the host andesite are similar in their morphology and trace element contents to the first MME zircon population, whereas zircons resembling the elongated, inclusion-rich crystals are scarce.

Our results suggest that crystal mushes can generate their own zircon populations through localized differentiation of interstitial melts. Zircons hosted by mafic crystal-mush enclaves reveal that highly evolved interstitial melts can act as isolated zircon-growth environments, producing zircon populations that are chemically distinct from, yet coeval with, the zircons found in eruptible intermediate magmas. Subsequent melt expulsion through compaction or mechanical disaggregation during remobilization of the crystal mushes may transfer these zircons into the main reservoir, where their original petrogenetic context is only cryptically preserved in the zircon chemical memory. Recognition of such cryptic zircon populations is therefore important when using zircon chemistry to reconstruct the evolution of magmatic systems.

Acknowledgements. This work was supported by a grant of the Ministry of Education and Research, CCCDI – UEFISCDI, project number PN-IV-P6-6.1-CoEx-2024-0042, within PNCDI IV.

Special session SS5

**Granites in the Carpathian-Balkan area
from pre- to post-collision**

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Alpine Late Cretaceous magmatism in the Western Carpathians (Slovakia)

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The Alpine Late Cretaceous Ochtiná–Rochovce magmatic system (Slovakia) and associated W–Mo porphyry mineralization are unique in the Western Carpathians, which otherwise feature Variscan or Neogene magmatism. This isolated Late Cretaceous occurrence contrasts with adjacent segments of the Alpine orogenic belt; the Eastern Alps are devoid of such magmatism, whereas it is widespread in the Eastern Carpathians (e.g., the Banatitic Magmatic and Metallogenic Belt; Richards 2015). Thus, constraining the genesis of the Ochtiná–Rochovce system is crucial to understanding the Late Cretaceous evolution of the Western Carpathians. In this study, we investigate felsic and mafic bodies using integrated petrographic, mineralogical, geochemical, and geochronological approaches.

During the Late Cretaceous, two distinct sources underwent partial melting: (i) the heterogeneous lower crust, with dominant metaigneous lithologies ± metasedimentary ± mafic components, and (ii) the metasomatized subcontinental lithospheric mantle (SCLM). At ca. 83 Ma, an initial magmatic pulse derived from the SCLM resulted in the emplacement of a shoshonitic gabbroic body. Then, at ca. 82 Ma, a monzogranitic magma of calc-alkaline, magnesian, and high-K affinity derived from the lower crust was emplaced beneath the gabbro as a small pluton. Shortly after, a second pulse of mafic magma derived from the SCLM rose into the magma chamber and interacted with the G1 mush, resulting in partial hybridization. Finally, at ca. 81.5 Ma, a strongly hybridized syenoleucogranitic magma (G2) was emplaced as dykes; the largest body is associated with a W–Mo porphyry deposit within the overlying country rocks. While these geochemical features suggest emplacement in an arc setting, tectono-metamorphic studies indicate a post-collisional extensional environment (Janák et al. 2001). This is consistent with the lack of pervasive deformation in the magmatic rocks. The preservation of subduction-related geochemical signatures in syn- to post-collisional magmas is proposed to result from chemical modification of the crust and SCLM (Richards 2015). This process played a key role in the genesis of the Ochtiná–Rochovce system, where partial melting of the metasomatized SCLM resulted in mafic magmatism occurring as a gabbro or being hybridized within granitic bodies. In addition to the SCLM, the extensional tectonics allowed for the partial melting of the lower crust.

The geochemical–metallogenic dichotomy between Western and Eastern Carpathian Late Cretaceous granitoids was mainly controlled by their distinct tectonic regimes (post-collision vs. onset of collision, respectively; Janák et al. 2001; Richards 2015). This west-to-east increase in the abundance of Late Cretaceous magmatism likely reflects variations in subduction dynamics and subducted slab characteristics.

Acknowledgements. This research was supported by grants APVV-22-0134, APVV-22-0092, SRG 25-33, and UK/1028/2025.

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Geochemical characteristic of Sveti Nikola I-type granitoid (West Balkan zone, Bulgaria)

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The Sveti Nikola granitoid is a Variscan intrusive body (314 Ma) that built up a significant part of the West Balkan zone, Bulgaria. It intrudes a low-grade variegated diabase-phyllitoid complex and it is followed by the more primitive Prekop gabbro-diorite intrusion. The petrographic varieties of the studied rocks include monzogranite and granodiorite; quartz monzonites are present only in the marginal zone. The rocks possess a massive structure and a coarse-grained to porphyritic on potassium feldspar texture; mafic microgranular enclaves (MME) evidence the phenomenon of mingling of granitic and more mafic magma.

The granitoids are metaluminous, only in hydrothermally altered areas they have a slightly peraluminous character. They are fairly enriched in alkalis, as $\Sigma\text{Na}_2\text{O} + \text{K}_2\text{O}$ is between 6 and 7.4 wt. %, thus the rocks belong to the HKCA series. The rocks display a regular decrease of TiO_2 , FeO , MgO , CaO , and an increase of Na_2O and K_2O with silica content. These features attest that fractionation of mafic minerals and plagioclase was responsible for the slight in-situ magma differentiation. The granitoids present low to moderate contents of transition metals, implying that the granitic magma was not a differentiate of a mantle melt. The LIL elements, thorium and uranium show significant enrichment levels – up to 40 ppm Th and 11 ppm U. Rare earth elements (ΣREE 150–300 ppm) display fractionated trends with $\text{La}_\text{N}/\text{Lu}_\text{N}$ between 9 and 12 and a weak europium anomaly (Eu^* is from 0.95 to 0.8), confirming that plagioclase was among the fractionated phases.

On the spiderdiagram the granitoids present negative Nb–Ta and Ti anomalies and high LILE to HFSE ratios, which is typical for rocks formed in an orogenic setting. On the tectonic discrimination diagrams the rocks plot in the field of post-collisional to VAG granitoids. The whole-rock chemistry implies derivation via partial melting of a metabasaltic to metatonalitic source with limited addition of a sediment (metagreywacke) component. The presence of MME and of the Prekop gabbro-diorite intrusion attests that crustal melting was facilitated by the heat impulse of mantle-derived magmas.

Acknowledgements. The financial support provided by the FNI (Ministry of Education and Science of Bulgaria) through project КП-06-H84/4 is acknowledged.

The Western Carpathians granitic rocks evolution over the Variscan subduction/collision processes

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The Variscan Orogen represents a set of typical Paleozoic subduction/collision orogeny processes that produced various igneous, metamorphic, and sedimentary rocks and affected a significant part of Europe. The contrasting magmas were produced throughout the orogen's evolution from oceanic subduction at an active continental margin, through oceanic closure and continental collision with progressive slab break-off, to the post-collisional and post-orogenic/rifting stages. The European Variscides were formed by a Himalayan-type continental collision between Laurussia and Gondwana, during the closure of the Rheic, Rhenohercynian, and Paleotethys oceans, creating the supercontinent Pangaea. However, the Variscan orogeny in Europe is notorious for its voluminous granitic magmatism. Compositional variability (from diorites to leucogranites) and the wealth of chronological data suggest that their origin was a long-term, multi-stage process. Although the Western Carpathians belong to Alpine Europe, their crystalline basement shares many similarities with the stable Variscides.

The Variscan granitic rocks form a significant component of the basement of the Western Carpathians in Slovakia. Generally, it is possible to distinguish the following periods of genesis of Variscan granitoids from the Tatric and Veporic units due to changing tectonic and metamorphic (geodynamic) conditions: **a) subduction stage** (ca. 372–367 Ma) with the first evidence of melting and migmatization; **b) collisional period** (367–332 Ma). However, relatively soon after the onset of continental collision, subduction of the oceanic lithosphere induced flow in the surrounding asthenosphere, causing a tear in the subducting oceanic plate. This period, 367–360 Ma, is referred to as the *initial continental collision (b1)*, characterized by the formation of non-homogenized nebulites and diatexites. The rising hot asthenosphere filled the “slab window” in the subducting plate until it completely broke apart, resulting in increased mantle melt contribution and the formation of gabbro-diorites and diorites before 360–357 Ma; this period is then separately distinguished as the *slab break-off stage (b2)*. Since the continental crust was sufficiently thickened and overheated, syn-collisional metamorphism became more intense. Although heat from the underlying mantle magma heated not only the lower crust but also softened the continental middle and upper crust, leading to increased partial melting, migmatization, and granitoid production. The reduced density of the crustal rocks triggered gravitational instability, causing the collapse of the collisionally thickened orogen. An oblique collision with dominant transpression created space in the crust for pluton formation and led to a “flare up” of granitoid magmatism; this period before 357–345 Ma is referred to as the *late-collisional period (b3)*. However, when the character of the Variscan orogen changed from convergent to divergent, due to extensional crustal thinning, decompression melting occurred during rapid uplift and exhumation of the Variscan basement in the *post-collisional period*, ca. 345–332 Ma ago (**b4**).

Acknowledgements. This study was financially supported by the Slovak Research and Development Agency under contract APVV-22-0092 and by the Scientific Grant Agency of the Ministry of Education, Science and Culture of the Slovak Republic VEGA-2/0002/24.

From Variscan continental collision to post-collisional rifting: local and regional correlations of granitoids in the basement of the Tisza Mega-unit and the Apuseni Mts

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Large granitoid intrusions are widespread across the Central European Variscan Orogenic Belt and are associated with subduction, continental collision, or post-collisional rifting. In the Tisza Mega-unit, Late Paleozoic granitoids occur in several distinct areas, including the Apuseni Mts, the eastern Pannonian Basin, and the Mecsek Mts; however, the available petrogenetic and geochronological information is often limited or incomplete. Therefore, the major objectives of this research were (1) to explore the Late Paleozoic magmatic and geodynamic evolution of the Tisza Mega-unit through the comprehensive study of several granitoid bodies, (2) to compare the studied granitoids with each other to establish local correlations within the Tisza Mega-unit, and (3) to place the new results into a regional framework through regional correlations.

The investigated granitoids include the Codru granodiorite and the Highiş granitoids from the southwestern Apuseni Mts (Romania), the Battonya granitoids from the eastern Pannonian Basin (Battonya–Pusztaföldvár Basement Ridge, Hungary), and granitoid pebbles from Lower Miocene siliciclastic sequences in the western Mecsek Mts (Hungary). Analytical methods applied to all studied materials included detailed petrography, bulk-rock major and trace element geochemistry, and zircon U–Pb geochronology. To further explore correlations and post-magmatic alteration processes, heavy-mineral analysis and sericite and/or illite K/Ar dating were also conducted on selected samples.

The Codru granodiorites and the Battonya granitoids show strong mineralogical, textural, geochemical, and geochronological similarities, suggesting their local correlation. These two-mica, S-type granitoids are most likely associated with Late Devonian (~370 Ma) to Early Carboniferous (~360–340 Ma) magmatism. Their geochemical characteristics are consistent with slab break-off-related magmatism and indicate a transition from Variscan subduction to continental collision. In contrast, the Highiş syenogranites and the monzogranite pebbles from the Mecsek Mts are significantly younger, yielding Middle Permian (~270–260 Ma) ages. However, they display markedly different mineralogical and geochemical characteristics. The two-mica, S-type monzogranite pebbles are slightly older (~270 Ma) and most likely represent post-collisional magmatism, whereas the younger (~268–263 Ma) Highiş syenogranites are A-type and exhibit a rift-related geochemical signature. The latter also display strong geochemical and geochronological similarities to Permian (~270–260 Ma) felsic volcanic rocks throughout the Tisza Mega-unit (Apuseni Mts, eastern Pannonian Basin, and southern Transdanubia), suggesting a large-volume extensional magmatic episode.

On a regional scale, the Early Carboniferous and Middle Permian magmatic episodes identified in this study can be correlated with similar igneous events documented in the Western Carpathians, indicating a shared Paleozoic evolutionary history along the southern margin of the European Plate. Together, these magmatic records reflect the transition from Variscan continental collision to post-collisional extension and rifting within the Tisza Mega-unit.

Acknowledgements. This study was supported by the Hungarian National Research, Development and Innovation Fund (projects K131690, K108375, and FK148576) and by the Hungarian University Research Scholarship Programme (projects EKÖP-24-4-SZTE-633 and EKÖP-577-SZTE).

Special session SS6

**Isotopes and Multiproxy in the Earth System:
reconstructing climatic events at various time scales**

Conveners:

*Ana-Voica Bojar, Franz Neubauer, Victor Barbu, Gottfried Tichy,
Hans-Peter Bojar, Octavian G. Dulu*

The Climate Signature of Wines: Insights from Romanian Isotope Records

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Stable isotope fingerprints are widely used in wine authentication because they preserve information on geographical origin and production conditions. Beyond provenance assessment, the same isotopic tracers contain valuable environmental information reflecting climatic forcing, hydrological conditions and vine physiological responses during grape development. As a result, wine isotope records developed for authenticity control represent an underexplored resource for investigating recent hydroclimatic variability and environmental stress in viticultural systems.

As a case study, we analysed the isotopic information preserved in 487 Romanian wines produced between 2018 and 2024 across eight major viticultural regions characterized by contrasting hydroclimatic conditions. Multi-isotope signatures ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$, D/H_I and D/H_{II}) were interpreted in relation to regional climatic indicators derived from ERA5-Land reanalysis data, including air temperature, precipitation, relative humidity, potential evapotranspiration (ET_o) and the Standardized Precipitation–Evapotranspiration Index (SPEI).

The results reveal a coherent multi-isotope response to hydroclimatic variability across Romania. Distinct regional isotope patterns reflect both geographic and climatic gradients, while interannual variability mirrors changing environmental conditions during grape development. Relative to the mean isotope composition observed during 2018–2023, the 2024 vintage exhibited an enrichment of approximately +2.6‰ in $\delta^{18}\text{O}$ and +0.9‰ in $\delta^{13}\text{C}$. This shift coincided with the warmest ripening season of the study period, with mean July–September temperatures reaching 23.3 °C across the analysed regions and seasonal ET_o approaching 384 mm. In contrast, the lowest SPEI values were recorded during the drought years 2020 and 2022, reaching –2.0 in Dobrogea and falling below –1.5 in several other viticultural regions.

The strongest regional isotopic enrichments in 2024 were observed in Crişana–Maramureş (+4.6‰) and Banat (+4.5‰), while substantial positive anomalies were also recorded in Transylvania (+3.1‰) relative to the regional mean observed during 2018–2023. Interestingly, the largest isotopic anomalies were not observed in Dobrogea, the warmest and driest wine-growing region, but in the cooler western and central regions of Romania. This pattern suggests that wine isotope signatures respond not only to absolute climatic conditions, but also to departures from regional climatic norms. The observed isotope patterns were consistent with changes in temperature and evaporative demand, suggesting that these factors may exert a stronger influence than precipitation deficits alone.

This study demonstrates that wine isotope records preserve measurable information on both hydrological and physiological dimensions of environmental stress. The combined behaviour of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ reflects interactions between atmospheric conditions, water availability and vine adaptive responses, generating a climate-sensitive isotopic signature that can be traced across regions and vintages. These findings highlight the broader scientific value of isotope datasets originally developed for authenticity control and demonstrate their potential for investigating recent hydroclimatic variability and climate-driven ecosystem responses in viticultural landscapes.

Acknowledgements. This research was funded by the Romanian Ministry of Education and Research, through Project PN 23 15 03 01 “The implementation of integrated isotopic-chemical nuclear analytical methodologies for the authentication of traditional Romanian food products (IsoPRod)” and UEFISCDI grant No. 11CoEx/2026 “Nutritional security by innovative strategies for boosting sustainable protein resources exploitation (PROfutureFOOD)”.

Tracing climate signals in lake systems: insights from modern isotope monitoring and sedimentary carbonates

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Lake sediments are among the most important natural archives for reconstructing past environmental and climatic change. In particular, the stable isotope composition of lacustrine carbonates ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) has been widely applied to infer variations in temperature, precipitation, evaporation and hydrological balance. Nevertheless, the climatic interpretation of sedimentary isotope records remains challenging because the isotopic signatures preserved in carbonates are influenced by multiple interacting limnological, hydrological and geochemical processes operating within individual lake systems. Modern monitoring studies are therefore essential for improving the reliability of paleoenvironmental reconstructions.

This presentation summarizes results from isotope hydrology, limnological monitoring and sediment-trap investigations conducted in postglacial hardwater lakes of northern Poland. Multi-year observations from Lake Żabińskie, one of the best-studied varved lakes in Central Europe, demonstrated that precipitation, evaporation, thermal stratification and seasonal mixing significantly influence the isotopic composition of lake waters and recently precipitated carbonates. The results indicate that carbonate $\delta^{18}\text{O}$ reflects both the isotopic composition of precipitation and air temperature, while carbonate precipitation approaches isotopic equilibrium mainly during the summer season.

In addition, the investigations of thirty lakes distributed along a west–east climatic gradient across Poland have proved that evaporation is a dominant control on lake-water isotope composition and that the timing of carbonate precipitation varies across the region. Lakes in western Poland tend to preserve a stronger spring signal, whereas lakes located in the more continental eastern region preferentially record summer environmental conditions and precipitate carbonates closer to isotopic equilibrium.

These findings demonstrate that lakes with similar morphology and hydrochemistry may archive different seasonal climate information. Consequently, robust paleoclimate reconstructions require detailed interdisciplinary and multiproxy studies, including knowledge of isotope fractionation processes, lake hydrology and carbonate formation dynamics.

Acknowledgements. This work was supported by the CLIMPOL project (Polish–Swiss Research Programme, PSPB-086/2010) and by research activities carried out at the Silesian University of Technology in collaboration with the University of Gdańsk and international research partners.

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The Middle Miocene Climatic Transition (MMCT) at Muntele Piatra Verde, Eastern Carpathians, Romania

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The Middle Miocene Climatic Transition (MMCT), spanning 16 to 13 million years ago (Ma), represents a pivotal turning point in Cenozoic climate history. This period marked the abrupt end of the Langhian climatic optimum, characterized by a relative global warmth, initiating a shift toward severe global cooling during the Serravallian. A primary hallmark of the MMCT was the rapid, major expansion of the East Antarctic Ice Sheet (Steinthorsdottir *et al.*, 2020) driving the global climate pathways and shifting mid-latitude environments from a state of relative warmth to persistent cooling. Deep Sea Drilling Project (DSDP) ocean cores recovered from the Atlantic, Pacific, and Indian Oceans show highly consistent sedimentary and isotopic records that confirm the cooling trend.

In order to investigate the impact of the MMCT on the intercontinental seas a complete detailed profile was collected from a site sector of the Central Paratethys. The sedimentary sequences of the Muntele Piatra Verde key outcrops developed under marine conditions (Bojar *et al.*, 2018; Bojar *et al.*, 2020). Based on foraminifer distribution, oxygen isotope measurements on *Orbulina* sp., carbonate content and mineralogy along with previous lithostratigraphic and radiogenic data, a sequence of local events was correlated to the stratotype section from Ras il-Pellegrin for the transition (Abels *et al.*, 2005). The carbon isotope signal was interpreted in terms of seasonal variation and paleoproductivity, which varied widely during the MMCT. Finally, the investigations provide a regional insight into the effect of the MMCT on climate change at mid-latitude sites in the Central Paratethys allowing a quantitative comparison with data from various sections.

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Relationship between climatic fluctuations, *Homo sapiens*, and *Ursus spelaeus* (Rosenmüller, 1794) during MIS 3

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An analysis of radiocarbon data demonstrates that late Pleistocene cave bears (*Ursus spelaeus*) underwent highly dynamic population fluctuations within the Carpathian and Apuseni Mountains during Marine Isotope Stage 3 (MIS 3), spanning from over 60,000 to less than 30,000 years cal BP. Based on a comprehensive dataset of more than 110 radiocarbon ages extracted from key fossil sites such as Cioclovina Uscată, Peștera cu Oase, Peștera Muierii, and Peștera Urșilor, Bojar *et al.*, 2025 reconstructed a clear demographic timeline for the species. The statistical distribution of these dates reveals that the cave bear population reached its maximum expansion between 50,000 and 40,000 years cal BP, followed by a sharp demographic decline between 40,000 and 35,000 years cal BP, and a subsequent partial recovery between 35,000 and 30,000 years cal BP.

The study emphasizes the ecological importance of these specific cave systems, which served as critical, long-term shelters and hibernation sites for the bears during the harsh environmental phases of the Late Pleistocene. However, the youngest radiocarbon data also indicate a significant turning point: fossil remains of anatomically modern humans (*Homo sapiens*) younger than 35,000 years cal BP prove that humans began actively accessing and occupying the exact same cave systems. This chronological overlap meant that humans were encroaching upon the vital spaces where cave bears persisted to hibernate, triggering a severe spatial conflict. Ultimately, the research supports a multifactorial extinction model; while deteriorating global climate conditions and increasingly restricted food sources placed immense natural strain on the herbivores, the targeted presence and hunting pressure of *Homo sapiens* acted as a decisive, additional anthropogenic stress factor that drove *Ursus spelaeus* to its final extinction.

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New data concerning the unconsolidated sediments in the Serbian Danube sector and its main tributaries utilizing X-ray diffraction, instrumental neutron activation analysis, X-ray fluorescence, and optical microscopy

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For a more in-depth investigation of the recent, unconsolidated sediments in the Serbian part of the Danube River and its principal tributaries – Sava and Tisa, 12 samples of recent sediments were collected and analyzed by several complementary analytical methods.

Accordingly, X-ray diffraction (XRD) permitted the identification of several mineralogical phases, e.g. quartz, calcite, dolomite, clinochlore, and muscovite, to which minerals belonging to the alkali and plagioclase feldspar groups are added. Among them, quartz, as oxide, showed the highest mass fraction, of 65 to 95%, while feldspars presented the lowest one, up to 3%.

A tree diagram based on the Mahalanobis distances showed the presence of two main clusters, which evidenced rather a phenomenological grouping in two clades: one consisting of quartz and muscovite, alkali feldspars and clinochlore, while the other one consisted of carbonates (calcite and dolomite) and the plagioclase feldspars.

Optical microscopy evidenced the presence of opaque minerals, whose total amount was less than 3%. The mineralogy of the opaque minerals is a supplementary source of information regarding the provenance of the sedimentary material.

In their turn, INAA and XRF allowed determining the mass fraction of about 38 elements, useful in characterizing the origin of the sediments as well as the degree of contamination with some Presumably Contaminating Elements (PCE).

Accordingly, the incompatible and High Field Strength Elements (HFSE) pointed towards a dominant felsic origin of the sedimentary material, close to the Upper Continental Crust (UCC), but without any sign of significant recirculation. As regards the presence of PCE, INAA and XRF showed increased mass fractions of V, Cr, Co, Ni, Zn, As and Sb with respect to UCC, but relatively lower values of Cd and Hg, confirming the existence of some anthropogenic contamination processes, mainly in the vicinity of large urban areas such as Novi Sad or Belgrade.

New mineralogical, geochemical and isotopic data for the characterization of a fragment of the Mundrabilla (Australia) meteorite from the National Geological Museum collection

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The Mundrabilla meteorite, classified as a medium octahedrite nickel-iron type, having kamacite as dominant mineral, was discovered in 1911 in Mundrabilla (Australia). The most important fragments weigh between 3.5 kg and 24 tons. For more details regarding the structure and composition of a 1.5 kg fragment of the Mundrabilla meteorite existing in the collection of the National Geological Museum, Bucharest, a small fragment was extracted using a water-jet cutter. Several analytical techniques, such as XRD, SEM-EDX, and ultra-low background gamma-ray spectrometry, were used to analyze it.

The XRD study revealed the presence of α -FeNi kamacite with the crystal-chemical formula $\text{Fe}_{0.937}\text{Ni}_{0.063}$ (calculated based on SEM-EDX analysis). The cell parameters of kamacite, as determined by least squares refinement of the X-ray powder data, were: $a = 2.8717(7) \text{ \AA}$ and $V = 23.68 \text{ \AA}^3$. Besides it, XRD evidenced the presence of troilite, an iron sulfide mineral with the simple formula FeS, mainly found in meteorites. On the diffraction pattern, small amounts of schreibersite and olivine were also observed.

Complementary to XRD, SEM-EDX permitted the identification of Ti-, Si- and Cr-bearing phases such as chromite, diopside, clinopyroxene, feldspar and a polymorph of TiO_2 .

The gamma-ray spectroscopy performed in the ultra-low background laboratory at Slănic Prahova evidenced the presence of ^{26}Al and ^{60}Co , two cosmogenic radionuclides produced by cosmic neutrons through the spallation of ^{28}Si or resulting from the β -decay of ^{60}Fe , which is also generated by the neutron activation of the stable ^{58}Fe . Both ^{26}Al and ^{60}Fe are long-lived isotopes with half-lives of 0.747 and 2.62 My, respectively, which explains their presence in meteorites, allowing also the estimation of the moment of its impact.

Application of X-ray powder diffractometry in the study of crystallographic transformations of malachite used as a pigment in traditional paintings

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The work presents XRD analyses concerning crystallographic transformations on 4 malachite samples: untreated, CO₂-, NO₂- and SO₂-gas treated malachite. The unit-cell parameters refined for the untreated malachite sample are $a = 9.503(3)$ Å, $b = 11.982(8)$ Å, $c = 3.239(1)$ Å, $\beta = 97.75(2)^\circ$ and $V = 364.45(1)$ Å³. Malachite was chosen as one of the oldest known pigments used in paintings.

The structure of malachite is built up by ribbons of edge-sharing CuO₆ octahedra running along the c -axis; the ribbons are linked together through corner-sharing, giving rise to corrugated layers parallel to (010) that are interconnected through carbonate groups, which are inserted between these corrugated layers, assuring an interlayer linkage. The carbonate trigonal groups are located in the (100) plane, so that the substitution of the C⁴⁺ cations by smaller or larger cations will mainly influence the a and b unit-cell dimensions.

The treatment with NO₂ and SO₂ caused partial replacement of the C⁴⁺ ions with N⁵⁺ and S⁴⁺, respectively, inducing slight distortions of the structural blocks due to the contraction or the expansion of some of the (XO₃) groups in the structure. Malachite exposure to NO₂ causes N-for-C partial substitutions. As a result, in the N-substituted malachite, both a and b parameters are smaller than those in the untreated one, whereas the c unit-cell parameter remains, within the limit of errors, practically constant. The shrinkage of the unit-cell volume is also visible.

For the SO₂-treated malachite, the unit-cell parameters show practically no changes considering the limit of errors. A slight decrease of the sample crystallinity is due to a reaction producing a copper sulfate and explains the loss of some small reflections from the malachite pattern. No changes in the malachite structure could be imagined, since the coordination number of the S⁶⁺ cation could be only 4 and 6, which precludes a replacement of the three-fold coordinated C in the carbonate groups, as in the case of N.

In its turn, the CO₂-treated malachite shows a visible change in unit-cell parameters explained only by structural changes. The malachite sample used for the study is more hydrous than expected for assuring the stoichiometry based on the ideal formula. The only possible way to locate more water than that corresponding to the ideal formula is by partial substitution of the hydroxyl anions by H₂O molecules, balancing the substitution with corresponding vacancies in the octahedral sites. By consuming water, the gas treatment reduced these vacancies, resulting in a monoclinic cell with a smaller β angle. In the case of the CO₂-treated sample, we can presume that the octahedral distortion of the two independent Cu²⁺ sites in the malachite structure, attributed to the Jahn-Teller effect of Cu²⁺, increased, which is normal considering that the initial vacancies in the octahedral sites were occupied by copper cations. As a result, the Jahn-Teller elongated axes of CuO₆ octahedra expanded, determining a normal increase of the a and decrease of the b unit-cell parameters. As in previous cases, the c unit-cell parameter remains practically constant, within the limit of errors.

Laser-based approaches to tree-ring isotope analysis: assessing LA-CRDS versus LA-IRMS

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Stable isotope analysis of tree rings provides key insights into past environmental and climatic variability. Traditionally, elemental analyzers (EA) coupled to isotope ratio mass spectrometers (IRMS) have served as the standard for spatially resolved $\delta^{13}\text{C}$ measurements in wood and cellulose. However, recent advances in laser ablation as a sample introduction technique for both IRMS (LA-IRMS) and cavity ring-down spectroscopy (LA-CRDS) offer promising alternatives, combining rapid analysis, reduced sample preparation, and high spatial resolution.

In this study, we present a comparative assessment of LA-CRDS and LA-IRMS for $\delta^{13}\text{C}$ measurements in tree-ring research. Both systems employ pulsed nanosecond solid-state lasers at 213 nm (Teledyne Photon Machines), coupled via a dedicated ablation chamber (isoScell $\Delta 200$, Terra Analytic) to either a Picarro G2201-i CO_2 isotope analyzer or a Sercon HS2022 IRMS. Key analytical performance metrics – including accuracy, precision, and achievable spatial resolution – are evaluated to determine the suitability of each approach for high-resolution dendroisotopic applications.

Our results demonstrate that both techniques provide robust and spatially resolved isotope data, while offering distinct advantages depending on the analytical context. In particular, laser-based approaches enable higher analytical throughput, simplified workflows, and reduced infrastructure requirements compared to conventional EA-IRMS setups, without compromising data quality. These findings highlight the growing potential of LA-IRMS and LA-CRDS as flexible and efficient tools for tree-ring isotope analysis.

This methodological advancement opens new opportunities for high-resolution dendroclimatology and environmental research, facilitating broader application of isotope techniques to climate reconstructions, ecosystem studies, and the tracing of anthropogenic influences.

Special session SS7

**Mineralogy as a modern interdisciplinary science
for the 21st century**

Convener:

Razvan Caracas

Gold in Pyrite: Atomic-Scale Insights from Ab Initio Simulations

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Gold in pyrite is commonly associated with arsenic, but the atomic-scale mechanism controlling this Au–As coupling remains unclear. Here, we use ab initio simulations to investigate how gold is incorporated into arsenian pyrite. By comparing single Au substitution with a series of coupled substitutional configurations, we show that Au incorporation at the Fe site is energetically unfavorable when occurring alone, whereas As is the most effective co-substituent in stabilizing Au within the pyrite lattice (Gao et al., 2026).

This stabilization arises from structural and electronic effects. The As substitution modifies the local pyrite lattice and creates a coordination environment more suitable for accommodating large Au atoms (Gao et al., 2026). Electronically, As dopants reduce the occupation of high-energy electronic states, thereby lowering the energetic penalty of the substitution and stabilizing the defect configuration. These results suggest that the common Au–As association in pyrite reflects an intrinsic atomic-scale mechanism rather than a simple geochemical coincidence.

On this basis, we propose that physicochemical parameters act as extrinsic controls on gold precipitation, whereas crystal-structural modifications provide the intrinsic control on gold incorporation and preservation in pyrite. Our study provides new insight into the co-occurrence and coupled enrichment of trace elements in ore-forming systems, with a particular focus on pyrite-hosted gold deposits.

Acknowledgements. R.C. acknowledges support from the European Research Council (grant DAWN) and the HERMES IdEx programme (ANR-18-IDEX-0001) implemented by the Université Paris Cité.

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The influence of solid-fluid interaction on fluid composition and computational approach

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Solid-fluid interaction, as a result of thermodynamic instability during global element cycling, influences both the solid and fluid composition. During metasomatism, chemical equilibrium between the solid and infiltrated fluid is initiated leading to the formation of new solid phases and the change of the already present mineral composition that is in equilibrium with the infiltrated fluids. The composition of the infiltrated fluid is often considered to change by extracting the composition that is added to the newly formed mineral phase.

Here, we present amphibole formation via clinopyroxene-supercritical fluid interaction in an amphibole bearing mantle xenolith from the Perşani Mountains Volcanic Field at the nanoscale to highlight a new approach which predicts fluid composition change during solid-fluid interaction. Element diffusion, along the clinopyroxene-amphibole interface misfits revealed with scanning transmission electron microscopy, occurs during amphibole growth and leads to micron-scale to nanoscale element differentiation (Lange et al., 2023, 2026). To better quantify and predict element migration together with mineral interface geometry molecular simulation has to be applied, which is a promising tool to constrain kinetic parameters.

Acknowledgements. The study was supported by the MTA-FI FluidsByDepth Lendület (LP2022-2/2022), Pannon Lith2Oscope Lendület (LP2018-5/2024) and the Nanomin project. Thomas Pieter Lange and István János Kovács received funding from the Research Grant Hungary (RGH 531001) grant.

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Special session SS8

**Salt systems across scales: Deposition, Deformation,
Geohazards and Subsurface Applications**

Conveners:

Dan Mircea Tamas, Marta Adamuszek, Piotr Krzywiec

Microstructures and rock salt rheology at geological timescales – examples from Romanian salt microtectonics

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Rock salt deforms over a wide range of strain rates depending not only on stress conditions but also on the specific salt properties, which ultimately control the dominant deformation mechanism and hence representative flow laws. Salt's typical excellent sealing capacity has trapped hydrocarbons around the world, is used for large-scale subsurface energy storage and makes it a candidate for radioactive waste repositories. To assess barrier integrity and design geotechnical facilities that are hosted in rock salt, the proper definition of material behaviour in numerical modelling is crucial for making reliable predictions and the assessment of potential risk. A key challenge still remains the selection and validation of laboratory-derived flow laws, which are limited to comparatively short experiment durations and sample sizes, especially when it comes to long term predictions of layered salt formations. Microstructural analysis of naturally deformed salt can mitigate related uncertainties, point to relevant processes and deepen our geological understanding.

The salt bodies of the Romanian Carpathian fold-and-thrust-belt and the Transylvanian Basin (Tămaş et al., 2024) constitute a unique natural laboratory for studying such salt deformation. Here, we focus on integrating microstructural analysis with field observations and mapping of two salt-detachment shear zones: (1) The Mânzăleşti salt exposure, interpreted as a tectonically highly sheared and decapitated diapir (Tămaş et al., 2021; Tămaş et al., 2025), and (2) the spectacularly folded rock salt of the Ocnele Mari mine, where significant influence of small amounts of impurities on salt viscosity and bulk rheology was demonstrated through analysis of multilayer fold shape and numerical modelling of multilayer folding (Adamuszek et al., 2021).

(1) At Mânzăleşti, the fine-grained halite matrix contains centimetre-scale power-law distributed and fragmented porphyroclasts. Together with the isoclinal folds and pervasive subhorizontal foliation at the outcrop-scale, intense low-angle shearing of a preexisting salt structure was interpreted. Microstructural observations indicate deformation by a combination of dislocation creep, water-assisted dynamic recrystallisation and solution-precipitation creep. Differential stresses of up to 4 MPa during deformation were inferred based on grain-size- and subgrain-size piezometry, which points to significantly higher stresses than those typically reported from diapiric salt.

(2) Microstructures of multilayered rock salt of the Ocnele Mari mine show halite grains with strong shape-preferred orientations towards the fold axial planes. Together with boudinaged impurity-rich layers and halite fibres, this points to dominant fluid-assisted dynamic recrystallization and pressure-solution creep during folding, which supports linear (Newtonian) viscous rheology in our numerical models. Additionally, few subgrain-rich grains indicative of dislocation creep were analysed, possibly capturing paleo stresses from an earlier deformation phase. Here, impurities control halite grain size and promote rheological stratification, generating viscosity contrasts of approximately one order of magnitude despite impurity contents of only around 10%.

With these two examples, we demonstrate how halite microstructure analysis can contribute to the understanding of salt-body deformation in the geological history with implications for constraining salt-flow laws used in numerical modelling of salt.

Acknowledgements. This talk is dedicated to the late Janos L. Urai, who passed away in May 2023. Janos played a key role in the conceptualization, writing, and interpretation of the presented results and profoundly advanced the understanding of salt deformation processes through his work.

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Pre-orogenic salt and rift inheritance: New perspectives on the evolution of the Eastern Alps and Western Carpathians

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The interpretation of the structure of the Northern Calcareous Alps and the Inner Western Carpathians has traditionally relied on assuming a simplified pre-contractual configuration. Common assumptions include, for instance, a layer-cake stratigraphy or linear transition from proximal to distal facies, limited decoupling between cover and basement during extension, or a simple one-directional distribution of proximal to distal domains in rift systems. In the case of the Eastern Alps and Western Carpathians, however, such assumptions require complex structural models that often contain internal contradictions, including conflicting orogenic vergence or unresolved debates on presence and/or the location of Mesozoic oceanic domains.

We argue that by integrating modern concepts of salt tectonics and of rift systems, a revised evolution for these orogens can be proposed that resolve some long-standing paradoxes. In the Eastern Alps, the development of a salt-rich rift system offers an explanation for the origin of the pelagic Hallstatt facies without invoking the presence of a true oceanic domain. In the Western Carpathians, the occurrence of salt within a hyper-extended rift system may account for the complex relationships between the Silica and its adjacent tectonic units as well as for the apparent absence of its original basement. Furthermore, recognizing the non-linear architecture and evolution of rift systems may help explain the distribution and nature of Mesozoic oceanic domains across the region extending from the Eastern Alps to the Western Carpathians.

In this contribution we review key aspects of salt tectonics and rift system development that may significantly improve our understanding of the Eastern Alps and Western Carpathians. These concepts could potentially be applied to other segments of the Dinaric-Carpathian-Balkan orogenic system.

Toward an Integrated Hydrogeological Model of the Slănic Prahova Salt–Sedimentary System

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The Slănic Prahova area is a complex salt–sedimentary system shaped by the interaction between a Miocene Badenian salt body, groundwater flow, historical underground mining, active geomorphological processes and urban development. Recent GEOMONITOR investigations have established a detailed remote-sensing and geophysical baseline on the right flank of the Slănic valley. By contrast, the left flank remains less documented, although it hosts active deformation features, dissolution-related subsidence, episodic collapse processes and potentially important groundwater pathways.

Our contribution to the current state is a systematic data collection methodology and their establishment in a georeferenced database consisting of new geological, geophysical, hydrogeological, meteorological and remote-sensing data for the left flank of the Slănic River. At this stage, the study defines the investigation logic and data-integration strategy needed to extend the existing right-flank baseline toward the left flank and develop a unified valley-scale hydrogeological model. Geophysical, remote-sensing and meteorological observations are treated as monitoring and diagnostic tools for constraining this model. Integrated with new geological and hydrogeological investigations, these datasets will support the reconstruction of groundwater flow, dissolution dynamics and subsurface connectivity across both valley flanks.

Building on the left-flank inventory, a staged investigation plan defines the spatial and methodological priorities for observations. Remote-sensing monitoring will be used to detect and track surface deformation patterns, including subsidence and slope-instability features, while targeted geophysical surveys will focus on sectors where deformation indicators, legacy mining information and hydrogeological evidence suggest dissolution zones, structural discontinuities or preferential groundwater pathways. These investigations aim to clarify the hydrogeological functioning of the salt-bearing system developed above the upper surface of the Slănic salt body.

Priority areas include the Baia Baciului–Ocna din Deal–Ocna din Vale sector, which spans both sides of the valley but contains key left-flank deformation and dissolution features. Additional left-flank targets include Baia Roșie, while Dorobănești, on the right flank, is considered a secondary reference zone for evaluating potential cross-valley connections.

Hydrogeological data, including sodium fluorescein tracer-test results obtained by the University of Bucharest between September 2025 and May 2026, provide direct constraints on groundwater circulation beneath the Slănic creek bed and between former mining areas, salt lakes and known collapse zones. These observations will be integrated with historical records of water losses, former mine-drainage levels and field investigations to reassess existing hypotheses regarding groundwater flow and salt dissolution.

The left-flank dataset will subsequently be integrated with the right-flank GEOMONITOR database to construct an integrated hydrogeological interpretation of the Slănic system, constrained by geophysical, remote-sensing, meteorological, geological and historical evidence. This framework aims to link groundwater flow, salt dissolution, subsurface structure, surface deformation and urban vulnerability within a coherent valley-scale perspective.

Acknowledgements. This work was conducted within project No. 28Sol(T28)/2025, funded by the Ministry of Education and Research through UEFISCDI.

The Role of Subgrain Piezometry in Understanding Salt Deformation: Examples from the Mânzălești Salt Diapir

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The study of salt deformation has considerable scientific, societal, and economic importance. Characterizing salt grain size is essential because, under most conditions relevant to tectonic movement and geotechnical facilities, it fundamentally dictates the dominant deformation mechanisms operating within a salt body.

While dislocation creep is independent of grain size, solution-precipitation creep (pressure solution) is extremely sensitive to it, with strain rates being inversely proportional to the cube of the grain diameter (Schlöder & Urai, 2005; Urai et al., 2008 and references therein). Determining grain-size distribution is therefore critical for accurately predicting cavern convergence rates, evaluating long-term surface subsidence, and ensuring the safety of underground energy storage or radioactive waste repositories.

Subgrain-size piezometry is a vital tool for reconstructing paleostress histories and determining the differential stress in rock salt. Because the mean diameter of subgrains is inversely proportional to the differential stress acting on salt crystals (see Schlöder & Urai, 2005 and references therein), measuring these microscopic features allows researchers to quantify the intensity of salt flow.

For this study, we analyzed samples from the Mânzălești Salt Diapir, located in the Romanian Eastern Carpathian Bend Zone. This location provides a natural laboratory for the study of salt from multiple perspectives, including archaeology and anthropology, karst-related features, salt tectonics, and geoheritage (Tămaș et al., 2025 and references therein). The investigated locality represents one of numerous salt outcrops situated in front of the Tarcău Nappe and is characterized by sub-horizontal foliation, isoclinal folds, and recent uplift rates reaching up to 55 mm/year (Tămaș et al., 2021, 2025).

To complement the existing differential stress data, we applied subgrain-size piezometry to a series of samples from the Mânzălești Salt Diapir. After manually tracing and measuring hundreds of subgrains, we calculated differential stress values of up to 3.62 MPa. The results not only confirm the high values (4 MPa) reported by Tămaș et al. (2021), but also show the value of subgrain-size piezometry as a quantitative method for reconstructing stress conditions and deformation histories in natural evaporite systems.

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Tracing an active antropo-saline karst system in Slănic (Prahova) area – alternative hypotheses and supporting data/information

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The hydrogeological and geological framework of the Slănic salt karst area plays a critical role in the initiation and evolution of instability processes such as subsidence, sinkhole development and even surface collapse in some cases. The origin of such collapse event that occurred in April 2024 is the main goal of the actual research in the Slănic area and requires clarification of triggering factors and the development of a conceptual model, based on direct and indirect investigations.

By and large the focus of the documented technical activities dealing with local hydrogeological aspects are related only to the groundwater bodies that interfere with old and actual salt exploitation works occurring probably since 1780 on the eastern side of Slănic River. Important hydrogeological investigations supported by tracing tests were conducted during 1985–1987 (Prospecțiuni SA, unpublished report) and in 1996 (Povară et al., 1997), demonstrating that the water influxes from the riverbed and from the eastern slopes of the Slănic river are at the origin of some of the water points, active within the mining works.

Within the frame of the GEOMONITOR project, detailed geological mapping, borehole logging, and hydrogeological monitoring have been undertaken to characterize lithological sequences, fault systems, and groundwater dynamics. The collapse of the bottom of the monitoring FP8 well and the identification of small water losses from the phreatic aquifer freely flowing toward the collapsed interval to some –30 mbRP, were considered an important opportunity to perform a tracer test starting from the vicinity of the main collapse event occurred on 23 August Street.

The versatile sodium fluorescein tracer was chosen for the test and the whole experiment was designed in terms of tracer mass to be injected, type of monitoring, sampling frequency, monitoring points and approvals from local bodies of MEWF (Ministry of Environment, Water and Forests). Five locations distributed along Slănic river and five points located underground (galleries and shafts) were chosen for discrete (water samples) and cumulative monitoring with active charcoals pellets in sachets. Several difficulties impeded on the established protocol for monitoring, particularly in case of the most active water point located on 8th floor of Victoria Mine abandoned in 1992, and hence no coherent quantitative/analytic interpretation of the breakthrough curve was possible.

In spite of this, the results were positive and a direct connection between the injection point and the monitored water point on 8th floor of Victoria Mine was confirmed which means that a direct underground link between the residential area from the western bank of Slănic River and the deep salt exploitation levels developed on its eastern bank is a sensitive reality.

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Methodological Insights from Initial FullWaver ERT Test Surveys in the Slănic Prahova Evaporitic Environment (Romania)

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Structural monitoring of the evaporitic environment at Slănic Prahova requires high resolution, deep imaging, supported by a thorough understanding of the complex geological setting. From a stratigraphic perspective, the area is a complex geological domain characterized by a salt massif located along the axis of the Miocene syncline. The salt body is associated with a sedimentary succession comprising various lithologies, collectively referred to as the “breccia complex.”

The dynamics of hydrogeological flow, together with salt deposits from the region, generate continuous structural instability, including landslides, ground subsidence, and other related phenomena. Previous geophysical investigations using conventional Electrical Resistivity Tomography (ERT) encountered limitations due to the terrain morphology and high degree of urbanization. These constraints arise from the requirement for collinear electrode deployment and interconnected cables, which restrict both profile length and investigation depth; on the other hand, they provide better resolution and highlight detailed aspects of the subsurface. The previous ERT datasets from the area are used to characterize similar low-resistivity zones with brine present due to continuous salt dissolution.

To overcome these limitations, we implemented a novel geoelectrical survey using the FullWaver system. This method has successfully characterised complex environments, such as mud volcanoes, where, despite the very low resistivity values ($<1 \text{ ohm} \cdot \text{m}$) caused by the high brine content it successfully mapped deep structures (Mihai et al., 2024). The system is a data logger recording full-waveform potential time series on two channels. It uses independent potential-measuring stations (V-FullWaver), while current injections are performed with separate mobile stations (I-FullWaver). This setup eliminates the need for multi-core heavy cables, allowing for non-standard or non-linear configurations. The system offers significant flexibility in electrode positioning and adaptability to terrains with rough topography and complex urban environments. Furthermore, the equipment is capable of measuring apparent resistivity, chargeability, and spontaneous potential.

To achieve deep volumetric imaging, we deployed independent V-FullWaver receivers along a $\sim 1 \text{ km}$ pseudo-2D profile, extending from a salt outcrop across an urban suffosion zone. Despite the cable-free geometry’s flexibility, the acquisition faced site-specific challenges: highly conductive salt anomalies, high contact resistances on asphalt, and urban electromagnetic interference.

While data post-processing is ongoing, this study focuses on the FullWaver methodology, highlighting the operational constraints and adaptations necessary for high-resolution, deep geoelectrical imaging in complex, urbanized evaporitic environments.

Acknowledgements. This work was carried out within the project No. 28Sol(T28)/2025, funded by the Ministry of Education and Research, through UEFISCDI (Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding).

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Salt diapir morphology, the interaction between erosion and salt migration, Slănic Prahova, Romania

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Salt morphology is shaped by the sedimentological processes during deposition, tectonic process after the deposition and subsequent migration and ultimate if it reaches the surfaces as a salt diapir, piercing the sediments, by the erosional and weathering processes. Hence the resulted morphology and geometry of the salt diapir embeds all the processes, hence constraining them is a must for the understanding of the salt diapir evolution and the surfaces process which can trigger geo-hazards, especially when anthropic activities, such as mining, modify its relative stability. This is the case for the Slănic Salt Diapir, well known and mined since medieval times, as salt was one of the important commodities in the area. The Miocene salt is present in all the external nappes of the Carpathians fold and thrust belt outcropping along major thrust system (Lopătari), core of the anticline (Băicoi) or in the syncline like in the Slănic case. Using existing geological data and new acquired reflection seismic data, calibrated with well markers, we have reinterpreted the morphology of the salt diapir. New seismic data have been acquired using either cable or 3 component standalone geophones and a hammer or a source generator, hence the resulted frequencies and amplitude are slightly different. The salt top geometry shows that the diapir has an NNE-SSW orientation roughly parallel with the present day Slănic River with the culmination at the eastern bank where the active/touristic salt mines are present, and where the salt was encountered at around 5–9 meters below salt breccia and quaternary deposits. East-ward it deepens rapidly more than 100 meters, creating a steep salt wall as proven by the drilled wells. The western flank of diapir is more complex, while North-ward it deepens, although the exact geometry is poorly constrained only on the vintage gravity data, South-ward it is rising up and now outcrops at Baia Baciului Lake, initially covered by a thin layer of Quaternary and salt breccia deposit, removed by the dome shaped salt mines collapse. This culmination is separated from the main one by a deep trench, more than 100 m deep, parallel with the Slănic River. The seismic reflection lines help deciphering the internal architecture of shows that the base of this trench is erosive with reflectors truncated below and overlapping of the base surface, and the new well data shows that it is filled with Quaternary deposits made of lacustrine mud (with wood remains inside), sands and angular cobbles and pebbles of possible colluvium or alluvium deposits, in several cycles, bounded by erosional surfaces. The above described architecture might be the result of the salt erosion and dissolution by river, sediment loading of the trench which might also enhance salt inflation in the trench wall.

Acknowledgements. This research was financially supported by the project 28SOL(T28) GEOMONITOR PN-IV-6-3-SOL-2024. We are also gratefully to SALROM – Slănic Prahova for providing existing documentation.

Integrated Multi-Temporal and Multi-Scale Monitoring of Ground and Building Deformation in the Slănic Salt-Karst Area (Romania)

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Ground deformation in salt-karst environments represents a major geomorphological hazard, particularly in areas affected by active dissolution, suffosion, landslides, and anthropogenic influence. The Slănic salt-karst area (Romania) is a complex and dynamically evolving geosystem, where recent collapse events, including the major 2024 urban failure, have highlighted the urgent need for integrated monitoring strategies to detect long-term deformation trends and rapid local changes affecting terrain and built infrastructure.

This study presents a multi-temporal and multi-scale monitoring framework integrating UAV LiDAR, airborne LiDAR, GNSS observations, photogrammetry, terrestrial laser scanning (TLS), precise leveling, total station measurements with prisms mounted on buildings, and multi-temporal InSAR analysis to investigate ground and structural deformation processes in the Slănic area. UAV campaigns conducted using LiDAR sensors and photogrammetric cameras generated high-density point clouds, orthophotos with centimeter-level spatial resolution, and Digital Terrain Models. Airborne LiDAR acquisitions provided regional-scale topographic continuity and detailed geomorphological information over the entire salt-karst basin.

To capture long-term deformation dynamics, Sentinel-1 ascending and descending datasets were processed using Multi-Temporal InSAR (MT-InSAR/PSI) techniques, enabling the identification of persistent subsidence patterns between 2018 and 2024. The InSAR time series revealed vertical deformation rates reaching up to ~2 cm/year in the central and western sectors of the study area, particularly near the Slănic riverbed, active suffosion zones, and mapped landslide bodies. Ground-based GNSS observations, repeated topographic measurements, TLS surveys, and prism monitoring on buildings provided independent constraints to validate displacement signals and improve the spatial interpretation of deformation patterns at both the terrain and structural scales.

The integration of satellite, airborne, and close-range datasets enabled the correlation of geomorphological features, deformation rates, structural behavior, and anthropogenic changes across different spatial and temporal scales. LiDAR and TLS-derived products revealed subtle morphological anomalies, fractures, localized settlements, building inclinations, and subsidence detectable at the centimeter- to millimeter-scale, while repeated total station and leveling measurements provided high-precision validation of local deformation processes. InSAR analysis contributed regional context and temporal continuity to the integrated monitoring framework.

The proposed framework demonstrates the significant added value of multi-sensor integration for hazard assessment, deformation quantification, structural monitoring, and early-warning support in salt-karst environments, providing a scalable methodology applicable to other unstable geomorphological and urbanized regions.

Acknowledgements.

This work was carried out within the project No. 28Sol(T28)/2025, funded by the Ministry of Education and Research, through UEFISCDI (Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding).

Outcomes of surface and groundwater monitoring activities in salt exploitation areas (relevant case studies: Ocna Șugatag, Ocna Mureș, Slănic-Prahova)

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The general monitoring activities in salt exploitation areas are directed to assessment of the effects on the topographic surface or to the periodic evaluation of the stability of created voids/caverns (either through dissolution or dry mining). Thus, at least in Romania (but not only) the monitoring of both *surface water and groundwater* (SW-GW monitoring) is marginally accounted for, albeit one of the main processes affecting the geomorphological equilibrium in such areas is the (uncontrolled) dissolution of salt formations by fresh water.

Practically, most questions (and even panic) appear only when the exploitation activity is significantly affected by the water inrush, triggering also dramatic changes of the landscape in and around the exploited area (Slănic Prahova, Ocna Mureș etc). Moreover, even in such cases requiring detailed investigation and an integrated SW-GW monitoring the recommended continuation of the monitoring activities is at best partially if not totally ignored.

The recurrence of all types of specific hazards in salt exploitation areas pinpoints again on the almost compulsory consideration of a long-term SW-GW monitoring regardless the possible evidence of a short-term equilibrium between the hydro-geological systems and the high volume of anthropic voids generated during exploitation.

The monitoring systems can be structured from simple to complex in order to record few categories of parameters by using the adequate equipment and technics relevant to climatic evolution, surface water, groundwater (either as inflows and outflows, observation boreholes etc), installed in salt mining areas. The minimum time for data acquisition should cover at least one year including all seasonal changes that can control the water fluxes directed to the exploitation areas.

The main outcomes of the monitoring activity generally refer to: piezometric maps, conceptual and/or numerical models of GW flow systems, losses on creeks, correlations with water points emerging in different types of voids resulted from exploitation (shafts, rooms or galleries).

The practical illustration of the above aspects is conducted on the basis of the results obtained from detailed investigation and SW-GW monitoring in three case studies, i.e. Ocna Șugatag (Iurkiewicz et al., 2022), Ocna Mureș and Slănic Prahova (ongoing program, in the frame of GEOMONITOR Project). According to the integrated data interpretation, enhanced monitoring activities (periodic or permanent, at short and medium-long term) were proposed, targeting a better knowledge of the local water/salt ecosystem in order to alleviate or even prevent the occurrence/recurrence of destructive events.

Acknowledgements. This work was partially carried out within the project GEOMONITOR, ctr. no. 28Sol(T28)/2025, funded by the Ministry of Education and Research, through UEFISCDI (Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding).

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Assessment of salt dissolution processes based on periodic video (CCTV) investigation of an observation borehole

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Direct observations of active halite dissolution are extremely rare because the resulting underground cavities develop below ground surface and remain inaccessible to direct investigation. Their evolution is therefore commonly inferred from hydrogeological, geophysical, and surface monitoring data (Gutiérrez et al., 2014). Such observations provide rare field evidence of the processes controlling groundwater circulation, cavity evolution, and collapse development in geological settings underlain by rock salt deposits.

The study was conducted in the town of Slănic Prahova (Romania) within the framework of the GEOMONITOR Project. Periodic video investigations (CCTV) were performed as part of the project in several existing observation boreholes used for groundwater level monitoring. Among these, one piezometer unexpectedly provided direct access to an active dissolution cavity, enabling documentation of its temporal evolution within a rock salt formation.

At the time of installation, neither the presence of a rock salt interval beneath the borehole nor the existence of a subsurface cavity was known. Initial CCTV investigations performed in June 2025 identified sediment accumulation at the base of the piezometer and an open drainage pathway, confirmed by rapid infiltration of a saline solution poured into the borehole. Repeated inspections revealed continuous groundwater inflow from a shallow phreatic aquifer entering the borehole and draining toward its lower section. This hydraulic connection supplied undersaturated groundwater to the salt-bearing interval and acted as the primary driver of halite dissolution and cavity development.

Periodic CCTV investigations documented three main stages of evolution: initiation of drainage toward a subsurface cavity, active cavity enlargement driven by groundwater-controlled salt dissolution, and progressive collapse development associated with hydraulic reorganization and partial cavity infilling.

These observations indicate a progressive hydrogeological evolution from localized halite dissolution toward a groundwater-controlled collapse structure, a mechanism commonly associated with sinkhole formation in evaporite terrains. The periodic CCTV monitoring of the piezometer ended when the borehole was sealed by grouting in March 2026 as a preventive measure due to the proximity of residential buildings, roads, and underground utility networks.

This case study represents a rare example in which the evolution of an active dissolution cavity was documented through direct observation, rather than inferred from indirect evidence. The observations contribute to a better understanding of the hydrogeological mechanisms controlling groundwater-driven salt dissolution, cavity enlargement, internal erosion, and collapse propagation within a rock salt formation.

Acknowledgements. This work was carried out within the project GEOMONITOR, ctr. no. 28Sol(T28)/2025, funded by the Ministry of Education and Research, through UEFISCDI (Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding).

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One Salt, Two Salts, Three Salts, More? Insights into the Miocene evaporitic history of the Romanian Carpathians

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The Romanian Carpathians are of global significance in the study of salt tectonics (e.g. Tămaş et al., 2018), serving as the type locality for the term “diapir”, introduced by Ludovic Mrazec in 1907 to describe “folds with a piercing core” (Mrazec, 1910). Despite this long history of investigation, the depositional history and exact number of evaporitic events during the Miocene remain subjects of significant geological controversy (Tămaş et al., 2018 and references therein). Over the years, interpretations have ranged from models proposing a single Middle Miocene evaporitic event (e.g. Athanasiu, 1916) to scenarios involving multiple salt horizons spanning from the Paleogene to the Pliocene (e.g. Mrazec & Teisseyre, 1902). Although regional consensus has gradually converged toward a simpler framework, many fundamental questions regarding the origin, preservation, and distribution of evaporites within the Romanian Carpathians remain unresolved.

Current regional interpretations typically recognize two primary salt horizons: the lower salt, generally assigned to the Burdigalian, and the upper salt, deposited during the Badenian salinity crisis (e.g. Schlöder et al., 2019, 2023; Krézsek et al., 2023). These evaporites were originally deposited in the foreland basin before being incorporated into the complex fold-and-thrust architecture of the Carpathian orogenic system. However, recent advances in seismic interpretation, combined with well and outcrop data, suggest that the stratigraphic record may be more complex than generally assumed. Modern structural restoration of regional cross-sections and detailed mapping of subsurface salt bodies provide insights into the number and distribution of evaporitic levels throughout the Romanian Carpathians (e.g. Schlöder et al., 2019, 2023; Krézsek et al., 2023). These datasets raise important questions regarding the potential existence of additional evaporitic horizons, particularly within younger syntectonic successions, and also the possible recycling of older salt bodies into younger piggy-back basins during ongoing contraction and basin evolution.

By analyzing regional seismic interpretations, balanced cross-sections, well data, and outcrop data, this contribution aims to review our current understanding of the geometry, distribution, and preservation of salt bodies throughout the Romanian Carpathians. Ultimately, we seek to stimulate discussion of the timing, number, and significance of Miocene evaporitic events and to contribute to a more comprehensive depositional and tectonic model for these salt-tectonic provinces.

Acknowledgements. The work of D.M.T. and A.T. was supported by a grant of the Ministry of Research, Innovation and Digitization, CNCS – UEFISCDI, project number PN-IV-P2-2.1-TE-2023-0402, within PNCDI IV.

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Multidisciplinary Characterization of a Complex Urban Salt-Karst System: Insights and Results from the GEOMONITOR Project (Slănic Prahova, Romania)

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The urban area of Slănic Prahova represents a dynamic geodynamic environment where historical salt mining interacts with natural karstification and mechanical suffusion in unconsolidated deposits. Following the ground collapse on 23 August Street in April 2024, the GEOMONITOR project implemented an integrated framework to characterize subsurface processes and the surface response. This presentation provides the project's concluding insights, highlighting the complementarity among different monitoring strategies used to decode this evolving system.

The research is structured around three main pillars. First, a real-time monitoring network was deployed, consisting of temporary broadband seismic stations, GNSS units, and structural sensors (accelerometers and biaxial tiltmeters) installed in buildings. This network enabled continuous capture of signals related to ground vibrations and structural deformation, providing a baseline for identifying accelerations associated with instability.

Second, geological and hydrogeological monitoring was conducted through updated 1:5,000 scale mapping and a network of boreholes. This component relied on both dedicated drills and the integration of pre-existing boreholes into the monitoring scheme. These points were used to continuously track hydrostatic levels and to conduct structural inspections with submersible CCTV cameras, providing direct evidence of subsurface conditions.

Third, the project focused on the evolution monitoring of the primary collapse zone and areas subject to geotechnical interventions, such as stabilization injections. These pillars are supported by recurrent geophysical and geodetic surveys (ERT, GPR, and TLS), which provided high-resolution snapshots of subsurface changes and surface volumetric shifts.

A key validation of this integrated approach was the identification of a newly emerging risk area within the urban perimeter. In this case, the monitoring system successfully detected subsurface cavity migration and internal erosion through combined CCTV inspections and multi-method geophysical signatures before significant surface manifestations occurred. This served as a proof-of-concept for the project's detection and characterization capabilities. The results are integrated into a Digital Portal, providing local authorities with a validated technical base for urban planning and risk management, demonstrating the project's direct societal utility in vulnerable saline terrains.

Acknowledgements. This work was carried out within the project No. 28Sol(T28)/2025, funded by the Ministry of Education and Research, through UEFISCDI (Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding).

Multi-Scale Monitoring of Ground Deformation and Structural Response in the Slănic Salt-Karst Area (Romania): Real-Time Assessment and Early Warning Framework

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Recent advances in real-time monitoring technologies enable the timely deployment of multi-sensor observation networks, improving the understanding of hazard evolution while providing the basis for operational early-warning systems and evidence-based decision-making. The April 2024 event in Slănic highlighted the need for operational monitoring systems capable of supporting rapid risk assessment and decision-making in a complex urban salt-karst environment. Continuous monitoring is particularly critical in Slănic, given also its exposure to strong ground shaking generated by intermediate-depth Vrancea earthquakes.

To effectively address these requirements, the study presents a real-time monitoring and early-warning framework developed within the GEOMONITOR project for detecting and quantifying multi-scale ground deformation and structural response.

The real-time monitoring network integrates 14 survey GNSS stations (sGNSS) installed on the ground, 2 Continuously Operating Reference Stations (CORS GNSS), and 4 GNSS stations mounted on buildings to track ground and structural displacements with centimetric precision. Dynamic responses are monitored through a network comprising four seismic stations and one accelerometer deployed in free-field conditions, three borehole seismometers, and four building-mounted accelerometers, providing continuous information on ground instability, seismic and anthropogenic activity. Structural response is further assessed using four biaxial inclination sensors and two tiltmeters installed on instrumented buildings, enabling the early detection of differential settlement and progressive tilting. In parallel, meteorological parameters are continuously recorded to evaluate potential environmental effects on deformation processes and to identify possible correlations with observed ground and structural responses.

A key aspect of the proposed framework is the complementarity between the real-time monitoring system and recurrent surveys, including terrestrial laser scanning (TLS), high-precision topographic and levelling measurements, and UAV-based observations.

All observations are integrated into a centralized platform that performs automated threshold-based alerting and near real-time multi-sensor data visualization. Particular attention is given to the challenges associated with the deployment and operation of such a complex real-time monitoring system, including sensor configuration, data acquisition, real-time processing, visualization, reporting, and alert generation. The limitations and operational constraints of the proposed framework are also discussed.

Preliminary results demonstrate the operational value of the proposed multi-sensor monitoring system, with observations already supporting the generation of technical reports communicated to local authorities for risk-informed decision-making and emergency management. The acquired datasets provide critical information for structural engineers and stakeholders involved in risk mitigation and infrastructure safety. Beyond the case study of Slănic, the proposed framework offers strong potential for scalability and transferability to other salt-karst or multi-hazard environments that require integrated real-time monitoring and early warning capabilities.

Acknowledgements. This work was carried out within the project No. 28Sol(T28)/2025, funded by the Ministry of Education and Research, through UEFISCDI (Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding).

Special session SS10

Tracing mineralization vectors for the magmatic-hydrothermal systems of the Carpathian-Balkan Area

Conveners:

Gabriella B. Kiss, Stefan Metodiev, Istvan Marton

Architecture of an exceptionally high-grade Au skarn system at Čoka Rakita, eastern Serbia: Mineral and geochemical constraints

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Čoka Rakita is recently discovered high-grade gold skarn system in the north-western sector of the Timok Magmatic Complex in eastern Serbia. The deposit is part of the prolific Bor district, hosting world-class porphyry Cu-Au and high-sulfidation epithermal deposits, as one of the most perspective segments of the Apuseni-Banat-Timok-Srednogie metallogenic belt in Eastern Europe.

Mineralization is hosted by a sequence of Jurassic and Cretaceous sedimentary and volcano-sedimentary units overlying Paleozoic low-grade metamorphic basement. The sequence is intruded by a series of Late Cretaceous sill-like diorite bodies and monzodiorite dykes and a large composite monzonite intrusion. Diorite sills and stocks are considered to be the main causative intrusions for large-scale magmatic fluid circulation responsible for skarnification of the sedimentary formations and development of spatially restricted endoskarn alteration in the diorites and the monzonite intrusion.

The architecture of the skarn system at Čoka Rakita has been investigated using a combination of field and laboratory techniques, such as whole-rock geochemistry, SWIR spectroscopy, optical and cathodoluminescence petrography, quantitative mineralogy (QEMSCAN), LA-ICP-MS analyses of trace elements in various prograde and retrograde skarn minerals and sulfides.

The major orebody at Čoka Rakita consists of a dominantly lithologically controlled high-grade manto-like skarn Au-Cu mineralization in calcareous sedimentary units at the hanging-wall contact of the diorite sill. The prograde skarn assemblage, indicative of oxidizing conditions, is dominated by andradite-grossular garnet, with minor pyroxene (diopside) and wollastonite. Gold mineralization, occurring mainly as visible native gold, is associated with a retrograde skarn assemblage, comprising epidote, quartz, K-feldspar, albite, pyrite and calcite. Gold is also present in minor chalcopyrite-bornite ± molybdenite-chalcocite assemblages.

Deep (down to 1000 m from the present-day surface) stratabound Cu-Au-polymetallic mineralization is found in marble-skarn altered limestones at the base of the sedimentary sequence. Gold in this mineralization type is associated with garnet, pyroxene, actinolite, calcite, silica, with higher amount of sulfides (chalcopyrite, bornite, chalcocite, molybdenite) and magnetite.

In the diorite porphyries and the upper portion of the volcano-sedimentary sequence lower-grade gold mineralization occurs as porphyry-style stockwork veining and disseminations, associated dominantly with potassic alteration assemblage (secondary biotite-K-feldspar-magnetite) and later sericite-pyrite dominated overprint.

Understanding of the spatial distribution of mineralization and alteration styles at Čoka Rakita has important implications for the future exploration activities in the Bor district, where a new style of high-grade mineralization has been defined for the first time in a historical district hosting dominantly porphyry and high-sulfidation epithermal ore bodies.

Acknowledgements. This study was logistically and financially supported by DPM Metals. Assistance from and collaborative work with the exploration team in Bor are greatly appreciated.

Geochemical vectoring within post-collisional magmatic-hydrothermal systems: A case study from North Macedonia

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As a part of the Tethyan Metallogenic Belt, the Balkan Peninsula hosts well-developed record of Oligocene–Pliocene (31.0–1.8 Ma) calc-alkaline to shoshonitic post-collisional magmatism as well as associated magmatic–hydrothermal mineral systems. North Macedonia, in particular, provides exceptional exposures of the complete spectrum of such mineral systems, ranging from porphyry to epithermal deposits.

The deepest part of the mineral system is represented by porphyry Cu deposits (e.g., Buchim, Borov Dol, Kadica, Ilovica). This type of mineralization is spatially and temporally associated with latitic to latitic–andesitic subvolcanic intrusions emplaced into pre-existing lithologies of the Serbo-Macedonian Massif and the Vardar Zone. Mineralization occurs as stockworks and disseminations concentrated along intrusive contacts and within adjacent wall rocks. The ore assemblage is dominated by chalcopyrite, bornite, and cubanite, with variable amounts of pyrite, magnetite, hematite, and native gold. Fluid inclusion studies combined with geothermometric constraints indicate formation temperatures of 380–680 °C, at depths of 6–12 km, from highly saline fluids (25–75 wt.% NaCl equiv.).

The mineral system also hosts both proximal and distal skarn deposits. Proximal skarns (e.g., Damjan) formed through direct interaction between Oligocene magmatism and carbonate-rich flysch lithologies of the Vardar Zone. They are characterized by magnetite- and hematite-rich assemblages, accompanied by abundant retrograde skarn minerals including epidote, amphibole, chlorite, quartz, and carbonates, with minor chalcopyrite, pyrite and pyrrhotite. In contrast, distal skarns formed by infiltration of magmatic fluids into Paleozoic marbles of the Serbo-Macedonian Massif (e.g., Sasa, Toranica), hosting Pb–Zn–Ag sulfide mineralization that overprints both prograde (anhydrous) and retrograde (hydrous) Ca–Fe–Mg–Mn silicate assemblages. These distal skarns formed at temperatures of 350–475 °C and depths of 1–4 km from moderately saline aqueous fluids (4–12 wt.% NaCl equiv.), under conditions of progressively increasing water activity and sulfur fugacity.

The Carlin-like Allchar deposit is a typical example of mesothermal mineralization in the area. The deposit is predominately hosted in calcareous sedimentary rocks at intersections of high-angle faults in permeable stratigraphy of the Vardar Zone. The mineralization is spatially and temporally associated with a Pliocene high-K calc-alkaline to shoshonitic volcano-plutonic center. The Au–As–Sb–Tl-rich mineralization formed at temperatures >200 °C from moderate salinity aqueous-carbonic fluids (3–21 wt.% NaCl equiv.).

The epithermal ore deposits are common. In general, these deposits occur as Pb–Zn–sulfide–quartz ± carbonate veins (e.g., Zletovo) or as Cu–Au dissemination (e.g., Plavica) in shallow portions of post-collisional volcanic rocks. They were formed at temperatures <300 °C from low to moderate saline aqueous fluids (<15 wt.% NaCl equiv.).

Barite (-polymetallic) mineralisations in the Tulgheş Group (Eastern Carpathians, Romania)

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The Lower Palaeozoic Tulgheş Group of the Eastern Carpathians hosts a Ba-Mn-Cu-Pb-Zn metallogenic system. Kuroko-type VMS deposits are associated with the Tg3 felsic volcano-sedimentary succession (e.g., Baia Borşa, Leşu Ursului, Fundu Moldovei), whereas the Cambrian Ba-Mn Holdița-Broșteni occurrence is hosted by the older Tg2 graphitic schist, deposited during a marine basinal stage preceding the Tg3 bimodal volcanism (Kräutner & Bindea, 2002).

At Ostra, massive to semi-massive polymetallic sulphide lenses occur together with sulphide-bearing barite accompanied by silicification and locally developed kaolinite-dickite-alunite-bearing argillic alteration (Balázs et al., 2025). This mineralisation differs from the discordant barite-witherite veins and replacement bodies that were historically mined and attributed to Jurassic rifting (Gîrlescu, 2007). Barite-hosted fluid inclusions yield homogenisation temperatures of 140–190 °C and salinities of 5.26–7.59 wt.% NaCl equivalent, representing minimum trapping temperatures for the barite-forming stage. Independent pyrite-sphalerite geothermometry indicates higher temperatures of approximately 230 °C and > 250 °C, respectively, in proximal sulphide-rich domains. Sulphide-rich samples throughout the open pit show primitive-mantle-normalised Pb-Ag-Au-Zn-Cu patterns similar to Kuroko-type VMS ores. Contrasting $\delta^{34}\text{S}$ values of barite (+18.7 to +37.2‰) and pyrite (–21.25 to +6.11‰) indicate a multistage sulphur history, potentially involving early diagenetic microbial sulphate reduction followed by hydrothermal recrystallisation and/or mixing of sulphur sources. All these features suggest an early volcanogenic-hydrothermal stage potentially linked to the regional Tg3 VMS belt. The enrichment in Ba, Zn, Pb in relation to the nearby Leşu Ursului VMS might point to a spatial link between the two mineralised systems.

The Holdița-Broșteni mineralisation forms conformable, rhythmically banded barite-pyrite-quartz-carbonate beds with local Mn-rich horizons (Vodă & Vodă, 1980). In addition to previously reported Ba feldspars, Ba carbonates, apatite and sulphides (Hirtopanu et al., 2012), we identified K-bearing celsian, Sr-bearing apatite, variable Ba-Ca-Sr- and Mn-Fe-Mg carbonates, and a Ba-Ti-V-Cr oxide tentatively interpreted as a Cr-bearing mannardite. Textural relationships suggest an early apatite-Ba-feldspar-oxide-pyrite-barite assemblage, followed by replacement barite, Ba-carbonates and later carbonate-quartz formation. These relationships suggest synsedimentary mineralisation with hydrothermal input in a redox-stratified Tg2 basin, followed by greenschist-facies recrystallisation and Ba remobilisation. LA-ICP-MS analyses show Ni-dominant pyrite (262–405 ppm Ni; 31–117 ppm Co) with Co/Ni ratios of 0.12–0.38, consistent with sedimentary-diagenetic formation.

Acknowledgements. This work was supported by the ELTE Talent Support Travel Grant (B.B., Á.Á.), SEG-SR Grant (Á.Á.) and the Bolyai János Research Scholarship (G.B.K.).

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Unusual late Miocene glauconitic alteration in an early Miocene buried volcanic sequence near Paks, Hungary

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Disseminated and vein-type glauconitization has been documented in an Early Miocene buried stratovolcanic sequence in cores from two drill holes near Paks, near the regional-scale Mid-Hungarian Line. In veins, glauconitization is accompanied by symmetric calcite + chalcedony veins, with locally ankerite ± dolomite ± zeolite ± chalcopryrite ± galena and amethyst geodes. The rim of the veins is weakly brecciated. Glauconite is replacing the groundmass of the andesite and crystallizes in vugs of calcite veins.

Glauconite is extremely unusual in volcanic-hosted epithermal systems and typically occurs in shallow-marine or diagenetic environments. To understand the formation of glauconite hosted in the andesitic stratovolcanic sequence, detailed fluid-inclusion, geochemical, and isotopic analyses have been performed on the alteration products.

Fluid inclusion microthermometry of primary fluid inclusions found in euhedral calcite crystals indicates low-temperature (73–75 °C) minimum trapping temperatures and low salinities (3.5–4.5 NaCl equiv. wt%). Clumped isotope analysis provided a slightly higher temperature of 79 ± 4 °C. Pressure correction reveals 0–200 bar pressure of trapping that equals 0–200 m paleodepth below the paleo water table under hydrostatic conditions.

Stable isotope analyses performed on vein-filling calcite show highly variable values both for carbon ($\delta^{13}\text{C} = -21.54$ to -2.85‰ VPDB) and oxygen ($\delta^{18}\text{O} = -7.54$ to -25.63‰ VPDB). The highly negative $\delta^{13}\text{C}$ ($< -20\text{‰}$) values, characteristic of organic- or hydrocarbon-rich fluids, are more frequent in the deeper zones from 1460 to 2000 m. In the relatively shallower zones from 850 to 1400 m, two calcite generations, one with highly negative $\delta^{18}\text{O}$ values ($\delta^{18}\text{O} < -16\text{‰}$) and another with higher positive values ($\delta^{18}\text{O} > -6\text{‰}$), indicate the mixing of three fluid generations of various origins.

K/Ar radiometric ages of various glauconite grain-size fractions provide a consistent age around 10 Ma, which is significantly younger than the age of the volcanic activity around 19 Ma, dated by K/Ar method on rock-forming biotite.

Geochemical parameters of the studied mineral assemblage, as well as the significant (ca. 9 Ma) age gap, exclude any genetic relationship between the magmatic activity and the alteration. Furthermore, despite the volcanic environment, the low-temperature and low-salinity hydrocarbon-rich fluids challenge the classification of the fluid flow as a “hydrothermal system”.

In our model, Late Miocene tectonic activity along the Mid-Hungarian Line resulted in fracturation and brecciation in some tectonic zones within the volcanic sequence. Enhanced permeability facilitated the ascent of hydrocarbon-bearing basinal brines and mixing with shallow-level groundwaters. Reductive conditions necessary for glauconitization were controlled by the hydrocarbon-rich fluids, while Fe and K were provided by the breakdown of rock-forming biotite and amphibole. Notably, the low-temperature fluids were capable of transporting base metals like Cu and Pb, supporting the significance of the regional groundwater flow concept of Tóth (1999) in the formation of base-metal mineral deposits.

Acknowledgements. We gratefully acknowledge the support of Paks II. Zrt. and, in particular, Márton Veszely for facilitating the inspection and collection of the samples.

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Genesis of a Cu ore occurrence on the NE Darnó Hill (NE Hungary)

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The Darnóhegy Mélange Complex, found in northeastern Hungary, is a chaotic megabreccia with complex geological structure, which can be interpreted as an accretionary mélange formed during the closure of the Neotethys Ocean. Hence it can be interpreted as a displaced (along the Zagorje-Mid-Transdanubian Zone) fragment of the Dinarides (Kovács et al., 2010). It involves rocks of different ages and geneses: Triassic submarine basalt and associated deep-sea sedimentary rocks, Jurassic basalt and gabbroic bodies with grey and red radiolarites and surrounding Jurassic radiolarian shales. This complex is revealed by the investigated Mély Valley Quarry, which exposes Triassic basalt and Triassic as well as Jurassic radiolarite and other deep sea sedimentary rocks (Józsa et al., 2023). At the southwestern end of the quarry, rock samples from the Jurassic radiolarite are covered by secondary malachite. These rocks were used to investigate the copper ore occurrence of the area.

We identified the ore mineral paragenesis, containing digenite, chalcocite, chalcopyrite and bornite as well as established the mineral precipitation series. The copper sulphides occur both disseminated and vein-filling, and are associated with chlorite, epidote, calcite, titanite, apatite, sericite, clay minerals and barite as gangue minerals, but also covellite, malachite and iron oxyhydroxides occur as later alteration products. As a peculiarity, graphite occurs also in the ore-rich layers of the host sedimentary rock. The mineralisation was controlled by tectonic zones as well as by framboidal pyrite and organic matter-rich layers, based on field as well as microscopic observations.

Based on the petrography and the results of the whole rock geochemistry (XRF) and sulphide mineral geochemistry (EPMA) measurements carried out, this ore occurrence can be classified as reduced-facies type of the SSC (sediment-hosted stratabound copper) deposit model, with elevated Zn and V (up to 758 ppm), in addition to the sometimes very significant copper content (up to 7.22 wt%).

Even though these deposits can be extremely rich in copper, this studied locality is probably not of major economic importance, since the mélange structure of the host rock does not allow the ore body to be defined. Thus, the significance of the identified mineralisation is rather that it confirms the possibility of the formation of SSC-type mineralisation in the Dinaric-Hellenic part of the Neotethyan realm and thus stimulates further research.

Acknowledgements. M. Biró and F. Zaccarini are thanked for their help during this work. The work of G. B. Kiss is supported by the János Bolyai Research Scholarship awarded by the Hungarian Academy of Sciences. The work was partly supported by the NKKP project nr. 153046 financed from the National Research, Development and Innovation Office fund (Hungary).

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Geochemical features of chlorite from propylitic alteration associated with Elatsite porphyry copper deposit

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The Elatsite deposit is hosted in the basement composed of Carboniferous Vezhen pluton (mainly granodiorites) and Paleozoic metasediments, while the magmatic and hydrothermal activity are related to the emplacement of Late Cretaceous porphyritic rocks (e.g. Strashimirov et al., 2002). Propylitic alteration is well preserved in the granodiorites of the Vezhen pluton and in porphyritic rocks.

Our study is focused on the mineral chemistry of hydrothermal chlorite from the distant parts of the propylitic alteration developed in granodiorites. The most distant point is approximately 4.8 km from the center of the deposit, and the sampling was done in a grid with 300 m between the samples.

The lowest alteration intensity was observed at the most distal point, 4.8 km from the deposit centre, where magmatic biotite and amphibole are weakly altered to chlorite, titanite, carbonate and minor epidote. Moderate to high alteration intensity occurs approximately 2.2 km from the deposit center, where the magmatic plagioclase and potassium feldspar are altered mainly by sericite and carbonates, while biotite and amphibole are replaced by chlorite, epidote and titanite. All analyzed chlorites are classified as clinocllore (Bayliss, 1975), with Fe* ratio of 0.40–0.47, reflecting differences in precursor mineral composition. Our data suggests that the Ti and Al concentrations remain relatively constant, with only negligible variations related to distance from the deposit centre and precursor mineral type, therefore, the Ti/Al ratio is used to represent concentration changes in chlorites. Preliminary results for the trace and rare-earth elements distribution suggest that, from the distal point toward the 3.4–2.8 km interval, Cr, Rb and REE concentrations decrease, whereas Ni and, to a lesser extent, Co increase, while Cu and V remain relatively constant. The average formation temperatures of chlorite from the distal parts is estimated at about 275 °C, whereas the average temperature for the 3.4–2.8 km interval is 289 °C.

The results suggest that geochemical distribution of elements in chlorite from propylitic alteration is a promising exploration tool and shows similarities with results from other porphyry copper deposits (e.g. Wilkinson et al., 2015; Xiao et al., 2020).

Acknowledgements. This work has been carried out in the framework of the National Science Program “Critical and strategic raw materials for a green transition and sustainable development”, approved by the Resolution of the Council of Ministers № 508/18.07.2024 and funded by the Ministry of Education and Science of Bulgaria.

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A compositional perturbation model of hydrothermal biotite-to-chlorite transformation in Variscan peraluminous granitoids from Mt. Papuk, north-eastern Croatia

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The pseudomorphic replacement of biotite by chlorite is a diagnostic record of hydrothermal fluid circulation through basement rocks. The chemical compositions of both minerals sum to a constant and are therefore represented in a Simplex sample space, which differs from Euclidean space. In such space, standard statistical methods yield geometrically inconsistent results. Within the framework of Aitchison geometry, the compositional perturbation operator was applied to model the biotite-to-chlorite transformation in the Late Devonian peraluminous granitoids of Mt. Papuk (Slavonian Mountains, NE Croatia). Each chemically distinct hydrothermal fluid imposes a characteristic pattern of relative oxide gains and losses on the minerals it reacts with, producing a characteristic perturbation direction in the Simplex. The angular distribution of perturbation vectors computed from biotite–chlorite pairs therefore provides a geometric criterion for distinguishing a single fluid event from multiple superimposed ones, and the mean perturbation vector constitutes a transferable reference direction for comparison of hydrothermal fluid chemistries.

A perturbation model was constructed from 22 chemical analyses of biotite–chlorite pairs from the same sample, where chlorite replaces biotite within the same grain. The mean perturbation vector in the six-part Simplex is dominated by near-complete expulsion of TiO₂, with relative enrichment in Al₂O₃, MgO, MnO, and FeO, with SiO₂ remaining approximately constant. Individual pair vectors deviate from the mean direction by no more than 3.3° (mean 1.53°), and the first principal component of the clr-transformed dataset explains 99.82% of total variance along the alteration direction. The tight angular cluster precludes the involvement of multiple chemically distinct fluid events at this locality. The step-function character of the alteration progress coordinate α with no intermediate compositions points to a fluid-mediated coupled dissolution-precipitation mechanism.

The model was validated against 20 chlorites not used in model construction and from the same sample, which project onto the alteration line with similar α values as paired chlorites and small perpendicular residuals. The spread in α reflects grain-to-grain variability in reaction progress within the sample used to construct the model, while the small perpendicular residuals indicate that all chlorite formed by the same process regardless of how far the reaction proceeded in each grain. Projection of 119 biotite analyses from six samples distributed across Mt. Papuk onto the alteration line yields α values consistent with the biotite reference state of the model. However, their perpendicular residuals reflect inter-sample variability in primary biotite composition, expressed mainly as an inverse MnO–SiO₂ relationship.

The mean perturbation vector established here provides a reference direction for biotite-to-chlorite alteration in peraluminous Variscan granitoids, against which vectors from other localities can be compared using the angular distance metric of Aitchison geometry, providing a geometrically rigorous basis for future inter-site comparison of hydrothermal fluid chemistries.

Acknowledgements. This work was carried out within the project “Complementary petrochronological characterization of granites, progressively metamorphic rocks and migmatites in the Papuk metamorphic complex (Slavonian Mts., Croatia) (PAPUKRON)” at the Croatian Geological Survey, funded by the National Recovery and Resilience Plan 2021–2026 of the European Union – NextGenerationEU, and monitored by the Ministry of Science, Education and Youth of the Republic of Croatia.

Wedge Zone Deep: a newly delineated high-grade mineralized zone at the Chelopech high-sulphidation Au–Cu deposit, Bulgaria

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The Wedge Zone Deep (WZD) prospect is a newly delineated zone of high-grade Au–Cu mineralization in the northern flank of the Chelopech Late Cretaceous high-sulphidation (HS) epithermal deposit, Bulgaria (DPM Metals, 20/05/2026: <https://dpmmetals.com/news-media/news-releases/>). It is hosted in subvolcanic diorite and phreatomagmatic breccia and is located approximately 250 m below the mine infrastructure. The prospect lies within a prospective corridor below the –100 m elevation and is spatially associated with the hanging wall of the Petrovden Fault. Its discovery resulted from deep drilling guided by a revised geological model of the Chelopech magmatic-hydrothermal system, which recognizes stronger vertical and lateral continuity between porphyry-proximal and HS environments than previously assumed.

Within this framework, the northern flank emerged as a favourable exploration domain because it preserves structurally prepared host rocks, including diorite and phreatomagmatic breccias, in an underexplored position beneath the main mine levels. The targeting concept also incorporated possible telescoping within the Chelopech system, whereby alteration and mineralization assemblages typically developed at shallower structural levels may be preserved at greater depth along long-lived fault corridors. This interpretation is consistent with the Chelopech hydrothermal system, in which lithological permeability, intrusive contacts and structurally focused fluid flow control ore deposition.

The newly defined mineralized zone is characterized by advanced argillic alteration and sulphide- and sulphosalt-rich mineralization expressed as massive sulphides, hydrothermal breccias and sulphide stockworks containing pyrite, enargite, luzonite and covellite. These features are consistent with HS mineralization styles recognized elsewhere in the Chelopech deposit, but at WZD they occur at greater depth than previously documented. Their distribution suggests control by northwest-southeast and east-west structures proximal to the Petrovden Fault, with ore localized within a steeply dipping, fault-proximal corridor.

Drilling returned significant intercepts, including 68.3 m grading 6.92 g/t Au and 0.30% Cu, 58.0 m grading 14.58 g/t Au and 0.67% Cu, and 81.0 m grading 7.83 g/t Au and 0.21% Cu. These results define the prospect over approximately 170 m along strike, 130 m wide and 300 m in vertical extent. The new drill data constrain both the external limits and internal architecture of the mineralized body, showing that sulphide-rich ore zones are more spatially restricted than the advanced argillic alteration envelope. WZD is interpreted as a steeply dipping HS mineralized body developed within a favourable structural-lithological trap in the northern flank of the deposit. The prospect remains open along strike and down-dip.

The results indicate that fertile hydrothermal conditions extended deeper into the northern flank than previously recognized and constrain the vertical preservation of HS mineralization in the Chelopech system. More broadly, WZD supports an exploration model in which blind high-grade HS mineralization may occur beneath the mine footprint where structurally focused fluid pathways intersect favourable host packages.

Mobility of trace elements in accessory minerals and its impact on whole-rock geochemistry: a case study from the Sharlo Dere area, Chelopech deposit

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The Chelopech deposit is one of the largest Cu–Au deposits in Europe. It is part of the Apuseni–Banat–Timok–Srednogorie magmatic and metallogenic belt. The deposit is associated with a Late Cretaceous magmatic–hydrothermal system (91.9 ± 0.2 Ma), characterized by a gradual transition from a deeper porphyry to a shallower high-sulfidation epithermal environment (Grigorova et al., 2022). The main aim of present study is to investigate the relationship between the geochemical behaviour of the trace elements in accessory minerals (zircon, apatite, titanite, rutile) and the geochemistry of host ore-bearing diorite porphyries, which have undergone different degrees of hydrothermal alteration. The study area is the Sharlo Dere prospect, located northeast of the Chelopech mine.

Zircons are found in all alteration types (propylitic, quartz–sericitic and advanced argillic), preserving their magmatic origin, but in the advanced argillic alteration (AAA) zone, mobility of Ce, Eu, Yb, Gd, Sm, Y and U is observed. In magmatic apatites, from propylitic to quartz–sericitic alteration, a decrease in La, Ce, and Sr elements, $(La/Sm)_N$ and $(Ce/Yb)_N$ ratios is observed. In the advanced argillic alteration zone, apatite is replaced by aluminium-phosphate-sulphate (APS) minerals. Titanites are magmatic (with high contents of REEs) and occur only in propylitic-altered rocks. Titanium remains a relatively inert element even in the more advanced altered rocks, due to the replacement of titanite by hydrothermal rutile. In the rutiles, enrichment of Nb and Ta is observed compared to their contents in titanites, indicating that these elements were likely remobilized and concentrated during hydrothermal processes.

Whole-rock geochemistry reflects the mobility of elements and changing mineral associations with the increasing intensity of alteration. From the propylitic to advanced argillic zone we observe a relative enrichment of Pb and Sr and strong depletion of MnO, MgO, CaO, Na₂O, Cs, Rb, K, Y, MREE–HREE and HFSE. The depletion of HREE, Y, and U might be related with the decreasing concentrations of these elements in zircons. The decrease of LREEs, Y, and Sr in the apatite from propylitic to quartz-sericite alteration is also reflected in the whole-rock geochemistry. The formation of APS minerals (e.g., svanbergite) in the AAA zone leads to increased Sr content and indicatively low Rb/Sr ratios. The LREEs are only slightly diminished possibly due to the retention in APS minerals and formation of hydrothermal apatite. The slight decrease of MREEs in the whole-rock may reflect the loss of titanite and amphibole.

The obtained results show that certain trace elements in accessory minerals can become mobile during hydrothermal alteration of varying intensity and impact the geochemistry of the whole rock, especially the balance of REE. This data confirms the importance of accessory minerals in the geochemical interpretation of hydrothermally altered rocks in magmatic-hydrothermal systems.

Acknowledgements. The study was partially supported by the National Scientific Program “Critical and strategic raw materials for a green transition and sustainable development” and REXPro project, contract BG-RRP-2.011-0040-C01/02.

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Silver in some Pb-Zn mineralisations along the Periadriatic-Balaton Lineament: implications of mineral chemistry

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Several Pb-Zn mineralisations are known around the Periadriatic-Balaton Lineament, from Italy to Hungary. Although this lineament is a Cenozoic fault system, its precursor dates back to the Mesozoic era. These galena-sphalerite-bearing mineralisations are mostly hosted by geologically correlating Triassic carbonates, though exceptions also occur. The most well-known examples are in Austria (e.g., Bleiberg), Slovenia (e.g., Mežica) and Italy (e.g., Raibl) (Melcher et al., 2023), but smaller mined occurrences in Hungary and Croatia can also be found (Benkó et al., 2014; Palinkaš et al., 2016). However, mineral chemical knowledge is scarce regarding these small locations. Therefore, the present study focuses on galena and fahlore mineral chemistry-based conclusions to complete the knowledge on the formation conditions and metal enrichments of some Hungarian and Croatian occurrences.

Electron probe microanalysis was used to determine fahlore and galena compositions of samples from the Balaton Highland (Balatonfüred, Sóly, Litér), the Velence Mts. (Pátka, Pákozd) and Szabadbattyán, Hungary as well as from the Medvednica Mts. (Rudnik Zrinski), Croatia. The results have proven that the most common trace elements are Cd, Bi, As and Fe (up to 0.65 wt%) in galena, and are Fe, Zn, Mn, Ag as well as Pb (up to 7.9 wt%) in fahlore. Zincian-tennantite was found in Balatonfüred and (Ag-rich) zincian-tetrahedrite was identified at Pátka and Szabadbattyán. The major hosts for Ag are the Cu-sulphides alteration products of fahlore (up to 7.5 wt%), though tetrahedrite itself can also contain this metal (up to 2.79 wt%). The typically 0.06–0.2 wt% Cd, 0.05–0.5 wt% Bi and 0.015–0.6 wt% Fe content ranges as well as the very low (<0.01 wt%) Ag content in galena seem to be characteristic features of the studied Alpine-type (MVT) mineralisations. The variation and distribution of the trace elements in the studied sulphides provide evidence of low temperature formation, as well as evolution of the hydrothermal fluid characteristics (cooling and changing of fO_2 and fS_2 conditions) upon the mineral precipitation.

This information not only provides evidence of classification the studied Hungarian locations as Alpine-type (MVT) mineralisations, but also strengthens the correlation among the occurrences and contribute to evaluate the economic significance of this deposit type.

Acknowledgements. Zs. Bendő, Zs. Benkó, Máté Biró, B. Fehér, E. Harman-Tóth, T. Mikus, L. A. Palinkaš, S. S. Palinkaš, S. Szakáll and F. Zaccarini are thanked for their help during this work. The work of G. B. Kiss is supported by the János Bolyai Research Scholarship awarded by the Hungarian Academy of Sciences. The work was partly supported by the NKKP project nr. 153046 financed from the National Research, Development and Innovation Office fund (Hungary).

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The Brevene South Porphyry: a newly discovered high-grade Au–Cu occurrence within the Chelopech magmatic-hydrothermal system

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The Brevene South Porphyry (BSP) target hosts a newly identified high-grade Cu-Au porphyry mineralization, occurring on the southeastern flank of the Chelopech magmatic-hydrothermal system, in the northern Late Cretaceous Panagyurishte ore district in Bulgaria (DPM Metals Press Release 03/06/2026, <https://dpmmetals.com/news-media/news-releases/>). The new discovery is located approximately 500 m below the main high-sulfidation type Cu-Au ore bodies that are currently exploited by underground mining. The EX_BRESPO_03 discovery hole returned a 713 m drill intercept averaging 1.16% Cu and 1.31 g/t Au, highlighting a remarkable zone of mineralization that remains open both laterally and at depth.

At the BSP target the exploration was guided by the geological concept that the Chelopech high-sulfidation epithermal mineralization may have transitioned into a deeper, multi-centered and potentially telescoped porphyry system. Alteration and mineralization encountered in previous deep drill intersections within the Chelopech mine area supported this model and were used to vector drilling toward the BSP target.

The BSP target is hosted by a deep-seated dioritic intrusion and associated breccias emplaced around the contact level of gneissic basement and Turonian clastic sediments. The newly discovered porphyry system exhibits hydrothermal and mineralogical zonation. The core of the system is characterized by preserved potassic alteration, marked by shreddy biotite, K-feldspar, and elevated K/Al ratios. This assemblage is locally overprinted by a high-temperature chlorite-actinolite-mica-magnetite-quartz-chalcopyrite alteration assemblage. Chlorite compositions evolve from Mg-rich varieties proximal to the potassic core to progressively Fe-rich compositions outward, reflecting decreasing temperature and increasing distance from the system center. The potassic domain is crosscut and surrounded by intensely veined zones comprising exceptionally dense quartz-dominated stockworks and sheeted veins. Distinctive “brain-rock” textures and discrete, convoluted unidirectional solidification textures (UST) are preserved in the apical part of the system and exhibit evidence of overprinting by high-temperature alteration and veining. The system includes subsequent high-silica flooded domains superimposed on relict phyllic alteration in the upper parts of the system, where they occur as extensive silica ledges hosting bornite-rich overprinting mineralization, and as narrow, structurally controlled, chalcopyrite-rich silica shoots that overprint potassic alteration within the deeper core of the system. Peripheral and transitional zones are characterized by paragonite-muscovite alteration associated with pyrophyllite and diaspore, accompanied by abundant anhydrite veining and elevated molybdenite contents.

The spatial distribution of these alteration assemblages, together with the vein architecture and mineralogical zonation, indicates a well-preserved and potentially significant Au-Cu porphyry system. Structural analysis indicates a dominant northeast-trending orientation developed throughout all vein groups within the porphyry system. An exception is the east-west trend, which is restricted to the quartz stage and is observed only in the early and late quartz vein generations.

The geological characteristics, as well as the scale and the high-grade nature of the BSP Au-Cu target collectively indicate that it has the potential to contribute significant mineral resources to the Chelopech mine and underline the exceptional fertility of the Late Cretaceous magmatic-hydrothermal systems of the Western Tethyan belt.

Enigmatic deep secondary enrichment mineralization at Dumitru Potok, eastern Serbia

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The Dumitru Potok prospect, located 1 km to the N-NE from the recently discovered Čoka Rakita high-grade gold skarn deposit, in the Late Cretaceous Timok Magmatic Complex (eastern Serbia), hosts deep stratabound Cu–Au–Ag mineralization in a marble-skarn altered limestone and is spatially associated with a dioritic porphyry intrusion.

By integrating detailed petrography, mineral chemistry, and drill-core observations from an east–west transect defined by eight drill holes, this study investigates the evolution of a Cu–Au–Ag skarn system and the processes controlling its metal distribution. Field relationships supported by optical microscopy, quantitative mineralogy (QEMSCAN) and optical cathodoluminescence define a skarn system characterized by prograde garnet- and locally pyroxene-dominated assemblages overprinted by an intensive retrograde alteration. The ore assemblage is dominated by chalcopyrite, bornite, chalcocite, digenite and native copper together with magnetite, hematite and goethite recording multiple mineralization stages. In addition, accessory Se-, Bi- and Co-bearing mineral phases, including clausthalite, aikinite, bismuthinite, carrollite and cobaltite occur closely associated with the hypogene Cu-sulfides throughout the system.

A pronounced lateral zonation is recognized across the prospect. The eastern sector is characterized by a typical hypogene Fe-oxide and Cu-sulfide association, comprising magnetite, hematite, chalcopyrite, bornite, digenite and chalcocite, hosted by green to red-brown garnet-rich skarn. In contrast, the western sector hosts a sulfur-deficient Cu assemblage at a depth of approximately 1 km, comprising native copper occurring as both veinlets and disseminations. Native copper in veinlets occurs largely as a monomineralic phase, whereas disseminated native copper is associated with minor native Au and Ag, together with chalcocite and digenite. This occurrence is hosted in strongly oxidized garnet skarn where primary garnet is moderately to pervasively replaced by carbonate–goethite ($\pm$ chlorite) assemblage, subsequently overprinted by quartz–carbonate. These mineralogical and alteration characteristics may reflect a deep secondary Cu-Au-Ag remobilization environment, potentially representing an unusual style of mineralization within the Dumitru Potok system. Additionally, native copper veinlets within the oxidized skarn are locally crosscut by calcite–chalcocite veins, indicating a younger hydrothermal overprint that may be related to mineralization at the nearby Frasen porphyry, interpreted to postdate the Dumitru Potok system by approximately 2 Ma based on unpublished DPM Metals data.

EPMA analyses indicate near-stoichiometric compositions of primary sulfides, pointing to limited chemical re-equilibration, whereas LA–ICP–MS trace element analyses show enrichment in Au, Ag, Cu, Zn, and Pb in goethite, reflecting late-stage metal redistribution under oxidizing conditions.

The coexistence of native copper in a deep hydrothermal environment, lacking Cu-oxides, carbonates, silicates and sulfates, distinct from typical supergene Cu-oxide systems, suggests non-classical formation mechanisms. Copper isotope analyses are currently being conducted to evaluate whether native copper formation is related to redox-controlled sulfide dissolution and reprecipitation or to a separate hydrothermal pulse, providing insights into Cu transport and precipitation in carbonate-hosted systems.

Acknowledgements. We thank the geologists of DPM Metals Inc. for their assistance and hospitality during fieldwork and acknowledge the company's financial and logistical support for this project.

Dumitru Potok Cu-Au Skarn Mineralization within a Larger Porphyry-Skarn-Carbonate Replacement System, NW Timok Magmatic Complex, Serbia

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The Dumitru Potok Cu-Au skarn deposit is situated on the northwestern margin of the Late Cretaceous Timok Magmatic Complex in eastern Serbia within the Apuseni–Banat–Timok–Srednogorie magmatic-metallogenic belt, one of the most significant Cu–Au provinces in Southeast Europe. Located approximately 1.5 km northeast of the Čoka Rakita high-grade gold deposit, Dumitru Potok is the principal prospect within a camp-scale porphyry-skarn-carbonate replacement system that also encompasses Rakita North, Frasen, and Valja Saka. The camp hosts a combined resource of 84.4 Mt at approximately 2.6 Moz Au and 1.9 Blb Cu, of which Dumitru Potok alone accounts for 64 Mt containing 2.2 Moz Au and 1.5 Blb Cu (Titley & Wagner, 2026).

The local stratigraphy comprises a Paleozoic basement of phyllite, meta-sandstone and meta-basalt, overlain by Jurassic and Cretaceous limestones dominantly recrystallized to marble. Above are clastic sediments, characterized by a general coarsening upward facies and an increased carbonate component (quartzite-dominated conglomerate to marl), followed by a debris-flow sequence with andesitic to basaltic components. Fertile, Late Cretaceous quartz monzodiorite intrusions drive mineralization and control the geometry and style of skarn development.

At Dumitru Potok, marble-hosted Cu-Au skarn is the dominant mineralization style, developed as lens-shaped contact skarns along the marble–quartz monzodiorite contact and as stratabound manto-like bodies along conglomerate-marble unconformity. The skarn assemblage comprises andradite–grossular garnet with secondary calcite, opaline silica, magnetite, hematite, and goethite, hosting chalcopyrite, bornite, chalcocite, digenite, and native copper mineralization.

Frasen porphyry Au–Cu mineralization is related to several generations of quartz–magnetite–pyrite–chalcopyrite veins in potassic-altered quartz monzodiorite. Distal, manto-like carbonate replacement bodies define an Au–Ag–Zn–Pb–Cu enriched zone hosted in marble, as well as near-surface “Chocolate Zone”, a strongly supergene oxidized residual deposit, containing gold associated with goethite–hematite pseudomorphing the pyrite. At Rakita North, marble-hosted Cu–Au–Ag mineralization is dominated by chalcopyrite with subordinate bornite, occurring as manto-like skarn bodies and stockwork veins.

Valja Saka is a geologically heterogeneous prospect hosting diverse mineralization styles. Shallow garnet altered marls carry Au mineralization analogous to the one in Čoka Rakita. Gold occurs in oxidized skarn-altered marble with low-sulfur assemblage and in association with pyrite–arsenopyrite–pyrrhotite. Distal polymetallic carbonate replacement Ag–Zn–Pb ± Cu-Au mineralization occurs in limestone, marls and sandstone.

The Dumitru Potok camp exhibits typical zonation of potentially telescoped magmatic-hydrothermal systems, from proximal porphyry and contact skarn through stratabound manto Cu-Au mineralization to distal polymetallic carbonate replacement, underscoring the camp as a multi-center magmatic-hydrothermal system with high exploration potential.

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New U-Pb zircon and Re-Os molybdenite age constraints on the magmatic-hydrothermal systems at the Čoka Rakita – Dumitru Potok – Frasen ore cluster, NW Timok, Serbia

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The Timok Magmatic Complex (TMC), located in eastern Serbia, forms part of the Late Cretaceous Apuseni-Banat-Timok-Srednogie magmatic-metallogenic belt. The existing age data suggest that the magmatic activity in the TMC lasted over a 10 m.y. period from ~89–92 Ma to 79–76 Ma, with a general westward younging of three distinct magmatic suites. The Valja Strž polyphase monzonitic pluton, emplaced along the westernmost margin of the TMC, has been constrained as the youngest magmatic product of the complex with an age of approximately 79 Ma. Numerous smaller intrusive bodies occur near the NE margin of this pluton, many of which are associated with zoned magmatic-hydrothermal systems that host important porphyry, skarn and carbonate-replacement type Au-Cu-Ag-Pb-Zn-Mo mineralization within the Čoka Rakita – Dumitru Potok – Frasen ore cluster (<https://dpmmetals.com/news-media/news-releases/>). This study reports new U-Pb LA-ICP-MS and CA-ID-TIMS age data on magmatic zircons and Re-Os age data on hydrothermal molybdenite aiming to constrain the temporal and genetic relationship between magmatism and mineralization in this part of the TMC.

Zircon separates were extracted from several intrusive lithologies, presented below, and gave obtained ages range from 82.37 ± 0.98 to 75.8 ± 1.5 Ma (LA-ICP-MS) and from 84.18 ± 0.11 to 79.402 ± 0.029 Ma (CA-ID-TIMS). All available results, particularly the CA-ID-TIMS high-precision age data, allow three magmatic episodes to be distinguished:

The ~83–84 Ma magmatic event produced numerous dioritic sill-like bodies that intrude the clastic sediments at Čoka Rakita (83.82 ± 0.11 Ma) and Dumitru Potok – Frasen (84.18 ± 0.11 Ma) and are ubiquitously altered by potassic- and overprinted by phyllic alteration; this is considered a pre- to early-mineral event.

The ~81 Ma magmatic event is recorded in a coarse-grained dioritic/monzodioritic dyke that is spatially associated to the porphyry Cu-Au mineralization at Dumitru Potok (80.688 ± 0.031 Ma) and from the felsic domain of a composite intrusion (Cint) at Frasen (81.203 ± 0.029 Ma). These zircon ages broadly overlap also with the 80.50 ± 0.47 to 81.66 ± 0.48 Ma Re-Os model age ranges of molybdenite collected from porphyry mineralization related veins at Čoka Rakita, Dumitru Potok and Frasen. The Cint at Frasen is believed to be associated with mafic magma injection and mixing of magmas with different oxidation states, which could easily be the driver for the formation of these Au-Cu-rich porphyry systems.

The ~79 Ma magmatic event had two most likely short-lived pulses. The first is recorded in coarse-grained equigranular monzonite from the Valja Strž pluton (79.481 ± 0.029 Ma) and from a phlogopite-bearing monzodiorite dyke from Čoka Rakita (79.485 ± 0.027 Ma), which are spatially associated to the Au-rich skarn mineralization. The second pulse is recorded in a pyroxene-bearing dyke at Čoka Rakita (79.402 ± 0.029 Ma), which based on cross-cutting relationships post-dates the gold mineralization event at Čoka Rakita.

Mineralization types in the Čoka Rakita deposit, Eastern Serbia

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Čoka Rakita is a high-grade gold skarn deposit located in eastern Serbia, within the northwestern part of the Late Cretaceous Timok Magmatic Complex (TMC), a segment of the Apuseni-Banat-Timok-Srednogorie metallogenic belt. Čoka Rakita contains 7.34 Mt of ore grading 6.44 g/t Au, equivalent to 1.52 million ounces of contained gold (Major et al., 2026) and is notable for its exceptionally high gold grades, distinctive mineralogical characteristics, and alteration patterns, making it an important example of skarn-hosted gold mineralization not only within TMC, but also across the broader Western Tethyan metallogenic province.

The host stratigraphy comprises Paleozoic metamorphic rocks overlain by Jurassic and Cretaceous limestones, siliciclastic to calcareous clastic sequence, marl, epiclastic rocks which are intruded by sill-like diorite and large monzonite pluton.

The main economic mineralization is hosted in exoskarn formed by the replacement of a calcareous clastic sedimentary sequence within a structural and stratigraphic trap bounded by the dioritic sill and monzonite intrusion. Mineralization is primarily lithologically controlled, occurring as massive stratabound bodies extending northwest-southeast and dipping approximately 40° eastward, with a secondary north-south structural control on the high-grade zone and the occurrence of subvertical brecciated zones. Mineralization also extends into the endoskarn of the diorite, up to several meters from the intrusive contact. Prograde assemblage is dominated by garnet (andradite-grossular), with subordinate wollastonite, and pyroxene, and a retrograde assemblage is primarily composed of chlorite, actinolite, epidote, and carbonate minerals. A typical feature of Čoka Rakita is the dominance of garnet over pyroxene and the occurrence of high-grade gold mineralization in sulfide-poor zones which is consistent with an oxidized gold skarn deposit type. Abundant red-brown garnet above the diorite intrusions is interpreted to mark the main hydrothermal fluid pathway. Gold typically occurs within microfractures of garnet or in its intergranular spaces, although it may also be hosted by pyrite, chalcopyrite, epidote, quartz, calcite, and K-feldspar. Native gold aggregates may reach several millimeters in size.

The main skarn mineralization is closely spatially associated with several other mineralization types, including: porphyry Au-Cu-Mo mineralization hosted by potassically altered diorite, structurally controlled Au mineralization in epiclastic rocks, as well as stratabound Cu-Au mineralization occurring in deeper stratigraphic levels within conglomerates and basal breccias and in skarn-altered marbles. The deeper stratabound Cu-Au mineralization in the marble and along its contact with the upper siliciclastic unit is mainly associated with garnet-dominated skarn alteration with Fe-oxide/hydroxide replacements in paleokarst zones, and an assemblage of chalcopyrite, bornite, and minor chalcocite. The presence of this deeper mineralization highlights significant exploration potential and suggests possible genetic and/or structural links between the Čoka Rakita system and the nearby Dumitru Potok deposit.

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Insights into Ore-Forming Fluids from Fluid Inclusion Studies in the Buchim–Borov Dol Porphyry Copper System, Republic of North Macedonia

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The Buchim–Damjan–Borov Dol ore district in North Macedonia represents a part of the Alpine–Carpathian–Dinaric metallogenic belt, located at the boundary of the Serbo-Macedonian Massif and the Vardar Zone, in the Lece–Chalkidiki zone. Its evolution reflects complex tectonic and magmatic processes following the closure of the Vardar Ocean in the Eocene. Post-collisional Miocene extension caused faulting, basin formation, and crustal fragmentation, enabling magma and hydrothermal fluid migration and ore formation. Key deposits include the Buchim and Borov Dol porphyry copper deposits and the Damjan iron skarn deposit.

The Buchim deposit formed as a result of multiple intrusive events involving trachytic to trachyandesitic magmas emplaced into metamorphic rocks of the Serbo-Macedonian Massif. These intrusions crystallized at shallow crustal levels, forming a network of stocks and dykes. The magmatic activity was accompanied by extensive hydrothermal processes, which played a key role in the development of the mineralization. The deposit hosts four ore bodies (Vrsnik, Cukar, Central, Bunardzik) with chalcopyrite as a dominant Cu-bearing phase. The Borov Dol deposit formed similarly from multiple trachytic–trachyandesitic intrusions into the Vardar Zone derived lithologies. The porphyry Cu mineralization is crosscut with Pb–Zn hydrothermal veins, reflecting the uppermost portion of the porphyry system.

Fluid inclusion studies from the Bunardzik ore body (the Buchim deposit) reveal a complex evolution of ore-forming fluids, with three main groups of fluid inclusions: high-temperature, high-salinity multiphase fluid and melt inclusions ($T_h > 500$ °C, ~60 wt.% NaCl equiv.), medium temperature, medium-salinity ($T_h = 300$ – 500 °C, 25–45 wt.% NaCl equiv.) multiphase fluid inclusions, and moderately saline ($T_h = 300$ – 500 °C, 15–20 wt.% NaCl equiv.) two-phase fluid inclusions. The identified fluid inclusion groups correspond to three distinct stages in the evolution of the fluids responsible for deposit formation. First group represents the primary ore-forming fluid, derived from a magmatic source and enriched in the metals necessary for mineralization. Second and third groups represent later evolutionary stages of the fluid system, characterized by progressive cooling and decreasing salinity, indicating the gradual modification of the original magmatic fluid during the later phases of the mineralizing process.

Fluid inclusion study at the Borov Dol deposit revealed high-temperature ($T_h = 580$ – 610 °C) multiphase inclusions with high salinities (>45 wt.% NaCl equiv.) and low-temperature ($T_h = 200$ – 325 °C) two-phase fluid inclusions with moderate salinities (8–16 wt.% NaCl equiv.). High-temperature multiphase inclusions reflect hot magmatic-hydrothermal fluids responsible for primary copper mineralization, while low-temperature two-phase inclusions correspond to later stages of hydrothermal fluid evolution, as similarly observed in the Buchim deposit.

A comparison between Borov Dol and Buchim shows that both deposits formed from high-temperature, high-salinity magmatic-hydrothermal fluids; however, Buchim exhibits a higher temperature range, indicating a deeper level of emplacement.

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Closure of the oceanic Meliata basin: Implications from detrital U-Pb zircon data from Lower Cretaceous trench deposits in the Eastern Alps

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A major open question is the mode and how the Meliata oceanic basin closed, and what is the relationship between the closure of the oceanic Meliata Basin and the Paleotethys Ocean. To address this question, we studied the U-Pb ages of detrital zircon from the Lower Cretaceous Rossfeld and Lavant formations of Eastern Alps, which are considered to represent the trench infilling deposited during the closure of the Meliata Basin synchronous with deformation and metamorphism. The special emphasis of our study is on the youngest Permian and Mesozoic ages to reveal the potential ages of ophiolitic and arc material as both the Rossfeld and Lavant formations are rich in ophiolitic material including chromite (Pober & Faupl, 1988).

Nearly all studied zircons show magmatic characteristics. The results of the Rossfeld Fm. are as follows: (1) The youngest grains range between 204 and 165 Ma and are similar to gabbro ages in the Dinaric Ophiolite in the Kalnik Complex (Medvednica) of Dinarides, which is a Late Jurassic to Early Cretaceous ophiolitic mélange unit emplaced during the closure of the oceanic Vardar Basin; (2) some late Early to early Late Triassic ages (e.g., 251 to 209 Ma) with felsic characteristics, which are very rare in the Austroalpine unit but widespread in Southalpine-Dinaric units; (3) typical Permian zircons (e.g., 277 to 273 Ma) as well known in Austroalpine and Southalpine units; (4) Early Variscan (e.g., 368 Ma and 360 Ma) and Main/Late Variscan (327 to 298 Ma); (5) some Silurian ages, which are rather rare in Austroalpine and Southalpine units; (6) typical Ordovician (e.g., ~465 Ma); and (7) Cambrian and Ediacaran-Cryogenian ages, which indicate Avalonian-Cadomian paleogeographic relationships as common for Austroalpine and Southalpine units.

The zircon ages of the Lavant Fm. detritus are similar, and only the younger ones are mentioned here: (1) The youngest grains (199 Ma and 207 Ma) are similar to oldest ages in the Dinaric Ophiolite; (2) late Middle to early Late Triassic magmatic zircons (227 Ma) are rare but occur as protolith ages of Austroalpine eclogites and rare magmatism in the Schladming/Tweng complexes; and (3) typical Permian zircons (e.g., 277 to 273 Ma) as well known in Austroalpine and Southalpine units.

The new data allows two alternative interpretations: Model 1 assumes a Neotethyan rift origin of zircons with ages between 251 and 209 Ma and an ophiolitic origin of the zircons between 165 and 207 Ma, which was closed and incorporated into the Austroalpine nappe complex. Model 2 suggests an arc origin of zircons with ages between 251 and 209 Ma due to B-subduction of the Paleotethyan lithosphere, which was formed during rifting at ca. the Silurian/Devonian boundary. In this case, the 207 to 165 Ma zircons could derive from the Meliata oceanic basin.

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Depositional and Metamorphic Framework of the Saualpe–Koralpe Complex: Tracking European Tethyan Evolution

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Determining the depositional age of high-grade metamorphic metasedimentary terrains is critical for constructing accurate geodynamic models of Tethyan evolutionary pathways. However, severe metamorphic overprinting and recrystallization often obliterate primary chronological signals, and the lithologic dependencies of neomorphic zircon growth remain poorly understood. This study addresses these challenges within the Saualpe–Koralpe Complex (SKC) of the European Eastern Alps — the type locality for eclogites. The SKC is a geodynamically pivotal unit that experienced Permian low-pressure/high-temperature (LP/HT) metamorphism, subsequently overprinted by intense early Late Cretaceous high-pressure (HP) metamorphism (95–90 Ma, 2.4 GPa, 650–730 °C).

We conducted U-Pb geochronology on detrital zircons across three distinct metasedimentary lithologies within the SKC, revealing strong lithologic controls on zircon texturing and age reset behavior. Mica-rich gneisses and micaschists: zircons are nearly entirely reset, distinctly recording the Cretaceous HP metamorphism and, subordinately, the Permian LP/HT event; pre-Permian detrital cores are virtually absent. Mica-poor gneisses: zircons display broad metamorphic rims tracking the Permian event, while preserving detrital cores with age populations spanning ca. 320 to 960 Ma. Quartzites: zircons appear remarkably unaffected by either the LP/HT or HP metamorphic events, preserving undisturbed detrital ages scattered between 460 and 995 Ma.

Combined data from the youngest single detrital grains establish a robust maximum depositional age of ca. 320 Ma for the SKC precursor sediments. Furthermore, a continuous smear of apparent ages between the Permian and Cretaceous suggests fluid-mediated dissolution-precipitation processes during the Cretaceous overprint. Our findings demonstrate that lithology dictates zircon behavior during polymetamorphism. We conclude that quartzites are the optimal target for deciphering provenance and maximum depositional ages in high-grade terrains, whereas mica-rich and mica-poor gneisses provide a complementary, high-fidelity record of complex metamorphic overprints.

Petrogenesis of high-silica granites in the Eastern Alpine Schladming Complex: Implications for the Proto-Tethyan tectonic evolution

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High-silica granites have great significance for understanding behavior of shallow magma systems, and formation and differentiation of the continental crust (Cashman et al., 2017). A suite of silica-rich granite was recognized in the west of Schladming Complex; these granites are characterized by high abundance of quartz and a low proportion of mafic minerals (typically <1%).

Zircon from the Schladming high-silica granite yield U-Pb concordant age of 449–436 Ma, indicating these granites formed in the Late Ordovician. Geochemical results show that these granites contain high SiO₂ (75.27–79.61 wt.%) and LREE (85.72–214.18 ppm) contents. Based on geochemical criteria, these Late Ordovician high-silica granites can be divided into two groups. Group 1 is characterized by low ratios of Zr/Hf (20.03–21.38) and contents of Fe₂O₃^T (0.12–0.90 wt.%), MgO (0.12–0.22 wt.%), HREE (12.70–22.67 ppm), which are similar to the highly fractionated granite. Group 2 contains relatively high ratios of Zr/Hf (35.43–35.95) and HREE (74.11–80.33 ppm) contents than Group 1. In the primitive mantle normalized pattern, these granites show subduction related features, including strong depletion in Sr, P, and Ti, moderate depletion in Nb, Ta, and Zr, and enrichment in Rb and K, indicating they are moderately to highly fractionated granites.

Highly fractionated granite mainly formed in the large-scale extensional tectonic setting (Wu et al., 2017). As a part of Silvretta-Gleinalpe Arc system, the Schladming Complex was situated in an active continental margin setting for a long period. To sum up, we proposed that the Late Ordovician moderately to highly fractionated granites in the western Schladming Complex are the results of subduction and rollback of the Proto-Tethys Ocean under the Gondwana.

Acknowledgements. This study was financially supported by the NSF of China (grant no. 42502201).

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On the multi-stage emplacement mode of the Neo-Tethyan accretionary wedge in southern Crete, Aegean Sea: insights from zircon U-Pb geochronology and geochemistry

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The Eastern Mediterranean occupies a key position within the western Tethyan tectonic domain and records the interaction of the Eurasian, African, and Arabian plates. Its evolution has been influenced by multiple tectonic processes, including the subduction and closure of the Paleo-Tethys and Neo-Tethys Ocean, and subsequent Cenozoic slab rollback and back-arc extension of the remnant eastern Mediterranean Neo-Tethys lithosphere. Crete, one of the major islands of the Aegean microplate, preserves a record of subduction, exhumation, metamorphism, and later extensional tectonics. However, the age, geochemical characteristics, and tectonic significance of the magmatic protoliths preserved within its lithotectonic units remain incompletely understood. The Cretan ophiolite-bearing *mélange* is the uppermost unit in southern Crete (Asterousia Nappe), which was emplaced over continental units (Lower and Upper tectonic units) with its Upper Carboniferous to Mesozoic, and potentially Oligocene cover sediments.

We studied the Cretan ophiolite-bearing *mélange*, which represents a remnant of an accretionary wedge formed during the Neo-Tethys subduction. Petrographic observations, zircon U-Pb geochronology, and whole-rock geochemical analyses from representative igneous and migmatized metamorphic rocks allow to distinguish investigated samples into four groups: (1) Late Carboniferous–Permian felsic rocks (~300–240 Ma), (2) Middle Jurassic mafic rocks (~165 Ma), (3) Late Cretaceous mafic rocks (~70 Ma), and (4) Late Cretaceous felsic rocks (~70 Ma), which appear to have formed by local migmatization. By resetting the U-Pb zircon system the Late Cretaceous felsic rocks show evidence for contemporaneous metamorphism. Major-element geochemistry indicates that the Late Cretaceous mafic rocks range from gabbro to diorite/basaltic andesite, whereas the felsic rocks are predominantly granitic to syenitic in composition, mostly belonging to the calc-alkaline to high-K calc-alkaline series. Trace-element and rare earth element (REE) data reveal geochemical differences among the age groups. The Jurassic mafic rocks display light enrichment of incompatible elements, suggesting a primitive, tholeiitic magma source formed at an oceanic ridge. In contrast, both the Late Carboniferous–Permian and Late Cretaceous felsic rocks are characterized by pronounced LREE and incompatible element enrichment and negative Eu anomalies, indicating magma differentiation and fractional crystallization. The Late Cretaceous felsic rocks also include syenite beside dominant granitic gneisses. The Late Cretaceous mafic rocks exhibit two groups, one with depleted light REE patterns like N-MORBs and one with moderate LREE enrichment and more complex trace-element signatures comparable to E-MORBs indicating an oceanic origin and heterogeneous magma sources and magmatic evolution.

The results indicate that southern Crete preserves evidence for at least three distinct magmatic episodes spanning from the Late Paleozoic to the Late Cretaceous. The contemporaneous Late Cretaceous mafic and felsic igneous rocks and evidence for metamorphism pose the question of thermal processes during formation and accretion of the Cretan ophiolite-bearing *mélange*. We propose preliminarily that overheated mafic magmas are responsible for the local anatexis, unusual for an accretionary wedge. The Carboniferous to Permian igneous rocks are interpreted as basement included in the Cretan ophiolite-bearing *mélange*. In summary, the identified magmatic events provide new constraints on the long-term tectonomagmatic evolution of the Tethyan realm in the Eastern Mediterranean.

The Plankogel Complex in the Eastern Alpine basement: an ophiolitic mélange

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Since the initial paper of Kleinschmidt (1975) the Plankogel Complex in Eastern Alps is considered as an ophiolitic mélange complex exposed in the hangingwall of the Saualpe-Koralpe Complex with its Cretaceous eclogites. It consists of a matrix of a coarse-grained garnet-micaschist and subordinate plagioclase micaschists, with a wide variety of embedded blocks of marbles, various types of amphibolites and Mn-quartzites. Preliminary detrital U-Pb and Lu-Hf zircon ages are reported in Chang et al. (2021). Thöni & Miller (2009) documented a two-stage metamorphic overprint in Permian (Sm-Nd: 269.6 ± 6.2 Ma; 0.46 GPa/540 °C) and Cretaceous times (1.0 GPa/600 °C).

Our extensive geochemical and U-Pb zircon dataset on all rocks from four areas yield the following results. Amphibolites are divided into subordinate N-MORB and E-MORB, and abundant ocean island basalt (OIB) types (alkali basalt); some ultramafic rocks have a komatiite-like signature. Excluding all uncertain cases, the U-Pb zircon signature is largely reset by metamorphic overprint at 251 ± 3.4 Ma leaving only very few relics of reliable magmatic zircons. These include such at 389 ± 9 Ma (N-MORB) and 334 ± 9 Ma (OIB). These young ages are consistent with young depleted Hf model ages (Chang et al., 2021). Other amphibolites are Cambrian in age (512.6 ± 1.8 Ma; Neubauer et al., 2025) and 416–420 Ma showing the wide age range of basaltic rocks. Pegmatite-like felsic rocks occur in the southern Koralpe region, formed at 277 ± 2.2 Ma and are overprinted by metamorphism at 257 ± 2.1 Ma. In part, zircons of metasedimentary rocks like Mn-quartzites are also affected by Permian to Triassic metamorphism and youngest clearly detrital zircons range between 407 and 320 Ma, the latter value is in line with the underlying Saualpe-Koralpe Complex (Chang et al., 2026).

Consequently, the most likely interpretation of the origin of the Plankogel Complex is that it probably represents an ophiolitic mélange complex formed during the Variscan closure of an oceanic basin, likely the Balkan-Carpathian Ocean, and collision of Gondwana with an earlier detached microcontinent.

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The Early Alpine (“Austrian/Cimmerian”) orogeny between Eastern Alps and Iran explained by the closure of the Paleotethys Ocean

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We propose a novel tectonic reconstruction for the western part of the Alpine-Himalayan mountain belt extending from Alps to Iran. This belt represents the superposition of two major orogenic belts: (1) the older one formed during Jurassic to early Late Cretaceous orogenic processes related to the consumption and final closure of the Paleotethys Ocean including the Meliata/Maliac oceanic basins; (2) the younger belt during the Cenozoic closure of the Alpine Tethys and Neotethys oceans. The new reconstruction is in line with recent paleomagnetic reconstructions (van Hinsbergen et al., 2020) considering also the recent reinterpretation of Late Triassic to Late Jurassic Paleotethyan Cimmerian tectonics in Iran (Shabanian & Neubauer, 2024).

In the European segment, Jurassic blueschist facies metamorphism between 160 and 150 Ma was due to Meliata B-subduction predating the earlier orogeny. In Rhodopes and the Karakaya Complex, the Cimmerian eclogite metamorphism is between ca. 215 and 200 Ma indicating Paleotethys B-subduction indicating a still open Paleotethys Ocean. But the most prominent feature of the earlier orogenic cycle is the “Austroalpine domain” in Alps, Carpathians and Balkan with its Early to early Late Cretaceous (“Austrian” or “Early Alpine”) orogenic deformation and associated metamorphism reaching eclogite facies and formation and Early Cretaceous turbiditic trench basins during A-subduction during plate collision. Late Cretaceous post-tectonic (Gosau) collapse-type basins associated with exhumation of metamorphic complexes followed the orogeny. In Iran, the oldest eclogites have an age of ca. 184 Ma, which formed due to A-subduction, and which are younger than the classical Early Cimmerian event. Jurassic Middle and Late Cimmerian orogenic ductile deformation and metamorphism widely overprinted the region. The transitional segment between the European “Austroalpine domain” and the Iranian “Cimmerian belt” are the Pontides in N-Turkiye including its Intrapontide oceanic suture and collision zone showing similar Cretaceous-aged deformation and metamorphism and Lower Cretaceous flysch basins as the “Austroalpine domain”.

Our data compilation shows that comparable features can be traced from Iran towards Alps showing that the delayed subduction of the wide Paleo-Tethys Ocean is the cause for the Early Alpine orogeny in the whole belt indicating diachronous westward propagating closure of the Paleotethys Ocean and subsequent consolidation. The subduction-related magmatism contemporaneous with Late Cretaceous collapse basins in the Carpathian to the Pontides segment formed due to ongoing Neotethys subduction.

This novel tectonic model also implies the need for new reconstructions for the Variscan and pre-Variscan orogenic belts in the western part Alpine-Himalayan mountain belt, which has built by continuous orogenic processes since Ediacaran times.

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Upper Cretaceous volcano-sedimentary complex of the Kostajnica area: Insights from the westernmost Sava Suture Zone

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The Late Cretaceous collision between the Adria and European plates marks a significant tectonic stage in the formation of the Alpine-Mediterranean-Himalayan orogenic system in the southeastern Europe, as evidenced by the Sava Suture Zone (SSZ). Kostajnica area, located in the central Croatia, presents the westernmost exposure of the SSZ characterized by volcano-sedimentary complex. The sedimentary succession records a transition from Scaglia-type laminated pelagic limestones deposited under low-energy, sediment-starved conditions to mixed carbonate-siliciclastic deposits and turbidites. Increased siliciclastic input upward in the succession indicates progressive uplift and enhanced terrigenous supply during basin evolution. Sandstones are dominated by volcanic lithic fragments compositionally similar to the associated basalts, indicating local derivation and syn-volcanic sedimentation. The foraminiferal assemblage of the analyzed carbonate rocks corresponds to the *Dicarinella asymetrica* planktonic foraminiferal zone, indicating a middle Santonian age to possibly base of Campanian. The volcanic rocks of the Kostajnica complex comprise hydrothermally altered basalts, i.e. spilites, with preserved primary igneous skeletal, dendritic and intersertal textures. The mineral assemblage is characterized by extensive albitization and saussuritization of plagioclase, whereas clinopyroxene is largely replaced by chlorite and epidote and opaque phases. Primary skeletal, dendritic, and intersertal textures indicate rapid cooling and undercooling during magma ascent. Subsequent alteration modified their geochemistry, reflected in elevated LOI, element mobility of Cs, Rb and Ba, enrichment of U, and generally low MgO. Geochemical data indicate an enriched MORB affinity with tholeiitic characteristics. They show LREE enrichment relative to N-MORB, with La_N/Yb_N ratios ranging from 2.35 to 3.37. Trace-element ratios (Dy/Yb, Gd/Yb, Sm/Yb, La/Sm) point to partial melting near the spinel–garnet transition zone, but predominantly closer to the spinel stability field, suggesting an initially enriched mantle source. The Kostajnica basalts are closely comparable to coeval mafic magmatism in the western SSZ, the North Kozara and Požeška Gora basalts, all of which display E-MORB characteristics and a tholeiitic affinity. In contrast, volcanic rocks from the central SSZ (Ripanj and Klepa) are distinctly more enriched and exhibit alkaline to transitional geochemical signatures. This distinction is clearly illustrated in the Th/Yb–Nb/Yb diagram, where the two groups form well-separated geochemical clusters. The biostratigraphic and geochemical data indicate that Santonian to Campanian tectono-magmatic activity was broadly contemporaneous across large parts of the SSZ and developed within a regionally extensional regime. However, significant geochemical variability exists, highlighting the complexity of Late Cretaceous tectono-magmatic processes and pronounced along-strike variations in magma sources and lithospheric controls. Nevertheless, the precise geodynamic setting remains unresolved, and it is still uncertain whether the magmatism formed within an active convergent system or during post-collisional transtension.

Acknowledgements. The presented work is supported by the Croatian Science Foundation project SECret (HRZZ IPS-2023-02-2683) and by the Science Fund of the Republic of Serbia project Recon Tethys (7744807).

Refining Cretaceous post-obduction convergence in the Dinarides based on detrital zircon geochronology and garnet chemistry

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Foreland basins are one of the major features of convergent plate boundaries that can develop both on the upper and lower plate due to lithospheric loading. Such basins formed on the lower, Adriatic plate of the Dinarides as a response to Cretaceous–Paleogene convergence processes following Neotethys ophiolite obduction. Studying the provenance of their sedimentary infill provides crucial information on the exhumation of various units during the initial stages of orogenesis. Previous studies investigated specific areas of these basins in detail, but a regional dataset is generally missing. We focused on detrital zircon geochronology and garnet major-element geochemistry of sandstones from different stratigraphic levels collected from northwestern Croatia to eastern Bosnia and Herzegovina. The data covers almost the entire length of the Dinarides and provides a basis for regional interpretation. Detrital zircon age spectra display a major distinction between Lower Cretaceous compared to Upper Cretaceous and Paleocene sandstones. The Lower Cretaceous sandstones have a prominent Permo-Triassic population, while the Upper Cretaceous and Paleocene ones are characterized by a complete absence or by an almost negligible number of Mesozoic zircons. Furthermore, regardless of age, different samples display various proportions of specific Paleozoic (e.g. Variscan and Cenerian) and Precambrian populations. Interestingly, contribution of Late Cretaceous and Early to Middle Jurassic magmatism is statistically insignificant and recorded only in few samples. Detrital garnets display variable composition, but they are mainly almandine, while a minor part has elevated pyrope or spessartine component. They are mostly sourced from low to medium grade metamorphic rocks. These results affirm previous observations that different source rocks supplied siliciclastic detritus in the Early Cretaceous compared to Late Cretaceous and Paleocene, additionally providing detailed insight into the temporal and spatial diversity of sediment sources during the initial stages of orogeny. Comparison with presently scarce but growing regional data from basement units will give a new perspective for interpretation of Adriatic plate evolution during Adria-Europe convergence during the Cretaceous and Paleocene.

Acknowledgements. The presented work is supported by the Croatian Science Foundation project SECret (HRZZ IPS-2023-02-2683).

Detrital zircon U–Pb ages and provenance of Upper Cretaceous and Triassic sedimentary rocks in the Central Srednogie and Sakar–Strandja zones: implications for Variscan and Tethyan tectonic evolution

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The Central Srednogie and Sakar–Strandja zones in southeastern Europe both contain Gondwanan-affinity basement and record Variscan orogenesis and Paleo- to Neo-Tethyan tectonic evolution. These basement units are unconformably overlain by Late Paleozoic–Mesozoic to Cenozoic sedimentary successions, yet their sediment provenance remains poorly constrained. Here, we present an integrated study of petrography, detrital zircon U–Pb geochronology, and zircon trace-element geochemistry of Triassic and Upper Cretaceous sedimentary rocks from the Central Srednogie and Sakar–Strandja zones. The sandstones are mostly classified as lithic arkoses. Detrital zircon U–Pb ages from the Triassic and Upper Cretaceous sandstones of the Srednogie zone show prominent Carboniferous (346–300 Ma), Silurian–Ordovician (482–422 Ma), and Neoproterozoic (646–542 Ma) age populations. By contrast, the Sakar–Strandja samples additionally contain Permian–Triassic zircon populations (298–204 Ma), and the Upper Cretaceous sandstones from the Central Srednogie Zone locally yield Early Permian age population (297–285 Ma) and minor Late Cretaceous zircons (86–72 Ma). Zircon Th/U ratios and trace-element characteristics indicate that most detrital zircons are of magmatic origin. In contrast, minor grains (366–317 Ma, ca. 465 Ma, and subordinate 440–408 Ma) are characterized by lower Th/U ratios and flatter HREE patterns and may represent metamorphic zircons. Together, these data suggest that the Central Srednogie and Sakar–Strandja zones received detritus from similar, locally exposed basement sources, including Variscan magmatic rocks, early Paleozoic magmatic and metamorphic rocks, and older Gondwanan-affinity sources. The Triassic zircons in the Sakar–Strandja samples reflect detritus contributions from Triassic granitoids associated with the Paleotethys subduction. The Late Cretaceous zircons in the Central Srednogie sandstones indicate contemporaneous input from a Neo-Tethyan subduction-related magmatic arc during sedimentation. Minor low-Th/U metamorphic zircons record Variscan and older Paleozoic, Cenerian, tectonothermal events in the source regions and demonstrate that the source regions were part of both, the Cenerian and the Variscan orogenic belts.

On Triassic migmatization, Variscan metamorphism and paleogeographic origin of the Raabalpen Complex, Eastern Alps (Europe)

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The thermal consequences of postorogenic processes like emplacement of magmatic bodies due slab break-off, ongoing extension either due to rifting, post-collisional collapse or slab delamination are poorly constrained. In Alps, the transition from the Carboniferous Variscan orogeny to ongoing Alpine, Permian to Triassic rifting is well constrained by the sedimentary evolution of cover sediments, and, in the past two decades, also by methods constraining the post-metamorphic cooling (e.g. Marotta & Spalla, 2007; Schuster & Stüwe, 2008; Petri et al., 2023). The timing of peak P-T conditions of these Permian processes is well accepted but its prolongation to Triassic times remains poorly constrained except in a single recent study from the Dervio-Olgiasca Zone in the western part of the Southern Alps (Real et al., 2025). In this study, we report, for the first time, a concordant U-Pb age of 242.7 ± 1.1 Ma of metamorphic zircons constraining the peak temperature conditions of migmatization in meta-clastic rocks of the Raabalpen basement complex. The Middle Triassic age of metamorphism is also supported by new concordant U-Pb ages of metamorphic zircons from granite gneisses at 245.1 ± 1.8 Ma, which have Permian protoliths (274.9 ± 1.4 Ma; 274.0 ± 5.4 Ma). Together, the Middle Triassic age of ~ 245 – 243 Ma is interpreted by prolonged extreme heating by lower crust extension forming the Strallegg Gneiss dome during rifting. Furthermore, relict zircons from migmatites in the Raabalpen Complex also constrain two stages of the Variscan amphibolite-grade metamorphism. Although overprinted by polymetamorphism, detrital zircons are preserved in the Raabalpen Complex and include age populations of 448, 480, 564, 632 and 688 Ma constraining a Cadomian-Avalonian source. The youngest age is at 412 Ma constraining a maximum Early Devonian depositional age of parts of the Raabalpen Complex.

Acknowledgements. The study was funded by National Natural Science Foundations of China (Grants 42272244; 42502201; 91755212) and Taishan Scholars (ts20190918).

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Special session SS12

Basement and cover rocks of the South Carpathians

A session celebrating the extraordinary career of
Dr. Viorica Iancu of the Romanian Geologic Institute

Convener:

Mihai Ducea

The origin and evolution of the Sebeş-Lotru terrane, South Carpathians (Romania)

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The Sebeş-Lotru terrane (SLT) is the largest basement unit of the South Carpathians and of the Dacia superterrane, and one of the largest basement terrains in Alpine Europe. It represents the metamorphosed basement of the Alpine Getic thrust sheet and is covered in places by Alpine unmetamorphosed rocks. Its relationships to most other basement units in the South Carpathians is tectonic and related to the assembly of a Mesozoic-aged fold and thrust belt; only its juxtaposition against greenschist facies rocks to the north and east in a small area of the Cibin and Lotru Mts is documented to be Permian, possibly early Triassic. SLT was metamorphosed to amphibolite facies during the Variscan orogeny. Previous regional zircon (detrital and igneous) U-Pb studies have shown a continuous Ediacaran to early Silurian magmatic arc, with some small amount of additional inherited ages older than 2 Ga. A major 460–470 Ma zircon age peak dwarfs all other ages in the zircon archive and reflects a flare-up event at that time.

We review here new whole rock geochemical and radiogenic isotopic ($^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$) data from SLT basement orthorocks of the Cindrel, Sebeş and Lotru Mountains in the central South Carpathians. We also report new Sm-Nd garnet ages of the spatially extensive mica schist of Negovanu, detrital zircon U-Pb analyses and U-Pb zircon ages of pegmatites that cross-cut the metamorphic fabric. Most rocks are mafic and intermediate with calc-alkaline compositions and trace elemental patterns typical for subduction-related magmatic rocks. Isotopic ratios are relatively un-radiogenic at the time of igneous crystallization. Overall, the trace elements and isotopes of the magmatic rocks are consistent with a transitional island arc origin. The presence of various inherited Precambrian age peaks in the volcano-sedimentary detrital record demonstrates the proximity to the larger Gondwana mass. The Negovanu Mare schist is a cover sequence that rests unconformably over the island arc assemblages. Negovanu was deposited after the end of arc magmatism (440 Ma) and received a mixture of material from the arc and from a cratonic continental mass, probably similar to today's modern north east Africa, as evidenced by detrital zircon patterns in the Negovanu Mare. Together all SLT units were metamorphosed at ~323–340 Ma in the Cibin Mountain area. Leucocratic pegmatitic granites forming dikes that clearly cross-cut the metamorphic fabric, were emplaced at around 317–323 Ma.

The SLT is similar to other basement terranes identified elsewhere in Europe and has a peri-Gondwanan origin. Its arcs are probably related to the development and closure of the Rheic ocean. SLT was juxtaposed against another Cambro-Ordovician terrane free of Variscan metamorphism during the latest Permian. The exact evolution and history of docking to larger continental masses during the Paleozoic remains unresolved for the SLT and nearby terranes. The end Permian was a time for collision of the SLT to the Sibişel terrane, which is immediately to the north and east in modern coordinates, possibly the suture of Paleo-Tethys closure in the South Carpathians.

New Data on the Ultramafic Rocks from the Valea Muntelui Complex, Cindrel Mountains, Southern Carpathians

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Ultramafic complexes embedded within the Getic-Supragetic crystalline basement of the Southern Carpathians preserve critical records of mantle dynamics, ophiolitic accretion and subsequent metamorphic overprinting; the Valea Muntelui suite in the Cindrel Mountains is one such scarcely researched but geologically significant occurrence. This study presents the petrographic, mineralogical and geochemical characterization of ultramafic rocks recovered from two drill cores (F3 and F10) within the complex. Optical microscopy, SEM-EDS, Raman spectroscopy, XRF and LA-ICP-MS analyses were employed to identify lithological types, mineral assemblages and whole-rock geochemistry. Four distinct lithologies were recognized: peridotites and pyroxenites/meta-ultramafites displaying variable degrees of serpentinization, alongside basement gneisses and amphibolites. In peridotites, olivine relicts (Fo_{75–85}) occur within mesh-textured serpentine matrices, accompanied by diopside clinopyroxene and tremolite-actinolite amphibole. Pyroxenites contain clinopyroxene (diopside–augite series), zoned amphiboles, chlorite, talc and locally enstatite. Raman spectroscopy identifies lizardite as the dominant serpentine polymorph, consistent with low- to moderate-temperature serpentinization. Whole-rock geochemistry reveals elevated MgO (20–30 wt%), Ni and Cr concentrations, with depleted Ti, Nb, Zr and alkalis, confirming a strongly magnesian, sub-alkaline character. Spider diagrams normalized to N-MORB and primitive mantle show a negative Nb anomaly coupled with relative Th and LREE enrichments, indicating a depleted mantle source possibly modified by supra-subduction zone processes (Pearce, 2008; Dilek & Furnes, 2011). Overall, the geochemical and mineralogical evidence supports the interpretation of the Valea Muntelui ultramafic rocks as a metamorphosed ophiolitic or supra-subduction zone suite, contributing to the understanding of tectonometamorphic evolution in the Southern Carpathians (Codarcea, 1965).

Acknowledgements. The authors are thankful to MINERAL PROIECT INVEST SA for the access to samples from Valea Muntelui. The authors are thankful for the support provided by the GeoEcoLab Laboratory, Geological Institute of Romania, for access to SEM-EDS and Raman spectroscopy, and the PetroChron Laboratory, University of Bucharest, for XRF and LA-ICP-MS analyses. This work was funded under the national project PN 23-39-02-02.

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Tectono-metamorphic zonation and simple shear zones in the prealpine basement of the South Carpathians as result of mapping, petrological observation and integrated analytical data

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The geological constitution of the pre-Mesozoic metamorphic-magmatic basement is different in the Danubian and Getic-Supragetic (GSG) units of the South Carpathians. Neoproterozoic protoliths are widespread in the Danubian nappes, while in the GSG basement they are documented for Lotru and Făgăraș units. The Danubian basement preserves Neoproterozoic protoliths with Pan-African affinities related to Drăgșan (oceanic crust) and Lainici-Păiuș (continental crust). In both the Danubian and GSG units, scarce discontinuous successions of Ordovician to Upper Silurian and Lower Carboniferous ages show a prograde metamorphism in low-medium grade metamorphic conditions. The Neoproterozoic Danubian gneissic units (Drăgșan and Lainici-Păiuș) are overprinted by low-grade Variscan metamorphism. By contrast, Variscan medium to high grade metamorphism strongly affected the pre-metamorphic formations (Gondwana derived) of pre-Upper-Carboniferous GSG. Low-grade, Alpine regional metamorphism affected only the Danubian units.

The tectono-metamorphic zonation in the prealpine basement is revealed by mapping and petrologic data as a composite result of prograde regional/retrograde metamorphism and inversion processes. The pre-Mesozoic basement units are characterized by apparent metamorphic zonation as an effect of syn-tectonic and/or post-tectonic events. Individual tectono-stratigraphic units display contrasting metamorphic and deformation features (e.g. S1-S2 foliations and B1, B2 folds at micro-meso scale) and are separated by deep seated shear zones.

An apparent inverted tectono-metamorphic zonation and an inverted pressure field gradient in the pre-Alpine Danubian basement is due to the Paleozoic overthrust of Drăgșan onto Lainici-Păiuș unit. Contrasting geothermal gradients are characteristic for Drăgșan (MP) and Lainici-Păiuș (LP) facies series. The tectonic boundary in greenschist facies conditions (stilpnomelane/chlorite/biotite zones) separating these units suggest an overthrust emplaced at higher crustal levels. Associated granitoids are of Upper Proterozoic and Lower Carboniferous-Permian ages. The internal part of the Danubian preserves a key-zone plate boundary and remnants of a Paleozoic ophiolitic complex and a new cycle of Devonian rifting and oceanic spreading affecting the Neoproterozoic terranes of the Gondwana supercontinent, followed by tectonic inversion, nappe stacking and magmatic arc activity during Lower Carboniferous. The LP-HT syn-tectonic blastesis of sillimanite-K-feldspar/cordierite-garnet/andalusite-garnet parageneses crop out in contact zones. Unconformable Upper Carboniferous-Permian sedimentary cover seals the entire nappe stack, granitoids and their associated HT-LP mylonites.

In the GSG basement, two main Variscan phases (rifting/opening and contraction/collision) are suggested by the lithological and geotectonic setting of the preserved sequences: Lower Paleozoic (mainly Ordovician) and Upper Devonian-Lower Carboniferous. Cryptic paleosutures are indicated by basic-ultrabasic rocks (basic protoliths, eclogites, garnet peridotites). Spatially associated granitoids are of Cadomian, Ordovician and Lower Carboniferous age. In the internal, gneissic areas, the apparent transition from one unit to another is induced by dynamic metamorphism, in amphibolite facies conditions. Epidote-amphibolite mylonites (including tectonic lenses of eclogites) crop out in external areas (Leaota-Iezer). Shear zone related metamorphic zonation is spatially associated with structural discontinuities and connected with the main tectonic boundaries of thrust or strike slip type; the neoblastic (syn-tectonic) mineral parageneses mark narrow metamorphic zones, overlapping the former structures.

The South Carpathians: relative timing of the Alpine polyphase nappe stacking, basement-cover relationships and magmatic markers as documented by geological mapping and research

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The main basement-cover domains of the Alpine South Carpathians derived from the Dacia continental microplate and are classified as Median and Marginal Dacides, corresponding to the allochthonous Getic-Supragetic and Danubian nappe stacks. The entire Cretaceous basement-cover nappe complexes and the Paleogene-Neogene highlands sedimentary basins are thrust in the Middle Miocene (intra-Sarmatian) onto the foreland fold and thrust units of the Getic Depression, both overthrusting the Moesian platform. To the west, the Mid Cretaceous nappe pile is transgressively overlain by the Paleogene-Neogene sedimentary deposits of the Pannonian Basin which seal the tectonic contact with Jurassic sedimentary and magmatic rocks of the Mureş-Vardar ophiolitic paleosuture units.

Simplified regional structure and major thrust faults related to Middle and Upper Cretaceous events are presented for the South Carpathians basement and cover; post-nappe sedimentary markers and magmatites, as well as crustal transcurrent faults are highlighted. Detailed images reveal the time and space relationships between distinct structural units and thrust lines.

The paper shows versions of various published and unpublished maps 1:50 000, together with the original results supporting the current geological information on the Alpine structure of the South Carpathians, achieved in decades of mapping and research.

Polystage Cretaceous nappe stacking corresponds to two major phases: Mid Cretaceous (intra-Aptian, Austrian) and Upper Cretaceous (intra-Senonian, Laramide/Getic) involving basements and Triassic-Lower Cretaceous sedimentary successions.

Albian-Lower Senonian post-tectonic covers seal the Mid Cretaceous nappes, the uppermost Senonian-Paleogene seal the intra-Maastrichtian thrusts of older structures, while thick basinal successions record gaps and facies changes.

Large scale Laramide overthrust of the Getic-Supragetic over the Severin-Obârşia Closani thrust onto Arjana, Coşuştea and Danubian nappe complexes underline the large tectonic Danubian window, later involved in exhumation-extension processes.

Two interpretations of the Cretaceous nappe structures from the Danubian window are known: Middle Cretaceous thrust units crosscut by Laramide thrusts, resulting in an asymmetric fan-like regional structure, or a synchronous Laramide duplex structure of the Upper and Lower intra-Danubian nappes.

Magmatic and volcanic events are recorded in the Getic-Supragetic units (the Cretaceous Magmatic Metallogenic / Banatitic Belt). They are related to contraction/supra-subduction (Campanian intrusions) and post-Laramide extension geotectonic events (Upper Senonian-Paleogene, volcanic and volcano-sedimentary deposits – Poiana Ruscă and Haţeg basins).

Alpine, low-grade regional metamorphism is recorded in the Danubian units and in the Severin and Coşuştea nappes; thermal/HT and metasomatic metamorphism occur in the contact zones of the Banatitic intrusions (Bocşa - Ocna de Fier, Sasca - Moldova Nouă, Poiana Ruscă areas).

Regional Neogene post-nappe transcurrent faults (vertical and strike-slip) are exposed in both Getic-Supragetic and Danubian units (e.g. Cerna-Jiu and Timok Faults). An important E-W transcrustal major fault is known in the northern part of the Mureş - Sebeş - Cibin Mountains and N-S oriented normal faults are mapped in the western Banat area.

Eclogites of the Cozia Formation: a new occurrence in the Southern Carpathians

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Several distinct lithotectonic units of the pre-Alpine basement belonging to the Getic–Supragetic domain contain relics of high-pressure metamorphism (Iancu & Seghedi, 2007; Săbău et al., 2024). The eclogites of the Cozia Formation represent an additional example of high-pressure rocks preserved within a gneissic host-rock assemblage from the Southern Carpathians. The eclogite-facies paragenesis consists of clinopyroxene (jadeite content of 45–60%), garnet (pyrope content of ~23–24%), kyanite, quartz, and phengite. The garnet–clinopyroxene assemblage indicates peak metamorphic conditions of $P = 21\text{--}23$ kbar and $T = 700\text{--}800$ °C. Quartz and kyanite occur within high-pressure metamorphic segregations formed during ductile deformation. These segregation bands, characterized by coarse-grained and strongly oriented kyanite crystals, developed syn-kinematically under peak or near-peak eclogite-facies conditions. The prograde metamorphic evolution responsible for the development of the high-pressure parageneses was followed by decompression under amphibolite-facies conditions. This retrograde stage is marked by the formation of secondary clinopyroxene–plagioclase symplectites surrounding omphacite at $P = 7\text{--}10$ kbar and $T = 620\text{--}740$ °C, as well as by amphibole–plagioclase coronas around garnet. Retrogression under amphibolite-facies conditions is further supported by the occurrence of a grossular-rich garnet generation formed during decompression. Corundum–albite symplectites formed after the transformation of kyanite, similar to eclogites from Valea Romanilor, Căpățâni Mountains, Southern Carpathians (Săbău et al., 2024). Geochemical data indicate that the Cozia eclogites display tholeiitic affinities. Based on their petrological and geochemical characteristics, the Cozia eclogites are comparable to the Type IIb basalt-derived eclogites described by Gavril Săbău for the Southern Carpathians (Săbău & Massonne, 2003). The tectonic interpretation suggests that the present-day geological structure resulted from the tectonic emplacement of eclogites into crustal rocks that did not experience eclogite-facies metamorphic conditions.

Acknowledgements. We thank the GeoEcoLab Laboratory (Geological Institute of Romania) and PetroChronLab (Faculty of Geology and Geophysics) for access to SEM–EDS and XRF facilities. We also thank Geostud for facilitating access to the drill core samples.

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A tribute to Dr. Viorica Iancu's Scientific Contribution in Mineral-Water exploration

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Romanian scientist Dr. Viorica Iancu is known for her work on the crystalline basement of the South Carpathians, but earlier, in the 1970s, she worked as a hydrogeologist, and among others, two significant publications from that time should be highlighted. One deals with the mineral waters and CO₂ of the Covasna zone in the East Carpathians, entitled *Corelația dintre tectonică, apele mineralizate și CO₂ în zona Covasna* (The Correlation between Tectonics, Mineralized Waters and CO₂ in the Covasna Zone), by Viorica Iancu and Andrei Apostol, published in *Dări de seamă ale Institutului de Geologie și Geofizică*, vol. LXV (1977–1978). The other publication studies the Govora hydromineral reservoir in the Southern Subcarpathians: *Cercetări hidrogeologice și aspecte ale exploatării raționale a zăcămintului hidromineral Govora* (Hydrogeological Researches and Aspects of the Rational Exploitation of the Govora Hydromineral Reservoir), by Viorica Iancu, Ana Capotă, Ion Ianculescu, Mircea Florian and Liviu Blaga, presented at the Symposium on the Protection and Rational Exploitation of Mineral-Water Deposits, Călimănești, 1978, and published in *Studii tehnice și economice, seria E, Hidrogeologie*, no. 14. She led both publications, each of which grew out of several years of fieldwork and careful data interpretation.

The main conclusion of both publications is that the waters and gases are controlled by faults, not by continuous aquifers. Iancu and her coauthors found the same arrangement at Covasna and at Govora, one set of longitudinal fractures and one set of transverse ones, breaking the reservoir into compartments and deciding where deep water and gas could rise. Their conclusion was that there are no continuous water-bearing strata with steady mineralization, but rather zones, and their configuration is complicated and structurally controlled.

The main achievement at Covasna was to connect the mineral waters and the CO₂ to the same set of faults. The authors separated the closed compression faults, which seal, from the open tension fractures, which let water and gas move up. The waters keep a HCO₃-Cl-Na hydrochemistry along these fractures whatever rock they pass through. The CO₂ anomalies and the low geoelectric resistivity zones both line up with the fractures.

Govora was a harder case: one compartmentalized anticline holding two different waters, the I-Br-Na-Cl water reservoir and one SO₄-water reservoir. Dr. Viorica Iancu and her coauthors showed how the anticline, cut by the Blidari fault along its length and by a transverse fault set, was broken into blocks that make the aquifers hard to correlate, and used that to explain why the two waters differ. Here they also reached for isotopic investigations: from the deuterium content they worked out that the reservoir waters are mixed with surface waters down to a depth of about 500 meters, below which the reservoir water sits unmixed. The paper ends with practical advice on how to work the reservoir and protect it.

Both papers highlight that mineral-water deposits are controlled by geological structure, and both bring together geological, geophysical and hydrogeochemical evidence in the investigations of these resources.

Acknowledgements. B.-M.K. acknowledges funding from the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

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Lithologic sequence, markers, apparent lateral transitions and monazite U-Th-Pb^T metamorphic age constraints in the Lotru Metamorphic Suite, South Carpathians

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The internal structure of the South Carpathian basement units has elicited various and sometimes conflicting views and interpretations (Gheuca, 1998; Săbău & Massonne, 2003; Iancu & Seghedi, 2007; Balintoni et al., 2010; Ducea, 2026). The most prevalent feature is the incorporation of a dated eclogitic belt documenting a Variscan suture (Medaris et al., 2003) in the medium grade Getic Basement. The eclogite pods are hosted in a sheared and variegated matrix, mostly micaceous, but containing amphibolitic and gneissic lithologies, as well as scattered ultramafics, or appear as larger bodies encapsulated in K-feldspar gneiss, which straddle directly the structurally lowermost term of the sequence, the Valea Căprăreasa Complex (VCC).

VCC is composed of high-grade rocks, typically kyanite, K-feldspar-bearing biotite gneiss, garnet-kyanite metatexite to diatexite, partly coronitic granitoids, microblastic biotite gneiss occasionally containing micromelt laminae, tonalitic grey gneiss. Distinctive are large garnets, kyanite paramorphs after sillimanite, K-feldspar containing kyanite needles, marginal replacement of K-feldspar by fine-grained polygranular plagioclase, occasional coarse sillimanite neoformation in biotite-rich lithologies.

Structurally above VCC, often replacing laterally or overlying the eclogite-bearing mélange, a characteristic pink microcline gneiss (Pălăniș - PG) develops regionally, overlain by a thin Mn-silicate/carbonate-bearing marker level (Delinești - DL).

The uppermost term of the sequence, overlying DL, seldom other deeper-seated terms, or areal rock assemblages different from the above-mentioned succession, is represented by the metapelitic Negovanu Mare Formation (NMF) - porphyroblastic garnet-staurolite-kyanite ($\pm$ rutile) micaschist recording a prograde monometamorphic event with peak pressures higher than its substratum.

In some remarkable instances the eclogite-PG-DL sequence appears truncated by strongly contrasting assemblages containing cordierite, sillimanite and K-feldspar and magnesian-peraluminous granites producing a thermal overprint (Căpățâna Mts. - Ursu), kinzigitic rocks associated with marble and sillimanite schists (Godeanu, Cernei Mts., Timiș couloir), or moderately contrasting sillimanite rocks containing garnet and staurolite (Lotru, Mănăileasa Mts.).

Monazite data yield Paleozoic metamorphic ages in VCC centred at 470 Ma in metagranite, 420 Ma in partly sillimanite-overprinted garnet-biotite rocks and 450–478 Ma in pebbles from Permian conglomerates.

The upper part of the sequence is dominated by Carboniferous to Permian ages. Rocks of the NMF and DL yielded 360–300 Ma culminating at 320 Ma, or 285 Ma for monazite in kyanite schists, 320 Ma in monazite replacing apatite, and a continuous array between 397–300 Ma in monazite corroded by cerianite and stetindite in mixed rocks at the DL/NMF boundary, containing also hematite, Mn-bearing phlogopite, ferrimuscovite and REE-bearing mangano-manganian epidote.

The discordant structures outlined above exhibit conspicuously younger metamorphic ages, 250 down to 200 Ma in kinzigite assemblages, 280–220 Ma in the sillimanite-staurolite assemblage, and an array down from 450 Ma to a massive peak at 165 Ma in granitoids (Ciocovanu) of the Căpățâna Mts.

The most likely geodynamic scenario implies northward subduction and docking to Laurussia of a Cenerian fragment, overridden by the subduction-accretion complex, overthrust by a juvenile Variscan metapelitic unit, and erosional/tectonic removal of the upper plate, followed by extensive gneiss doming until the Jurassic, at certain variance with the models presented by Săbău & Massonne (2003) and Ducea (2026).

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Errata

Session GS5 Economic Geology

Assessment of the Critical Element Potential of the Helesfa and Gyód Serpentinites, Southeastern Hungary

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Beyond Ni laterites, large-tonnage, low-grade disseminated Ni–Co sulfide deposits in serpentinised ultramafic rocks may become increasingly important targets in response to growing CRM (Critical Raw Material) demand. The first serpentinite body in South Transdanubia, SW Hungary, was discovered near Helesfa in 1961 by drilling targeted at magnetic anomalies beneath thin Pannonian sedimentary cover. A second serpentinite body of comparable size was subsequently confirmed near Gyód in 1962, also beneath Pannonian sediments and likewise by drilling on magnetic anomalies. The Helesfa serpentinite body was intersected by two boreholes, whereas the Gyód body was intersected by one. The Helesfa body occurs within granite, while the Gyód body is hosted by metamorphic rocks of the Baksa Complex; in both cases, the contacts are tectonic. The geometry and dimensions of the serpentinite bodies remain poorly constrained, and further geophysical investigations and soil gas analyses are currently in progress. SEM–EDS analyses were carried out on several samples from the three serpentinite-intersecting boreholes, together with ICP–MS analyses on a total of 21 core samples. These comprise seven samples from Helesfa-1 at 112 m, 121 m, 196 m, 250 m, 300 m, 400 m and 432.8 m; eight samples from Helesfa-2 at 134.6 m, 143 m, 161.5 m, 224 m, 283 m, 300 m, 330 m and 374 m; and six samples from Gyód-2 at 70 m, 82 m, 90.5 m, 104 m, 115.2 m and 125 m. The investigated core samples are derived from the rock collections of SARA Geological Survey, Eötvös Loránd University, and the University of Szeged.

SEM–EDS observations revealed disseminated pentlandite, heazlewoodite and millerite grains, mostly 2–100 µm in size, enclosed in a silicate matrix. Similar-sized Ni–Co–(As)–S phases also occur. In some cases, galena and sphalerite are associated with nickel sulfides, indicating a hydrothermal overprint. This interpretation is further supported by X-ray powder diffraction data, which show that the rocks contain a few percent quartz, dolomite and calcite.

Aqua regia digestion clearly indicates that Ni and Co are predominantly hosted by sulfide phases. The average aqua regia-soluble Ni concentration is 2055 mg/kg in the Helesfa core samples, ranging from 1490 to 2270 mg/kg, and 2017 mg/kg in the Gyód samples, ranging from 1580 to 2410 mg/kg. The Helesfa samples contain, on average, 107 mg/kg Co, ranging from 91.3 to 116 mg/kg, whereas the Gyód samples average 97.4 mg/kg Co, ranging from 93.2 to 113 mg/kg. The Au, Pt and Pd contents of the samples were also analysed by fire assay combined with ICP–OES; all three elements were found to be at or below the detection limit of 0.01 mg/kg.

In contrast, LiBO₂ fusion of the aqua regia-insoluble silicate and oxide fraction yielded a maximum Ni concentration of only 73 mg/kg across all analysed core samples. The presence of sulfide-bound Ni, together with associated Co concentrations of approximately 100 ppm, is favourable from the perspective of potential processing and economic evaluation. However, metallurgical testing is required to assess whether the flotation recovery of these fine-grained sulfides could be economically viable.

High-resolution morphotectonic analysis for assessing fault activity: case studies from northern Greece

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Northern Greece exhibits complex neotectonic deformation, active fault systems, and a diverse geomorphological landscape shaped by long-term tectonic and erosional processes. Previous studies (e.g. Pavlides et al., 1987; Mountrakis et al., 1998; Burchfiel et al., 2008) provided insights into the fault systems and tectonic processes that controlled the evolution of the region. The study areas discussed here have been affected by significant recent earthquakes in 1995 (Kozani–Grevena) and 1996 (Konitsa). Both areas are located within active extensional regime and associated normal faulting. These normal faults have had an important role in shaping the landscape, influencing drainage development and valley incision (Mountrakis et al., 1998; Chatzipetros & Stergiou 2025).

The present study investigates the relationship between active tectonics and drainage network evolution through quantitative morphotectonic analysis using high-resolution Digital Elevation Models (DEM) of 2×2 m spatial resolution. The analysis focuses on selected drainage basins and fault-controlled geomorphic features in the meioseismic areas of Kozani–Grevena and Konitsa earthquake sequences.

The methodological workflow, implemented in ArcGIS Pro, consists of DEM processing, detection of neotectonic structures, and evaluation of their influence on the landscape through three key analyses: (1) calculating and categorizing topographic slope values, (2) assessing disruptions in landforms, and (3) analyzing regional drainage networks. Longitudinal river profiles were constructed to analyze the presence and distribution of knickpoints and a series of morphotectonic indices was calculated using computational techniques (Keller and Pinter, 2002) such as the Asymmetry Factor (AF), Transverse Topographic Symmetry Factor (TTSF), Hypsometric Integral (HI), Valley Floor Width-to-Height Ratio (Vf), Mountain Front Sinuosity (Smf), and Stream Length-Gradient Index (SL).

The results demonstrated asymmetrical drainage patterns in both basins, indicating that the tectonic structures have a major influence on the current topographic relief. In Kozani–Grevena basin, the NW margin exhibits smooth topography, whereas the SE margin is characterized by steeper slopes and heavily influenced drainage pattern, that are confirmed by the field study. The active Konitsa Fault affects the configuration of the drainage network of Aoos River basin, since it influences the several of its branches and smaller streams within the basin. Its recent tectonic activity has driven the uplift of the Tymfi massif, which directly controls the geomorphological evolution and active erosion patterns observed across the study area.

Acknowledgements. The authors would like to thank the Hellenic Cadastre, Greek Digital Design Standard 2007-13, reissue 2014-20, for providing the high-resolution data used in this study.

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Europe's First UNFC-Based Critical Raw Materials Map: Data Harmonisation and EGDI Integration in the GSEU Project

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The secure, sustainable and transparently traceable supply of critical raw materials is one of the fundamental prerequisites for a green and digital transition of the European Union. The Critical Raw Materials Act (CRMA), which entered into force in 2024, requires or promotes the application of the United Nations Framework Classification for Resources (UNFC) in several areas, including the assessment of critical raw material projects, exploration results, national exploration programmes and mining waste [1, 2]. Consequently, European-level databases and map-based visualisation tools are becoming increasingly important, as they provide not only geological information, but also comparable information on the maturity, feasibility and data confidence of individual raw material projects.

The UNFC is a project-based, principles-based classification system that evaluates resource projects along three main axes. The E axis expresses environmental-socio-economic viability, the F axis represents technical feasibility and project maturity, while the G axis provides a measure of confidence in the underlying geological data and estimates [1]. The combination of these three axes makes it possible to classify and compare raw material projects at different levels of maturity – from early-stage exploration occurrences to operating mining projects – within a single harmonised system [1]. A further advantage of the UNFC is that it is not limited to mineral raw materials, but can also be applied to other natural and anthropogenic resources, thereby providing a broader framework for sustainable resource management [1].

One of the key objectives of the Geological Service for Europe (GSEU) project is the harmonisation of European data on critical raw materials, as well as the further development and integration of UNFC application into European geological data infrastructures [3, 4]. Work Package 2 (WP2) of the GSEU project, involving more than 30 partners, focuses on the reassessment of primary onshore and offshore critical raw materials and secondary raw material potential, including mining waste-related resources. It also supports the development of resource management systems and data models [3, 4]. One of the most important outcomes of this work is the integration of UNFC data fields into the MIN4EU (Minerals for Europe) database, the joint European earth-resource database of EuroGeoSurveys, which will be accessible through the European Geological Data Infrastructure (EGDI) [3].

The UNFC data collection for critical raw materials started in 2025 with the coordination of the Department of Mineral Resource Inventory and Mining Royalty Revenue of the Supervisory Authority for Regulatory Affairs. The aim of the data collection was to compile the national datasets available in the partner countries – which differ in structure and level of detail – into a common UNFC-based template. During the development of the template, particular emphasis was placed on the spatial identification of occurrences, the harmonisation of data related to raw materials and deposit types, the recording of project status, and the traceability of the information forming the basis of UNFC classification [3].

Based on the data received by May 2026, 16 countries had provided CRM UNFC information. Following two rounds of data quality control, the readiness level of the dataset exceeded 95%. Altogether, 382 UNFC-based estimates were submitted, represented by 573 records in the working spreadsheet. On the basis of the names, coordinates and deposit types of critical raw material occurrences, 963 unique mineral occurrences were identified. Approximately 30% of these are already present in the MIN4EU database, while the remaining 70% can be treated either as new data or as aggregated records or entries with different naming conventions. Therefore, the detailed matching of the CRM UNFC dataset with MIN4EU is one of the next major tasks of the project, to be carried out in the second half of 2026 with the involvement of experts from the partner countries [3].

Testing of the import into MIN4EU has already started in cooperation with Work Package 7 (WP7) of GSEU, the Geological Survey of Slovenia, the Geological Survey of Denmark and Greenland, and the Supervisory Authority for Regulatory Affairs. For map-based visualisation, a dedicated symbolisation has been prepared by combining the logic of the previous European critical raw materials map with UNFC

colour codes. As a result, a map layer can already be developed in the EGDI test environment that displays not only the location of critical raw material occurrences, but also their UNFC project status and classification attributes. Following successful import, partner review and validation, the UNFC-based critical raw materials map is planned to become publicly available in EGDI by the end of 2026 [3].

The resulting map will not replace national mineral resource inventories, regulatory databases or company-level reporting systems. Its primary function is to make the most important information related to critical raw material occurrences and projects comparable at the European scale in a harmonised form. The map-based visualisation can contribute to the transparency of European raw material management data, the interpretation of differences between Member States and regions, the identification of data gaps, and the implementation of the objectives of the CRMA [2, 3]. The CRM UNFC data collection and EGDI integration carried out within the GSEU project therefore represent an important step towards more harmonised, more sustainable and more policy-relevant European critical raw materials data management.

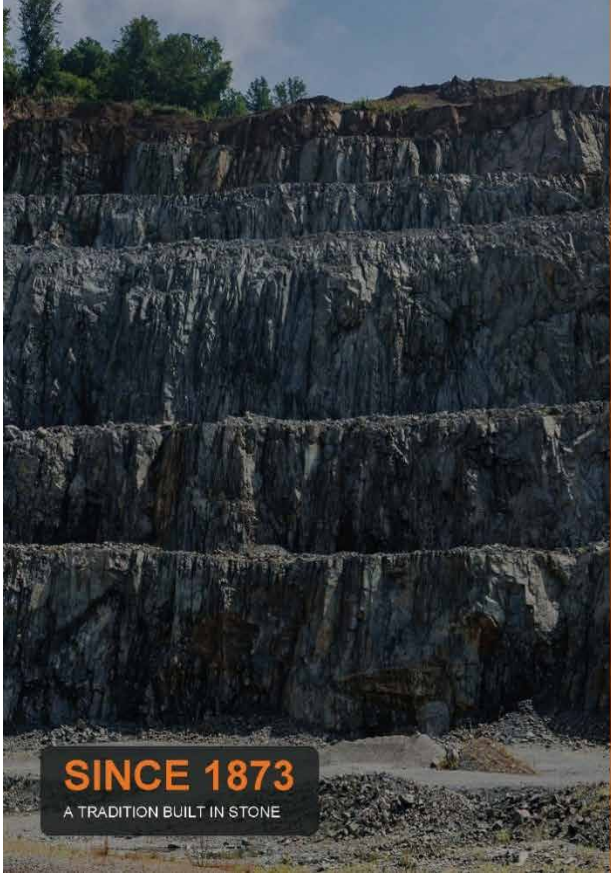
Acknowledgements

This work was carried out within the Geological Service for Europe (GSEU) project, funded by the European Union under project number 101075609 – GSEU – HORIZON-CL5-2021-D3-02. The authors acknowledge the contributions of the GSEU partner organisations involved in data collection, harmonisation and EGDI/MIN4EU implementation.

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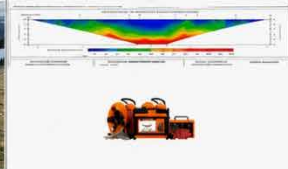

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